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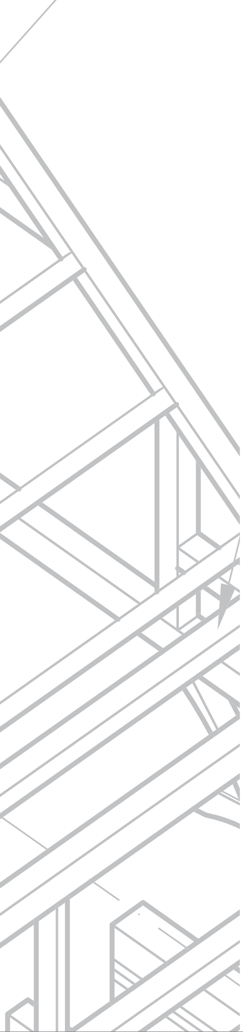
ARCHITECTURAL GRAPHIC STANDARDS

KEITH E. HEDGES · THE AMERICAN INSTITUTE OF ARCHITECTS | TWELFTH EDITION

12

STUDENT EDITION



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GRAPHIC STANDARDS
STUDENT EDITION

TWELFTH EDITION

KEITH E. HEDGES, AIA, NCARB
EDITOR-IN-CHIEF

AUTHORED BY
THE AMERICAN INSTITUTE OF ARCHITECTS

THE MAGNUM GROUP
ILLUSTRATOR

WILEY

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A NOTE FROM THE PUBLISHER

Over the years, I have seen my fair share of battered editions of *Architectural Graphic Standards* (*AGS*) in architects' offices; even in the pick-up trucks of construction contractors. As an amateur architect and an author who has written about architecture, I have my own treasured volumes. Why not? *AGS* is a classic and a testament to a long partnership between Wiley publishing and the American Institute of Architects. It may be one of the only professional reference books to have its own history, beginning with *Drafting Culture: A Social History of Architectural Graphic Standards* (MIT Press, 2008), written by practicing architect, historian, and Professor of Architecture at Georgia Tech, George Barnett Johnston.

We do not know why John Wiley (1808–1891), the son of our founder, chose to publish a book for architects and their customers, but he chose well. Andrew Jackson Downing's *Cottage Residences* was published by Wiley & Putnam in 1842. An influential pattern book of houses, it was consulted across America by house builders and led to the widespread construction of residences in the picturesque "Carpenter Gothic" style. It is still in print today. With Downing's book, John laid the foundation for an architecture list that included many reprints of the work of John Ruskin.

The publication of the 12th edition is a defining moment in *AGS*'s 84-year history. As we like to say in publishing, content is escaping the confines of a book. The precursor for this on *AGS* was the introduction of a CD in 1996 and an ebook in 2007. In this edition, however, *AGS* becomes completely digital with its content fully searchable online. There are, of course, those who still treasure a book or prefer both print on paper and digital. The new edition will also be available in book form.

With this fully digital edition, our objective is to make an architect's work life easier. We have deepened our definition of what it means to create a complete and trusted companion for architects in the office, on a worksite, or anywhere one pleases. I haven't seen many architects climb a scaffold with an *AGS* under their arm, but I have seen many with handheld devices.

As Wiley's digital capabilities evolve, we want you, our customers, to find working with our content to be as effortless as possible. We understand this dramatic shift in the context of defining ourselves as a learning company devoted to the educational and professional needs of our customers from the beginning of their architectural education to the end of their professional careers. In premier undergraduate architecture programs with which I am familiar, students work collaboratively in digital environments foreshadowing the work environment at architectural firms where they will be employed. Even in small offices, collaboration in a digital environment is part of the work routine. In short, we at Wiley are ready to meet you, the architect, where, when, and how you work.

We believe deeply in our mission to serve you; we are appreciative of your needs; and we will continue to connect with them as we redefine publishing in a world reshaped by digital experiences.

Peter Booth Wiley

Chairman Emeritus and Member of the Board of Directors of John Wiley & Sons, Inc.

A NOTE FROM THE AIA

Across the years, *Architectural Graphic Standards* (*AGS*) has retained its name, and the commitment of the American Institute of Architects (AIA) has remained unwavering in its mission—to provide an indispensable resource for the design and construction industry. However, the content of *AGS*, entirely irrespective of format and media, has changed in significant ways. To serve a rapidly transforming profession, the industry's bible had to change with it. Consider the expanding range of modern architectural practice. When the first edition of *AGS* was published more than eight decades ago, wellness, resilience, sustainability, and accessibility were not on the profession's or *AGS*'s radar. The initiative behind Charles George Ramsey and Harold Reeve Sleeper's first edition (1932) centered wholly around creating a "technical" touchstone of graphic standards for architectural drafting, at a time when architects were actively pursuing their professionalization as a distinct body.

Times change. Today, obesity, an aging population, and the impact of climate change have emerged as among the most urgent issues of the 21st century, issues that lend themselves to design thinking on a global scale. The current scope of architectural services has expanded enormously beyond what could ever have been imagined in the early 1930s in response to client and community needs.

Along with the "what" of architectural practice, the "how" of project delivery has likewise altered, especially in the last decade. Computers and electronic media have compressed time and space, as architecture spreads globally. Practice is evolving toward greater collaboration. Architects can work more efficiently and creatively, but they require quick access to current technical information, from codes to new building materials, to avoid costly errors.

The 12th edition supports the ways we access and process knowledge—visually. In doing so, the latest edition of *AGS* gives new life to what the Editor-in-Chief Dennis Hall identifies as the intent of the first authors: to produce a graphic-centric resource.

I thank Dennis Hall, his editors, the countless contributors of content—both written and visual—as well as the proofreaders and fact checkers. That so many hands could weave a seamless resource testifies to their dedication to serve our varied, demanding profession.

From the very first time the AIA and Wiley joined hands as partners for the sixth edition in 1970, we have built a valued, mutually supportive relationship that has benefitted generations of architects, growing with and guiding the architectural profession in the pursuit of excellence. Through all the iterations of *Architectural Graphic Standards*, our commitment to quality continues, but never wavers. Use this distinctive new resource well, and prosper.

Robert Ivy, FAIA
EVP/Chief Executive Officer
The American Institute of Architects

ARCHITECTS' TRIBUTES TO *ARCHITECTURAL GRAPHIC STANDARDS*

To mark the publication of the 12th edition of *Architectural Graphic Standards* (*AGS*) and its digital launch with Architectural Graphic Standards Online (www.graphicstandards.com), Wiley approached architects from some of the most forward-looking practices in the United States; these firms were specifically selected for their strong vision and their engagement in making design and construction. We asked them to each provide a short statement, commenting on what *AGS* means to them, how it has contributed to their practice, and how they anticipate *AGS* being used in the future with the further evolution of the digital and data-driven design techniques.

What is marked is the attachment that these prominent architects all have to *AGS*. This is poignantly expressed by Steven Ehrlich, Founding Partner of Ehrlich Architects in Culver City, California, which won the 2015 AIA National Firm Award:

> I treasure my sixth edition of *Architectural Graphic Standards*, which was given to me as a birthday present by my parents in 1973. I had just returned from three years of traveling and practicing architecture in Africain the Peace Corps, and was starting a residential design-build practice in Vermont. My mother inscribed the book: "May this be the beginning of a very happy and exciting future." My engineer-inventor father, a tough guy, wrote, "Learn it all by heart. But if you need any further info call me. Good luck for good architecture."
>
> I have used the *AGS* so much over the years that it is now literally held together by duct tape. The launch of the online edition ensures that it will continue to be an essential reference for architects in the digital age. While technology has transformed our profession in thrilling ways, we do not (yet) live in a virtual world: Buildings are still made of wood and steel and mortar.
>
> *Steven Ehrlich, FAIA, RIBA*

For Robert Siegel, Design Director at Gensler, *AGS* has been a ubiquitous presence for an architect who thrives on design:

> As F.K. Ching's *Form, Space, and Order* is to deciphering the conceptual and formal basis of architecture, *Architectural Graphic Standards* is to creating the built environment. I love to draw and invent. Since I started my practice, I've depended upon *Architectural Graphic Standards* for its beautifully detailed dimensional diagrams at all scales: from describing the human body in space to defining the turning radii of vehicles. This information helps me to design bespoke buildings and interiors that function perfectly and are easy to use. I imagine that future editions of *Architectural Graphic Standards* will include a detailed and interactive digital model of the human body and of groups of people, both in static and dynamic modes. This information can be integrated into the design process so that the measure of human needs in architecture is more integrated than ever before.
>
> *Robert Siegel, AIA, NCARB*

Corie Sharples is Principal of SHoP Architects in New York, a firm that has in the last couple of decades helped redefine the relationship between design and construction. Here she describes how *AGS* represents an essential information tool:

> From the founding of SHoP almost 20 years ago, my partners and I recognized that there was an enormous and inefficient division between thinking and doing in architecture. A lot of what we've tried to do since is work to bridge that gap: to unify the process of design with the process of building, to close the distance between theory and practice. We've tried to prove in the real world that the best architectural results, the most creative, come when architects are able to control the process of construction through the intelligent management of building information. We've developed a lot of proprietary methods and technologies over the years to help us get there. But, looking back, even to the time before our firm bought its first computer, we had a copy of *Graphic Standards* by our side. The clarity of images and diagrams in the book was an early inspiration for our own approach to communication. It was our first real information tool: a resource so complete in its technical data that it let our creativity run free.
>
> *Corie Sharples AIA*

Claire Weisz, Principal-in-Charge of WXY Studio, an award-winning urban design and planning office, also in New York, closes by reminding us not only how *AGS* provides a visual lexicon, but also how its development over time acts as an effective barometer as summed up by the great Modernist architect Eero Saarinen in a foreword to the 1956 edition:

> As far as touchstones of architecture practice go, *Architectural Graphic Standards* is our lexicon. Not only do we need and use the latest edition in our libraries, but we also see the book as a milestone of achievement; as a way to measure the passage of time whereby nothing is lost. Years ago the principal at my first job in architecture rewarded my youthful enthusiasm with his fifth edition from 1956—since the sixth has long been in use. With a foreword written by no other than Eero Saarinen—and in a great-looking font—it remains within close reach of my desk to this day. Not every book has a summary from one of architecture's luminaries and it doesn't disappoint in its clear snapshot. Agreeing with his predecessors' estimate of its value as an essential part of architectural practice, serving to gather facts and references too complex to be memorized and, perhaps more critically, too scattered to be found in one place in an architect's office. But in particular I am fond of how he used the wonderful term "contemporaneous" to describe its essential value. That is what is striking about the mechanism of reissuing it as needed by the field. Saarinen in ending his evaluation of Architectural Graphic Standards stated that it "will show the future the dizzy speed and expanding horizons of architectural development and practice in our time." Now after almost 60 years dizzying may be an understatement, but this index to the state of the art of building today still holds its own.
>
> *Claire Weisz, FAIA*

With thanks to Steven Ehrlich, Robert Siegel, Corie Sharples, and Claire Weisz.

TIMELINE

The increase in size and complexity of *Architectural Graphic Standards* since its initial publication has mirrored the extraordinary accomplishments of architecture in the 20th century.

Architectural Graphic Standards Highlights		Architecture Landmarks
	1910	*Pennsylvania Station*, New York, New York (McKim, Mead and White)
John Wiley & Sons publishes *Architectural Details*, a prototype for *Architectural Graphic Standards*	**1924**	
	1929	*La Villa Savoye*, Poissy, France (Corbusier)
	1930	*Chrysler Building*, New York, New York (William Van Alen)
Wiley publishes first edition of *Architectural Graphic Standards*	**1932**	
	1934	*Fallingwater*, Bear Run, Pennsylvania (Frank Lloyd Wright)
10,000th copy sold	**1936**	
100,000th copy sold	**1947**	
	1949	*The Glass House*, New Canaan, Connecticut (Philip Johnson)
Fourth edition published: changes in building technology trigger 80% increase in length over prior edition	**1951**	
Fifth edition published: final edition prepared by Charles Ramsey and Harold Sleeper	**1956**	
	1958	*Seagram Building*, New York, New York (Ludwig Mies van der Rohe)
	1966	*Salk Institute*, La Jolla, California (Louis Kahn)
Sixth edition published: first edition edited by American Institute of Architects; incorporates Uniformat organization	**1970**	*John Hancock Center*, Chicago, Illinois (Bruce Graham/Skidmore Owings and Merrill)
	1973	*AIA Headquarters*, Washington, DC (The Architects Collective)
	1977	*Centre Pompidou*, Paris, France (Richard Rogers and Renzo Piano)
	1978	*National Gallery of Art East Wing*, Washington, DC (I.M. Pei)
	1982	*Vietnam Veterans Memorial*, Washington, DC (Maya Lin)
Ninth edition published: incorporates ADA guidelines; new material on building systems and energy-efficient design	**1994**	
First digital version of *Architectural Graphic Standards* released as CD, version 1.0	**1996**	*J. Paul Getty Museum*, Malibu, California (Richard Meier)
	1997	*Guggenheim Museum*, Bilbao, Spain (Frank Gehry)
1,000,000th copy sold	**1999**	*Reichstag*, New German Parliament, Berlin, Germany (Foster + Partners) *Jewish Museum* Berlin, Berlin, Germany (Daniel Libeskind)
Tenth edition of book and version 3.0 of CD published	**2001**	
	2003	*The Gherkin', 30 St Mary Axe*, London, UK (Foster + Partners)
Graphic Standards franchise expands with the release of *Interior Graphic Standards*	**2004**	*Seattle Central Library*, Seattle (Rem Koolhaas/OMA)
	2005	*De Young Museum*, San Francisco (Herzog & de Meuron)
In conjunction with American Planning Association, *Planning and Urban Design Standards* is released	**2006**	
Landscape Architectural Graphic Standards published To celebrate its 75th anniversary, eleventh edition of book and version 4.0 of CD published John Wiley & Sons celebrates 200th anniversary	**2007**	*Metropol Parasol*, Seville, Spain (Jürgen Mayer H)
The American Institute of Architects celebrates 150th anniversary	**2008**	*The Bird's Nest'*, National Stadium for Beijing Olympic Games, Beijing (Herzog & de Meuron)
	2009	*MAXXI Museum*, Rome (Zaha Hadid Architects)
Second Edition of Architectural Graphic Standards for Residential Construction book and CD-ROM 1.0 release Interior Graphic Standards, 2nd Edition and CD 2.0 release	**2010**	*Burj Khalifa*, Dubai (Skidmore, Owings and Merrill) *Guangzhou Opera House*, The People's Republic of China (Zaha Hadid Architects)
	2012	*The Shard*, London (Renzo Piano)
	2014	*One World Trade Center*, New York, New York (David Childs of Skidmore Owings & Merrill)
	2015	*The Shanghai Tower*, Shanghai, The People's Republic of China (Gensler)
Architectural Graphic Standards 12E releases Architectural Graphic Standards Online launches	**2016**	

INTRODUCTION

A BAROMETER OF CHANGE

As the go-to book for architects for over eight decades, *Architectural Graphic Standards* (*AGS*) provides a unique barometer for measuring change within the industry: tracking and assimilating shifts and innovations within the design/construction sector with each new edition. Change has never been more apparent or intense than in the last two decades, as the widespread adoption of technology has prompted significant transformation of the industry. This has had a far-reaching impact not only on the medium in which buildings are designed and constructed, but also on processes, standards, analytics, and ways of delivering professional services. Changes encompass the expansion of project delivery methods and role changes; new building codes and industry practices, which have been extended to include accessibility, sustainability, and building resilience guidelines; new building products and construction methods; and an evolution of new and expanded building information management organizational standards.

While all these changes are significant in the evolution of architectural graphics and the standards of practice of the architect, the expanding range of practice tools now available to architectural professionals has had a much more far-reaching effect. Only three decades ago, architects labored over drafting boards, producing so-called "working drawings" for the purpose of providing the contractor with a complete set of instructions on how to put together the building. Specifications were carefully written to reflect materials and methods of construction. However, as design professionals sought to shift liability away from themselves for the construction issues and new design and production tools increased production efficiency and the ability to manage building information, the final work product of the architect has evolved into "design intent" documentation. This type of construction document is more generic and highly dependent upon contractor coordination drawings and manufacturer's information, in order to explain the actual building construction. Building codes have recognized these changes in construction documents and have codified some building product manufacturers' installation instructions, as requirements to provide the minimum information necessary to construct buildings and to protect the health, safety, and welfare of the public.

Now with the 12th edition, *AGS* is undergoing a watershed moment in its own evolution as it shifts from being defined purely by the page and becomes available digitally online for the first time. Content is being liberated from the confines of a book binding and the limits of its previous electronic formats, whether as an ebook or in a CD form, to become a highly searchable online tool. Though it still remains available in print and ebook formats to provide users with the information in the medium of their choice, the online version fully acknowledges that AGS as an indispensable source for design and technical information for practitioners has to reflect the practices of architects of today: a profession that now spends nearly every day on screen and only has seconds available to search for the essential nugget of information it requires.

REVIVING THE GRAPHIC

Despite new online developments, the editorial vision for the 12th edition of *AGS* marks a return to the publication's essential characteristic—its highly visual quality—which generations of architects have prized. An over-arching aim of this edition has been to restore the more graphic-centric content. This remains true to the primary intent of the original authors, Charles George Ramsey (1884–1963) and Harold Reeve Sleeper (1893–1960); it has also been central to *AGS*'s success across the years as it is entirely in tune with how architects consume and communicate design information. To optimize on the effectiveness of this, it was also our ambition to provide more focused information. The editors constantly asked us, "What do architects need to know about this subject matter?" Our goal was to eliminate unimportant content and concentrate on relevant knowledge, ensuring that information is presented in a manner that is clear, complete, concise, and correct. Finally, we wanted to recognize the evolution of construction documents and were mindful of today's best industry practices. It is also important to recognize what *AGS* is not. This book is not intended to repeat information in *The Architect's Handbook of Professional Practice* (American Institute of Architects, 15th edition, Wiley, 2014), regarding firm management, project delivery, or contracts, but complement that knowledge with more technical information on the graphic instruments in the service of the architect. While *AGS* does not focus on building types or spaces, some design information regarding the construction of unique spaces and building types is included.
The 12th edition of *AGS* concentrates on the core knowledge of architectural design and the creation of the built environment. As the great architect and educator Mies van der Rohe liked to say: "Architecture begins when you place two bricks carefully together." Likewise, Mario Botta said, "The first act of architecture is to put a stone on the ground. That act transforms a condition of nature into a condition of culture; it's a holy act." Both architects

understood the importance of how to use materials creatively and correctly in creating great architecture. *AGS* will continue to provide architects with the knowledge to understand the elements of a building and the implications of technology and construction as part of the design process.

ORGANIZING AND MANAGING BUILDING INFORMATION

While graphics are a far better medium for communicating design ideas than words, in today's complex world of "big data," words are necessary to convey building performance requirements and other nongraphic information. As architects, we are not only the designers of our buildings, but also the managers of the information necessary to procure, construct, and operate the facility. *AGS* recognizes the importance of terminology as notations on drawings, building code requirements, manufacturer's installation instructions, and for electronic search tools. Careful attention has been paid to ensure the consistent use of proper construction terminology throughout *AGS*. Terminology has been coordinated with the 2010 edition of UniFormat™, MasterFormat™ 2014 Update, the OmniClass Construction Classification System™ tables, and the International Building Code. These building information organizational structures are used in *AGS* as a means of organizing chapters into sections and information within the chapters. We can also expect the future of architectural graphics to be highly dependent upon the ability to organize, retrieve, and reuse information.

THE FUTURE OF ARCHITECTURAL GRAPHICS

Architectural graphics as a part of the architect's instruments of service have evolved and will continue to do so. The interoperability of building information is critical to the future of a profession and an industry that must improve efficiency in processes and building performance. This is dependent upon our ability to gather, manage, and use building information to achieve better aesthetic, functional, and technical performance of our designs. International efforts in the creation of global unique identifiers (GUIDs) that associate properties of construction objects with specific products is a first step in achieving this goal, but we can only achieve goals we can measure and we must develop practice tools to verify and monitor building performance at every level. These evolving practice tools are only a few of the evolutional changes in a rapidly expanding industry of traditional and specialty practices. For the last 84 years, *AGS* has sought to provide design professionals, owners, and contractors knowledge regarding best practices in architectural graphics as a means of creating architecture. We recognize the changes and challenges of our industry and are poised to create electronic tools to continue the legacy of Ramsey and Sleeper in sharing design knowledge. The new online version of *AGS* will enable continuous updates of critical information and the latest standards of practice. The ability to link knowledge from a wide array of Wiley design publications and industry experts will make this tool truly indispensable.

The American Institute of Architects (AIA) was founded upon the lofty goal of architects working together to improve our profession and the creation of the built environment through knowledge sharing. I am honored and pleased to have contributed to this worthy goal and the 12th edition of *Architectural Graphic Standards*.

Dennis J. Hall, FAIA, FCSI
Editor-in-Chief of Architectural Graphic Standards

PREFACE

For more than eight decades, the Architectural Graphics Standards (AGS) has been the iconic book, which guided the design of the built environment in the 20th and 21st century North American by bringing complex ideas to visual life like no other comprehensive manuscript. The AGS is an indispensable professional resource that articulates the state-of-the-art in holistic building design and construction through a graphic-centric composition. The visual delivery of information uniquely unites the gap between concept and practice with incredible content breadth and depth.

Revised for the first time since 2008, the AGS Student Edition thoughtfully frames the significantly new and updated content into an academic companion piece suitable for a wide range of design and technical curricula throughout a student's architecture education, and even into the early stages of professional practice. The Student Edition covers the design and documentation process for the building materials and elements of several project types, and features considerably new and updated content such as the emergent theme of resiliency in buildings. A strong index offers direct access to hundreds of architectural elements from over a thousand illustrations.

You will discover that this flagship book is much more than our first 'go-to' resource. The book bears stories of legend. I urge you to find your professor's AGS on her bookshelf and ask. You will see a face light up and regale in a reflective tale of late night studio adventures. Architecture is a passion that burns in many of us, and your new Student Edition is the tinder. Virtually everything needed to realize a design idea is at your fingertips, as you will experience your own swashbuckling tales of enlightenment.

Many thanks to the AIA, and the AGS editors and contributors in establishing the truly exceptional underlying framework; the Wiley team of Margaret, Lauren, Kalli, and others for injecting life into the Student Edition and bringing it to fruition; the advisory board of Chris, Danielle, Leslie, Michael, Randy, Tony, and Traci for their insightful feedback; and my wife Kathy and children Sarah and Brice for their patience and encouragement.

Keith E. Hedges, AIA, NCARB

Editor-in-Chief of Architectural Graphic Standards, Student Edition

SECTION 1

DESIGN PRINCIPLES & CONSTRUCTION DOCUMENTATION

FUNCTIONAL PLANNING

1

HUMAN FACTORS

Human factors information refers to the variables that affect human performance in the built environment, such as human physiology and human psychology. Data accumulated from the fields of engineering, biology, psychology, and anthropology are integrated in this multidisciplinary field. "Fit" describes a design that uses human factors information to create a stimulating but nonstressful environment for human use. Some areas of fit are physiological, psychological, sensual, and cultural.

ANTHROPOMETRICS AND ERGONOMICS

The field of anthropometrics provides information about the dimension and functional capacity of the human body. "Static anthropometrics" measures the body at rest; "dynamic anthropometrics" measures the body while performing activities defined as "work." Dimensional variation occurs in anthropometric data because of the large range of diversity in the human population. To utilize anthropometric charts effectively, a designer must identify where a subject user group falls in relation to these variables. The factors that cause human variations are gender, age, ethnicity, and race. Patterns of growth affected by human culture cause variation in human measure as well. Percentiles that refer to the frequency of occurrence describe dimensional variation on anthropometric charts: that is, the mean percentile (50 percent), the small extreme percentile (2.5 percent), and the large extreme percentile (97.5 percent). "Ergonomics" is the application of human factors data to design. This term was coined by the U.S. army when it began to design machines to fit humans, rather than trying to find humans to fit machines.

HUMAN BEHAVIOR

Human behavior is motivated by innate attributes such as the five senses and by learned cultural attributes. Each human has a unique innate capacity to gather sensual information. How that information is understood is determined by personal and cultural experience. "Proxemics" is the study of human behavior as it relates to learned cultural behavior. Human behavior is motivated by the innate nature of the animal, and this behavior is expressed and modified by each person's learned culture and traditions.

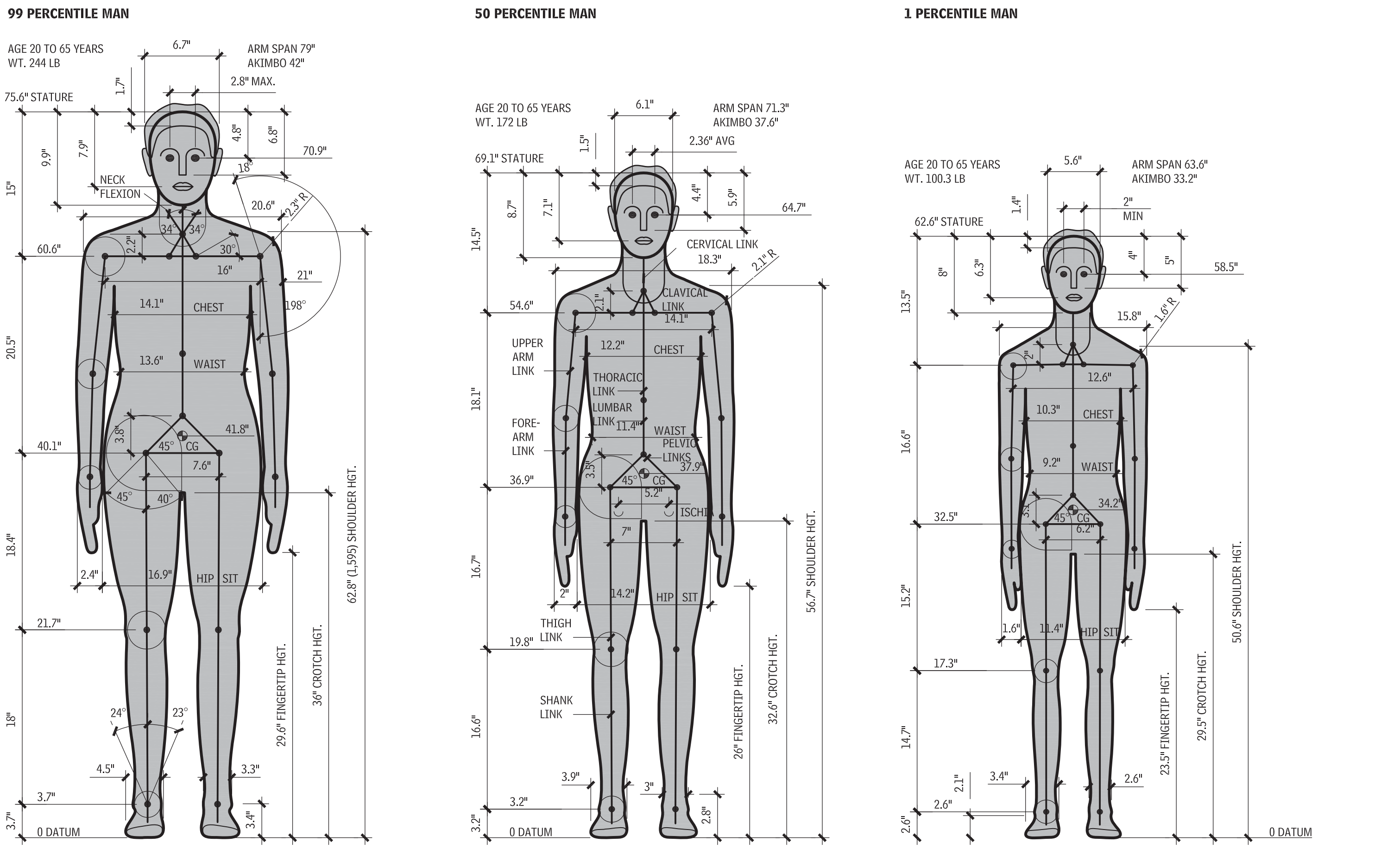
INNATE HUMAN ATTRIBUTES

The five senses determine human comfort levels in the environment and are a part of human factors studies.

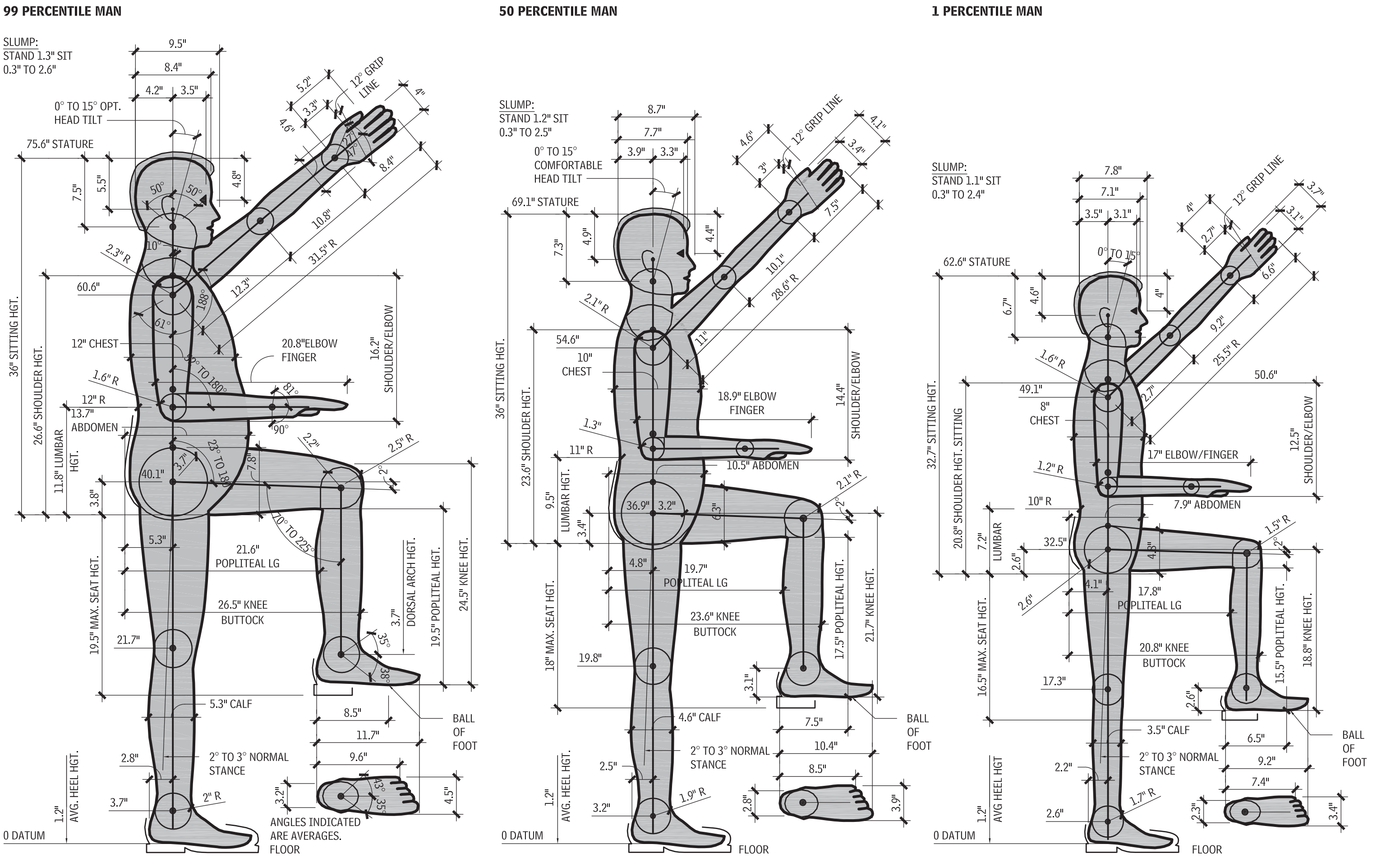
- *Site:* Behavioral scientists agree that, for human beings, seeing is the most engaged sense for gathering information. Physical form is perceived when visual data is organized into patterns, and that data is integrated with memories and emotions. Visual form is perceived as having a context with boundaries. Visual form can be understood to be a dynamic system of directional lines of forces that are innate, kinetic, and independent of the representational content of a form. Once a form's attributes have been perceived, humans tend to give the perceived form symbolic meaning. This meaning is cultural and personal, resulting from associations and past experiences.
- *Touch:* Touch is essential to human development and growth. Texture is learned most completely through skin contact. Human skin is sensitive to temperature, pain, and pressure. Vision and touch are interwoven in sighted humans. Memory of tactile experiences allows humans to understand their environment through visual scanning.
- *Hearing:* Humans can use hearing to determine distances. Sound moves in concentric circles and in horizontal and vertical planes. The ear transmits these airborne vibrations to the brain where it is processed and assigned meaning. The ability to focus hearing is called "sensory gating." The ability to gate sound varies and diminishes with aging.
- *Smell and taste:* Research about smell is difficult to conduct because human sensitivity to smell is highly variable over time and from person to person. A person's sense of smell to an odor can fatigue quickly during exposure. Smell is defined in terms of commonly perceived odors such as flowery, putrid, burned, resinous, and spicy. Taste and smell are closely related in human experience.

ANTHROPOMETRIC DATA

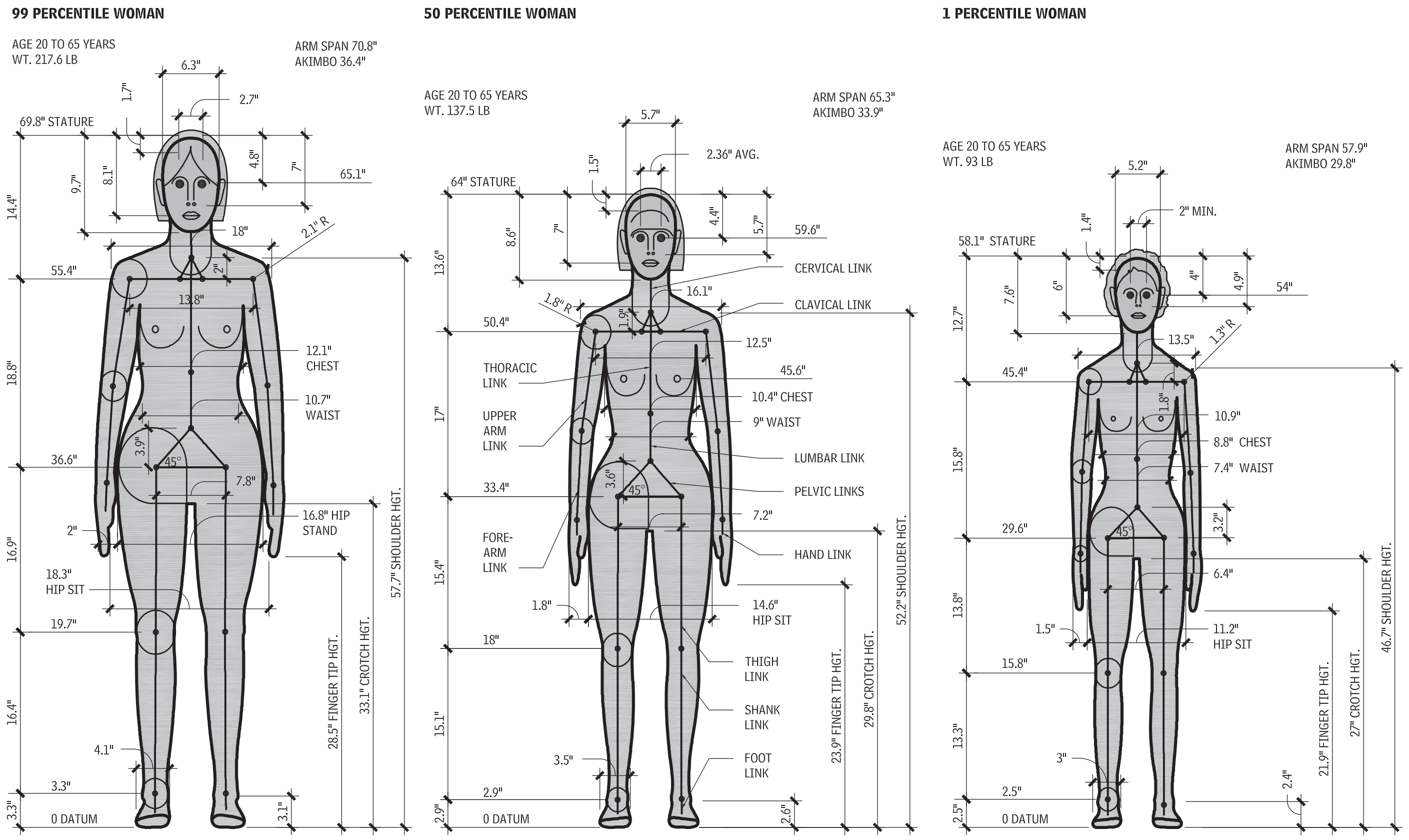
MEASURE OF MAN—FRONT VIEW
1.1



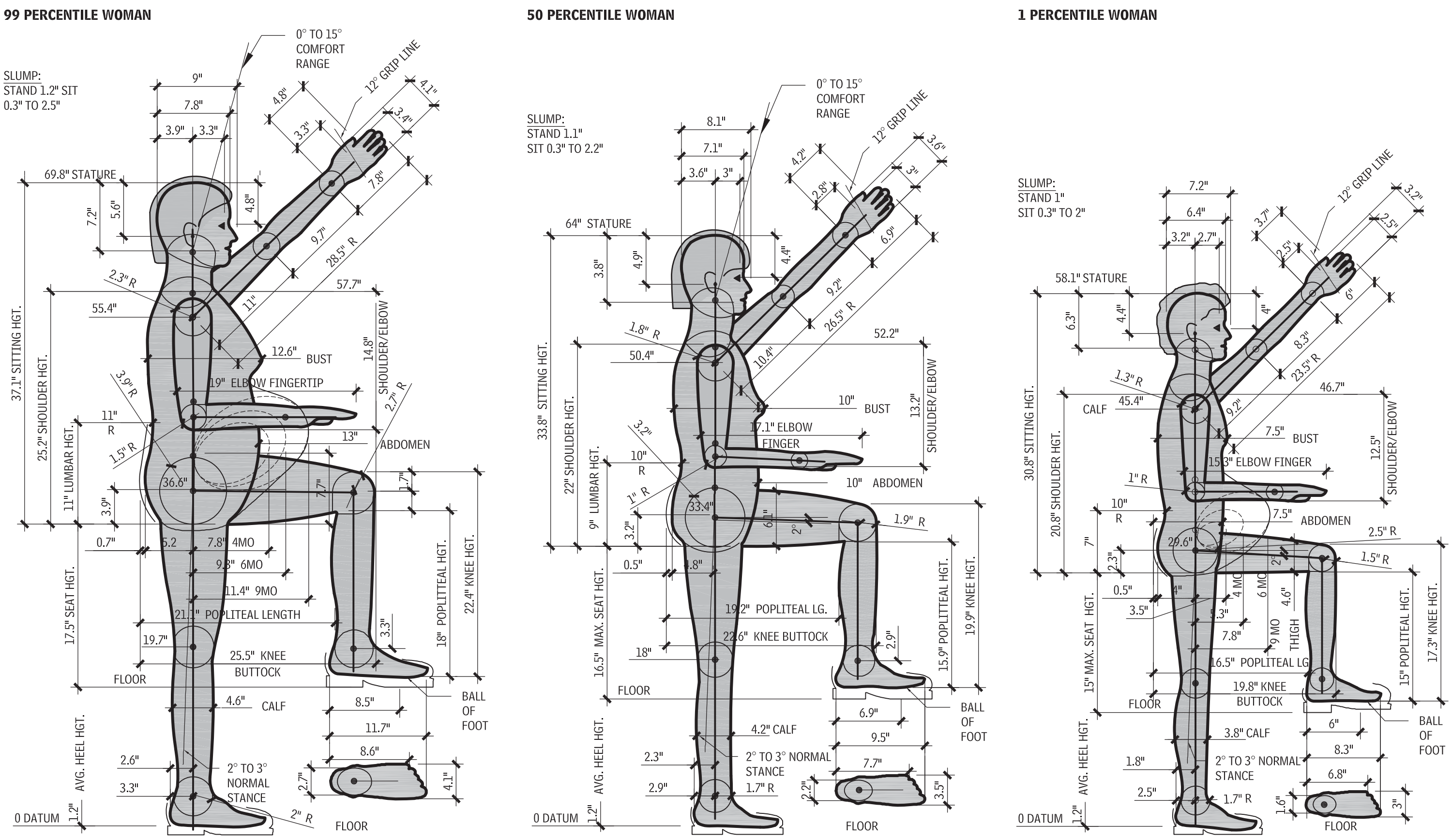
MEASURE OF MAN—SIDE VIEW
1.2



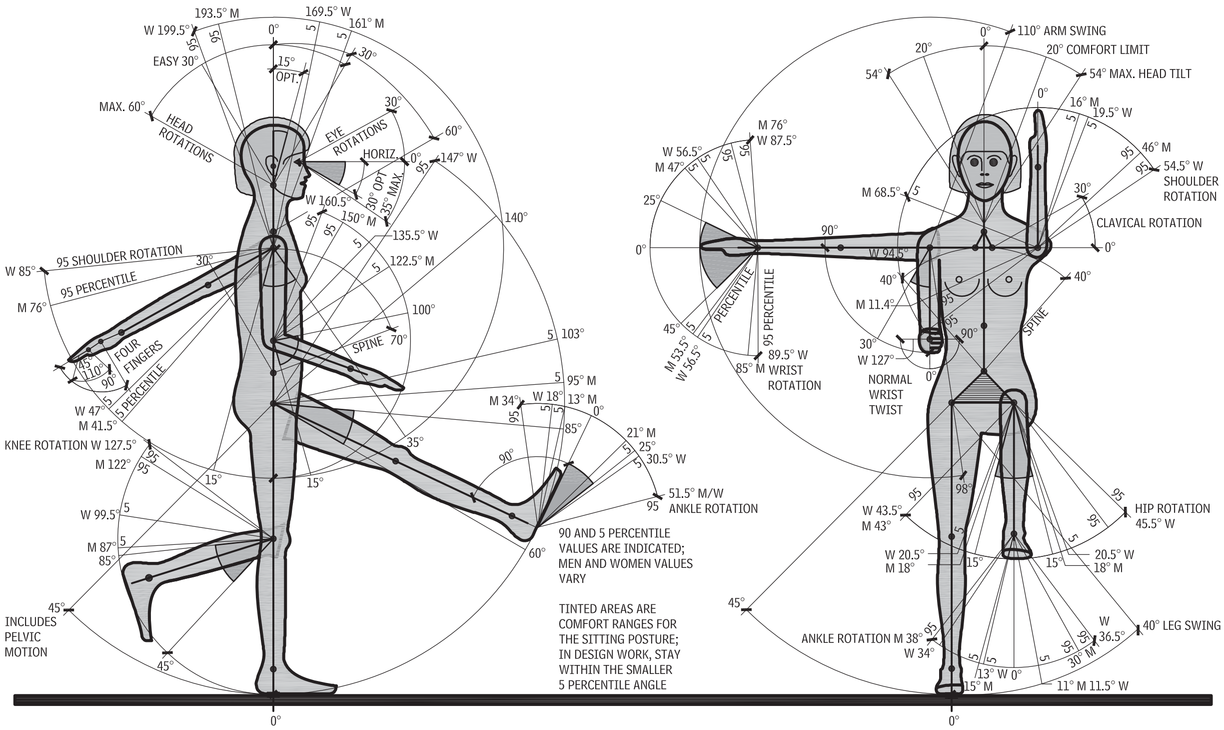
MEASURE OF WOMAN—FRONT VIEW
1.3



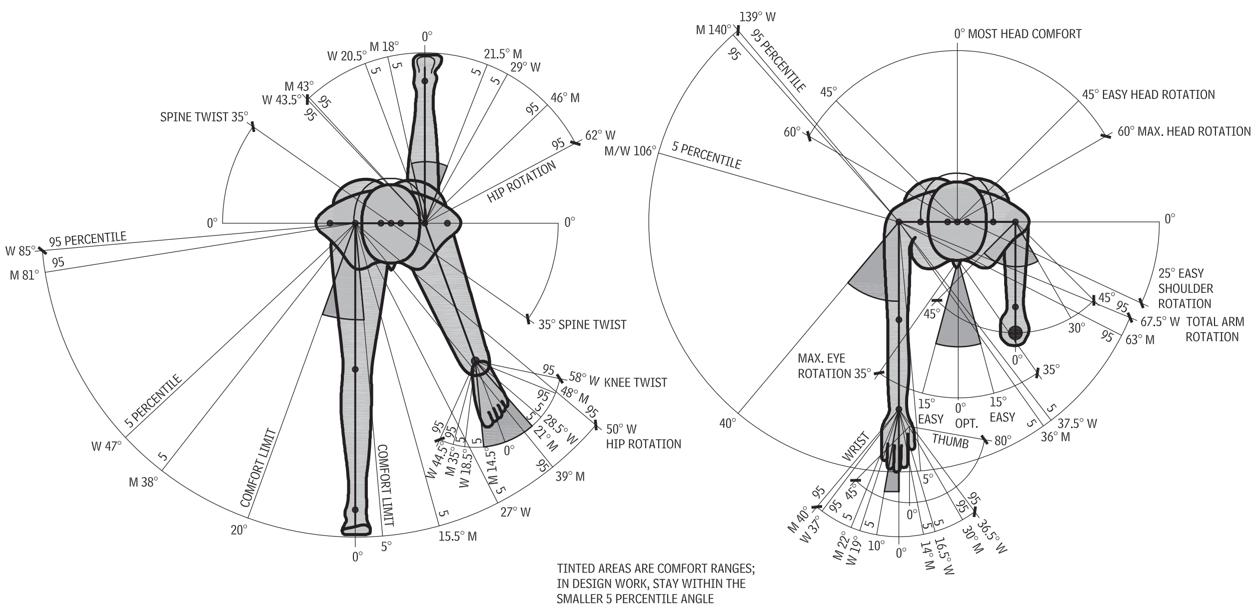
MEASURE OF WOMAN—SIDE VIEW
1.4



ANGLE MOVEMENTS OF BODY COMPONENTS
1.5



ANGLE MOVEMENTS OF BODY COMPONENTS—TOP VIEW
1.6



NOTE

1.1–1.6 Timeline data adapted from Papilia and Wendkos Olds, 1989.

Contributor:
Alvin R. Tilley, Henry Dreyfus Associates, *The Measure of Man & Woman: Human Factors in Design,* John Wiley & Sons, New York, 2001.

UNIVERSAL AND ACCESSIBLE DESIGN

"Universal design is a process that enables and empowers a diverse population by improving human performance, health and wellness, and social participation" (Steinfeld and Maisel, 2012). Proponents of universal design view it as an approach to good design, and they posit that by considering the full range of human ability across our lifetimes (small/big, young/old, with varying abilities across every size and every stage of life), designers can provide better environments for everyone. In short, "Universal design strives to make life easier, healthier, and friendlier for all people" (Steinfeld and Maisel, 2012). While universal design must also be accessible, it exceeds the minimum requirements of accessible design standards to provide optimum conditions for people with and without disabilities.

Some equate universal design with accessible design; however, there are distinct differences. Accessible design is the design of a certain percentage of features to conform to technical requirements as required by laws such as the Architectural Barriers Act (ABA), the Rehabilitation Act, the Fair Housing Amendments Act (FHAA), and the Americans with Disabilities Act (ADA). It does not guarantee inclusion for everyone, nor does it guarantee good design in a holistic sense.

This section will explain the differences and relationship between these two very different approaches to design. One addresses the full range of human experience and abilities and the other derives from an accommodation model that has a narrower focus. The section will provide details on the basic minimum requirements for accessible design and offer suggestions on where designers should exceed the minimum to provide a more welcoming and inclusive environment for all people by addressing universal design goals.

This section is divided into three subsections:

- *Universal design:* This subsection will provide a background on the philosophy and goals of universal design and present four case studies of universal design in public buildings and housing.
- *Accessible design:* This subsection will discuss the legislative history and regulatory process of accessible design and introduce important federal laws such as the Americans with Disabilities Act (ADA), Fair Housing Amendments Act (FHAA), Architectural Barriers Act, and the Rehabilitation Act.
- *Technical criteria:* This subsection will provide detailed drawings for how to comply with key accessible design standards and provide suggestions on how to exceed those standards to exemplify best practices in universal design.

UNIVERSAL DESIGN

Our bodies and minds are in a constant state of change across our lifetime. We are not static. We are also exceedingly diverse—young and old, small and big, fast and slow; we come in shades of many skin colors and with many different backgrounds, aspirations, and ways of life. Increasingly, we humans are gaining more control over our world, our bodies, and our minds. To design universally is to design for improving the human experience of the built environment for all. It recognizes that the designed environment can improve life experiences at the individual and societal level. Universal design is a manifestation of the increasing control we have over our world, through discovery and application of knowledge. In addition to being a philosophy that puts the needs of people first, universal design has a practical side as well. Universal design is a continual improvement process that seeks to achieve the best possible outcomes with the means available, recognizing that not every project and context has the resources available.

Universal design is most successful when fully integrated within a project. As a design movement, it is the result of a meeting of minds between human-centered design approaches and the disability rights movement. In the 1970s, architect Michael Bednar suggested that the value of "barrier free design," the term used at the time to address the removal of design practices that discriminated against people with disabilities, extends to all of us, not just the few barrier free environments (*Barrier Free Environments*, Stroudsburg, PA: Dowden, Hutchinson, and Ross, Inc., 1977).

Ron Mace would give the movement its name and its first definition in his book, *Universal Design: Barrier Free Environments for Everyone* (Los Angeles, CA: Designers West, 1985): "Universal design is the design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design."

In the 1990s, Mace worked with a group of fellow advocates and designers (architects, product designers, engineers, and environmental design researchers) to create the Principles of Universal Design, providing a conceptual framework for implementing universal design as an essential part of good design. The authors of the Principles argued that there was a business case for widespread adoption of the concept—increasing markets through the design of more usable products and environments. This marked a significant shift away from the regulatory approach taken by codes and standards. The Principles included a set of design criteria focused primarily on issues of usability: (1) equitable use, (2) flexibility in use, (3) simple and intuitive use, (4) perceptible information, (5) tolerance for error, (6) low physical effort, and (7) size and space for approach and use.

While the Principles proved to be valuable to early adopters of universal design, proponents of the concept across the world recognized that usability alone is not sufficient to encourage widespread adoption and to address design goals important to the broader population (see Steinfeld and Maisel, 2012). For example, more usable environments alone do not necessarily open opportunities for participation in society for people with disabilities, women, or minority groups. What good is a more usable school building to women if the schools do not provide enough security for their safe education? Additionally, a neighborhood design that does not support walking contributes to increased levels of obesity and further disability, regardless of how usable the buildings in a community might be. In addition, the Principles did not provide any evidence base or benchmarking strategy for achievement. In order to encourage adoption by the broader professional community and public, the Center for Inclusive Design and Environmental Access (IDeA Center) at the University at Buffalo—State University of New York developed eight Goals of Universal Design to complement the Principles. Each of the eight goals represents specific outcome measures and corresponds to a knowledge base from research in fields including human performance, social participation, and wellness. The first four goals focus on human performance in the knowledge areas of anthropometry, biomechanics, perception, and cognition, while the last four goals address health and social participation outcomes.

EIGHT GOALS OF UNIVERSAL DESIGN

GOAL ONE: BODY FIT

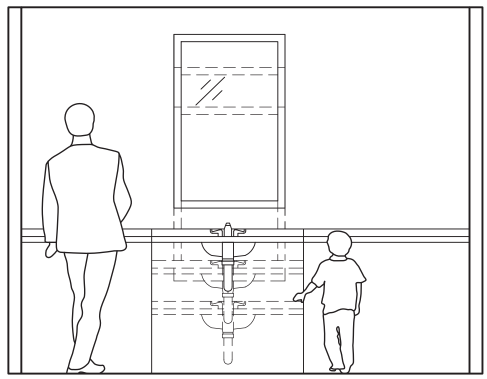
Accommodate a wide range of body sizes and abilities (see Figure 1.7).

GOAL TWO: COMFORT

Keep demands within desirable limits of body function (see Figure 1.8).

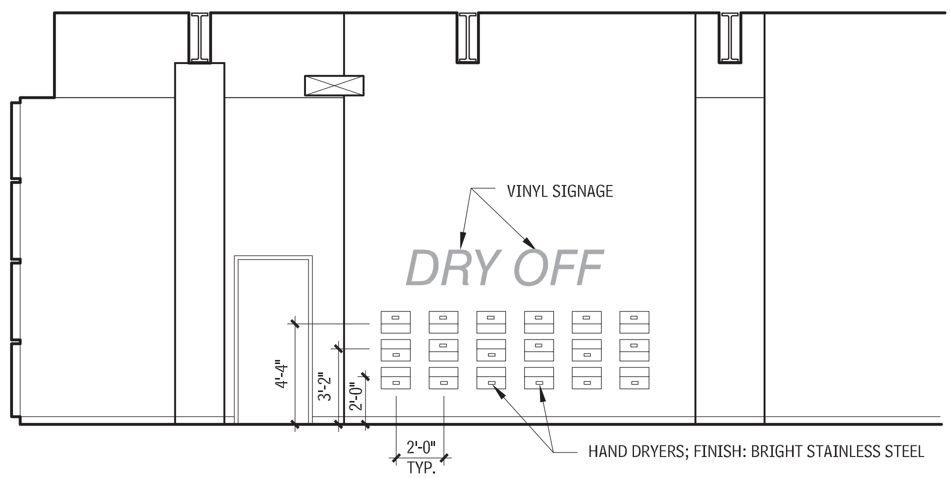
ADJUSTABLE-HEIGHT LAVATORY AND VANITY
1.8

In addition to achieving the goals of body fit and personalization, this adjustable-height lavatory and vanity allows adults and children to comfortably reach the faucets and use the mirror.



WATER PLAY ENVIRONMENT—WALL OF DRYERS
1.7

Architect Koning Eizenberg Architecture and the exhibit designers, Springboard Architecture Communication Design, turned a mundane hand dryer into something more at the Pittsburgh Children's Museum. They took an object that is simple to use and clear in its utility, multiplied it, mounted it within multiple reach ranges, and transformed it into an experience.



NOTE

1.7 Springboard Architecture Communication Design LLC, Pittsburgh.

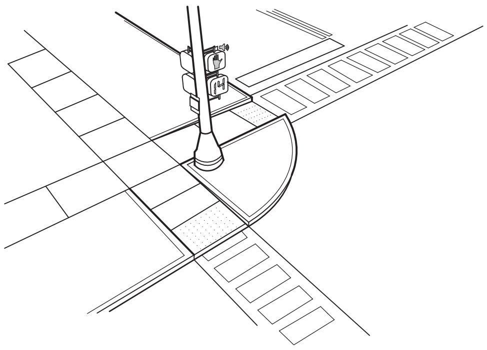
Contributors:
Dr. Ed Steinfeld, AIA and Jonathan White, Center for Inclusive Design and Environmental Access (IDeA Center), University at Buffalo, New York

GOAL THREE: AWARENESS

Ensure critical information for use is easily perceived.

MULTISENSORY INTERSECTION DESIGN
1.9

This intersection design has several features that improve awareness for all people. Curb ramps with return curbs guide pedestrians in the direction of the safe crossing zone. The detectable warnings let people know they are about to enter the street. Countdown timers, pictograms, and an audible beacon all let people know when it is safest to cross while high-contrast markings alert drivers to the presence of a crossing zone.

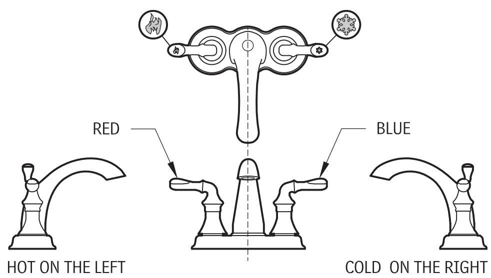


GOAL FOUR: UNDERSTANDING

Methods of operation and use are intuitive, clear, and unambiguous.

FAUCET FOLLOWING COMMON CONCEPTUAL MODEL
1.10

This faucet follows the common conceptual model of having the cold lever on the right and hot on the left. The faucet is coded with color and pictograms to aid in understanding by children and non-English speakers: blue snowflake for cold, red flame for hot.



GOAL FIVE: WELLNESS

Contribute to health promotion, avoidance of disease, and prevention of injury.

MULTIMODAL STREETSCAPE SECTION
1.11

This right-of-way provides a choice of transportation method, encouraging healthy alternatives to the automobile.

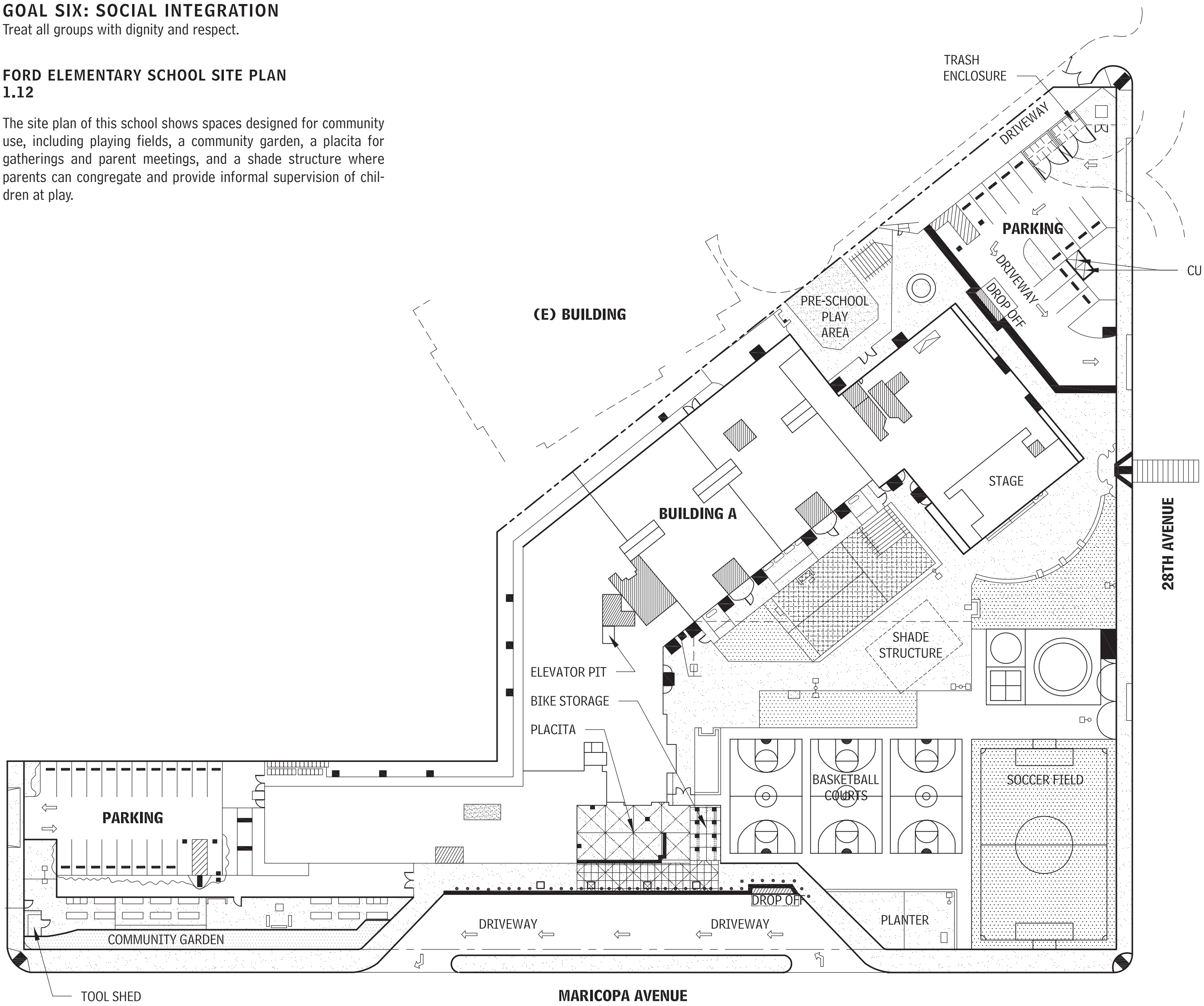
Contributors:
Dr. Ed Steinfeld, AIA and Jonathan White, Center for Inclusive Design and Environmental Access (IDeA Center), University at Buffalo, New York

GOAL SIX: SOCIAL INTEGRATION

Treat all groups with dignity and respect.

FORD ELEMENTARY SCHOOL SITE PLAN 1.12

The site plan of this school shows spaces designed for community use, including playing fields, a community garden, a placita for gatherings and parent meetings, and a shade structure where parents can congregate and provide informal supervision of children at play.



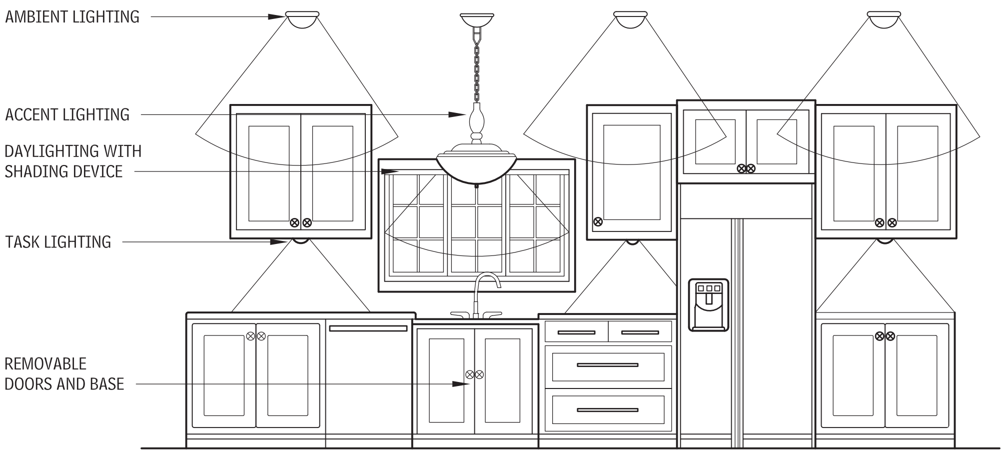
Contributor:
Sally Swanson Architects, San Francisco, California

GOAL SEVEN: PERSONALIZATION

Incorporate opportunities for choice and the expression of individual preferences.

KITCHEN LIGHTING
1.13

Kitchens are one room of the house requiring sufficient light for detailed tasks such as cutting vegetables. This kitchen has several levels of lighting to suit anyone's preference or needs and adjust for different times of day and mood.

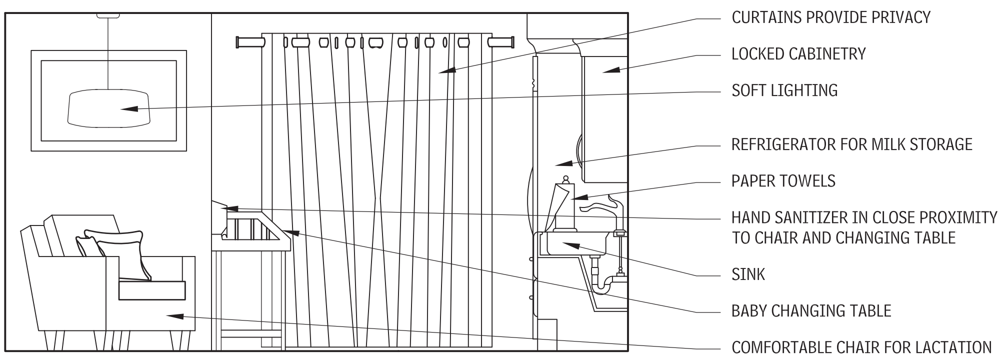


GOAL EIGHT: CULTURAL APPROPRIATENESS

Respect and reinforce cultural values and the social and environmental context.

LACTATION ROOM
1.14

Lactation rooms are an increasingly common example of how to break down cultural barriers, allowing mothers to comfortably breastfeed or pump with privacy if desired.



ACCESSIBLE DESIGN

"Accessible" is a design term first appearing in the 1950s, describing elements of the physical environment that are usable by people with disabilities. Originally, the term described facilities that wheelchair users would be able to access, but the term has evolved to include designs for a wider group of people with more diverse needs, such as people with hearing and vision limitations.

Continuing advances in medicine and technology have changed the character of disability since the introduction of accessible design. The population with disabilities is now more diverse, with many more people who have severe disabilities able to live independently and participate in community life. New technologies for wheeled mobility, including power wheelchairs, scooters, and seating and positioning systems, have increased the complexity of design for wheeled mobility. New building technologies, such as residential elevators, wheelchair lifts, and power-door operators, have made the provision of accessible facilities more practical and less expensive. Accessible design will continue to change as medical advances and technologies continue to evolve.

From an architect's perspective, appropriate accessible design for public facilities and multifamily housing is different from custom design of residences or workplace accommodations for people with disabilities. Public accessibility standards establish general design specifications that broadly accommodate minimal needs. Design for a specific user in a private residential setting or work environment should address that user's specific needs and involve much more interaction with the client to ensure the design accommodates the person's preferences. It is also likely that people with disabilities will appreciate universal design approaches because they improve function beyond minimum requirements and increase social participation and safety.

LAWS, REGULATIONS, AND STANDARDS

Architects should become familiar with the federal legislative process and its terminology to help them understand the intent of laws, their requirements, and their continuing evolution. A "law" is an act of a legislative body. A "regulation" is developed by a regulatory agency such as the Department of Justice or the Department of Housing and Urban Development. A regulation defines the specific ways that a law is implemented. A "standard" is a stand-alone document, often used to implement a regulation. A "voluntary consensus standard" is developed by a standards organization such as the American National Standards Institute (ANSI) or the National Fire Protection Association (NFPA), which has rules governing the process of standards development to ensure equity and fairness. A standard can be referenced by a model code, which can in turn be adopted by a regulatory agency. Standards can also be issued by standards setting agencies of the government and referenced in their own regulations. "Guidelines" are a general term that can refer to nonbinding design criteria or to the equivalent of standards. Guidelines are sometimes issued by one government agency and then adopted as standards by another. Laws can also incorporate standards by reference or even include their full text.

At present, the laws, regulations, and standards governing the implementation of accessible design are highly complex; therefore, architects must educate themselves, and stay abreast of current developments to ensure that they have a good grasp of the requirements. Further, it behooves the architect to research the applicable laws, regulations, and standards that apply to each specific building carefully. Federal laws such as the Americans with Disabilities Act (ADA) and Fair Housing Amendments Act (FHAA), have built-in penalties for architects whose work does not comply. Thus, there is an incentive for the architect to understand thoroughly the legal requirements of accessible design regulations and their underpinnings. Guidance information such as technical assistance manuals and bulletins on interpretation are available on all the federal regulations, although it is not all collected in one place. In addition to the regulations themselves, additional information is available in the legislative history of each act and in the numerous documents issued during the "rule-making process." Architects can monitor rule-making activities to anticipate new rules and avoid unpleasant surprises late in the design stages of projects.

Contributors:
Dr. Ed Steinfeld, AIA and Jonathan White, Center for Inclusive Design and Environmental Access (IDeA Center), University at Buffalo, New York

Available information at the state and local level may be more difficult to find but most state regulations are based on federal requirements or model codes. The architectural guidelines and standards for laws such as the ADA are periodically revised through the rule-making process. To understand the complex nature of accessible design laws, regulations, and standards, architects should first understand the legislative process and accessible design regulatory history.

ACCESSIBLE DESIGN LEGISLATIVE PROCESS

Civil rights laws are the basis for accessible design requirements. Governing bodies such as the United States Congress, state legislatures, and local governments enact laws to achieve a particular public policy objective; for instance, the right of people with disabilities to access and use public buildings. The legislation specifies the measures necessary to achieve the policy objective. The legislation might directly reference a particular standard or it might authorize a government agency to develop and maintain a guideline or standard. The administrative process for implementing federal laws requires public notice in the Federal Register and a public comment period for any proposed new regulations or guidelines. Federal standards become regulations when the Department of Justice incorporates them in the Code of Federal Regulations. States have similar processes and often have parallel legislation.

Civil rights laws often include provisions for both facility design and operations. Provisions that address operations create legal responsibilities that are shared between facility designers and facility operators. Architects should carefully record programming decisions with implications for accessibility, since the intended use of a new space often establishes the specific accessibility requirements that apply. For example, in the ADA, requirements for an employee workspace are different from those for a public space. If a facility operator changes the use of a space after the building is completed, compliance becomes the owner's rather than the architect's responsibility. Architects should carefully evaluate an owner's project funding sources to determine which local, state, and/or federal accessibility requirements apply. It is important to do this prior to preliminary design because the requirements can affect some basic early design decisions.

Accessibility regulations have two parts: technical criteria and scoping requirements. Technical criteria are the specifications for how to achieve the policy objective; i.e., "what and how." For example, to ensure people who use wheeled mobility devices can use a drinking fountain, there must be a knee clearance height of at least 27 in. Scoping is the extent to which the technical criteria must apply; i.e. "when and where." The technical criteria may apply to all project elements or to only a fraction of the elements. Scoping criteria specify how many items of what type need to be accessible, for example, at least 50 percent of drinking fountains, or 100 percent of dwelling units. One level of complexity in current accessibility regulations is caused by the presence of scoping requirements in different sections of regulations. For example, there may be scoping provisions in a beginning section of the document, and there may be scoping provisions integrated with the technical criteria. Often there are exceptions and conditional options buried deep within the technical criteria of the documents that are difficult to find.

Sometimes, scoping and technical criteria can be in two different documents. State and local governments often adopt a document developed by the International Code Council and the American National Standards Institute, the *ICC/ANSI A117.1 Standard,* to achieve their public policy objectives. Some may adopt it using a separate law while others incorporate it via reference in their building codes along with other fire and safety standards. The International Building Code (IBC) includes scoping provisions but adopts the A117.1 standard by reference for its technical provisions. Currently, ICC/ANSI A117.1 is the only consensus standard for accessible design in the United States. Since 1986, no versions of A117.1 have scoping criteria. The IBC model code and the state or local codes usually base their scoping criteria on federal regulations. The purpose of removing the scoping was to encourage adoption by states and promote uniformity; however, many states and some municipalities have modified the IBC scoping criteria and several states have their own independent accessibility "code" that differs substantially from the ICC/ANSI A117.1 standard.

The federal government empowers its standard-setting agencies to develop their own standards and processes for implementing disability rights laws such as the ADA and FHAA; however, the U.S. Access Board, a small federal agency, is charged with developing accessibility guidelines for several federal laws. This creates a complex relationship between the Access Board's guidelines, federal regulations of different agencies, and the state and local building codes across the United States. Although many of the accessible design requirements in the civil rights laws and the codes are similar, there have been considerable differences, especially since state and local rule-making, federal rule-making activities, and the revision cycles of model standards and codes are not synchronized. Despite significant efforts to harmonize national model codes and ICC/ANSI A117.1 with the federal requirements, there are still differences.

Due to this complexity, architects must be able to determine which laws, regulations, and standards apply to any project and which is more stringent for any particular element. To help reduce complexity, federal agencies identify "safe harbors," which are regulations or standards the agency certifies to be substantially similar to their own standards, permitting their use as an alternative to the federal regulations. However, federally specified safe harbors are sometimes older standards, already superseded by state or local regulations. Furthermore, unlike municipal officials, federal agencies do not issue building permits and typically do not inspect construction prior to occupancy unless they are funding a project. Civil rights law enforcement is a "complaint-based process." Federal agencies may choose to act on a citizen complaint, or a complainant may elect to seek direct relief through federal courts. Legal decisions regarding such complaints gradually refine unclear rules but the policies embedded in those decisions are not organized for designers to easy reference. Victims of discrimination under the Act can be awarded compensatory and/or punitive damages. Courts can also order remediation in the form of renovations to buildings, to bring them into compliance. Retrofitting and other conditions of remediation are considerably more expensive than complying with the law in the first place when costs are minimal. There is no statute of limitations on compliance. Complaints may be filed at any time, and violations are often uncovered during the course of due diligence. The latter can affect the sale and sales price of a property. The responsibility for compliance rests with building owners, architects, contractors, and others involved in the design and construction of covered buildings.

To add to the complexity, some of the regulations have not changed at all since they were issued while others have changed considerably. For example, while the ADA Standards were revised significantly in 2010, the FHAA Guidelines have not been changed since they were issued in 1991, the same year the original ADA Standards were issued. Some federal agencies still use "legacy" accessibility standards such as the Uniform Federal Accessibility Standards (UFAS) for some of their construction programs, and recent standards such as the 2010 ADA Standards for other programs. When more than one program is used to fund a single project, the applicable standards can be quite difficult to ascertain. Further, the date of construction or application for a building permit can trigger different regulations and standards. When architects are hired to assess compliance with building codes, they need to know what regulations or standards were in force at the time the building was designed or constructed and what applies in the present. Architects should therefore monitor federal activities related to the type of buildings they design and be familiar with the legislative history of different laws to ensure they are aware of the most current regulations, design standards, and interpretations.

REGULATORY HISTORY OF ACCESSIBLE DESIGN

In the 1950s and 1960s, disabilities rights advocates organized and petitioned federal, state, and local governments to enact legislation that would allow people with disabilities to have access to the same public institutions to which others have access.

In 1961, ANSI published the first national standard for accessible design: Accessible and Usable Buildings and Facilities, (A117.1). Many states and local jurisdictions adopted ANSI A117.1 as their accessibility code, although they often modified selected standards to suit their communities. It quickly became the most widely used accessible design standard in the United States.

In 1968, the Architectural Barriers Act (ABA) was the first federal legislation to require accessible design in facilities owned or leased by the federal government, or financed by certain agencies of the federal government. It empowered those agencies to develop standards for accessible design. The ANSI A117.1 Standard was referenced by most of the agencies.

In 1973, Congress passed the Rehabilitation Act to address the absence of federal accessibility standards for buildings constructed by entities receiving federal funds and the lack of an enforcement mechanism. This Act created the Architectural and Transportation Barriers Compliance Board (Access Board) to develop and issue minimum guidelines for design standards to be used by the four federal standard-setting agencies. The Act required any facility built with federal funds, or built by entities that receive federal funds (such as public schools and government contractors) to be accessible to people with disabilities.

A consensus committee periodically revises ANSI A117.1 and in 1980, they expanded it significantly to reflect new research and to include housing standards. By 1982, the Access Board published "Minimum Guidelines and Requirements for Accessible Design" based largely on this document.

In 1984, the four standard-setting agencies (General Services Administration, Department of Defense, Department of Housing and Urban Development, and U.S. Postal Service) developed the Uniform Federal Accessibility Standards (UFAS) to comply with the ABA and the Rehabilitation Act. The 1980 ANSI A117.1 served as the basis for the requirements in UFAS but the agencies added additional scoping requirements and specific sections that apply to the types of buildings they construct and fund. The UFAS requires that at least 5 percent of the units in multifamily and single-family housing projects constructed with any financial assistance from the federal government be accessible to people with mobility impairments and 2 percent to be accessible to people with communication impairments.

In 1988, Congress amended the Fair Housing Amendments Act (FHAA) to prohibit discriminating against individuals based on disability. The U.S. Department of Housing and Urban Development (HUD), which oversees the regulations related to Fair Housing, was given the responsibility of developing regulations for implementing the Act which are called the Fair Housing Accessibility Guidelines (FHAG). Architects need to be aware of HUD's interpretation of this Act. *The Fair Housing Act Design Manual* is the authoritative source of information on interpretations of the FHA regulations. FHAG dwelling units are of a lower accessibility standard than previous dwelling unit requirements found in the UFAS and in many state building codes; however, the regulations apply to *all* units in high-rise buildings and ground floor units in walk-ups.

In 1990, the President signed the Americans with Disabilities Act (ADA) into law. It was a landmark piece of legislation that prohibited discrimination based on disability in employment, state and local government, places of public accommodation, transportation, and telecommunications. It provided new civil rights protections for people with disabilities. New federal accessibility standards, the ADA Accessibility Guidelines (ADAAG), similar to the 1986 ANSI A117.1 Standards, were developed that addressed the design and operation of places of employment (Title I), state and local government facilities and programs (Title II), and privately owned public accommodations (Title III). The ADAAG did not include housing design requirements.

The International Code Council (ICC) started administering the ANSI reorganized A117.1 Standard in 1998 and expanded it to include technical requirements for dwelling and sleeping units consistent with the requirements of the FHAG. These are known as "Type B" dwelling units. The original ICC/ANSI A117.1 and UFAS housing requirements, as amended, became known as "Type A."

Contributors:
Dr. Ed Steinfeld, AIA and Jonathan White, Center for Inclusive Design and Environmental Access (IDeA Center), University at Buffalo, New York

In 2003, ICC/ANSI again expanded A117.1 to add "Accessible Units," which have a higher level of accessibility than the Type A and B units, which are less accessible and have adaptability features. In 2004, the Access Board harmonized their latest ADA-ABA Guidelines with the 2003 version of ICC/ANSI A117.1. Over the next few years, the federal agencies previously using UFAS began using these guidelines to comply with the ABA and Rehabilitation Act.

In 2009, ICC/ANSI A117.1 added a "Type C" unit designation that addresses basic accessibility to single-family homes and other units not covered by other legislation. This is the result of the "visitability" movement started in 1986 by an advocacy organization called Concrete Change, directed by Eleanor Smith. Visitability provides a basic level of access to all homes that supports short-term use by people with disabilities and reduces the cost necessary to adapt the dwelling further. Many states and municipalities mandate visitable housing but there is a lot of variability in the requirements and scope of coverage. The Type C units provide a uniform set of guidelines for local and state adoption. A proposed federal law, the Inclusive Housing Design Act, would require visitability in all new housing receiving federal assistance, which could include any federal mortgage insurance. The details of Type C and visitability ordinances are not discussed here because it is a subject more appropriate for the Architectural Graphic Standards for Residential Construction.

In 2010, the Department of Justice published new ADA Standards for Accessible Design based on the 2004 ADA-ABA guidelines. It includes guidance for residential dwelling units. In 2014, HUD began allowing use of the 2010 ADA Standards as an acceptable alternative to UFAS (with certain exceptions found in the Federal Register at 79 FR 29671). Designers may use UFAS for projects under the auspices of HUD if they choose, and must use UFAS where required by HUD's exceptions.

ICC/ANSI anticipates publication of a new edition of A117.1 in 2016. This version will have major changes to fundamental requirements such as clear floor space and turning space based on more recent research than the research underlying the current standards, which was conducted in the late 1970s. While it is too early to know when state, local, or federal entities will adopt the 2016 edition, architects should begin familiarizing themselves with the new requirements as they generally exceed current minimum requirements and provide accessibility for a greater number of people with disabilities.

DETERMINING THE APPROPRIATE STANDARD

Architects practicing in the United States understandably may be overwhelmed by the long regulatory history of accessible design and the complex way in which it is implemented. The following table can help designers determine the appropriate accessible design standard to use for any given project. The first step is to determine which laws and regulations apply. Project accessibility requirements may be determined by answering the following questions:

- What type of building or structure will be built?
- Who owns the facility?
- Will some construction funds come from a government agency?
- What other government funding will the project receive?
- Who are the intended users of a space or component?

The table lists the applicable standards for many types of projects.

FEDERAL ACCESSIBLE DESIGN REQUIREMENTS

AMERICANS WITH DISABILITIES ACT (ADA) REQUIREMENTS

The 2010 ADA Standards include design requirements for new facility construction, and for additions to and alterations of existing facilities that are owned, leased, or operated by both private entities and state or local governments. However, design standards and management responsibilities differ between the two owner groups: Title II for state and local governments and Title III for private entities. Title II includes the regulations at 28 CFR 35.151 and Title III includes the regulations at 28 CFR 36 subpart D. Both include the 2004 ADA-ABA Guidelines at 36 CFR part 1191, appendices B and D. The DOJ published these requirements collectively as the 2010 ADA Standards for Accessible Design.

Under Title III, owners and operators of existing private facilities that serve the public have ADA construction responsibilities under what is called "readily achievable barrier removal." Under Title II, local governments also have the additional responsibility of making all their new and existing programs accessible and are held to a higher standard. Meeting this ADA responsibility for municipal programs may sometimes require new construction or physical modifications to existing facilities. The ADA also prescribes employer responsibilities for changing their policies or modifying their facilities to accommodate employees with disabilities (Title I).

Several ADA concepts affect the design requirements for any specific building, such as "path-of-travel" components for renovation projects and the "elevator exception" for small multistory buildings. It is imperative that architects familiarize themselves with these aspects of the law as well as with the design standards to help their clients fulfill their responsibilities.

The concept of "program accessibility," which is similar to Section 504 of the 1973 Rehabilitation Act for Federal Programs, is a key component of Title II. The ADA requires state and local governments to provide access to all their programs for people with disabilities. Local government program responsibility includes policies and operations as well as the built environment. To provide access to existing inaccessible programs, state and local governments were required to develop and implement a "transition plan" that included a self-evaluation and listed the necessary changes. State and local governments should have implemented those transition plans by now. The plan can address inaccessible programs by altering policies and procedures, by modifying physical structures, or by a combination of both strategies. Although not every habitable space in every existing building needs to be accessible, enough accessible spaces to ensure access to all programs are needed. For example, if a school has only one accessible science laboratory and it is not sufficient to accommodate all grade levels, another accessible laboratory may be needed.

In new construction, all spaces need to be accessible, unless otherwise noted by the regulations.

FAIR HOUSING AMENDMENTS ACT (FHAA) REQUIREMENTS

The FHAA covers new multifamily housing constructed by either private entities or local governments. Generally, the FHAA covers projects with four or more total dwelling or sleeping units in one structure that are built for sale or lease. This includes apartments and condominiums, as well as all types of congregate living arrangements such as dormitories, boarding houses, sorority and fraternity houses, group homes, assisted-living facilities, and nursing homes. Even condominiums that are individually designed are covered. The law applies to all units if the building has an elevator or only ground floor units if there is no elevator. Only the first floor of multistory units must comply with the law. Townhouses can be exempted because they are multistory units and do not contain an elevator but they must be constructed a certain way to be considered single-family units. Existing housing structures, remodeling, conversion, or reuse projects are not covered by FHAA. The law's design standards include requirements for both individual dwelling units and common-use facilities such as lobbies, corridors, and parking.

The Fair Housing Accessibility Guidelines (FHAG) allow the exclusion of certain dwelling units because of site considerations such as steep topography and floodplains. The guidelines include site practicality tests for analyzing site constraints. Several major scoping issues such as multistory dwelling units and multiple ground-floor levels are discussed in the supplementary information included in the FHAG.

The requirements are modest and do not constitute full accessibility, yet they address a growing demand from the aging population (market) for housing in which they can live more safely and for a longer period. To assist design professionals in meeting the requirements for compliance, HUD has developed training and published the *Fair Housing Act Design Manual*. Prior to project design, architects should carefully review this material as well as the guidelines themselves.

The Fair Housing Accessibility Guidelines have seven basic design requirements. Refer to the Technical Criteria section of this chapter for detailed information on how to comply with the seven design requirements:

1. Accessible Building Entrance on an Accessible Route
2. Accessible Public and Common Areas
3. Usable Doors
4. Accessible Route Into and Through the Covered Unit
5. Light Switches, Electrical Outlets, Thermostats, and Other Environmental Controls in Accessible Locations
6. Reinforced Walls for Grab Bars
7. Usable Kitchens and Bathrooms

HUD recognizes the following 10 safe harbors. When used with the Fair Housing Act, HUD's regulations, and the Guidelines, compliance with any one of these will fulfill the Fair Housing Act's access requirements:

1. HUD Fair Housing Accessibility Guidelines published on March 6, 1991 and the Supplemental Notice to Fair Housing Accessibility Guidelines: Questions and Answers about the Guidelines, published on June 28, 1994
2. HUD Fair Housing Act Design Manual
3. ANSI A117.1 (1986)
4. CABO/ANSI A117.1 (1992)
5. ICC/ANSI A117.1 (1998)
6. Code Requirements for Housing Accessibility, 2000 (CRHA)
7. International Building Code (2000), as amended by the 2001

APPLICABLE ACCESSIBILITY STANDARDS FOR SAMPLE PROJECTS
1.15

PROJECT DESCRIPTION	LAWS	STANDARDS
Federally owned, leased, or financed public facility	1968 Architectural Barriers Act 1973 Rehabilitation Act	ABA Standards (similar to 2010 ADA Standards for Accessible Design)
Federally owned, leased, or financed housing	1968 Architectural Barriers Act 1973 Rehabilitation Act 1988 Fair Housing Amendments Act (if multifamily)	UFAS or 2010 ADA (with exceptions) UFAS or 2010 ADA (with exceptions) Fair Housing Accessibility Guidelines, ICC/ANSI A117.1 (2003), or other Safe Harbor
Local government-owned public facility	1990 Americans with Disabilities Act (Title II) 1973 Rehabilitation Act (if part of federal program or receiving federal funding)	2010 ADA Standards for Accessible Design ABA Standards (similar to 2010 ADA Standards for Accessible Design)
Local government-owned housing	1990 Americans with Disabilities Act (Title II) 1973 Rehabilitation Act (if part of federal program or receiving federal funding) 1988 Fair Housing Amendments Act (if multifamily)	2010 ADA Standards for Accessible Design UFAS or 2010 ADA (with exceptions) Fair Housing Accessibility Guidelines, ICC/ANSI A117.1 (2003), or other Safe Harbor
Privately owned public accommodation or commercial facility	1990 Americans with Disabilities Act (Title III)	2010 ADA Standards for Accessible Design
Privately owned multifamily housing	1990 Americans with Disabilities Act (Title III) (public spaces) 1988 Fair Housing Amendments Act (private spaces)	2010 ADA Standards for Accessible Design Fair Housing Accessibility Guidelines, ICC/ANSI A117.1 (2003), or other Safe Harbor

NOTES

1.15 a. All projects may be subject to state or local laws and building codes in addition to those listed above.
b. There may be various combinations of the project descriptions above. For example, a private tenant in a government-funded building, or a federal program operating out of a privately owned building, such as a Social Security office in a mall.
c. Certain buildings may be exempt from federal requirements such as religious facilities; however, exemptions may not apply if the organization receives government funding, such as for meals or childcare programs, or if they have tenants not covered by the exemption.
d. Temporary facilities must meet the same federal standards as similar permanent facilities.

Contributors:
Dr. Ed Steinfeld, AIA and Jonathan White, Center for Inclusive Design and Environmental Access (IDeA Center), University at Buffalo, New York

Supplement to the International Codes
8. International Building Code (2003) *with one condition
9. ICC/ANSI A117.1 (2003) *with one condition
10. International Building Code (2006)

Other solutions and standards may be used only if they meet or exceed the minimum specifications set forth in the guidelines. The ICC/ANSI A117.1 Standard only contains technical criteria so it must be used in conjunction with the scoping requirements found in the Act, the regulations, and guidelines or the IBC. It is generally advised to use the most recent safe harbors, as those are more likely to have greater consistency with state and local codes.

Following the Fair Housing Act Guidelines is not the same as providing full accessibility. These requirements, like the accessibility requirements for places of public accommodation, are minimum guidelines. Some states and local jurisdictions will require greater accommodations than the FHAG. Thus, architects may want to consider going further, for example meeting ICC/ANSI A117.1 Type A unit requirements in all units, and ICC/ANSI A117.1 (Accessible Units) requirements in at least 5 percent of each unit type.

TECHNICAL CRITERIA

As discussed earlier, technical criteria are the design specifications for achieving compliance with various laws. The scoping section of the applicable standard or building code will specify when, where, and how many elements need to conform to the technical criteria. Sometimes, the technical criteria change depending on scoping. This section will illustrate the typical technical criteria as specified by ICC/ANSI A117.1 (2009) and will provide some alternatives that would allow minimum compliance with certain laws such as the FHA. It will also illustrate best practices to exceed the minimum specifications. This section focuses primarily on design for wheeled mobility because their needs have the greatest effect on building design. There are many other requirements not illustrated here.

HOW TO USE THIS SECTION

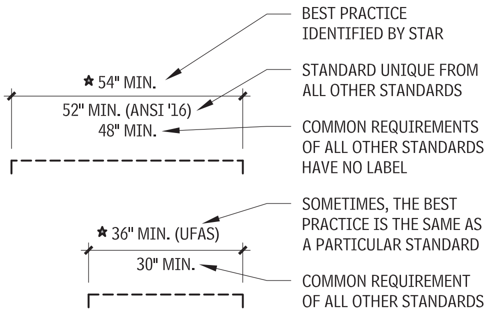
The drawings and illustrations presented herein combine the requirements for several standards and regulations and include best practices as well. A star identifies dimensions in illustrations that are best practices, typically exceeding the minimum dimensions. Illustrations without a star have no research evidence to support one dimension over another. The illustrations also note new requirements that have been approved for inclusion in the upcoming 2016 edition of ICC/ANSI A117.1, as of the time of this writing, although not finalized prior to publication of this book. Sometimes, the ICC/ANSI A117.1 (2016) dimension is also a best practice because it was adopted based on the latest research. Some illustrations may have multiple dimensions: (1) best practice (identified by star), (2) ICC/ANSI A117.1 (2009) requirements (no label), and (3) requirements of other standards or future standards (labeled accordingly). As with any resource book, it is important to realize that the illustrations depict general compliance requirements under typical conditions. Unless otherwise specified, the dimensional requirements in this section represent minimum and maximum requirements as specified by ICC/ANSI A117.1 (2009). Consult with applicable codes and standards for more detailed specifications.

BUILDING BLOCKS

"Building blocks" provide the design foundation for accessibility and universal design. Designing access for wheeled mobility users provides generous space clearances for all building users and makes the built environment feel spacious and comfortable for all people. Critical components of the building blocks include floor surfaces, maneuvering and turning space, knee and toe clearance, and functional reach distances. The building blocks are a set of rules that apply in similar ways across a variety of spaces and situations. Learning the building blocks is a critical step for all designers and architects toward creating inclusive and accessible spaces.

GRAPHICS KEY
1.16

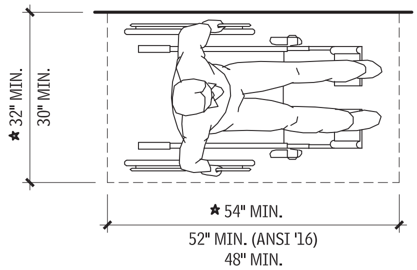
This figure represents the way in which technical criteria are dimensioned in this chapter.



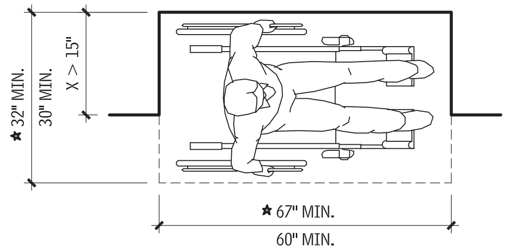
MANEUVERING CLEARANCES

MANEUVERING CLEARANCES
1.17

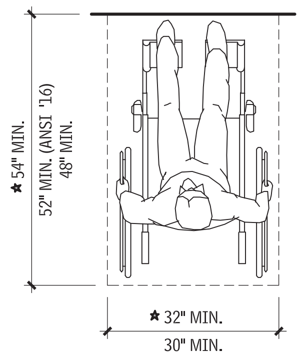
Floor surfaces of a clear floor space must have a slope no steeper than 1:48. One full, unobstructed side of the clear floor space must adjoin or overlap an accessible route or adjoin another clear floor space.



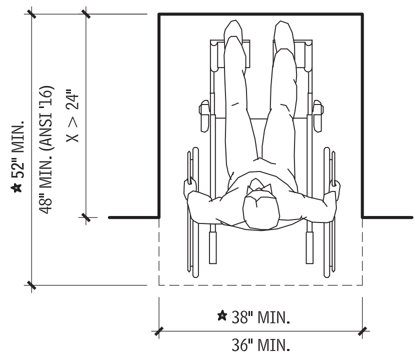
PARALLEL APPROACH



PARALLEL APPROACH–ALCOVE



FORWARD APPROACH



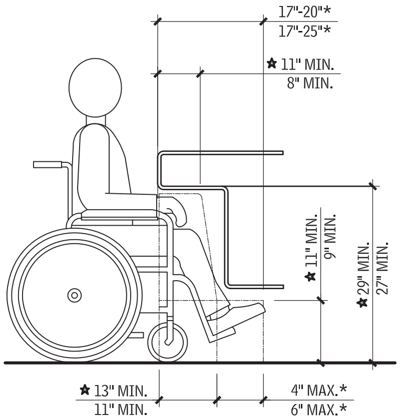
FORWARD APPROACH–ALCOVE

Contributors:
Dr. Ed Steinfeld, AIA and Jonathan White, Center for Inclusive Design and Environmental Access (IDeA Center), University at Buffalo, New York

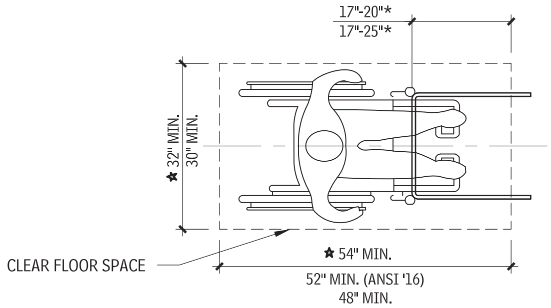
KNEE AND TOE CLEARANCES
1.18

Designers have the option of using a T-shaped or circular turning space where a turning space is required.

KNEE AND TOE CLEARANCES: ELEVATION



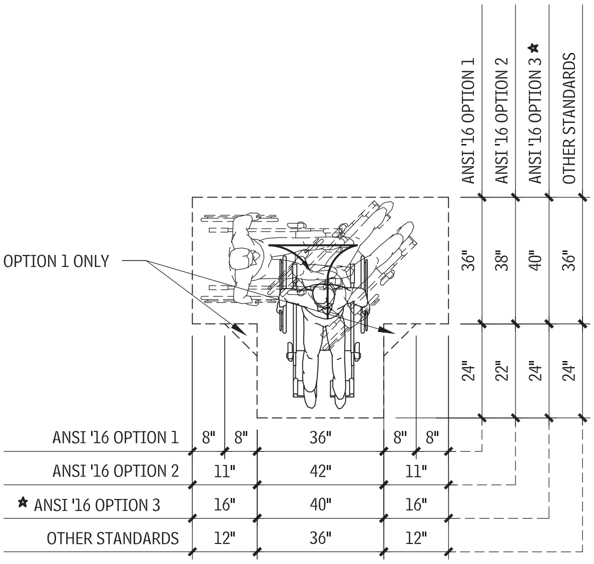
KNEE AND TOE CLEARANCES: PLAN



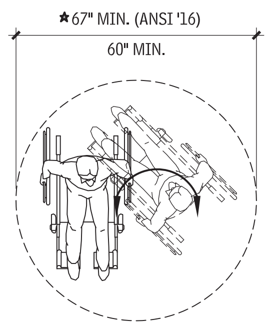
* MAY EXCEED MAXIMUM, BUT MAY NOT BE COUNTED AS PART OF CLEAR FLOOR SPACE

WHEELCHAIR TURNING SPACE
1.19

Knee and toe clearance that is included as part of a T-shaped turning space is allowed only at the base of the T, or on one arm of the T. In some configurations, the obstruction of part of the T-shape may make it impossible for a wheelchair user to maneuver to the desired location. ICC/ANSI A117.1 (2016) will require that knee and toe clearance included as part of a circular turning space overlap only 10 in. of the circular turning space. Floor surfaces of a turning space must have a slope that is no steeper than 1:48 and has no level changes.



MIN. T-SHAPED TURNING SPACE DIMENSIONS

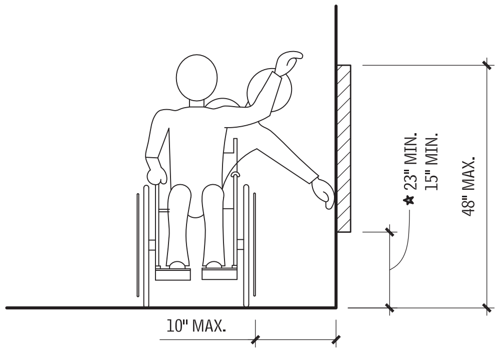


MIN. CIRCULAR TURNING SPACE DIMENSIONS

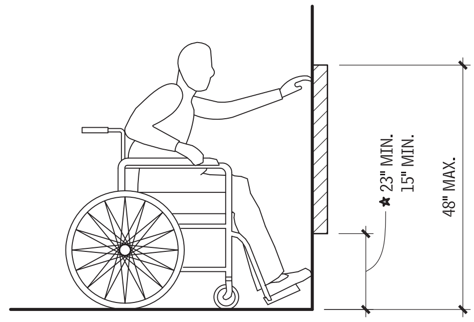
Contributors:
Dr. Ed Steinfeld, AIA and Jonathan White, Center for Inclusive Design and Environmental Access (IDeA Center), University at Buffalo, New York

REACH RANGES
1.20

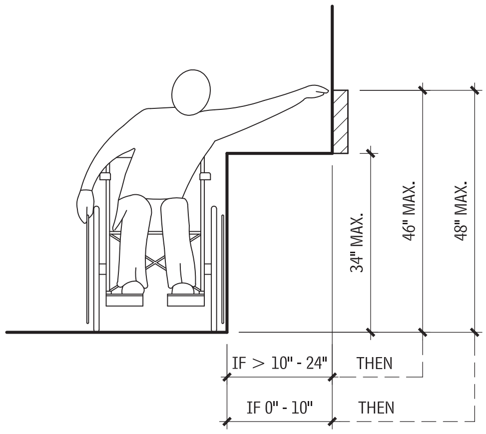
Existing elements may be located 54 in. maximum above the floor or ground. The 48-in. reach limit does not apply to tactile signs. Tactile signs must be installed so the tactile characters are between 48 and 60 in. above the floor. Below this height, tactile characters are difficult to read by standing people, as the hand must be bent awkwardly or turned over (similar to reading upside down) to read the message.



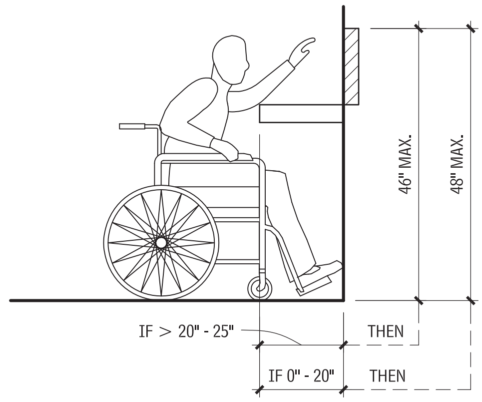
UNOBSTRUCTED SIDE REACH



UNOBSTRUCTED FORWARD REACH



OBSTRUCTED SIDE REACH



OBSTRUCTED FORWARD REACH

ACCESSIBLE ROUTES AND WALKING SURFACES

REQUIREMENTS FOR ACCESSIBLE ROUTES

Accessible routes generally require the following:

- *Site arrival points:* From each type of site arrival point (public transportation stops, accessible parking spaces, passenger loading zones, and public streets or sidewalks) to an accessible entrance.
- *Entrances:* Consult the applicable regulation to determine the required number of accessible entrances. Standards generally require that at least 60 percent of the public entrances, but no less than one, be accessible. The FHAG requires at least one, but may exempt some facilities from this requirement due to extreme site conditions. Consult the FHAG for site implacability tests; however, the prevailing attitude is that most sites can be made accessible.
- *Within a site:* Between accessible buildings, facilities, elements, and spaces on the site.
- *Interior routes:* Where an accessible route is required and the general circulation path is an interior route, the accessible route must also be an interior route.
- *Relation to circulation paths:* Accessible routes must coincide with or be located in the same area as a general circulation path. Avoid making the accessible route a "second-class" means of circulation. Consult the applicable regulations for additional specific requirements regarding location of accessible routes.
- *Directional signs:* Where the accessible route departs from the general circulation path and is not easily identifiable, directional signs should be provided as necessary to indicate the accessible route. The signs should be located so that a person does not need to backtrack.
- *Multilevel buildings and facilities:* Between all levels, including mezzanines, in multistory buildings, unless exempted.
- *Accessible spaces and elements:* An accessible route must connect all spaces and elements that are required to be accessible.
- *Toilet rooms and bathrooms:* The ADA and model codes generally require that all toilet and bathing rooms be accessible. This does not trigger a requirement for accessible routes if the floor level is not otherwise required to have an accessible route.

COMPONENTS OF ACCESSIBLE ROUTES

Accessible routes are only permitted to include the following elements:

- Walking surfaces with a slope of 1:20 or less
- Curb ramps
- Ramps
- Elevators
- Platform (wheelchair) lifts (The use of lifts in new construction is limited to locations where they are specifically permitted by the applicable regulations. Lifts are generally permitted to be used as part of an accessible route in alterations.)

Each component has specific technical criteria that must be applied for use as part of an accessible route. Consult the applicable code or regulation.

CURBS AND PARKING

Follow these design guidelines for accessible curb ramps and passenger loading.

- Design storm drainage utilities to shed water away from curb ramps.
- The dimensions shown are for new construction. When these dimensions are impractical for alterations, refer to guidelines and standards.
- Refer to applicable codes, standards, and regulations for detectable warning requirements and locations. Some have unique requirements and others do not include requirements for these features.

PASSENGER LOADING ZONES

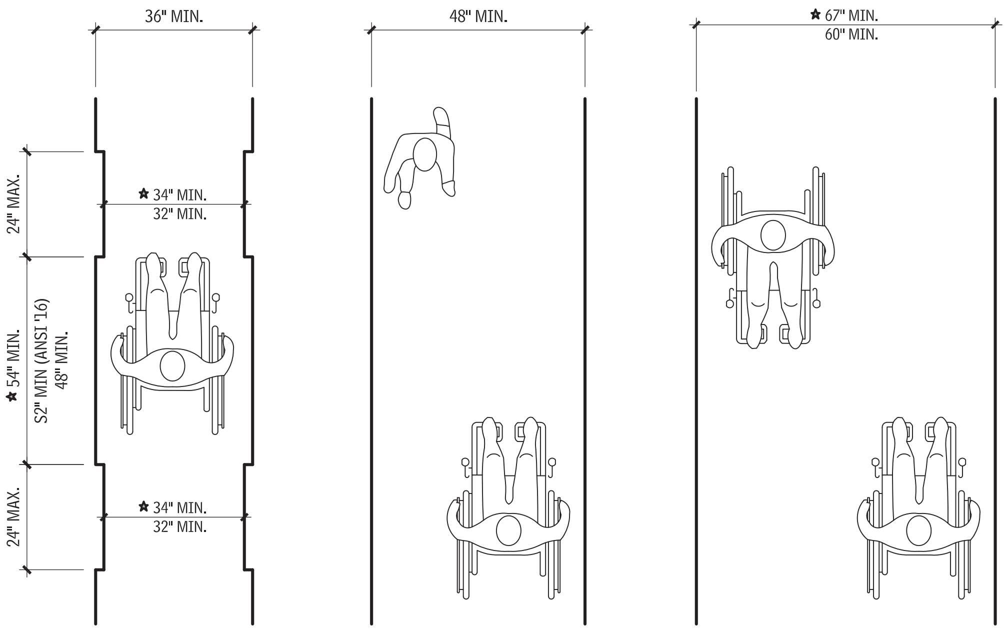
If passenger loading zones are provided, at least one must be accessible or one accessible space for each 100 linear feet of passenger loading zone provided. An accessible passenger loading zone is also required where there is valet parking.

The accessible passenger loading zone vehicle space must have an adjacent access aisle as long as the vehicle space. The access aisle must be marked, at the same level as the vehicle pull-up space, and adjoin an accessible route, including a curb ramp if the passenger loading zone is not level with the adjacent sidewalk. Curb ramps, signs, or other objects are not permitted in the access aisle.

The vehicle pull-up space and access aisle must be level, with slopes no steeper than 1:48. The accessible parking loading zone and the vehicular route to the entrance and exit serving it must have a vertical clearance of 9 ft-6 in., minimum.

Contributors:
Dr. Ed Steinfeld, AIA and Jonathan White, Center for Inclusive Design and Environmental Access (IDeA Center), University at Buffalo, New York

CLEAR WIDTH OF AN ACCESSIBLE ROUTE
1.21

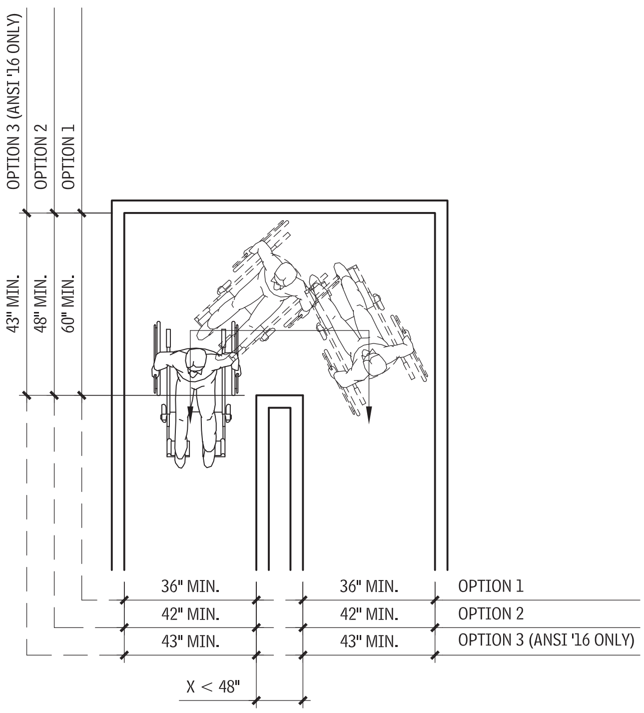


INTERIOR ACCESSIBLE ROUTE FOR SINGLE WHEELCHAIR

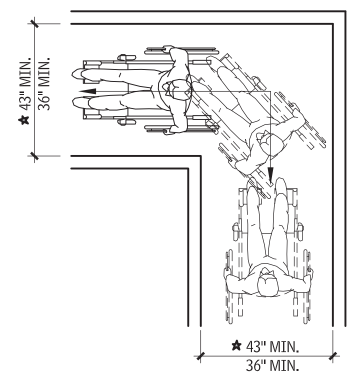
EXTERIOR ACCESSIBLE ROUTE (ANSI '16) AND AMBULATORY PERSON PASSING WHEELCHAIR

ACCESSIBLE ROUTE ALLOWING 180° TURN AND TWO PASSING WHEELCHAIRS

CLEAR WIDTH AT TURNS
1.22



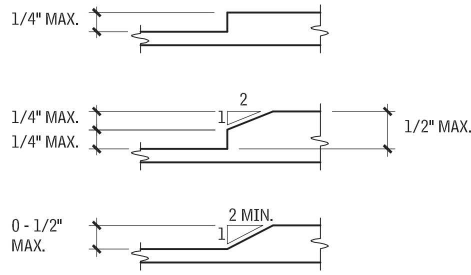
180° TURN AROUND AN OBSTRUCTION



90° TURN

CHANGES IN LEVEL
1.23

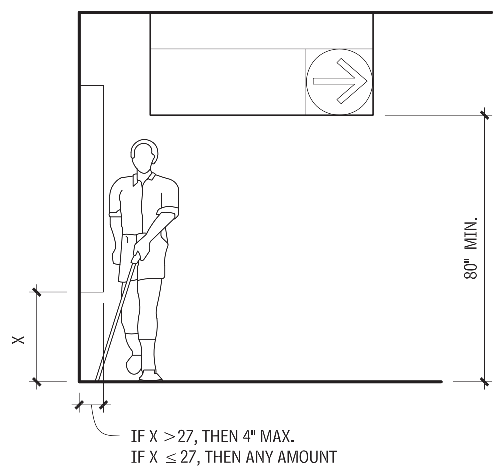
Changes in level greater than 1/2 in. must be ramped. Some standards prohibit changes in level in clear floor space, maneuvering clearances, wheelchair turning space, and access aisles.



PROTRUDING OBJECTS IN CIRCULATION PATHS

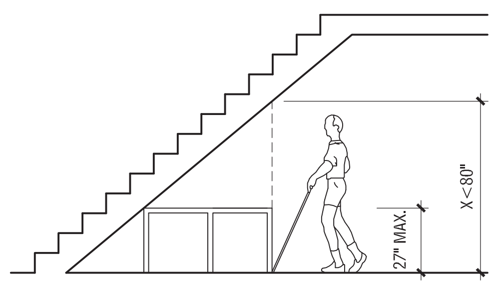
DIMENSIONS OF PROTRUDING OBJECTS
1.24

Wall sconces, fire extinguisher cabinets, drinking fountains, display cases, signs, and suspended lighting fixtures are examples of protruding objects. Some standards allow doorstops and door closers 78 in. minimum above the floor. Protruding objects are not permitted to reduce the required width of an accessible route.



REDUCED VERTICAL CLEARANCE
1.25

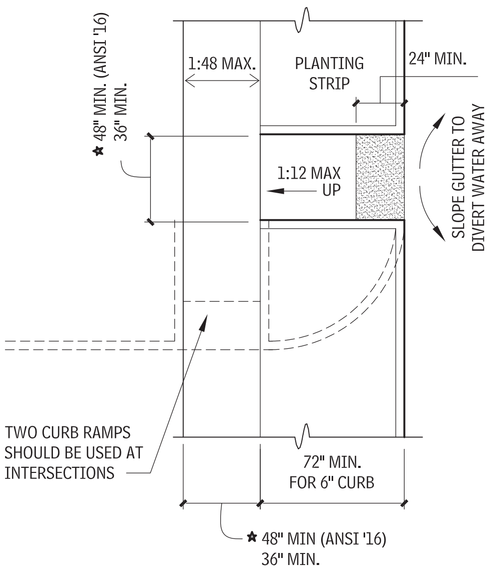
Protection from overhead hazards can be provided by built-in elements such as planters or railings, or curbs. Designers can reduce or eliminate most overhead hazards (e.g., low-headroom hazards can be avoided by enclosing areas under stairs and escalators).



Contributors:
Dr. Ed Steinfeld, AIA and Jonathan White, Center for Inclusive Design and Environmental Access (IDeA Center), University at Buffalo, New York

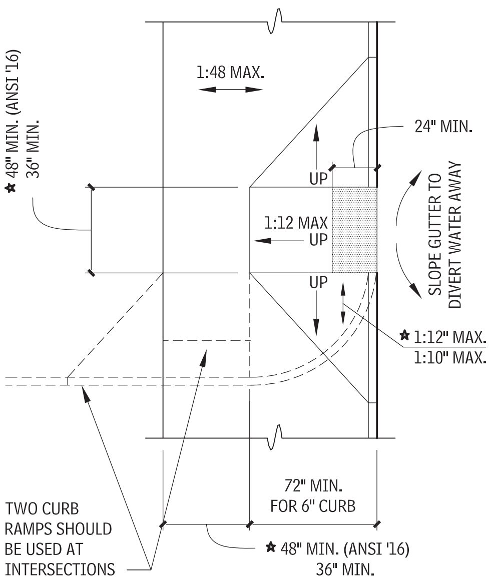
CURB RAMP WITH RETURN CURB
1.26

Use this where planting strip or other objects reduce likelihood of pedestrians walking perpendicular across ramp.



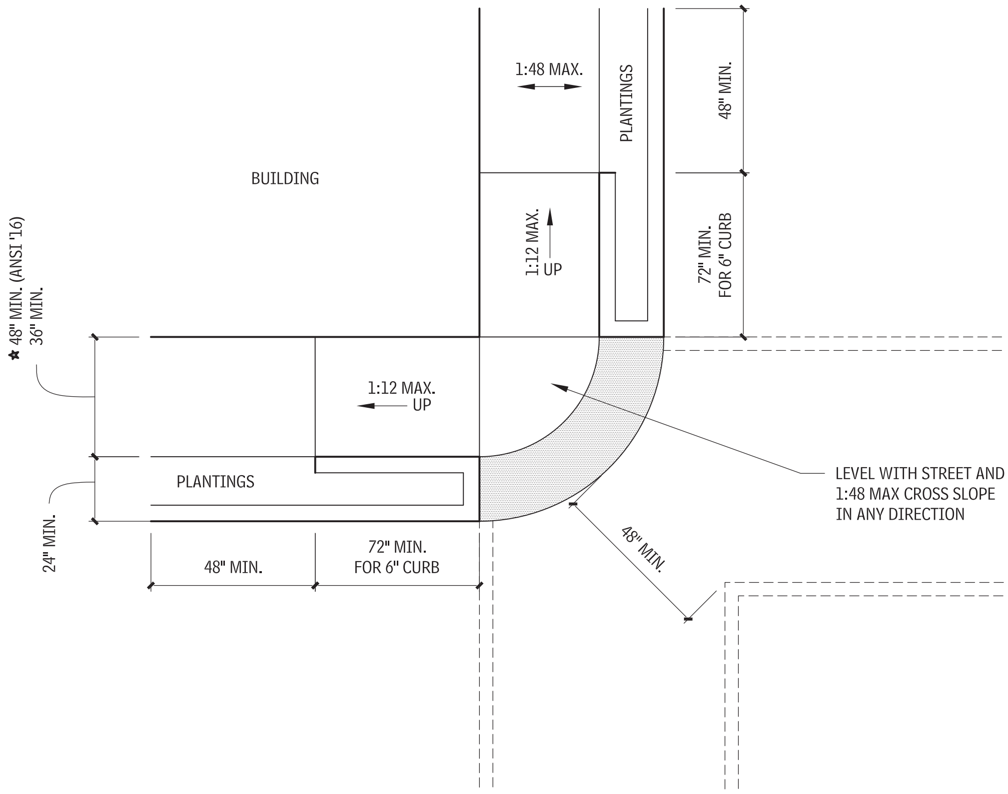
CURB RAMP WITH FLARE
1.27

Use this to prevent tripping if pedestrians could walk perpendicular across ramp.



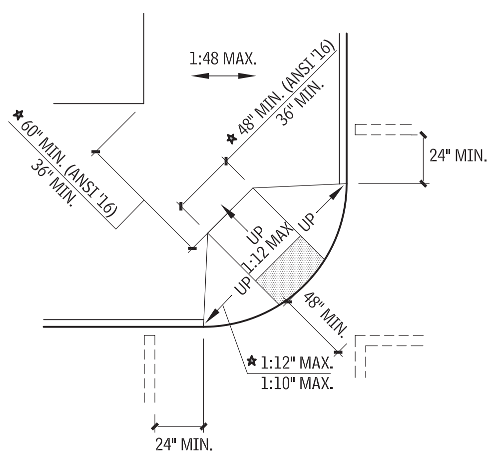
BLENDED EDGE
1.28

Use this for high-volume pedestrian traffic when distance between vehicular way and structure is very narrow.



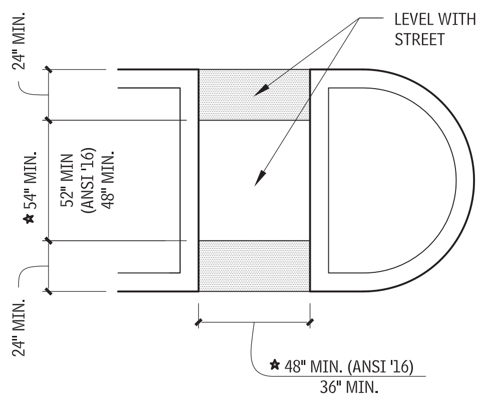
DIAGONAL CURB RAMP
1.29

Use this where there is insufficient space for two curb ramps at a corner.



CUT-THROUGH ISLAND
1.30

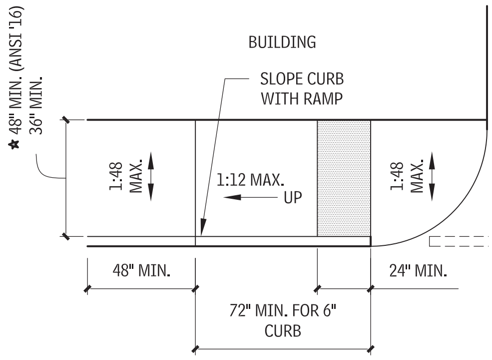
Use this where a crosswalk would otherwise be obstructed by an island.



Contributors:
Dr. Ed Steinfeld, AIA and Jonathan White, Center for Inclusive Design and Environmental Access (IDeA Center), University at Buffalo, New York

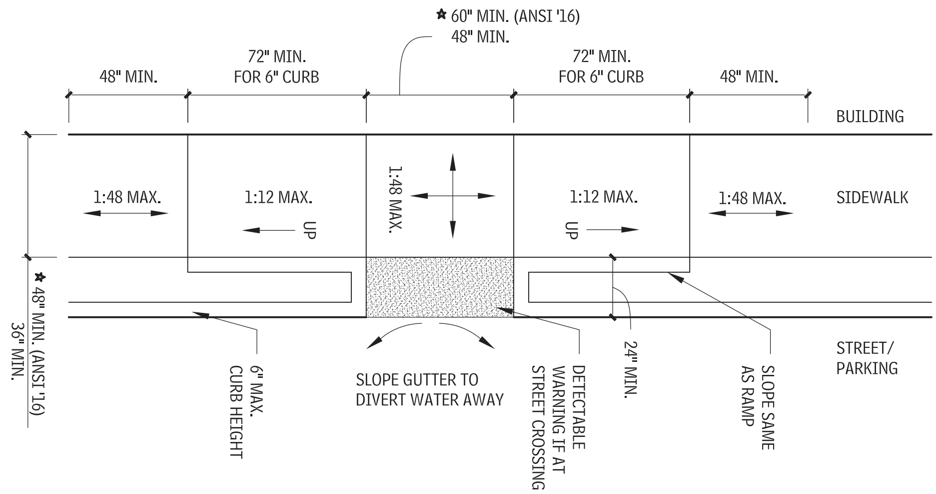
PARALLEL CURB RAMP
1.31

Use this where pedestrian route only crosses a vehicular way in one direction.



90-DEGREE TURN TO CURB RAMP
1.32

Use this when there is insufficient sidewalk space for return curb or flares at an access aisle or mid-block crossing.

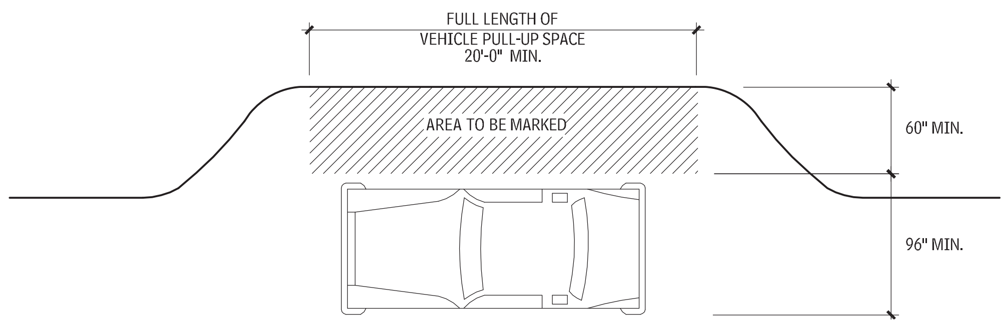


ACCESSIBLE PARKING

The information provided here conforms to the 2010 Americans with Disabilities Act Standards for Accessible Design. State and local regulations may require greater access (for example, some states require wider access aisles).

- The access aisles must be accessible from the passenger side of the vehicle. Backing into 90-degree stalls from a two-way aisle is an acceptable method of achieving this; but with angled parking, the aisle must be on the right side of the vehicle space.
- Vehicular overhead clearance at a van-accessible stall, adjacent access aisle, and along the path of travel to and from a van-accessible stall should be 8 ft-2 in. In parking structures, van-accessible stalls may be grouped on a single level.
- Access aisles must be clearly marked to prohibit parking and be the same length as the adjacent parking space. They also must be at the same level as parking stalls (not above, at sidewalk height). Required curb ramps cannot be located in access aisles.
- Parking spaces and access aisles should be level, not exceeding 1:48 (≈2 percent) in any direction.
- The stalls required for a specific facility may be relocated to another location if equivalent or greater accessibility in terms of distance, cost, and convenience is ensured.
- Accessible stalls in the numbers shown in the accompanying table must be included in all parking facilities.
- The access aisle must join an accessible route to the accessible entrance. As a best practice, designers should configure accessible routes to minimize wheelchair travel behind parked vehicles.
- Signs with the International Symbol of Accessibility are required for accessible spaces. Signs must be mounted 5 ft. minimum from the ground surface to the bottom of the sign.
- Accessible parking spaces must be on the shortest accessible route to the accessible building entrance. If there is more than one accessible entrance with adjacent parking, accessible parking must be dispersed and located near the accessible entrances. The accessible parking spaces must be located on the shortest route to an accessible pedestrian entrance in parking facilities that do not serve a particular building.
- When different types of parking are provided (for example, surface, carport, and garage spaces), the accessible parking spaces must be dispersed among the various types.

ACCESSIBLE PASSENGER LOADING ZONE
1.33



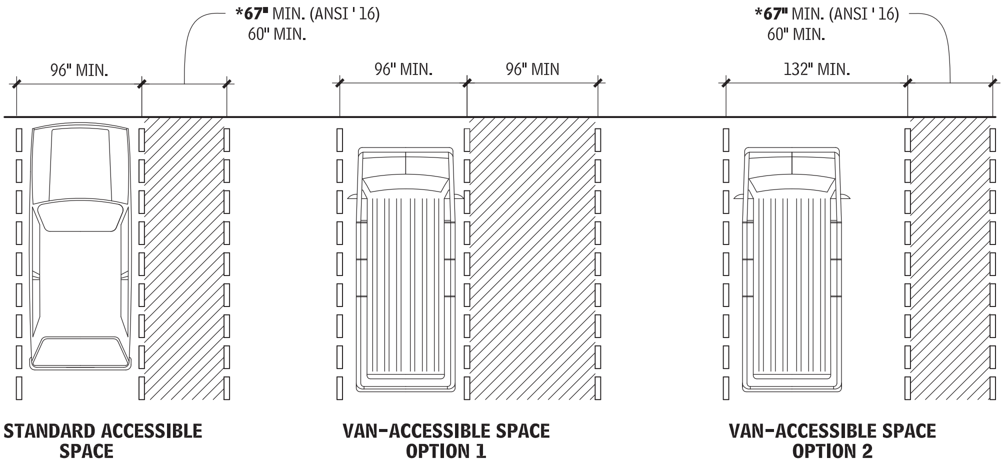
REQUIRED MINIMUM NUMBER OF ACCESSIBLE PARKING SPACES
1.34

TOTAL SPACES PROVIDED	REQUIRED MINIMUM NUMBER OF ACCESSIBLE SPACES	OF THE ACCESSIBLE SPACES, MINIMUM NUMBER REQUIRED TO ALSO BE VAN ACCESSIBLE
1 to 25	1	1
26 to 50	2	1
51 to 75	3	1
76 to 100	4	1
101 to 150	5	1
151 to 200	6	1
201 to 300	7	2
301 to 400	8	2
401 to 500	9	2
501 to 1000	2% of total	1 for every 6 or fraction thereof
More than 1000	20, plus one for each 100 or fraction thereof over 1000	1 for every 6 or fraction thereof

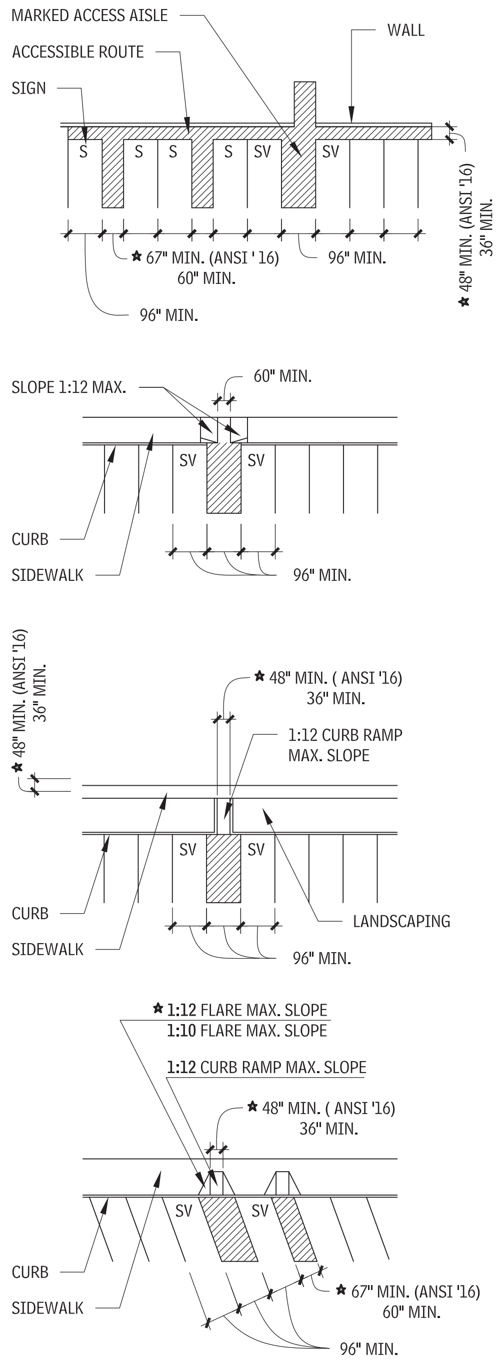
NOTES: The following are exceptions to the requirements outlined in the accompanying table:

1. At hospital outpatient facilities, 10 percent of the parking spaces serving visitors and patients must be accessible.
2. At rehabilitation facilities and outpatient physical therapy facilities, 20 percent of the spaces provided for visitors and patients must be accessible.
3. The information in the table does not apply to valet parking facilities, but such facilities must have an accessible loading zone. One or more self-park, van-accessible stalls are recommended for patrons with specially equipped driving controls.
4. The requirements for residential facilities differ slightly among applicable codes and guidelines, but generally, one space must be provided for each residential dwelling unit required to be accessible. If more than one space is provided per unit, then 2 percent of the additional parking per unit is required to be accessible, in addition to visitor spaces as per the table. This parking must be dispersed among the various types of parking including surface, covered carports, and detached garages.

PARKING SPACE AND ACCESS AISLE LAYOUT
1.35



ACCESSIBLE PARKING LAYOUTS
1.36

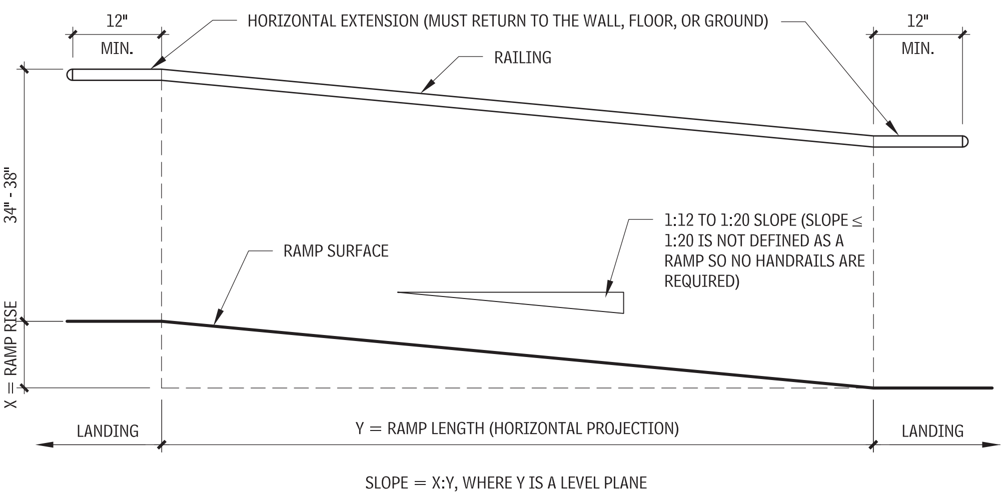


S = ACCESSIBLE PARKING SIGN
SV = VAN-ACCESSIBLE PARKING SIGN

RAMPS

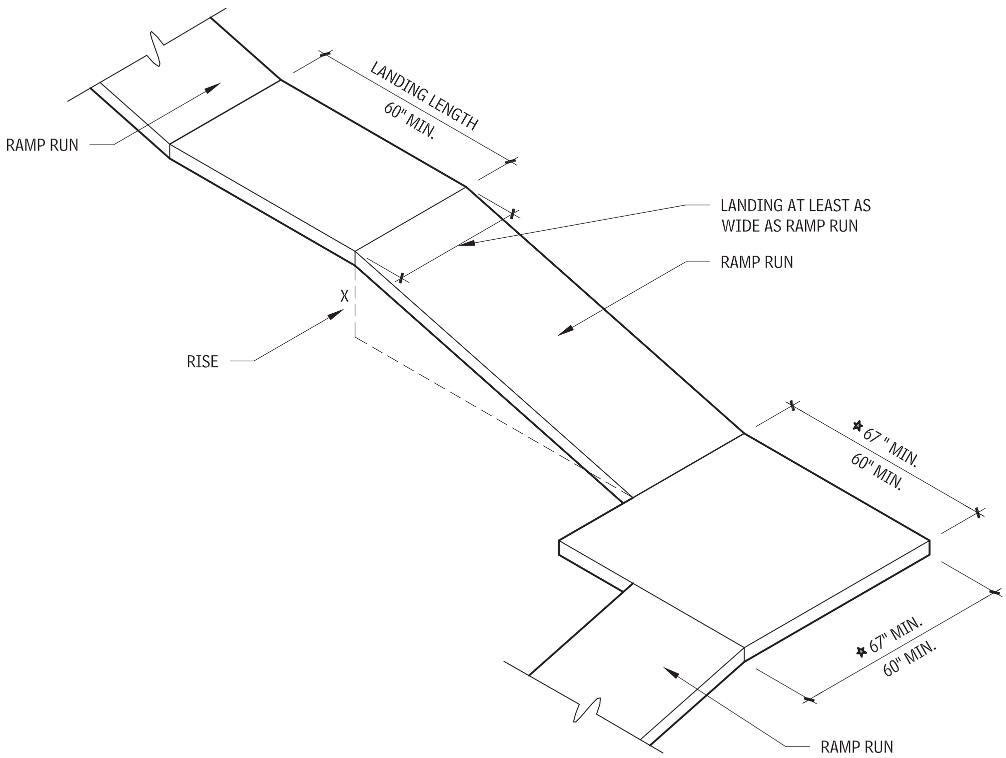
COMPONENTS OF A RAMP
1.37

Surfaces with a running slope greater than 1:20 are considered ramps. Accessible ramps must have running slopes of 1:12 or less. Provide ramps with the least possible running slope. Wherever possible, accompany ramps with stairs for use by those individuals for whom distance presents a greater barrier than steps. Maximum cross slope for ramps is 1:48. Design outdoor ramps and approaches so water will not accumulate on surface.



RAMP LANDINGS
1.38

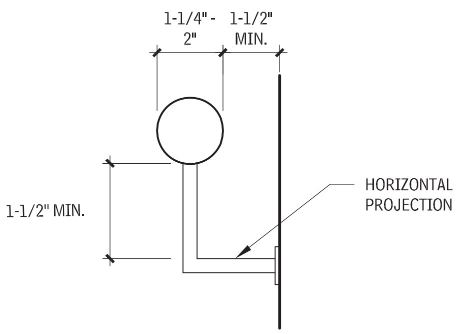
Landings should be level at top and bottom of ramp run and at least as wide as the run leading to it. A landing as shown is required where a ramp changes direction. Provide level maneuvering clearances for doors adjacent to landings. Note that required handrails and ramp edge protection are not shown in this drawing. All ramps must have edge protection and most building codes require a guardrail that does not allow passage of a 4-in sphere when the drop-off adjacent to any walking surface is greater than 30 in. This would include ramps, stairs, and landings.



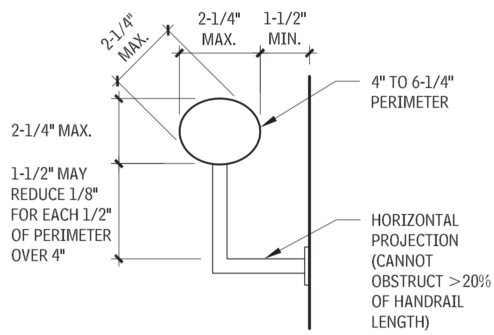
	X	MAXIMUM SLOPE
NEW CONSTRUCTION	ANY RISE	1:12
EXISTING *	6 INCHES MAX.	1:10
EXISTING *	3 INCHES MAX.	1:8

* EXISTING BUILDING EXCEPTION ONLY PERMITTED WHERE NECESSARY DUE TO SPACE LIMITATION

HAND RAIL DESIGN
1.40



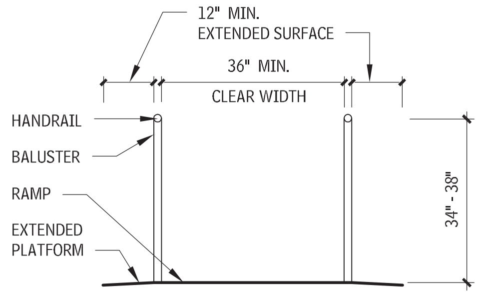
CIRCULAR



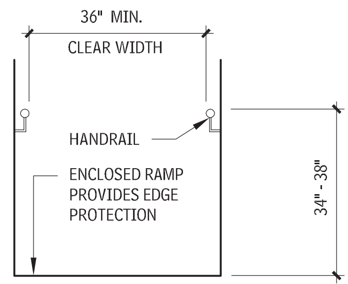
NONCIRCULAR

RAMP CROSS SECTIONS
1.39

Handrails are required on both sides of ramps when rise is greater than 6 in. Provide continuous handrails at both sides of ramps and stairs and at the inside handrail of switchback or dogleg ramps and stairs. If handrails are not continuous at bottom, top, or landings, provide handrail extensions as shown in Figure 1.37. Ends of handrails must be rounded or returned smoothly to floor, wall, or post. Provide handrails of size and configuration shown and gripping surfaces uninterrupted by newel posts or other construction elements. Handrails must not rotate within their fittings. Handrails and adjacent surfaces must be free from sharp or abrasive elements.

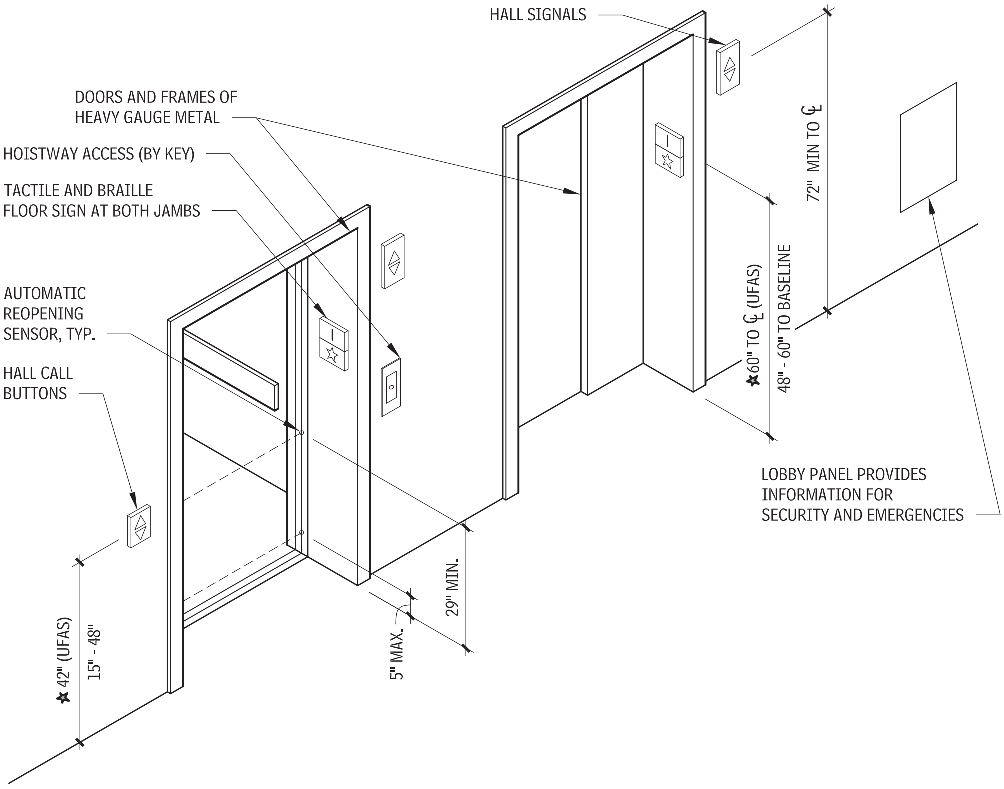


RAMP WITH EXTENDED SURFACE



ENCLOSED RAMP

ELEVATOR LOBBY
1.41



ELEVATORS

LOBBY

Model codes may allow or require elevators to serve as a means of egress in some circumstances when standby power is provided.

Elevator doors must open and close automatically and have a reopening device that will stop and reopen the car and hoistway door if the door is obstructed. Although the device cannot require contact to activate, contact can occur before the door reverses direction. The device must remain effective for at least 20 seconds.

Tactile designations at each jamb of hoistway doors should be 2 in. high, a maximum of 60 in. above the floor. A five-pointed star should be included at the main entry level.

Hall call buttons should be raised or flush, 15 to 48 in. (some standards require 42 in. exact) unobstructed above the floor measured to the centerline of the highest operable part, with the up button located above the down button.

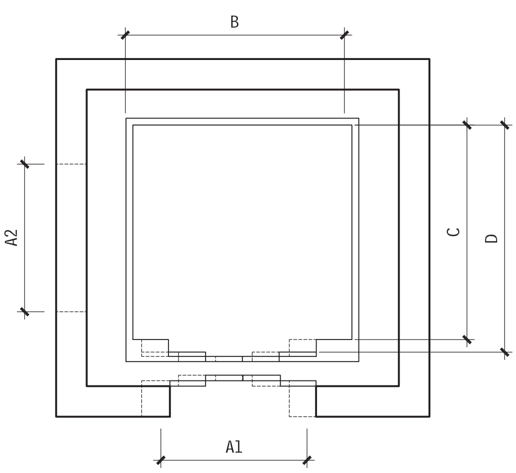
Audible hall signals should sound once for cars traveling in the up direction and twice for cars traveling down. Check the applicable regulations for required decibel level and frequency of audible signals. In-car signals are permitted in lieu of hall signals, as long as they meet all the requirements for visibility and timing.

GENERAL REQUIREMENTS AND CAR INTERIOR

ASME A17.1, "Safety Code for Elevators and Escalators," covers general elevator safety and operational requirements. It has been adopted in virtually all jurisdictions. All sizes shown in this section are based on ICC/ANSI A117.1, which contains extensive accessibility provisions for passenger elevators, destination-oriented elevator systems, limited-use/limited-application elevators, and private residence elevators. Consult the applicable accessibility regulations for elevator exceptions and requirements.

INSIDE DIMENSIONS OF ELEVATOR CARS
1.42

Accessible Elevators: A 5/8-in. tolerance is permitted at 36-in. elevator doors, allowing the use of standard 35.43-in. clear-width doors. Any other car configuration that provides a 36-in. door and either a 60-in. diameter or T-shaped wheelchair turning space within the car, with the door in the closed position, is permitted. Inside car dimensions are intended to allow an individual in a wheelchair to enter the car, access the controls, and exit.



TYPE/USE	DOOR POSITION	A1, A2 MIN."	B MIN."	C MIN."	D MIN."	MIN. SQFT
★ NEW ELEVATOR	**CENTERED**	**42**	**80**	**51**	**54**	**N/A**
NEW ELEVATOR	OFF-CENTER	36	68	51	54	N/A
NEW ELEVATOR	ANY	36	54	80	N/A	N/A
NEW ELEVATOR	ANY	36	60	60	N/A	N/A
PRIVATE RESIDENTIAL ELEVATOR	CENTERED	32	36	52 (ANSI '16) 48	N/A	N/A
NEW LULA	CENTERED	32	42	54	N/A	15.75
EXCEPTIONS:						
EXISTING ELEVATOR	CENTERED	32	36	54	N/A	16
NEW LULA - ADJ. DOOR *	CENTERED	36, 42 *	42	54	N/A	18
NEW LULA - ADJ. DOOR *	CENTERED	36, 36 *	51	51	N/A	N/A
EXISTING LULA	CENTERED	32	36	54	N/A	15

NOTES: * DOORS PROVIDED ON FRONT AND SIDE. SECOND DIMENSION IS ADJACENT SIDE DOOR A2.
LULA DESIGNATES LIMITED-USE/LIMITED-APPLICATION ELEVATOR.

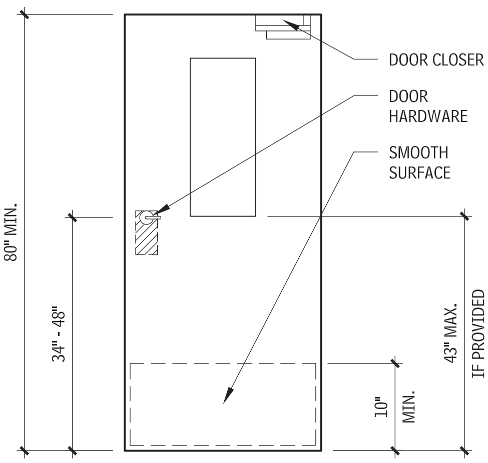
★ DENOTES BEST PRACTICE

ACCESSIBLE DOORS

Manual doors and doorways and manual gates on accessible routes must comply with accessibility requirements. With double-leaf doors and gates, at least one of the active leaves must comply.

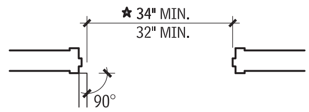
ACCESSIBLE DOOR FEATURES
1.43

Specify door hardware that can be operated with one hand, without tight grasping, pinching, or twisting of the wrist. Thresholds are typically limited to 1/4 in. maximum height, or 1/2 in. maximum height if the top 1/4 in. is beveled at a 1:2 maximum slope; however, some standards allow a 3/4-in. height beveled at a 1:2 maximum slope for existing or altered thresholds and patio sliding doors in some residential dwelling units. Interior doors (other than fire doors) should be able to be operated with 5 lb. of force. Exterior doors and fire doors may be regulated by the authority having jurisdiction. Door closers must be adjusted so that there is at least a five-second interval from the time the door moves from 90° to 12° open.

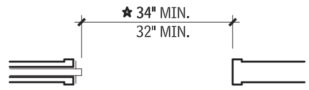


CLEAR WIDTH OF ACCESSIBLE DOORWAYS
1.44

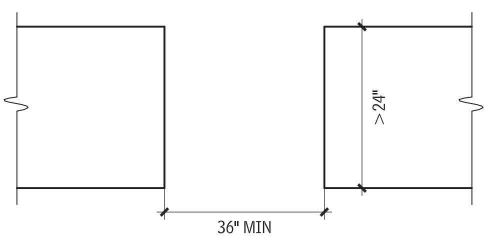
For a hinged door, the clear width is measured between the face of the door and the doorstop with the door open at a 90° angle. For a sliding or folding door, the clear width is measured between the edge of the door and the jamb with the door fully open. Hardware must be accessible with the door in fully open position. Openings and doorways without doors more than 24 in. in depth must have a clear width of 36 in. minimum. Doors in dwelling units covered by FHAG are permitted to have a "nominal" 32-in. clear width. HUD allows a 2 ft-10 in. with 31–5/8-in. clear width swing door to satisfy this requirement. ICC/ANSI A117.1 (2003) allows a 31–3/4-in. clear width in Type B dwelling units.



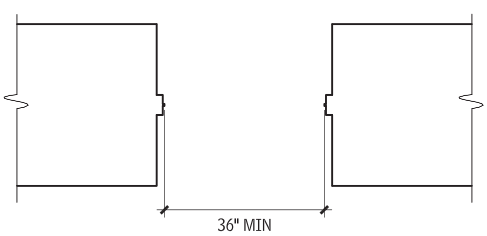
HINGED DOOR



SLIDING OR FOLDING DOOR

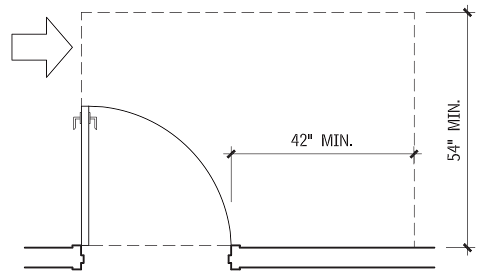


DEEP OPENING

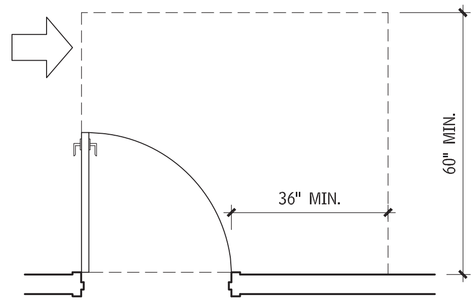


DOORWAY WITHOUT DOOR

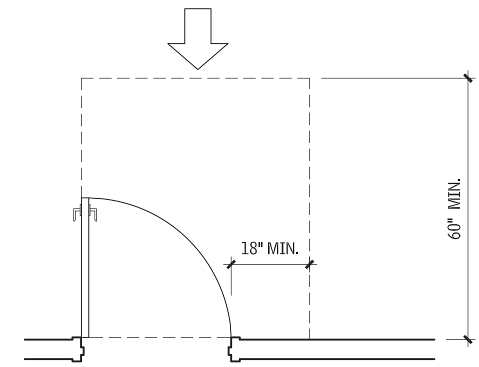
PULL-SIDE MANEUVERING CLEARANCE AT SWINGING DOORS
1.45



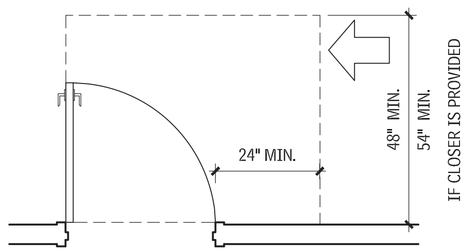
HINGE APPROACH



HINGE APPROACH



FRONT APPROACH



LATCH APPROACH

Contributors:
Dr. Ed Steinfeld, AIA and Jonathan White, Center for Inclusive Design and Environmental Access (IDeA Center), University at Buffalo, New York

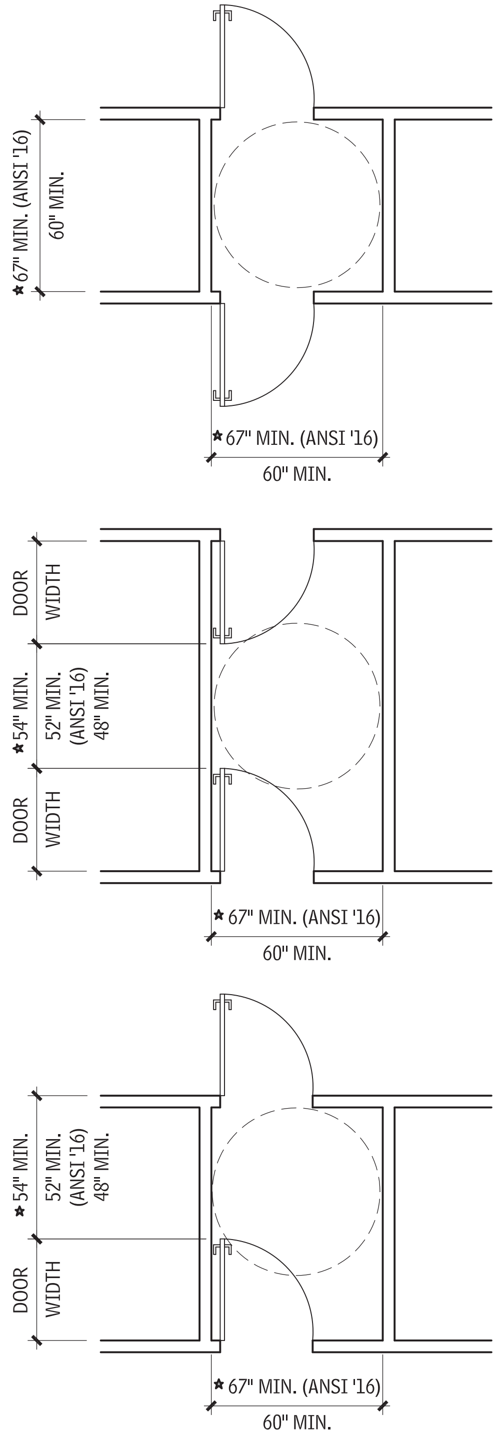
ACCESSIBLE TOILET AND BATHING ROOMS

Accessible design of toilet and bathing rooms is the most complex of any standard and code item. Fixture requirements vary among the common accessibility standards and guidelines. The Americans with Disabilities Act (ADA) Standards for Accessible Design provide accessibility requirements for general public buildings and accommodations as well as residential dwelling units and units in transient lodging, medical and long-term care facilities, and detention and correction facilities. The Fair Housing Accessibility Guidelines (FHAG) include two options for bathroom design, designated as Option A and Option B. The primary difference is that Option B provides a more accessible approach to the bathtub. In covered dwellings with two or more bathrooms, all bathrooms must comply with Option A, or at least one must comply with Option B requirements. In covered units with only one bathroom, either Option A or B may be used. Some residential facilities may be covered by both the ADA and the FHAA—for example, dormitories and nursing homes. HUD also permits the 2010 ADA to be used as an alternative standard (with some exceptions) for residential dwelling units formerly required to comply with UFAS by the ABA or Rehabilitation Act.

ICC/ANSI A117.1 includes the technical requirements for four types of bathrooms with mobility features and the technical requirements for the bathrooms vary significantly among these types:

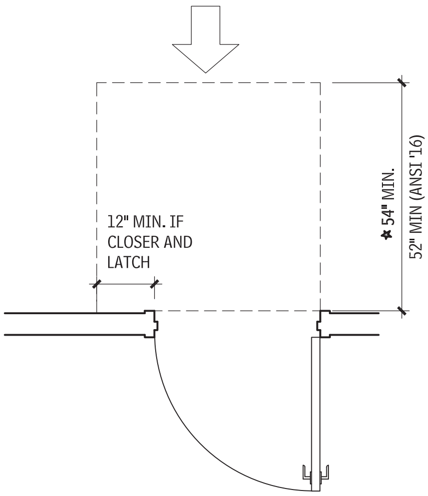
- *Accessible:* Bathrooms not in residential dwelling units or in accessible dwelling units generally have the strictest requirements. The number of accessible units required by the building code typically is based on a percentage of the total number of units provided in the facility.
- *Type A:* Type A dwelling units are required by the building code in multifamily residential facilities, including apartment buildings, condominiums, monasteries, and convents. The number of units required to comply with these requirements is generally based on a percentage of the total number of units provided. Refer to the applicable building code.
- *Type B:* The requirements for Type B dwelling units are intended to be consistent with the technical requirements of the FHAG, although as of the date of this publication, the most recent version of ICC/ANSI A117.1 accepted by HUD as a safe harbor is the 2003 version.
- *Type C:* The requirements for Type C dwelling units are for covered private single-family homes and generally only require first-floor access to a half-bath and Type B clearances at the toilet as well as reinforcement for the future installation of grab bars.

TWO DOORS IN SERIES
1.47

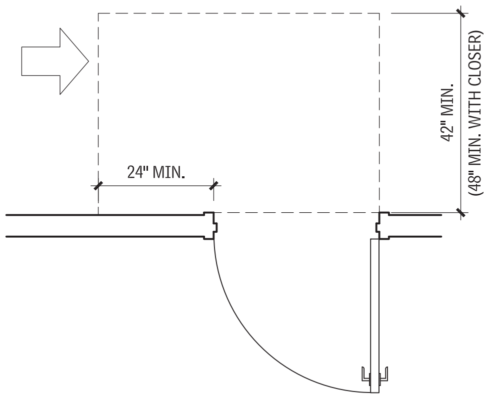


NOTE: Turning space is permitted to overlap door swing where indicated.

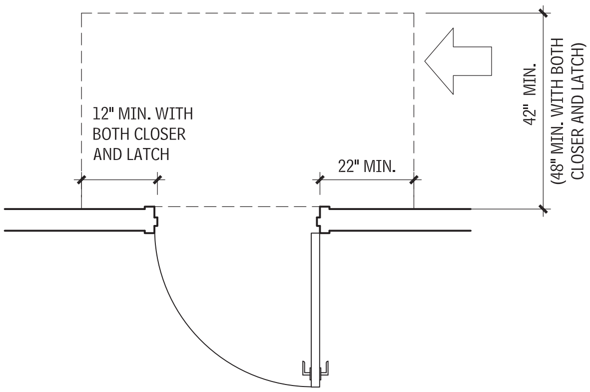
PUSH-SIDE MANEUVERING CLEARANCE AT SWINGING DOORS
1.46



FRONT APPROACH



LATCH APPROACH



HINGE APPROACH

Contributors:
Dr. Ed Steinfeld, AIA and Jonathan White, Center for Inclusive Design and Environmental Access (IDeA Center), University at Buffalo, New York

Approach clearance requirements for the different accessibility standards are illustrated in this section. All dimensional criteria are based on ICC/ANSI A117.1 and adult anthropometrics. The differences among other standards are noted only where more stringent.

LAVATORIES

Generally, knee and toe clearance is required below accessible lavatories. The lavatory overflow is permitted to project into the knee clearance. All residential dwelling unit types require forward approach, with the exception of FHAG and ICC/ANSI A117.1 (Type B and C units), which allow a parallel approach centered on the basin, or removable cabinetry for a future forward approach. ICC/ANSI A117.1 (Type A) and ADA residential dwelling units also allow adaptable cabinetry beneath the lavatory provided it can be removed without removing or replacing the lavatory and the flooring and walls already have a finished appearance.

ICC/ANSI A117.1 (Accessible Units) requires vanity size and proximity to the lavatory to be comparable to the nonaccessible units in a project.

ADA, ICC/ANSI A117.1 (except Type B and C units), and UFAS include requirements for faucets, mirror height, and pipe protection. All pipes located beneath these lavatories must be insulated or otherwise protected to prevent users from contact with the pipes. Lavatory controls should be within accessible reach range, be operable with one hand, and not require tight grasping, pinching, or twisting of the wrist. Automatic controls are acceptable. Manually activated, self-closing faucets should operate for not less than 10 seconds.

Mirrors located above lavatories, sinks, and vanities must be mounted with the bottom edge of the reflecting surface 40 in. maximum above the floor. Other mirrors must be mounted with the bottom edge of the reflecting surface 35 in. maximum above the floor.

URINALS

ICC/ANSI A117.1 allows wall-hung and stall-type urinals; it does not require an elongated urinal rim for a wall urinal; however, other regulations may. Manually operated flush controls must be located 44 in. maximum above the floor.

TOILETS

Generally, no other fixture is permitted in the toilet clear floor space and the toilet must be located adjacent to a side wall to accommodate grab bars. In residential dwelling units, UFAS, ICC/ANSI A117.1 (Types A, B, and C), FHAG, and ADA allow a lavatory within this space. The toilet is not required to be adjacent to a side wall, but if it is not, it must have 18 in. minimum clearance on both sides to accommodate the future installation of swing-up or floor-mounted grab bars. Toilet distance to side wall varies by standard. Refer to Figure 1.49 for dimensional requirements of each standard.

In addition to clearance requirements, UFAS, ICC/ANSI A117.1, and the ADA include provisions for toilet seat height. Seats must not spring to return to a lifted position. They also specify the location and operation of flush controls and toilet paper dispensers. Manually operated flush controls must be located on the open side of the toilet; they may not be centered above the toilet. ICC/ANSI A117.1 (Type A) requirements also include seat height requirements and the location and operation of flush controls. The hatched area in Figure 1.49 indicates the allowable location of the toilet paper dispenser. Dispenser outlets must be within the range shown. Dispensers should allow continuous paper flow, not control delivery.

The grab bar arrangement can influence the floor plan of an accessible bathroom. The grab bar requirements of ICC/ANSI A117.1 (Accessible and Type A), UFAS, and ADA can become critical factors in toilet and bathroom arrangements. Figure 1.49 depicts typical grab bar positions at the toilet. The ADA, ICC/ANSI A117.1 (Types A, B, and C), and FHAG allow reinforcement for future installation of grab bars in residential dwelling units in lieu of pre-installed grab bars. ICC/ANSI A117.1 (Types B and C) and FHAG grab bar standards permit a 24-in. side grab bar if space does not allow a 42-in. grab bar. ICC/ANSI A117.1 (Types B and C) and FHAG also allow the installation of swing-up grab bars in lieu of side- and rear-wall grab bars, so the wall adjacent to the toilet may be shorter or omitted entirely. Swing-up grab bars must be on both sides of the toilet, centered 15.75 in. from the toilet centerline.

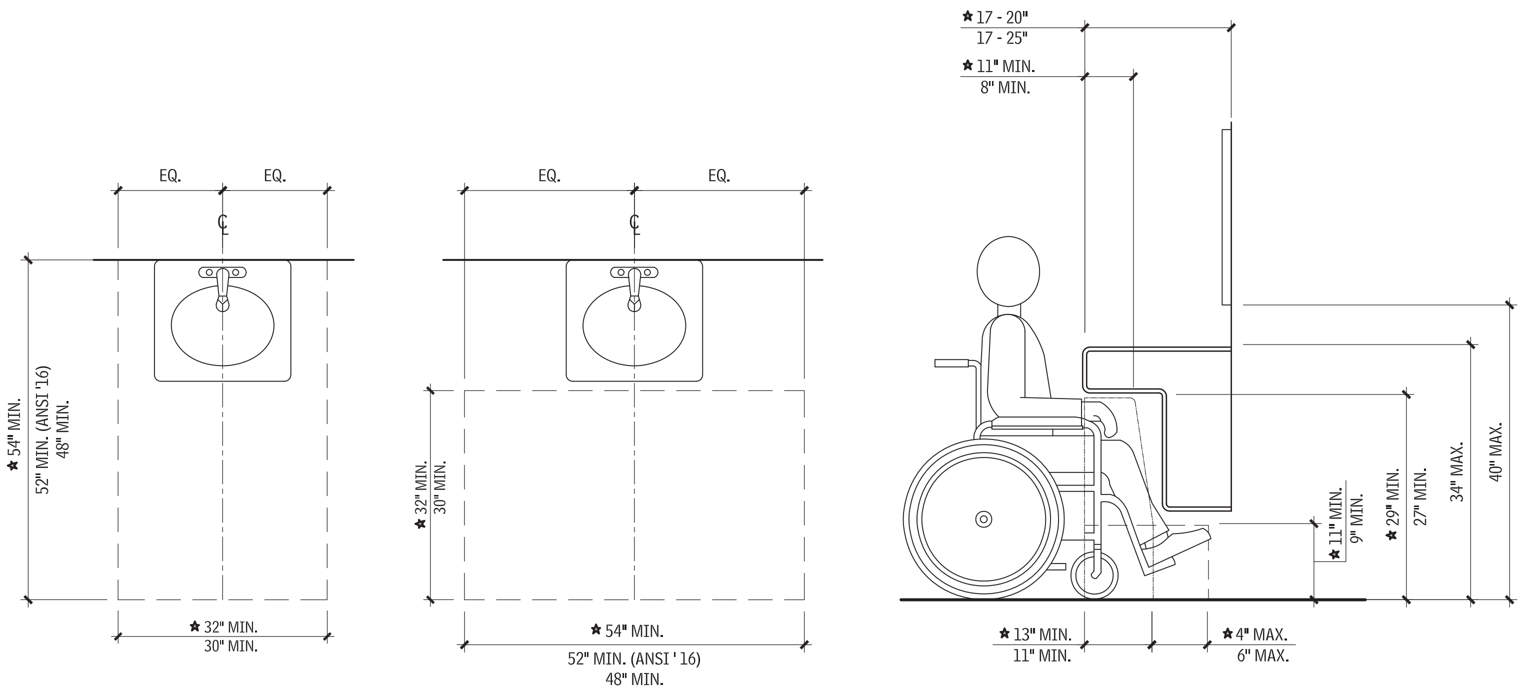
TOILET COMPARTMENTS

Where toilet compartments are provided, at least one compartment must be wheelchair-accessible. Where six or more toilet compartments are provided in a toilet room, in addition to the wheelchair-accessible compartment, a 36-in.-wide ambulatory accessible compartment is also required. Left- or right-handed configurations are acceptable. The door to the toilet compartment must be self-closing and have an accessible pull on both sides near the latch. The locking mechanism must be operable with one hand, and not require tight grasping, pinching, or twisting of the wrist.

Minimum compartment size varies based on presence of toe clearance under the partition wall, toilet mount (side or wall), and if the stall is for adults, children, or if it is an ambulatory stall. Use the accompanying figure and table to determine the appropriate minimum stall size.

LAVATORIES
1.48

Sinks and lavatories for children ages 6 to 12 with a 31-in. maximum rim or counter surface may have a knee clearance of 24 in. minimum. Parallel approach is permitted at lavatories and sinks used primarily by children ages 5 and younger.



Contributors:
Dr. Ed Steinfeld, AIA and Jonathan White, Center for Inclusive Design and Environmental Access (IDeA Center), University at Buffalo, New York

SINGLE-USER TOILET ROOMS

In new construction, all public and common-use toilet rooms are generally required to be accessible. In accessible toilet rooms, at least one of each type of fixture and accessory provided must be accessible. A wheelchair turning space is required within accessible toilet rooms. Doors are not permitted to swing into the required clear floor space at any fixture, except in single-user rooms where a clear floor space is provided beyond the swing of the door. UFAS does not provide this exception in single-user rooms. The same is true of single-user bathing rooms, which will be discussed later in this section.

Recent model codes require accessible single-user toilet rooms in certain assembly and mercantile occupancies. Single-user rooms are typically unisex facilities, which is beneficial for parents with small children and for people with disabilities who require personal assistance in using toilet facilities, as the assistant may be a person of the opposite sex. A requirement for unisex facilities usually applies when a total of six or more toilets (or toilets and urinals) are provided in the facility or in certain occupancy areas. Unisex facilities must be located within 500 ft. and within one floor of separate-sex facilities. In facilities with security checkpoints, such as airport terminals, unisex facilities must be located on the same side of the checkpoint as the separate-sex facilities.

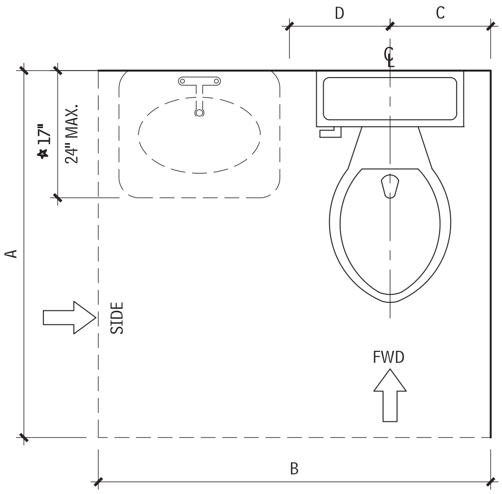
Where multiple single-user toilet rooms are clustered in a single location and each serves the same population, 5 percent, but not less than one of the rooms must be accessible. Signs must identify the accessible room(s), when not all rooms are accessible.

Single-user toilet rooms provided within a private office are permitted to be adaptable for future accessibility. Making the room accessible is permitted to involve replacement of the toilet and lavatory, changing the swing of the door, and installing grab bars in previously reinforced walls. Certain conditions permit accessible unisex toilet rooms in alterations in lieu of altering existing separate-sex facilities, provided they are located in the same area and on the same floor as the existing inaccessible facilities. Consult with applicable standards and codes.

Doors to single-user toilet rooms must have an accessible locking mechanism inside the room. Single-user toilet rooms require a single toilet and lavatory with an optional urinal. Fixtures provided in single-user rooms are permitted to be included in the number of required plumbing fixtures.

If storage is provided in separate-sex facilities, it must also be provided in a unisex facility. Likewise, when bathing fixtures are provided in separate-sex facilities, an accessible shower or bathtub must be provided in the unisex bathing room. Refer to the single-user bathing room section for more details.

WATER CLOSETS
1.49



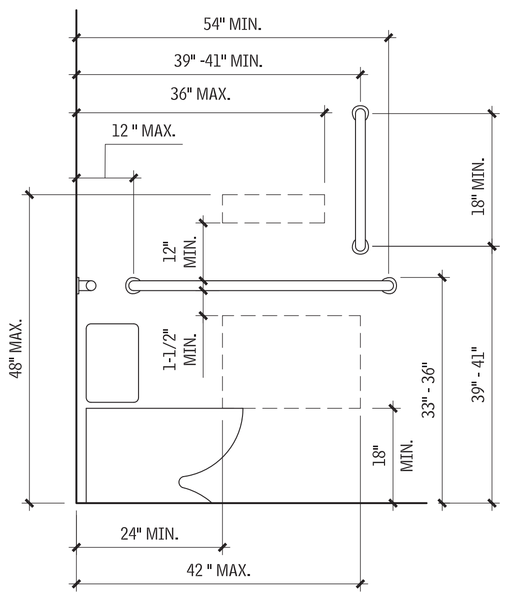
USE	APPROACH	A" (MIN.)	B" (MIN.)	C"	D"	LAVATORY PERMITTED	PERMITTED BY STANDARD
★ PUBLIC/RESIDENTIAL	EITHER	56	60	16-18 *	N/A	NO ***	ALL STANDARDS
RESIDENTIAL DWELLING	FRONT	66	60	16-18 *	18	YES	ADA, ANSI A, ANSI B, FHAG
RESIDENTIAL DWELLING	FRONT	66	48	18	18	YES	UFAS, ANSI B, FHAG
RESIDENTIAL DWELLING	SIDE	56	60	18	18	YES	UFAS, ANSI B, FHAG
RESIDENTIAL DWELLING	EITHER	66	48	16-18 *	15 **	YES	ANSI B, FHAG
RESIDENTIAL DWELLING	SIDE	56	48	16-18 *	15 **	YES	ANSI B, FHAG

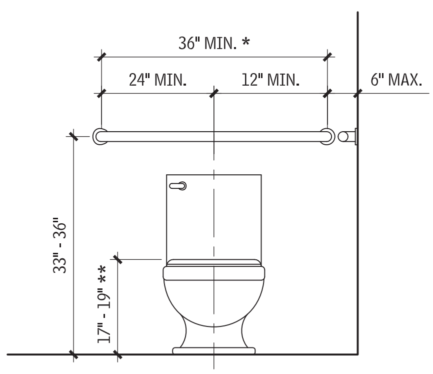
* 18 IN FHAG AND UFAS

** 18 IF SIDE WALL WILL NOT ACCOMMODATE A 24 " GRAB BAR 12" FROM REAR CORNER.

*** ALLOWS SIDE TRANSFER TO TOILET

★ DENOTES BEST PRACTICE





* 24" ALLOWED IF ADJACENT RECESSED FIXTURE LIMITS WALL SPACE (EXCEPT UFAS).

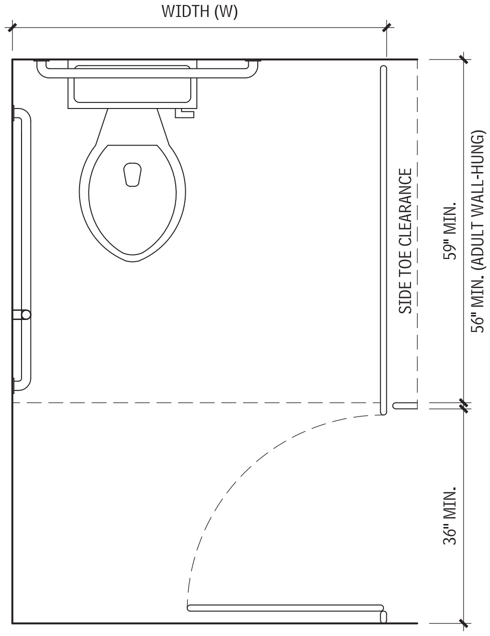
** 15-19" ALLOWED IN ICC/ANSI A177.1 (TYPE A).

NOTE

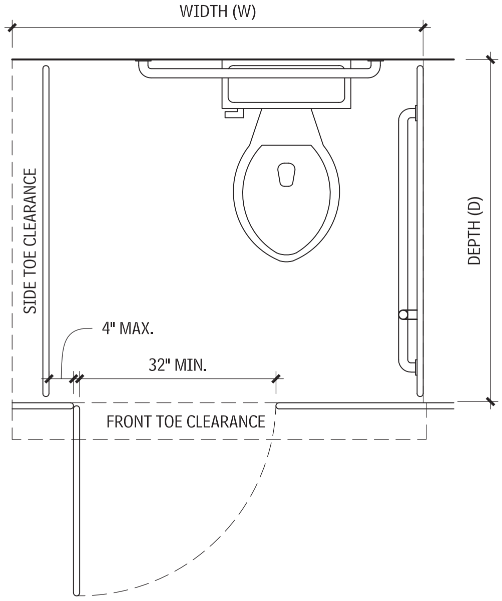
1.49 Vertical grab bar is only required by ICC/ANSI A117.1. It is omitted by other standards and is not required in Type A and B residential dwelling units.

Contributors:
Dr. Ed Steinfeld, AIA and Jonathan White, Center for Inclusive Design and Environmental Access (IDeA Center), University at Buffalo, New York

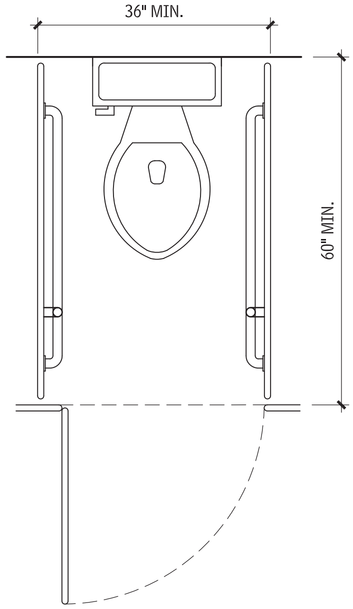
TOILET COMPARTMENTS
1.50



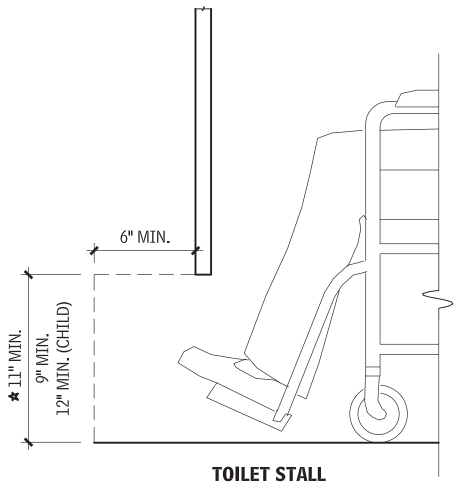
END OF ROW



MIDROW



AMBULATORY ACCESSIBLE



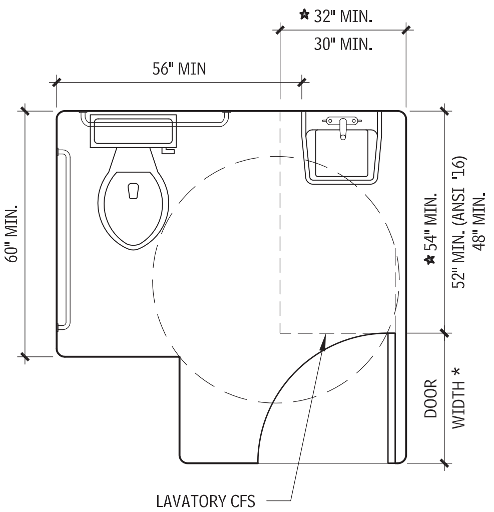
TOILET STALL TOE CLEARANCE

MINIMUM WHEELCHAIR ACCESSIBLE TOILET STALL SIZE

6" TOE CLEARANCE LOCATION	MIN STALL WIDTH (W)	MIN STALL DEPTH (D)	MIN STALL DEPTH (D) IF WALL-HUNG TOILET IN ADULT STALL
NO TOE CLEARANCE	66"	65"	62"
AT FRONT ONLY	66"	59"	56"
AT SIDE ONLY	60"	65"	62"
AT BOTH SIDE AND FRONT	60"	59"	56"

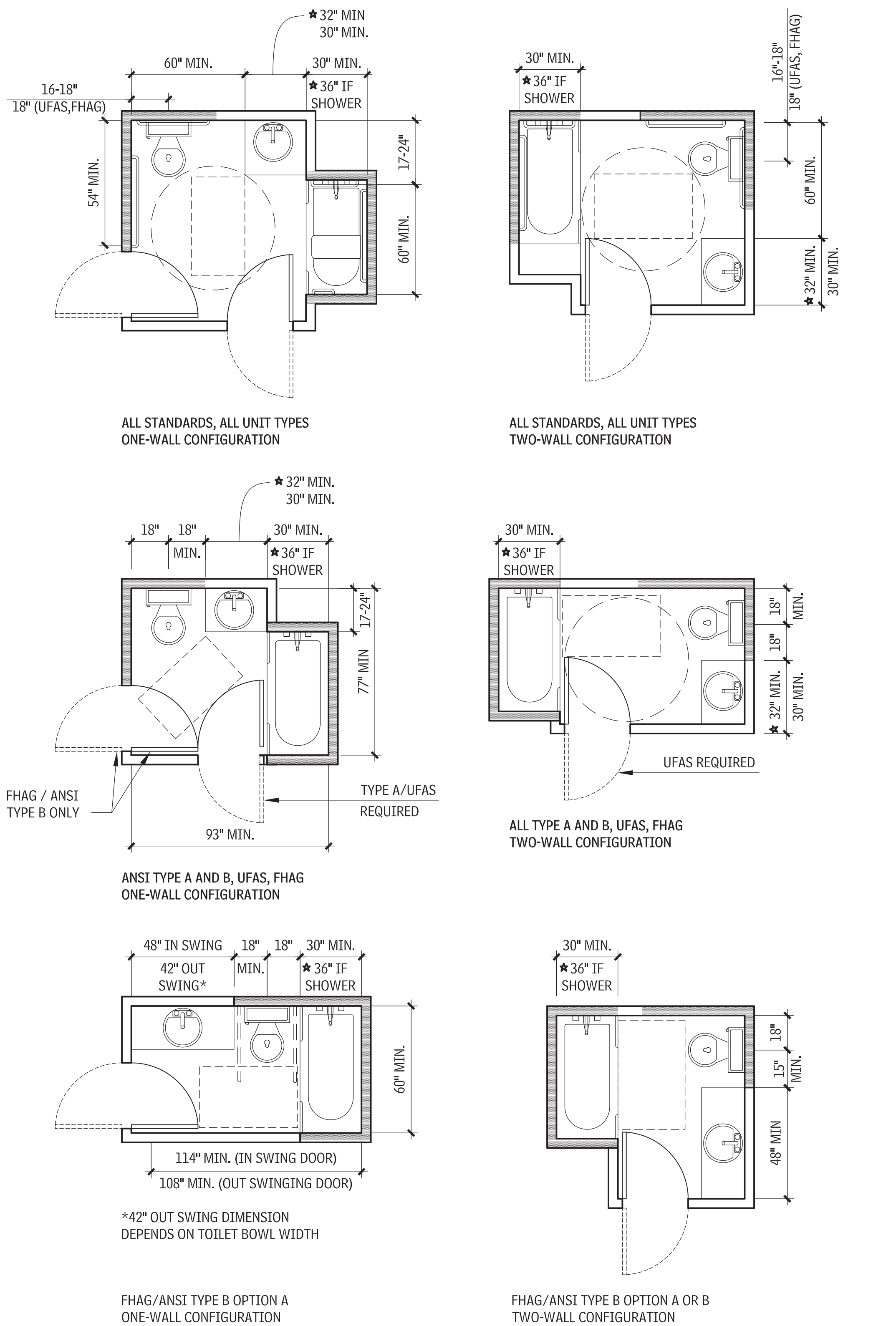
Contributors:
Dr. Ed Steinfeld, AIA and Jonathan White, Center for Inclusive Design and Environmental Access (IDeA Center), University at Buffalo, New York

SINGLE-USER TOILET ROOM LAYOUT
1.51



* ONLY UFAS REQUIRES THAT THE DOOR NOT ENCROACH UPON THE FIXTURE CLEAR FLOOR SPACE IN SINGLE-USER TOILET AND BATHING ROOMS. OTHER STANDARDS PERMIT AN OVERLAP IF THERE IS A CLEAR FLOOR SPACE WITHIN THE ROOM AND OUTSIDE THE SWING OF THE DOOR

BATHROOM LAYOUTS
1.52



SINGLE-USER BATHROOMS

The requirements of single-user toilet rooms also apply to single-user bathrooms. The accompanying figure depicts several layout options based on the minimum clear floor space for the fixtures, grab bar position, and door location. Each bathroom plan must provide the fixture clearances required by the applicable standard. In addition, maneuvering space must be provided, although the amount of space varies by unit type.

ICC/ANSI A117.1 (Accessible and Type A units), UFAS, and the ADA require either a circular or a T-shaped wheelchair turning area within the room. Turning space can generally include knee and toe space under fixtures and accessories, as far as the building blocks section permits. The door swing may overlap the turning space. The clear floor space at a fixture is frequently more stringent than the turning space. With the exception of UFAS, the door swing may overlap the clear floor space at fixtures, provided there is enough clear space to position a wheelchair clear of the door swing. Door maneuvering clearances must also be considered.

Bathrooms in ICC/ANSI A117.1 (Type B units) and FHAG must be "usable" rather than "accessible"; therefore, the minimum maneuvering clearance required is smaller. In these units, there must be enough clear space to position a wheelchair clear of the door swing and a turning space is not required. All of the standards permit required floor space for fixtures to overlap with the required maneuvering space.

Note the accompanying figure does not depict each fixture's clear floor space. Refer to the section on each fixture for specific dimensions. Dimensions provided refer to finish dimensions and do not provide a tolerance. Consider adding at least 2 in. to the overall size to allow for adjustments in the field. Doors in the figure are assumed to be 36 in. wide. Refer to the doors section for more detailed requirements.

Contributors:
Dr. Ed Steinfeld, AIA and Jonathan White, Center for Inclusive Design and Environmental Access (IDeA Center), University at Buffalo, New York

PUBLIC RESTROOMS

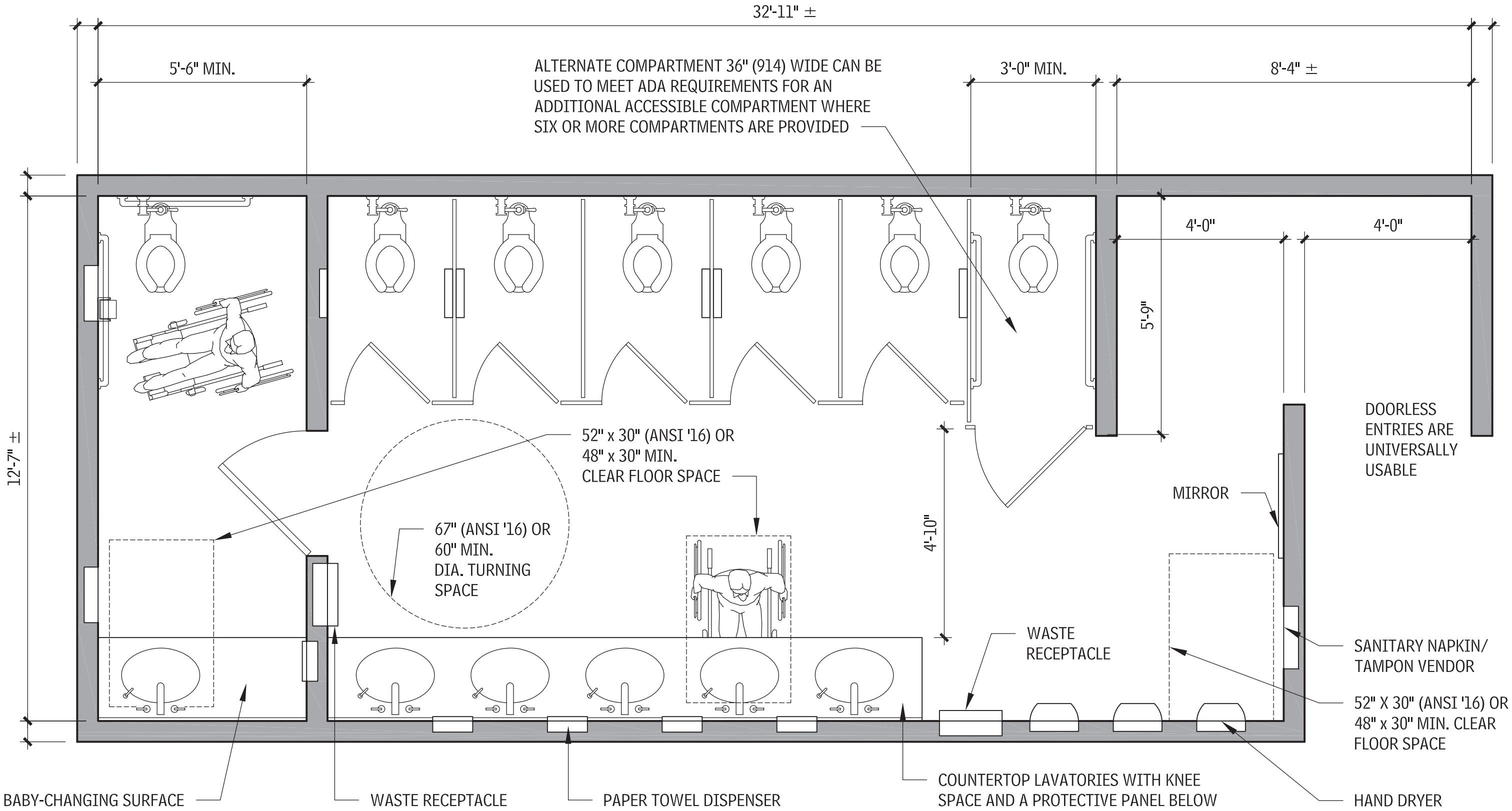
The spacing and location of plumbing fixtures and toilet rooms should respond to occupant needs and code requirements. The design professional should be aware of how water is piped to plumbing fixtures and how waste is plumbed from fixtures, along with general venting requirements. Even during preliminary design, the design team should begin to address the requirements for accumulation and flow of water through horizontal and vertical piping. Additional design issues needing to be considered include coordination of plumbing fixture location with toilet compartments and urinal screens, toilet and bath accessories, and tub and shower doors.

CODES AND STANDARDS

Plumbing codes establish minimum acceptable standards for the design and installation of plumbing systems and the selection of the components they comprise. Requirements for plumbing system design should be based on the adopted code of the jurisdiction of the project.

The word "approved" is often used in conjunction with components and devices that come in contact with potable water and products used for human consumption or use. Nonetheless, a responsible code official or agency must examine and test these items to determine whether they are suitable for a particular intended use. Only materials and devices approved by the local jurisdiction can be used in plumbing systems. Plumbing design drawings and utility services also must be examined and found to be in compliance with local codes, rules, and regulations.

WOMEN'S TOILET ROOM WITH OPEN VESTIBULE
1.53



NOTE

1.53 Bobrick Washroom Equipment, Inc., North Hollywood, California.

Contributor:
Alan H. Rider, AIA, Daniel, Mann, Johnson, & Mendenhall, Washington, DC.

ENVIRONMENT

2

ENVIRONMENTAL FACTORS

SOLAR RADIATION AND BUILDING ORIENTATION

OPTIMUM ORIENTATION

To visualize the thermal impacts on differently exposed surfaces four distinct geographical locations approximately at the 24°, 32°, 40°, and 44° latitudes are shown in Figure 2.1. The forces are indicated on average, clear winter and summer days. The air temperature variation is indicated by the outside concentric circles. Each additional line represents a 2°F difference from the lowest daily temperature. The direction of the impact is indicated according to the sun's path as temperatures occur. (Note the low temperatures at the east side, and the high temperatures on west-facing surfaces.) The total (direct and diffuse) radiation impact on the each side of the building is indicated with arrows. Each arrow represents 250 Btu/sq. ft. day radiation. Figure expresses the radiation in numerical values. The values show that in the upper latitudes, the south side of a building receives nearly twice as much radiation in winter as in summer. This effect is even more pronounced at the lower latitudes, where the ratio is about one to four. Also, in the upper latitudes, the east and west sides receive about 2–1/2 times more radiation in summer than in winter. This ratio is not as large in the lower latitudes; but it is noteworthy that in summer these sides receive two to three times as much radiation as the south elevation. In the summer, the west exposure is more disadvantageous than the east exposure, as the afternoon high temperatures combine with the radiation effects. In all latitudes the north side receives only a small amount of radiation, and this comes mainly in the summer. In the low latitudes, in the summer, the north side receives nearly twice the impact of the south side. The amount of radiation received on a horizontal roof surface exceeds all other sides.

The optimum orientation will lie near the south; however, it will differ in the various regions, and will depend on the daily temperature distribution.

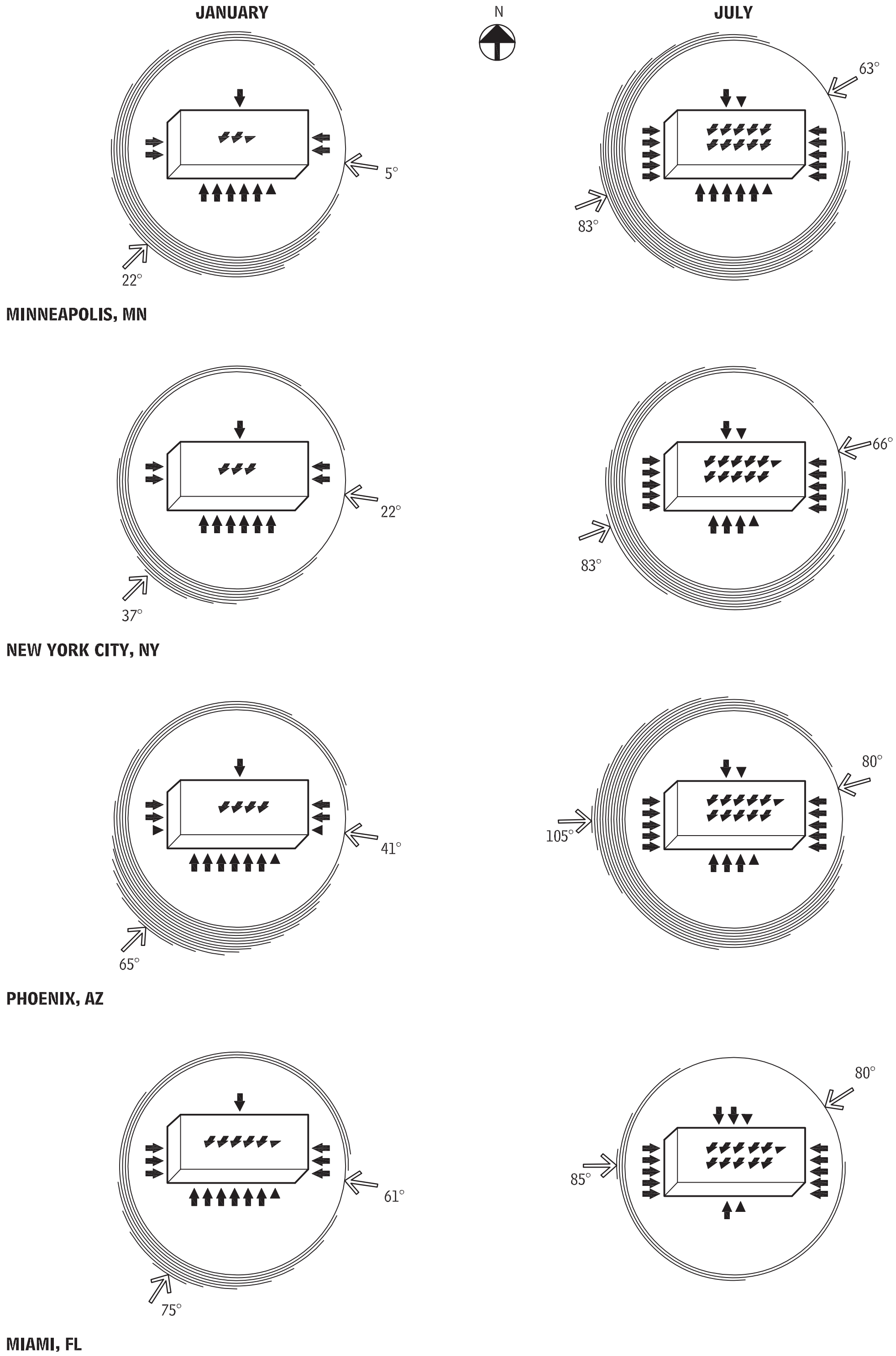
In all regions an orientation eastward from south gives a better yearly performance and a more equal daily heat distribution. Westerly directions perform more poorly with unbalanced heat impacts.

SOLAR CONSTANT

The sun is located at one focus of the Earth's orbit, and we are only 91.4 million miles away from the sun in late December and early January, while the Earth-sun distance on July 1 is about 94.4 million miles.

Solar energy approaches the Earth as electromagnetic radiation at wavelengths between 0.25 and 5.0 μm. The intensity of the incoming solar irradiance on a surface normal to the sun's rays beyond the Earth's atmosphere, at the average Earth-sun distance, is designated as the solar constant, I_{SC}. Although the value of Isc has not yet been precisely determined by verified measurements made in outer space, the most widely used value is 429.2 Btu/sq. ft. hr. and the current ASHRAE values are based on this estimate. More recent measurements made at extremely high altitudes indicate that Isc is probably close to 433.6 Btu/sq. ft. hr. The unit of radiation that is widely used by meteorologists is the langley (Ly), equivalent to one k cal/sq. cm. To convert from langleys/day to Btu/sq. ft. day, multiply Ly/day by 3.67.

THERMAL IMPACT BASED ON GEOGRAPHIC LOCATION
2.1



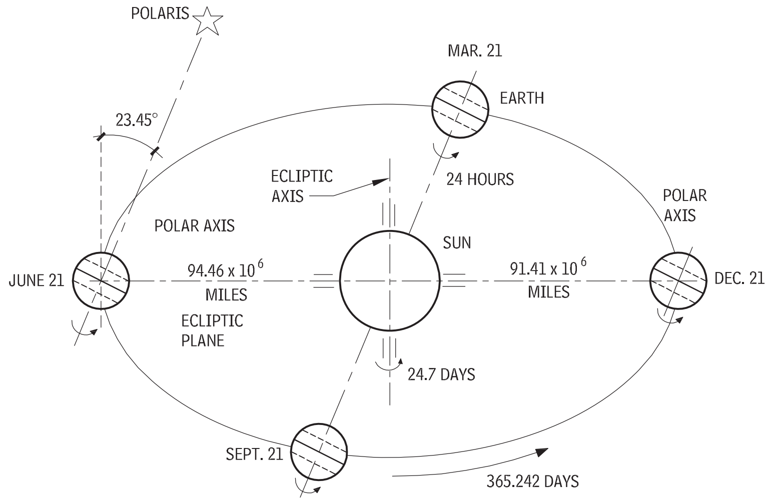
TOTAL DIRECT AND DIFFUSED RADIATION (BTU/SQ. FT. DAY)
2.2

LATITUDE	SEASON	EAST	SOUTH	WEST	NORTH	HORIZONTAL
44° LATITUDE	WINTER	416	1374	416	83	654
	SUMMER	1314	979	1314	432	2536
40° LATITUDE	WINTER	517	1489	517	119	787
	SUMMER	1277	839	1277	430	2619
32° LATITUDE	WINTER	620	1606	620	140	954
	SUMMER	1207	563	1207	452	2596
24° LATITUDE	WINTER	734	1620	734	152	1414
	SUMMER	1193	344	1193	616	2568

COMPASS ORIENTATION

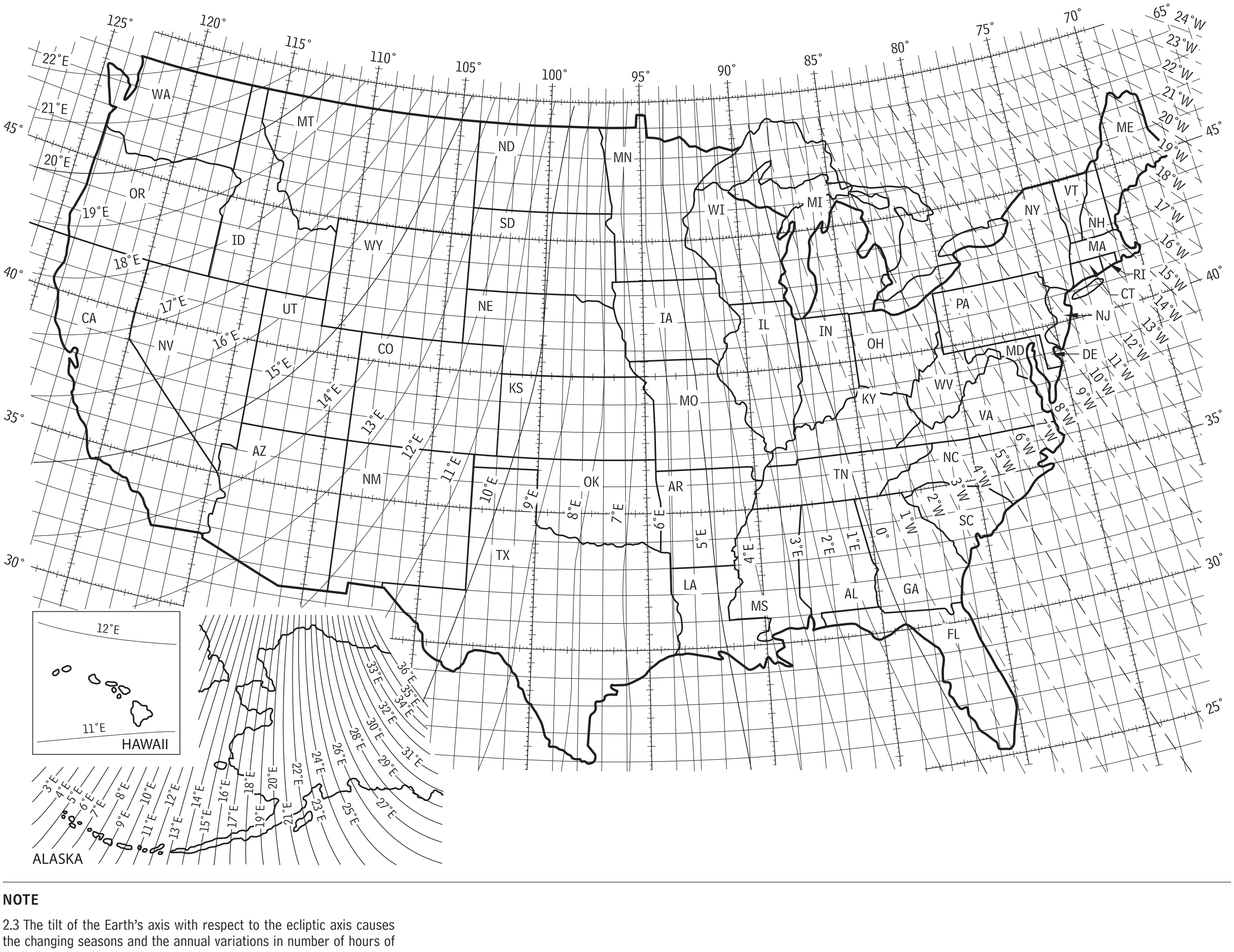
In Figure 2.4, the wavy lines from top to bottom show the compass variations from the true north. At the lines marked E the compass will point east of true north; at those marked W the compass will point west of true north. According to the location, correction

ANNUAL MOTION OF THE EARTH ABOUT THE SUN
2.3



ORIENTATION AND TRUE NORTH

ISOGONIC CHART OF THE UNITED STATES (FROM DEPARTMENT OF THE INTERIOR GEODETIC SURVEY 1975)
2.4



NOTE

2.3 The tilt of the Earth's axis with respect to the ecliptic axis causes the changing seasons and the annual variations in number of hours of daylight and darkness.

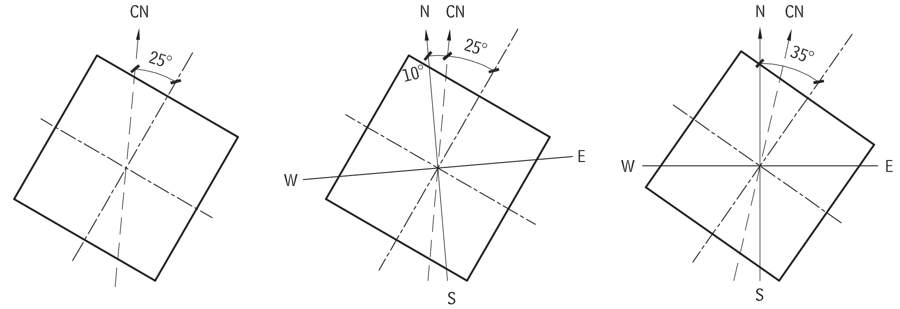
should be done from the compass north to find true north. Figure 2.5 provides an example for locating true north at a project site in Wichita, Kansas, through orientation correction.

THERMAL FORCES INFLUENCING ORIENTATION

The climatic factors such as wind, solar radiation, and air temperature play the most eminent role in orientation. The position of a structure in northern latitudes, where the air temperature is generally cool, should be oriented to receive the maximum amount of sunshine without wind exposure. In southerly latitudes, however, the opposite will be desirable; the building should be turned on its axis to avoid the sun's unwanted radiation and to face the cooling breeze instead.

Adaptation for wind orientation is not of great importance in low buildings, where the use of windbreaks and the arrangement of openings in the high and low pressure areas can help to ameliorate the airflow situation. However, for high buildings, where the surrounding terrain has little effect on the upper stories, careful consideration has to be given to wind orientation.

COMPASS ORIENTATION, VARIATION, AND CORRECTION
2.5



1. COMPASS ORIENTATION **2. COMPASS VARIATION** **3. ORIENTATION CORRECTION**

STEP 1. Find the compass orientation on the site.

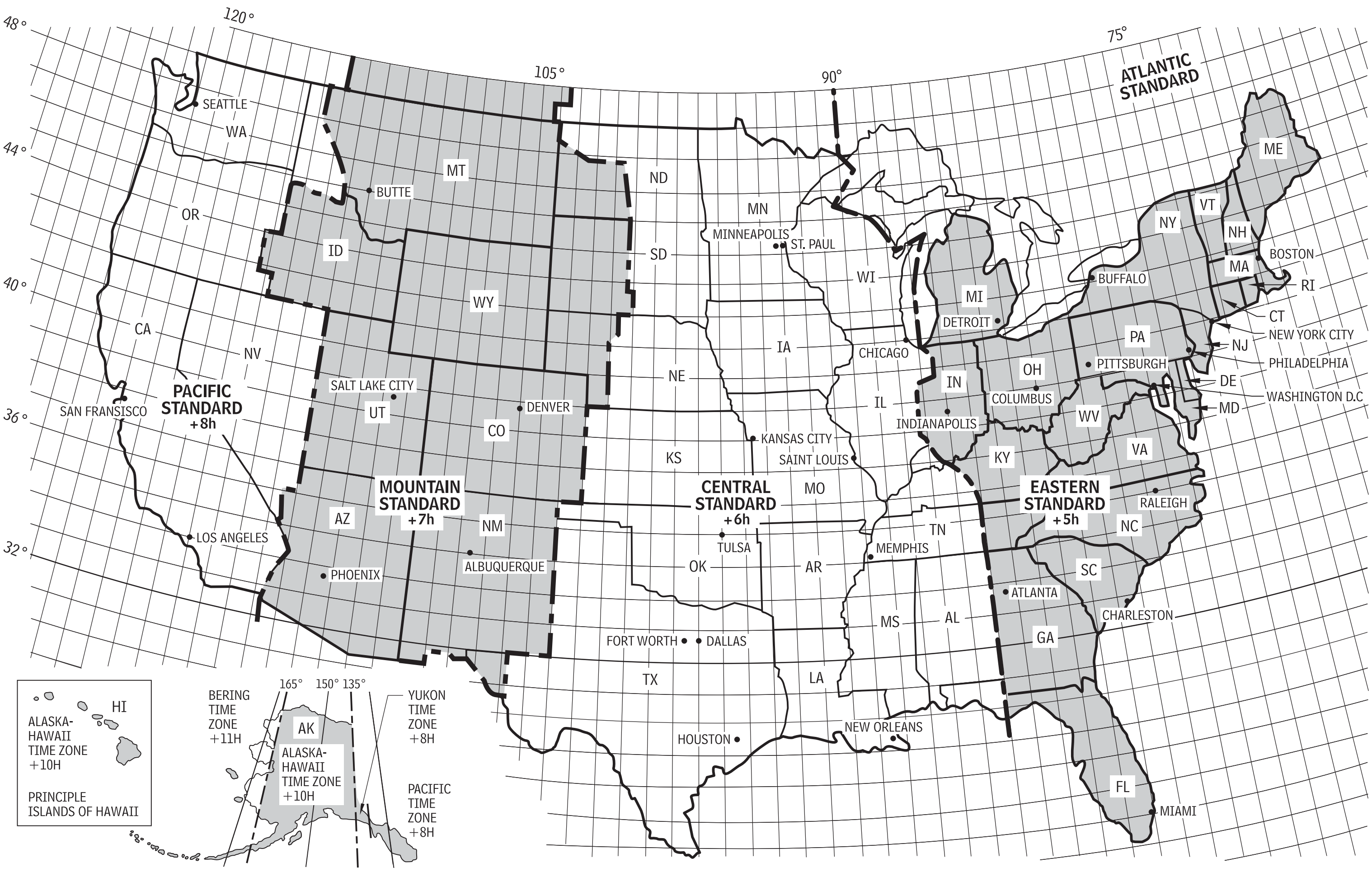
STEP 2. Locate Wichita on the isogonic chart. The nearest compass variation is the 10°E line.

STEP 3. Adjust the orientation correction to true north.

The figures illustrate a building that lies 25° east with its axis from the compass orientation.

SOLAR TIME

STANDARD TIME ZONES OF THE UNITED STATES
2.6



NOTE

2.6 Greenwich Standard Time is 0 h.

Contributor:
Victor Olgyay, AIA, Princeton University, Princeton, New Jersey.

SOLAR PATH AND SOLAR ANGLE

SOLAR ANGLES

The position of the sun in relation to specific geographic locations, seasons, and times of day can be determined by several methods. Model measurements, by means of solar machines or shade dials, have the advantage of direct visual observations. Tabulation and calculated methods have the advantage of exactness. However, graphic projection methods are usually preferred by design professionals, as they are easily understood and can be correlated to both radiant energy and shading calculations.

At the Earth's surface the amount of solar radiation received and the resulting atmospheric temperature vary widely, primarily because of the daily rotation of the Earth and the fact that the rotational axis is tilted at an angle of 23.45° with respect to the orbital plane. This tilt causes the changing seasons with their varying lengths of daylight and darkness. The angle between the Earth-sun line and the orbital plane, called the solar declination, d, varies throughout the year, as shown in Figure 2.9 for the 21st day of each month.

Very minor changes in the declination occur from year to year, and when more precise values are needed, the almanac for the year in question should be consulted.

The Earth's annual orbit about the sun is slightly elliptical, and so the Earth-sun distance is slightly greater in summer than in winter. The time required for each annual orbit is actually 365.242 days rather than the 365 days shown by the calendar, and this is corrected by adding a 29th day to February for each year (except century years) that is evenly divisible by 4.

To an observer standing on a particular spot on the Earth's surface, with a specified longitude and latitude it is the sun that appears to move around the Earth in a regular daily pattern. Actually it is the Earth's rotation that causes the sun's apparent motion. The position of the sun can be defined in terms of its altitude β above the horizon (angle HOQ) and its azimuth ø, measured as angle HOS in the horizontal plane.

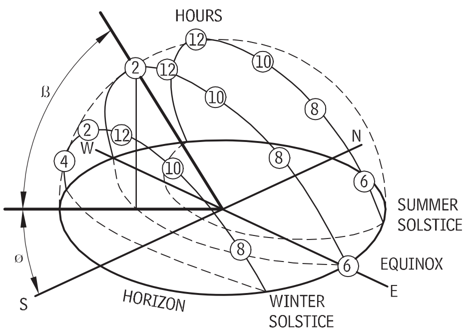
At solar noon, the sun is, by definition, exactly on the meridian that contains the south-north line, and consequently the solar azimuth ø is 0.0°. The noon altitude β is: $90° - L + \delta$.

Because the Earth's daily rotation and its annual orbit around the sun are regular and predictable, the solar altitude and azimuth may be readily calculated for any desired time of day as soon as the latitude, longitude, and date (declination) are specified.

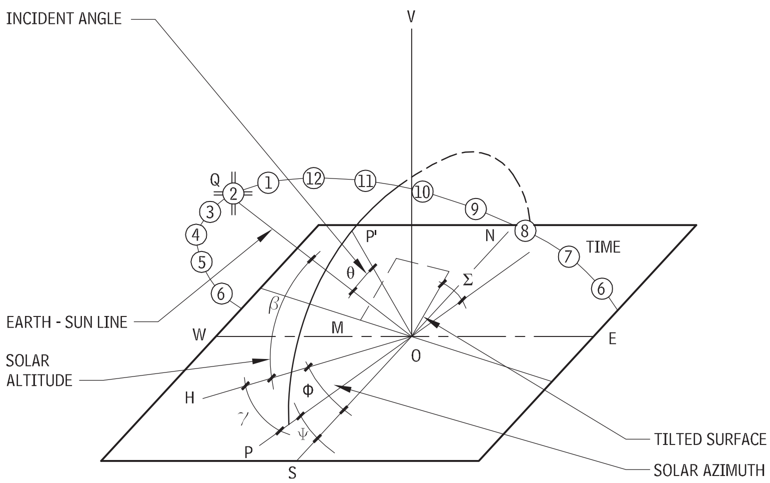
SOLAR PATH DIAGRAMS

A practical graphic projection is the solar path diagram method. Such diagrams depict the path of the sun within the sky vault as projected onto a horizontal plane, as shown in Figures 2.10 through 2.15. The horizon is represented as a circle with the observation point in the center. The sun's position at any date and hour can be determined from the diagram in terms of its altitude (β) and azimuth (ø). The graphs are constructed in equidistant projection. The altitude angles are represented at 10° intervals by equally spaced concentric circles; they range from 0° at the outer circle (horizon) to 90° at the center point. These intervals are graduated along the south meridian. Azimuth is represented at 10° intervals by equally spaced radii; they range from 0° at the south meridian to 180° at the north meridian. These intervals are graduated along the periphery. The solar bearing will be to the east during morning hours, and to the west during afternoon hours.

SOLAR ANGLE DIAGRAM
2.7



SOLAR ANGLES WITH RESPECT TO A TILTED SURFACE
2.8



SOLAR ANGLES
2.9

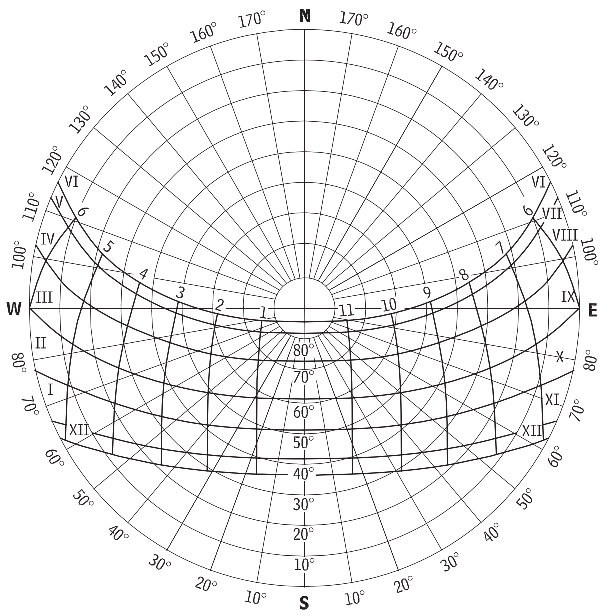
JAN	−19.9°	APR	+11.9°	JUL	+20.5°	OCT	−10.7°
FEB	−10.6°	MAY	+20.3°	AUG	+12.1°	NOV	−19.9°
MAR	0.0°	JUN	+23.5°	SEP	0.0°	DEC	−23.5°

NOTE

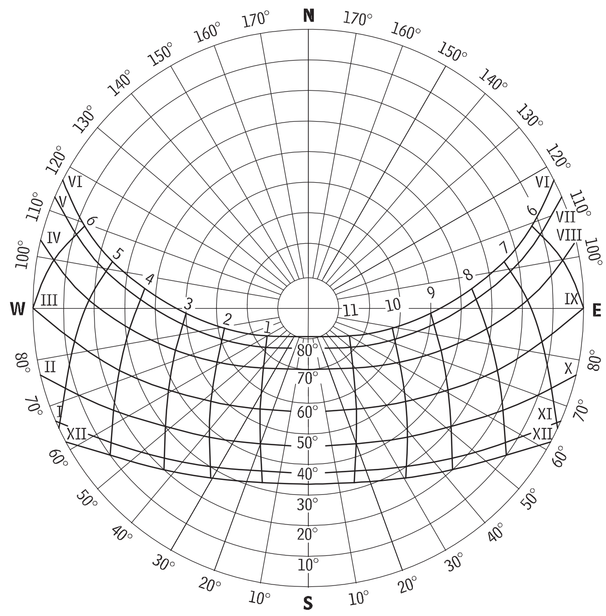
2.8 Q designates the sun's position so OQ is the Earth-sun line while OP' is the normal to the tilted surface and OP is perpendicular to the intersection, OM, between the tilted surface and the horizontal plane.

Contributors:
John I. Yellott, PE, College of Architecture, Arizona State University, Tempe, Arizona; Victor Olgyay, AIA, Princeton University, Princeton, New Jersey.

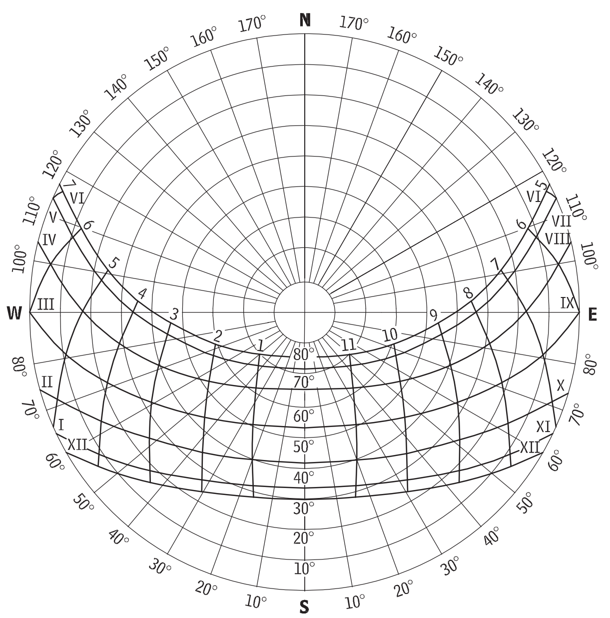
28°N LATITUDE
2.10



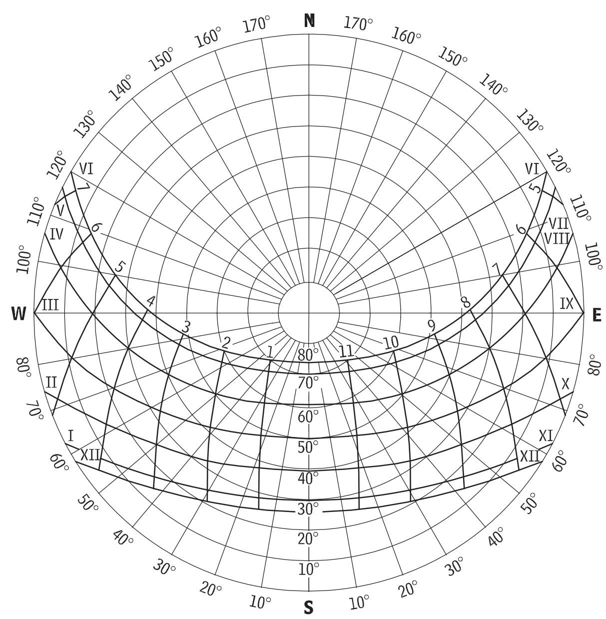
32°N LATITUDE
2.11



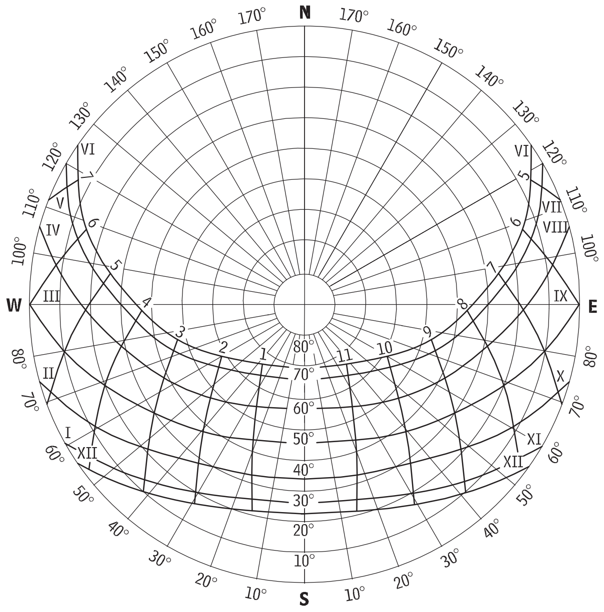
36°N LATITUDE
2.12



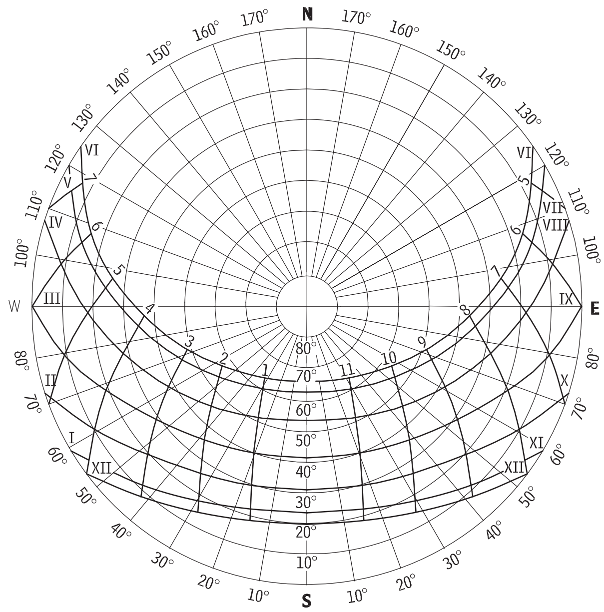
40°N LATITUDE
2.13



44°N LATITUDE
2.14



48°N LATITUDE
2.15



The Earth's axis is inclined 23°27′ to its orbit around the sun and rotates 15° hourly. Thus, from all points on the Earth, the sun appears to move across the sky vault on various parallel circular paths with maximum declinations of ±23°27′. The declination of the sun's path changes in a cycle between the extremes of the summer solstice and winter solstice. Thus the sun follows the same path on two corresponding dates each year. Due to irregularities between the calendar year and the astronomical data, here a unified calibration is adapted. The differences, as they do not exceed 41′, are negligible for architectural purposes.

The elliptical curves in the diagrams represent the horizontal projections of the sun's path. They are given on the 21st day of each month. Roman numerals designate the months. A cross-grid of curves graduate the hours indicated in Arabic numerals. Figures 2.10 through 2.15 show eight solar path diagrams at 4° intervals from 28°N to 48°N latitude.

DECLINATION OF THE SUN
2.16

DATE	DECLINATION	CORRESP. DATE	DECLINATION	UNIFIED CALIBR.
June 21	+23°27′			+23°27′
May 21	+20°09′	July 21	+20°31′	+20°20′
Apr. 21	+11°48′	Aug. 21	+12°12′	+12°00′
Mar. 21	+0°10′	Sep. 21	+0°47′	+0°28′
Feb. 21	−10°37′	Oct. 21	−10°38′	−10°38′
Jan. 21	−19°57′	Nov. 21	−19°53′	−19°55′
Dec. 21	−23°27′			−23°27′

EXAMPLE

Find the sun's position in Columbus, Ohio, on February 21, 2 p.m.:

STEP 1. Locate Columbus on the map. The latitude is 40° N.
STEP 2. In the 40° sun path diagram, select the February path (marked with II), and locate the 2 hr. line. Where the two lines cross is the position of the sun.
STEP 3. Read the altitude on the concentric circles (32°) and the azimuth along the outer circle (35°30′W).

SOLAR POSITION AND HEAT GAIN

CALCULATION OF SOLAR POSITION

The solar position to any location and time can be accurately calculated by relating the spherical triangle formed by the observer's celestial meridian, the meridian of the sun, and the great circle passing through zenith and the sun. The following formulas can be used to find the solar altitude and azimuth angles:

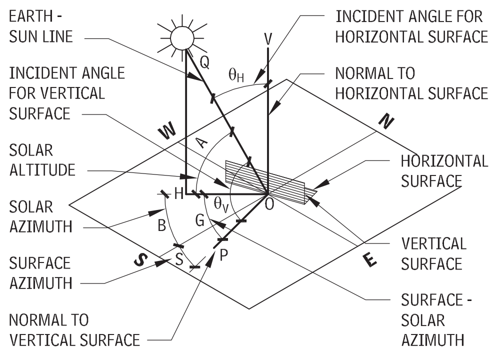
$$\sin \beta = \cos L \cos \delta \cos H + \sin L \sin \delta$$
$$\cos \phi = (\sin \beta \sin L - \sin \delta)/(\cos \beta \cos L)$$

where:

- β = solar altitude above the horizon
- L = latitude of the location; conventionally negative for southern hemisphere latitudes
- δ = declination of the sun at the desired date, which is the angle between the Earth-sun line and the equatorial plane (north declinations are conventionally positive; south declinations negative)
- H = hour angle of the sun = 0.25 × (number of minutes from local solar noon); H is zero at solar noon and changes 15 degrees per hour
- ϕ = solar azimuth, which is the angular distance measured from the south between the south-north line and the projection of the Earth-sun line in the horizontal plane

SOLAR-SURFACE ANGLES

SOLAR SURFACE ANGLES
2.17



The direction of the Earth-sun line OQ is defined by the solar altitude A (angle HOQ) and the solar azimuth B (angle HOS). These can be calculated when the location (latitude), date (declination), and time of day (hour angle) are known. The surface azimuth S is the angle SOP between the south-north line SON and the normal to the surface OP. The surface-solar azimuth G is the angle HOP.

The angle of incidence q depends on the orientation and tilt of the irradiated surface. For a horizontal surface, qH is the angle QOV between the Earth-sun line OQ and the vertical line OV. In Figure 2.17, the vertical surface shown as facing SSE, the angle of incidence qv is the angle QOP between the Earth-sun line OQ and the normal to the surface, OP. For surfaces such as solar collectors, which are generally tilted at some angle T upward from the horizontal, the incident angle qt may be found from the equation:

$$\cos \theta t = \cos A \cos S \sin T + \sin A \cos T$$

Contributor:
Victor Olgyay, AIA, Princeton University, Princeton, New Jersey.

CALCULATION OF SOLAR IRRADIATION

It is necessary to know the amount of solar energy falling on exposed surfaces in order to evaluate the importance of solar shading. Because shading devices primarily protect surfaces from direct solar irradiation, only these energy calculations are described here.

The magnitude of direct solar irradiation is, first of all, a function of the sun's altitude and the apparent solar constant and atmospheric extinction coefficient. The latter two parameters take into account the annual variation of the Earth-sun distance and the atmospheric water vapor content. The intensity of direct solar irradiation under clear atmospheric conditions at normal incidence can be calculated by:

$$I_{DN} = A \exp(-B/\sin\beta)$$

where:

I_{DN} = direct normal solar intensity at the Earth's surface on clear days
exp = base of natural logarithms
A = apparent solar constant or apparent normal incidence intensity at air mass zero
B = atmospheric extinction coefficient

Figure 2.18 indicates direct normal solar irradiation on clear days as a function of solar altitude on the solstices and the equinoxes.

I_{DN} AS A FUNCTION OF SOLAR ALTITUDE (BTU/SQ FT/HR)
2.18

β	JUNE 21	MAR. 21/SEPT. 21	DEC. 21
5	33	55	77
10	106	142	173
15	156	195	226
20	189	228	258
25	212	250	279
30	229	266	294
40	251	286	314
50	264	298	325
60	272	306	332
70	277	310	336
80	280	313	339
90	281	314	339

SOLAR IRRADIATION

The direct irradiation received by any given surface is also a function of the angle of incidence of the solar beam relative to that surface. The angle of incidence is the angle between the direct solar rays and a line normal to the irradiated surface.

For horizontal surfaces, the cosine of the angle of incidence is equal to the sine of the solar altitude. The direct irradiation on horizontal surfaces is thus calculated by:

$$I_{DH} = I_{DN} \times \sin\beta$$

For vertical surfaces, the incident angle depends on the solar altitude and the surface-solar azimuth. The surface-solar azimuth (g) is the angular distance between the solar azimuth and the azimuth of the surface. The surface azimuth is the angle between south and the normal to the surface, measured counterclockwise from south. The direct irradiation on vertical surfaces can thus be calculated by:

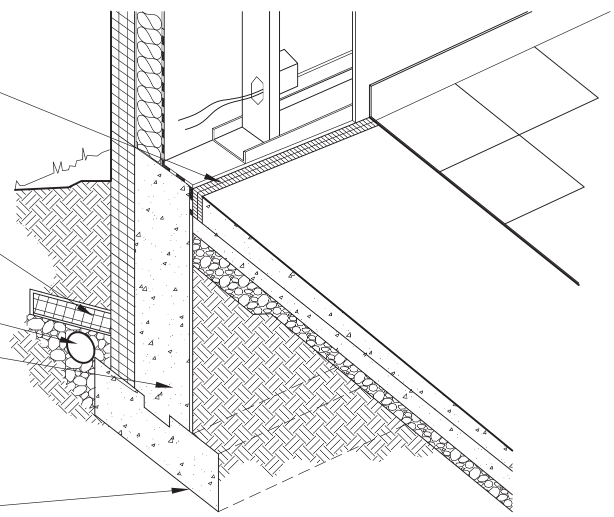
$$I_{DV} = I_{DN} \times \cos\beta \cos\gamma$$

CLIMATE ZONE

DESIGNING FOR COLD AND UNDERHEATED CLIMATES

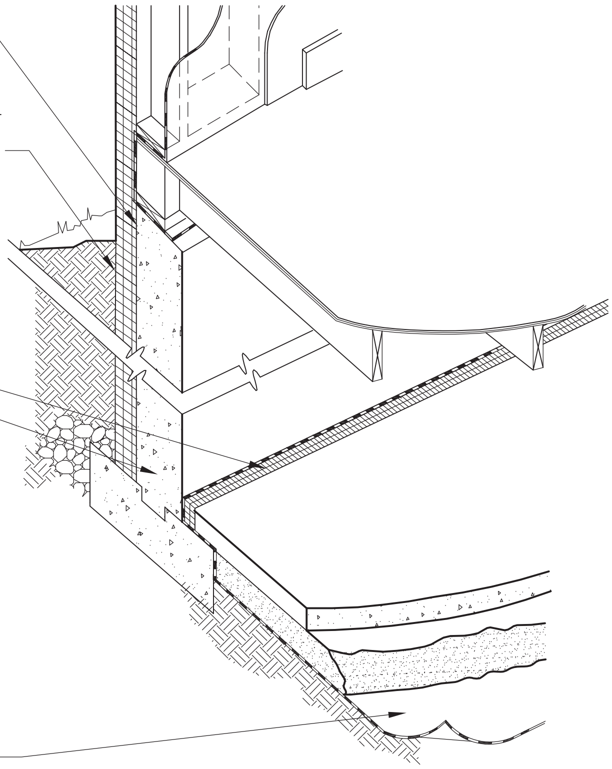
Cold and underheated climate conditions occur over the northern half of the United States and in mountainous regions. These conditions can be generally quantified as where the frost depth is 12 in. or greater. Designing foundations for these conditions is treated in a more typical manner, such as: providing a foundation below the frost depth, including a basement, and providing insulation on the exterior to reduce the cold ground temperatures from reaching the structure.

SLAB-ON-GRADE CONSTRUCTION IN COLD CLIMATES
2.19

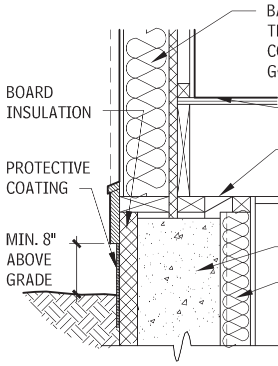


Contributors:
Edwin Crittenden, FAIA, and John Crittenden, AIA, Anchorage, Alaska; G.H. Johnston, *Permafrost Engineering, Design and Construction,* National Research Council of Canada, John Wiley & Sons, New York; Arvind Phukan, *Frozen Ground Engineering*, Prentice Hall, Englewood, New Jersey; Eb Rice, *Building in the North*, Geophysical Institute, University of Alaska, Fairbanks, Alaska.

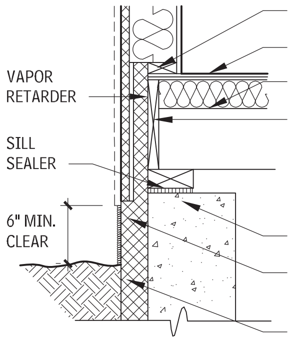
BASEMENT CONSTRUCTION IN COLD CLIMATES
2.20



ENERGY-EFFICIENT WALL SECTIONS FOR UNDERHEATED CLIMATES
2.21

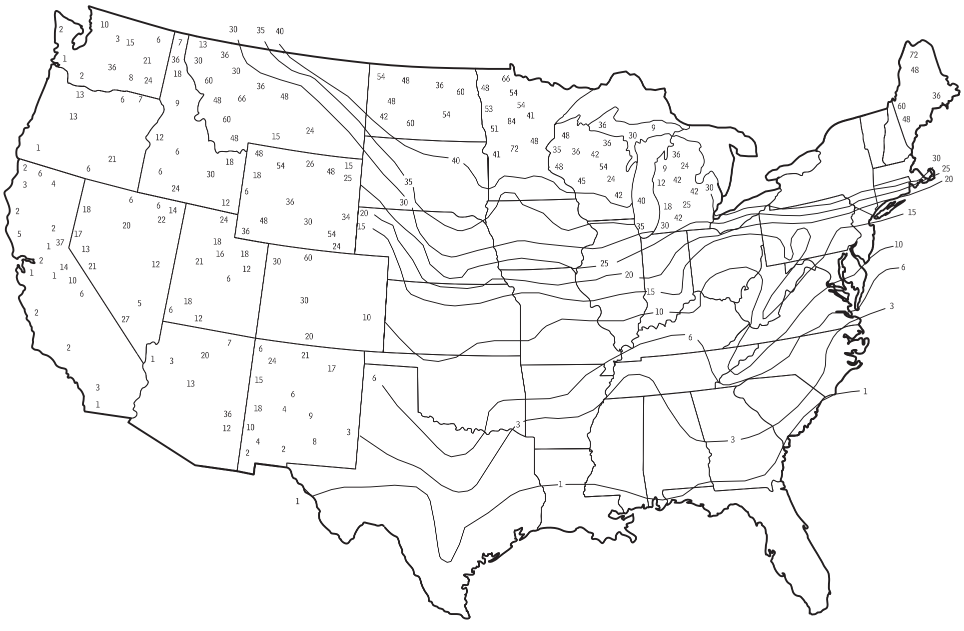


INSULATION ON INSIDE OF CONSTRUCTION



INSULATION ON OUTSIDE OF CONSTRUCTION

AVERAGE DEPTH OF FROST PENETRATION (IN.)
2.22



FROST ISSUES

Detrimental frost action in soils is obviously limited to those areas of the United States where subfreezing temperatures occur on a regular basis and for extended periods of time. "Frost action," as used in this context, is the lateral or vertical movement of structures supported on or in the soil. Frozen soil is, in itself, not necessarily detrimental to the supported structures. It becomes detrimental when, through the growth of ice lenses, the soil, and whatever is resting on the soil above the ice lenses, heaves upward. This causes foundations and the structures supported by the foundations to distort and suffer distress. Other common problems are the heaving of sidewalks, pavements, steps, retaining walls, fence poles, and architectural features.

The depth of frost penetration is directly related to the intensity and duration of the freezing conditions, a measure that is termed the *freezing degree day index*. In milder climates in the United States, the local building codes might stipulate a frost protection depth for foundations of 12 in. In the northern portions of the United States, the frost protection depth might be 42 to 60 in. required by local building codes. These guidelines are usually conservative, but there are situations where deeper frost protection depths are warranted. For instance, if the emergency entrance to a hospital is on the north side of the hospital, where the sun never warms the pavement adjacent to the building, and the pavement is kept 100 percent snow-free for safety reasons, then the frost penetration can easily exceed the code requirements.

Contributors:
Richard O. Anderson, PE, Principal Engineer, Somat Engineering, Taylor, Michigan; Eric K. Beach, PC, Rippeteau Architects, Washington, DC; Stephen N. Flanders and Wayne Tobiasson, Cold Regions Research and Engineering Laboratory, U.S. Army Corps of Engineers, Hanover, New Hampshire; Donald Watson, FAIA, Rensselaer Polytechnic Institute, Troy, New York; Kenneth Labs, New Haven, Connecticut.

DESIGNING FOR HOT ARID CLIMATES

CLIMATE IMPLICATIONS

Though classified as arid and overheated, severe desert climates in the United States typically have four distinct periods for determining comfort strategies.

The *hot dry season*, occurring in late spring, early summer, and early fall, has dry, clear atmospheres that provide high insulation levels, high daytime air temperatures, very high sol-air temperatures, and large thermal radiation losses at night, producing a 30°F to 40°F daily range. Nighttime temperatures may fall below the comfort limits and are useful for cooling. Low humidity allows effective evaporative cooling.

The *hot humid season* occurs in July and August. In addition to high insulation, it is characterized by high dew point temperatures (above 55°F), reducing the usefulness of evaporative cooling for comfort conditioning. Cloudiness and haze prevent nighttime thermal re-radiation, resulting in only a 20°F or less daily range. Lowest nighttime temperatures are frequently higher than the comfort limits. Thus, refrigeration or dehumidification may be needed to meet comfort standards.

The *winter season* typically has clear skies, cold nights, very low dew point temperatures, a daily range of nearly 40°F, and the opportunity for passively meeting all heating requirements from isolation.

The *transitional* or *thermal sailing season* occurs before and after the winter season and requires no intervention by environmental control systems. This season can be extended by the passive features of the building. Other desert climates have similar seasons but in different proportions and at cooler scales.

CONSTRUCTION DETAILS

Capitalize on climatic conditions by incorporating construction practices that respond in beneficial ways to the environment, including:

Insulate coolant and refrigerant pipes from remote evaporative towers and condensers for their entire length.

In hot locations, use roof construction similar to the cold climate roof detail.

Do not use exposed wood (especially in small cross sections) and many plastics, as they deteriorate from excessive heat and high ultraviolet exposure.

Although vapor retarders may not be critical to control condensation, implement them as a building wrap or wind shield, both to control dust penetration and to avoid convective leaks from high temperature differentials.

Avoid thermal bridges such as extensive cantilevered slabs.

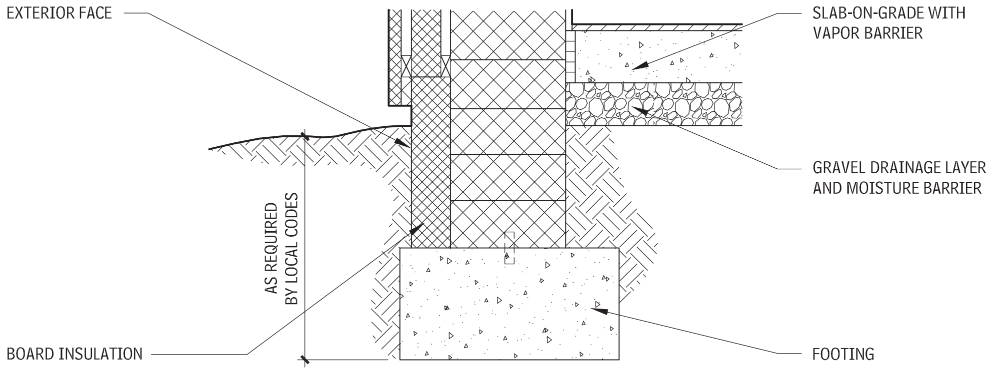
Radiant barriers and details appropriate to humid overheated climates are at least as effective as vapor retarders, but avoid holes in assembly where convection would leak their thermal advantage.

Ventilate building skin (attic or roof, walls) to relieve sol-air heat transfer.

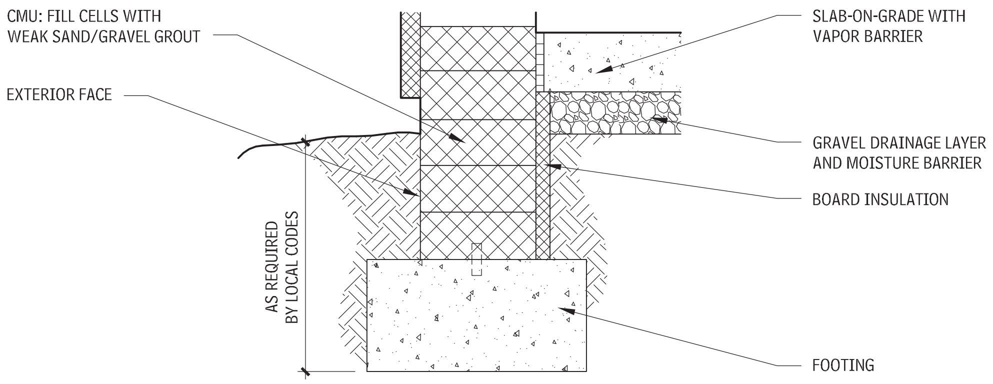
DESIGNING FOR HUMID, OVERHEATED CLIMATES

Humid, overheated conditions are most severe along the Gulf Coast, but occur across the entire southeastern United States. Atmospheric moisture limits radiation exchange, resulting in daily temperature ranges less than 20°F. High insulation gives first priority to shading. Much of the overheated period is only a few degrees above comfort limits, so air movement can cool the body. Ground temperatures are generally too high for the Earth to be useful as a heat sink, although slab-on-grade floor mass is useful. The strategies are to resist solar and conductive heat gains and to take best advantage of ventilation.

TYPICAL WALL SECTIONS FOR HOT, ARID CLIMATES
2.23

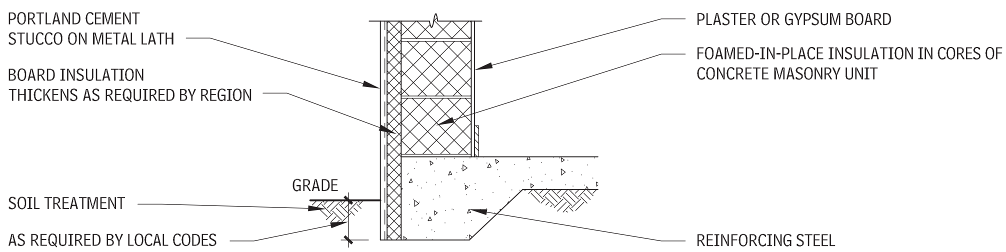


HIGH ENERGY-EFFICIENT

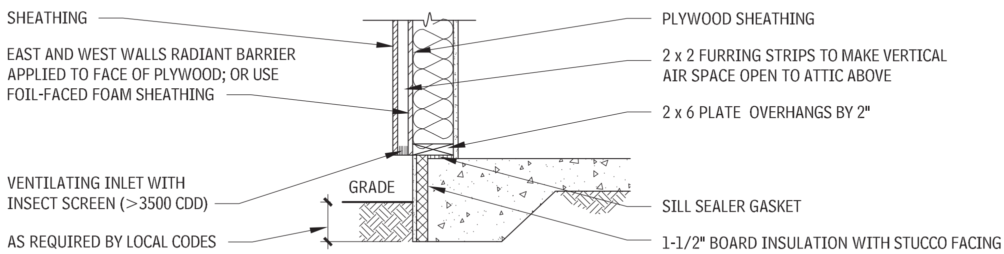


ECONOMIC ENERGY-EFFICIENT

ENERGY-EFFICIENT WALL SECTION: VENTED SKIN MASONRY WALL WITH INSIDE INSULATION FOR HUMID, OVERHEATED CLIMATES
2.24



ENERGY-EFFICIENT WALL SECTION: VENTED SKIN WALL WITH RADIANT BARRIER FOR HUMID, OVERHEATED CLIMATES
2.25



Contributors:
Donald Watson, FAIA, Rensselaer Polytechnic Institute, Troy, New York; Jeffrey Cook, Arizona State University, Tempe, Arizona; Kenneth Labs, New Haven, Connecticut; K. Clark and P. Paylore, *Desert Housing: Balancing Experience and Technology for Dwelling in Hot Arid Zones*, Office of Arid Land Studies, University of Arizona, Tucson, Arizona, 1980; J. Cook, *Cool Houses for Desert Suburbs*, Arizona Solar Energy Commission, Phoenix, Arizona, 1984; Donald Watson, FAIA, Rensselaer Polytechnic Institute, Troy, New York; Kenneth Labs, New Haven, Connecticut; Subrato Chandra, Philip W. Fairey, Michael M. Houston, and Florida Solar Energy Center, *Cooling with Ventilation*, Solar Energy Research Institute, Golden, Colorado, 1982; K.E. Wilkes, *Radiant Barrier Fact Sheet*, CAREIRS, Silver Spring, Maryland; P. Fairey, S. Chandra, and A. Kerestecioglu, *Ventilative Cooling in Southern Residences: A Parametric Analysis*, PF-108–86, Florida Solar Energy Center, Cape Canaveral, Florida 1986.

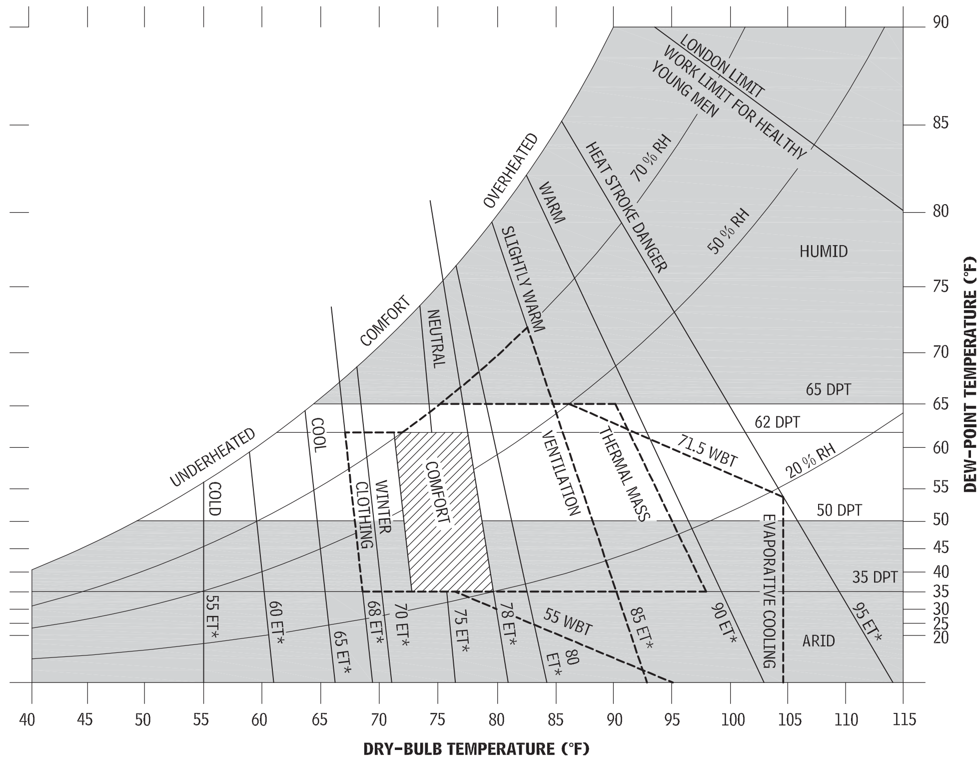
THERMAL COMFORT

CLIMATE DATA

STRATEGIES OF CLIMATE CONTROL

The bioclimatic chart (Olgyay, *Design with Climate*, updated by Givoni and Arens) is presented here in standard psychrometric format. Plotting temperature and humidity data on the chart identifies cooling strategies for buildings dominated by envelope loads. The heavy lines in Figure 2.26 delineate limits within which ventilation, massive construction, evaporative space cooling, and clothing can maintain thermal comfort indoors.

BUILDING BIOCLIMATIC CHART (AFTER GIVONI)
2.26



VENTILATION

Whole-house (exhaust) fans provide up to 20 air changes per hour and, like continuous cross ventilation, maintain indoor temperatures close to the outdoors. As long as outdoor conditions are within the comfort zone, "air-exchange ventilation" maintains indoor comfort. "Body ventilation" is best provided by ceiling (paddle) fans. They are effective up to 70 percent relative humidity and 85°F effective temperature (ET), with a maximum air speed of 3 fps and light clothing (0.4–0.6 clo).

THERMAL MASS

A very massive building envelope can maintain indoor comfort if outdoor air temperature does not exceed the thermal mass limit on the chart (roughly equal to 89°F ET). This requires that (1) the envelope is shaded or reflective enough that its average daily outside surface temperature is no higher than the daily mean air temperature; (2) the envelope is massive enough to average daily temperature fluctuations; and (3) there is no daytime ventilation of the indoors. Nighttime ventilation extends the upper limit by cooling the envelope from both sides.

EVAPORATIVE SPACE COOLING

Intake ventilation air is evaporatively cooled by drawing it through wetted mats or filters. The technique is suited to arid and semiarid regions and requires a fan-powered ventilation system. The limits are 71.5°F wet-bulb temperature and in excess of 105°F dry bulb, which is a conservative upper bound.

OTHER CLIMATIC ELEMENTS

Wind speeds and direction are important for site analysis and for orienting the building for shelter from winter winds and to capture cooling breezes. Solar radiation data ("irradiation" or "insolation") is necessary for solar heating and daylighting design. Insolation, measured in Btu/sq. ft./day (or per hour), is a function of latitude, sky conditions, and angle of incidence to the receiving surface (*see* Kusuda and Ishii, 1977). Ground temperatures at various depths can be estimated from well-water temperatures (*see* Labs, 1981).

TERMINOLOGY

The effective temperature, ET, refers to any set of temperature and humidity conditions that gives the same sensation of comfort as the stated temperature at 50 percent relative humidity (RH). ET plotted in Figure 2.26 assumes light office clothing (0.6 clo) and very little air movement. A clo is the insulating value of clothing. A business suit is 1.0 clo. One can feel as comfortable at 80°F with 20 percent RH as at 76°F at 80 percent RH; both are 78°F ET. The ASHRAE comfort zone is bounded by an upper humidity limit of about 62°F dew point; 65°F is a conservative limit. A mean daily dew-point temperature of 50°F produces diurnal air temperature swings in excess of 30°F.

ADAPTIVE THERMAL COMFORT

A relationship exists between outdoor the environmental conditions and the perceived indoor human comfort due to behavioral, physiological, and psychological human thermal adaption.

HEATING DEGREE DAYS

Design professionals should combine data derived from climatic control maps with data derived from the average number of Heating Degree Days (HDD) in a region when designing for different parts of the country. Figure 2.27 provides winter weather data and design conditions for locations within the United States.

WINTER WEATHER DATA AND DESIGN CONDITIONS FOR THE UNITED STATES
2.27

STATE OR PROVINCE	CITY	LATITUDE (°′)	LONGITUDE (°′)	ELEVATION (FT)	WINTER DESIGN TEMPERATURE[a]	AVERAGE WINTER TEMPERATURE[b]	AVERAGE MONTHLY HEATING DEGREE DAYS[c]									
							SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	TOTAL
AL	Birmingham	33 3	86 5	61	21	54.2	6	93	363	555	592	462	363	108	9	2551
AK	Fairbanks	64 5	147 5	436	–47	6.7	642	1203	1833	2254	2359	1901	1739	1068	555	14,279
AZ	Tucson	32 1	111 0	2584	32	58.1	0	25	231	406	471	344	242	75	6	1800
AR	Little Rock	34 4	92 1	257	20	50.5	9	127	465	716	756	577	434	126	9	3219
CA	Sacramento	38 3	121 3	17	32	54.4	0	62	312	533	561	392	310	173	76	2419
	San Diego	32 4	117 1	19	44	59.5	21	43	135	236	298	253	214	135	90	1458
	San Francisco	37 5	122 3	52	40	55.1	102	118	231	388	443	336	319	279	239	3001
CO	Denver	39 5	104 5	5283	1	37.6	117	428	819	1035	1132	938	887	558	288	6283
CN	Hartford	41 1	73 1	7	9	37.3	117	394	714	1101	1190	1042	908	519	205	6235
DE	Wilmington	39 4	75 3	78	14	42.5	51	270	588	927	980	874	735	387	112	4930
DC	Washington	38 5	77 0	14	17	45.7	33	217	519	834	871	762	626	288	74	4224
FL	Miami	25 5	80 2	7	47	71.1	0	0	0	65	74	56	19	0	0	214
GA	Atlanta	33 4	84 3	1005	22	51.7	18	124	417	648	636	518	428	147	25	2961
	Savannah	32 1	81 1	52	27	57.8	0	47	246	437	437	353	254	45	0	1819
HA	Honolulu	21 2	158 0	7	63	74.2	0	0	0	0	0	0	0	0	0	0
ID	Boise	43 3	116 1	2842	10	39.7	132	415	792	1017	1113	854	722	438	245	5809
IL	Chicago	42 0	87 5	658	–4	35.8	117	381	807	1166	1265	1086	939	534	260	6639
IN	Indianapolis	39 4	86 2	793	2	39.6	90	316	723	1051	1113	949	809	432	177	5699
IA	Des Moines	41 3	93 4	948	–5	35.5	96	363	828	1225	1370	1187	915	438	180	6588
KS	Topeka	39 0	95 4	877	4	41.7	57	270	672	980	1122	893	722	330	124	5182
KY	Lexington	38 0	84 4	979	8	43.8	54	239	609	902	946	818	685	326	105	4683
LA	New Orleans	30 0	90 2	3	33	61.8	0	12	165	291	344	241	177	24	0	1254
ME	Portland	43 4	70 2	61	–1	33.0	195	508	807	1215	1339	1182	1042	675	372	7511
MD	Baltimore	39 1	76 4	146	3	43.7	48	264	585	905	936	820	679	327	90	4654
MA	Boston	42 2	71 0	15	9	40.0	60	316	603	983	1088	972	846	513	208	5634
MI	Detroit	42 2	83 0	633	6	37.2	87	360	738	1088	1181	1058	936	522	220	6232
MN	Minneapolis	44 5	93 1	822	–12	28.3	189	505	1014	1454	1631	1380	1166	621	288	8322
MS	Jackson	32 2	90 1	330	25	55.7	0	65	315	502	546	414	310	87	0	2239
MO	Columbia	39 0	92 2	778	4	42.3	54	251	651	967	1076	875	716	324	121	5046
MT	Billings	45 5	108 3	3367	–10	34.5	186	487	897	1135	1296	1100	970	570	285	7049
NE	Omaha	41 2	95 5	978	–3	35.6	105	357	828	1175	1355	1126	939	465	208	6612
NV	Las Vegas	36 1	115 1	2162	28	53.5	0	78	387	617	688	487	335	111	6	2709
NH	Concord	43 1	71 3	339	–3	33.0	177	505	822	1240	1358	1184	1032	636	298	7383
NJ	Trenton	40 1	74 5	144	14	42.4	57	264	576	924	989	885	753	399	121	4980
NM	Albuquerque	35 0	106 4	5310	16	12.0	12	229	642	868	930	703	595	288	81	4348
NY	New York	40 5	74 0	132	15	42.8	30	233	540	902	986	885	760	408	118	4871
NC	Charlotte	35 0	81 0	735	22	50.4	6	124	438	691	691	582	481	156	22	3191
ND	Bismarck	46 5	100 5	1647	–19	26.6	222	577	1088	1463	1708	1442	1203	645	329	8851
OH	Cleveland	41 2	81 5	777	5	37.2	105	384	738	1088	1159	1047	918	552	260	6351
	Columbus	40 0	82 5	812	5	39.7	84	347	714	1039	1088	949	809	426	171	5660
OK	Oklahoma City	35 2	97 4	1280	13	48.3	15	164	498	766	868	664	527	189	34	3725
OR	Salem	45 0	123 0	195	23	45.4	111	338	594	729	822	647	611	417	273	4754
PA	Pittsburgh	40 3	80 1	1137	5	38.4	105	375	726	1063	1119	1002	874	480	195	5987
RI	Providence	41 4	71 3	55	9	38.8	96	372	660	1023	1110	988	868	534	286	5954
SC	Columbia	34 0	81 1	217	24	54.0	0	84	345	577	570	470	357	81	0	2484
SD	Rapid City	44 0	103 0	3165	–7	33.4	165	481	897	1172	1333	1145	1051	615	326	7345
TN	Nashville	36 1	86 4	577	14	48.9	30	158	495	732	778	644	512	189	40	3578
TX	Dallas	32 5	96 5	481	22	55.3	0	62	321	524	601	440	319	90	6	2363
	Houston	29 4	95 2	50	32	61.0	0	6	183	307	384	288	192	36	0	1396
UT	Salt Lake City	40 5	112 0	4220	8	38.4	81	419	849	1082	1172	910	763	459	233	6052
VT	Burlington	44 3	73 1	331	7	29.4	207	539	891	1349	1513	1333	1187	714	353	8269
VA	Lynchburg	37 2	79 1	947	16	46.0	51	223	540	822	849	731	605	267	78	4166
WA	Seattle	47 4	122 2	14	27	46.9	129	329	543	657	738	599	577	396	242	4424
WV	Charleston	38 2	81 4	939	11	44.8	63	254	591	865	880	770	648	300	96	4476
WI	Green Bay	44 3	88 1	683	–9	30.3	174	484	924	1333	1494	1313	1141	654	305	8029
WY	Casper	42 5	106 3	5319	–5	33.4	192	524	942	1169	1290	1084	1020	651	381	7410

NOTES

2.27 a. Based on 97.5 percent design dry-bulb values found in *ASHRAE Handbook of Fundamentals*, 1977.
b. October–April, inclusive. *ASHRAE Systems Handbook*, 1976.
c. Based on the period 1931–1960, inclusive. *ASHRAE Systems Handbook*, 1976.

DAYLIGHTING

DAYLIGHTING DESIGN

Architects understand design of space and light as a central principle of form making. The term daylighting requires clear definition, as it represents multiple design intentions, often at cross-purposes. Daylighting design incorporates strategies for controlling the way light enters a building while also considering energy, lighting design, operable shades, and controls. Daylighting design uses scientific tools, but is ultimately an art, concerned with comfort, quality of light, and space, as well as more measurable attributes such as footcandle levels and energy savings.

SYSTEMS INTEGRATION

Sustainable design is universally understood to be about whole systems integration, and nothing illustrates the case better than daylighting, which optimizes the relationship between energy, task visibility, comfort, cost, controls, color, character, and connection to the outdoors. Daylight can achieve very different goals through systems integration. One building might strive to keep direct sun from entering, another might seek optimal visual comfort, and still others might use daylighting primarily to achieve energy efficiency.

Algorithms that model energy performance of daylighting strategies are beginning to be integrated into existing energy modeling software. Good design incorporates the qualitative aspects of daylighting as part of an overall lighting and envelope strategy, optimizing user control of lighting and operable window shades or window blinds.

DESIGN VALUES AND DAYLIGHTING

Daylighting design is part of a broader approach to building. Maximizing energy efficiency often means compromising daylight. A small amount of dark-tinted glass in an office building might be the energy solution, but it yields an interior that feels disconnected from the outdoors, gloomy, and dependent on low-level light. There is no one right answer, but the degree of connectedness to the outside world desired and the nature of outdoor light quality are critical factors. In a mostly cloudy climate, clear glass and light monitors can be elements of an essential design strategy. In a climate with intense direct sun, finding ways to reflect light, modulate brightness in increments, and provide relief from glare can be the keys to good daylighting. A number of these factors are defined briefly here:

Daylight and views: Daylight and views are often linked as concepts, but there is no real basis for this connection other than the fact that both involve exterior wall openings. A building that affords great views does not, by definition, provide great daylighting, and a well-daylit building might afford no views at all! What constitutes a view is easily defined in technical terms as a window with a view beyond the foreground of the building. High-quality views are more difficult to define.

Ambient brightness: The brightness of the sky dome at various times of day is critical. Bright, cloudy days actually have higher ambient brightness than clear, sunny days. Outdoor light on a surface can be measured at as much as 10,000 footcandles (fc), but the human eye can read comfortably at fewer than 10 fc (even at 1). This ambient level changes throughout the day. Modeling can measure the sky dome under both clear and cloudy conditions.

Daylight factor: The quantitative measurement of openings and transparency in the building envelope is referred to as the *daylight factor*. It is not a measure of daylight quality and does not take glare into account.

Illuminance and luminosity: Measurement of light incident on a surface, or *illuminance* (measured in lumens per square meter, or footcandles), is not the same measurement as what the eye sees reflected from the surface. The reflected light luminance, or *luminosity* (measured in candelas per square meter, or footlamberts), is what makes up the field of view; and relative brightness within that field is what determines level of both comfort and stimulation. Because good lighting design involves the skillful use of reflected light through the illumination of wall and ceiling surfaces, luminance is a critical measurement. Most lighting design guidelines, however, measure footcandles incident on a work surface.

Adaptation to light intensity: The human eye is resilient and can adapt to changes in light level by approximately a factor of 10. For example, entering a building on a day with 10,000 fc light level to below a canopy with ambient light of 1000 fc is still relatively comfortable. Entering the foyer of the building with a level of 100 fc is again comfortable, making it possible to move to an interior office with 10 fc. Without intermediate steps the eye has trouble adjusting and takes a moment to refocus. This phenomenon is a serious factor in many situations, such as transitioning from brightly illuminated service stations to driving on a dark highway, where the eye might take several minutes to readjust. Adaptation decreases with age and eyestrain.

Glare: Glare is defined as discomfort or interference with visual perception caused by a high differential in light levels within the field of view. The eye adapts to the brighter area, making adaptation to the darker area difficult or impossible.

Perimeter daylight, glass location, and building section: Bringing light into a space and reflecting it onto the ceiling and high wall surfaces is critical to good daylighting. Glass below desk height is of little value to daylighting. A variety of light-reflecting devices are available for this purpose. A good rule of thumb is to use high, clear, continuous horizontal glass that can be shaded from low-angle sun as needed. If a commercial building has a high floor-to-floor section that yields a generous clear interior height, this transom zone, generally above the height of interior doors, can have glass of 2 ft. high or more. The appropriate height for an interior space depends on use and building width. In general, well-daylit buildings in Europe and the United States are 50 to 80 ft. wide. A 60-ft building width with high ceilings can allow virtually continuous daylight and a central space that benefits from all exposures. More common office buildings in the United States have deep floors of 100 ft. or more, yielding a 25-ft potential daylight zone at the perimeter and a 50-ft zone at the core, which is fully dependent on electric lighting.

Roof windows and skylights: Light travels in a straight line with minimal diffusion. In general, areas below a skylight (even on a cloudy day) will form a bright spot that contrasts dramatically with the space around it. Roof windows and skylights acting in conjunction with reflective surfaces bounce light back to the ceiling and even eliminate direct-beam penetration. Skylights in art museums often employ baffles or fabric or glass diffusers inside or outside the building envelope. Without some form of diffusion, skylights alone must be larger to be effective daylighting devices. Larger skylights become sources of heat gain and heat loss, but can also provide a welcome connection to the outdoors.

Light monitors and clerestories: These provide light in a more controlled manner than skylights. A monitor is a rooftop structure with a vertical glass and a roof. A clerestory is like a monitor, but with glass on only one side. An east-west orientation and strategically sized overhangs can make a monitor a very effective daylight source, one that eliminates many of the issues associated with skylights. Direct-beam penetration is controlled, vertical surfaces are illuminated, potential leaks and heat loss are reduced, and snow cannot cover the protected vertical surfaces.

Light shelves: Light shelves reflect direct sunlight onto the ceiling into a space. A light shelf can be located inside or outside the building. Light shelves are not exterior shades by definition, but an exterior sun shade with a reflective top surface can be a light shelf. A secondary but important function of light shelves is the screening of glare caused by direct views of the sky. Once this glare is reduced, overall light levels in a space can be reduced while maintaining comfort.

Exterior shading: Shading elements such as overhangs and awnings can limit direct-beam penetration into a space. Such elements also cut down on daylight. The best solution in any particular situation involves consideration of the planning and use of the space, climate, and expectations related to use and comfort. Exterior shading on southern exposures is almost always beneficial, as it keeps direct sun out at midday in the summer and lets light and corresponding heat into buildings in the winter. Shading of vision glass is beneficial, as it is lower on the wall than transom glass and of lesser value in terms of reflectance deep into the space. At the same time, this shading of vision glass can help block direct view of the sky, reducing glare in the field of view.

Interior window shades and window blinds: Window blinds and roller window shades are the most common and economical means of sun control. Although they do little to combat heat gain, shades and blinds are an integral part of any daylighting strategy. Reflective window blinds function as adjustable daylighting devices, reflecting light onto the ceiling. Roller window shades and pleated window shades are available in a variety of fabrics with measurable levels of light transmittance, interior and exterior colors, and automation systems.

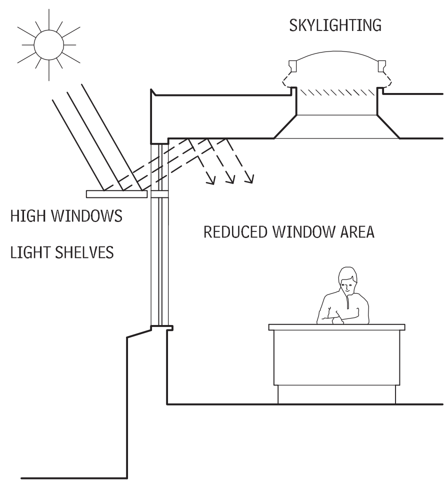
MODELING

Daylighting comprises two interrelated concepts: providing appropriate light levels on surfaces and mitigating direct-beam light penetration when it is unwanted. Computer daylight modeling can address both.

Computer modeling: The ease with which three-dimensional modeling now simulates solar movement is making this the preferred strategy employed by increasing numbers of designers. Computer simulations are a permanent record allowing more iterations than a physical model.

DAYLIGHTING STRATEGIES

DAYLIGHTING
2.28



The architect should consider the following items in designing an energy-efficient nonresidential building, regardless of size and building type.

Place windows high in the wall of each floor. Windows placed high in the wall near the ceiling provide the most daylight for any given window area, permitting daylight to penetrate more deeply into the interior.

Use light shelves. Light shelves are horizontal projections placed on the outside and below a window to reflect sunlight into the interior. Typically placed just above eye level, the light shelf reflects daylight onto the interior ceiling, making it a light-reflecting surface (instead of a dark, shaded surface typical of a conventional interior ceiling). At the same time, the light shelf shades the lower portion of the window, reducing the amount of light near the window, which is typically overlit. The result is more balanced daylighting with less glare and contrast between light levels in the interior.

Size windows according to use and orientation. Because window glass has little or no resistance to heat flow, it is one of the primary sources of energy waste and discomfort. Window areas should be shaded against direct solar gain during overheated hours. Even when shaded, windows gain undesired heat when the outdoor temperature exceeds the human comfort limit. Window areas should, therefore, be kept to a reasonable minimum, justified by clearly defined needs for view, visual relief, ventilation, and/or daylighting.

Use skylighting for daylighting, with proper solar controls. Skylighting that is properly sized and oriented is an efficient and cost-effective source of lighting. Consider that for most office buildings, sunlight is available for nearly the entire period of occupancy and that the lighting requirement for interior lighting is only about 1 percent of the amount of light available outside. Electric lighting costs, peak demand charges, and work interruptions during power brownouts can be greatly reduced by using daylight. Cost-effective, energy-efficient skylights can be small, spaced widely, with "splayed" interior light wells that help reflect and diffuse the light. White-painted ceilings and walls further improve the efficiency of daylighting (by as much as 300 percent, when compared with dark interior finishes). Skylights should include some means to control undesired solar gain by one or more of the following means: (1) Face the skylight to the polar orientation; (2) provide exterior light-reflecting sun shading; and (3) provide movable sunshades on the inside, with a means to vent the heat above the sunshade.

DAYLIGHTING OPPORTUNITIES

An atrium with the predominant function to provide natural lighting takes its shape from the predominant sky condition. In cool, cloudy climates, ideally, the atrium cross section would be stepped outward as it gets higher, to increase overhead lighting. In hot, sunny locations with clear sunny skies, the cross section is like a large lighting fixture designed to reflect, diffuse, and make usable the light from above. Daylighting design is complicated by the movement of the sun as it changes position with respect to the building throughout the day and the year.

WINTER GARDEN ATRIUM DESIGN

Healthy greenery can be incorporated in atrium design. The designer needs to know the unique horticultural requirements for the plant species for lighting, heating, and cooling, which could be quite different from those for human occupancy. Generally, plants need higher light levels and cooler temperatures than might be comfortable for humans. The most efficient manner to keep plants heated is with plant bed or root heating, as with water tubes or air tubes in gravel or earth. Plants also benefit from gentle air movement, which reduces excessive moisture that might rot the plants, and circulates carbon dioxide needed for growth.

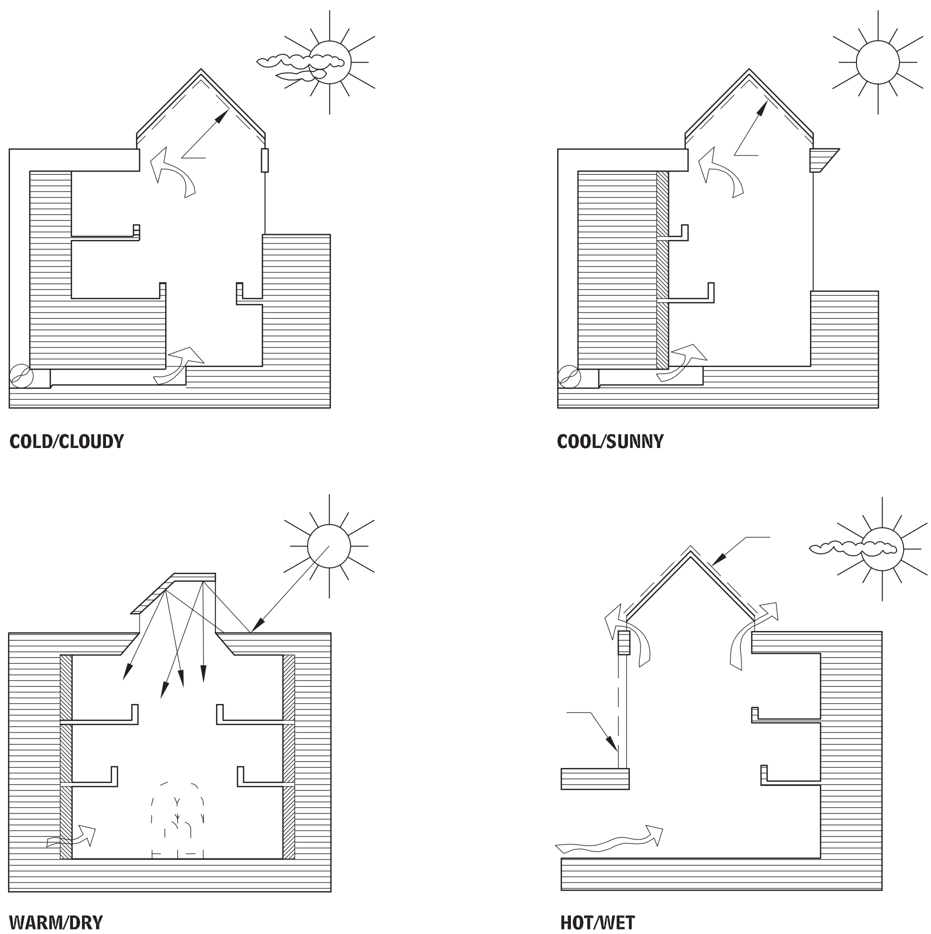
COLOR TEMPERATURE

Interaction of sunlight with the atmosphere results in color changes throughout the day. The appearance of colors and textures of materials and coatings is strongly affected by this interaction. Cities and regions throughout the world are known for their light quality. Los Angeles has a bright, even, flat light created by dispersion of light through smog and mist. Coastal light, in general, benefits from the reflection off the water. Combinations of solar altitude, presence and location of water vapor in the atmosphere, surface water, color and topography of the surrounding landscape, and dust particles create a unique profile of ambient light. Material choice wedded to the light quality of a place is critical to the success of good design. Good architectural daylighting takes the unique nature of place into account.

Color temperature is measured in degrees Kelvin based on the radiation emitted from a theoretical object called a "black body radiator." When the radiator is heated, it changes from black to red to yellow to white to blue. The lower the Kelvin rating, the warmer, or more yellow, the light. The higher the rating, the cooler, or more blue, the light.

Research indicates that humans prefer cooler light at higher intensity and warmer light at lower intensity. Dim fluorescent lights appear gloomy; likewise, bright, warm color lights are uncomfortable.

ATRIUM DESIGN
2.29



COLOR TEMPERATURE
2.30

SOURCE	KELVIN RATING (K)
Candle	1800
Indoor tungsten	2800
Warm fluorescent	2850
Sunrise/sunset	3000
Outdoor sunlight	5500
Cool fluorescent	4100–6500
Outdoor shade/cloudy	7500
North sky	10,000

COLOR RENDITION

Another significant variable in lighting and daylighting related to sustainable design is the capability of the source to accurately reproduce colors compared to the continuous spectrum of the sun. The sun has a color rendition index (CRI) of 100 (percent). Light from radiation of an incandescent filament also has a CRI of 100. Fluorescent lights, however, have lower CRI, as they attempt to re-create the full spectrum through phosphors that cover multiple segments of the visible spectrum to achieve the appearance of while light.

COLOR RENDITION INDEX (CRI)
2.31

SOURCE	CRI
Candle	100
Indoor tungsten	100
Warm fluorescent	52
Sunrise/sunset	100
Outdoor sunlight	100
Cool fluorescent	56–93
Outdoor shade/cloudy	100
North sky	100

Some whites are whiter than others, and by a greater margin than is generally understood. A bright white paint can be far more reflective than off-white, which is an order of magnitude more reflective than colors. Pure white can be close to 90 percent reflective, off-white at 80 percent. Black is only 4 percent reflective, and deep colors are between 10 and 30 percent reflective. The implications of this for daylighting (and for urban heat island effect) are significant. White roofs reach a maximum temperature of 110°F, whereas dark asphalt or rubber roofs reach 190°F.

GLASS SELECTION

The visible transmittance of glass (Vt) is critical to the success of daylighting. In general, clear glass, even with low-E coatings, provides less shading and allows more heat gain than tinted or more heavily coated glass. See Table 9.9 for window types and visible transmittance.

CONTROLS, SENSORS, AND FIXTURES

Perimeter lighting can be turned off when daylighting is effective. In continuously occupied space with individual switches, this can be accomplished by individuals who learn to control their workspace—in other words, no automation. The other extreme is a fully automated building where photocells and motors adjust lights and shading devices. Each project needs to weigh pros and cons of user control and automation.

Photosensors that raise and lower window or sun shading devices and modulate light fixtures can be used in concert with time clocks and occupancy sensors to achieve a fully integrated system.

Here is an example strategy:

1. Perimeter office lights are off at the beginning of the workday, and window shades are raised automatically before sunrise.
2. Occupants can choose to turn on overhead lights in the office and dim to a comfortable level.
3. An occupancy sensor turns off light when an occupant leaves the room for a set period of time and returns it to the same level when the occupant returns.
4. Exterior sun control devices are programmed to be lowered automatically in preset increments by time clock in summer months and manually at other times of year.

ACOUSTICS

DESIGNING FOR SOUND

Sound is energy produced by a vibrating object or surface and transmitted as a wave through an elastic medium. Such a medium may be air (airborne sound) or any solid common building material, such as steel, concrete, wood, piping, gypsum board, and so on (structure-borne sound). A sound wave has *amplitude* and *frequency*.

The amplitude of sound waves is measured in *decibels* (dB). The decibel scale is a logarithmic scale based on the logarithm of the ratio of a sound pressure to a reference sound pressure (the threshold of audibility). The values of a logarithmic scale, such as the decibel levels of two noise sources, cannot be added directly. Instead, use the simplified method described in Figure 2.53. For example, 90 dB + 20 dB = 90 dB; 60 dB + 60 dB = 63 dB.

AMPLITUDE (DECIBELS)
2.32

Difference between sound levels (in dB)	0 to 1	2 to 3	4 to 9	10
Add this number to higher sound level	3	2	1	0

SUBJECTIVE REACTIONS TO CHANGE IN SOUND LEVEL
2.33

CHANGE IN SOUND LEVEL, DB	CHANGE IN APPARENT LOUDNESS
1 to 2	Imperceptible
3	Barely perceptible
5 to 6	Clearly noticeable
10	Significant change—twice as loud (or half as loud)
20	Dramatic change—four times as loud (or a quarter as loud)

FREQUENCY

The frequency of sound waves is measured in *hertz* (Hz; also known as cycles per second) and grouped into *octaves*; an octave band is labeled by its geometric center frequency. An octave band covers the range from one frequency (Hz) to twice that frequency (f to 2f). The range of human hearing covers the frequencies from 20 to 16,000 Hz. Human hearing is most acute in the 1000- to 4000-Hz octave bands.

The human ear discriminates against low frequencies in a manner matched by the A-weighting filter of a sound-level meter, measured in dBA, or A-weighted decibels. This is the most universally accepted single-number rating for human response to sound.

SOUND ABSORPTION PROPERTIES OF MATERIALS

All materials and surfaces absorb some sound. The percentage of incident sound energy that is absorbed by a material, divided by 100, equals the *coefficient of absorption*, which ranges from 0 to 0.99. The coefficient varies as a function of frequency, measured in hertz.

Any material can be tested in a proper laboratory to determine its coefficient of absorption values, as per ASTM C 423, "Standard Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method."

The *sound absorption coefficient* for a given material may vary depending on the thickness of the material, how it is supported or mounted, the depth of the airspace behind the material, and the facing in front of the material. In general, thicker, porous materials absorb more sound. The airspace behind a material will increase the absorption efficiency, especially at low frequencies. Thin facings degrade high-frequency absorption.

SOUND ENERGY ABSORPTION MECHANISMS

There are three mechanisms by which sound energy is absorbed or dissipated as it strikes a surface. In all cases, sound energy is converted to heat, although not enough heat to be felt.

Porous absorption entails the use of soft, porous, fuzzy materials such as glass fiber, mineral wool, and carpet. The pressure fluctuations of a sound wave in air cause the fibers of such materials to move, and the friction of the fibers dissipates the sound energy.

Panel absorption involves installation of thin lightweight panels such as gypsum board, glass, and plywood. Sound waves cause these panels to vibrate. Sound absorption for a panel is greatest at its natural or resonant frequency.

Cavity absorption entails the movement of air pressure fluctuations across the narrow neck of an enclosed air cavity, such as the space behind a perforated panel or a slotted concrete masonry unit, also called a *Helmholtz resonator*. Friction of the resonating air molecules against the wall of the neck converts sound energy to heat. If there is also insulation within the cavity, additional energy is extracted via the porous absorption mechanism.

ACOUSTIC MEASUREMENT TERMS

Following are acoustic measurement terms:

- *Apparent Sound Transmission Class (ASTC):* Field measurement that covers all sound transfer paths between spaces. Previously referred to as the Noise Isolation Class (NIC).
- *Articulation index (AI):* Measures how materials affect speech intelligibility in offices.
- *Average room absorption coefficient (average coefficient of absorption):* Total room absorption divided by total room surface area.
- *Coefficient of absorption (absorption coefficient):* Percent of sound energy absorbed by a material.
- *Decibel (dB):* Measures sound pressure (perceived as relative loudness).
- *Hertz (Hz):* Measures frequency (perceived as high or low pitch).
- *Impact Isolation Class (IIC):* Measures impact sound transmissions through floor assemblies.
- *Noise criteria (NC):* Standard spectrum curves used to describe a given measured noise.
- *Noise Isolation Class (NIC):* Formerly used to estimate sound isolation between two enclosed spaces; replaced by ASTC.
- *Noise reduction (NR):* Measures actual difference in sound pressure levels at any two points along a sound path.
- *Noise reduction coefficient:* Average of sound absorption coefficients at four frequency bands. Replaced by SAA, similar ratings but less accurate.
- *Sabin:* Unit of sound absorption.
- *Sound absorption average (SAA):* Average of sound absorption coefficients.
- *Sound absorption coefficient:* Measures absorptive property of a material in a specified frequency band.
- *Sound transmission class (STC):* Provides an estimate of the performance of a partition in certain common sound insulation situations.
- *Sound transmission loss (TL):* Measures attenuation of airborne sound through a construction assembly.
- *Speech absorption coefficient (SAC):* Tool for evaluating the effectiveness of ceiling materials for sound absorption.

MEASURING SOUND ABSORPTION

One measure of the quality of sound in a room is the *average coefficient of absorption* for all surfaces combined. As determined by using the average coefficient of absorption, the quality of sound in a room can be evaluated as 0.1, 0.2, or 0.3. A room with an average coefficient of 0.1 is rather acoustically *live*, loud, and uncomfortably noisy; one with an average coefficient of 0.2 is comfortable, with well-controlled noise; and one with 0.3 is rather acoustically *dead*, suitable for spaces in which the emphasis will be on amplified sound, electronic playback, or a live microphone for teleconferencing.

The *sound absorption average* (SAA) is a new single-number measure of sound absorption that is replacing the *noise reduction coefficient* (NRC) rating. The SAA is the average of sound absorption coefficients of a material from 200 to 2500 Hz inclusive. The method for determining the SAA is defined by ASTM C 423, as described below.

Pink noise (a mixture of sound waves that diminish in intensity proportionately with frequency) is emitted from two loudspeakers in the receiving room. While the sound is triggered on and off, 50 sample decay rates (from 80 to 500 Hz) are measured with (referred to as *full room*) and without (referred to as *empty room*)

Contributors:
Mark Rylander, AIA, William McDonough + Partners, Charlottesville, Virginia; Mark Rylander, AIA, William McDonough + Partners, Charlottesville, Virginia; Cline McGee, AIA Hall Architects, Inc., Charlotte, North Carolina; Peter Novak, CEO, Sundolier, Inc., Boulder, Colorado.

the test specimen installed in the chamber. The decay rate data is used to calculate the empty- and full-room absorption. The empty- and full-room absorption is used to calculate the SAA rating.

Although NRC ratings have been replaced by the SAA, manufacturers often continue to report only NRC values, and NRC values are often given for historic comparison.

Usually, the numerical value of the NRC is almost the same as that of the SAA. A rating of 0.35 is considered indicative of good sound absorption, whether given as an NRC or SAA rating.

Figure 2.34 gives representative absorption coefficients at various frequencies for some typical materials. To determine values not provided here, refer to the manufacturer's data or extrapolate from similar constructions. All materials have some absorption values that can be determined from proper test reports. NRC values are provided for reference.

MEASURING SOUND ABSORPTION DETAIL

The following figures provide detail for measuring sound absorption.

ROOM ACOUSTICS

The *sabin* is defined as a unit of sound absorption. One square meter of 100 percent absorbing material has a value of one metric sabin. The unit is named in honor of Wallace Clement Sabine, considered the father of acoustic design.

The total sabins in a room can be determined by adding together the sabins of all the surfaces, which vary as a function of frequency. Because most materials absorb more high-frequency sound waves than low-frequency ones, it is typical to find more sabins in a room at high frequencies than at low frequencies.

In general, sound energy that is not absorbed will be reflected; thus, surfaces with low coefficients of absorption can be used to encourage sound reflection when appropriate.

PROPERTIES OF SOUND

Distance and time are two defining properties of sound. Outdoors, sound drops off 6 dB each time the distance from a source is doubled (inverse square law). Indoors, the reflecting sound energy in a room reaches a constant level as a function of the sound-absorbing units (sabins) in the room.

Outdoors, sound ceases when the source stops. Indoors, sound energy lingers; this decay is called *reverberation*. The *reverberation time* (RT) is defined as the length of time in seconds that it takes for sound to decay by 60 dB. Reverberation time is directly proportional to the volume of a space and inversely proportional to the units of absorption (sabins) in it.

Shorter reverberation times greatly enhance speech intelligibility and are imperative in listening environments for people with hearing impairments and for rooms with live microphones for teleconferencing. Longer reverberation times add richness to concert and liturgical music.

USE OF SOUND-ABSORPTIVE MATERIALS

Sound-absorptive materials (such as acoustic tile, glass fiber, wall panels, carpet, curtains, etc.) can be added to a room in order to control or reduce noise levels or shorten reverberation time. Noise control is especially helpful when the noise sources are distributed around a room, as in a gymnasium, classroom, or cafeteria.

GUIDELINES FOR USE OF SOUND ABSORPTION
2.35

ROOM TYPE	TREATMENT
Classrooms, corridors and lobbies, patient rooms, laboratories, shops, factories, libraries, private and open-plan offices, restaurants	Ceiling or equivalent area; add additional wall treatment if room is quite high
Boardrooms, teleconferencing rooms, gymnasiums, arenas, recreational spaces, meeting and conference rooms	Ceiling or equivalent; add wall treatments for further noise reduction and reverberation control and to eliminate flutter or echo
Auditoriums, churches, acoustically sensitive spaces	Special considerations and complex applications

SOUND TRANSMISSION

The property of a material or construction system that blocks the transfer of sound energy from one side to another is *sound transmission loss* (TL), which is measured in decibels. Specifically, TL is the attenuation of airborne sound transmission through a construction during laboratory testing, according to ASTM E 90, "Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements."

Transmission loss values range from 0 to 70 or higher. A high TL value indicates a better capability to block sound; that is, more sound energy is lost (transformed into heat energy) as the sound wave travels through the material.

Sound transmission class (STC) is a single-number rating system designed to combine TL values from many frequencies. STC values for site-built construction range from 10 (practically no isolation; e.g., an open doorway) to 65 or 70 (such high performance is only achieved with special construction techniques). Average construction might provide noise reduction in the range of STC 30 to 60.

It is very difficult to measure the STC performance of a single wall or door in the field because of the number of flanking paths and nonstandard conditions. Field performance is measured with *Apparent Sound Transmission Class* (ASTC) ratings, which cover effects from all sound transfer paths between rooms. ASTC ratings, previously referred to as the *Noise Isolation Class* (NIC), are derived by using the STC procedure (ASTM E 413, "Classification for Rating Sound Insulation") to rate the uncorrected sound-level difference spectrum without correction or normalization factors.

TRANSMISSION LOSS

Design of construction and materials for high transmission loss builds on three principles: mass, separation, and absorption.

Mass: Lightweight materials do not block sound. Sound transmission through walls, floors, and ceilings varies with the frequency of sound, the weight (or mass) and stiffness of the construction, and the cavity absorption.

Separation: Improved TL performance without an undue increase in mass can be achieved by separation of materials. A true double wall with separate unconnected elements performs better than the mass law predicts for a single wall of the same weight.

Absorption: Use of soft, resilient, absorptive materials in the cavity between wythes, particularly for lightweight staggered or double-stud construction, increases transmission loss significantly. *Viscoelastic* (somewhat resilient but not fully elastic) materials, such as certain insulation boards, dampen or restrict the vibration of rigid panels such as gypsum board and plywood, increasing transmission loss somewhat. Follow manufacturer-recommended installation details.

If two layers of dense material are separated by an airspace (rather than being continuous), they create two independent walls. The improvement in transmission loss depends on the size of the airspace and the frequency of the sound. Avoid rigid ties between layers in all double-wall construction.

When a wall or surface of a room is made up of two or more different structures (e.g., a window in an outside wall or a door in an office), the TL performance (or STC) of the composite construction should be evaluated by combining the TL (or STC) values of the components. Note that small gaps and cracks, such as the perimeter of an ungasketed door, can dramatically degrade the performance of a high-TL construction.

NOISE REDUCTION

Noise reduction (NR) depends on the properties of a room and is the actual difference in sound pressure level between two spaces. It is the amount of sound blocked by all intervening sound paths between rooms, including the common wall but also the floor, ceiling, outside path, doors, and other flanking paths.

Noise reduction also depends on the relative size of a room. If the noise source is in a small room next to a large receiving room (e.g., an office next to a gymnasium), the noise reduction will be greater than the TL performance of the wall alone because the sound radiating from the common wall between office and gym will be dissipated in such a large space. On the other hand, if the noise source is in a large room next to a small one (as from a gym to an office next door), the noise reduction will be far less than the TL of the wall alone because the common wall, which radiates sound, is such a large part of the surface of the smaller room. An adjustment for this ratio, plus the contribution of the absorptive finishes in the receiving room, enters into the calculation of actual noise reduction between adjacent spaces.

SOUND ISOLATION

One of the most common goals in the design of sound isolation construction is achievement of acoustic privacy from a neighbor. This privacy is a function of whether the signal from the neighbor is audible and intelligible above the ordinary background noise level in the environment. Noise reduction is measured as a field performance, where it is evaluated and given an STC value. The privacy index is equal to noise reduction plus background noise that masks speech sounds.

SOUND-ABSORBING COEFFICIENTS FOR VARIOUS MATERIALS
2.34

MATERIAL	125 HZ	250 HZ	500 HZ	1000 HZ	2000 HZ	40,000 HZ	NRC
Marble	0.01	0.01	0.01	0.01	0.02	0.02	0.00
Gypsum board, 1/2″ (13 mm)	0.29	0.10	0.05	0.04	0.07	0.09	0.05
Wood, 1″ (25 mm) thick, with airspace behind	0.19	0.14	0.09	0.06	0.06	0.05	0.10
Heavy carpet on concrete	0.02	0.06	0.14	0.37	0.60	0.65	0.30
Acoustic tile, surface mounted	0.34	0.28	0.45	0.66	0.74	0.77	0.55
Acoustic tile, suspended	0.43	0.38	0.53	0.77	0.87	0.77	0.65
Acoustic tile, painted (est.)	0.35	0.35	0.45	0.50	0.50	0.45	0.45
Audience area: empty, hard seats	0.15	0.19	0.22	0.39	0.38	0.30	0.30
Audience area: occupied, upholstered seats	0.39	0.57	0.80	0.94	0.92	0.87	0.80
Glass fiber, 1″ (25 mm)	0.04	0.21	0.73	0.99	0.99	0.90	0.75
Glass fiber, 4″ (100 mm)	0.77	0.99	0.99	0.99	0.99	0.95	1.00
Thin fabric, stretched tight to wall	0.03	0.04	0.11	0.17	0.24	0.35	0.15
Thick fabric, bunched 4″ (100 mm) from wall	0.14	0.35	0.55	0.72	0.70	0.65	0.60

Normal privacy, in which you are aware of a neighbor's activity but not overly distracted by it, can usually be achieved with a privacy index of 68 or higher. Confidential privacy, in which you are unaware of the neighbor, usually requires a privacy index of 75 or higher.

A quiet environment with little or no natural background sound between neighbors requires a higher degree of sound separation construction to achieve the same privacy as does a noisier environment with louder background sound.

The level of continuous background noise, such as that provided by the heating, ventilating, and air-conditioning (HVAC) system or by electronic masking, has a significant impact on the quality of construction selected and must be coordinated with the other design parameters.

Ratings for interior occupied spaces depend on the nature of the exterior background noise—its level, spectrum shape, and constancy—as well as thermal considerations and the client's budget.

The STC ratings shown in Figure 2.36 for music practice rooms are guidelines only. These spaces typically require double-layer construction with resilient connections between layers or, preferably, structurally independent "room within a room" construction.

SOUND ISOLATION DETAIL

The following figure provides STC data for sound isolation.

SOUND ISOLATION CRITERIA
2.36

OCCUPANCY	SOURCE ROOM	ADJACENT AREA	BACKGROUND LEVEL IN SOURCE ROOM:	
			QUIET	NORMAL
School buildings	Classrooms	Adjacent classrooms	STC 42	STC 40
		Corridor or public areas	STC 40	STC 38
		Kitchen and dining areas	STC 50	STC 47
		Shops	STC 50	STC 47
		Recreation areas	STC 45	STC 42
		Music rooms	STC 55	STC 50
		Mechanical equipment rooms	STC 50	STC 45
		Toilet areas	STC 45	STC 42
	Music practice rooms	Adjacent practice rooms	STC 55	STC 50
		Corridor and public areas	STC 45	STC 42
Executive areas, doctors' suites, confidential privacy	Office	Adjacent offices	STC 50	STC 45
		General office areas	STC 48	STC 45
		Corridor or lobby	STC 45	STC 42
		Washrooms and toilet areas	STC 50	STC 47
Normal offices, normal privacy requirements, group meeting rooms	Office	Adjacent offices	STC 40	STC 38
		Corridor, lobby, exterior	STC 40	STC 38
		Washrooms, kitchen, dining	STC 42	STC 40
	Conference rooms	Other conference rooms	STC 45	STC 42
		Adjacent offices	STC 45	STC 42
		Corridor or lobby	STC 42	STC 40
		Exterior	STC 40	STC 38
		Kitchen and dining areas	STC 45	STC 42
Large offices, computer work areas, banking floors, etc.	Large general office areas	Corridors, lobby, exterior	STC 48	STC 35
		Data processing areas	STC 40	STC 38
		Kitchen and dining areas	STC 40	STC 38
Motels and urban hotels, hospitals, dormitories	Bedrooms	Adjacent bedrooms	STC 52	STC 50
		Adjacent single bathroom	STC 50	STC 45
		Adjacent living rooms	STC 45	STC 42
		Dining areas	STC 45	STC 42
		Corridor, lobby, or public spaces	STC 45	STC 42

SOUND TRANSMISSION CONTROL REGULATIONS

The International Building Code (IBC) sets requirements for sound transmission control in residential buildings. It applies to common interior walls, partitions, and floor and ceiling assemblies between adjacent dwelling units or between dwelling units and adjacent public areas such as corridors, stairs, or service areas.

Ratings for multifamily housing depend on nighttime exterior background levels and other factors directly related to the location of a building. Grades I, II, and III are discussed in *A Guide to Airborne, Impact, and Structureborne Noise Control in Multifamily Dwellings*, HUD TS-24 (1974).

The STC ratings of building assemblies are established when tested in accordance with ASTM E 90, "Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements." Impact insulation class (IIC) ratings for floor-ceiling assemblies are established when tested in accordance with ASTM E 492, "Standard Test Method for Laboratory Measurement of Impact Sound Transmission through Floor-Ceiling Assemblies Using the Tapping Machine."

The requirements do not apply to dwelling entrance doors, which must be tight fitting to the frame and sill.

IMPACT NOISE

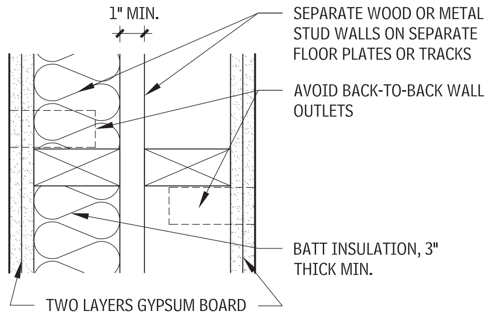
Floors are subject to impact or structure-borne sound transmission noises such as footfalls, dropped objects, and scraping furniture. Parallel to the development of laboratory STC ratings for partition constructions is the development of an impact insulation class (IIC). This is a single-number rating system used to evaluate the effectiveness of floor construction in preventing impact sound transmission to spaces beneath the floor. The current IIC rating system is similar to the STC rating system.

Testing for IIC ratings is a complex procedure using a standard tapping machine. The machine cannot simulate the weight of a person walking across a floor; therefore, the creak or boom that footsteps cause in a wood-framed floor cannot be reflected in the single-figure impact rating produced from the tapping machine. The correlation between tapping machine tests in the laboratory and field performance of floors under typical conditions may vary greatly, depending on the construction of the floor and the nature of the impact.

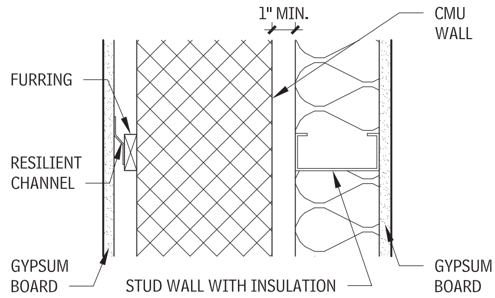
NOTE

2.36 Adapted from Benjamin Stein, John S. Reynolds, Walter T. Grondzi, and Alison G. Kwok, Mechanical and Electrical Equipment for Buildings. Reference 2015 International Building Code (IBC) for STC AND IIC code requirements.

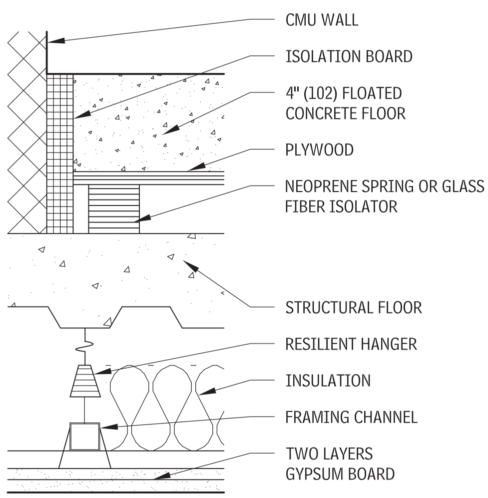
TYPICAL HIGH SOUND ISOLATION CONSTRUCTION
2.37



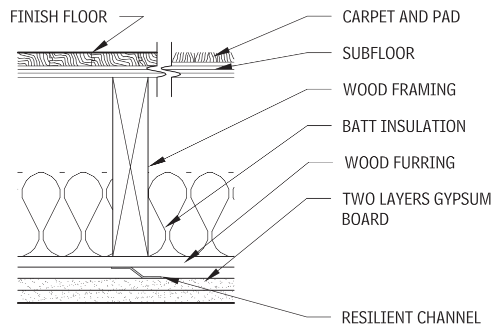
DOUBLE STUD WALL



DOUBLE WALL – CMU AND STUD



FLOOR/CEILING CONSTRUCTION – CONCRETE



FLOOR/CEILING CONSTRUCTION – WOOD

BACKGROUND NOISE CRITERIA DETAIL

The following figure provides NC ratings for background noise criteria.

RECOMMENDED BACKGROUND NOISE CRITERIA
2.38

TYPE OF SPACE	USES	NC RATING RANGE	A-WEIGHTED DECIBELS
Sensitive listening spaces	Broadcast and recording studios, concert halls	NC 15 to NC 20	25 dBA
Performance spaces	Theaters, churches (no amplification), video and teleconferencing (live microphone)	NC 20 to NC 25	30 dBA
General presentation spaces	Large conference rooms, small auditoriums, orchestral rehearsal rooms, movie theaters, courtrooms, meeting and banquet rooms, executive offices	NC 25 to NC 30	35 dBA
Quiet areas	Offices, small conference rooms, classrooms, private residences, hospitals, hotels, libraries	NC 30 to NC 35	40 dBA
Public spaces	Restaurants, lobbies, open-plan offices, clinics	NC 35 to NC 40	45 dBA
Service and support spaces	Computer equipment rooms, public circulation areas, arenas, convention floors	NC 40 to NC 45	50 dBA

ACOUSTIC PARTITIONS

The reduction of airborne sound transmission, such as normal conversation and other office noise, is identified by STC ratings. The STC does not identify reductions of impact or vibration noise, which are classified by the IIC ratings. Impact and vibration noises may require isolation and sound dampening through means other than the partition.

Partition STC ratings are dependent on the partition mass, resiliency or isolation, dampening, and sound absorption. Multilayer partitions have more mass than single-layer partitions. Wood studs are less resilient than steel studs and transmit more sound. Isolating wood studs by staggering their placement or using resilient channels improves the resistance to sound transmission. Sound attenuation insulation provides sound dampening and absorption.

Acoustic partitions require sealant at the perimeter edges of the partition assembly, as well as at openings in the gypsum board panel such as junction boxes and other wall penetrations.

Published sound-rating assembly performance is developed under controlled laboratory conditions. Actual performance may vary from the published STC rating.

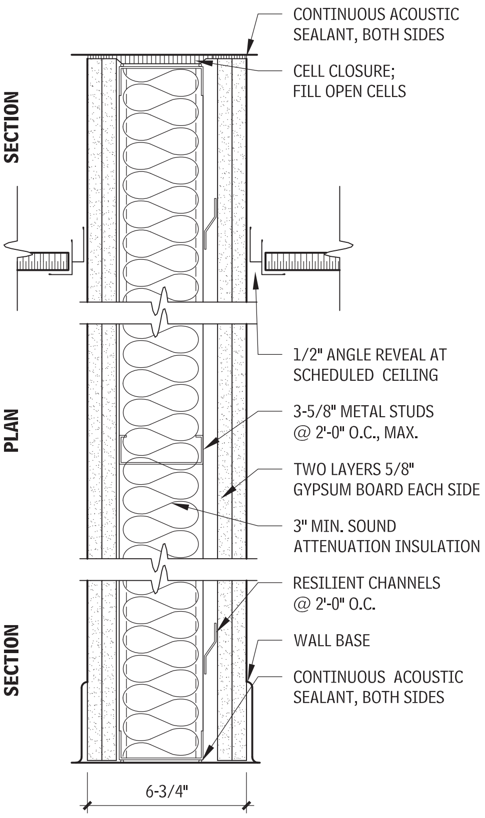
RECOMMENDED STC VALUES
2.39

RECEIVING ROOM	SOURCE ROOM	STC
Offices requiring privacy (doctors, executives)	Lobby or corridor	50
	General office	45
	Adjacent office	50
	Toilet room	55
Other office areas	Lobby or corridor	45
	Kitchen or dining room	45
Conference and training rooms	Other conference room	50
	Adjacent office	50
	General office	50
	Lobby or corridor	50
	Toilet room	55
Hotel bedrooms	Adjacent bedroom, living room, or bathroom	55
	Lobby or corridor	55
Classrooms (K to 12)	Adjacent classroom	45
	Laboratory	50
	Lobby or corridor	50
	Kitchen or dining room	50
	Vocational shop	55
	Music room	55+
	Toilet room	50
All areas	Mechanical room	60

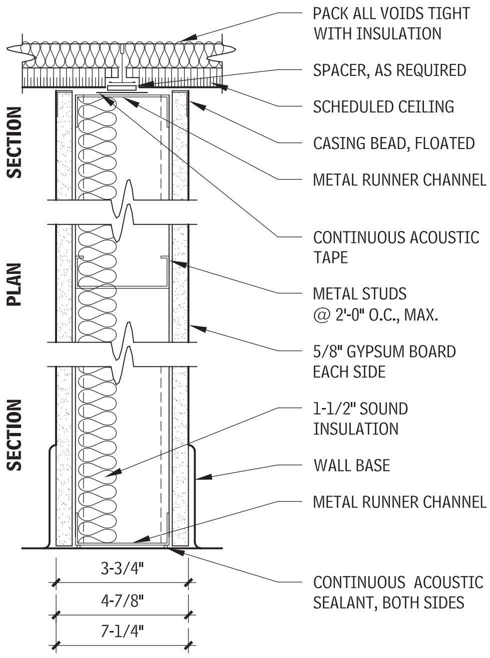
Contributors:
Jim Johnson, Wrightson, Johnson, Haddon & Williams, Inc., Dallas, Texas; Doug Sturz and Carl Rosenberg, AIA, Acentech, Inc., Cambridge, Massachusetts.

ACOUSTIC PARTITION DETAILS

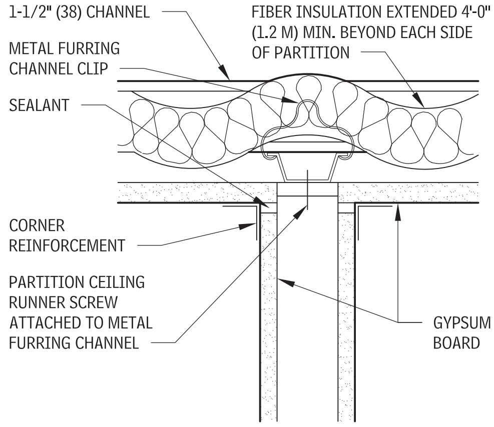
DOUBLE-LAYER GYPSUM BOARD PARTITION
2.40



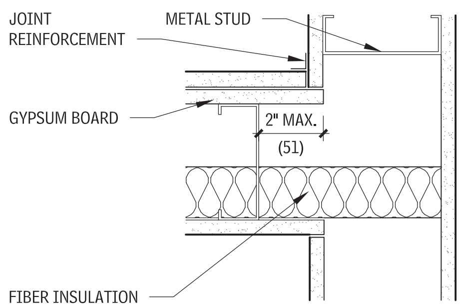
CEILING-HEIGHT PARTITION WITH SOUND ATTENUATION
2.41



SOUND-ISOLATED ASSEMBLIES
2.42



INTERRUPTED CEILING



PARTITION INTERSECTION

SOUND CONTROL WINDOWS

Depending on the intended function, many spaces require a certain level of sound isolation from surrounding areas. Many common building components are available with specific acoustic ratings, but generally require specialized design and construction to achieve good performance. For example, where a high level of sound isolation is required between spaces that also need a visual connection, standard window assemblies may not be sufficient. Acoustic windows typically have two panes of laminated glass 1/4 to 1/2 in. (6 to 13 mm) thick, separated by a 1- to 4-in. (25 to 102 mm) airspace, and have been designed as an assembly to meet specific performance requirements up to approximately STC 55.

OPEN OFFICE ACOUSTICS

Open offices can provide great flexibility in office arrangements and workflow. However, because workstations or cubicles do not have full-height partitions, noise can be a major problem. The extent to which speech is distracting depends on its level of intelligibility. An overheard conversation may be annoying or distracting, while an inaudible murmur may not. When designing open offices, the need for communication between workstations should be evaluated in light of work functions and practical separation.

Acoustics in open-plan systems furniture installations present unique challenges. Sound travels in all directions and may be difficult to contain. The use of acoustic panels somewhat improves sound absorption, but the noise from telephones, conversation, equipment, and other sources is usually audible. An acoustic ceiling and carpet on the floor will absorb some of the sound. An acoustic engineer can offer suggestions on how to contain and control noise. Sound-masking systems, utilizing white noise, are increasingly considered a necessity.

Speech intelligibility and acoustics in an open-plan office can be rated in terms of an articulation index (AI), which is a measure of the ratio between a signal (a neighbor's voice or intrusive noise) and steady background noise (ambient noise from mechanical equipment, traffic, or electronic sound masking). When communication is desired, for example, in classrooms or teleconference rooms, it is preferable to have a high AI so that people can hear well. In an office environment, however, it is preferable to have a low AI, which is more conducive to concentration.

AI values range from near 0 to 1.0:

- *Near 0:* Very low signal and relatively high noise, with no intelligibility or good speech privacy
- *Near 1.0:* Very high signal and low noise with excellent communication or no speech privacy

Low AI ratings for open-plan office spaces can be achieved in three primary ways: by blocking sound, by covering (*masking*) sound, and by absorbing sound.

BLOCKING SOUND

Partial-height barriers or partitions are necessary to block direct sound transmission between workstations. The barriers must be high enough and wide enough to interrupt the line of sight between a source and a receiver; hence, the first 4 ft. (1.2 m) or so of barrier height do not help speech privacy significantly. Barrier heights of 5 ft. (1.5 m) are a minimum requirement for acoustic separation, and heights of 6 ft. (1.8 m) are typical for normal privacy.

The barrier should be able to block sound at least as well as the path for sound traveling over the barrier, which means a minimum laboratory STC value of 24. Barriers or screens should extend to the floor or leave only an inch or so open at the bottom. There should be no open gaps between adjacent panels. Barriers may need to have sound-absorbing facings to reduce reflections to the next workstation.

MASKING SOUND

The character and level of background sound is perhaps the most important acoustic design consideration for an open-plan office. A modest level of background or ambient sound will cover, or mask, annoying, intrusive sounds. Masking sound should be neither too loud nor too quiet, between 45 and 50 dBA. Conference rooms and private offices, which require lower levels of background noise, should have plenum treatments so they are shielded from direct exposure to the masking sound.

Sound-masking systems comprise a noise generator, an equalizer to shape the sound spectrum properly, amplifiers, and loudspeakers hidden above an accessible acoustic tile ceiling. Such systems generate a broadband, pleasant-sounding, evenly distributed masking noise. The sound in the plenum filters down through the ceiling and provides an even blanket of sound that will mask the intrusive sound from a neighbor.

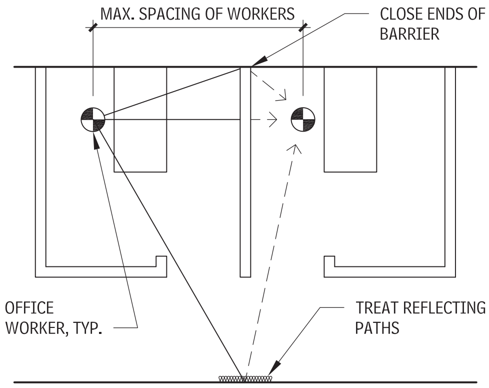
Avoid untreated sound leaks in the ceiling, such as openings for return air; these become noticeable hot spots and draw unwanted attention to the sound from the ceiling. Masking sound from two channels can improve spatial uniformity. Ceiling height and plenum

NOTES

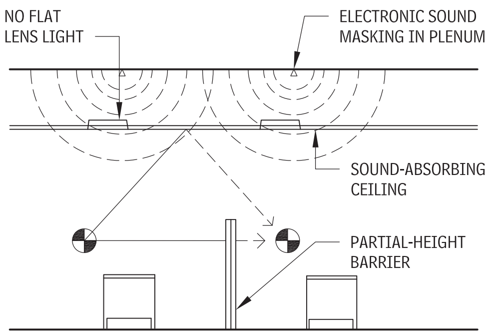
2.40 This figure shows a nonrated partition that can achieve a two-hour rating with Type X gypsum board. This design offers additional security due to a double layer of gypsum board. The resilient channel provides higher-performance sound control. Acoustic sealant is required for an STC rating of 55 to 60.

2.41 This figure shows a nonrated partition commonly used in commercial and high-quality residential construction. The ceiling is installed prior to installation of the partition. Normal conversation is not audible, but loud sounds may be transmitted through the partition. STC rating of 40 to 44.

SOUND CONTROL IN OPEN OFFICES
2.43



PLAN



SECTION

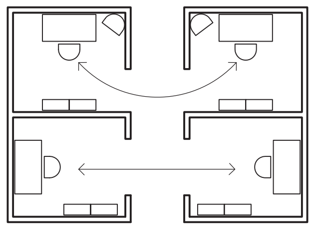
conditions (fireproofing, beams, ducts, etc.) will determine loudspeaker spacing and location. Electronic sound masking should be professionally designed and installed.

ABSORBING SOUND

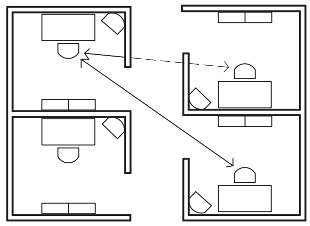
The ceiling in an open-plan office is the most important surface to treat with highly efficient sound-absorbing material. Glass fiber ceiling panels often have NRC/SAA values of 0.85 or higher and are the preferred material for open-plan spaces. Regular mineral fiber acoustic panels have typical NRC/SAA values of about 0.55 to 0.65. Hard sound-reflective materials such as exposed structure or gypsum board will dramatically reduce privacy and increase annoying sound levels in an office. Most ceiling tile manufacturers provide extensive NRC/SAA data for their products and have special products with high absorptive performance for use in open-plan spaces. Materials must also be selected for their ability to reflect light.

Most sound-absorbing materials are measured in a reverberation chamber in accordance with ASTM C 423, "Standard Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method," to determine their random incidence sound absorption coefficients. For office acoustics, the most useful measurement is the capability of a material to absorb sound at an incident angle of 40° to 60° from a flat ceiling and at frequencies weighted to reflect the relative contribution to speech intelligibility. A beneficial tool for evaluating the effectiveness of ceiling materials for sound absorption is the *speech absorption coefficient* (SAC).

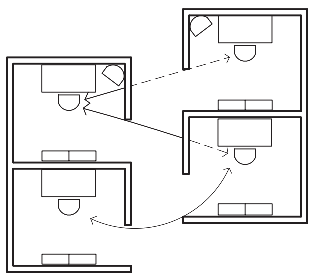
OPEN-OFFICE CONFIGURATIONS FOR ACOUSTIC PRIVACY
2.44



POOR LAYOUT



FAIR LAYOUT



PREFERRED LAYOUT

OTHER FACTORS

The following factors affect acoustic performance in open offices:

- Arrange offices so that entrances are offset, and eliminate direct line of sight or an open view through doorways from one workstation to another.
- Workstations should be 8 to 10 ft. (2.4 to 3 m) apart so voice levels are adequately reduced over distance. Higher ceilings can help reduce noise transfer.
- Light fixtures in the ceiling plane should not have hard lenses or be placed directly above a partition because the fixture can then act as a mirror for sound across the barrier.
- Absorptive material may be necessary on some barriers or reflecting surfaces (e.g., walls, file cabinets).
- Carpet helps reduce footfall and impact noise and is a great benefit in open offices.
- Voice levels should be kept to a minimum; even the best acoustic treatments cannot prevent disturbances caused by loud voices and hands-free amplified telephone use.

All the factors outlined above are interrelated. For example, doubling the distance between adjacent workstations will reduce a nearby conversation by 5 dBA, while raising the height of a 5-ft (1.5-m) barrier to 6 ft. (1.8 m) may reduce the sound path over the top by 3 dBA. Changing from a mineral fiber acoustic ceiling tile to a glass fiber ceiling tile may reduce reflected noise by 5 dBA. Adding sound masking may change the ambient level by 10 to 20 dBA.

An acoustics consultant can evaluate proposed layouts and materials as part of the design process. The acoustic outcome of a design should be analyzed before construction.

As a rough initial guideline, offices in which freedom from distraction is the only criterion will require highly efficient sound-absorbing ceilings and an electronic background masking sound at levels between 45 and 50 dBA. For normal speech privacy, these conditions should be augmented by keeping workstations 8 to 10 ft. (2.4 to 3 m) apart and adding partial-height barriers at least 5 ft. (1.5 m) high, with increased attention to office layout and reflecting sound paths. Confidential privacy requires higher partitions and greater attention to related details; it is extremely difficult to achieve this in an open plan.

PERFORMANCE ACOUSTICS

Theaters and performance spaces are rooms in which good hearing conditions are critical to the use of the space. The design of a performance space generally requires input from an acoustic consultant.

Sound generated by speakers or musicians should be projected efficiently to the audience and captured within the space. The *sending end* of the room (i.e., the stage) should be acoustically hard. Walls near the performer should be angled or splayed to enhance projection and prevent *flutter echoes* at the stage. Walls and ceilings in the audience area should be hard so they can reflect sound, unless absorptive treatment is needed to eliminate problematic reflections or focusing or to reduce reverberation time for particular program needs.

Good hearing environments should maximize the signal-to-noise ratio. In addition to the desired signal being well projected, unwanted noise should be eliminated. To accomplish this requires very low background sound levels (NC 20 for concert halls, NC 25 for smaller theaters) from mechanical equipment. Sound-lock vestibules eliminate intrusive noise from a lobby and allow latecomers to enter without acoustic interference to the show. Carpeted aisles help reduce footfall noise. Noise from exterior environmental sources should also be considered. Avoid lightweight roofs, which will transmit rain noise.

SPACIOUSNESS

Because of the lateral configuration of the human ear, sound signals that are slightly different in each ear allow the listener to hear an acoustic quality called *spaciousness*, which is highly desired for classical music. This sense of spaciousness can be enhanced if the distribution of sound through a large hall is diffused, enabling the ear to hear reflections from many facets of the side and rear walls. This diffusion can be enhanced by protrusions and angled surfaces on the side walls. Diffusion is also important for other musical applications. Sometimes spaciousness is also referred to as *envelopment*.

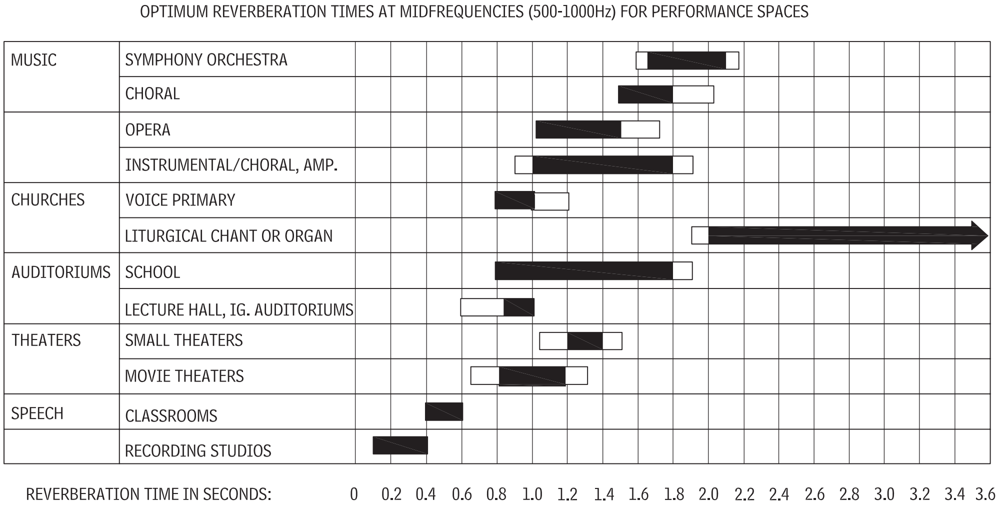
REVERBERATION TIMES

Room volume and area of absorption can be calculated to predict reverberation times (RTs). The design factor affecting RT the most is ceiling height. The relationship between the volume of a hall and the number of seats is often a good approximation of sound quality in the room.

In wide halls with high ceilings, seats in the center of the orchestra often suffer from lack of early reflections. Reflecting canopies or arrays over the front rows can bring reflected sound to these seating areas, which otherwise may suffer from poor articulation.

Contributors:
Jim Johnson, Wrightson, Johnson, Haddon & Williams, Inc., Dallas, Texas; Doug Sturz and Carl Rosenberg, AIA, Acentech, Inc., Cambridge, Massachusetts; Jay Pulaski, Equipment Planners, Inc., Summit, New Jersey; lauckgroup, Dallas, Texas; Shawn Parks, Rhode Island School of Design, Providence, Rhode Island; Jim Johnson, Wrightson, Johnson, Haddon & Williams, Inc., Dallas, Texas.

REVERBERATION TIMES AT 500 TO 1000 HZ FOR PERFORMANCE SPACES
2.45



Often seats at the rear of the balcony do not experience this problem, and these seats have excellent acoustics. This gives preference acoustically to rectangular and diamond-shaped halls.

The range of reverberation times for each room type is a function of the room volume: The larger the room volume, the closer is the distance to the longer end of the range. The smaller the room volume, the closer is the distance to the shorter end of the range. Some considerations to keep in mind:

- Church reverberation requirements vary greatly based on size, room volume, and music style. Some contemporary services resemble folk rock concerts, while others have a cathedral-style liturgy with an organ.
- Music recording is often done in studios similar to those used for speech recording, for future mixing. Some classical recording is done in rooms with higher reverberation times.

Contributors:
Abigail Cantrell, AEC Acoustics, Manassas, Virginia; Joshua Dachs, Jules Fisher Associates, Inc., Theater Consultants, New York, New York; Carl Rosenberg, AIA, Acentech, Inc., Cambridge, Massachusetts.

RESILIENCE IN BUILDINGS

3

OVERVIEW

Natural and manmade hazardous events can impose a devastating cost upon society. As Figure 3.1 shows, the costs of some of these disasters in the United States alone can be staggering. Stakeholders of civil infrastructure have a vested interest in reducing these costs by improving and maintaining operational and physical performance of facilities.

Throughout history, infrastructure resilience has been defined in numerous ways, the most widely used and most objective was by the National Infrastructure Advisory Council (NIAC) in 2009, which states:

> Infrastructure resilience is the ability to reduce the magnitude and/or duration of disruptive events. The effectiveness of a resilient infrastructure or enterprise depends upon its ability to anticipate, absorb, adapt to, and/or rapidly recover from a potentially disruptive event.

No city is immune to challenges, whether natural or manmade, and given the world's growing population, more people than ever are in the potential path of catastrophe. Fortunately, cities can become resilient and withstand shock and stress if planned well. As conditions change over time, cities that are resilient can evolve in the face of disaster and stop failure from rippling through systems; they can reestablish function quickly and avoid long-term disruptions.

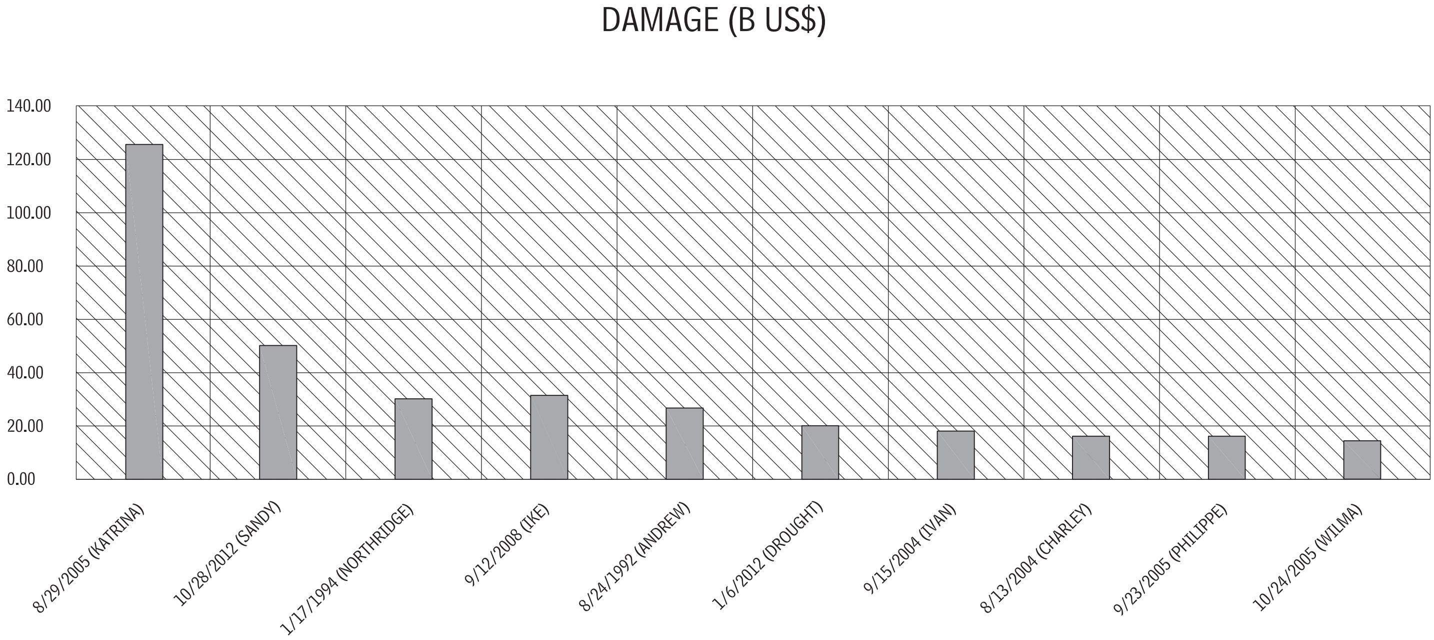
This chapter explores different aspects of resilience management, to control and help reduce the rapidly increasing costs of manmade and natural hazards and ensure that civil infrastructure exhibits a high degree of resilience. A definition of resilience that incorporates four components—robustness, resourcefulness, recovery, and redundancy—is presented and its manifestation in building systems is covered.

Stakeholders of buildings stand to benefit from resilience management. Businesses locate where they can rely on critical infrastructure. Communities that become resilient will increasingly attract businesses because executives know they can rely on the services and workforce availability, even in the face of disruptive events.

Natural and manmade hazardous events are unpredictable, but they are still inevitable and impose a devastating cost to civil infrastructure. By improving and maintaining the operational and physical performance of our nation's building stock, strategies for resilience can be developed.

When planning and designing buildings, it is appropriate to try to mitigate the potential of the spiraling cost of operational failures by opting for more resilient performance through well-thought-out investments in better planning and designs. It no longer makes sense to wait until after a crisis to implement resilience efforts. Resiliency strategies for buildings should be discussed and implemented now, so that there is a greater chance of increased performance, not only today but for the future, benefiting all building stakeholders.

DAMAGES FROM RECENT NATURAL DISASTERS IN THE UNITED STATES
3.1



NOTE

3.1 Source: EM-DAT International Disaster Database 2014

Contributors:
Mohammed Ettouney Ph.D., P.E., MBA, F.AEI, Dist.M.ASCE, Mohammed Ettouney, LLC, West New York, NJ, Roger J. Grant, CSI, CDT, National Institute of Building Science (NIBS), Washington, DC.

COMPONENTS OF BUILDING RESILIENCE

THE 4RS

The National Infrastructure Advisory Council (NIAC) 2009 determined that resilience can be characterized by three key features:

Robustness: the ability to maintain critical operations and functions in the face of crisis. This includes the building itself, the design of the infrastructure (office buildings, power generation, distribution structures, bridges, dams, levees), or in system redundancy and substitution (transportation, power grid, communications networks).
Resourcefulness: the ability to skillfully prepare for, respond to and manage a crisis or disruption as it unfolds. This includes identifying courses of action and business continuity planning; training; supply chain management; prioritizing actions to control and mitigate damage; and effectively communicating decisions.
Rapid recovery: the ability to return to and/or reconstitute normal operations as quickly and efficiently as possible after a disruption. Components [of rapid recovery] include carefully drafted contingency plans, competent emergency operations, and the means to get the right people and resources to the right places.

Redundancy: backup resources in case of failure.

These four resilience features are simply called the 4Rs. Resilience is multidisciplinary and needs the cooperation of different disciplines for successful outcomes. Without multidisciplinary cooperation and contributions, there cannot be successful or efficient resilient infrastructure.

A beneficial illustration of resilience was introduced first by Mary Ellen Hynes (2001) and then by Bruneau, et al (2003). Figure 3.2 shows graphically how to objectively estimate the resilience of an asset or community by using resilience charts.

ASSET (BUILDING) RESILIENCE AND COMMUNITY RESILIENCE

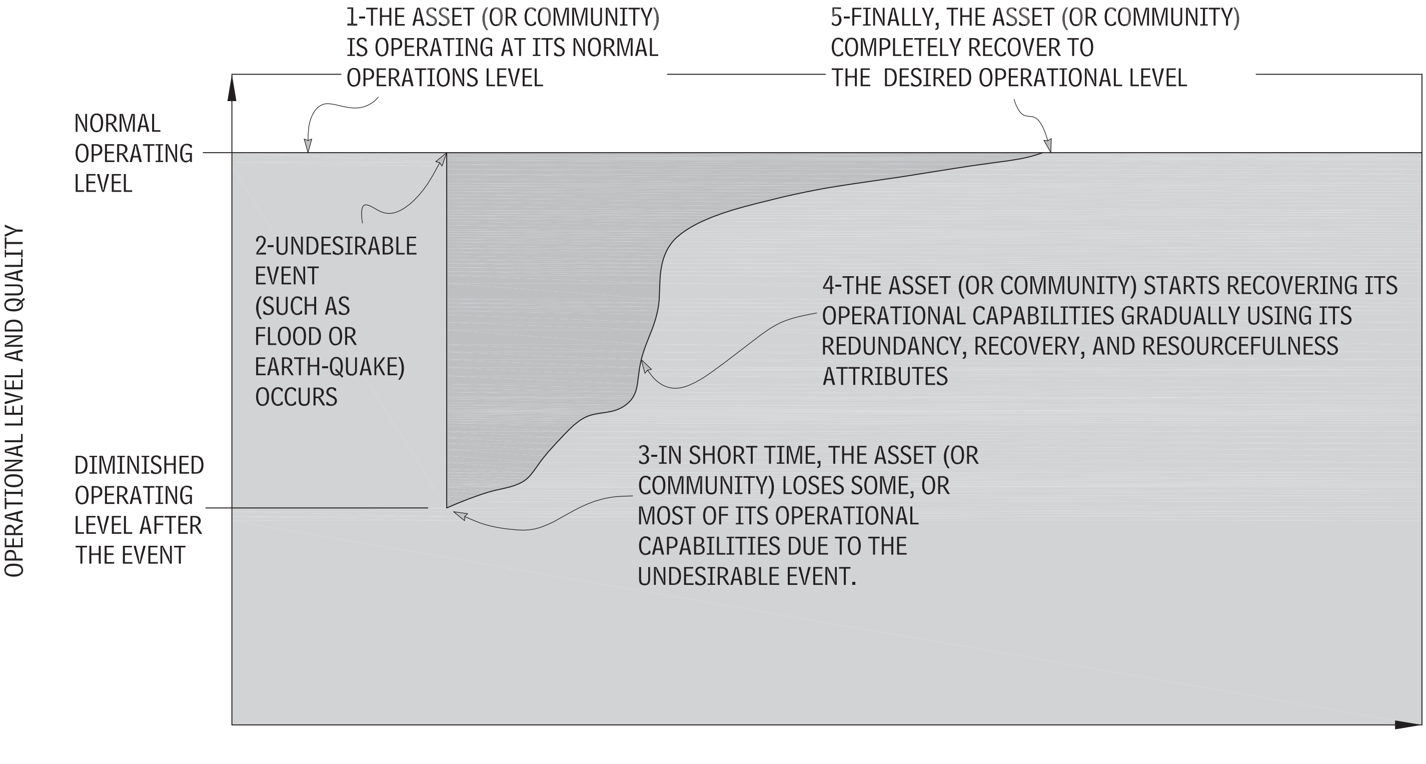
One of the objectives is to clarify distinctions and relationships between three of the emerging paradigms: risk, resilience, and sustainability. First, risk is expressed as the relationship between a particular hazard (or threat) that might degrade the performance of the infrastructure under consideration and the consequences that might result from a degradation of performance (Gutteling and Wiegman 1996, FEMA 2005, and NRC 2010). Most professional industries, such as engineering, finance, insurance, and medicine, adopt a variant of this particular definition of risk (Gutteling and Wiegman, 1996). In the building/infrastructure community, FEMA (2005) uses an objective risk definition which states:

Risk rating = function (Consequence, Threat, Vulnerability—C, T, V)

The type of risk function also depends on the desired degree of complexity of risk analysis.

It was established earlier that a reasonable resilience definition relates resilience to robustness, resourcefulness, recovery, and redundancy (the 4Rs). It can be shown that the 4Rs can be recast as a subset of C, T, V. Ettouney and Alampalli, 2012a and 2012b, proposed a relationship similar to that shown in Figure 3.3.

COMPONENTS OF RESILIENCE CHART
3.2



6-THE AREA UNDER THIS CURVE REPRESENT A MEASURE OF THE RESILIENCE OF THE ASSET (OR COMMUNITY).
--SMALLER AREA REPRESENT HIGHER RESILIENCE SINCE IT INDICATES SHORTER RECOVERY TIMES AND / OR LESSER DEGREE OF OPERATIONAL INTERRUPTIONS.
--LARGER AREA REPRESENTS LOWER RESILIENCE SINCE IT INDICATES LONGER RECOVERY TIMES AND / OR HIGHER DEGREE OF OPERATIONAL INTERRUPTIONS.

RELATIONSHIPS BETWEEN RISK AND RESILIENCE
3.3

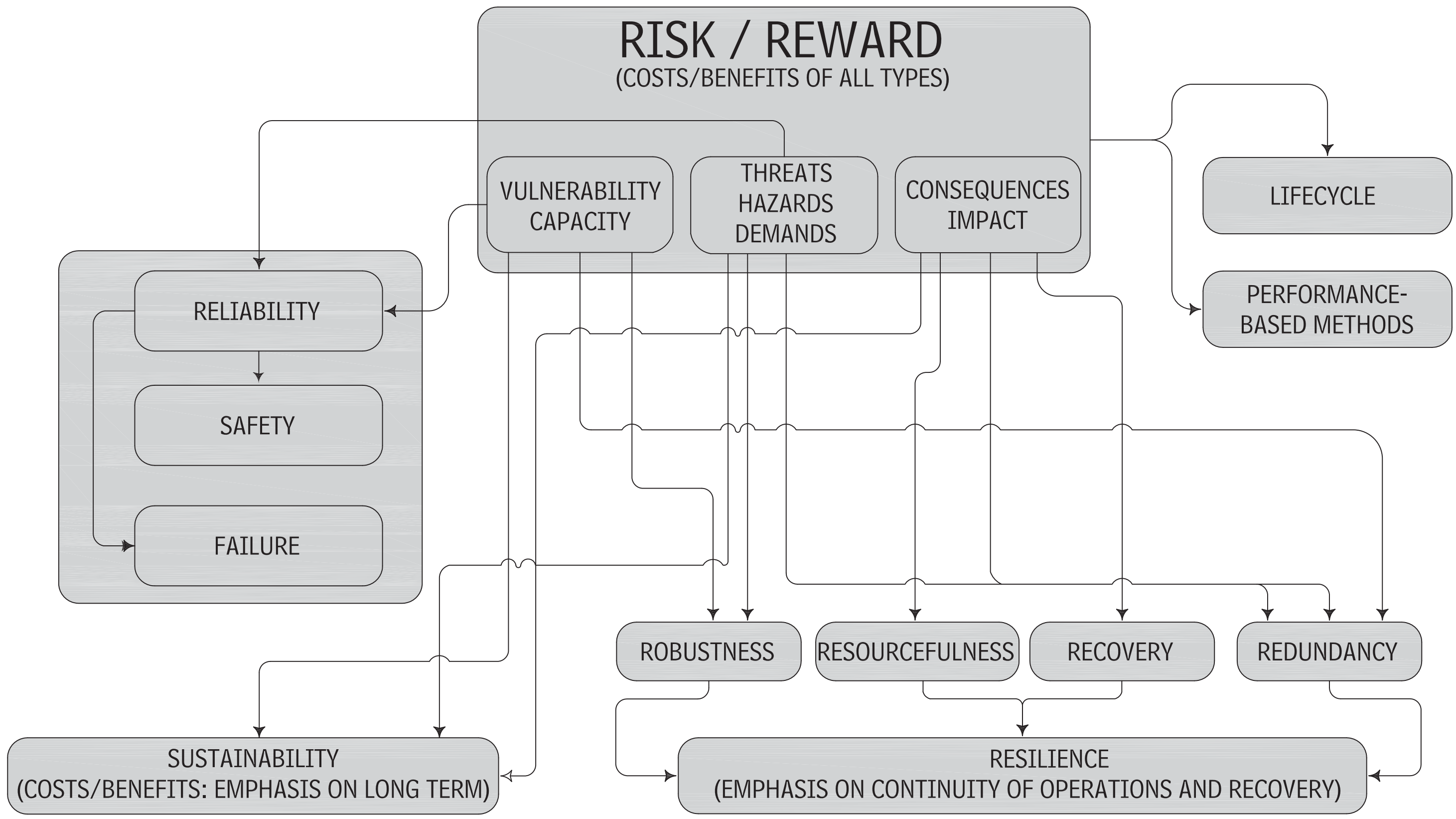
RISK COMPONENTS	RESILIENCE COMPONENTS			
	ROBUSTNESS	RESOURCEFULNESS	RECOVERY	REDUNDANCY
Consequence	Minor	Major	Major	Major
Threat	Major	Minor	Minor	Major
Vulnerability	Major	Minor	Minor	Major

RESILIENCE MANAGEMENT–BASED BUILDING DESIGNS

There is an essential distinction between asset resilience and community resilience. As the label implies, asset resilience is the resilience of a single asset. For immediate purposes, an asset is considered to be an individual building. Note that other types of assets are also feasible such as bridges, mass transit stations, transmission towers, or tunnels. DHS (2009) and the American Society of Civil Engineers (ASCE) Report Card (2013), each contain a comprehensive list of types of assets.

Asset resilience is described using the resilience definition above with the 4Rs. Within an asset, different parameters (sometimes referred to as considerations) control asset resilience. These parameters can be categorized as components of one or more of the 4Rs. Table 3.6 shows a simplified example of building components and categorizations in an asset resilience setting. Note that *Columns* fit in more than one resilience component (robustness and redundancy). In addition to the categorizations of Table 3.5, a functional diagram, called a network or a graph, needs to be established. This network shows dependencies of different parameters. The dependencies are expressed by arrows from the controlling parameter to the dependent parameter. If there is no obvious dependence between two linked parameters, then a simple line connecting the two parameters is used. Figure 3.6 shows a simple network for asset resilience of a tall building. Capturing important parameters (both operational and physical) as well as their interdependencies as shown in Table 3.5 and Figure 3.6 are essential first steps for achieving successful asset resilience management.

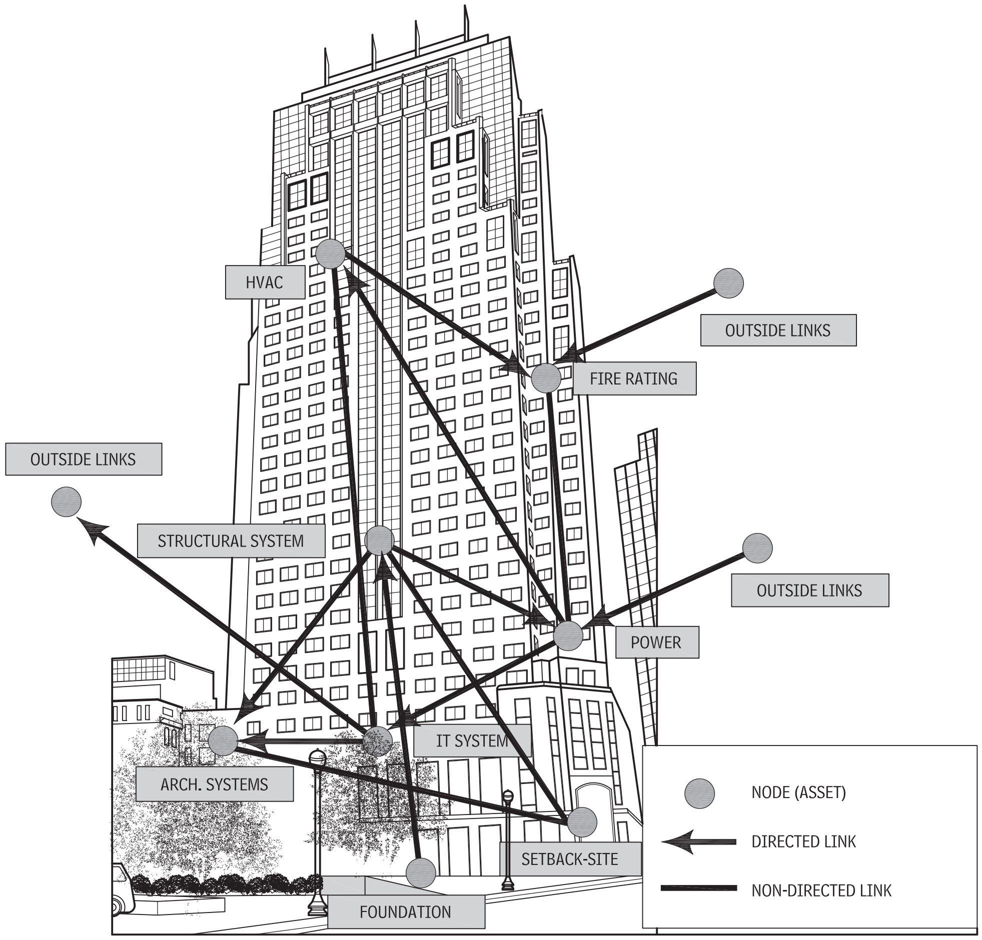
RISK, RESILIENCE, SUSTAINABILITY INTERRELATIONSHIPS
3.4



RESILIENCE EXAMPLE OF INDIVIDUAL BUILDING AS AN ASSET
3.5

RESILIENCE COMPONENTS	BUILDING PARAMETERS (CONSIDERATIONS)
R1: Robustness	Columns
	Structural connections
R2: Resourcefulness	Maintenance of building
	Memorandum of understandings (MOUs) between different organizations
R3: Recovery	Roadways leading to building
	Training of all kinds
R4: Redundancy	Columns
	Main water pipes into building
	Electric and/or power lines

ASSET RESILIENCE LINKS FOR RESILIENCE MANAGEMENT (SIMPLIFIED TALL BUILDING EXAMPLE)
3.6

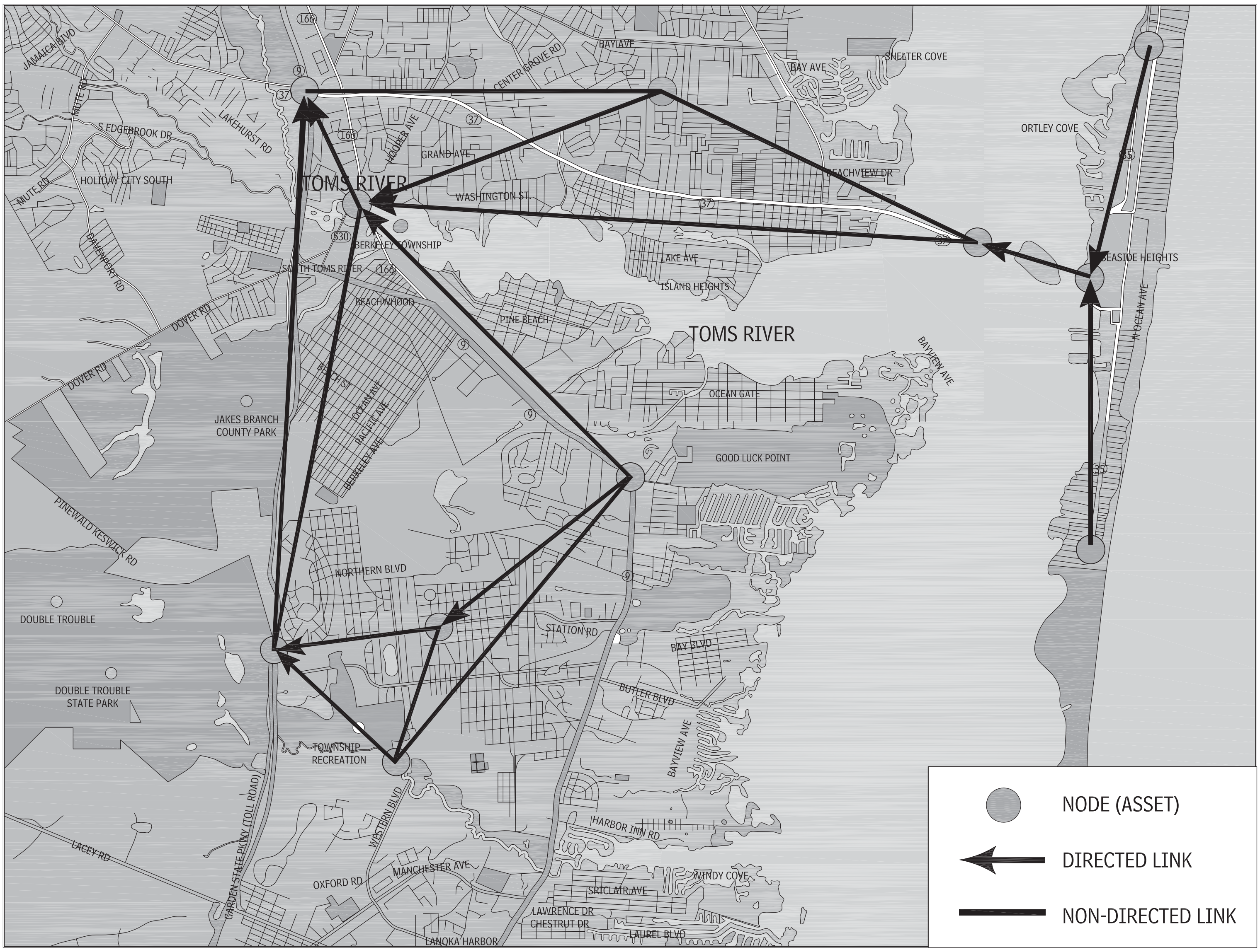


COMMUNITY RESILIENCE

We now turn our discussion to community resilience. As the name implies, a community is comprised of several assets (nodes) that are interconnected via links that may be assets themselves. The nodes and links constitute a community's network. Community resilience is dependent on the resilience of the network's individual asset components (both nodes and links). As an essential step of community resilience management, a greater understanding of the resilience of nodes and links is needed. In addition, community resilience will depend on the topology of the network and how different nodes are linked together.

The size of the community is completely subjective. A community could be a simple campus comprising a small number of buildings (such as a small hospital or college). A community could be a transportation network, a small town, a region, a state, or even a whole country. Each of the 4Rs of community resilience is a function of all of the 4Rs of its nodes and links as well as the topology of the network. Figure 3.7 shows a simple resilience network for a small community.

COMMUNITY NETWORK FOR RESILIENCE MANAGEMENT
3.7



HAZARD–SPECIFIC CONSIDERATIONS

OVERVIEW

Achieving resilience in the design of new facilities and the renovation of existing ones focuses on increasing the robustness of the structures and establishing the warranted redundancies needed to achieve the desired performance in response to hazards. Consideration of resourcefulness and recovery should also be part of the planning process although these resilience components are more directly related to operational programs. This section addresses design considerations to increase resilience primarily through strengthening and configuration to minimize the impact from natural and manmade hazard events.

DURABILITY

Durability, the ability to resist wear and decay, is to be lasting and enduring over time.

Durability for buildings depends on the quality of the design and construction of the building. The physical condition of the building is, over time, dependent on the quality of the materials and systems used and the nature of how all elements are combined and installed to resist degrading in its natural environment as well as during extraordinary events.

Design strategies for durability look to these qualities and to anticipation of both normal and extraordinary events that might impact the viability of the building and its functions.

LONG-TERM PERFORMANCE

Design strategies for long-term viability are built on the choices affecting the ability of the building or facility to remain functional over time.

- Lessen the amount of required maintenance
- Design to extraordinary events beyond code
- Plan for upgrades and replacements

Each building system is first considered individually and designed to stand alone, but also is designed to work together in a whole building system. Knowing the level to which each system is designed and knowing the vulnerabilities inherent in each is the basis for its use.

Contributor:
Mohammed Ettouney Ph.D., P.E., MBA, F.AEI, Dist. M. ASCE, Mohammed Ettouney, LLC, West New York, NJ

The assessment of each system informs the design on how best it can be integrated into the whole where the vulnerabilities of each system are taken into account.

The goal for planning a resilient building is to design and construct integrated systems, to locate and protect critical elements of each system so as to enhance survivability, and facilitate maintenance and repair.

CLIMATE CHANGE

Climate change and variability increase the probability of adverse conditions and events both in frequency and severity. Building design standards that address durability are based on the best estimates of the probability of damaging events and then balancing the probability of those events against the investment it might require to address such occurrences.

Standards based on past performance and probability may not be adequate to address a rapidly changing climate or a sudden break from the "normal" past.

A resilient design strategy for any building needs to assess its particular environment and if any of the potential climatic threats in that environment are likely to increase.

Even the less than extraordinary events that degrade buildings may increase and result in an increased need to repair and maintain elements of the building and site. These should be considered during the design phase so as to mitigate possible degradation.

TECHNOLOGICAL OBSOLESCENCE

Another aspect of resilience is the ability to maintain the technology of building functions. Critical design decisions include:

- Systems' maintainability over time and ability to adjust to new and evolving systems
- Ease of replacing critical elements of a system
- Capability to add upgrades, or new systems

MAINTAINABILITY

The relation between resilience and maintainability can be measured on at least two scales. One is the ease and cost effectiveness of regular maintenance, and the other is the ability to restore and maintain a system after a damaging event.

Design considerations for maintainability include:

- Standardization and availability of systems or components
- Ease of access for normal maintenance
- Access for major maintenance and replacement of components
- Resilience of logistics affecting service, maintenance, and repair
- Backup for inputs needed to operate systems, including energy, monitoring, control, and spare parts
- Extent of inputs required for restoration and general maintenance

Standalone buildings or systems may be less vulnerable to wide area disruptions and require little or no recovery from such events; but those same buildings may be less resilient in an event directly affecting that building. A balance must be struck between on-site resilience, which demands less of the surrounding community in recovery, and off-site resilience, which can support the recovery of each building.

SAFETY

Protection from natural hazard events is broadly identified as "safety" and is analyzed by hazard type. The type of load created by the hazard requires different responses from the building to withstand a threat event.

GRAVITATIONAL AND LATERAL LOADS

Buildings are required to withstand both gravity loads that act vertically and lateral loads that may either be in the form of wind pressures applied to the building envelope or base motions that generate inertial forces. Both types of these natural occurrences are correlated by statistical studies to determine the magnitude as a function of likelihood (or return period). As would be expected, the moderate levels of such lateral load effects occur frequently with very short return periods but the extreme levels of these lateral load effects are relatively infrequent. Because of this statistical variation in the magnitude of load effects, building codes provide both prescriptive and performance-based approaches to resist both moderate and extreme levels of these lateral load effects. Fundamental to the resistance of both wind and seismic loading is the presence of lateral load-resisting structural systems that are capable of withstanding the corresponding forces and moments and can transfer the accumulated effects to the foundation. While these lateral load-resisting systems must be strong enough to prevent material failure or connection dismemberment, they must also be stiff enough to limit lateral sway motions and to prevent secondary P-Delta effects from precipitating global instabilities. Building structures must therefore satisfy both strength and serviceability requirements.

WIND

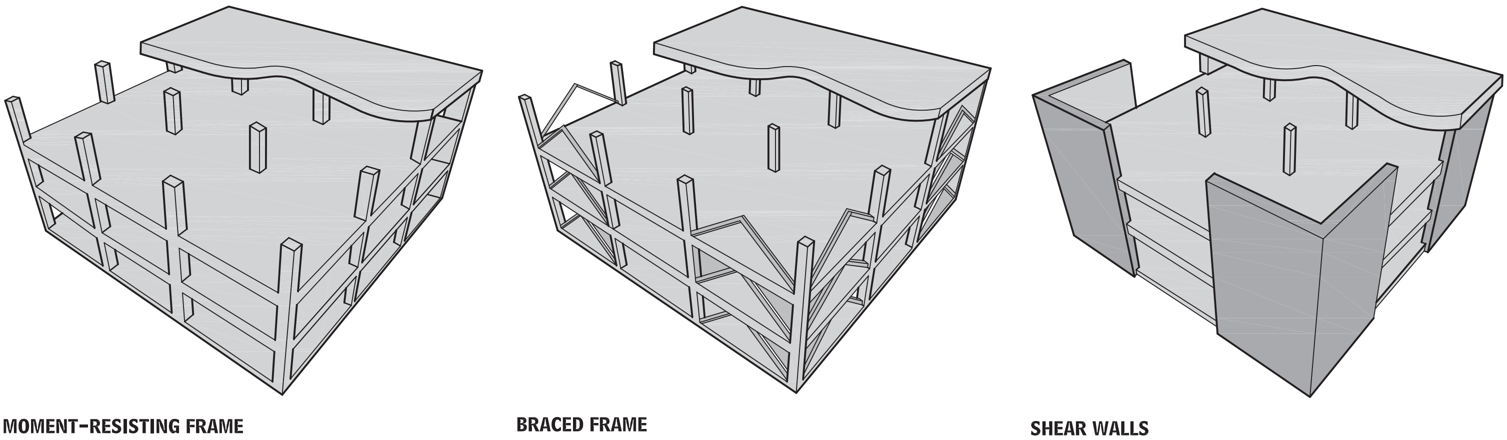
Wind loads are defined in terms of 3-second gust speeds and these velocities are related to design pressures. As wind gusts sweep across a landscape, caused by differential atmospheric pressures, they are influenced by the topography of the region and the density of objects (trees, buildings, etc.) at the ground surface. Wind velocities are found to be fairly constant above a "gradient height" that is determined by the terrain's exposure category, and drag effects reduce these velocities closer to the ground; the smoother the ground surface the lower the gradient height. Buildings are assigned risk categories based on the use and occupancy, and wind speed maps are assigned to each category along with a corresponding return period that ranges from once in 300 years for low hazard structures to once in 1700 years for assembly or essential structures. The wind speed maps account for the hurricane-prone regions along the Atlantic and Gulf coasts and the specified velocities are amplified accordingly.

Wind speeds are calculated at the elevation of the building and are factored by the effects of topographic directionality and the openness of the building envelope. Pressures are applied to either the windward face as an inward load or to the roof, sides, and leeward faces as a suction load. Openings in the facade will produce either internal pressures or internal suctions. Two sets of forces are calculated based on the calculated wind pressures: forces that are applied to the global lateral-load-resisting system and forces that are applied to local cladding and components. Globally, the net forces collected over the building surface are transferred through the floor diaphragms and these lateral loads are combined with the gravity loads when designing the lateral-load-resisting system. Locally, the cladding and component loads are used to design the facade elements.

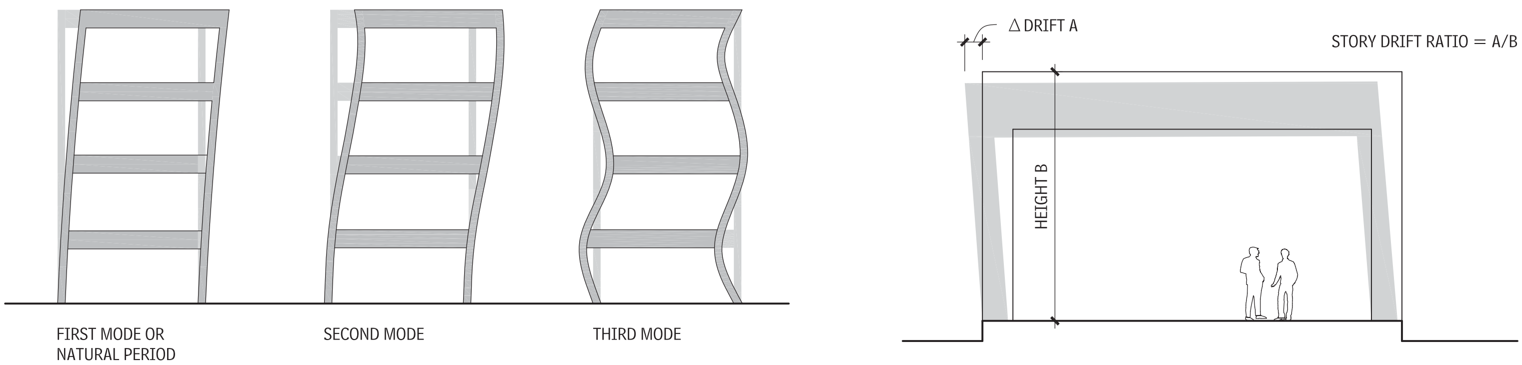
Lateral-load-resisting systems may be composed of combinations of moment frames, braced frames, and shear walls. Moment frames rely on the interactive bending of beams and columns to develop the lateral stiffness, whereas shear walls behave as stiff beams cantilevered from the foundation. Shear walls tend to be significantly stiffer than moment frame buildings and in most cases buildings with significant shear wall systems are treated as "sway inhibited" structures. Moment frame construction tends to be less stiff and there is greater concern for secondary P-Delta effects.

For rigid diaphragm buildings, such as concrete floor systems, the percentage of lateral force will be distributed to the various lateral-resisting components in proportion to the relative stiffness of the various lateral-resisting elements. For flexible diaphragm buildings, such as timber construction, the percentage of lateral force will be distributed in proportion to the tributary areas that are exposed to wind.

STRUCTURAL SYSTEMS FOR RESISTING WIND LOAD AND SEISMIC-INDUCED STORY DRIFT
3.8



SEISMIC INDUCED STORY DRIFT
3.9



SEISMIC

Seismic forces are induced by the building components as the building's inertia resists the lateral base motions. These inertial forces are related to the base acceleration through Newton's Second Law of Motion (force equals the product of mass and acceleration). Similar to wind loads, seismic base acceleration maps define a short period (0.2 second) and long period (1 second) ground motion parameter. The maps are constructed to provide a uniform probability of hazard, corresponding to a 1 percent probability of collapse in 50 years. These ground motion parameters are multiplied by site coefficient factors, based on site classification, that either amplify or reduce the intensity of design ground acceleration. Since the induced seismic force depends to a great extent on the structure's frequency of vibration, the factored ground motion parameters are used to develop a design response spectra that defines acceleration as a function of building period. In general, the design response spectra is constant for relatively stiff buildings, decays inversely proportional to the building period for more massive or more flexible buildings, and decays inversely proportional to the square of the building period for very flexible or very massive buildings.

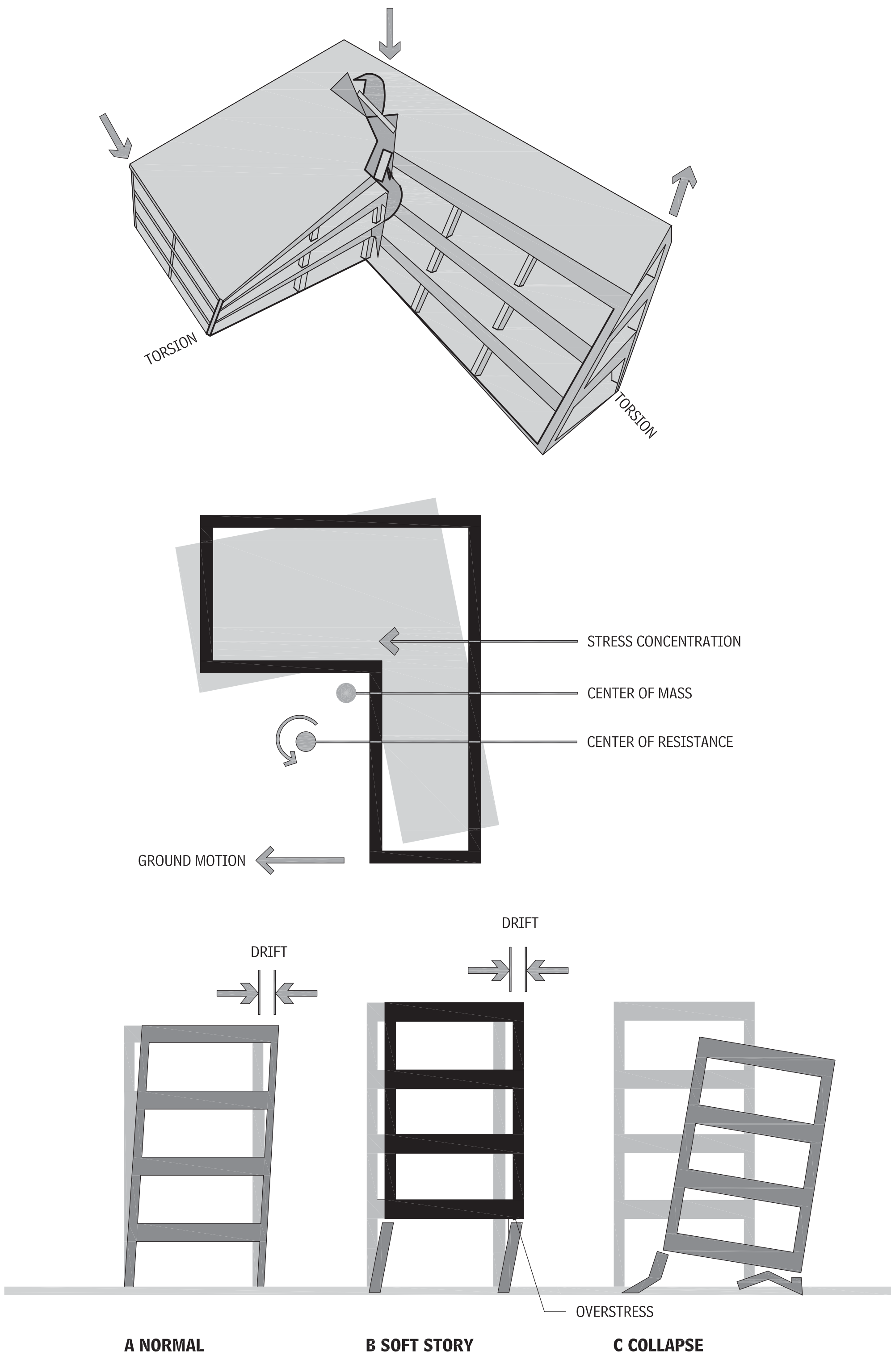
Building occupancy types, ranging from low-hazard to assembly or essential structures, are used to define importance factors and risk categories. The importance factors are used to scale the intensity of the spectral values and the risk categories are used to define both the analytical methods and the structural systems that may be permitted for a range of building heights. Since earthquakes are extraordinary events that vary in intensity, buildings are expected to be undamaged in response to relatively low-intensity events but are permitted to sustain modest amounts of damage in response to much greater magnitudes of ground motion. In order to enable buildings to sustain these modest amounts of damage, they are required to adhere to relatively strict rules governing structural systems and detailing requirements. By adhering to these rules, the buildings will deform in a ductile manner that will permit large inelastic deformations that dissipate considerable amounts of energy prior to structural failure.

In order to minimize stress concentrations and eccentric load paths, both vertical and torsional irregularities should be minimized to the greatest extent possible. Similarly, the greatest uniformity in both mass and stiffness are desirable attributes for buildings that may have to resist seismic forces. The Figures 3.9 and 3.10 images depict both a damaging torsional mode resulting from a horizontal irregularity and a soft story failure resulting from a vertical change in story stiffness.

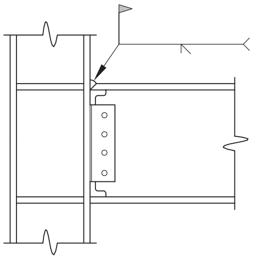
WIND AND SEISMIC CONNECTIONS

The different structural system types—bearing walls, building frame, moment frame, dual system secondary moment frames (SMF), dual intermediate moment frames (IMF), wall frame, and cantilever column—are permitted for specific risk categories and building heights with corresponding response modification coefficients and deflection amplification factors. In this manner, the appropriate level of ductile inelastic deformation is permitted in response to the most extreme ground motion. Moment-resisting frames, braced frames, and shear wall systems are depicted in Figure 3.8. Detailing of the connections, splices, and other structural conditions are required to follow preapproved and tested practices. Examples of seismic connections for concrete and steel moment frames are shown in Figure 3.11 (Aghayere & Vigil, 2015). The rigorous analytical methodology and preapproved detailing is the most effective means of designing structures to withstand extraordinary events and to make sure the details deliver the desired performance.

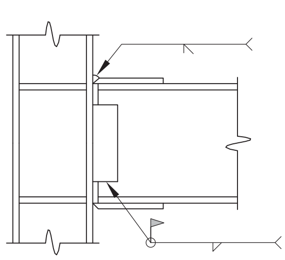
SEISMIC IMPACTS ON BUILDINGS
3.10



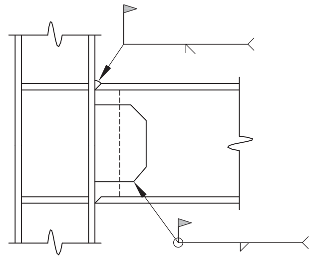
SEISMIC-RESISTANT CONNECTION DETAILS
3.11



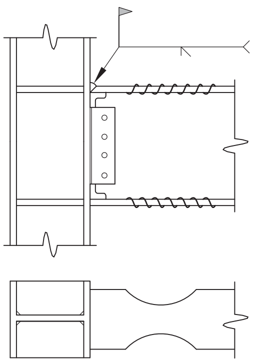
(A) WELDED FLANGE (OMF)



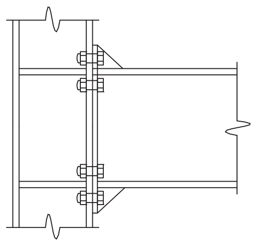
(B) WELDED FLANGE PLATE (OMF, SMF)



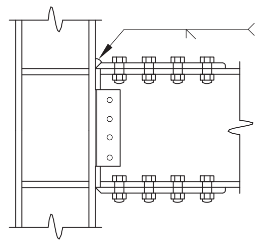
(C) FREE FLANGE (OMF, SMF)



(D) REDUCED BEAM SECTION (IMF, SMF)



(E) BOLTED END PLATE (IMF, SMF)



(F) BOLTED FLANGE PLATE (OMF, SMF)

It is essential to provide a continuous path of resistance from roof to foundation to dissipate both lateral and uplift forces. Connections along this load path will guarantee uninterrupted resistance. Seismic and wind forces are transferred from the roof diaphragm to shear walls and through the walls into the ground at the foundation. Shear walls resist horizontal forces in the roof and floor diaphragms and so must be connected to them. It is important to apply wall sheathing to the full wall height, nailing it to the top plate, blocking, or rim joist, as well as to the mud sill or bottom plate. Shear wall height/width ratios are an important consideration; consult a structural engineer for their design. The details illustrated show several connection paths; for each specific design, a structural engineer familiar with seismic and wind-resistant construction should be consulted. Many of the requirements for high-wind situations apply to seismic loading as well, except in shear wall design.

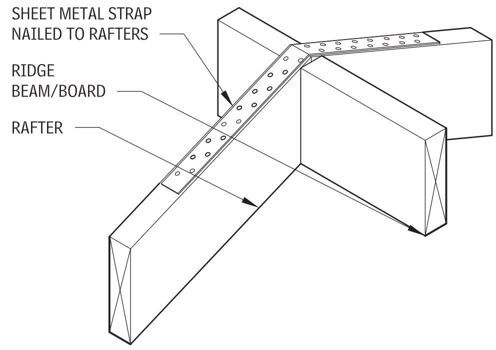
SEISMIC RECORDING INSTRUMENTATION

In regions of moderate to high seismicity (earthquakes), building codes and international standards require installation of seismic recording instrumentation for certain types of both new and existing buildings. Seismic recording instrumentation consists of two types of sensor equipment:

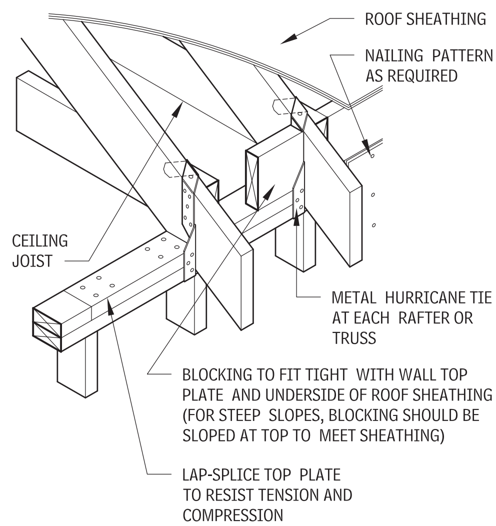
- Strong motion accelerograph
- An accelerometer

This instrumentation is deployed at strategic locations within a building structure to provide recorded data of the building's response to earthquake ground shaking at the building site. Figure 3.13 charts typical recorded ground motions at a building's roof, ground floor, free-field, and bedrock.

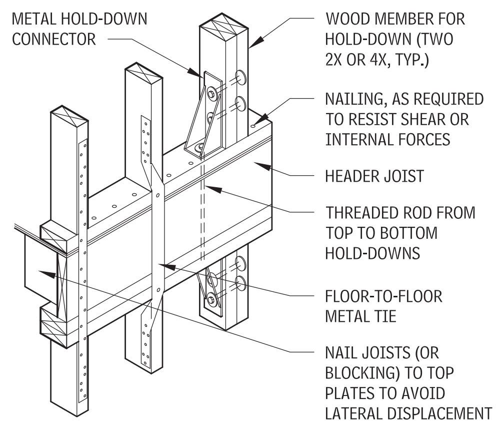
WIND AND SEISMIC CONNECTOR FRAMING
3.12



RIDGE UPLIFT STRAP



ROOF DIAPHRAGM PERIMETER



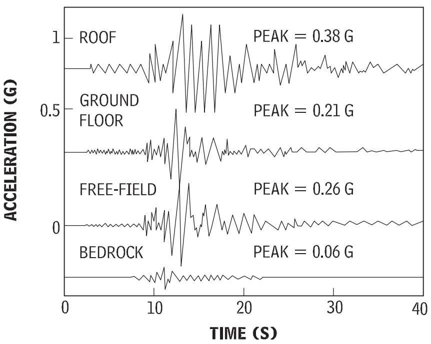
TIES BETWEEN FLOORS

NOTE

3.12 Ties between floors: Wood members (studs) must be sized for the load-carrying capacity at the critical net section.

Contributor:
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland.

TYPICAL RECORDED GROUND MOTIONS
3.13



PURPOSE OF GROUND MOTION DATA RECORDING

The primary purpose of recording ground motion data from buildings and other instrumented structures is to facilitate analytical investigations. This analysis correlates actual building performance with expected performance. This information can be used to improve building codes and better predict the response of structures to earthquake ground motions, resulting in fewer losses of life and property. Such information can be used to provide critical time-dependent information to agencies responsible for earthquake preparedness and emergency response in large urban areas. Data can also be utilized to greatly reduce the time and extent of post earthquake building damage inspections. Automated procedures can then be utilized for rapid analysis of recorded sensor data prior to building inspections regarding the degree of damage immediately following a damaging earthquake.

SEISMIC INSTRUMENTATION EQUIPMENT

Seismic instrumentation equipment includes accelerographs, accelerometers, and cabling and digital recorders:

Accelerographs: Triaxial accelerographs, analog or digital, are the most widely deployed instruments by national and international organizations. A triaxial accelerograph contains two orthogonal horizontal accelerometers and one vertical accelerometer within the unit, which also houses the recording components.

Accelerometers: New installations normally consist of force-balance accelerometers with digital recording transducers, available in uniaxial, biaxial, or triaxial models. Sensors are usually installed in the building structure and in the free-field or downhole adjacent to the structure. The accelerometers are bolted to the building frame or floor, and data is transmitted to a central recording location by shielded cable. Triaxial accelerometers are the preferred models, as they include three force-balance accelerometer modules mounted orthogonally in one package. Sensors typically allow for recording ranges of plus/minus 0.25 to plus/minus 4 g, with recording bandwidth ranges from DC to 200 Hz.

Cabling and digital recorders: Accelerometers are interconnected by cabling to centrally located digital recorders for synchronized timing. There should be a junction box at each location where the main cable breaks out, to pick up more accelerometers. The junction box should be sized according to the number and size of the cables, which will be connected in and/or passing through it. The digital recorder should be located such that it is the shortest possible run to an outside wall, to facilitate installation of a GPS option. Digital recording systems can download data to a laptop, or transfer by modem or other communications media.

BUILDING CODE REQUIREMENTS

In certain locations, buildings of a certain size or height may require earthquake recording instrumentation. Municipalities may further require additional instrumentation, including complete strong motion accelerograph specifications for complete systems, installation, data retrieval, and servicing.

EXAMPLE INSTRUMENTED BUILDING

In 1998, the historic Court of Appeals Building in San Francisco, California, was rehabilitated and retrofitted with a base-isolation system. The U.S. Geological Survey (USGS), with the cooperation of the U.S. General Services Administration (GSA), installed a total of 36 channels of accelerometers with state-of-the-art digital recording capability. The dense array of recorders will provide vital data on the performance of the isolators and the response of the superstructure to future earthquakes. A free-field station has been deployed close to the building to provide key input data for evaluation of structures in the proximity of the Court of Appeals Building and to contribute to the assessment of the variation of ground motion within downtown San Francisco.

SEISMIC INSTRUMENTATION PROGRAM

A seismic instrumentation program should be configured to provide enough information to reconstruct the response of a building in enough detail to compare the mathematically modeled response with laboratory simulations and tests. The goal is to improve mathematical prediction models and provide data to assess reasons for damage to the structure. Nearby free-field and ground-level earthquake response recordings will further support comparisons with building response recordings to understand effects of soil-structure interaction. A complete set of recordings should provide useful data to verify analytical models, correlate observed damage, improve building codes, and facilitate retrofit strategies. The primary goal of seismic instrumentation programs is to assess how actual buildings and structural and nonstructural components respond to earthquakes.

IMPLEMENTATION AND MAINTENANCE OF THE INSTRUMENTATION PROGRAM

Implementation of a code-mandated or voluntary seismic instrumentation program is normally the responsibility of the building owner, although federal and state programs, including the U.S. Geological Survey (USGS) and the California Geological Survey (CGS), may provide assistance with implementation and maintenance of these programs.

Energy utilities, hospitals, and universities have developed their own specifications and procedures to implement and maintain these programs. Maintenance of instrumentation and processing of earthquake response data is normally the responsibility of the enforcement agency or a designated agent, such as the USGS and CGS.

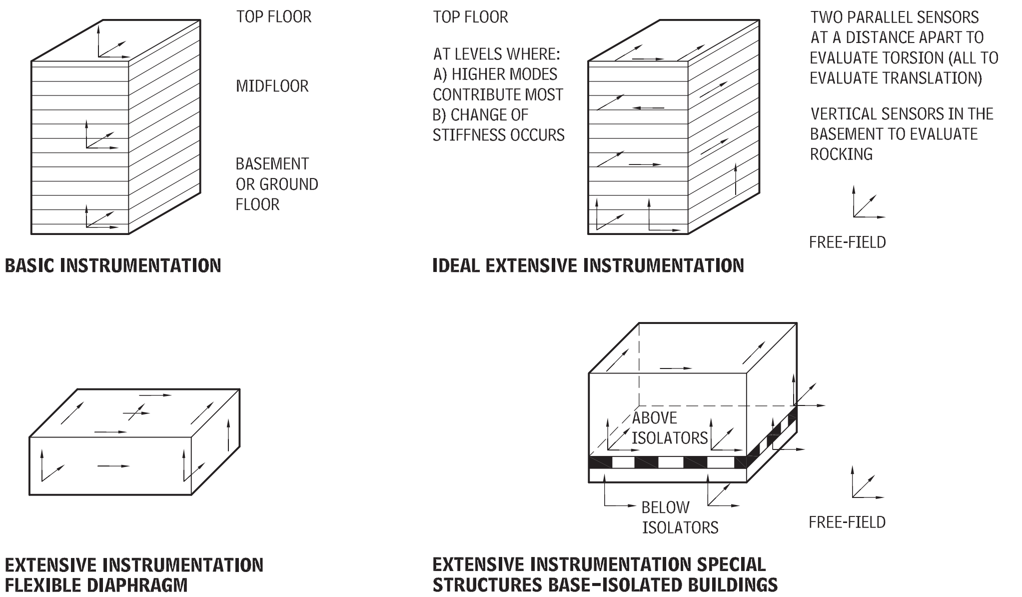
TYPICAL BUILDING INSTRUMENTATION SCHEMES

Local codes vary and should be consulted for requirements of building information schemes. The most basic scheme usually consists of three accelerograph sensors placed at the top, middle, and ground or foundation levels of a building. Because of the limited number of sensors in this configuration, only enough data is retrieved to serve as a basis to monitor, rather than fully analyze, the building's response.

A more extensive type of instrumentation scheme includes at least three horizontal accelerometers corresponding to two translational and one rotational degree-of-freedom. These horizontal accelerometers are required for each of the first four fundamental modes of vibration of the structure, resulting in a total of 12 accelerometers. If significant vertical motion and rocking is expected, at least three additional vertical accelerometers are required at the basement level.

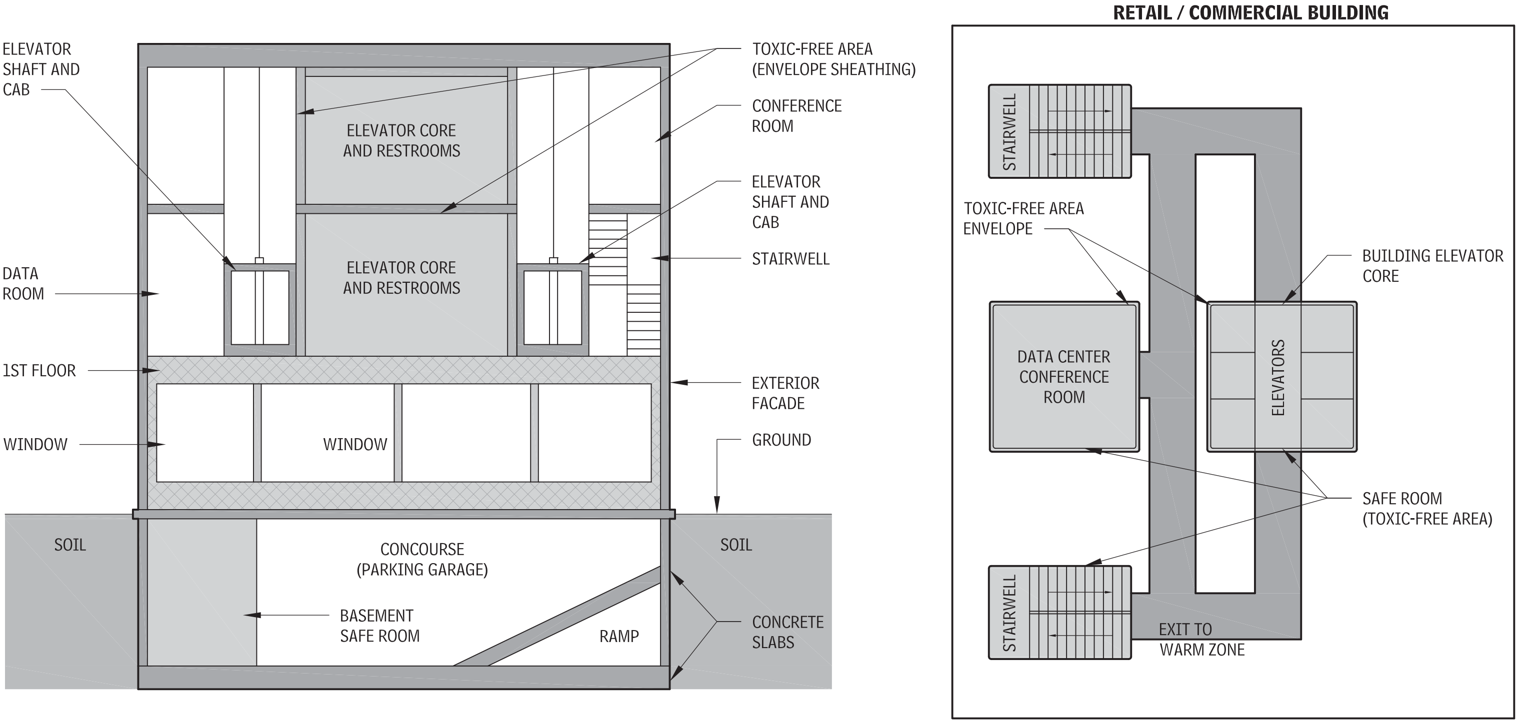
Additional extensive instrumentation schemes can be used for special-purpose buildings, such as structures with flexible diaphragms, or base-isolated buildings. To make full use of the recorded data and accurately correlate the responses of an instrumented building, recording sensors must be synchronized with high-precision digital recording devices. This allows postprocessing data to reconstruct the overall behavior of the structure.

TYPICAL INSTRUMENTATION SCHEMES
3.14



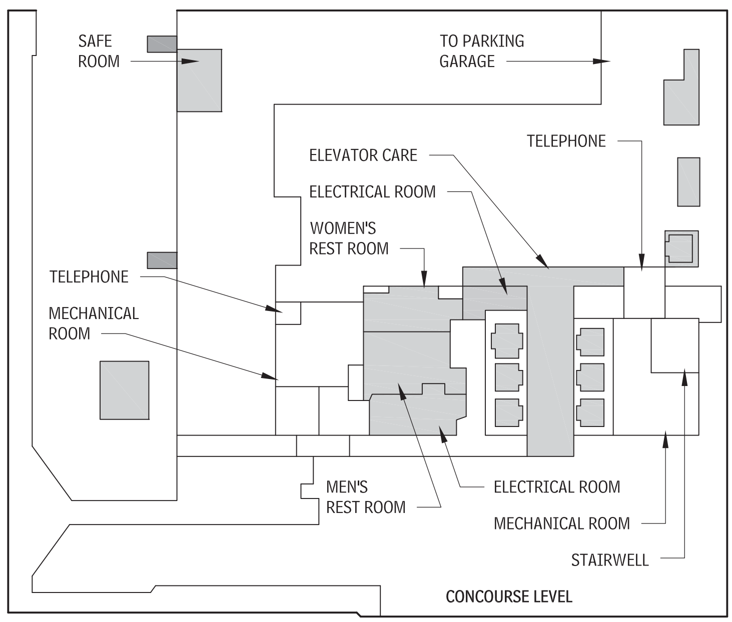
Contributor:
Ken Shook, Cerami & Assoc., Inc., New York, New York.

EXAMPLES OF INTERNAL SHELTER LOCATIONS IN RETAIL/COMMERCIAL BUILDINGS
3.15



SHELTER

Buildings are not typically designed to resist tornados; however, buildings in tornado-prone areas often provide "safe rooms" or shelters as areas of refuge. The concept of shelter-in-place requires sufficient space internal to the building, away from the exterior facade, for the building population to assemble. Interior partitions should be constructed of debris-mitigating materials, preferably reinforced block walls.



FLOOD

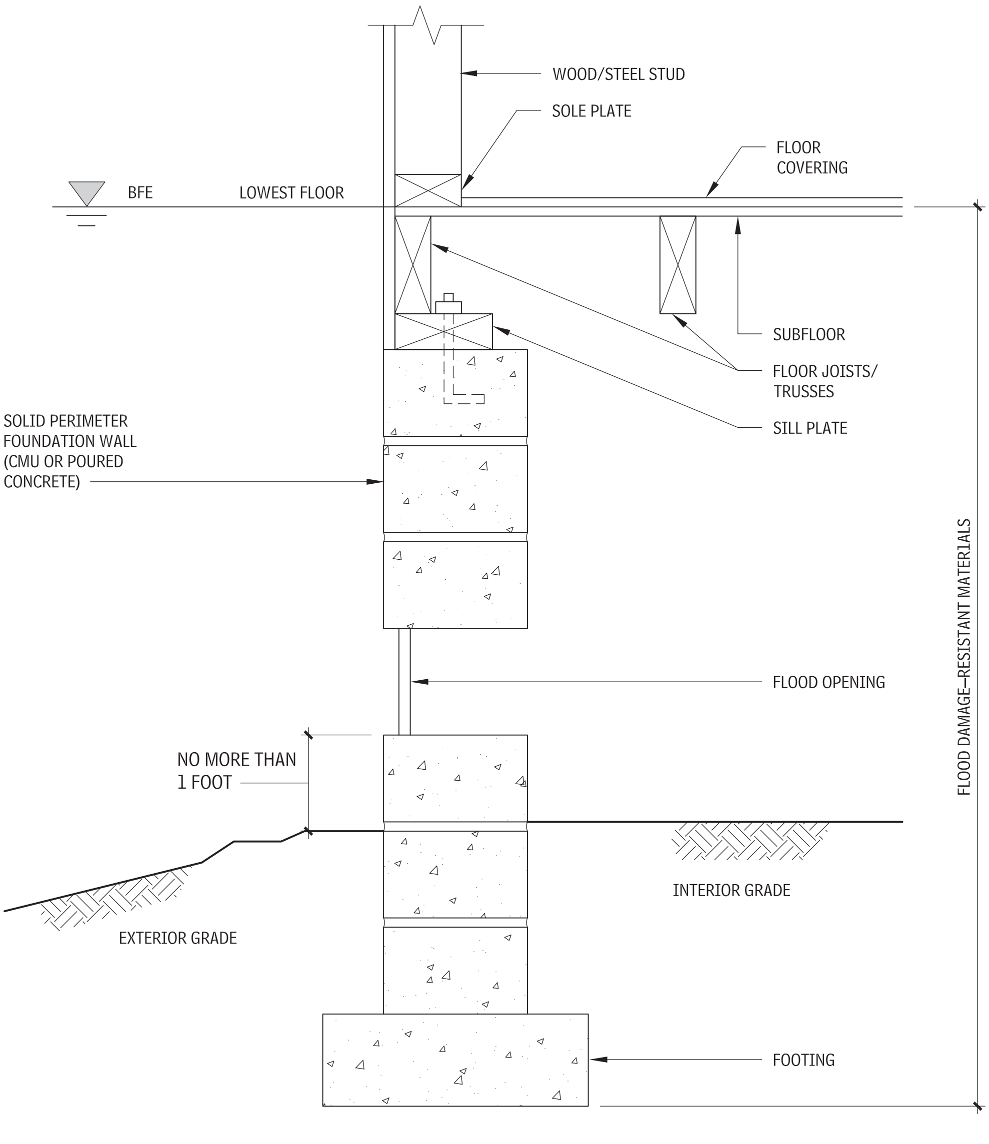
Flooding hazards are associated with water damage and hydrostatic loading on exposed surfaces. The base flood elevation (BFE) defines the elevation of the flooding, including wave height, with a 1 percent change of exceedance in any year and the corresponding design flood elevation is provided in flood hazard maps produced by the regional authority having jurisdiction. Flood insurance rate maps (FIRMs) are produced by the Federal Insurance and Mitigation Administration to define special flood hazard areas and risk premium zones. Waterproofing must be comprehensive up to the design flood elevation in order to protect property within the building. The structure must be able to withstand the hydrostatic loads, hydrodynamic loads, wave loads, and debris impact loads. Hydrostatic forces are based on the weight of standing water that increases with depth, and hydrodynamic forces account for the effects of moving water. Wave loads are associated with the periodic cresting and falling of the water surface; these waves may "break" against the structure. As upstream debris from damaged structures is swept up in the flood waters, downstream buildings become vulnerable to debris impact.

Design level flood loads are based on hurricane-generated storm tides but these loads only apply when the water level exceeds the local ground elevation. As a result, the statistical characteristics of flood loads depend on the ground elevation. Flood loads may be applied laterally to the vertical surfaces that resist the water pressure and as uplift to horizontal surfaces beneath the design flood elevation. Walls and slabs subjected to flood loads must be adequately reinforced and braced to resist the resulting pressures.

Making a building flood resistant involves the use of resilient materials, which must be resistant to excessive humidity and require no more than cleaning and cosmetic repair following three days (or more) contact with flood waters. Some of the flood-resistant materials include glazed brick, concrete, concrete block, glass block, stone with waterproof grout, naturally decay-resistant lumber, marine grade plywood, and cement board. A more detailed list of flood damage–resistant materials may be found in FEMA Technical Bulletin 2. All structural interfaces below the flood level, such as building foundations and equipment, must be adequately anchored to resist buoyancy uplift forces and lateral movement. Mechanical, plumbing, and electrical systems must be moved above the flood level so as to protect heating, ventilation, plumbing appliances, ducts, electrical panels, meters, and switches. Waterproof enclosures and coatings may be required where sensitive equipment cannot be moved.

In addition to flood waters inundating a property and the forces they may impose, flooding often causes sanitary sewer lines and wastewater systems to back-up and cause additional damage. Backflow and automatic shutoff valves must be installed on any pipes that leave the building or are connected to equipment below the base flood elevation. Fuel supply lines must be equipped with float-operated automatic shutoff valves.

FLOOD-RESISTANT FOUNDATION DESIGN
3.16



FIRE

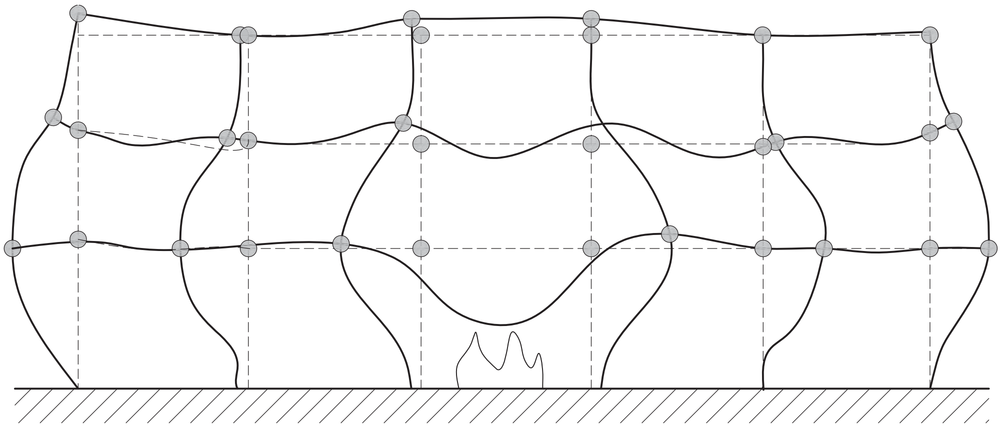
Fire is among the most common catastrophic hazards in the United States. According to National Fire Protection Association (NFPA), in 2013 U.S. fire departments responded to over a million fires that caused over 3000 civilian fire fatalities, nearly 16,000 civilian fire injuries, and an estimated $11.5 billion in direct property loss. Passive and automatic fire protection systems are effective in detecting, containing, controlling, and extinguishing a fire in its early stages. Designers must take an integrated systems approach to address the four primary sources of fire: natural, manmade, wildfire, and incidental. While code compliance will protect against loss of life and limit fire impact on the community, it doesn't necessarily protect the building assets and, as a result, additional considerations should be integrated with the minimum required fire safety measures. The inclusion of a fire protection engineer on the design team will produce a performance-based design approach that addresses both the code-mandated requirements and project-specific criteria. The Society of Fire Protection Engineers (SFPE) and NFPA published the *Engineering Guidelines to Performance-Based Fire Protection Analysis and Design of Buildings.*

Fire protection involves the construction type and size of a project, exposures and separation requirements, fire ratings of materials and systems, occupancy types, interior finishes, and exit stairway enclosures. Additional considerations are the remoteness of exit stairways; exit discharge locations; areas of refuge; accessibility of exits; and fire detection, notification, and system survivability. The design of fire suppression systems addresses the adequacy of water supply, automatic fire extinguishing systems, standpipes, and fire department hose outlets. Emergency power, lighting, and exit signage must be survivable.

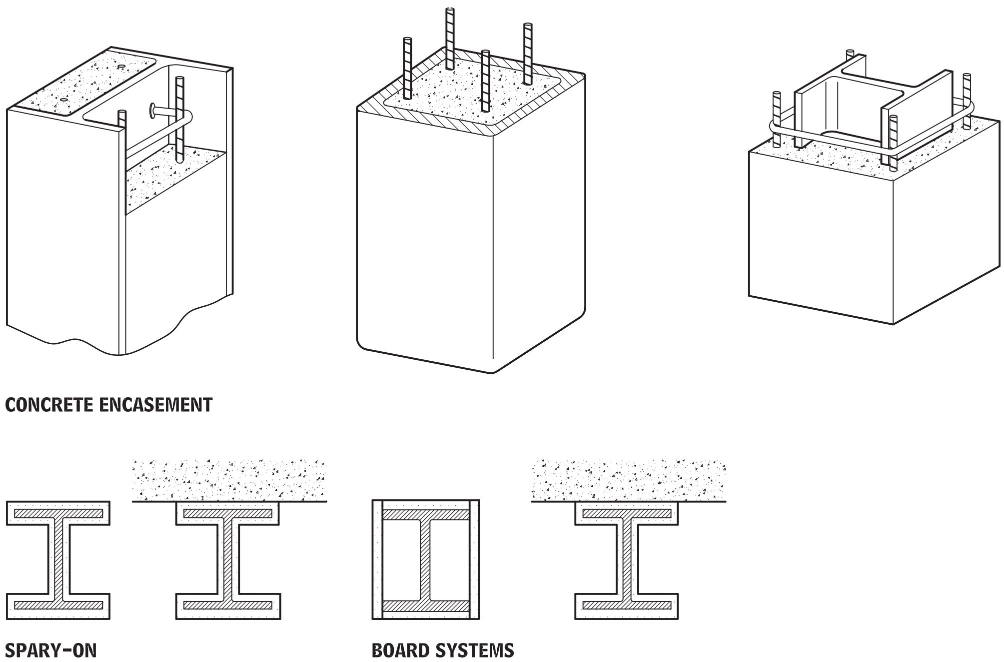
Fire protection engineering is a multidisciplinary field that coordinates mechanical (sprinklers, standpipes, smoke control), electrical (fire alarm), architectural (egress systems), and structural (fire-resistant design) professionals in a comprehensive strategy. In addition to satisfying prescriptive codes and standards, the fire protection engineer will use equivalency or alternate methods to portions of the building that achieve the fire safety goals while preserving project-specific aesthetics and functionality.

Sustained and prolonged exposure to elevated temperatures weakens structural materials and precipitates collapse as shown in Figure 3.17 *(Buchanan, 2001).* Fireproofing materials are therefore used to insulate the structural materials to minimize the heat gain and to delay the weakening of the structure. Steel is most susceptible to elevated temperatures and fireproofing materials may be cementitious (such as concrete encasement), board systems (such as calcium silicate and gypsum), spray-on systems, and intumescent paints. Each system has advantages and disadvantages,

EFFECTS OF FIRE ON UNPROTECTED BUILDING SUPERSTRUCTURE
3.17



TYPICAL STRUCTURAL SYSTEM FIRE PROTECTION APPLICATION DETAILS
3.18



which dictate their use. However, the effectiveness of each system is established through extensive testing in fire labs under controlled conditions. Hollow steel sections can be filled with concrete to improve fire performance and in rare occasions, hollow sections have been filled with water. Although concrete materials are less vulnerable to sustained heat, concrete spall can leave reinforcing steel exposed to sustained high temperatures and weaken the structure. Adequate thicknesses of concrete cover will limit the potential for reinforcing steel to be damaged before a fire can be brought "under control." Examples of different fireproofing details are shown in Figure 3.18 *(Buchanan, 2001).*

SECURITY

A physical attack against a facility, its assets, or its occupants, may potentially disrupt building operations and functionality. The duration and magnitude of disruption will depend on the type of attack (vandalism up through weapons of mass destruction), the areas/functions/personnel impacted, and the mitigation measures in place at the time of the attack. A facility may also experience collateral effects of an attack on a nearby facility, including a potentially similar level of disruption. Inclusion of appropriate security and hardening features into the site and facility design will aid in providing robustness against such attacks, resulting in a more resilient facility.

Design provisions should also be considered for maintaining an appropriate post-event security posture for the facility after a disruptive event has occurred (including deliberate physical attack, accident, or natural hazard).

BLAST RESISTANCE

Explosions can be generated from a variety of sources and conditions, and can be intentional (e.g., terrorist attack) or accidental (e.g., chemical plant malfunction). An explosive event results in a blast wave or shock front that expands outward in all directions at high velocity that will produce time-variant pressure loads on any surface that is directly or indirectly exposed to the blast wave as it expands. These loads can vary significantly across a building's exterior surfaces based on the size, geometry, and location of the building. Explosions can also be either external or internal to the building. The two must be treated differently, as effects from reflections and gas pressure buildups are typically more pronounced in an interior blast event.

There are three ways to approach blast protection for buildings:

- Reduce the blast loading on the facility
  - Increase standoff to the facility, and/or
  - Decrease the design basis explosive charge size
- Structurally harden the facility
- Accept a higher level of damage/risk for the facility

One or more of these constraints are typically fixed for design projects, which limits available options for blast resistance.

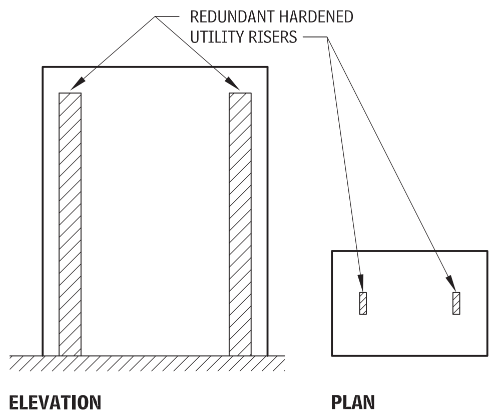
Blast design considerations for exterior explosive threats include:

- Perimeter protection (standoff distance, vehicle barrier design, screening)
- Structural response (walls, slabs, roofs, frames/columns, foundation)
- Windows (glass, frames, and attachments)
- Fragments (primary and secondary)

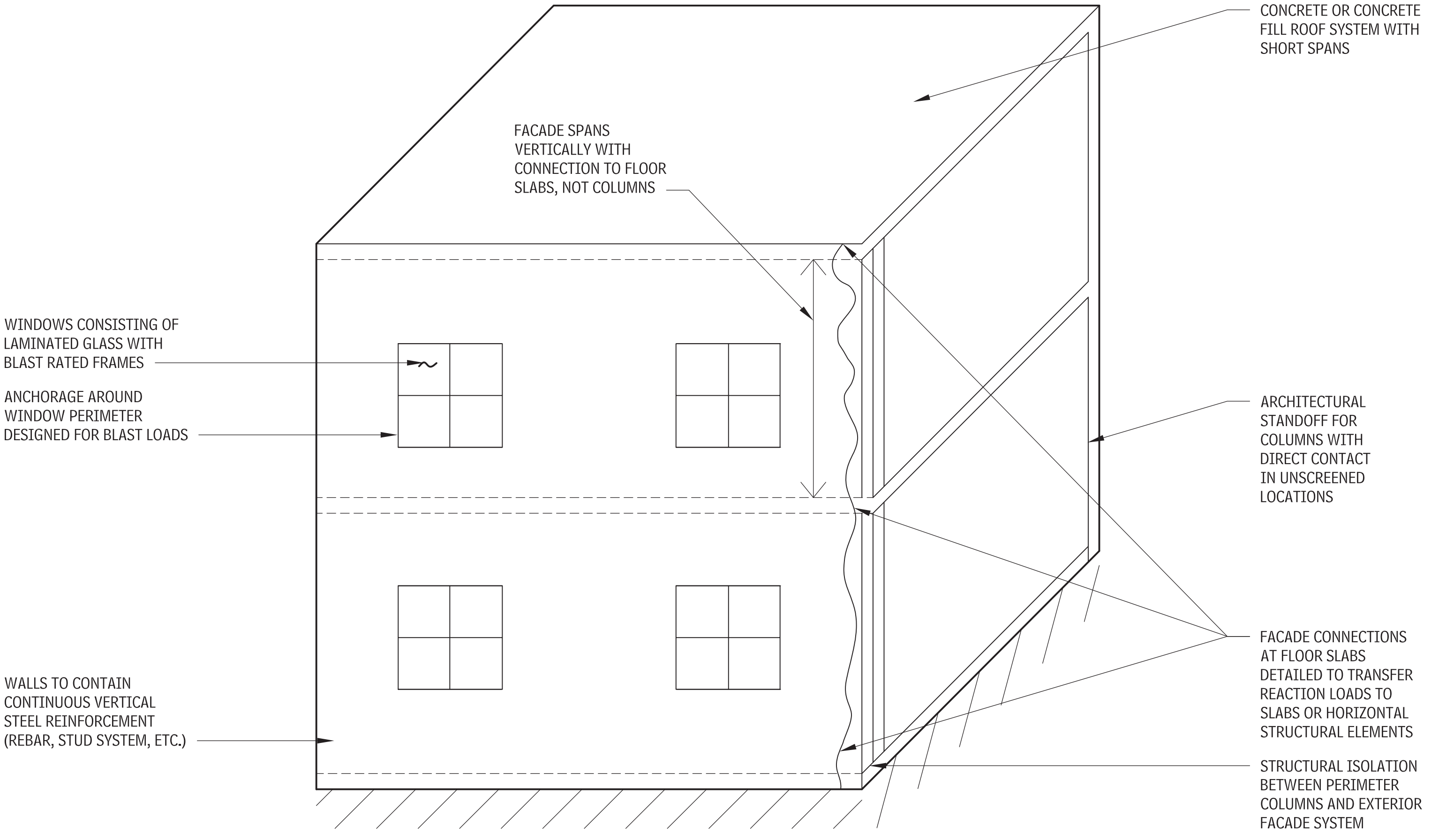
Blast design considerations for interior explosive threats include:

- Confined volume
- Location (basement, exterior room)
- Windows (glass, frames, and attachments)
- Structural response (walls, slabs, framing/columns)
- Proximity to critical systems or personnel
- Fragments, fire, smoke damage

HARDENED UTILITY RISERS
3.20



GENERAL BLAST PROVISIONS FOR BUILDINGS
3.19



Provide at least one bay of standoff between critical infrastructure systems (fire, water, power, communications, alarms, etc.) and vulnerable locations such as the building exterior, lobbies, mail rooms, loading docks, and the like.

Infrastructure systems should be provided in hardened utility risers. Isolate critical infrastructure systems from riser walls that may be exposed to either direct or indirect (infill) blast loads.

Perimeter protection is the first line of defense in providing security for a facility. It is used to define boundaries, provide protection, and deter or delay unauthorized access. In addition to defining the physical limits of a facility and controlling access to it, a perimeter barrier also creates a physical and psychological deterrent to unauthorized entry. It delays intrusion into an area, making the possibility of detection and apprehension more likely. It also aids security forces in controlling access and assists in directing the flow of people and vehicles through designated entrances.

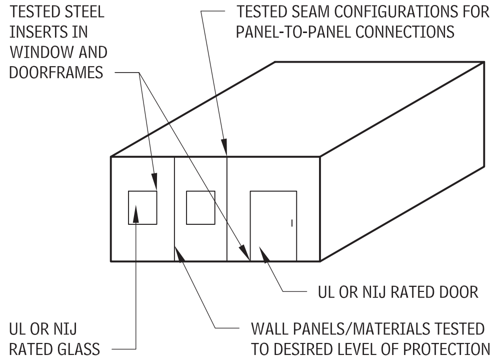
BALLISTIC PROTECTION

Ballistic-resistant design considerations include:

- Underwriters Laboratory (UL) or National Institute of Justice (NIJ) rated window glazing (typically several inches thick with multiple glass, polycarbonate, and laminate layers)
- UL or NIJ rated doors
- Tested steel inserts placed in window and doorframes
- Wall panels/materials tested to the desired level of protection with detailing for panel-to-panel seams. Note that most standard or layered building materials do not currently have standard ratings for ballistic resistance.

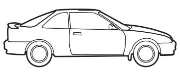
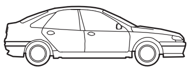
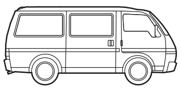
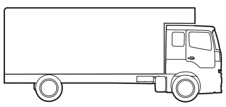
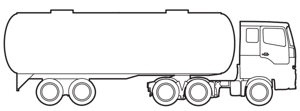
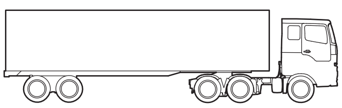
Vendors of ballistic mitigation products should provide test results demonstrating that the design/product will perform as intended.

GENERAL BALLISTIC PROTECTION PROVISIONS FOR BUILDINGS
3.23



BLAST-RESISTANT CONSTRUCTION

EFFECTS OF BLAST ON VEHICLES
3.21

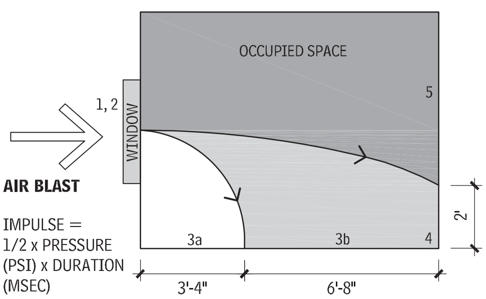
VEHICLE TYPE		MAXIMUM EXPLOSIVES CAPACITY (LB)	LETHAL AIR BLAST RANGE (FT)	MINIMUM EVACUATION DISTANCE (FT)	FALLING-GLASS HAZARD (FT)
	Compact sedan	500 (in trunk)	100	1,500	1,250
	Full-size sedan	1,000 (in trunk)	125	1,750	1,750
	Passenger van or cargo van	4,000	200	2,750	2,750
	Small box van (14' box)	10,000	300	3,750	3,750
	Box van or water/fuel truck	30,000	450	6,500	6,500
	Semitrailer	60,000	600	7,000	7,000

BALLISTICS-RESISTANT CONSTRUCTION

No construction can be truly bulletproof, but ballistics-resistant construction is possible. Protected areas should be designed to withstand a level of attack based on the threat at that location, in particular the type of arms expected. Each component in a ballistics-resistant assembly must be ballistics-resistant; there can be no weak links and no gaps. Therefore, it is essential to consult a specialist in ballistics-resistant construction.

Effective protection combines ballistics-resistant assemblies with appropriate detection, alarm, communication, escape, and retaliation capabilities. The complete ballistics-resistant environment makes it possible for personnel to escape, retaliate against attack, summon help, and defend themselves against the threat of gunfire, flame, and chemical or mechanical attack.

EFFECTS OF BLAST ON WINDOWS
3.22



PERFORMANCE CONDITION	PROTECTION LEVEL	HAZARD LEVEL	GLAZING SYSTEM RESPONSE
1	Safe	None	Glazing does not break. No visible damage to glazing or frame.
2	Very high	None	Glazing cracks but is retained by the frame. Dusting or very small fragments near sill or on floor acceptable.
3a	High	Very low	Glazing cracks. Fragments enter space and land on floor no farther than 3.3' from the window.
3b	High	Low	Glazing cracks. Fragments enter space and land on floor no farther than 10' from the window.
4	Medium	Medium	Glazing cracks. Fragments enter space and land on floor and impact a vertical witness panel at a distance of no more than 10' from the window at a height no greater than 2' above the floor.
5	Low	High	Glazing cracks and window system fails catastrophically. Fragments enter space, impacting a vertical witness panel at a distance of no more than 10' from the window and at a height greater than 2' above the floor.

Source: GSA Test Protocol: GAS TS01

Contributor:
Charles Ruotolo, PE, Ducibella Venter & Santore, North Haven, Connecticut.

BALLISTICS-RESISTANT DESIGN CONSIDERATIONS

These guidelines apply to security doors and frame assemblies:

- The entire unit should be certified as a ballistics-resistant assembly by an independent testing laboratory.
- Ballistics-resistant doors are heavier than regular doors, so the frame and hinges must be reinforced.
- The frame must be constructed of ballistics-resistant material equivalent to that of the door itself. A proper fit between the door and the frame is required to prevent gaps that could permit ballistic penetration. Ideally, the door and frame should be supplied by the manufacturer as a single unit.
- Use of appropriate hardware is important. The lockset should be mortised with 5/8-in. minimum throw on the latch bolt and be thoroughly armored to prevent the door from unlatching after assault.
- The door should be equipped with a heavy-duty closer, to ensure it closes completely.

Similar guidelines apply to ballistics-resistant window assemblies:

- The entire unit should be certified as a ballistics-resistant assembly by an independent testing laboratory.
- All elements in an assembly must be ballistics-resistant, including voice communication equipment and trays.
- The window frame must be ballistics-resistant, as well as substantial enough to retain the glazing material under the impact of a projectile.
- The window should be designed so that the frame and the glass form an integral unit.

UL-LISTED BALLISTIC LEVELS
3.24

BALLISTIC LEVELS	PROJECTILE CALIBER
UL Level 1	9 mm Parabellum
UL Level 2	.357 Magnum
UL Level 3	.44 Magnum
UL Level 4	.30 30–06
UL Level 5	.30 7.62 NATO
UL Level 6	9 mm Parabellum (high-velocity load)
UL Level 7	.223 5.56 NATO
UL Level 8	.30 7.62 NATO

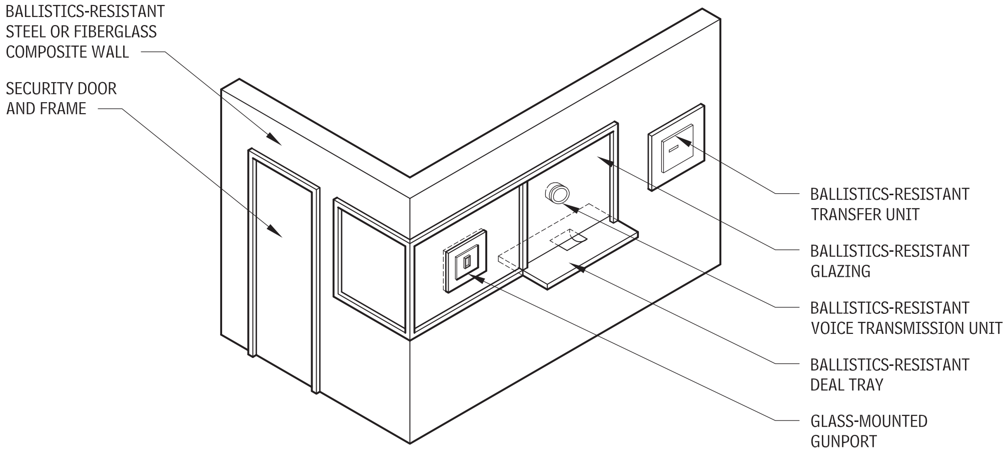
FORCED ENTRY/PHYSICAL ATTACK RESISTANCE

Forced entry design considerations for exterior physical attack include:

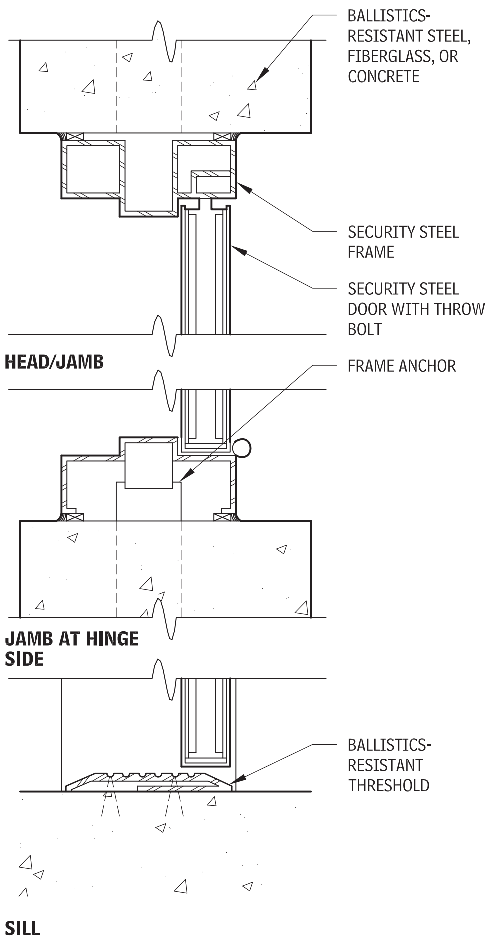
- Door and frame assemblies, including sidelights, door glazing, door louvers, and corresponding hardware (locks and latch sets, hinges, strikes, door closers, and frame anchors)
- HVAC and related ventilation louvers
- Window systems, including glazing and framing, frame anchors, deal trays, pass-through drawers, and speaking apertures
- Walls and wall panel systems

Validation of forced entry systems is performed through testing, typically using methods developed by the U.S. State Department, ASTM, and others. Ratings requirements should be provided in the project specifications and are typically defined in terms of method of physical attack and minutes of protection provided against such attack. Vendors of forced entry systems should provide test results showing compliance with the desired level of protection. Systems validated through testing should be installed using the configuration under which they were tested.

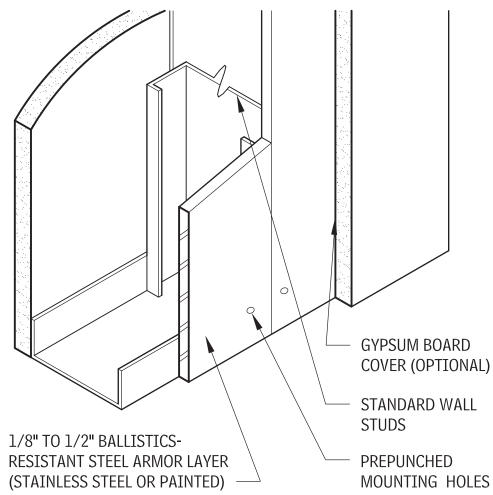
BALLISTIC-RESISTANT WALL
3.25



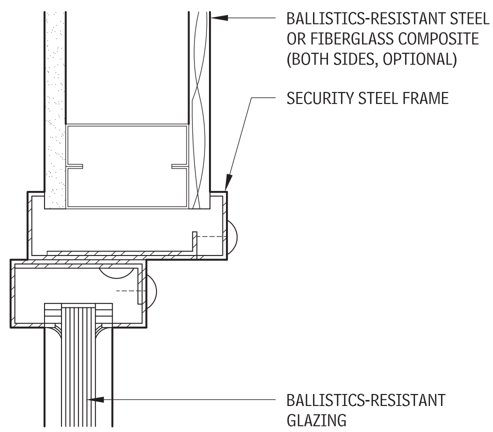
BALLISTICS-RESISTANT DOOR IN CONCRETE WALL
3.26



BALLISTICS-RESISTANT COMPOSITE WALL PANEL
3.27



BALLISTIC-RESISTANT WINDOW HEAD/JAMB
3.28



TYPICAL BALLISTICS-RESISTANT MATERIALS
3.29

MATERIAL	FUNCTIONS AND CHARACTERISTICS	THICKNESS	WEIGHT	REMARKS
STEEL	Cost-effective shielding against direct assault	1/8" to 1"	6 to 24 psf	—
	Thin			
	Can be fabricated for retrofit			
	Easy installation			
GLASS	Cost-effective vision-panel shield	1–3/16" to 2"	15 to 31 psf	One-way security glass is available 5/8" to 1–5/8" thick; weight 7.1 to 18.2 psf
	Scratch-resistant, chemical-resistant			
	Substantial assault can defeat glass			
PLASTICS (ACRYLIC)	Lighter weight and more impact-resistant than glass	1–1/4"	7.8 psf	Glass-clad polycarbonate is available 1" to 1–11/16" thick; weight 9.6 to 17.6 psf
	Spall-resistant			
	Relatively high cost			
	Substantial assault can defeat plastic			
COMPOSITES	Can be opaque or transparent	1/4"–1–1/8"	2.5 to 11.5 psf	Available in 4' x 8' sheets
	Lighter-weight alternative for direct assault shielding			
	Composite vision panels can be made stronger than glass			
	Workable; suitable for custom installation			
	Relatively high cost			

CYBERSECURITY

The Target Stores data hack in 2013 brought increased attention to the network connectivity of facilities/buildings operations and maintenance vendors, the organization's business IT systems, and the facility/building control systems.

Buildings are increasingly relying on building control systems with embedded communications technology, with such technology enabled via the Internet. These systems provide critical services that allow a building to meet the functional and operational needs of building occupants, but they can also be easy targets for hackers and people with malicious intent. Attackers can exploit these systems to gain unauthorized access to facilities; be used as an entry point to traditional informational technology (IT) systems and data; cause physical destruction of building equipment; and expose an organization to significant financial obligations to contain and eradicate malware or recover from a cyber-event.

The facility/building control systems such as the Building Automation Systems (BAS), Energy Management Systems (EMS), Physical Security Access Control Systems (PACS), and Fire Alarm Systems (FAS) are just beginning to be considered as potential hacking points into an organization. These control systems are often referred to as Operational Technologies (OT) and use a combination of traditional IT protocols such as TCP and UDP, and unique protocols such as Modbus, BACnet, LonTalk, and DNP 3 to communicate with the sensors, devices, and actuators.

IT is about data; OT is about controlling machines and OT is increasingly becoming more Internet Protocol (IP)-based. The Internet of Everything, Smart Grid, Smart Cities, Smart Buildings, and Smart Cars are redefining the boundary between IT and OT. As the IT and OT systems have converged, so have the risk and vulnerabilities of hacking and using the OT systems as a point of entry and then pivoting up the network and taking control of other system assets.

COMPARING IT AND OT SYSTEMS
3.30

	INFORMATION TECHNOLOGY	OPERATIONAL TECHNOLOGY
Purpose	Process transactions, provide information	Control or monitor physical processes and equipment
Architecture	Enterprise-wide infrastructure and applications (generic)	Event-driven, real-time, embedded hardware and software (custom)
Interfaces	GUI, Web browser, terminal, and keyboard	Electromechanical, sensors, actuators, coded displays, hand-held devices
Ownership	CIO, IT	Engineers, technicians, operators, and managers
Connectivity	Corporate network, IP-based	Control networks, hard-wired twisted pair and IP-based
Role	Supports people	Controls machines

The National Institute of Standards and Technology (NIST) has been a primary source of IT cyber standards and guides. The NIST SP 800–37 and NIST SP 800–53 publications, the SANS Top Twenty controls, and ISO standards have been used by both government and industry as IT best practices for many years.

KEY CYBER ISSUES

- Building control system protocols such as Modbus, BACNet, and LonTalk are not encrypted or authenticated.
- Many system integrators do not employ basic cyber hardening of the IT front end of the control systems.
- Many of the operator log-ins for Web portal access use *htpp* (port 80) and not *https* (port 443).
- Social engineering and phishing of facility operators and maintainers will likely succeed, with limited tools to prevent or identify the exploit.
- NIST SP 800–82 R2 Industrial Control Systems Security Guide provides guidance and best practices.
- Tools like Kali Linux, DHS CSET, Shodan, Sophia, and Diggity need to become part of the facility tool bag.
- Continually monitor and conduct security audits of the building control systems.

Contributors:
Roger J. Grant, CSI, CDT, National Institute of Building Science (NIBS), Washington, DC; Martin Denholm, SmithGroupJJR; Robert Smilowitz Ph.D., P.E. Thornton Tomasetti - Weidlinger Protective Design Practice, New York, NY.; Joseph L. Smith, PSP and Kenneth W. Herrle, P.E., CPP, PMP, Applied Research Associates, Inc., Vicksburg, Mississippi; Michael Chipley PhD GICSP PMP LEED AP, PMC Group, Centreville, VA.

SUSTAINABILITY

Sustainability focuses on decreasing the environmental impact of a building's construction and operation. That focus results in design strategies that decrease overall energy and material use and incorporate renewable resources wherever possible. Sustainability can play an important part in overall resilience by improving the ability of buildings to withstand threats, and recover from damaging events.

ENERGY AND ENVIRONMENTAL IMPACT

Reducing energy and other resource consumption and waste generation during the building process and in building operation reduces the impact on the environment and contributes positively to sustainability of the design.

Design considerations:

- Lower energy demands to decrease size and vulnerability of supporting infrastructure
- Prioritize energy use to aid response and recovery from damage
- Renewable materials that lessen the impact of providing materials for repair and restoration
- Renewable and recyclable materials to lessen the impact of disposal and replacement
- Maximize use of available natural resources.

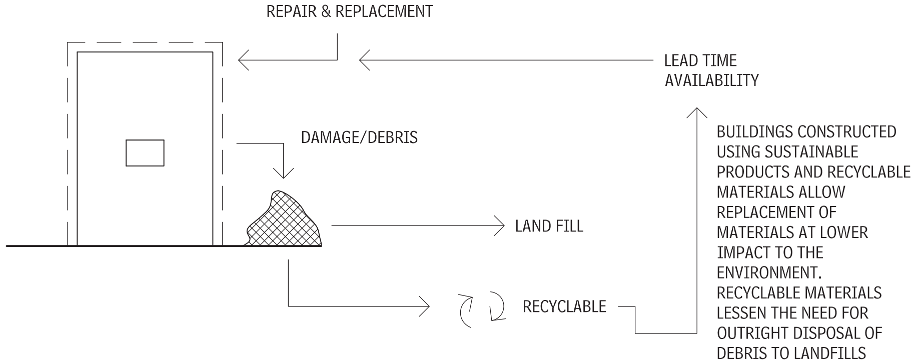
PASSIVE SURVIVABILITY

Sustainability strategies can be cross-purposed with resilience strategies in many aspects of building and site design. Site selection and design are important aspects of both sustainable and resilient design.

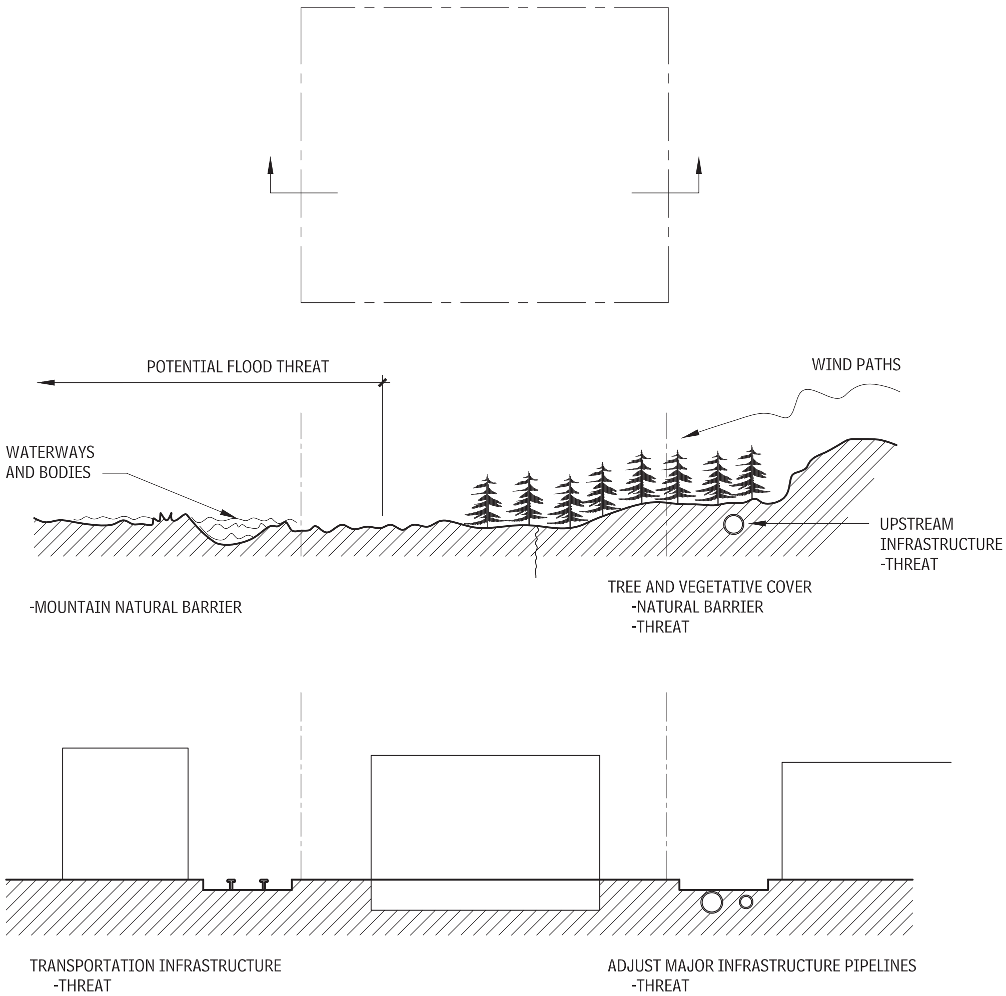
Design considerations:

- Avoid areas and sites of greater environmental vulnerability from water, fire, and wind threats.
- Maintain natural barriers and systems that prevent damage from environmental threats.
- Implement water management and natural water flow and drainage to both lessen environmental impact and to protect buildings from such events.
- Install renewable on-site energy production to maintain operations.
- Employ water and rainwater reuse and recycling to enhance potable and non-potable availability pre- and post-event.
- Use natural systems to improve the building's ability to recover operations.

DIAGRAM OF RECYCLABLE MATERIALS LIFECYCLE
3.31



NATURAL BARRIERS GRAPHIC
3.32



BOTH NATURAL FEATURES AND BUILT FEATURES CAN PROVIDE PROTECTION AND POSE VULNERABILITIES. MAINTAINING THESE BARRIERS HELPS TO MITIGATE DAMAGE: ATTENTION TO THE VULNERABILITY SIDE OF THE SURROUNDING ENVIRONMENT CAN PREVENT ADVERSE AFFECTS.

GOOD PRACTICES

OVERVIEW

Design strategies that not only increase robustness but also facilitate incorporation of resourcefulness and planning for recovery and warranted redundancy should be implemented. In some cases these strategies are simply achieved through effective configuration and use of site and building features. In other cases, more extensive additions of systems are required.

BUILDING FUNCTION AND TENANTS

Resilience is a strategy to enhance the ability of a building, facility, or community to both prevent damage and to recover from damage. Each building has some particular function for which it is designed. Each function, each particular tenant, has a set of requirements and support systems necessary for that function. Attention should be paid to those particular needs in arriving at the specific resilience strategy and design. Achieving resilience for tenants will involve a combination of physical characteristics of the building that determine its ability to withstand disruptive events and programs and procedures that minimize impact and enable an appropriately rapid return to operations. An effective building design should anticipate and incorporate both types of resilience achievement elements.

Some of the important functional and operational factors affecting the resilience strategy are:

- Importance of the building's function to the community
- Role the building function fills in the institution or business in which it is involved
- Effect of damage and recovery on the building's surrounding neighbors and environment
- Economic importance of timely recovery of the building's operation

BUILDING SITING AND LAYOUT

Building siting and layout should use a defense-in-depth approach against physical attack which considers concentric and progressive levels of defense, implemented through a combination of physical attributes (setback, hardening, access, avenues of approach, etc.), technology (CCTV, alarms, etc.), and planned operational processes for the facility. The goal is effective threat deterrence, detection, delay, response, and, finally, physical denial in the case of the occurrence of an undesirable event.

Siting and layout should also account for potential natural hazards that may impact the site such as flooding and wildfire, high wind debris from adjacent sites, as well as potential off-site accident hazards such as hazardous substance release or explosions that may impact the site, including any compounded impact from combined hazards.

Building siting and layout must also consider expedient access to the site and the facility by first responders such as the fire department, police, and medical response vehicles and personnel, including access to applicable critical infrastructure to support their individual missions.

Defensive locations for critical utilities and backup systems should be selected. Defensive locations should be considered for protection from manmade threats, natural hazards, and potential accidents with a goal of maintaining post-event operability, or rapid restoration of services based on the specific needs of the facility. Redundant utility feeds to the site (power, water, communications, gas, etc.) should be used to the greatest extent possible.

Site considerations should also include egress pathways and areas of refuge for building evacuees, including multiple physically separated locations with appropriate standoff distances. Elimination of line-of-sight targeting for ballistic protection should be considered in the design. Design in urban areas presents challenges in these approaches.

When designing for resilience, site selection must also consider the level of resilience of the surrounding community for the proposed site, particularly with regard to basic infrastructure and services such as transportation and deliveries, public and private utilities, and post-event availability of building tenant employees who reside in the surrounding community. For most facilities, prolonged outages and shortages in the surrounding communities will impact building resilience from a recovery perspective.

PASSIVE DESIGN

Passive measures developed to provide protection for building personnel, property, equipment, and operations against potential manmade threats and natural hazards that may test a building's resilience include the effective use of architecture, lighting, landscaping, and other building and site features specifically designed to:

- Deter threats
- Deny threats
- Mitigate the impact of threats

Perimeter protection passive design features are used to control pedestrian and vehicle access to the site. Multiple methods can be used to accomplish this for a variety of configurations and rating levels:

- *Fixed bollards;* Provide vehicle control and enforced vehicle standoff, but are ineffective for pedestrian control.
- *Fencing:* Provides vehicle and pedestrian control, as well as enforced vehicle standoff when integrated with a vehicle cable system or similar measure.
- *Fixed barriers:* Provide vehicle control and enforced vehicle standoff; level of pedestrian control varies widely based on type and configuration.
- *Curbs:* Provide a low level of vehicle control and nonenforced vehicle standoff, but are ineffective for pedestrian control.
- Street furniture, lampposts, and retaining walls built to withstand vehicle impacts
- Boulder fields, ha-ha walls, berms, tree cover, and other landscape features
- Water retention ponds, fountains, bioswales and other water features, either decorative or part of a water management system.

Redundancy, structural and facade hardening, Crime Prevention Through Environmental Design (CPTED), and locations of critical systems within and around the building or site should also be considered as passive design measures. Structural and facade hardening for blast resistance are often sufficient to mitigate many natural hazard threats.

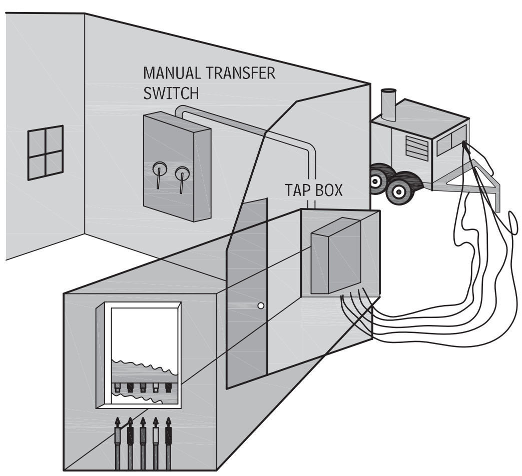
Passive design measures should also include appropriate anchorage and attachment of exterior critical infrastructure systems for natural hazards that may impact the facility.

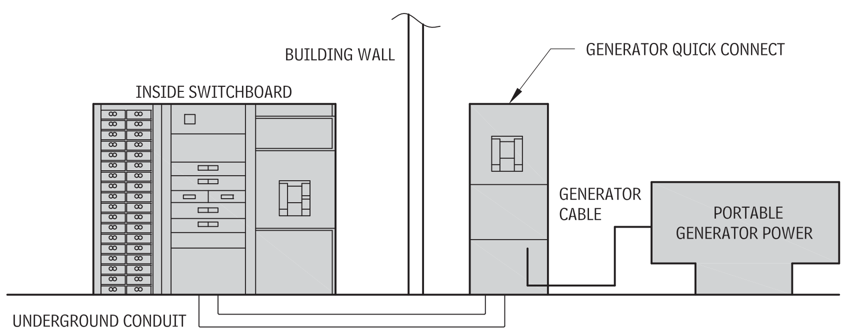
ACTIVE SYSTEMS

Active measures developed to provide protection for building personnel, property, equipment, and operations against potential threats and natural hazards that may test a building's resilience include the effective use of tested systems, equipment, and technologies specifically designed to:

- Deter threats
- Detect/report threats
- Deny threats
- Respond to threats

GENERAL EMERGENCY POWER QUICK CONNECTS FOR BUILDINGS
3.33





GENERATOR QUICK CONNECT SCHEMATIC

Contributors:
Roger J. Grant, CSI, CDT, National Institute of Building Science (NIBS), Washington, DC; Martin Denholm, AIA, LEED AP, BD+C, BSCP, SmithGroupJJR, Washington, DC; Mohammed Ettouney Ph.D., P.E., MBA, F.AEI, Dist.M.ASCE, Mohammed Ettouney, LLC, West New York, NJ; Robert Smilowitz Ph.D., P.E. Thornton Tomasetti - Weidlinger Protective Design Practice, New York, NY; Joseph L. Smith, PSP and Kenneth W. Herrle, P.E., CPP, PMP, Applied Research Associates, Inc., Vicksburg, MS.

Active design components selected to provide these functions include:

- Electronic security and surveillance systems/networks (CCTV cameras, monitoring stations, etc.)
- Electronic access control systems (card readers, biometric readers, electromagnetic locks, intrusion detection systems, etc.)
- Electronic notification systems (annunciators, duress buttons, radios, etc.)
- Pedestrian and vehicle access infrastructure (turnstiles, doors, gates, mantraps, portals, active vehicle barriers, etc.)
- Standby emergency power with auto transfer switch and on-site fuel storage
- Wireless backup for landline communications
- Sump pumps for submerged areas containing critical functions

CONTINUED OPERATIONS GOALS

In assessing the importance of continued operations during design, tenant use should be paramount, as various locations throughout the building may have different needs regarding continued operations. As part of the planning and design process, evaluating the benefits of building resilience based on risk and continuity of operations should be performed. As noted earlier, this can be done using the DHS IRVS tool. Design considerations include:

- Evaluating needs for tenant-specific operations
- Identifying resiliency options to maintain mission-critical functions for each tenant
- Quantifying impact to each tenant from loss of partial or full operational functionality, including financial impact, reputation/political impact, and others
- Consideration of cascading impacts to external customers from loss of tenant operations

To maintain continued operability of the building post-event, or resumption of building operations, the building owner should be prepared to obtain MOUs/MOAs with service providers regarding priority of service and potential work-arounds to maintain/restore service.

CRIME PREVENTION

Security design and access control is more than bars on windows, a security guard booth, a camera, or a wall. Crime prevention involves the systematic integration of design, technology, and operation for the protection of three critical assets—people, information, and property. Protection of these assets is a concern and should be considered throughout the design and construction process.

The most efficient, least expensive way to provide security is during the design process. Designers who are called on to address security and crime concerns must be able to determine security requirements, must know security technology, and must understand the architectural implications of security needs.

The process of designing security into architecture is known as "crime prevention through environmental design" (CPTED). It involves designing the built environment to reduce the opportunity for, and fear of, stranger-to-stranger predatory crime. This approach to security design is different from traditional crime prevention practice, which focuses on denying access to a crime target with barrier techniques, such as locks, alarms, fences, and gates. CPTED takes advantage of opportunities for natural access control, surveillance, and territorial reinforcement. It is possible for natural and normal uses of the environment to meet the same security goals as physical and technical protection methods.

CPTED strategies are implemented by:

Electronic methods: Electronic access and intrusion detection, electronic surveillance, electronic detection, and alarm and electronic monitoring and control
Architectural methods: Architectural design and layout, site planning and landscaping, signage, and circulation control
Organizational methods: Manpower, police, security guards, and neighborhood watch programs

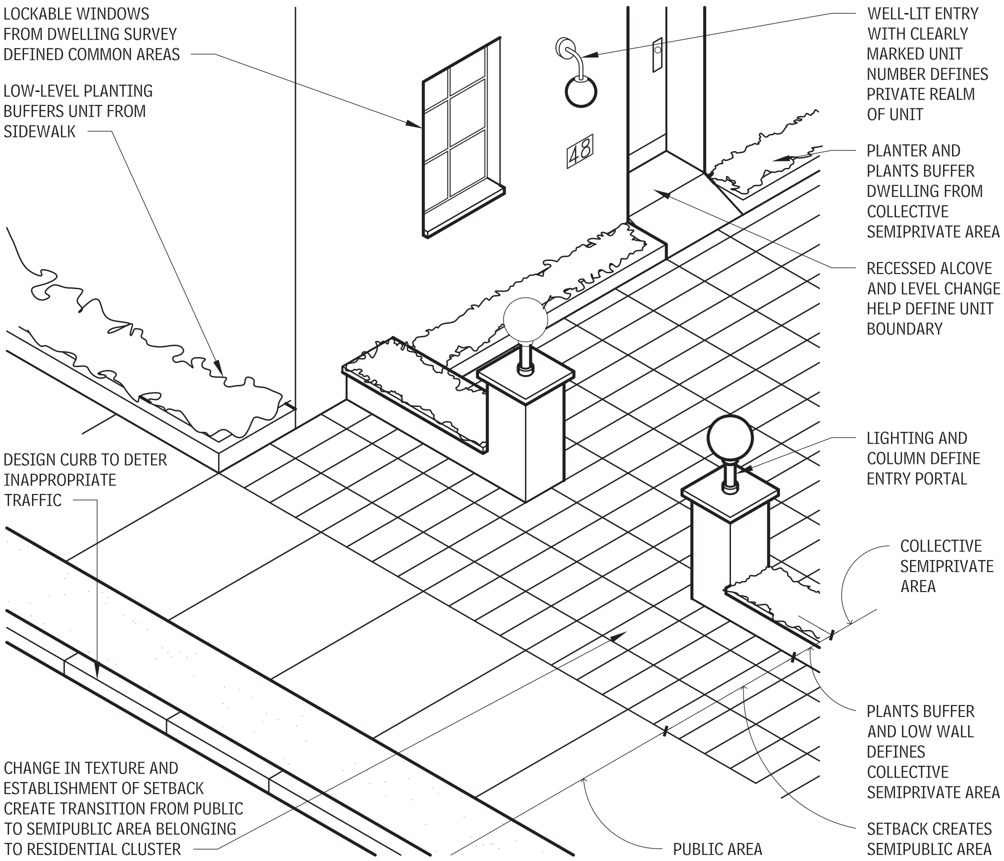
CPTED CONCEPTS

Concepts involved in crime prevention through environmental design are described below.

DEFENSIBLE SPACE

Oscar Newman coined the expression "defensible space" as a term for a range of mechanisms, real and symbolic barriers, strongly defined areas of influence, and improved opportunities for surveillance that combine to bring the environment under the control of its residents.

SECURITY LAYERING OF SPACES
3.34



NATURAL ACCESS CONTROL

Natural access control involves decreasing opportunities for crime by denying access to crime targets and creating a perception of risk in offenders. It is accomplished by designing streets, sidewalks, entrances, and neighborhood gateways to mark public routes, and by using structural elements to discourage access to private areas.

NATURAL SURVEILLANCE

A design concept intended to make intruders easily observable, natural surveillance is promoted by features that maximize visibility of people, parking areas, and entrances. Examples are doors and windows that look onto streets and parking areas, pedestrian-friendly sidewalks and streets, front porches, and adequate nighttime lighting.

TERRITORIAL REINFORCEMENT

Physical design can create or extend a sphere of influence. In this setting, users develop a sense of territorial control, while potential offenders perceive this control and are discouraged from their criminal intentions. Territorial reinforcement is promoted by features that define property lines and distinguish private spaces from public spaces, such as landscape plantings, pavement design, gateway treatments, and fences.

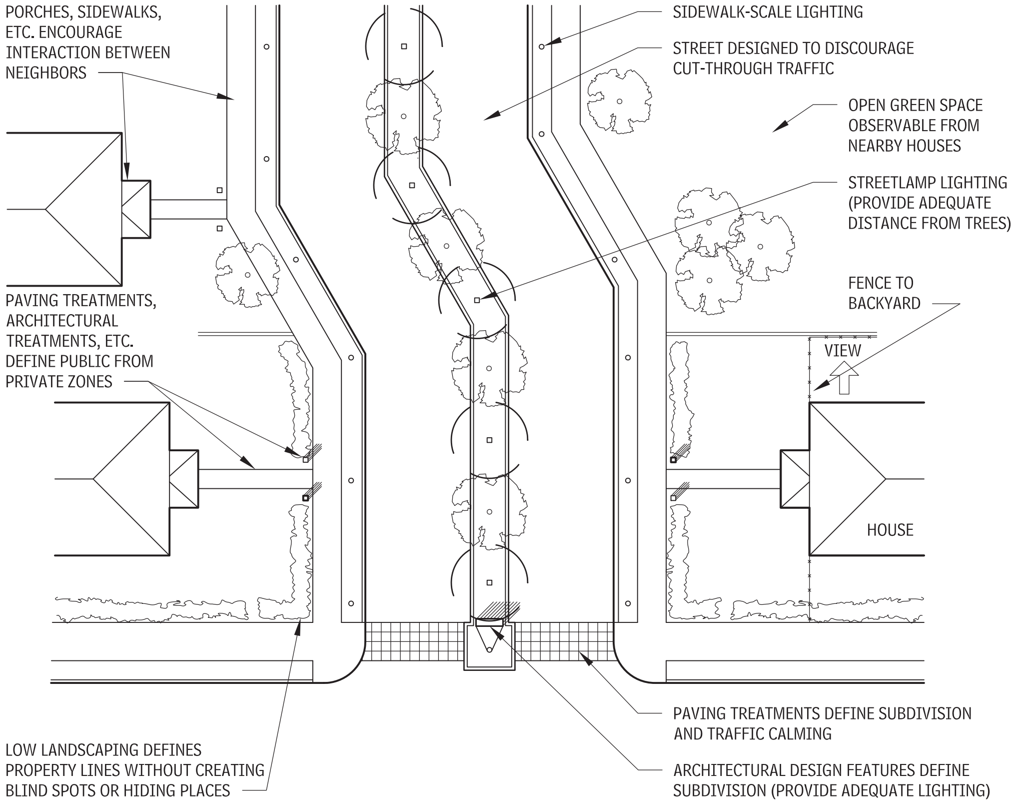
MANAGEMENT AND MAINTENANCE

It is important to maintain neighborhoods and residences, and keep security components in good working order. Equipment and materials used in a dwelling should be designed or selected with safety and security in mind.

LEGITIMATE ACTIVITY SUPPORT

Legitimate activity for a space or dwelling is encouraged through the use of natural surveillance and lighting, and architectural design that clearly defines the purpose of the structure or space. Crime prevention and design strategies can discourage illegal activity and protect a property from chronic problem activity.

CRIME PREVENTION THROUGH ENVIRONMENTAL DESIGN—PLAN VIEW
3.35



STRATEGIES

Designing CPTED and security features into buildings and neighborhoods can reduce opportunities for, and vulnerability to, criminal behavior and help create a sense of community. The goal in is to create safe places through limited access to properties, good surveillance, and a sense of ownership and responsibility.

NATURAL ACCESS CONTROL AND SURVEILLANCE

- Use walkways and landscaping to direct visitors to the proper entrance and away from private areas.
- All doorways that open to the outside as well as sidewalks and all areas of the yard should be well lit.
- Make the front door at least partially visible from the street and clearly visible from the driveway or parking lot.
- Windows on all sides of the building should provide full views of the property. The driveway should be visible from the front or back door and from at least one window.
- Properly maintained landscaping should provide good views to and from the building.

TERRITORIAL REINFORCEMENT

- Entryways or vestibules create a transitional area between the street and the building.
- Define property lines and private areas with plantings, pavement treatments, or fences.
- The street address should be clearly visible from the street, with numbers a minimum of 5 in. high and made of nonreflective material.

SUBDIVISIONS AND OFFICE PARKS

NATURAL ACCESS CONTROL

- Limit access to the subdivision without completely disconnecting it from neighboring areas. However, try to design streets to discourage cut-through traffic.
- Paving treatments, plantings, and architectural design features such as columned gateways can guide visitors away from private areas.
- Locate walkways where they can direct pedestrian traffic and remain unobscured.

NATURAL SURVEILLANCE

- Landscaping should not create blind spots or hiding places.
- Locate open green spaces and recreational areas so they can be observed from nearby houses.
- Use pedestrian-scale street lighting in areas with high pedestrian traffic.

TERRITORIAL REINFORCEMENT

- Design lots, streets, and houses to encourage interaction between neighbors.
- Accent entrances with changes in street elevation, different paving materials, and other design features.
- Clearly identify residences with street address numbers that are a minimum of 5 in. high and are well lit at night.
- Property lines should be defined with post-and-pillar fencing, gates, and plantings to direct pedestrian traffic.
- All parking should be assigned.

MULTI-FAMILY DWELLINGS

NATURAL ACCESS CONTROL

- Balcony railings should never be made of a solid, opaque material or be more than 42 in. high.
- Define parking lot entrances with curbs, landscaping, and/or architectural design; block dead-end areas with a fence or gate.
- Common building entrances should have locks that automatically lock when the door closes.
- Limit access to the building to no more than two points.

NATURAL SURVEILLANCE

- Make exterior doors visible to the street or neighbors, and ensure they are well lit.
- All four building facades should have windows. Site buildings so that the windows and doors of one unit are visible from those of other units.
- Assign parking spaces to each unit and locate them next to the unit. Designate special parking spaces for visitors.
- Parking areas and walkways should be well lit.
- Recreation areas should be visible from a multitude of windows and doors.
- Dumpsters should not create blind spots or hiding places.
- Shrubbery should be no more than 3 ft. high for clear visibility and tree canopies should not be lower than 8 ft. 6 in.

TERRITORIAL REINFORCEMENT

- Define property lines with landscaping or post-and-pillar fencing, but keep shrubbery and fences low to allow visibility from the street.
- Accent building entrances with architectural elements and lighting and/or landscape features.
- Doorknobs should be 40 in. from window panes.
- Clearly identify all buildings and residential units with well-lit address numbers a minimum of 5 in. high.
- Common doorways should have windows and be key-controlled by residents.
- Locate mailboxes next to the appropriate residences.

LIFECYCLE CONSIDERATIONS

OVERVIEW

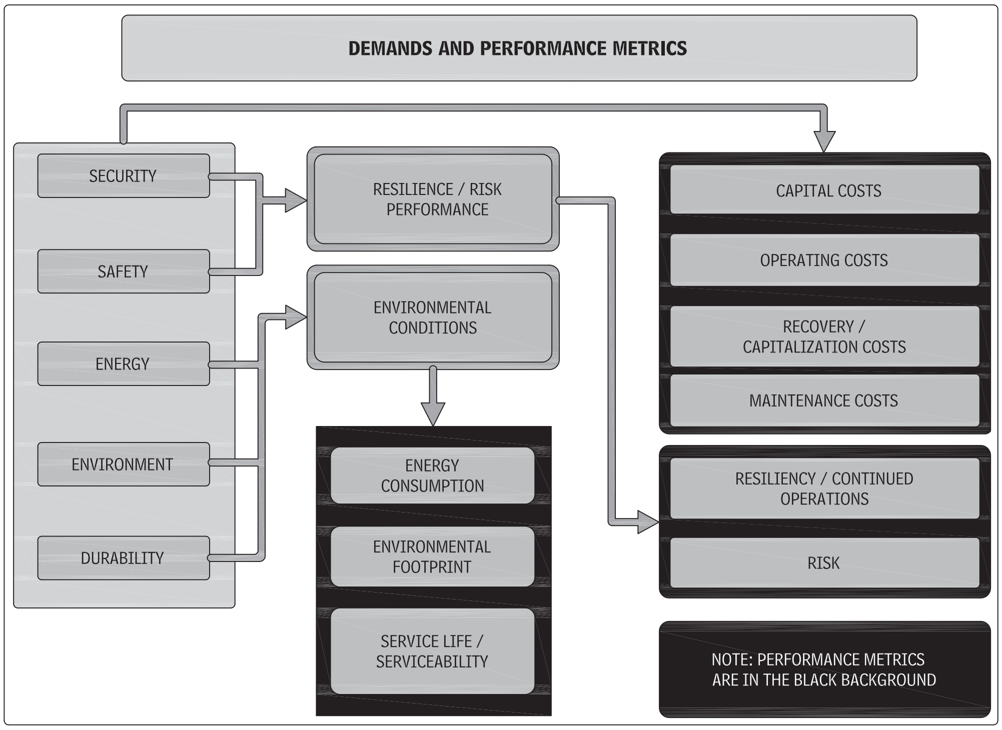
Incorporating resilience into new building designs, existing building retrofits, and ongoing building operations can carry significant costs. To justify investments in resilience it is imperative to evaluate the cost/benefit relationship of the investments over the full lifecycle of the facility. To evaluate increasing resilience, it is necessary to identify performance (or for safety and security objectives, protection) levels and their impact on reducing risk and increasing resilience. With performance/protection levels identified, the costs associated with achieving the performance/protection identified can be calculated and used to evaluate the benefits of higher resilience. The relationships between functional performance, risk, resilience, and cost are identified in Figure 3.36.

Establishing the tradeoffs between performance and cost requires evaluating the relationships between the cost of providing building systems, their performance over the life of the facility, including response to undesirable events and the interrelationships between systems and performances. Traditional first-cost-estimating approaches cannot effectively handle these evaluations. Evaluating Total Cost of Ownership (TCO) is a more effective way to analyze all of the cost factors identified in Figure 3.36. TCO is calculated by establishing capital cost for the building or improvement and then adding to it the discounted costs of future expenses (operations, maintenance, recovery) to arrive at a TCO. TCO can then be compared for different configurations to perform a cost analysis of the benefits of increasing performance to increase resilience. This methodology is implemented in a DHS project entitled Owners Performance Requirements for Building Envelopes. More information about the approach and access to a tool that implements it is available in DHS (2011) and at www.oprtool.org.

SHORT-TERM VERSUS LONG TERM RESILIENCE PLANNING

It has been shown that long-term planning can help immensely in cost savings (see FEMA [1996] and MMC [2005]). An objective way to accommodate such long-term cost savings is by following a reasonable resilience management procedure during planning, design, and throughout the life span of the building. Some details of resilience management components are offered in the chapter appendices.

RISK, RESILIENCE AND PERFORMANCE RELATIONSHIPS
3.36



Contributors:
Roger J. Grant, CSI, CDT, National Institute of Building Science (NIBS), Washington, DC; Martin Denholm, AIA, LEED AP, BD+C, BSCP, SmithGroupJJR, Washington, DC; Mohammed Ettouney Ph.D., P.E., MBA, F.AEI, Dist.M.ASCE, Mohammed Ettouney, LLC, West New York, NJ; Robert Smilowitz Ph.D., P.E. Thornton Tomasetti - Weidlinger Protective Design Practice, New York, NY; Joseph L. Smith, PSP and Kenneth W. Herrle, P.E., CPP, PMP, Applied Research Associates, Inc., Vicksburg, MS.

ARCHITECTURAL CONSTRUCTION DOCUMENTATION

4

PROCUREMENT DOCUMENTS

The procurement (Bidding) documents consist of three components: the project manual, the contract drawings, and the addenda. See Figure 4.1

The project manual contains the procurement requirements and text-based contract documents (owner-contractor agreement, general conditions of the contract, supplementary conditions, and specifications). The specifications identify, in narrative form, the qualitative, performance, and installation requirements for products, materials, and workmanship, as well as the administrative procedures that govern each tract.

The contract drawings are the graphic illustration of the project. They show the size, form, and representation of materials and systems, and the relationships between them. The contract drawings are bound separately from the project manual.

The documents may need to be modified during the procurement period. These modifications are issued as addenda. An addendum can modify the drawings, the project manual, or both. Addenda can be issued in response to questions by bidders or proposers, or to reflect architect- or owner-initiated changes.

AIA CONTRACT DOCUMENTS

AIA Contract Documents are divided into six alphanumeric series by document use or purpose. Current AIA Documents, by Series, are categorized as follows:

A-Series: Owner/Contractor Agreements
B-Series: Owner/Contractor Agreements
C-Series: Other Agreements
D-Series: Miscellaneous Documents
E-Series: Exhibits
F-Series: Reserved
G-Series: Contract Administration and Project Management Forms

THE BIDDING PROCESS

The goal of the bidding and negotiation process is to determine the price a contractor will charge a client to construct the building described by the construction documents. There are five primary forms of bid prices:

Stipulated sum: This approach is often referred to as a lump-sum or fixed-sum bid. The bid price is offered as a single-number value that represents all the costs required to build the project.

Guaranteed maximum price: Also known as GMP or GMax, the guaranteed maximum price is the cost of construction that the contractor assures the client for which the project will be built.

Cost plus: Also known as time and material or T&M pricing, this approach is based on the actual cost of the work. The contractor and subcontractors provide the client a detailed accounting of the cost of materials, equipment, and systems included in the project.

Unit prices: Unit prices are frequently used when a project's full scope of work is unknown. The cost for each specific unit of work, including materials, labor, fees, overhead, profit, and similar factors, are defined in the owner-contractor agreement.

Target price: Target pricing is used most often for design-build projects, where the owner identifies the construction cost as part of the procurement documents. A design-build team that can provide the most scope for that cost is awarded the project.

REQUEST FOR INFORMATION

During the bidding period, bidding contractors may have questions about the project, the documents, or the bidding requirements. The procurement documents should define procedures for contractors to submit questions to the owner (or the owner's CM advisor) or the architect. These requests for information (RFI) procedures should also be discussed in the pre-bid meeting. One person, who may be the owner, the CMa, or the architect, should be designated to receive all RFIs.

RFI responses must be distributed to all bidders, not just to the bidder requesting the information. RFI responses are not part of the contract documents unless they are issued as an addendum to all bidders.

SUBSTITUTION REQUESTS

The procurement documents will usually allow bidding contractors to propose alternatives to specified products, suppliers, or systems. Such proposals are defined as substitution requests. The instructions to bidders should define the information required to be submitted to allow the architect to properly evaluate a substitution request.

The proposed substitution information must provide documentation that demonstrates compliance with the performance criteria and design intent of the contract documents. It should include:

A statement indicating why the specified product, fabrication, or installation cannot be provided.

Coordination information, including a list of all changes to other portions of the work that will be necessary to accommodate the proposed substitution.

A list of all modifications needed to other parts of the work, including construction performed by the owner and separate contractors.

CONSTRUCTOR DOCUMENTATION AND SUBMITTALS

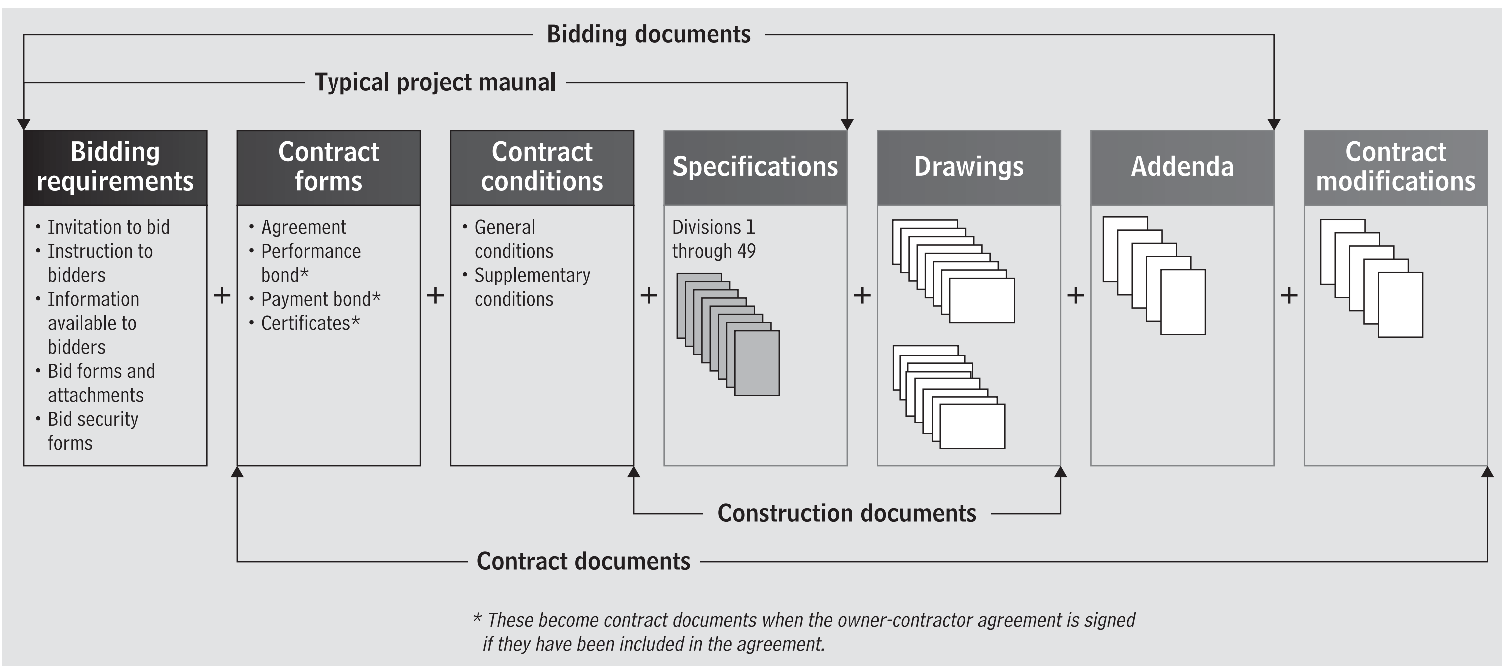
During the construction phase, the primary objective of the architect is to deliver contract administration (CA) services and work with the contractor toward providing the owner with a successful project that substantially conforms to the design concept. The general contractor and/or construction manager is responsible for maintaining certain minimum submittals to document decisions by the owner, architect and contractor.

The contract documents prepared by the architect illustrate the completed project, but they are not a complete set of instructions on how to build the building. Instead, the documents express the design intent for the contractor to use in preparing its work plan. A primary part of the contractor's work plan is contractor submittals. These include detailed drawings (referred to as "shop drawings") prepared and approved by the contractor, detailed information or data from the product manufacturers, and physical product samples.

Submittals are a part of the contractor's work plan documents that illustrate in detail how the contractor plans to construct the work, and they must be submitted to the architect for review and approval. The architect determines which parts of the work require submittals, and the contractor is prohibited from performing those portions of the work without approved submittals.

Constructor documentation is generally divided into three categories: Coordination Submittals, Action Submittals, and Informational Submittals.

PROCUREMENT DOCUMENTS
4.1



NOTE

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Contributor:
Cline McGee, AIA, Charlotte, North Carolina.

DRAWINGS

IDEOLOGY OF CONSTRUCTION DRAWINGS

Innovation and creativity are two words usually associated with aesthetic design. However, they can also be applied both to the methods of preparing construction drawings as well as to how architects convey that information to the document users. Modern architectural construction drawings can be so much more than a discrete assemblage of electronically generated parts and pieces. They can graphically weave a story not unlike a great novel. The very act of producing the drawings can be done in such a manner as to help foster a better understanding by the preparers of what they are doing, with the beneficial result of higher-quality work.

As construction drawings are developed, what goals and expectations should be established? Here are some suggestions:

- Produce drawings that are user friendly.
- Organize drawings so clearly that indexes, certain references, and perhaps even sheet numbers can become unnecessary.
- Create drawings that are graphically descriptive to such an extent that references and schedules can become superfluous.
- Use techniques that lessen the printed graphic density to the extent that drawing scales can be significantly reduced.
- Organize and place information in context with related elements that enhance understanding and visually reveal mistakes.

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NATIONAL CAD STANDARD

The U.S. National CAD Standard (NCS) is a compilation of related documents published by several organizations for the purposes of creating a national standard for construction-related CAD documents. The demand for a national CAD standard comes from two sources. First, major facility owners such as the federal government were looking to establish a mechanism for organizing graphic facility information so that it could be easily stored and retrieved. Whereas most architects think about drawings only as construction documents, many facility owners perceive them as the basis of facility management documents. This information is used throughout the lifecycle of a facility for operation, renovations, additions, and, finally, facility decommissioning and demolition. What has now come to be known as the facility cycle was a major impetus in the participation by the U.S. Department of Defense (DoD) in the creation of the NCS.

The second major reason for the creation of the NCS was the demand by design professionals to develop standards to allow sharing of information and to minimize the need for each user group to create their own CAD standards, which required teams to adapt different CAD standards for each project, thus wasting time and money while achieving no benefit. The NCS was perceived as a method to provide uniformity from project to project and save time in production, thus allowing architects to spend more time on design. It was also viewed as a means to allow CAD software vendors to create tools around these standards that would make the production of the construction documents easier and faster.

The National Institute of Building Sciences, the American Institute of Architects, the Construction Specifications Institute, and the Tri-Service CAD/GIS Technology Center are the contributing organizations to the NCS. The NCS is updated periodically; the information presented here reflects NCS version 3.1, updated in January 2005.

ORGANIZATION

UNIFORM DRAWING SYSTEM MODULES 01 THROUGH 08

Published by the Construction Specifications Institute

- *Module 01: Drawing Set Organization:* Provides guidelines for the organization of a drawing set, drawing set order, and sheet identification system.
- *Module 02: Sheet Organization:* Provides guidelines for the layout of the drawing sheet, location and numbering of drawings on the sheet, sheet sizes, title block area, and supplemental drawing sheet layout.
- *Module 03: Schedules:* Provides guidelines for the layout of schedules and use of schedules, both on drawings and in the project manual.
- *Module 04: Drafting Conventions:* Provides guidelines for the production of construction drawings, including line weights, dimensioning, orientation, notations, and other graphic drawing conventions.
- *Module 05: Terms and Abbreviations:* Provides a searchable list of preferred and nonpreferred terms, as well as abbreviations used on drawings.
- *Module 06: Symbols:* Provides standard symbols organized by MasterFormat, 2004 edition, divisions, and symbol type classification structure.
- *Module 07: Notations:* Provides guidelines for locating and using notations on drawings, including general notes, general discipline notes, general sheet notes, reference keynotes, and sheet keynotes.
- *Module 08: Code Conventions:* Provides guidelines for presenting code-related data on drawings. This module establishes types of code-related information, preferred location, and format for display of the information.

AIA CAD LAYER GUIDELINES

Published by the American Institute of Architects

- Provides guidelines and organizational structure for creating CAD layer names for all disciplines.

TRI-SERVICE PLOTTING GUIDELINES

Published by the CADD/GIS Technology Center

- Provides guidelines for pen color and line weight.

APPENDICES

Published by the National Institute of Building Sciences

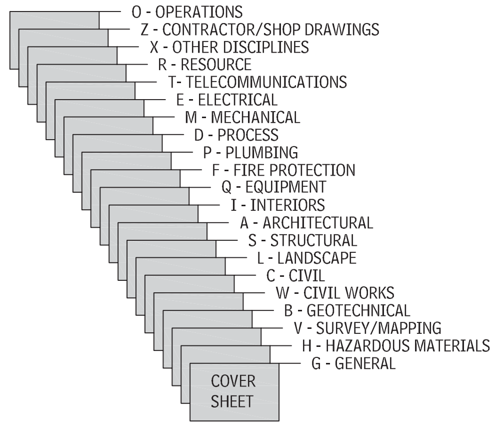
- Appendix A—Statement of Substantial Conformance
- Appendix B—Optional and Recommended NCS Items
- Appendix C—Memorandum of Understanding
- Appendix D—Members of the NCS Project Committees
- Appendix E—NIBS Consensus Process
- Appendix F—NCS Rules of Governance
- Appendix G—Facility Information Council Board
- Appendix H—Implementation of U.S. National CAD Standard

DRAWING CONVENTIONS

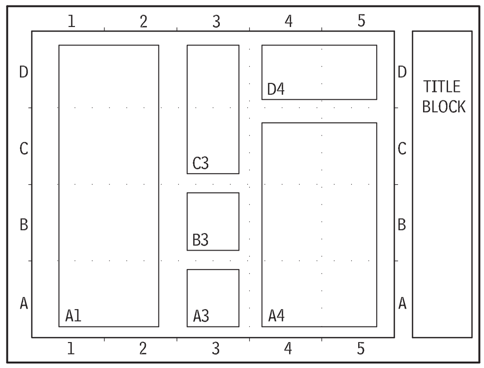
APPLICATION OVERVIEW

Following are examples of a few of the many guidelines and standards included in the NCS.

DRAWING SET HIERARCHY
4.2



DRAWING SHEET ORGANIZATION
4.3



NOTES

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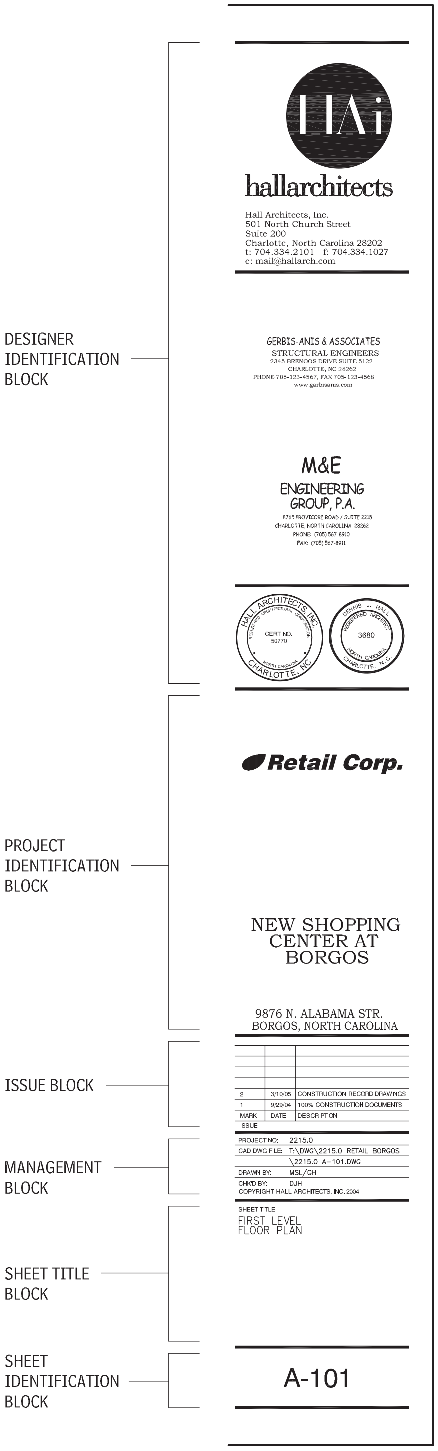
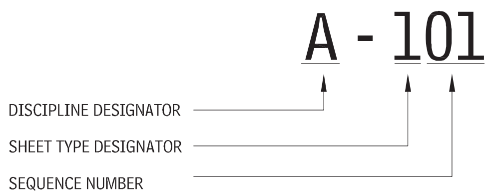
4.3 Reprinted with permission from The Architects Guide to the U.S. National CAD Standard, Hall and Green, 2006.

TITLE BLOCK ORGANIZATION
4.4



SHEET IDENTIFICATION FORMAT
4.5



DISCIPLINE DESIGNATORS	
G	GENERAL
C	CIVIL
L	LANDSCAPE
S	STRUCTURAL
A	ARCHITECTURAL
F	FIRE PROTECTION
P	PLUMBING
M	MECHANICAL
E	ELECTRICAL
R	RESOURCE INFORMATION

SHEET TYPE DESIGNATORS	
G	GENERAL
1	PLANS
2	ELEVATIONS
3	SECTIONS
4	LARGE SCALE VIEWS
5	DETAILS
6	SCHEDULES AND DIAGRAMS
7	----
8	----
9	3D VIEWS, ISOMETRICS PERSPECTIVES AND PHOTOS

DIMENSIONING METHODOLOGY

Provide only critical dimensions on plans so as to keep them as uncluttered as possible. Consider the building trades using the dimensions and the sequencing of their work.

Because tolerances vary in construction, the as-built dimensions do not always coincide with the design dimensions. Dimensioning from established grids or structural elements, such as columns and structural walls, assists the trades that must locate their work prior to that of others.

GRAPHIC SYMBOLS

Graphic symbols are representations of objects, materials, or words. *Module 6, Symbols of the Uniform Drawing System (UDS),* produced by the Construction Specifications Institute (CSI), is the portion of the U.S. National CAD Standard (NCS) that classifies, organizes, and presents graphic symbols used in construction documents. This discussion is a summary of the information contained in the Symbols module.

The UDS Symbols module provides a hierarchy for the organization of symbols. Symbols are first organized by MasterFormat 2004 Level 2 numbers, then by symbol classification type, and then alphabetically by description.

NOTES

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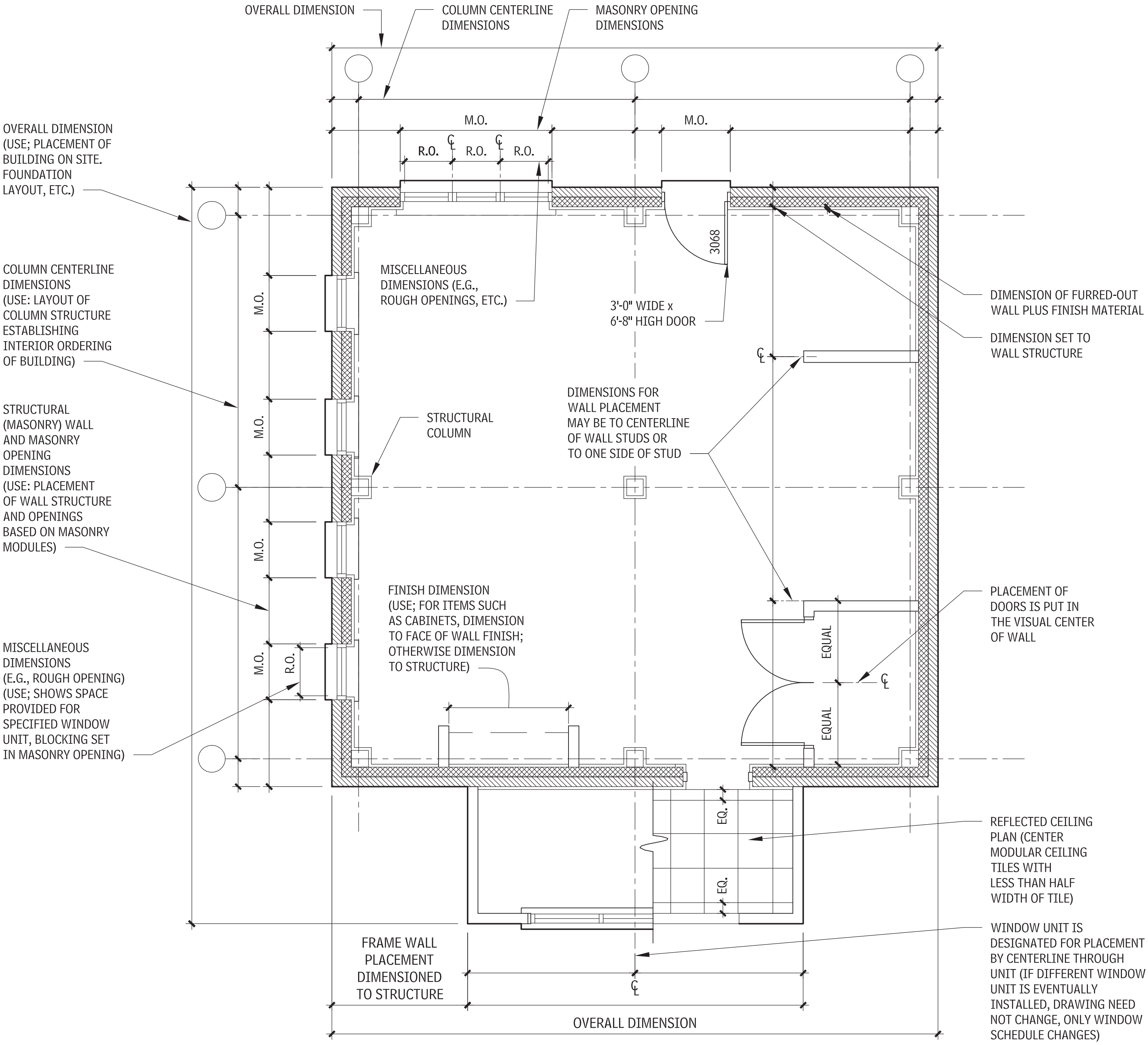
4.5 Reprinted with permission from The Architects Guide to the U.S. National CAD Standard, Hall and Green, 2006.

DIMENSIONING METHODOLOGY
4.6



NOTES

4.6 a. Dimensions under 1 ft. should be given in inches. Dimensions 1 ft. and over should be given in feet-and-inches.
b. Use a diagonal line to separate the numerator from the denominator in a fraction. Do not use decimal fractions preceded by a zero (for example 0.5 ft.).
c. Dimension points should be indicated with a short, blunt 45-degree line, called a hatch mark. Hatch marks are usually oriented differently for vertical and horizontal dimensions. Modular dimension points may be designated with an arrow or a dot.
d. Masonry dimensions are in increments of 8", i.e., 8", 1'-4", 2'-0", 2'8", etc.
e. Contractors generally prefer dimensions for interior walls to be from face-of-stud to face-to-stud.

Contributors:
Daniel Hayes, AIA, Washington, DC; John Ray Hoke, Jr., FAIA, Washington, DC; Cline McGee, AIA, Charlotte, North Carolina.

SYMBOL CLASSIFICATION STRUCTURE

The U.S. National CAD Standard provides six classifications of symbols. Following is a listing of the symbol types, description, and examples of each.

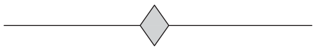
IDENTITY SYMBOLS

Identity symbols are those symbols that indicate individual objects but are not representations of the objects. Identity symbols are generally used to indicate objects such as valves, fire alarms, light fixtures, and electrical outlets.

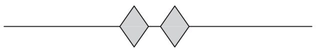
LINE SYMBOLS

Line symbols are symbols that indicate continuous objects and are drawn using either single or double lines. Line symbols are generally used to indicate objects such as walls, ductwork, and utility lines.

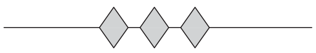
LINE SYMBOLS
4.7



1-HOUR FIRE-RESISTIVE CONSTRUCTION



2-HOUR FIRE-RESISTIVE CONSTRUCTION



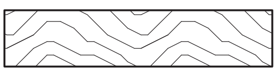
3-HOUR FIRE-RESISTIVE CONSTRUCTION

STORM DRAINAGE

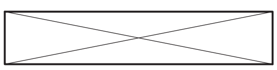
MATERIAL SYMBOLS

Material symbols are symbols that graphically indicate construction materials or material of existing conditions. Material symbols may be shown in elevation, section, or plan views. Material symbols are generally used to indicate objects such as brick, stone, earth, wood, concrete, and steel.

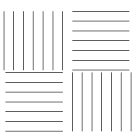
MATERIAL SYMBOLS
4.8



FINISH WOOD



END GRAIN CONSTRUCTION LUMBER

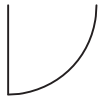


EARTH

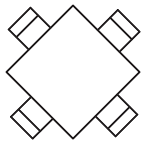
OBJECT SYMBOLS

Object symbols are symbols that represent specific physical objects. Object symbols are generally used to indicate objects such as doors, windows, toilet fixtures, and furniture.

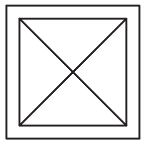
OBJECT SYMBOLS
4.9



LEFT SINGLE-HINGED DOOR



SQUARE TABLE WITH ARMLESS CHAIRS

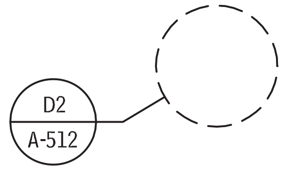


SHOWER STALL

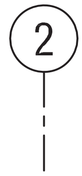
REFERENCE SYMBOLS

Reference symbols are symbols that refer the reader to information in another area of the set of drawings, or give basic information regarding the drawings or data on the sheet. Reference symbols include such symbols as elevation indicators, detail indicators, north arrow, graphic scale, section indicators, and revision clouds.

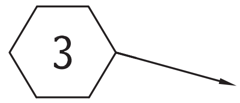
REFERENCE SYMBOLS
4.10



DETAIL INDICATOR



COLUMN GRID INDICATOR



SHEET KEYNOTE

TEXT SYMBOLS

Text symbols are symbols that graphically indicate a word or words and may be in notations on drawings.

CONSTRUCTION SPECIFICATIONS

INTRODUCTION

GENERAL

There are numerous ways of organizing facility and construction information, from various points of view starting with project conception throughout the facility's lifecycle. The OmniClass Construction Classification System, UniFormat, MasterFormat, and SectionFormat are the four primary structures for classifying and organizing facility information.

OMNICLASS CONSTRUCTION CLASSIFICATION SYSTEM

The *OmniClass*™ Construction Classification System (OCCS) is designed to provide a standardized basis for classifying information created and used by the North American architectural, engineering, and construction (AEC) industry, throughout the full facility lifecycle, from conception to demolition, and encompassing all of the different types of construction that make up the built environment. Created by the OCCS Development Committee, an all-volunteer cross-industry coalition of organizations, firms, and individuals, OmniClass is intended to be the means for organizing, sorting, and retrieving information and deriving relational applications.

Industry organizations are beginning to realize that a greater degree of harmonization in classifying information is now necessary and possible. The classification tables in the industry-created OmniClass address these criteria in an effort to make this harmonization a reality.

OmniClass' scope is designed to encompass objects at every scale of the built environment, from completed structures, large projects, and multistructure complexes to individual products and component materials. Deviating from many of the systems that have preceded it, OmniClass also addresses actions, people, tools, and information that are used or take part in the design, construction, and maintenance of these structures. It is anticipated that OmniClass will be used throughout a facility's lifecycle, starting with facility conception, continuing through design and construction, and finally to demolition and recycling of its components. The means to address classification throughout the lifecycle are provided through both a table to track and document the stages, and also through properties to describe dating information for components and for modifications to the facility as a whole.

OmniClass Table 22, Work Results is based on the concepts incorporated into MasterFormat 2004. Conversely, the indexes and explanations of MasterFormat 2004 draw information from *OmniClass Table 21, Elements* and *Table 23, Products*, making it an application of OmniClass. Reference to other OmniClass tables is also made in the *Applications Guide*. For information on OmniClass, visit the OCCS website at http://www.omniclass.org.

UNIFORMAT

CSI/CSC *UniFormat*™ is designed to provide a standardized basis for classifying the physical elements of a facility by their primary function without regard to the particular work results that will be used to achieve the function. Substructure, shell, interiors, and services are examples of basic functional elements. The functional elements are often systems or assemblies. The shell element can be broken down into superstructure (structural frame), exterior enclosure (exterior wall assemblies), and roofing (roofing assemblies). The services element can be broken down into conveying (elevator systems); plumbing (domestic water distribution); heating, ventilating, and air-conditioning (heat generation); fire protection (fire sprinkler systems); and electrical (lighting systems). UniFormat is an application of *Table 21, Elements* of OmniClass.

MASTERFORMAT

CSI/CSC *MasterFormat*™ is an organizational structure used to arrange information by traditional construction practices or "work results." The primary uses of MasterFormat include organization of the project manual, detailed cost estimating, and drawing notations including reference keynotes.

SECTIONFORMAT

CSI/CSC *SectionFormat*™ provides a uniform approach to organizing specification text within specification sections contained in a project manual. SectionFormat is a companion organizational tool to MasterFormat. MasterFormat provides a standardized system for sequence, numbers, titles, and scope of the elements, including sections, of a project manual. SectionFormat provides a standardized system to organize the data within each specification section.

OMNICLASS CONSTRUCTION CLASSIFICATION SYSTEM

The OmniClass™ Construction Classification System (known as OmniClass™ or OCCS) is a new classification system for the construction industry. OmniClass is a classification scheme useful for numerous applications, from organizing library materials, structuring product literature, and structuring project information to providing a classification structure for databases. It incorporates existing systems as the basis of many of its tables—MasterFormat™ for work results, UniFormat for elements, and EPIC (Electronic Product Information Cooperation) for structuring products.

OmniClass is a strategy for classifying the entire built environment.

The activities conducted throughout the lifecycle of any structure generate an enormous amount of data that needs to be stored, retrieved, communicated, and used by all parties involved. Advances in technology have increased the opportunities for gathering, providing access to, and exchanging this information.

OmniClass is a publication of the OCCS Development Committee who has continually been updating and refining the OmniClass tables. This manuscript references the 2005 edition of the tables, published in late 2005.

ISO 12006–2, "Organization of Information about Construction Works—Part 2: Framework for Classification of Information," and ISO/PAS 12006–3, "Organization of Information about Construction Works—Part 3: Framework for Object-Oriented Information," define methods of organizing the information associated with the construction and affiliated industries, and also promote a standard object-modeling definition for concepts addressed. Of these two standards, ISO 12006–2 has more immediate impact on OmniClass, and the OCCS Development Committee has closely adhered to this standard in establishing and defining the tables that make up OmniClass.

OmniClass consists of 15 distinct tables, each of which represents a different facet of construction information. Each table can be used independently for the classification of a particular type of information, or be combined to classify more complex subjects.

The 15 interrelated OmniClass tables are:

- Table 11—Construction Entities by Function
- Table 12—Construction Entities by Form
- Table 13—Spaces by Function
- Table 14—Spaces by Form
- Table 21—Elements (Including Designed Elements)
- Table 22—Work Results
- Table 23—Products
- Table 31—Phases
- Table 32—Services
- Table 33—Disciplines
- Table 34—Organizational Roles
- Table 35—Tools
- Table 36—Information
- Table 41—Materials
- Table 49—Properties

UNIFORMAT

UniFormat™ is an arrangement of construction information based on physical parts of a facility called elements or systems and assemblies. These elements are characterized by their function without identifying the products that compose them. Elements render a view of a constructed facility different from the view rendered by a breakdown of building materials, products, and activities. UniFormat is primarily used to organize preliminary project descriptions, preliminary cost estimates, and standard drawing detail filing. It is intended to complement MasterFormat.

The Construction Specifications Institute (CSI) and Construction Specifications Canada (CSC) jointly produce UniFormat. UniFormat is updated periodically; the information herein reflects the 2001 edition.

UniFormat classifies information into the following nine Level 1 categories:

- Project Description
- A—Substructure
- B—Shell
- C—Interiors
- D—Services
- E—Equipment and Furnishings
- F—Special Construction and Demolition
- G—Building Sitework
- Z—General

The nine categories can be used to arrange brief project descriptions and preliminary cost information. Category Z—General is designated by the last letter of the alphabet so the system can expand beyond building construction. When so expanded, this category will remain at the end.

Titles in Levels 1 through 3 can be applied to most project descriptions and preliminary cost estimates. Levels 4 and 5 are available for use on detailed, complex projects. Level 4 and 5 titles and detailed listings provide a checklist to ensure comprehensive and complete application of UniFormat.

The transition from a document organized according to UniFormat to one organized according to MasterFormat may be easier by using MasterFormat extensions. When MasterFormat six-digit number extensions have been added, the document organized according to UniFormat may be searched or sorted according to the MasterFormat extension to regroup information. Sorting in this manner may help discover, for example, a list of elements common to cast-in-place concrete construction within the project.

Most project manuals are arranged using MasterFormat. Specifications using both MasterFormat and UniFormat should not be combined into a single project manual.

Performance specifying can be used at many levels, from a single product to major subsystems or entire projects. The choice of using either MasterFormat or UniFormat allows the architect to access a range of options. Performance specifying encourages competitive bidding based on nonproprietary requirements and, in its broadest application, is used for design-build projects. CSI's *Construction Specifications Practice Guide* provides detailed discussions about this application.

The design-build project delivery has created a need for an organizational structure for communicating functional performance requirements, including organizing design-build requests for proposals. To communicate project performance requirements to design-build entities in requests for proposals, owners or architects must describe those requirements. In turn, design-build contractors must use performance requirements to communicate their proposals. UniFormat provides this organizational structure.

MASTERFORMAT

MasterFormat™ is a master list of numbers and titles classified by work results or construction practices, primarily used to coordinate project manuals, organize detailed cost information, and relate drawing notations to specifications.

Construction projects use many different kinds of delivery methods, products, and installation procedures, but one thing is common to all—the need for effective teamwork by the many parties involved to ensure the correct and timely completion of work. The successful completion of projects requires effective communication among the people involved, and that in turn requires easy access to essential project information. Efficient information retrieval is only possible when everyone uses a standard filing system. MasterFormat provides such a standard filing and retrieval scheme, which can be used throughout the construction industry.

The Construction Specifications Institute (CSI) and Construction Specifications Canada (CSC) jointly produce MasterFormat. MasterFormat is updated periodically; the information in this text refers to the 2014 update.

MASTERFORMAT STRUCTURE

GROUPS AND SUBGROUPS

All of the following MasterFormat groups and subgroups can be included in project manuals:

- *Procurement and Contracting Requirements Group* (Division 00) contains:
  - *Introductory Information:* Indexing and general-information documents are found at the beginning of project manuals.
  - *Procurement Requirements and Contracting Requirements:* Referred to in MasterFormat 95 as the "Zero Series Numbers and Titles" and now included in Division 00, they are to be used in the definition of the relationships, processes, and responsibilities for projects.
- *Specifications Group:* This group contains the following five subgroups. Each subgroup is broken down into Divisions as listed. This group has now grown from 16 divisions to 49 divisions (16 of which are designated reserved for future expansion).
- *General Requirements Subgroup:* Division 01.
- *Facility Construction Subgroup:* Divisions 02 through 19.
- *Facility Services Subgroup:* Divisions 20 through 29.
- *Site and Infrastructure Subgroup:* Divisions 30 through 39.
- *Process Equipment Subgroup:* Divisions 40 through 49.

Groups are not numbered, but are divided into *subgroups*. Subgroups are not numbered, but are divided into numbered *divisions*. Divisions are the top Level (Level 1) in the hierarchy of the classification system. The divisions include sets of numbered *titles* (Levels 2 through 4). In a project manual application, the titles are called *sections* that specify "work results" (Levels 2 through 4). Work results are permanent or temporary aspects of construction projects achieved in the production stage or by subsequent alteration, maintenance, or demolition processes through the application of a particular skill or trade to construction resources.

PROJECT MANUALS

DISCIPLINE AND TRADE JURISDICTIONS

MasterFormat's organizational structure used in a project manual does not imply how the work is assigned to various design disciplines, trades, or subcontractors. MasterFormat is not intended to determine which particular elements of the project manual are prepared by a particular discipline. Similarly, it is not intended to determine what particular work required by the project manual is the responsibility of a particular trade. A particular discipline or trade is likely to be responsible for subjects from multiple divisions, as well as from multiple subgroups.

CONTRACT DOCUMENTS

MasterFormat's organizational structure does not determine what is and is not a contract document. Generally, the documents included in the contracting requirements will include a definition and listing of the contract documents for a particular project.

In the procurement requirements and contracting requirements, some owners may use different terminology for some of the documents from those listed in MasterFormat. Users may alter the MasterFormat terms in favor of appropriate synonyms required by the owner. See the Master List of Numbers, Titles, and Explanations for examples.

In the procurement requirements and contracting requirements, MasterFormat 2004 numbers have been assigned to provide a consistent sequencing within the document. However, it is not necessary to renumber or retitle printed forms and standard documents published by various professional societies or contract issuing bodies to correspond with these numbers.

NAMING DATA FILES

MasterFormat is not intended to provide a technical or product data filing system as there is not necessarily a single location at which any particular technical subject or product may be located in the system. A product that is used for multiple purposes or work results may be located in multiple locations in MasterFormat. If MasterFormat is used for product data filing, then the user should be aware that for some products an arbitrary choice of where to file the data among multiple locations must be made. Names of products may be included in the titles in MasterFormat when they are synonymous with the work result. Products that might be included with a work result but not included in the title may be listed in the explanations column for the title, under the heading "Products."

Product data is identified using MasterFormat numbers and titles to clarify the relationship between products and specifications.

MasterFormat numbers can be used as suffixes within another cataloging system, such as the Dewey Decimal Classification, the Universal Decimal Classification, or the U.S. Library of Congress classification.

Suppliers' and subcontractors' data (such as qualification information or submittals) may be identified by the work result they supply or install. The work of suppliers and subcontractors often transcends section and division boundaries, so some method is required for multiple references to MasterFormat titles.

The inventory of construction products is made simpler by using the specification section number, perhaps as a suffix to a project number. If more than one product is specified in a section, then some form of suffix to the section number is needed to distinguish the products.

COST DATA APPLICATIONS

Cost classification requires identification of line items, which are often related to products and activities. An identification scheme based on MasterFormat can be flexible, varying with each construction project, or more rigid and uniform, establishing a single number and location for similar costs in many projects. OmniClass Table 21—Elements is also recommended when dealing with construction costing applications in the earlier stages of a project before particular work results have been selected. Similar to the way that OmniClass Table 22—Work Results is based on MasterFormat 2004, the Elements Table is based on the existing legacy system UniFormat.

Organizing unit-price databases using the same numbering and titling format for specifying and naming data files benefits the user with increased uniformity and standardization. Familiarity with MasterFormat allows users to relate specification requirements, product information, and cost data. Numbers and titles under "Procurement Requirements" and "Contracting Requirements" in Division 00 identify cost items related to bonds, insurance, permits, fees, and other general items. Numbers and titles in Division 01 identify unit costs for temporary construction facilities and controls, mobilization, project site administration, and other general requirement cost items. Numbers and titles in the other subgroups of the Specifications Group identify costs related to work results and their installation.

Organizing and tabulating cost reports may require indicating or summarizing products and activities. Using MasterFormat numbers and titles will aid users in making inferences about material costs while analyzing the report.

ORGANIZING DRAWING NOTATIONS

An important strategy for naming drawing elements is related to the need to link requirements between complementary documents. One must examine the entire set of contract documents to determine all of the requirements for a single product. Notations on drawings should use terminology consistent with that used in other contract documents, such as the specifications, to identify the specified work results and activities.

Reference keynoting applications have adopted MasterFormat as a base numbering system, to enhance cross-referencing and coordination between drawings and specifications. This formal method of linking between drawing objects and the specification is encouraging increased development of automated linking software. See the U.S. National CAD Standard, UDS Notations module for more information.

SECTIONFORMAT

SectionFormat™ provides a uniform approach to organizing specification text within a section of a project manual. The organization structure is based on three primary parts; each part is further divided into article subjects to standardize the location of information into a logical order.

The Construction Specifications Institute (CSI) and Construction Specifications Canada (CSC) jointly produce SectionFormat. SectionFormat is currently undergoing review and revision to reflect the current state of the industry. The revised document was published in late 2007.

SectionFormat consists of three primary parts: GENERAL, PRODUCT, and EXECUTION.

- *PART 1—GENERAL:* Describes administrative, procedural, and temporary requirements unique to the section. PART 1 expands on information covered in Division 1 with information specific to the section.
- *PART 2—PRODUCTS:* Describes materials, products, equipment, systems, or assemblies that are required for incorporation into the project. Manufactured materials and products are included along with the quality level required.
- *PART 3—EXECUTION:* Describes preparatory actions and the method in which products are to be incorporated into the project. Site-built assemblies and site-manufactured products and systems are included.

Each PART is divided into articles, which are then further divided into paragraphs and subparagraphs. If a section does not require the use of one or two of the three PARTS, then the PART number and title is stated and the words "Not Used" are placed under the PART title.

IMPLEMENTING SUSTAINABLE PRODUCTS AND PROCEDURES

In an effort to implement construction projects that have the least impact on the environment, specifiers routinely include into the specifications requirements such as the following:

- Low- or no-VOC paints, coatings, sealants, and adhesives
- Products with high recycled content
- Products that have been manufactured, harvested, or recovered regionally
- Roofing and paving materials with high reflectance values
- Particleboard and insulations with no added urea formaldehyde
- Flooring products that have received FloorScore certifications
- Lumber, trim, doors, casework, etc., that are certified as being harvested from sustainably managed forests
- Recycling of construction waste by the contractor
- Provision by the contractor of an indoor air quality plan during construction
- High R-values for exterior building components

SOURCE:
Reprinted with permission from *The Architects Handbook of Professional Practice, 15th edition, John Wiley & Sons, Inc., 2014.*

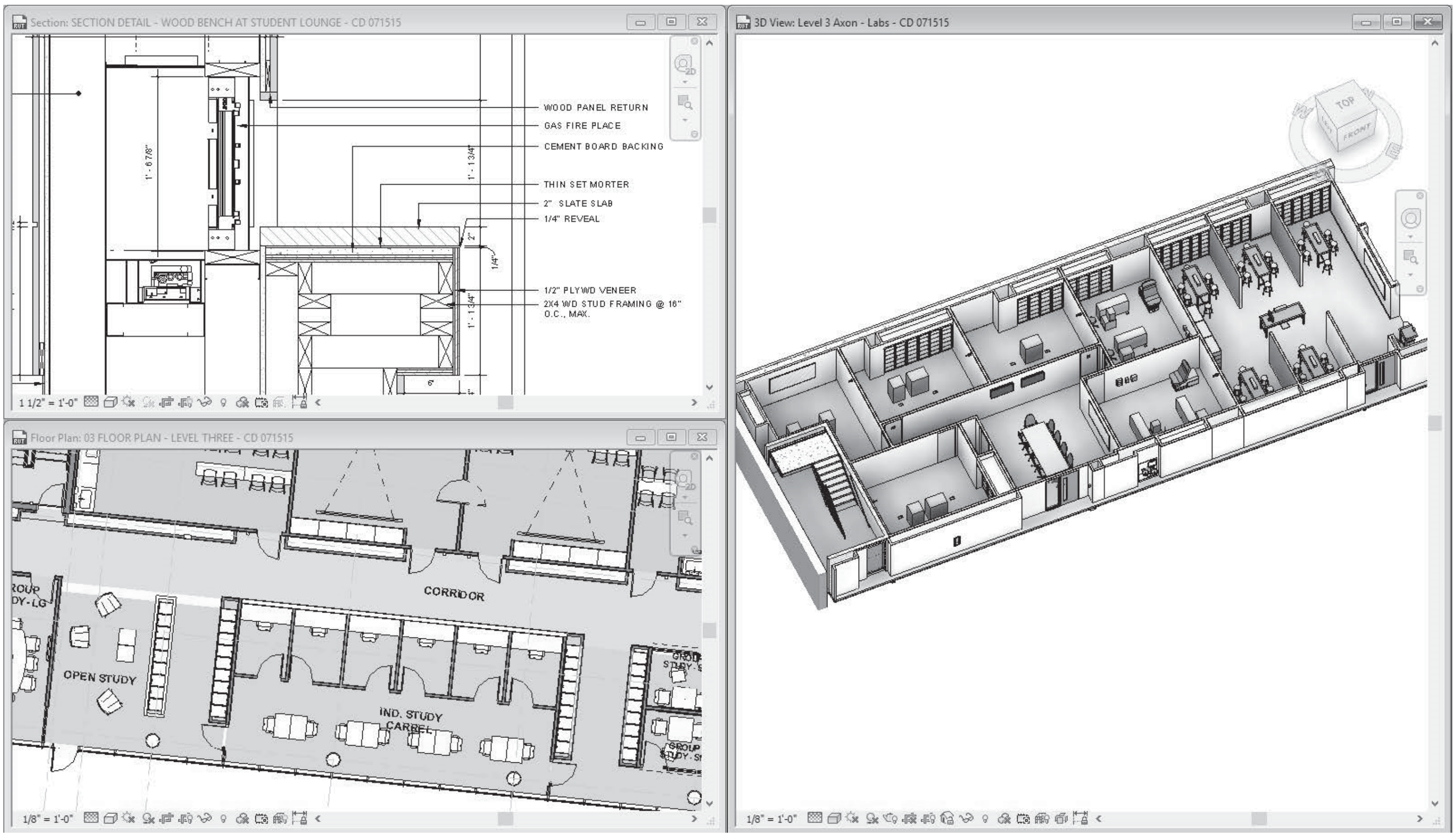
BUILDING INFORMATION MODELING (BIM)

A data model in any given domain describes the attributes of the entities in that domain, as well as how these entities are related to each other. All computer programs deal with some kind of data, so they must have some type of underlying data model. Traditional 2D CAD and generic 3D modeling programs such as Autodesk AutoCAD, Trimble SketchUP, Autodesk 3DS Max, Robert McNeel and Associates Rhinoceros 3D, and AutoDesSys form•Z internally represent data using geometric entities such as points, lines, rectangles, planes, and so forth. Thus, although these applications can accurately describe geometry in any domain, they cannot capture domain-specific information about entities. The drawings and models of buildings created with these applications don't carry much information about the building itself, and are essentially "dumb." They are used primarily for producing documentation and for visualization.

To overcome the limited intelligence of general-purpose geometric representations, every design-related industry has been developing and using object-based data models that are specific to their domains. In the case of the building industry, both researchers at universities and commercial software vendors have worked to develop a data model that is constructed around building entities and their relationships to one another. Geometry is only one of the properties, among others, of these building entities; thus, its primacy is greatly reduced, even though the interface to creating the model is still primarily graphic. Such a data model is rich in information about the building, which can be extracted and used for various purposes, be it documentation, visualization, or analysis.

Building information modeling (BIM) is the term that has been coined to describe the use of such a model. Several software applications are available that are built upon this concept, such as Graphisoft's ArchiCAD, Bentley MicroStation, Autodesk Revit, and many others.

EXAMPLE OF USING A BIM APPLICATION FOR BUILDING DESIGN: THE OPEN WINDOWS SHOW A PLAN, DETAIL SECTION, AND 3D VIEW OF THE SAME BUILDING DATA MODEL.
4.11



HOW BIM OVERCOMES THE LIMITATIONS OF CAD

Traditional 2D CAD technology has dominated the construction industry for decades, and technological progress has been severely constrained by the limited intelligence of such applications in representing buildings and the capability to extract the relevant information from the representation that is needed for design, analysis, construction management, operation, and so on. Drawings are no longer done manually, but the ubiquitous use of CAD applications in creating drawings has not revolutionized the construction industry in any way. CAD continues to have all the problems associated with manual drafting:

It is tedious and time-consuming to create separate plans, sections, elevations, details, and so forth, of the same building.

Any change made must be manually updated in all drawings and reports.

There is no guarantee of accuracy, consistency, or completeness.

Coordinating work based on these drawings between the different professionals is extremely difficult.

Conflicts and errors are detected in abundance at the construction site, necessitating expensive fixes.

At the end of the process, the owner/operator has nothing but a nonintelligent 2D representation of the building on which to base a lifetime of management, operation, and maintenance.

Analysis and evaluations of energy efficiency, circulation, egress, and other aspects of the building, haven't really become an integral part of the design process as the building data is not available in any intelligent format and has to be tediously reentered into analysis tools. As a result, the quality of the building suffers. In short, CAD simply replicates the processes of manual drafting by reducing building representations to dumb graphic entities and does little to reduce the inefficiency, waste, errors, and escalating costs that are all too common in the design, construction, and operation of a building.

Unlike CAD, which is general-purpose, BIM is specific to building design: It represents a building using intelligent objects that know about their properties and about their relationship to other objects. Therefore, with BIM, a full 3D representation of the building can be created that simulates how it would be in real life; from this information-rich model, any kind of data needed for design, analysis, visualization, documentation, construction management, operation, and so on, can be derived.

The potential benefits of implementing BIM are manifold:

Because it is customized for building design, it is faster and easier to create and edit a building model in a BIM application, compared to developing the drawings of the building in a CAD application.

Once the model is created, all other requirements, including 2D documentation, schedules, reports, 3D renderings, and animations, can be automatically derived from it, improving speed and efficiency.

All graphical and tabular views of the building are automatically synchronized when a change is made to the model, eliminating the inconsistencies found in construction documents created with conventional CAD software.

The minimization of drafting allows greater focus on design.

Interdisciplinary collaboration can be significantly improved, as it will be based on a shared building model.

Better support for analysis and evaluation tools will allow the building to be thoroughly and vigorously tested before it is built, instituting much higher standards of quality control than those in place today.

Conflicts are easier to identify in the building model and can be detected during the design phase, which can reduce the expensive fixes at construction time.

The model created during the design phase can be reused for subsequent phases such as construction and facilities management, saving costs.

The use of a "live" model for building maintenance can reduce operating costs significantly throughout the lifetime of the building.

In general, BIM is a methodology that has the potential to integrate and dramatically streamline operations and processes in the architecture, building, and construction and facilities operations and management industries.

REAL-WORLD EXAMPLE: LOBLOLLY RESIDENCE

To illustrate the application of BIM software, a real-world example is included here. It demonstrates how the Autodesk Revit family of products was used in the construction of a single-family residence, the Loblolly house, in Taylors Island, Maryland, on the Chesapeake Bay.

This 1800 sq. ft. weekend house was designed by Kieran Timberlake Associates (KTA) from Philadelphia, Pennsylvania. With a tight construction schedule and without access to skilled local labor, the architects embraced the precision of off-site shop-fabricated, site-assembled construction. This necessitated a three-dimensional understanding of the building and its components, which led to their use of BIM software.

KTA's systematic approach to Loblolly House allowed the architects to seamlessly combine standard on-site with unconventional off-site construction strategies. Use of Autodesk's BIM software, Revit, enabled them to improve communication among themselves, engineers, fabricators, and contractors, to collapse all phases of the project into a virtual snapshot. Design decisions were made in tandem with detailing, building system, fabrication, and shipping decisions.

The holistic nature of a single virtual model circumnavigated many of the unknowns that slow down traditional building processes. By understanding Revit's capabilities, as well as its limitations, KTA could customize the software in response to the specifics of the project. In many cases, they had to reteach the software how to "behave" with respect to issues of shop fabrication and modular construction. Proof of their mastery of the software is evident in the project's 30-day overall construction schedule.

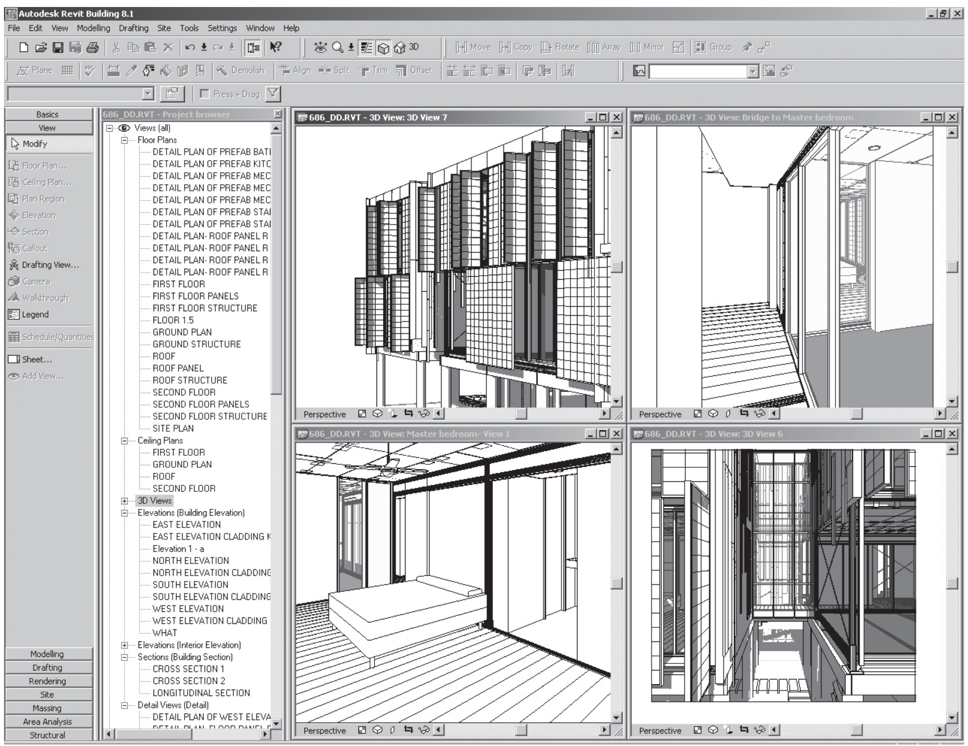
This example describes the attributes and benefits of Autodesk's Revit BIM software by examining each of the major construction components in the project: scaffolding, framing, and skin.

LOBLOLLY HOUSE—EXTERIOR RENDERING FROM BAY
4.12

Aside from the advantages of designing in three dimensions, this holistic approach allowed for more efficient coordination between systems and components, as well as more effective management of part schedules and cost models. With BIM software, one model is the sole source of all project information: It drives all details, fabrication drawings, finish schedules, and parts lists. As a shop-fabricated project, this degree of control became very important for KTA in Loblolly House.

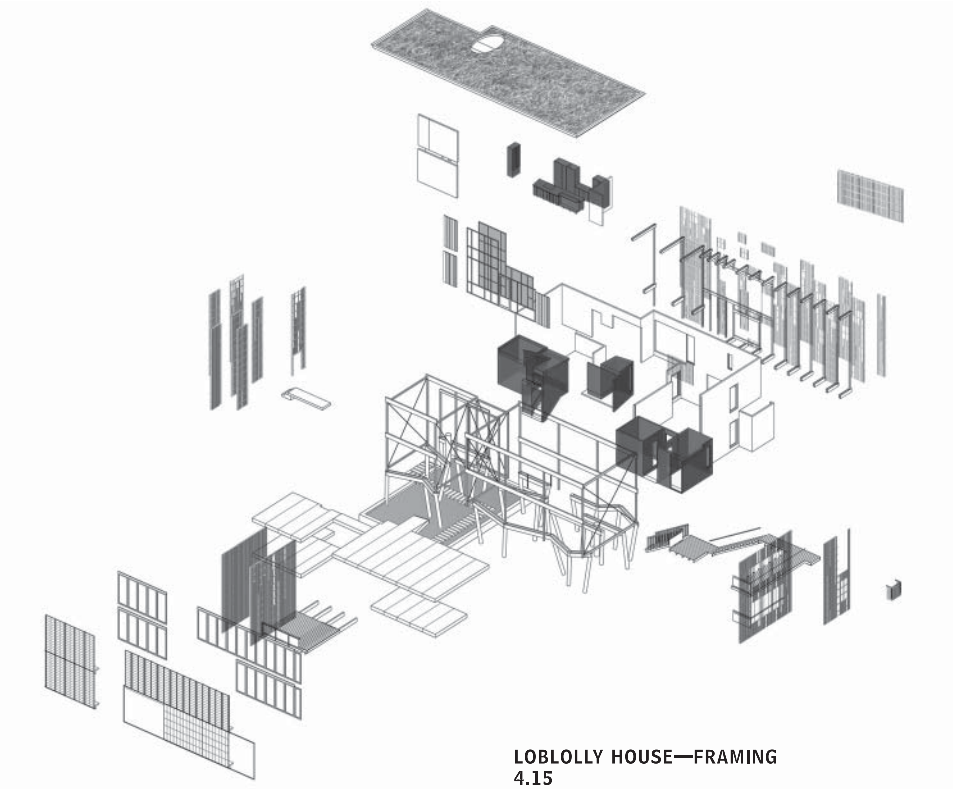
LOBLOLLY HOUSE—FOUR PERSPECTIVES
4.13

Screenshot of the Loblolly House in Revit. This virtual model of the house has all its layers "turned on," from four different interior and exterior perspectives.



LOBLOLLY HOUSE—EXPLODED DRAWING OF COMPONENTS
4.14

Exploded axonometric of Loblolly house with its four major components: scaffolding, cartridges, boxes, and exterior skin.



SCAFFOLDING

Fabricators extruded the aluminum profiles, which comprised the structural frame, cut them to size, then shipped them to the site for assembly. The characteristics of these profiles required a great degree of accuracy, so KTA created a library of aluminum profiles within the Revit model. This enabled them to assemble the frame virtually, much as it would be erected on-site. Each aluminum component contained embedded data, including the size of the profile, length, manufacturer and distributor information, and cost.

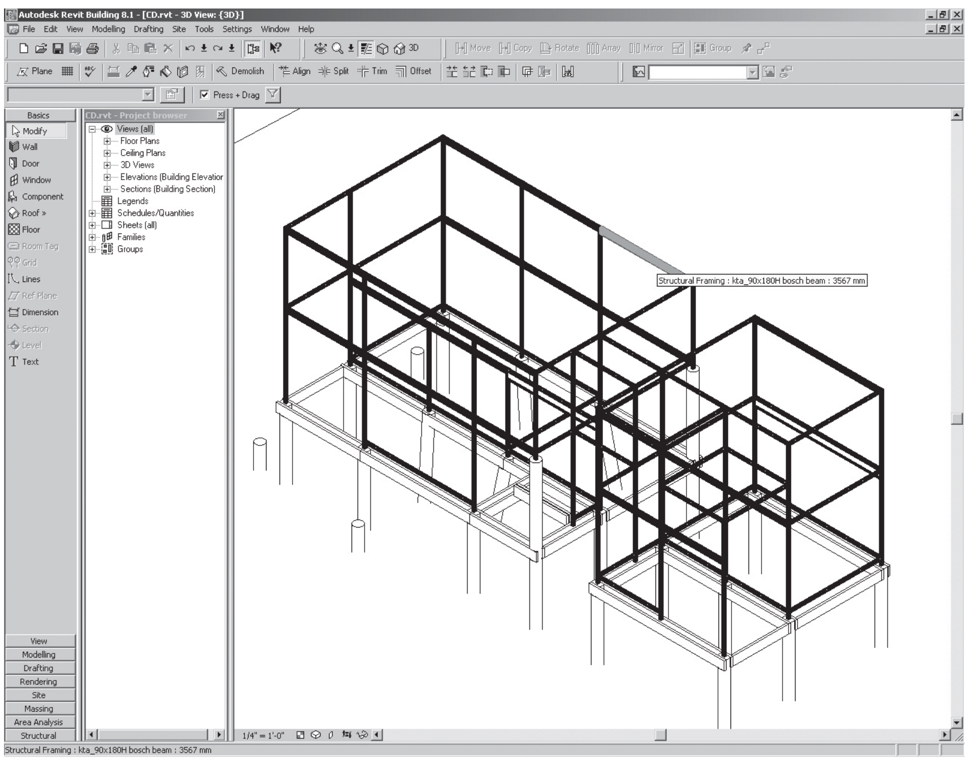
Modeling the project in Revit also allowed KTA to accurately study sequencing, detailing, and tolerances during the early design phases of the project. In the case of the scaffolding and all of the project's construction components, BIM software shortened the on-site assembly of all building elements above the piling foundation to an astonishing two weeks.

FRAMING

KTA used the schedule produced from the embedded information in Revit for a number of important purposes: coordination with the structural engineer, development of a cost model, and, most importantly, as a parts list for purchasing this material. Having a single model to which all participants in the design, fabrication, and construction of Loblolly House could refer greatly simplified communication and coordination of changes. This meant that material, detailing, and cost considerations found their way into the project very early in its development. Traditional, two-dimensional construction drawings gave way to a holistic virtual model.

LOBLOLLY HOUSE—FRAMING
4.15

The Revit screenshot in Figure 4.15 shows the relationship of the light aluminum framing elements to the heavier framing members supported by randomly placed pilings.



EXTERIOR SKIN

The construction team lifted and attached wood-framed, shop-fabricated wall panels with a cedar rainscreen to the structural frame. Windows and glazing were also installed off-site. Transparent and translucent panels were off-the-shelf products designed with custom-hinged and sliding assemblies. Fabricators produced these off-site as multilevel units before attaching them to the structural frame on-site. Offset 16 in. from a fully retractable, double-glazed storefront, the whole assembly created a high-performance cavity wall.

Unlike typical walls built on-site, these wall modules had to respect the limitations of shipping. Therefore, awareness of their parameters was particularly useful during fabrication. KTA understood the performance requirements of constructing a functional rainscreen wall. Using Revit allowed them to closely monitor the relationship between off-the-shelf and custom components to render the screen operationally sound.

OTHER APPLICATIONS RELATED TO BIM

All component specification information is captured within a BIM application, which means that any kind of data needed for design, analysis, visualization, documentation, construction management, operation, and so on, can be derived from it, thus allowing the building to be simulated as it would be in real life. There are many BIM applications that impact all aspects of design, construction, and operation.

Some examples are:

Computational design technologies: Recent improvements in visual programming coupled with reduced cost of computational power have led to a movement in design where building parameters can be driven through rapid iteration. Computational design is currently used to generate lower-cost material-saving structures, more energy-efficient buildings, and highly specialized constructions.

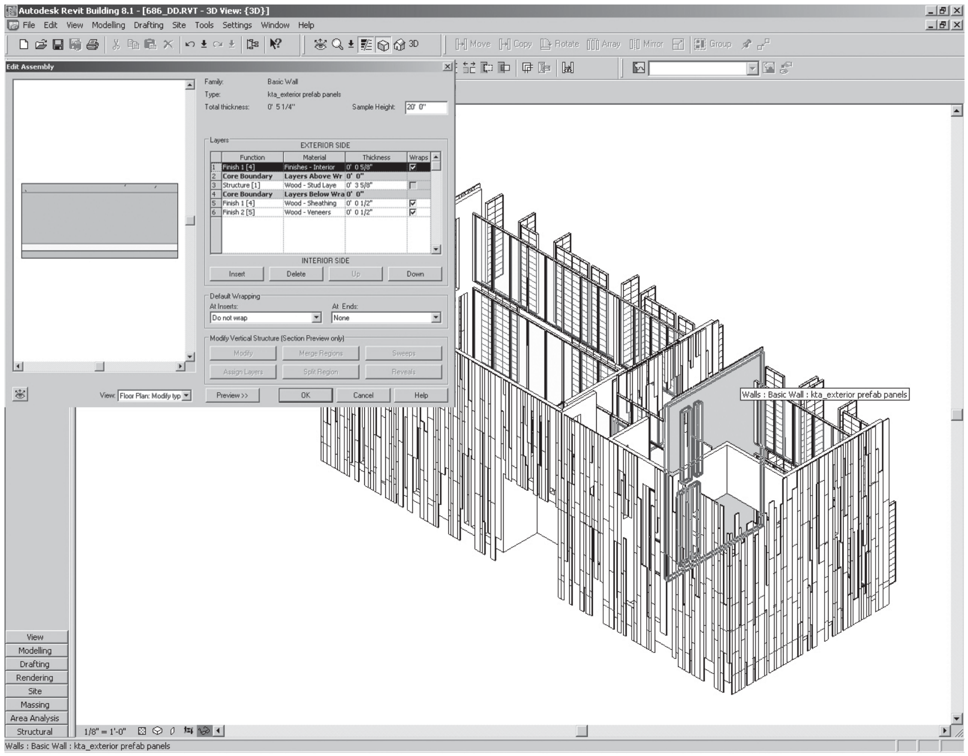
Tools that check a BIM for design and modeling errors: There are several tools available that aid in the detection of potential design problems, conflicts, and code violations. One of the key benefits of BIM is its capability to facilitate multidisciplinary collaboration, particularly when BIM is being used by all the different disciplinary professionals involved in a project. This category of tools includes the architectural, structural, HVAC, electrical, and plumbing components. There are several examples of such tools including open source and cloud-hosted solutions. "Collision detection" is accepted as common practice in the industry today.

Tools for energy analysis: These tools have a long history in the architecture, engineering, and construction (AEC) industry and have been used since the advent of computing. Prior to BIM, using these tools involved a great deal of manual entry of the building data, a tedious process that was prone to inaccuracy. With BIM, the building data is already available in a semantically meaningful form and the data can be directly input to an energy analysis tool. There are even some BIM applications that integrate building lifecycle and daylight analysis capabilities directly into the design tools. This allows for rapid design iteration while considering energy factors early in the design process when the designer has the most ability to affect change in the project.

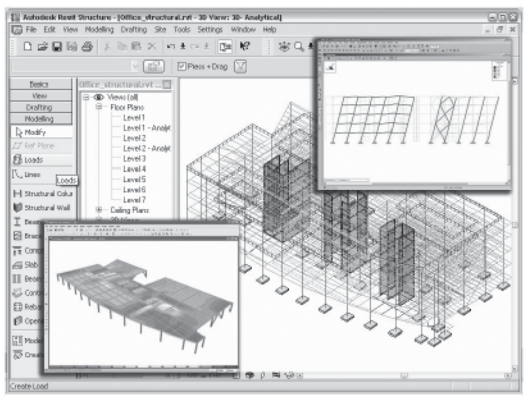
Structural design and analysis tools: Similar to energy analysis tools, these tools also have a long history of use in the industry and have traditionally relied on manual reentry of the building data. Now, BIM structural modeling tools exist that automatically link to industry standard structural analysis software. Some BIM applications provide a bidirectional link to the structural analysis tools, which not only automatically input the analytical model of the structure to those tools but also use the results of the analysis to automatically update the physical model and all the related documentation.

LOBLOLLY HOUSE—WOOD RAINSCREEN
4.16

The house's wood rainscreen is held away from an operable glass wall by 16 in.



BIDIRECTIONAL LINKS BETWEEN REVIT STRUCTURE AND STRUCTURAL ANALYSIS AND DESIGN APPLICATIONS
4.17



SOURCE: AUTODESK

Cost estimating tools: For cost estimating, BIM again removes the need for tedious, manual entry of building data into estimating tools, and provides the capability to directly link to the building model for quantity takeoff and scheduling. Some estimating modules also contain a 5D reporting system (i.e., 3D model plus time sequence plus cost) that use the construction model as the link between cost and time and produces cost-loaded schedules for financial analysis.

Specifications tools: There are a few examples of specifications tools that work with Building Information Models. By linking product specification directly to model elements users can automate much of the spec writing and keynoting processes, as well as reduce omissions and errors.

Code-checking tools: Of the various analysis and evaluation tools that can be supported by BIM, code-checking stands near the top of the list as one of the areas ripe for automation. Because BIM is so information-rich, it is able to support at least a partial code check.

INTEROPERABILITY AND THE IFC BUILDING MODEL

Most BIM applications by commercial vendors have proprietary internal data models and so cannot communicate their rich building information directly with each other unless they develop specific translators for this purpose. Neither can they communicate with other third-party analysis or evaluation tools unless a link has been custom-developed or the product has an Application Program Interface (API). This inhibits the free flow of building information across the various applications used by the individual players, becoming an impediment to achieving the full potential of BIM. What is required is that these applications be able to easily "interoperate," which is where the Industry Foundation Classes (IFC) comes in.

THE IFC MODEL

The IFC is an object-based building data model similar to that of commercial BIM applications, except that it is nonproprietary. It has been developed and maintained by the buildingSMART Alliance (formerly the International Alliance for Interoperability), a global consortium of commercial companies and research organizations founded, in 1995, as an industry-based not-for-profit organization. The IFC model is intended to support interoperability across the individual, discipline-specific applications that are used to design, construct, and operate buildings by capturing information about all aspects of a building throughout its lifecycle. It was specifically developed as a means to exchange model-based data between model-based applications in the AEC and facilities management (FM) industries, and is now supported by all of the major CAD/BIM vendors, as well as an increasing number of downstream analysis application vendors. With 14 chapters in 19 countries and 650 member companies funding its development, it is a truly global effort.

Because the IFC is an open data exchange format that captures building information, it can be used by the commercial BIM applications to exchange data with each other. This requires the application to be IFC-compliant, which means that it is capable of importing and exporting IFC files. Applications are assigned the IFC-compliant tag by going through a buildingSMART-supervised product certification process. The IFC model specification is posted publicly and is accessible to anyone, so developers can work with it and build the necessary IFC import and export capabilities into their applications.

Looking at the actual IFC model itself in some more detail, it represents not just tangible building components such as walls, doors, beams, ceilings, furniture, and so on, but also more abstract concepts such as schedules, activities, spaces, organization, construction costs, and others in the form of *entities*. All entities can have a number of *properties* such as name, geometry, materials, finishes, relationships, and so on.

ARCHITECTURE OF THE IFC MODEL

The main architecture of the IFC model shows how the model has been designed. From the broadest perspective, the model is divided into four separate layers, representing four different levels. Each layer comprises several diverse categories, and it is within each category, or *schema,* that the individual entities are defined. For example, the Wall entity (called IfcWall) falls in the Shared Building Elements schema, which in turn belongs to the Interoperability layer. The layering system is designed in such a way that an entity at a given level can only be related to or reference an entity at the same or lower level, but not an entity at a higher level. The modular design of the overall architecture is intended to make the model easier to maintain and grow. Lower-level entities can be reused in higher-level definitions and a clear distinction can be made between the different AEC/FM disciplinary entities so that the model can be more easily implemented in individual, discipline-specific applications.

Contributors:
Text: Lachmi Khemlani, PhD, Founder, AECbytes and Arcwiz Consulting, Union City, California.
Additional text and editing: Brian Russell, Adjunct Professor, Towson University BIM Institute, Community College of Baltimore County, Baltimore, Maryland.
Real-world examples: Marc Swackhamer, Assistant Professor, School of Architecture, University of Minnesota, Minneapolis, Minnesota; Brian Russell, Adjunct Professor, Towson University BIM Institute, Community College of Baltimore County, Baltimore, Maryland.

SECTION 2

MATERIALS

CONCRETE

5

CONCRETE FORMING AND ACCESSORIES

GENERAL

Concrete forming and accessories includes permanent and temporary forms, anchors, inserts, expansion and control joints, and waterstops for structural and architectural cast-in-place concrete. Concrete forms include metal pan forms, wood forms, plastic forms, slip forms, and corrugated paper forms for placing concrete. These may also include form liners and void forms.

CONCRETE FORMWORK

GENERAL

Formwork costs are a substantial part of the total expense of putting concrete in place. Thus, by developing design elements and details that simplify or standardize form requirements, the architect can help contain construction costs. The following are recommendations for economy in concrete forming:

- *Form reuse:* This is crucial to economy of construction. The design professional can facilitate form reuse by standardizing the dimensions of openings, columns, beams, and footings, using as few different sizes of each as possible. For example, where columns must change size, hold one dimension constant (e.g., width) while varying the other (depth). This enables at least half of the form panels to be used many times. Repeat the same floor and column layout from bay to bay on each floor and from floor to floor. This improves labor productivity and permits reuse of forms.
- *Mockups:* The architect and contractor should agree on the location and desired appearance of architectural surfaces before the exposed concrete work begins. Specify a mockup to help achieve this and to avoid disagreements during and after construction.
- *Large panel forms:* Wherever possible, make uninterrupted formed areas the same size. Increasing the size of such areas enables the contractor to combine form panels into gangs for efficient crane use.
- *Design details:* Intricacies and irregularities cost more and often do not add proportionately to the aesthetic effect.
- *Steel-framed plywood panels:* These are best when column heights or size varies widely. Ganged/hinged/custom column forms are used to improve labor efficiency when multiple reuse (10-plus) can be planned. The productivity gained with each cycle will offset the increased form costs.

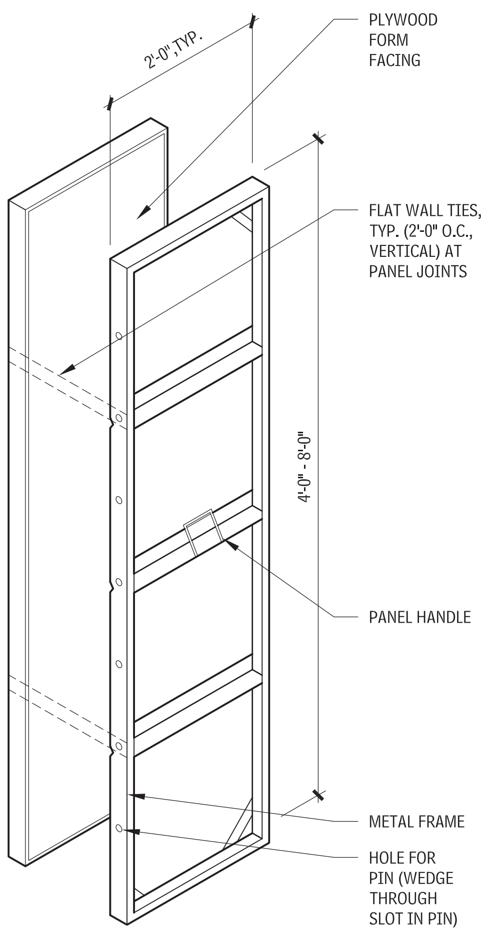
WALL FORMS AND PANELS

Commonly made of steel-framed plywood, panels are also available in aluminum. Wall ties (typically flat ties) and wall forms are held together by slotted pins that run through adjoining holes. A wedge pushed down into the slot alongside the wall form tightens the joint. Formwork service life can be extended by turning or replacing the plywood facing. To produce patterned concrete, reusable plastic liners may be used. For maximum economy, panels can be assembled in large gangs and set in place by crane. Steel-framed plywood panels and/or flat-tie wall forms are predominately used for structural concrete. The breakage of the flat tie and the steel frame imprint in the concrete can detract from concrete appearance.

FORMWORK JOINTS

Formwork joints are inherent in concrete work because of plywood panels. Architectural concrete will usually require a more aesthetic joint. A compressible foam gasket should only be used when a rustication is added. Epoxy on a 45-degree cut, tongued and grooved (with sealant), taped, splined (with sealant), and gasketed with closed-cell compressible material are frequently acceptable formwork joints for structural concrete. 2x joint backing is acceptable for plywood joints in a single direction, but are not practical for perpendicular joints.

MANUFACTURED CONCRETE FORMWORK
5.1



A good joint solution is to add a second layer of plywood to the formwork, staggering the joints from the face sheet. Though, difficult to achieve with site-built forms, applying joint sealant at formwork joints provides the most aesthetic joint. Because of limited access space, sealing formwork joints on both sides of a wall form is nearly impossible and will significantly increase the formwork cost.

BEAM-TO-COLUMN FORMWORK

In general, the least costly design to form has columns the same width or narrower than the beams they support, allowing the beam form to be erected in a continuous line. In mid-cost formwork design, the beam bottom forms are cut to fit around the column tops. In high-cost formwork design, the beam forms are fitted into pockets on both sides of the column forms.

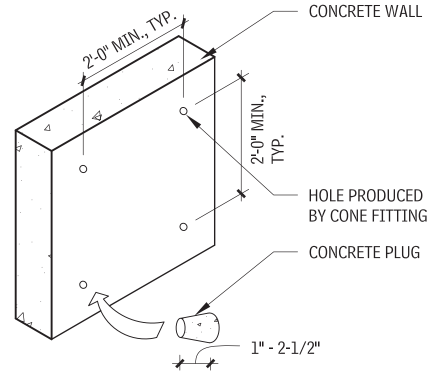
TIE PATTERNS

Installing and removing ties and patching tie holes are some of the most labor-intensive operations in concrete forming. Also, getting a durable, inconspicuous patch often proves difficult. Avoid this problem by specifying smooth cone fittings at the tie ends, then either leaving the resulting uniform tie holes exposed or plugging them with preformed concrete plugs and a bonding agent. Corrodible metal must have coverage of a minimum 1-1/2 in. of concrete. Contractors may propose tie spacing wider than 2 ft. o.c. to reduce the total number of ties to save money, but this requires stronger ties and heavier form supports.

For tie patterns that are *not* gang-formed, due to limited reusability, a 2-ft by 2-ft tie pattern should be a maximum with a 1-ft by 1-ft pattern a corresponding minimum.

For tie patterns that *are* gang-formed, a 4-ft by 4-ft pattern is a minimum spacing using the tie capacities. A corresponding maximum spacing is 6 ft. by 6 ft. Keep in mind the locations of vertical and horizontal construction joints when establishing tie locations. Exterior wall forms often require form anchors embedded in the concrete for each lift. The anchors can be patched, but doing so may detract from the concrete appearance.

FORM TIE PATTERN
5.2



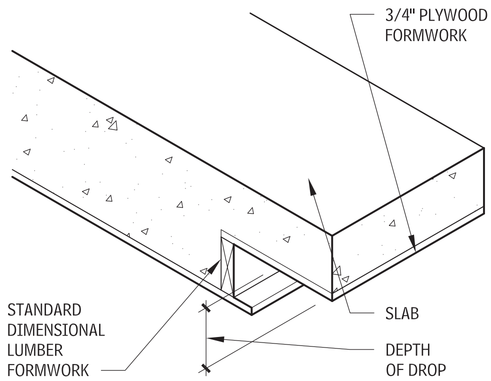
SPANDREL BEAMS

Flat beams designed to be equal in depth to the floor assembly are the least costly, as they most efficiently accommodate flying-form construction. Deeper, narrower beams cost more; but if deeper beams are required, costs can be controlled by making the beam the same thickness as the column depth and at least partially upturned. The upturned portion of the spandrel beam should be less than 30 in. for best economy. The most costly option is a column thicker than the beam. This requires a column collar with a construction joint.

LUMBER FORMS

Adapting design elements to the modular sizes of formwork lumber and plywood and dimensioning parts of the structure to fit the modules can save the expense of custom formwork. For example, to save the waste and time of sawing and piecing together the edge form, make the depth of the drop in a slab equal to the actual size of standard lumber, plus 3/4 in. for the plywood's thickness.

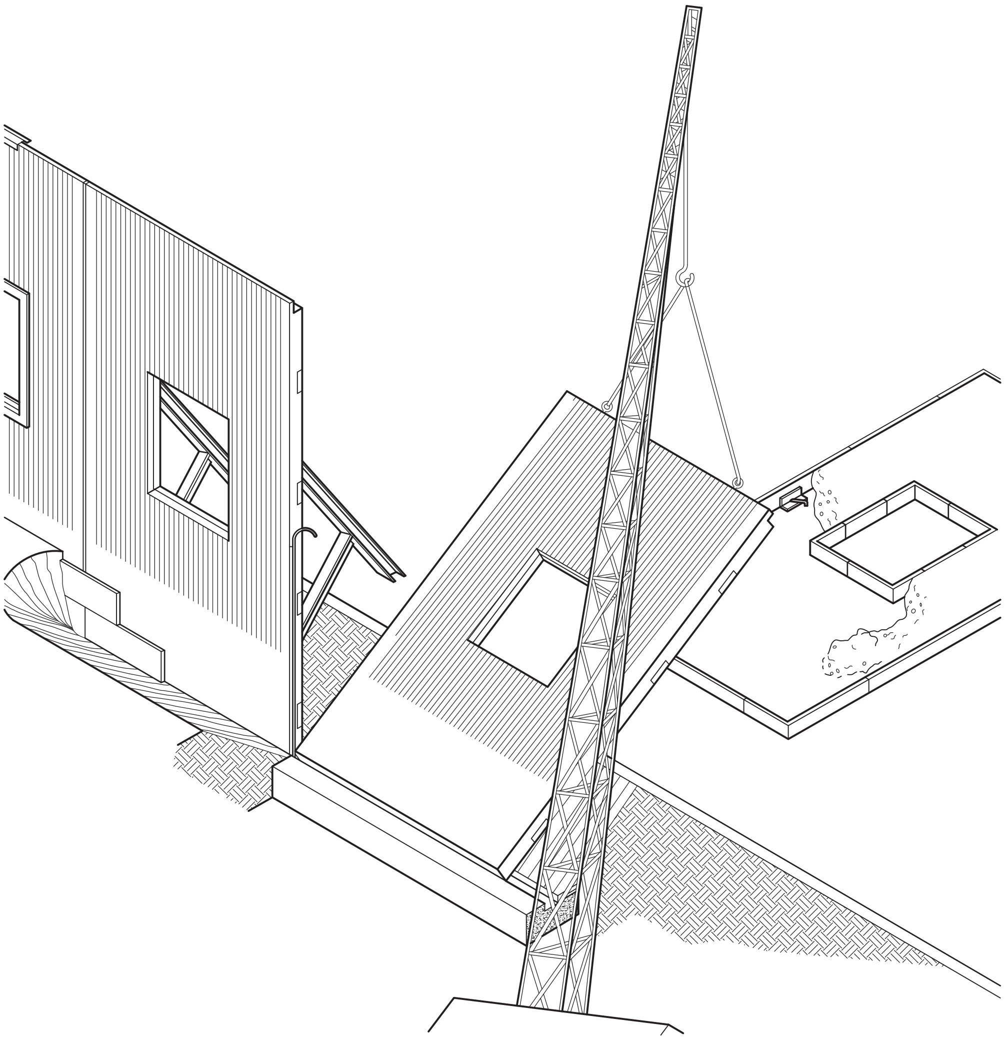
STANDARD LUMBER FORMS
5.3



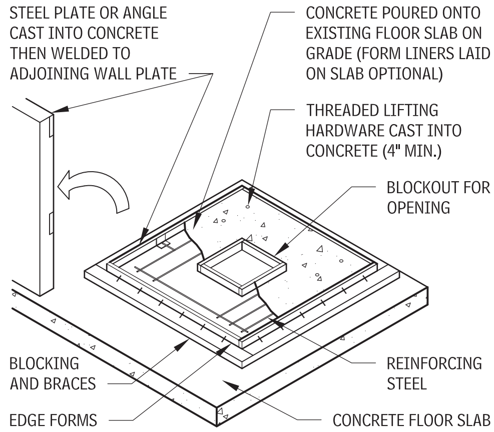
TILT-UP CONCRETE

In tilt-up concrete, walls are cast on the completed floor slab, which must be level, smoothly finished, and treated with a bond-breaking agent to permit easy separation. The wall is then tilted or lifted into vertical position and fastened to the adjoining wall piece. This method reduces formwork and labor and eliminates transportation requirements that may limit panel size.

TILT-UP CONCRETE
5.4

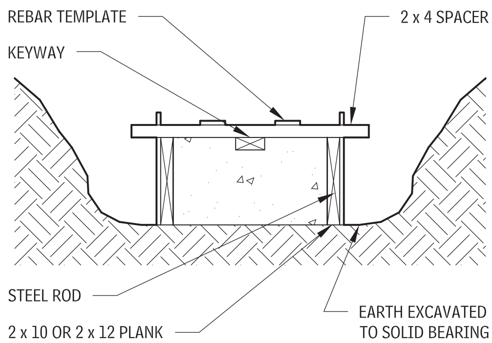


TILT-UP CONCRETE WALL FORMWORK
5.5

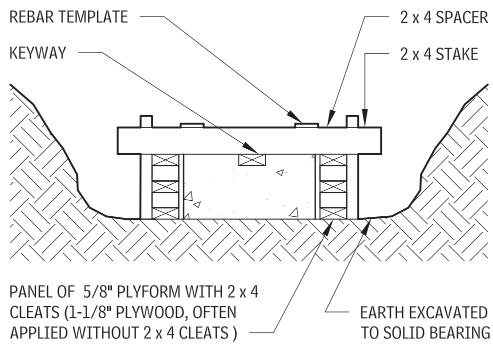


CONCRETE FORMWORK FOR COLUMNS AND FOOTINGS

FORMED FOOTINGS
5.6



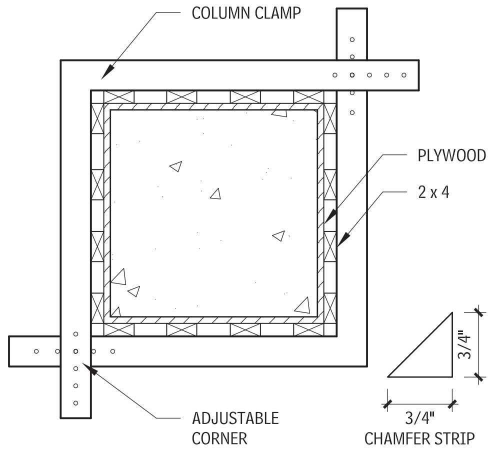
LUMBER FORMED FOOTING



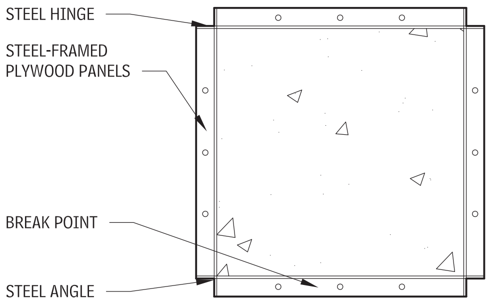
PANEL FORMED FOOTING

Contributors:
Mary K. Hurd, Engineered Publications, Farmington Hills, Michigan; Portland Cement Association, Skokie, Illinois; American Concrete Institute, Farmington Hills, Michigan.

COLUMN FORMWORK PLANS
5.7

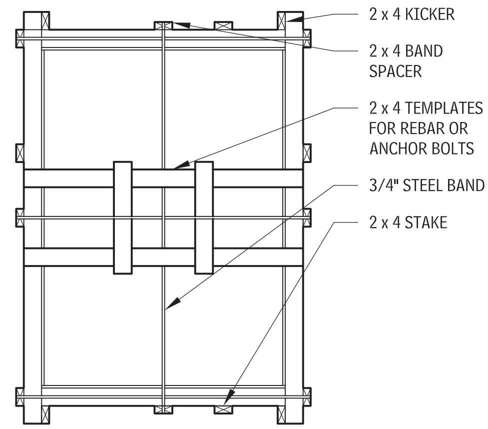


LUMBER/PANEL/COLUMN FORMWORK

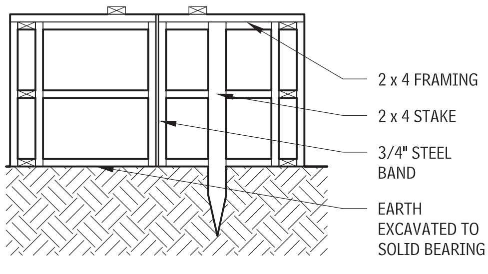


MANUFACTURED COLUMN FORMWORK

COLUMN FOOTING FORMWORK
5.8

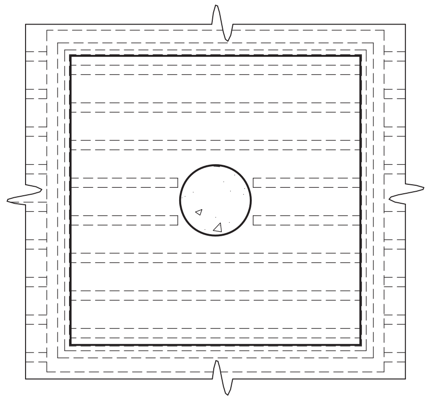


PLAN



ELEVATION

DROP PANELS AT COLUMN TOPS
5.9



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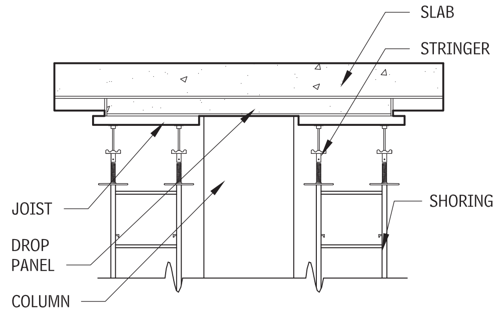
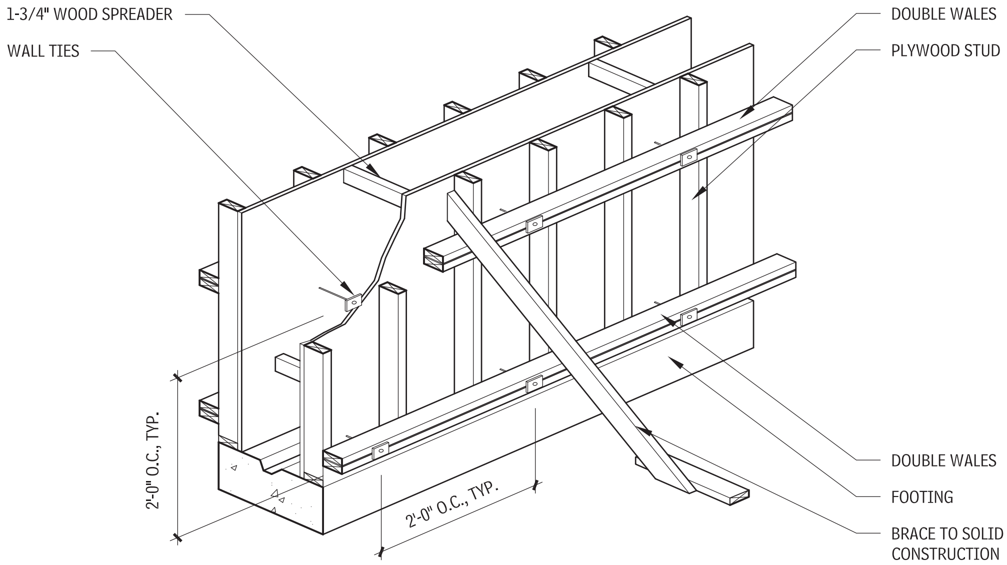


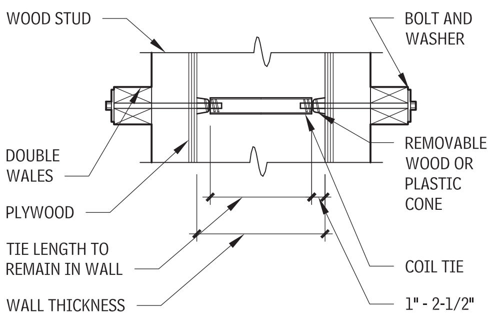
SECTION

CONCRETE FORMWORK FOR WALLS

TYPICAL SITE-BUILT WALL FORMWORK
5.10

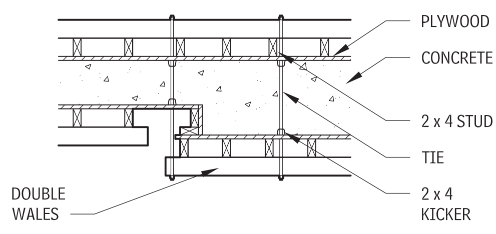


SITE-BUILT WALL FORMS
5.11



SECTION AT WALL TIE

TYPICAL WALL WITH OFFSET
5.12



PLAN

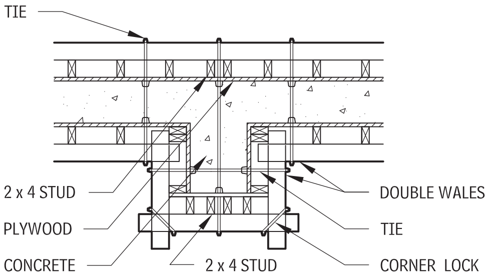
NOTES

5.7 a. It is recommended that chamfer strips be used at all outside corners to reduce damage to concrete when forms are removed. Consult manufacturers' guides and catalogs for ideal materials, pour rate, and outside temperature.
b. Many form suppliers offer various gang column forms with hinged corners for columns up to 48 in. square. Beyond that size most column formwork resembles wall formwork, with some type of internal tie for lateral pressure.

5.11 Consult manufacturers' recommendations for safe working loads on ties.

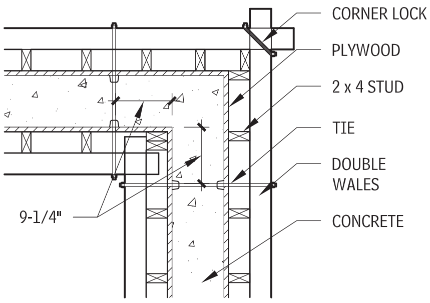
Contributors:
Tucker Concrete Form Company, Stoughton, Massachusetts; Portland Cement Association, Skokie, Illinois.

PILASTER
5.13



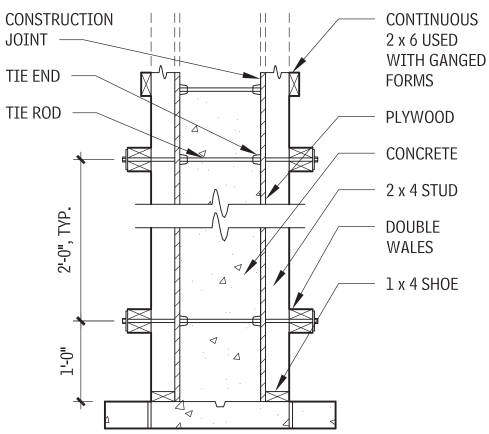
PLAN

TYPICAL CORNER
5.14



PLAN

TYPICAL SITE-BUILT WALL SECTION
5.15

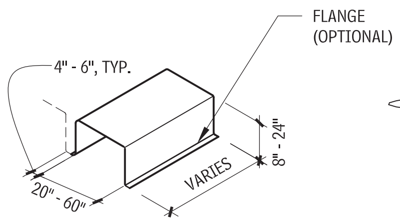


CONCRETE FORMWORK FOR SLABS AND BEAMS

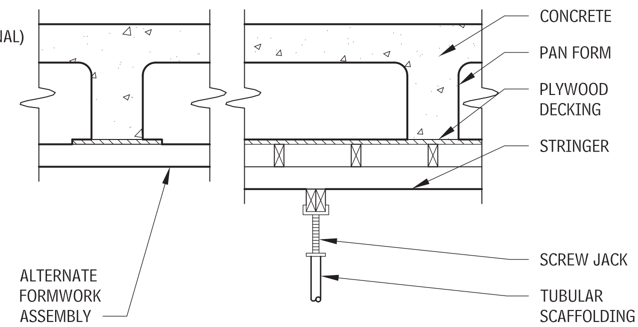
GENERAL

- Scaffolding, steel shores, or wood posts may be used under stringers, depending on loads and height requirements.
- For flat slabs of flat-plate forming, metal "flying forms" are commonly used.
- Patented steel forms or fillers can be special ordered for unusual conditions (see manufacturers' catalogs). Fiber forms are also on the market in similar sizes. Plyform deck is required for forming.
- Plywood decking is usually 5/8 in. minimum thickness; Exposure 1.

TYPICAL PAN FORM FOR ONE-WAY SLAB
5.16

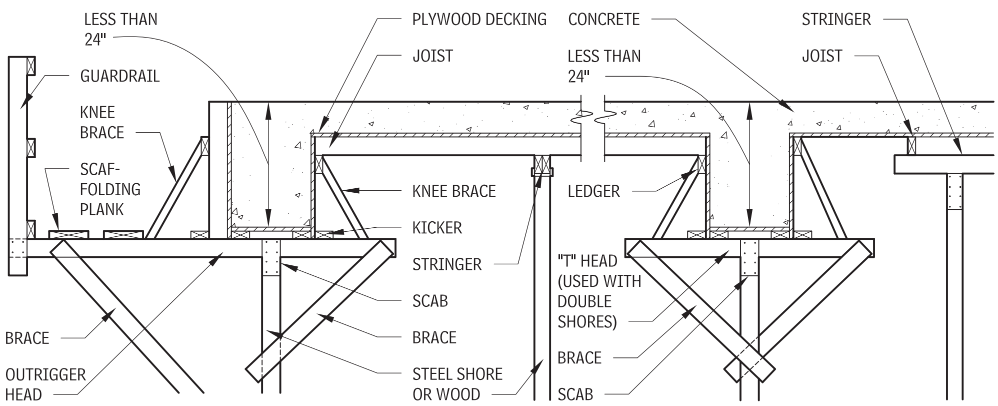


TYPICAL PAN FORM

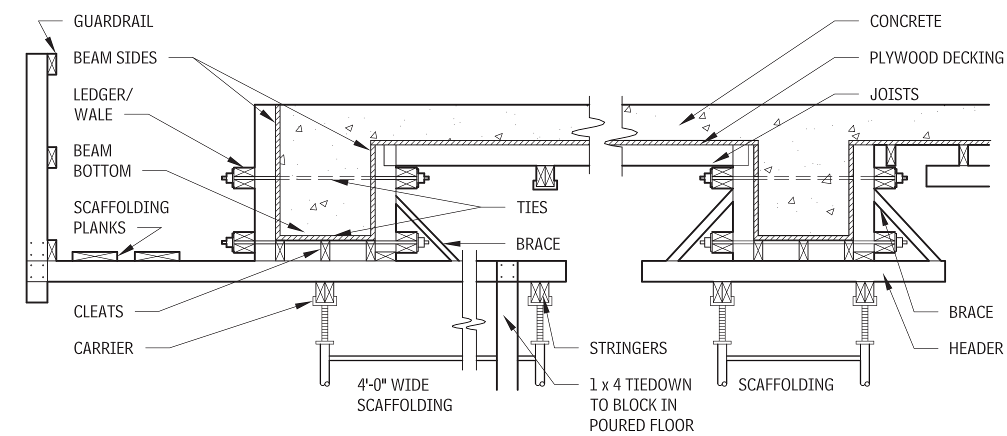


TYPICAL PAN FORMWORK

TYPICAL SLAB AND SHALLOW BEAM FORMING
5.17



TYPICAL SLAB AND HEAVY BEAM FORMING
5.18



NOTES

5.15 Verify size and spacing of components for each job. The combination of plywood, studs, walers, and ties must be chosen carefully to safely resist concrete pressure and limit deflection of the form face. Steel and aluminum studs and walers may be used in place of wood. Lateral pressure varies depending on the rate at which the form is filled, the temperature of the concrete, vibration procedures, and the type of admixtures used in the concrete.

1. Consult ACI SP-4, "Formwork for Concrete" for detailed design recommendations.

2. A wide variety of form ties are commercially available (see the section, Concrete Formwork Hardware, below). For concrete surfaces exposed to weather, select ties that have no corrodible metal closer than 1-1/2 in. to the exposed concrete surface. Ties should be tight-fitting and sealed to prevent leakage at holes in the forms.

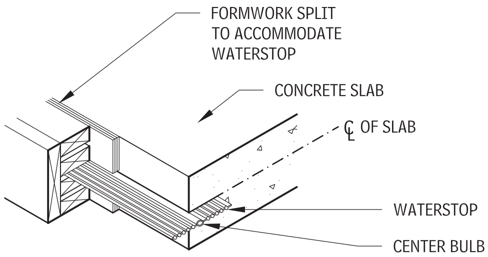
3. Ties fitted with wood or plastic cones should leave depressions at least as deep as the surface diameter of the cone. The holes may be filled with recessed plugs or left unfilled if noncorroding ties are used.

5.16 a. Forms are available in steel and lightweight fiberglass. Consult manufacturers for dimensions and rib-form variations. Typically, two types are available: nail-down flange (simplest, but produces rough, nonarchitectural surface) and slip-in type (based on nail-down form but with board insert for smooth appearance).

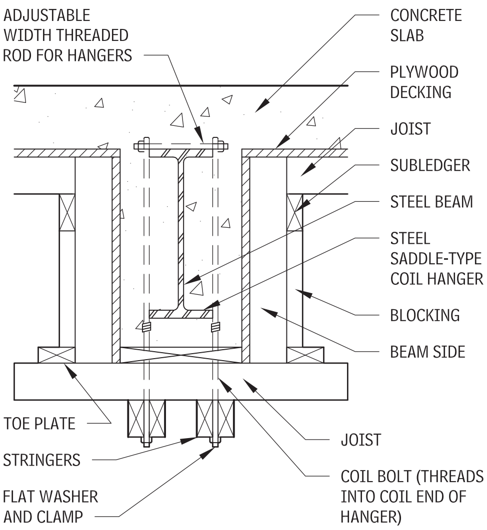
b. The details are all for typical flange-form type pans. Long-form type pans require different forming details.

Contributors:
Tucker Concrete Form Company, Stoughton, Massachusetts; Mary K. Hurd, Engineered Publications, Farmington Hills, Michigan; Portland Cement Association, Skokie, Illinois.

SLAB FORMWORK WITH WATERSTOP
5.19



TYPICAL SUSPENDED FORM WITH COIL SADDLE-TYPE HANGERS
5.20



CONCRETE FORMWORK ACCESSORIES

GENERAL

Concrete formwork accessories include ties, anchors, hangers, and spacers used to hold forms and reinforcements in place against the forces of uncured concrete and other loads applied during construction. Concrete ties are tensile units used to hold concrete forms together, and may be classified by use or by load-carrying capacity.

- *Use classification of formwork tie:* "Continuous single member," in which the entire tie rod extends through the wall and through both sides of the formwork (this can be a pullout tie or a snap-off tie), and "internal disconnecting," in which the tensile unit has an inner part with threaded connections to the removable external members.
- *Load-carrying classification of formwork ties:* Light-duty, which has safe working loads of up to 3750 lb. and heavy-duty, which will carry loads of more than 3750 lb. concrete ties.

Safe working load should be set at no more than half the tie's ultimate strength. Other hardware assemblies and configurations may be available; consult manufacturers for complete details.

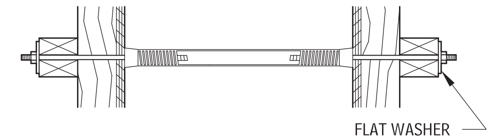
FORMWORK TIES

Coil ties are medium- to heavy-duty ties fabricated to accept a threaded bolt, which passes through the formwork lumber.

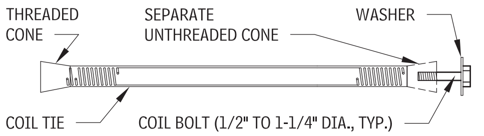
Flat ties are light-duty ties used with a wedge and bolt to secure and space modular wall forms.

Taper tie assemblies are generally used for heavy-duty loads of up to 50,000 lb. Taper ties are versatile in that their parts are removed after the concrete cures and may be reused. Ties may be installed after forms are in place.

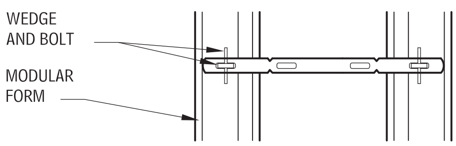
COIL TIES
5.21



SECTION



FLAT TIE
5.22



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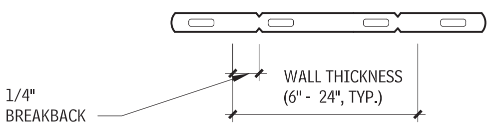
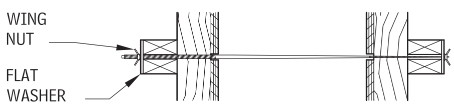


STEEL TAPER TIE
5.23



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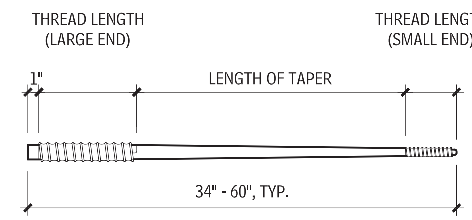
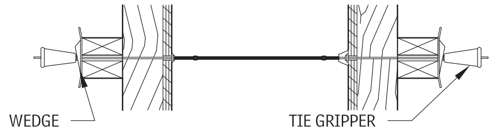


FIBERGLASS FORM TIE
5.24



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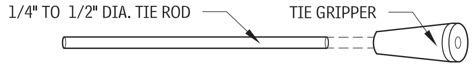


Fiberglass form ties are straight rods secured with reusable external metal grippers and have safe working loads ranging from 2250 to 25,000 lb. The ties are readily broken off or cut at the concrete surface and then ground flush.

Snap ties are for light-duty use, fabricated so the exposed ends of the tie can be snapped off at the breakback (a notch in the rod). The antiturn device makes it easy to break off the exposed end.

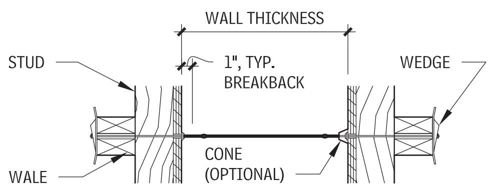
Anchors are used with coil ties to facilitate single-side forming of walls.

Steel wedges are placed at the outside threaded ends of pullout or snap tie rods, holding the formwork in place. Plastic or wood cones may be placed on the tie rod at the formwork wall surface, so that when the formwork is removed the tie rod ends are set back for subsequent finishing (with plugs, etc.).

The cam lock bracket is a light-duty assembly suitable for job-set forms.

Bar supports are used to maintain the design location of the reinforcement away from the wall sides or slab bottom. They are typically made of stainless-steel epoxy- or plastic-coated steel, or plastic.

SNAP TIES
5.25



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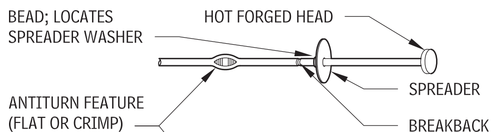
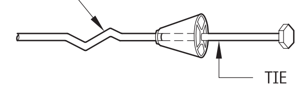


WASHER TYPE



CONE TYPE

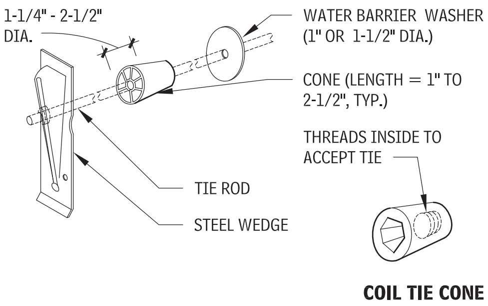
NOTES

5.19 Waterstops are flexible barriers used to prevent the passage of liquids and gases under pressure through joints in concrete slabs. Waterstops are typically made of polyvinyl chloride, and their shapes vary according to application. If a center bulb is specified, it must remain unembedded in the center of the joint.

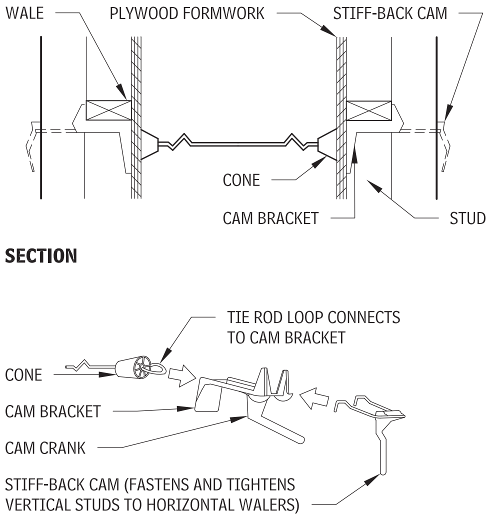
5.20 a. This type of formwork is used to fireproof structural steel beams by wrapping them in concrete.
b. Most applications require 4x wood members for subledger, blocking, and toe plate.

Contributors:
Tucker Concrete Form Company, Stoughton, Massachusetts; Portland Cement Association, Skokie, Illinois.

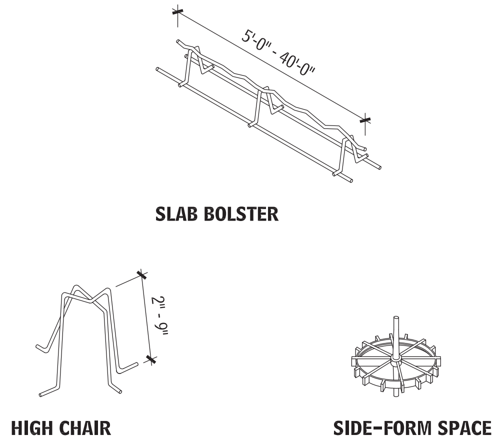
TIE ROD ACCESSORIES
5.26



CAM LOCK BRACKET
5.27



REINFORCING BAR AND MESH SUPPORTS
5.28



CONCRETE REINFORCING

GENERAL

Concrete reinforcing includes reinforcement of all types including tension, compression, and temperature-reinforcing steel, welded wire fabric (coated and uncoated), stressing tendon, and fibrous reinforcing to increase the structural capabilities of concrete.

REINFORCING STEEL, WELDED WIRE FABRIC REINFORCING, STRESSING TENDONS, AND FIBROUS REINFORCING

Steel reinforcement for concrete consists of reinforcing steel and welded wire fabric. Reinforcing steel, commonly known as bars, are manufactured by a hot-rolling process as round rods with ribs, or deformations, which inhibit longitudinal movement of the bar in the surrounding concrete. Bar sizes are indicated by numbers. For sizes #3 through #8 (#10 through #25), the numbers reflect eighths of an inch (millimeters) in the nominal diameter of the bars. Sizes #9, #10, and #11 (#29, #32, and #36) are round and correspond to the former 1 in., 1-1/8 in., and 1-1/4 in. square sizes. Sizes #14 and #18 (#43 and #57) correspond to the former 1-1/2 in. and 2 in. square sizes. The nominal diameter of a deformed bar is equal to the actual diameter of a plain bar with the same weight per foot (mass per meter) as the deformed bar. Epoxy-coated, zinc-coated (galvanized), and stainless steel reinforcing are used when corrosion protection is needed; stainless steel also has nonmagnetic properties.

Welded wire fabric is used in thin slabs, shells, and other designs in which available space is too limited to give proper concrete cover and clearance to deformed bars. Welded wire reinforcement, also called "mesh," consists of cold-drawn wire (plain or deformed) in orthogonal patterns; it is resistance-welded at all intersections.

Wire in the form of strand is used in prestressed concrete members.

ASTM STANDARD REINFORCING BAR SIZES
5.29

ASTM BAR DESIGNATION	CROSS-SECTIONAL AREA (SQ IN.)	NOMINAL WEIGHT (LB/FT)	DIAMETER (IN.)
#3 (#10)	0.11	0.376	0.375
#4 (#13)	0.20	0.668	0.500
#5 (#16)	0.31	1.043	0.625
#6 (#19)	0.44	1.502	0.750
#7 (#22)	0.60	2.044	0.875
#8 (#25)	0.79	2.670	1.000
#9 (#29)	1.00	3.400	1.128
#10 (#32)	1.27	4.303	1.270
#11 (#36)	1.56	5.313	1.410
#14 (#43)	2.25	7.65	1.693
#18 (#57)	4.00	13.60	2.257

SHRINKAGE AND TEMPERATURE REINFORCEMENT FOR STRUCTURAL CONCRETE
5.30

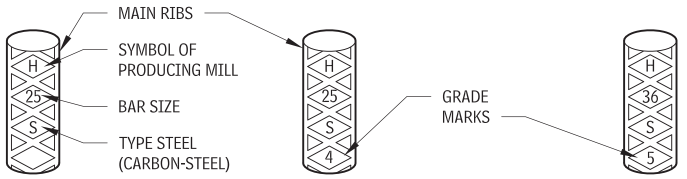
REINFORCEMENT		PERCENT OF CROSS-SECTIONAL AREA OF CONCRETE, ONE-WAY
GRADE	TYPE	
40/50	Deformed bars	0.20
—	Welded wire reinforcement	0.18
60	Deformed bars	0.18

COMMON STOCK STYLES OF WELDED WIRE FABRIC REINFORCING
5.31

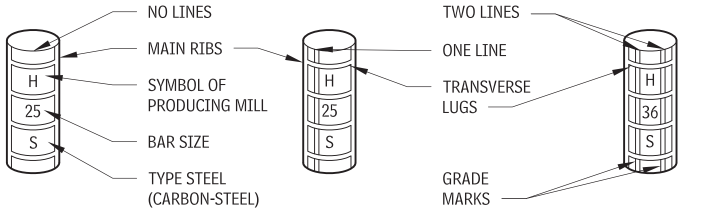
NEW DESIGNATION (W-NUMBER)	STEEL AREA (IN./SQ FT)		WEIGHT (LB/100 SQ FT)
	LONGITUDINAL	TRANSVERSE	
SHEETS AND ROLLS			
6 x 6 – W1.4 x W1.4	.028	.028	21
6 x 6 – W2.0 x W2.0	.040	.040	29
6 x 6 – W2.9 x W2.9	.058	.058	42
6 x 6 – W4.0 x W4.0	.080	.080	58
4 x 4 – W1.4 x W1.4	.042	.042	31
4 x 4 – W2.0 x W2.0	.060	.060	43
4 x 4 – W2.9 x W2.9	.087	.087	62
4 x 4 – W4.0 x W4.0	.120	.120	85

Contributors:
Mary K. Hurd, Engineered Publications, Farmington Hills, Michigan; Portland Cement Association, Skokie, Illinois.

REINFORCING BAR-GRADE MARK IDENTIFICATION
5.32



NUMBER SYSTEM



GRADE 40 (280)
GRADE 50 (350)

GRADE 60 (420)

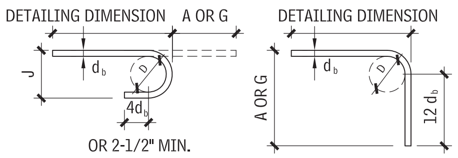
GRADE 75 (520)

LINE SYSTEM

REINFORCING BAR GRADES AND STRENGTHS
5.33

ASTM SPECIFICATION	MINIMUM YIELD STRENGTH (PSI)	MINIMUM TENSILE STRENGTH (PSI)
CARBON-STEEL ASTM A 615		
Grade 40 (280)	40,000	60,000
Grade 60 (420)	60,000	90,000
Grade 75 (520)	75,000	100,000
LOW-ALLOY ASTM A 706		
Grade 60 (420)	60,000	80,000
RAIL-STEEL ASTM A 996		
Grade 50 (350)	50,000	80,000
Grade 60 (420)	60,000	90,000
AXLE-STEEL ASTM A 996		
Grade 40 (280)	40,000	70,000
Grade 60 (420)	60,000	90,000

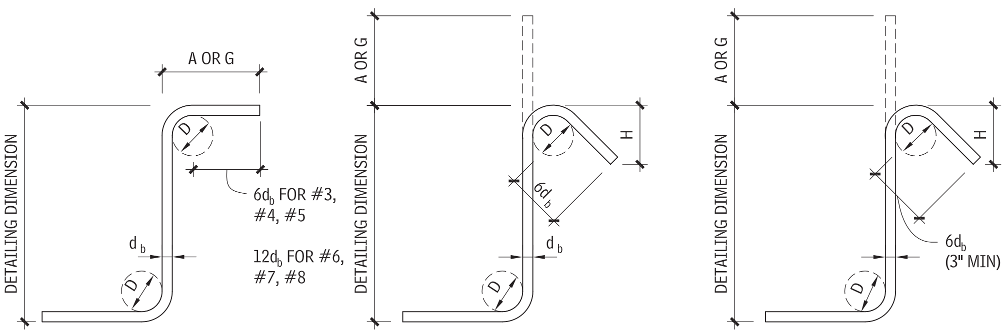
STANDARD REINFORCING BAR HOOKS
5.34



STANDARD HOOK

BAR SIZE	180° HOOK A OR G	180° HOOK J	180° HOOK D	90° HOOK A OR G	90° HOOK D
#3 (#10)	5”	3”	2-1/4”	6”	2-1/4”
#4 (#13)	6”	4”	3”	8”	3”
#5 (#16)	7”	5”	3-3/4”	10”	3-3/4”
#6 (#19)	8”	6”	4-1/2”	12”	4-1/2”
#7 (#22)	10”	7”	5-1/4”	14”	5 1/4”
#8 (#25)	11”	8”	6”	16”	6”
#9 (#29)	15”	11-3/4”	9-1/2”	19”	9-1/2”
#10 (#32)	17”	13-1/4”	10-3/4”	22”	10-3/4”
#11 (#36)	19”	14-3/4”	12”	24”	12”
#14 (#43)	27”	21-3/4”	18-1/4”	31”	18-1/4”
#18 (#57)	36”	28-1/2”	24”	41”	24”

STANDARD STIRRUP HOOKS AND TIES
5.35



STIRRUP HOOKS AND TIES

BAR SIZE	90° HOOK/TIE A OR G	90° HOOK/TIE D	135° HOOK/TIE A OR G	135° HOOK/TIE D	135° HOOK/TIE H	135° SEISMIC HOOK/TIE A OR G	135° SEISMIC HOOK/TIE D	135° SEISMIC HOOK/TIE H
#3 (#10)	4″	1-1/2″	4″	1-1/2″	2-1/2″	4-1/4″	1-1/2″	3″
#4 (#13)	4-1/2″	2″	4-1/2″	2″	3″	4-1/2″	2″	3″
#5 (#16)	6″	2-1/2″	5-1/2″	2-1/2″	3-3/4″	5-1/2″	2-1/2″	3-3/4″
#6 (#19)	12″	4-1/2″	8″	4-1/2″	4-1/2″	8″	4-1/2″	4-1/2″
#7 (#22)	14″	5-1/4″	9″	5-1/4″	5-1/4″	9″	5-1/4″	5-1/4″
#8 (#25)	16″	6″	10-1/2″	6″	6″	10-1/2″	6″	6″

NOTE

5.32 Steel type marks: S for Carbon (A615), W for Low Alloy (A706), I for Rail (A996), R for rail (A996), A for axle (A996).

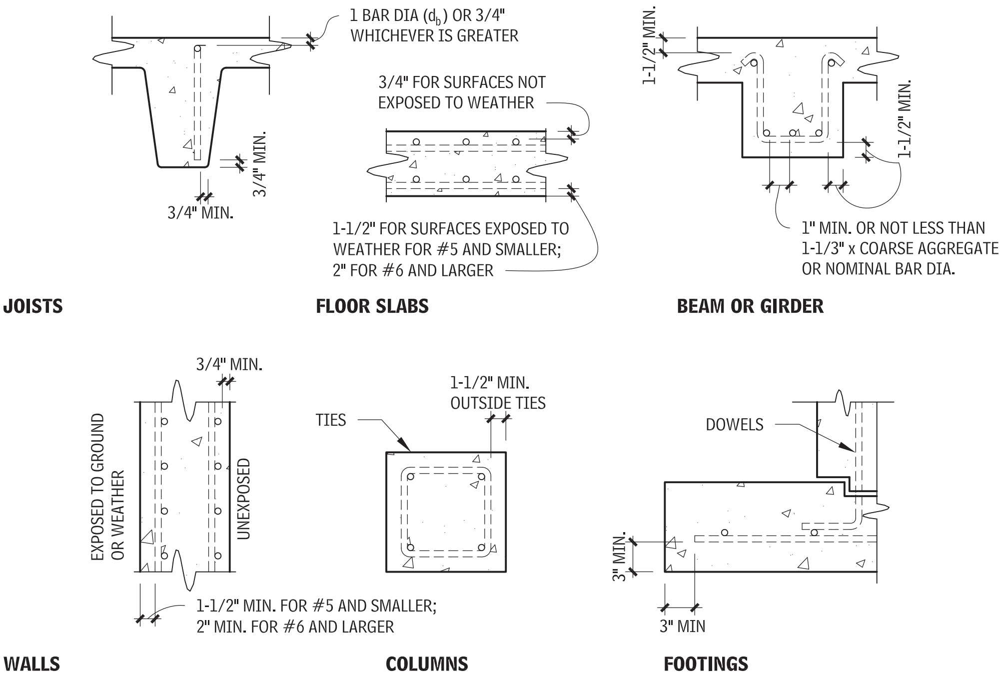
Contributors:
Concrete Reinforcing Steel Institute, Schaumburg, Illinois; Gordon B. Batson, PE, Potsdam, New York.

COMPRESSION LAP SPLICES AND DEVELOPMENT FOR REINFORCING BARS
5.36

STEEL GRADE KSI (MP_a)	CONCRETE COMPRESSION STRENGTH (f'_c)	LAP SPLICE IN $d_b \geq 12$ IN.	DEVELOPMENT, IN d_b (8 IN. MIN.)
40 (280)	3000	20	15
	4000	20	13
	5000	20	12
50 (350)	3000	25	19
	4000	25	16
	5000	25	15
60 (420)	3000	30	22
	4000	30	19
	5000	30	18
75 (520)	3000	44	28
	4000	44	24
	5000	44	23

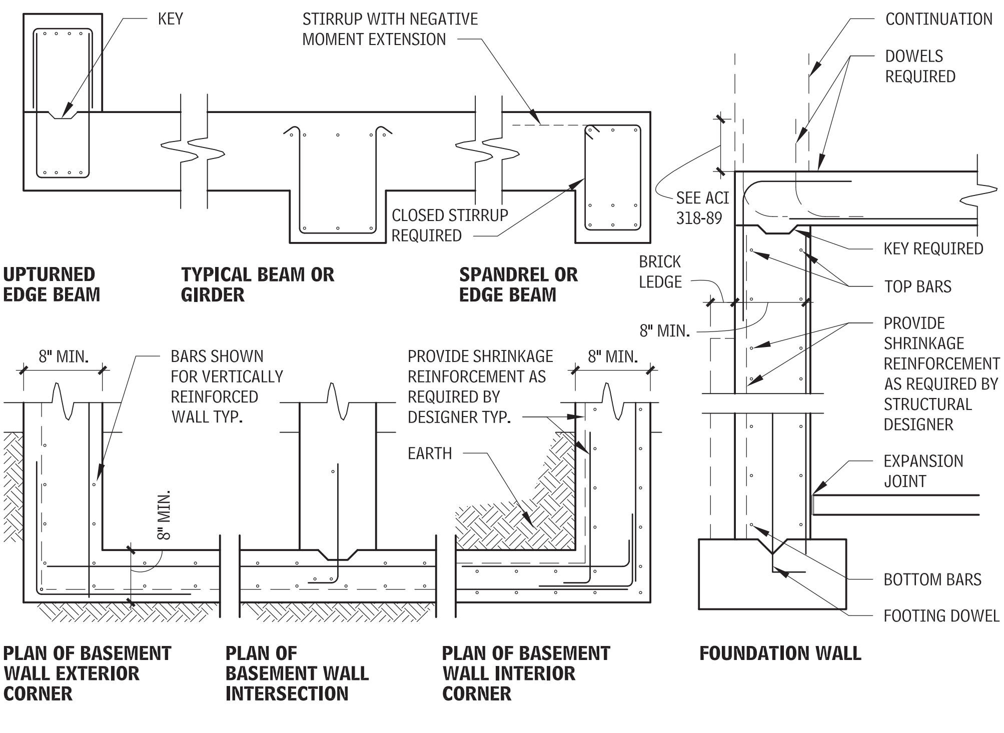
d_b = reinforcing bar diameter.

PROTECTION FOR REINFORCEMENT
5.37



PLACEMENT OF STEEL REINFORCING

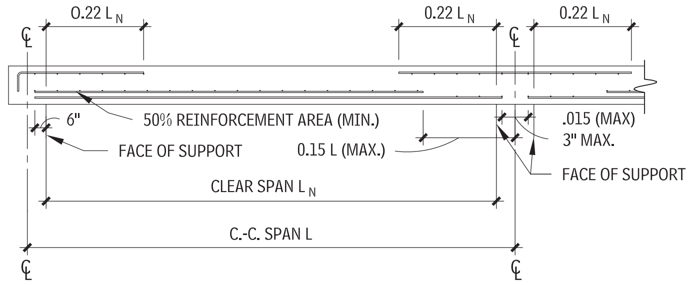
REINFORCING DETAILS
5.38



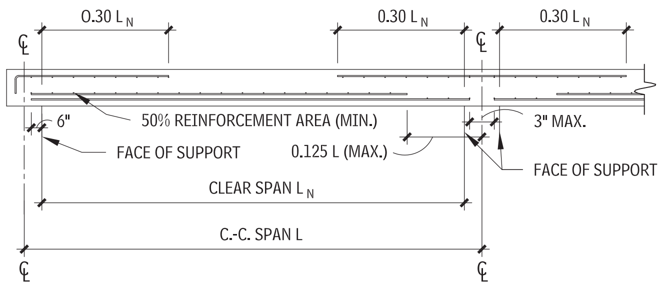
NOTES

5.36 a. Reinforcing bars #14 and #18 (#43 and #54) may not be used in lap splices except when lapped to #11 (#36) bars or smaller. To find the lap dimension, take the larger figure of either development of the larger bar or lap splice of the smaller bar.
b. Consult the Concrete Reinforcing Steel Institute (CRSI) for tension splices and development lengths.

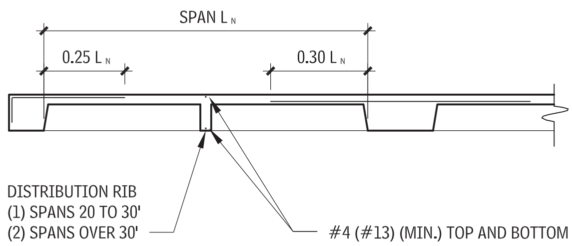
CONCRETE FLOOR CONSTRUCTION
5.39



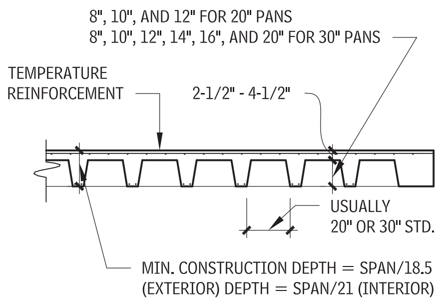
FLAT PLATE CONSTRUCTION – MIDDLE STRIP



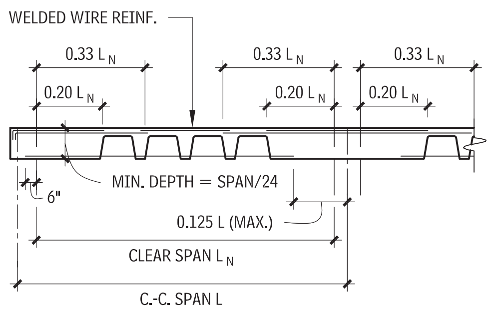
FLAT PLATE CONSTRUCTION – COLUMN STRIP



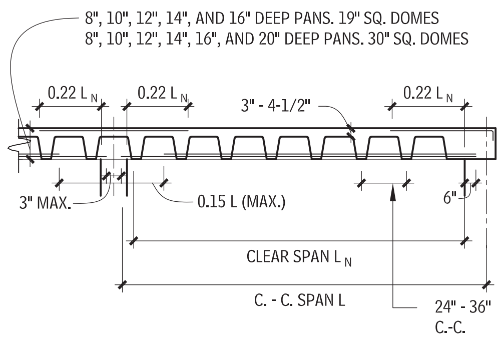
LONGITUDINAL SECTION – ONE-WAY CONCRETE JOIST CONSTRUCTION



CROSS SECTION

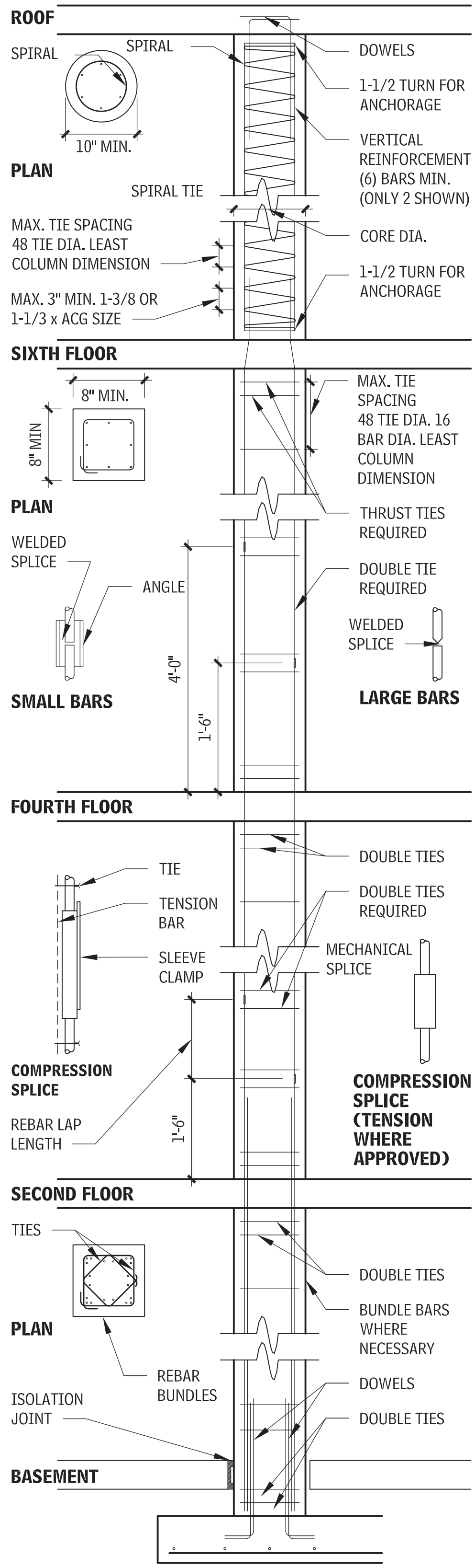


COLUMN STRIP WAFFLE FLAT SLAB – SQUARE BAY CONSTRUCTION



MIDDLE STRIP

COLUMN REINFORCEMENT
5.40



Contributors:
Concrete Reinforcing Steel Institute, Schaumburg, Illinois; Kenneth D. Franch, AIA, PE, Phillips Swager Associates, Inc., Dallas, Texas.

TYPICAL COMPONENTS APPLICABLE TO CONCRETE WORK

CAST-IN-PLACE CONCRETE

Cast-in-place concrete includes concrete mixture placement, finishing, and curing for structural, architectural, and specialty placed concrete. The concrete mixture generally includes aggregate, cement, and additives.

The aggregates portion of the concrete mixture is divided into fine and coarse aggregates. The fine aggregate is generally sand of particles less than 3/8 inch large. The coarse aggregate is crushed stone or gravel greater than 3/8 inch. Sand, crushed rock, or gravel concrete weighs 135 to 165 pcf. Lightweight aggregate is manufactured from expanded shale, slate, clay, or slag, and the concrete weighs 85 to 115 pcf. Normal weight aggregates must meet ASTM Specification C33. The aggregate represents 60 to 80 percent of the concrete volume.

When cement, aggregate, and water are mixed, a chemical reaction is started. Concrete gains strength through curing. Standard cement is assumed to achieve 100 percent of its design compressive strength 28 days after mixing begins. The majority of strength is gained in the first few days of curing. About one-half of the strength may be achieved in three days. Concrete cylinder compressive tests will be performed in advance of the 28 days.

CONCRETE ADMIXTURES

Concrete admixtures are supplementary materials other than portland cement, water, and aggregates that are added to the mixture immediately before or during mixing. Admixtures can be classified by function as follows: air-entraining admixtures; water-reducing admixtures; retarding admixtures; accelerating admixtures; superplasticizers; hydration-control admixtures; and miscellaneous admixtures that aid workability, bonding, dampproofing, gas-forming, grouting (non-shrink), coloring, and admixtures that reduce permeability and inhibit corrosion.

Concrete should be workable, finishable, strong, durable, water-resistant, and wear-resistant. These qualities can usually be achieved by selecting suitable materials or by changing the mix proportions. Admixtures may be necessary to meet design performance or intent.

The major reasons for using admixtures are to reduce the cost of concrete construction; to achieve certain properties in concrete more effectively than by other means; to ensure the quality of concrete during mixing, transporting, placing, and curing in adverse weather conditions.

- The effectiveness of an admixture depends on such factors as type, and amount of cement; water content; aggregate shape, gradation, and proportions; mixing time; slump; and concrete and air temperatures.
- Concrete samples should be made with the admixture and the job materials at temperatures and humidity levels anticipated on the job, to ensure compatibility with other admixtures and job materials and to allow observation of how the properties of the fresh and cured concrete are affected by local conditions.
- The cost of using admixtures should be compared with the cost of changing the basic concrete mixture.
- Recommended total air contents for different exposure conditions are shown for different aggregate sizes in the Figure 5.54.

CONCRETE ADMIXTURES BY CLASSIFICATION
5.41

TYPE OF ADMIXTURE	DESIRED EFFECT	MATERIAL
Accelerators (ASTM C 494, Type C)	Accelerate setting and early-strength development.	Calcium chloride (ASTM D 98); triethanolamine, sodium thiocyanate, calcium formate, calcium nitrate, calcium nitrite
Air detrainers	Decrease air content.	Tributyl phosphate, dibutyl phthalate, octyl alcohol, water-insoluble esters of carbonic and boric acid, silicones
Air-entraining admixtures (ASTM C 260)	Improve durability in environments of freeze-thaw, deicers, sulfate, and alkali reactivity. Improve workability.	Salts of wood resins, some synthetic detergents, salts of sulfonated lignin, salts of petroleum acids, salts of proteinaceous material, fatty and resinous acids and their salts, alkylbenzene sulfonates, salts of sulfonated hydrocarbons
Alkali-aggregate reactivity inhibitors	Reduce alkali-aggregate reactivity expansion.	Barium salts, lithium nitrate, lithium carbonate, lithium hydroxide
Bonding admixtures	Increase bond strength.	Rubber, polyvinyl chloride, polyvinyl acetate, acrylics, butadiene-styrene copolymers
Coloring admixtures	Colored concrete.	Modified carbon black, iron oxide, phthalicyanine, umber, chromium oxide, titanium oxide, cobalt blue (ASTM C 979)
Corrosion inhibitors (ASTM C1582)	Reduce steel corrosion activity in a chloride environment.	Calcium nitrite, sodium nitrite, sodium benzoate, certain phosphates of fluosilicates, fluoaluminates
Dampproofing admixtures	Retard moisture penetration into dry concrete.	Soaps of calcium or ammonium stearate or oleate, butyl stearate, petroleum products
Fungicides, germicides, and insecticides	Inhibit or control bacterial and fungal growth.	Polyhalogenated phenols, dieldrin emulsions, copper compounds
Gas formers	Cause expansion before setting.	Aluminum powder, resin soap, and vegetable or animal glue, saponin, hydrolyzed protein
Grouting agents	Adjust grout properties for specific applications (i.e., non-shrink grout for setting steel on masonry or concrete, fill reglets and cracks).	See air-entrained admixtures, accelerators, retarders, workability agents.
Permeability reducers	Decrease permeability.	Silica fume; fly ash (ASTM C 618), ground slag (ASTM C 989), natural pozzolans, water reducers, latex
Pumping aides	Improve pumpability.	Organic and synthetic polymers; organic flocculents; organic emulsions of paraffin, coal tar, asphalt, acrylics; bentonite and pyrogenic silicas; natural pozzolans (ASTM C 618, Class N); fly ash (ASTM C 618, Classes F and C); hydrated lime (ASTM C 141)
Retarders (ASTM C 494, Type B)	Retard setting time to offset effect of hot weather, to delay initial set for difficult placement, or for special finishing, such as exposed aggregate.	Lignin, borax, sugar, tartaric acids, and salts
Superplasticizers (ASTM C 1017, Type 1)	Increase slump to aid in pumping concrete; reduce water-cement ratio.	Sulfonated melamine formaldehyde condensates; sulfonated naphthalene formaldehyde condensates; lignosulfonates
Superplasticizer and retarder (ASTM C 1017,Type 2)	Increase slump to aid in pumping concrete with retarded set; reduce water.	See superplasticizers and water reducers.
Water reducer (ASTM C 494, Type A)	Reduce water demand at least 5%.	Lignosulfonates, hydroxylated carboxylic acids, carbohydrates (also tend to retard set, so accelerator is often added)
Hydration control admixtures	Suspend and reactivate cement hydration with stabilizer and activator.	Carboxylic acids, phosphorous-containing organic acid salts
Shrinkage reducers	Reduce drying shrinkage.	Polyoxyalkylene alkyl ether; propylene glycol
Water reducer and accelerator (ASTM C 494 and AASHTO M 194 Type E)	Reduce water content (minimum 5%) and accelerate set.	See water reducer, Type A (accelerator is added).
Water reducer and retarder (ASTM C 494 and AASHTO M 194 Type D)	Reduce water content (minimum 5%) and retard set.	See water reducer, Type A (retarder is added).
Water reducer—high range (ASTM C 494 and AASHTO M 194 Type F)	Reduce water content (minimum 12%).	See superplasticizers.
Water reducer—high range—and retarder (ASTM C 494 and AASHTO M 194 Type G)	Reduce water content (minimum 12%) and retard set.	See superplasticizers, and water reducers.
Water reducer—midrange	Reduce water content (between 6% and 12%) without retarding.	Lignosulfonates, polycarboxylates

NOTE

5.41 Superplasticizers are also referred to as high-range water reducers or plasticizers. These admixtures often meet both ASTM 494 and C 1017 specifications simultaneously.

SUPPLEMENTARY CEMENTITIOUS MATERIALS

Fly ash, ground-granulated blast-furnace slag, silica fume, and natural pozzolans are materials that, when used in conjunction with portland cement, contribute to the properties of the cured concrete through hydraulic or pozzolanic activity, or both.

Hydraulic materials will set and harden when mixed with water, whereas pozzolanic materials require a source of calcium, usually supplied by portland cement. Slags and some Class C fly ashes are hydraulic materials, and Class F fly ashes are typically pozzolanic. Collectively, these materials are referred to as supplementary cementitious materials (SCMs). Formally, a pozzolan is a siliceous or aluminosiliceous material that, in finely divided form and in the presence of moisture, chemically reacts with the calcium hydroxide released by the hydration of portland cement to form calcium silicate hydrate (similar to that produced by cement hydration). In very broad terms, the reactions may be considered to be:

Water + Cement → Calcium Silicate Hydrate + Calcium Hydroxide
Calcium Hydroxide + Pozzolan + Water → Calcium Silicate Hydrate

Calcium silicate hydrate is the primary compound that contributes to strength and impermeability of hydrated cement paste; in contrast, calcium hydroxide is not as strong and is more soluble. Conversion of calcium hydroxide to more calcium silicate hydrate may, therefore, be considered beneficial.

Supplementary cementitious materials in concrete mixtures may be used in addition to, or as a partial replacement for, portland cement in concrete, depending on the properties of the materials and the desired effect on concrete.

Supplementary cementitious materials can be used to improve a particular concrete property such as resistance to alkali-aggregate reactivity. The optimum amount to use should be established by testing to determine: (1) whether the material is indeed improving the property; (2) the correct dosage rate, as an overdose or underdose can be harmful or fail to achieve the desired effect; and (3) whether unintended effects occur—for example, a significant delay in early strength gain. Supplementary cementitious materials may react differently with different cements.

SPECIFICATIONS FOR SUPPLEMENTARY CEMENTITIOUS MATERIALS
5.42

GROUND-GRANULATED IRON BLAST-FURNACE SLAGS	
ASTM C 989/AASHTO M 302	
Grade 80	Slags with a low activity index
Grade 100	Slags with a moderate activity index
Grade 120	Slags with a high activity index
FLY ASH AND NATURAL POZZOLANS	
ASTM C 618/AASHTO M 295	
Class N	Raw or calcined natural pozzolans including
	Diatomaceous earths
	Opaline cherts and shales
	Tuffs and volcanic ashes or pumicites
	Calcined clays, including metakaolin and shales
Class F	Fly ash with pozzolanic properties
Class C	Fly ash with pozzolanic and cementitious properties
SILICA FUME	
ASTM C 1240	
HIGHLY REACTIVE POZZOLANS	
AASHTO M 341	

CONCRETE SURFACES, FINISHES, AND INTEGRAL COLOR

GENERAL

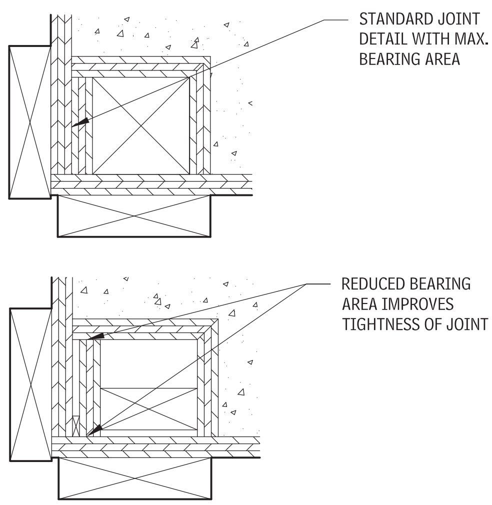
Architectural concrete and structural concrete are both made from portland cement, aggregate, and water, but they have entirely different concrete mix designs. A variety of architectural finishes and colors can be achieved by changing the mix of these three simple ingredients. The cost of production usually determines the limit of finish choices. There are three basic ways to change the appearance of a concrete surface finish:

- *Material variation* involves changing the size, shape, texture, and color of the coarse and fine aggregate, particularly in exposed aggregate concrete, and choosing white or gray cement.
- *Mold or form variation* involves changing the texture or pattern of the concrete surface by means of form design, form liners, or joint/edge treatments.
- *Surface treatment* involves treating or tooling the surface after the concrete has cured.

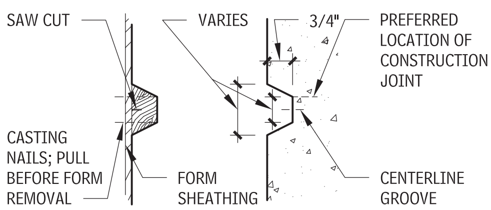
Design drawings for architectural concrete should show form details, including openings, joints (contraction, construction, and rustication), and other important specifics. Other factors that affect concrete surfaces are mixing and placing techniques, slump control, curing methods, and release agents.

- Choosing a placing technique (pumping, chute, bucket) is an important step toward achieving a desired architectural concrete surface and finish. Evaluate whether architectural concrete forms can also be used for structural concrete. Verify that the vibrators used are of the proper size, frequency, and power.

VOID FORM FOR CORNER REVEAL
5.43



RUSTICATION AT CONSTRUCTION JOINT
5.44



- Shop drawings should be carefully checked to determine conformance with contact documents. Require approval of forms and finishes; field mockups are advised, to evaluate the appearance of the concrete panel and the quality of workmanship.
- Release agents are chemical treatments applied to the liner or face of the form that react with the concrete to prevent it from sticking to the form. The best way to select a release agent is to evaluate several products on a test panel under actual job conditions. The curing compound, used to retard or reduce evaporation of moisture from concrete or to extend curing time, is typically applied immediately after final finishing of the concrete surface. Consult manufacturers and the American Concrete Institute for more detailed information about the compatibility of these treatments and the form surface material or other finishes and surfaces to be applied to the concrete.

AGGREGATE

Aggregate, one of five components of concrete, greatly affects the final appearance of the concrete surface. Aggregate should be selected on the basis of color, hardness, size, shape, gradation, method of exposure, durability, availability, and cost. Aggregate hardness and density must be compatible with structural requirements and weathering conditions.

Sources for coarse and fine aggregates should be kept the same for an entire job to avoid variations in the final surface appearance, particularly in light-toned concrete. Following are the common types of aggregate available:

- Quartz is available in clear, white, yellow, green, gray, and light pink or rose. Clear quartz is used as a sparkling surface to complement other colors and pigmented cements.
- Granite, known for its durability and beauty, is available in shades of pink, red, gray, dark blue, black, and white. Traprock such as basalt can be used for gray, black, or green.
- Marble probably offers the widest selection of colors—green, yellow, red, pink, gray, white, and black.
- Limestone is available in white and gray.
- Miscellaneous gravel, after being washed and screened, can be used for brown and reddish-brown finishes. Yellow ochers, umbers, buff shades, and pure white are abundant in riverbed gravels. Check local availability.
- Ceramic exhibits the most brilliant and varied colors when vitreous materials are used.
- Expanded lightweight shale may be used to produce reddish-brown, gray, or black aggregate. Porous and crushable, this shale produces a dull surface with soft colors. It should be tested for iron-staining characteristics and must meet ASTM C 330.
- Recycled concrete aggregate is produced when old concrete is crushed. Primarily used in pavement work, this material generally has a higher absorption rate and lower density than conventional aggregate. It should be tested for durability, gradation, and other properties, as with any new aggregate source.

EXPOSED AGGREGATE

An exposed aggregate surface is a decorative finish for concrete work, achieved by removing the surface cement to expose the aggregate. Aggregates suitable for exposure may vary from 1/4 in. to a cobblestone more than 6 in. in diameter. The extent to which the pieces of aggregate are revealed is largely determined by their size. Size is generally selected on the basis of the distance from which it will be viewed and the appearance desired.

Aggregates with rough surfaces have better bonding properties than those with smoother surfaces; bind is important, particularly when small aggregate is used. For better weathering and appearance, the area of exposed cement matrix between pieces of aggregate should be minimal, which makes the color of cement in exposed aggregate concrete less important.

Contributors:
Portland Cement Association, Skokie, Illinois; D. Neil Rankins, RGA/Virginia, Richmond, Virginia; Portland Cement Association, Skokie, Illinois.

EXPOSURE METHODS FOR ARCHITECTURAL CONCRETE SURFACES
5.45

METHOD	FINISH EFFECT	COLOR SOURCE	FORM SURFACE	CRITICAL DETAILS
1. As cast	Remains as is after form removal; usually exhibits board marks or wood grain	Cement first influence; fine aggregate second influence	Smooth and textured	• Slump = 2-1/2″ to 3-1/2″ • Joinery of forms Proper release agent • Point form joints to avoid marks
2. Abrasive blasted surfaces				
a. Brush blast	Uniform scour cleaning	Cement and fine aggregate have equal influence	All smooth	• Scouring after 7 days • Slump = 2-1/2″ to 3-1/2″
b. Light blast	Blasted to expose fine and some coarse aggregate (sandblast, water blast, air blast, ice blast)	Fine aggregate primary; coarse aggregate and cement secondary	All smooth	• 10% more coarse aggregate • Slump = 2-1/2″ to 3-1/2″ • Blasting between 7 and 45 days • Water and air blasting used where sandblasting is prohibited. • 1500 PSI concrete compressive strength, min.
c. Medium exposed aggregate	Blasted to expose coarse aggregate (sandblast, water blast, air blast, ice blast)	Coarse aggregate	All smooth	• Higher than normal coarse aggregate • Slump = 2″ to 3″ • Blast before 7 days
d. Heavy exposed aggregate	Blasted to expose coarse aggregate (sandblast, ice blast); 80% visible	Coarse aggregate	All smooth	• Special-mix coarse aggregate • Slump = 0″ to 2″ • Blast within 24 hours • Use high-frequency vibrator
3. Chemical retardation of surface set	Chemicals expose aggregate	Coarse aggregate and cement	All smooth; glass fiber best	• Chemical grade determines etch depth. • Stripping scheduled to prevent long drying between stripping and washoff.
	Aggregate can be adhered to surface.			
4. Mechanically fractured surfaces, scaling, bush hammering, jackhammering, tooling	Varied	Fine and coarse cement and aggregate	Textured	• Aggregate particles 3/8″ for scaling and tooling. • 2-1/2″ min. concrete cover over reinforced steel • 4000 PSI concrete compressive strength, min.
5. Combination/fluted	Striated/abrasive blasted/irregular pattern	The shallower the surface, the more influence fine aggregate and cement have.	Wood or rubber strips, corrugated sheet metal, or glass fiber	• Depends on type of finish desired • Wood flute kerfed and nailed loosely
	Corrugated/abrasive			
	Vertical rusticated/abrasive blasted			
	Reeded and bush hammered			
	Reeded and hammered			
	Reeded and chiseled			
6. Grinding and polishing	Terrazzolike finish	Aggregate and cement	All smooth	• Surface blemishes should be patched. • 5000 PSI concrete compressive strength, min.

VISIBILITY OF EXPOSED AGGREGATE DEPENDENT ON AGGREGATE SIZE
5.46

AGGREGATE SIZE, (IN.)	DISTANCE AT WHICH TEXTURE IS VISIBLE (FT)
1/4–1/2	20–30
1/2–1	30–75
1–2	75–125
2–3	125–175

SURFACE TEXTURE/FORM LINER

Patterned forms and liners make it possible to simulate in concrete the textures of wood, brick, and stone at a lower cost. The texture and resulting shadow patterns conceal minor color variations or damage that would be conspicuous and unacceptable on a smooth surface. Use of rustication strips at joints in textured liners simplifies form assembly work.

The choice of liner material may depend on whether the work is precast, cast-in-place, or tilt-up. Thin liners that work well for horizontal casting may wrinkle and sag in vertical forms, where sturdier liner materials are required. Form liners such as plastic foams can usually be used only once, whereas many elastomeric liners are good for 100 or more uses, with reasonable care.

Reusable aluminum wall forms, textured with various patterns, can also be used; sections are held together with metal pins. Typical sizes are 3 ft. by 8 ft. and larger.

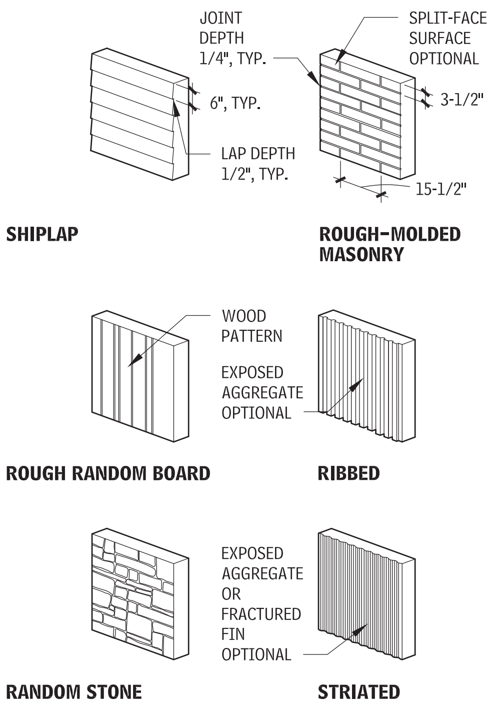
Making a preconstruction mock-up is helpful in choosing patterned liner materials. If built on-site, the mock-up can be used as a reference standard for inspectors and workers. If ribbed liners are specified, the largest aggregate particle should be smaller than the rib.

Typical form liner materials are:

- *Plyform:* Sandblasted, wire-brushed, or striated plyform can be used as form sheathing or as a liner inside other structurally adequate forms.
- *Unfinished sheathing lumber:* Used to produce rough, board-marked concrete, this lumber can be used as form sheathing or liner. Ammonia spray on wood will raise grain and accentuate the wood pattern.
- *Rigid plastics:* ABS, PVC, and high-impact polystyrene sheets can be molded or extruded to produce nearly any pattern or texture. Although typically supplied in sheets of 4 ft. by 8 ft., 4 ft. by 10 ft., and 4 ft. by 12 ft., they can be special ordered in lengths up to 30 ft. or longer.
- *Glass fiber-reinforced plastics (GFRP):* These look much like other plastics but are stronger and more durable, particularly laminated GFRP. Extruded GFRP is less expensive (and less durable). Custom lengths up to 40 ft. are available.
- *Elastomeric plastics:* These rubbery liners, typically polyurethane, are the most costly, but they are very strong and durable and flexible enough to accommodate finer details. Standard sheets in sizes up to 4 ft. by 12 ft. are available, as are larger custom sheets. Typically attached to form sheathing with adhesive, they are sensitive to temperature change and may deform; consult manufacturers.
- *Polystyrene foam:* Single-use liners are used to produce unique patterns for specific jobs.

Joints in the forms and liners must be executed carefully, and the liners handled properly to achieve high-quality workmanship. Check liners for compatibility with release agents and adhesives.

REUSABLE FORM LINER PATTERNS
5.47



INTEGRALLY COLORED CEMENT

Two standard types of cement are available, offering different shades of color: standard gray portland cement, and white cement. Integrally colored concrete is produced by adding mineral oxide pigments to concrete mixes made with one of these two types. Fine aggregates should be selected carefully, as they can enhance the color effect. The amount of coloring material should not exceed 10 percent by weight of the cement; any excess pigment may

NOTE

5.47 Consult manufacturers for other available patterns.

reduce concrete strength, and strong colors can be achieved with less than 10 percent pigment. White cement is used when lighter, more delicate shades of concrete are desired, although it is more expensive; darker hues can be produced using gray cement.

- Variations in components of the concrete mix mean that color formulas can only be approximate. After a basic color is selected, the exact shade should be determined by preparing a number of small panels, varying the ratio of pigment to cement, with aggregate playing a more important role in exposed aggregate mixes. To evaluate panels properly, store them for about five days under conditions similar to those on the construction site. Panels lighten as they dry.
- Batching, mixing, placing, and curing practices must be uniform, and sources of ingredients must be constant throughout a job to maintain color uniformity. Avoid admixtures that contain calcium chloride, as it can cause discoloration. Clean forms and non-staining release agents are vital. Consult pigment manufacturers' recommendations.
- Pigments should meet the quality standards of ASTM C 979. Finely ground iron oxides are the most widely used pigments for coloring concrete. Colors and their sources include blue (cobalt oxide), brown (brown iron oxide), buff (yellow iron oxide), green (chromium oxide), red (red iron oxide), and gray/slate (black iron oxide).
- Color-conditioning admixtures offer integral color and have additives that improve workability, better disperse color and cement, and reduce color bleeding for improved uniformity. Consult manufacturers.

COLORED CONCRETE SLABS

Colored concrete can provide a cost-effective simulation of natural stone or other building materials.

A pearly gray polished concrete floor can be a thing of beauty. But the days of gray-only for concrete floors are long gone. The color choices for concrete are as unlimited as dreams and imagination.

Particularly when used with concrete polishing, coloring can provide translucent, almost gem-like effects.

Following are the six most common ways to color horizontal concrete.

1. **Integral coloring.** Colorant added to concrete during mixing produces uniform color throughout the slab.
   The colorant may be liquid or powder. Integral color is for new installations only, and usually only for large monochrome areas, since the main application device is a ready mix truck. Integral colors are expensive because the entire depth of the slab is being colored.
2. **Shake-on colors.** Shake-on color consists of finely ground pigments and dry cement that are "broadcast" onto freshly placed concrete. The powder gets worked into the concrete during bull-floating.
   Bleed water from the plastic concrete wets the cement powder, causing it and the pigments to bond to the exposed surface. Because the pigments are concentrated in the top layer, grinding and polishing will remove the color. Since shake-on colors rely on water from freshly placed concrete, they are only suitable for use on freshly placed concrete.
3. **Acid stains.** Acid stains are formulas of acid, metallic salts, and water. The acid chemically reacts with minerals in the concrete, creating a unique, mottled color effect that's as durable as the wear zone of the concrete it's applied to. Acid stains are hazardous materials and require all the safety precautions common to acidic products.
   Concrete floors that have been acid stained must be neutralized and rinsed thoroughly to remove any excess acid. You must be careful when handling acid stains, also, because spills, sloshes, and drips instantly create permanent "features" in the floor. Acid stains can be used for retrofits or new installations.
4. **Acetone dyes.** The benefits of fast-drying solvent-based dyes are often overshadowed by the risks inherent with using highly flammable reduction solvents. Acetone, one of the most common reduction solvents, has a flash point of −4 degrees Fahrenheit and an odor and toxicity that makes it impractical to use in most occupied spaces. The color usually is applied after the floor has been polished with a 400-grit resin.
   Though solvent-based dyes can impart vivid colors, they aren't UV-stable. Sunlight, through a window or skylight, can fade the colors. Most require a topical protective treatment to lock in the color. Respirators and explosion-proof ventilation are required when installing solvent-based dyes on new or existing concrete floors.
5. **Water-based dyes.** Water-based stains and dyes have several advantages. They are odorless, safe and easy to apply, and dry quickly. Different colors can be easily mixed and matched, creating striking patterns and effects in areas large or small. Combined with hardening, densifying, and polishing, water-based stains can create a translucent, gemlike effect. However, water-based stains must be used with protective coatings to lock in the color. Like acetone dyes, they are not UV-stable and will fade in direct sunlight. Water-based dyes can be used for new installations or retrofits.
   Water-based colors are easily applied with pump-up or airless sprayers, followed by spreading with a microfiber pad. The color usually goes on before the floor has been hardened and densified.
6. **Color hardeners/densifiers.** Color hardeners/densifiers are a recent innovation in which fine pigments suspended in water are blended by the applicator with a lithium-silicate hardener/densifier. This allows hardening/densifying and coloring in one step. Apply color hardeners/densifiers to concrete floors ground no finer than with a 200-grit resin pad.
   The pigments in these products are similar to shake-on colors in that they are surface treatments, so polishing after application removes the color. Also like shake-on colors, most are UV-stable and suitable for exterior application. While a protective treatment to "lock in" the color isn't needed, strictly speaking, protective treatments are always a good idea for horizontal concrete, inside or out.

CONCRETE COATINGS

PROTECTIVE AND DECORATIVE COATINGS

Concrete surfaces may require a sealer or coating to protect against severe weather, chemicals, or abrasions; to prevent dusting of the surface layer; to harden the surface layer; or to add a decorative finish.

Sealers are usually clear and are expected to penetrate the surface without leaving a visible film. Coatings are clear or opaque and, while they may have some penetration, they leave a visible film on the surface. Sealers and coatings should allow vapor emission from the concrete but at the same time keep moisture from penetrating after curing.

Decorative coatings usually protect as well, and are formulated in a wide selection of colors. Decorative coatings include water-based acrylic emulsion, elastomeric acrylic resin, liquid polymer stain, solvent-based acrylic stain, portland cement–based finish coating, and water-based acidic stain (a solution of metallic salts).

PROTECTIVE COATINGS AND SEALERS
5.48

FINISH	USE
Cementitious acrylic polymeric coating	Aesthetic treatment
Two-component epoxy coating	Protects damp or underwater surfaces.
Solvent-based aliphatic urethane coating	Resists graffiti, chemicals, abrasion.
Epoxy coal tar-based coating	Waterproof; resists corrosion.
Coal tar-modified epoxy resin coating	Nonskid waterproof surface membrane
Water-based epoxy coating	Chemical and abrasion resistance for interiors
Vinyl ester-based coating	High chemical resistance
Aliphatic urethane coating	Chemical and abrasion resistance
Solvent-based acrylic methacrylate copolymer sealer	Reduces water penetration.
Silane/siloxane sealer-penetrating water repellent	Protects from deicers and freeze/thaw damage.

Floor-hardening agents are applied to reduce dusting and increase slightly the hardness at the surface. Consult a qualified specialist to determine the correct coating or sealer for a particular application. There may be restrictions on the use of solvent-based coatings and sealers in some areas due to the presence of volatile organic compounds (VOCs).

Contributors:
Grant Halvorsen, SE, PE, Wheaton, Illinois; Portland Cement Association, Skokie, Illinois.

MASONRY

6

TYPICAL COMPONENTS APPLICABLE TO MASONRY WORK

CLAY MASONRY UNITS

BRICK CLASSIFICATION

Brick and tile are classified according to the specific location where they are used. Standard specifications have been developed to produce uniform requirements for brick. ASTM International publishes the most widely accepted standards on brick. Standard specifications include strength, durability, and aesthetic requirements.

CLAY MASONRY CLASSIFICATION TYPES
6.1

TYPE OF BRICK UNIT	ASTM DESIGNATION
Building brick	C 62
Facing brick	C 216
Hollow brick	C 652
Paving brick	C 902
Paving brick (heavy vehicular)	C 1272
Ceramic glazed brick	C 126
Thin brick veneer units	C 1088
Chemical-resistant brick	C 279
Industrial floor brick	C 410

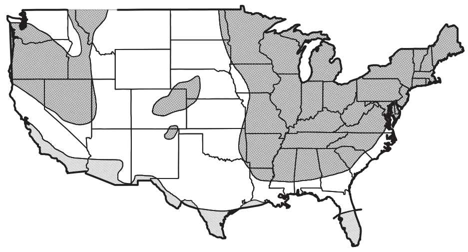
GENERAL REQUIREMENTS

Terms used in each standard for brick classification may include exposure, appearance, physical properties, efflorescence, dimensional tolerances, distortion, chipping, core, and frogs. Brick may be classified by use, grade (exposure), and type (appearance). Properties should be identified. Each ASTM standard has minimum requirements for grade and type, which will be used as the default property if another is not specified.

GRADE REQUIRMENTS FOR FACE EXPOSURE

Specific grades of brick are required to accommodate the various climates in the United States and the different applications in which brick can be used. Brick grades include Severe Weathering (SW), Moderate Weathering (MW), and Negligible Weathering (NW); each is based on the weathering index and the exposure they will receive. The weathering index is the product of the average annual number of freezing cycle days and the average annual winter rainfall in inches (see Figure 6.2). The exposure is related to whether the brick is used on a vertical or horizontal surface and whether the unit will be in contact with the earth (see Figure 6.3). A higher weathering index or a more severe exposure will require face brick to meet the SW requirements. The grades for each specification are listed in Figure 6.4.

U.S. WEATHERING INDEXES
6.2



LESS THAN 50
50 TO 500
500 AND GREATER

SEE TABLE 6.3 FOR EXPOSURE SPECIFICATIONS.

EXPOSURE
6.3

EXPOSURE	WEATHERING INDEX LESS THAN 50	WEATHERING INDEX 50 AND GREATER
IN VERTICAL SURFACES		
In contact with earth	MW	SW
Not in contact with earth	MW	SW
IN OTHER THAN VERTICAL SURFACES		
In contact with earth	SW	SW
Not in contact with earth	MW	SW

AESTHETICS AND SHAPES

Brick is readily available in many sizes, colors, textures, and shapes, all adaptable for virtually any style or expression. Brick's small module can be related to the scale of the wall, and its sizes can be combined to create different appearances and patterns. Sizes available are shown in Figure 6.5.

When specifying the size of units, dimensions should be listed in this order: width by thickness by length. The size of the brick influences cost because larger units require fewer bricks, usually resulting in less labor.

Specially shaped bricks are available to add interest to a wall, including water table bricks, radials, caps, copings, corners, and others. Consult the manufacturer for specific sizes and availability.

GRADE REQUIREMENTS FOR FACE EXPOSURES
6.4

ASTM STANDARD	MORE SEVERE EXPOSURE		LESS SEVERE EXPOSURE
C 62 Grade	SW	MW	NW
C 216 Grade	SW	MW	
C 652 Grade	SW	MW	
C 902 Grade	SX	MX	NX
C 126[a]	—	—	—
C1088 Grade	Exterior	Interior	

STANDARD NOMENCLATURE FOR BRICK SIZES
6.5

MODULAR BRICK SIZES								
UNIT DESIGNATION	NOMINAL DIMENSIONS (IN.)			JOINT THICKNESS[a] (IN.)	SPECIFIED DIMENSIONS[b] (IN.)			VERTICAL COURSING
	W	H	D		W	H	L	
Modular	4	2–2/3	8	3/8	3–5/8	2–1/4	7–5/8	3C = 8 in.
				1/2	3–1/2	2–1/4	7–1/2	
Engineer Modular	4	3–1/5	8	3/8	3–5/8	2–3/4	7–5/8	5C = 16 in.
				1/2	3–1/2	2–13/16	7–1/2	
Closure Modular	4	4	8	3/8	3–5/8	3–5/8	7–5/8	1C = 4 in.
				1/2	3–1/2	3–1/2	7–1/2	
Roman	4	2	12	3/8	3–5/8	1–5/8	11–5/8	2C = 4 in.
				1/2	3–1/2	1–1/2	11–1/2	
Norman	4	2–2/3	12	3/8	3–5/8	2–1/4	11–5/8	3C = 8 in.
				1/2	3–1/2	2–1/4	11–1/2	
Engineer Norman	4	3–1/5	12	3/8	3–5/8	2–3/4	11–5/8	5C = 16 in.
				1/2	3–1/2	2–13/16	11–1/2	
Utility	4	4	12	3/8	3–5/8	3–5/8	11–5/8	1C = 4 in.
				1/2	3–1/2	3–1/2	11–1/2	

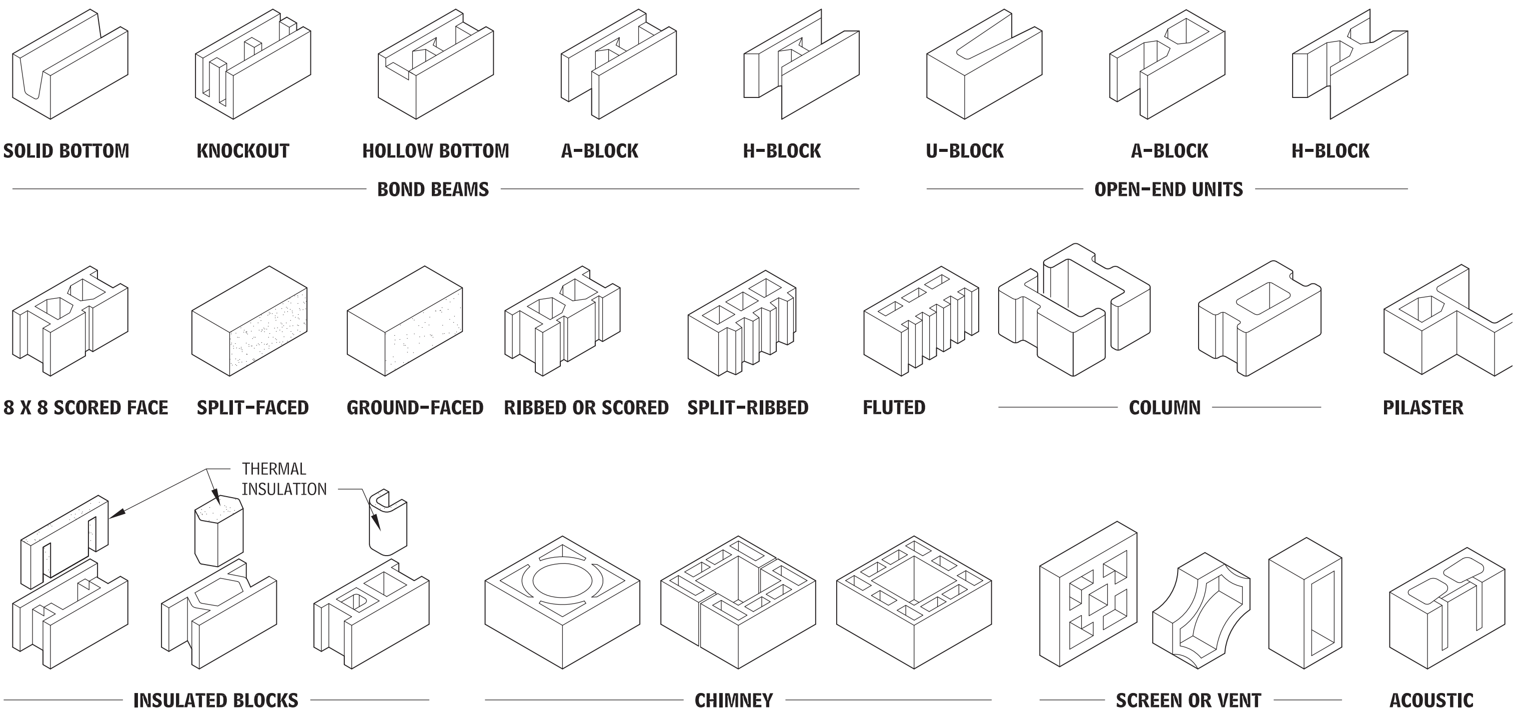
NOTES

6.3 See Figure 6.2 for U.S. Weathering Indexes.
6.4 a. No requirements for durability.
b. Based on durability and abrasion.
6.5 a. Common joint sizes used with length and width dimensions. Actual joint thicknesses vary between bed joints and head joints.
b. Specified dimensions may vary within this range among manufacturers.

STANDARD NOMENCLATURE FOR BRICK SIZES (continued)
6.5

NONMODULAR BRICK SIZES								
Standard		3/8	3–5/8	2–1/4	8	3C = 8 in.		
		1/2	3–1/2					
Engineer Standard		3/8	3–5/8	2–3/4	8	5C = 16 in.		
		1/2	3–1/2	2–13/16				
Closure Standard		3/8	3–5/8	3–5/8	8	1C = 4 in.		
		1/2	3–1/2	3–1/2				
King		3/8	3	2–3/4	9–5/8	5C = 16 in.		
			2–3/4	2–5/8	9–5/8			
Queen		3/8	3	2–3/4	8	5C = 16 in.		
			2–3/4	2–3/4	8			

COMMON CONCRETE MASONRY UNIT SHAPES
6.6



CONCRETE MASONRY UNITS

GENERAL

Concrete masonry units (CMU) conform to ASTM standard specifications. The most common concrete masonry units used in building construction are load-bearing units and concrete brick. Load-bearing units are commonly used for structural building applications and for exposed architectural facing applications. Non-load-bearing units are commonly used for partitions, fire-rated construction, and architectural veneers. Concrete brick are used for utilitarian purposes.

ASTM standards include requirements for the materials used in the manufacture of concrete masonry units, as well as performance requirements for the unit's dimensional tolerance, compressive strength, absorption (a measure of concrete void structure), and, sometimes, potential drying shrinkage. "Type" and "grade" are no longer used in classification of concrete masonry units.

Conventional gray concrete masonry units are the most common, and are frequently used as a backup building material or for utilitarian purposes. When used as an exterior product, these units may be prefaced with a resinous tile, painted, plastered, or otherwise coated.

Concrete masonry units are also available in a variety of colors, sizes, and textures to achieve a wide range of desired architectural effects. Lightfast, metallic-oxide pigments are used to integrally color the units, primarily in a variety of earth-tone colors. Significant advancements have also been made related to surface treatments to enhance appearance. Splitface units have rocklike textures. Tumbling and other methods are used to soften edges and provide an aged appearance to the units. Additionally, the face surface can be ground and polished. Integral water-repellent admixtures can be added during unit production to assist in repelling water from wind-driven rain.

Concrete masonry units are available in numerous sizes and configurations to accommodate construction needs. The outside dimensions of common units are indicated as width by height by length. The nominal dimensions are usually 3/8 in. larger than the actual unit dimensions to accommodate a standard mortar joint thickness. The most common nominal widths of concrete masonry units are 4 in., 6 in., 8 in., 10 in., and 12 in., but larger widths may be available. Nominal unit heights are usually 8 in. and 4 in., except concrete bricks, which are typically 2–2/3 in. high. Nominal unit lengths are usually 16 in. for concrete masonry units and 8 in. for concrete brick.

Specialty units are available for corners, openings, columns, and other construction needs. Acoustic concrete masonry units are made with slots, baffles, or other features to dampen sound and reduce noise within interior spaces. Individual manufacturers should be consulted for a complete list of available colors, textures, sizes, and configurations.

The weight of the units also varies. Depending on the aggregate used, concrete masonry units are typically made using concrete, with densities ranging from 85 to 145 lb. per cu ft. The lighter units tend to provide better fire resistance and have a better noise reduction coefficient for sound absorption, and often are more economical to place in the wall. Heavier units tend to provide increased compressive strength, have better sound transmission class values to minimize noise penetration, higher water penetration resistance, and greater thermal storage capabilities.

ASTM STANDARD SPECIFICATIONS CONCRETE MASONRY

- C 55—Concrete Brick
- C 73—Calcium Silicate Face Brick (sand-lime brick)
- C 90—Load-Bearing Concrete Masonry Units
- C 139—Concrete Masonry Units for the Construction of Catch-Basins and Manholes
- C 744—Prefaced Concrete and Calcium Silicate Masonry Units
- C 936—Solid Interlocking Concrete Paving Units
- C 1372—Segmental Retaining Wall Units

Contributors:
National Concrete Masonry Association, Herndon, Virginia; Grace S. Lee, Rippeteau Architects, PC, Washington, DC.

GLASS UNIT MASONRY

GLASS BLOCK: DESIGN DATA

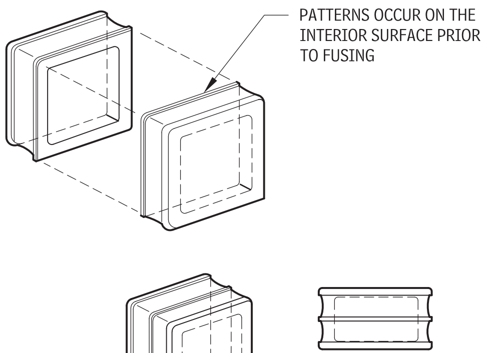
GENERAL

Glass block is a diverse building material whose many applications exhibit its multifaceted characteristics. The varying forms of glass block—type, thickness, size, shape, and patterns—along with the method of installation can be combined to create unique design solutions. Applications range from entire facades, windows, interior dividers, and partitions to skylights, floors, walkways, and stairways. In all applications, glass block units permit the control of light, both natural and artificial, for function or drama. Glass block also allows for control of thermal transmission, noise, dust, and drafts. Thick-faced glass block and solid 3-in. block are impact-resistant and can assist in security applications.

TYPES OF BLOCKS

The basic glass block unit is made of two halves fused together with a partial vacuum inside. Units may be transparent, translucent, or opaque, and may also be colored and/or patterned. Other options may be available; consult the manufacturer.

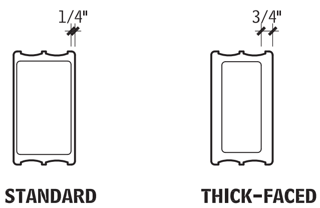
SQUARE GLASS BLOCK UNITS
6.7



Glass block is available in thicknesses ranging from a minimum of 3 in. for solid units to a maximum of 4 in. (nominal) for hollow units.

Some manufacturers provide thick blocks for critical applications where a thick-faced, heavier glass block is needed. These blocks have superior sound transmission rating properties, as their faces are three times as thick as standard units.

BLOCK FACE THICKNESS COMPARISON
6.8



Solar control units have either inserts or exterior coatings to reduce heat gain. Coated units require periodic cleaning to remove alkali and metal ions that can harm the coating. Edge drips are required to prevent moisture rundown on the surface.

End block units have a rounded, finished surface on one edge. They may be used to end interior partitions or walls, or serve as space dividers when installed horizontally.

Surface decoration may be achieved with fused-on ceramic, etching, or sandblasting.

TYPICAL THERMAL PERFORMANCE/LIGHT TRANSMISSION[a,c]
6.9

BLOCK TYPE	HEAT TRANSMISSION[b] U-VALUE (BTU/HR SQ FT °F)	THERMAL RESISTANCE[b] R-VALUE (HR SQ FT °F/BTU)	THERMAL EXPANSION COEFFICIENT(/°F)	VISIBLE LIGHT TRANSMISSION (%)	SHADING COEFFICIENT[d]
Standard (3–7/8 in. thick)	0.51 (0.48 with fibrous filter)	1.96 (2.08 with fibrous filter)	47×10^7	75	0.65
Reflective Coated	0.51	1.96	47×10^7	5–20	0.20–0.25
Thin (3–1/8 in. thick)	0.57 (0.54 with fibrous filter)	1.75 (1.85 with fibrous filter)	47×10^7	75	0.65
Solid	0.87	1.15	47×10^7	80	
Monolithic glass	1.04	0.96	47×10^7	90	1.00

STONE ASSEMBLIES

STONE USES AND PROPERTIES

GENERAL

Stone assemblies include both natural and cut stone that can be used in many construction applications. The major factors affecting the suitability and use of stone for construction fall under two broad, but overlapping categories: physical and structural properties and aesthetic qualities. The three factors of building stone that most influence their selection by design professionals for aesthetic reasons are pattern, texture, and color. Consideration also should be given to cost, availability, weathering characteristics, physical properties, and size limitations.

Stone patterns are highly varied, and provide special features that make building stone a unique material. Texture ranges from coarse fragments to fine grains and crystalline structures. Texture also varies with the hardness of minerals composing the stone. To accurately compare stone colors, the rock color chart published by the Geological Society of America (Boulder, Colorado) is recommended. Samples also may be used to establish acceptable color ranges for a particular installation.

Pattern, texture, and color all are affected by how the stone is fabricated and finished. Granites tend to hold their color and pattern, whereas limestone color and pattern change with exposure. Textures may range from rough and flamed finishes to honed or polished surfaces. The harder the stone, the better it takes and holds a polish.

Stone is obtained by quarrying and has two general shapes: cut and rubble.

- Rubble is irregular in size and shape. Collected natural stone includes excavated stone, field stone, and riverbed stone. It may

NOTES

6.9 a. Values equal ± 5 percent.
b. Winter night values.
c. To calculate instantaneous heat gain through glass block panels, see ASHRAE *Handbook of Fundamentals*.
d. Based on 8-in. square units: ratio of heat gain through glass block panels versus that through a piece of double-strength monolithic glass under specific conditions.

Contributor:
Grace S. Lee, Rippeteau Architects, PC, Washington, DC.

be weathered smooth, but remains irregular and uneven. The second type of rubble, quarry rubble, includes the fragments of stone left over from the cutting and removal of large stone slabs at the quarry. It has freshly broken faces, which may be sharp and angular.

- Cut stone is either dimension stone or cleft-faced stone. Cut stone is delivered from fabricators who have cut and dressed the stone to a specific size, squared to dimension each way, and to a specific thickness. Surface treatments include a rough or natural split face, smooth, slightly textured, or polished finishes. Ashlar is a type of flat-faced dimension stone, generally in small squares or rectangles, with sawed or dressed beds and joints, while dimension stone is typically in a larger block format.

PHYSICAL PROPERTIES OF STONE

The physical characteristics of a particular stone must be suitable for its intended use. It is important to determine the physical properties of the actual stone being used rather than using values from a generic table, which can be very misleading. Considerations of the physical properties of the stone being selected include modulus of rupture; shear strength; coefficient of expansion; creep deflection; compressive strength; modulus of elasticity; moisture resistance; and weatherability.

In addition to accessibility and ease of quarrying, building stone must satisfy requirements for strength, hardness, workability, porosity, durability, and appearance.

- Typically, the compressive strength of building stone is many times higher than required by the loads imposed on them in contemporary construction. Flexural and shear strength are relatively low. Both compressive strength and hardness are proportional to silica content.
- Hardness of stone is critically important only in horizontal planes such as flooring and paving, but hardness does have a direct influence on workability. Characteristics may vary from soft sandstone, which is easily scratched, to very hard stones such as granite.
- Workability refers to the ease with which a stone may be sawed, shaped, dressed, or carved, and will directly affect the cost of production. Workability decreases as the percentage of silica increases. Limestone, for instance, which contains little silica, is easily cut, drilled, and processed. Granite, in contrast, has high silica content, and is the most difficult stone to cut and finish.
- Porosity, the percentage of void content, affects a stone's absorption of moisture, thus influencing its ability to withstand frost action and repeated freeze/thaw cycles. Pore spaces are usually continuous, and often form microscopic cracks of irregular shape. Sandstone and limestone are more porous than granite and marble. Due to its porosity, stone selection should take into consideration both application and adjacent construction materials, such as sealant, that may cause staining of the stone.
- Closely linked to porosity are grain and texture, which influence the ease with which stones may be split, and for ornamental purposes contribute to aesthetic effects as much as color.
- Durability of stone, or its resistance to wear and weathering, is also considered analogous to silica content. This is perhaps the most important characteristic of stone because it affects the life span of a structure. Granite is more durable than other building stones because it contains more silica.

In terms of practicality and long-term cost, durability is the most important consideration in selecting building stones. Suitability will depend not only on the characteristics of the stone, but also on local environmental and climatic conditions. Water is the most active agent in the destruction of stone. In warm, dry climates, almost any stone may be used with good results. Stones of the same general type such as limestone, sandstone, and marble differ greatly in durability based on softness and porosity. Soft, porous stones are more liable to absorb water and to flake or deteriorate in heavy frosts, and may not be suitable in the colder and moister northern climates.

PHYSICAL PROPERTIES AND MINIMUM ASTM REQUIREMENTS
6.10

STONE TYPE	MAXIMUM ABSORPTION BY WEIGHT, ASTM C97 (%)	MINIMUM DENSITY, ASTM C97 (%)	MINIMUM COMPRESSIVE STRENGTH, ASTM C170 (PSI)	MINIMUM MODULUS OF RUPTURE, ASTM C99 (PSI)	MINIMUM ABRASION RESISTANCE ASTM C241 (HARDNESS)	MINIMUM FLEXURAL STRENGTH, ASTM C880 (PSI)	MAXIMUM ACID RESISTANCE, ASTM C217 (IN.)	THERMAL EXPANSION COEFFICIENT (10 V°F)	MODULUS OF ELASTICITY (PSI)	ULTIMATE SHEAR STRENGTH (PSI)	ULTIMATE TENSILE STRENGTH (PSI)
Marble ASTM C503								3.69–12.3C	1,970,000–14,850,000	1638–4812	50–2,300
I. Calcite	0.20	162	7500	1000	10	1000	N/A				
II. Dolomite	0.20	175	7500	1000	10	1000	N/A				
III. Serpentine	0.20	168	7500	1000	10	1000	N/A				
IV. Travertine	0.20	144	7500	1000	10	1000	N/A				
Limestone ASTM C568								2.4–3.0	3,300,000–5,400,000	900–1800	300–715
I. Low Density	12.0	110	1800	400	10	—	N/A				
II. Medium Density	7.5	135	4000	500	10	—	N/A				
III. High Density	3.0	160	8000	1000	10	—	N/A				
									5,700,000–8,200,000	2000–4800	600–1,000
Granite ASTM C615	0.40	160	19,000	1500	—	—	N/A	6.3–9.0			
Quartz-Based Stone ASTM C616								5.0–12.0	1,900,000–7,700,000	300–3000	280–500
I. Sandstone	20.0	135	2,000	300	8	—	N/A				
II. Quartzite Sandstone	3.0	150	10,000	1000	8	—	N/A				
III. Quartzite (Bluestone)	1.0	160	20,000	2000	8	—	N/A				
									9,800,000–18,000,000	2000–3600	3,000–4,300
Slate ASTM C629								9.4–12.0			
I. Exterior	0.25	—	—	Across grain, 9000	8	—	0.015				
II. Interior	0.45	—	—	Along grain, 7200	8	—	0.025				

TYPES OF STONE

The three rock classes are igneous, sedimentary, and metamorphic. Despite their abundant variety, relatively few types of stone are suitable as building materials. Granite, limestone, marble, slate, and sandstone are the most common building stones in the United States. Many others, such as quartzite and serpentine, are used locally or regionally, but to a much lesser extent.

GRANITE

Compressive strength may range from 7700 to 60,000 psi, but ASTM C615, "Standard Specification for Granite Dimension Stone" requires a minimum of 19,000 psi for acceptable performance in building construction. While the hardness of the stone lends itself to a highly polished surface, it also makes sawing and cutting very difficult. Granite is used for flooring, paneling, veneer, column facings, stair treads, flagstones, and in landscape applications.

LIMESTONE

The most "pure" form is crystalline limestone, in which calcium carbonate crystals predominate, producing a fairly uniform white or light gray stone of smooth texture. It is highest in strength and lowest in absorption of the various types of limestone. Dolomitic limestone is somewhat crystalline in form, and has a greater variety of texture. Oolitic limestone is noncrystalline, has no cleavage planes, and is very uniform in composition and structure.

The compressive strength of limestone varies from 1800 to 28,000 psi, depending on the silica content. ASTM C568, "Standard Specification for Limestone Dimension Stone" classifies limestone in three categories: I (low-density); II (medium-density); and III (high-density), with minimum required compressive strengths of 1800, 4000, and 8000 psi, respectively. Limestone is much softer, more porous, and more absorptive than granite. Although it is quite soft when first taken from the ground, limestone weathers hard upon exposure. Its durability is greatest in drier climates.

Impurities affect the color of limestone. Iron oxides produce reddish or yellowish tones while organic materials such as peat give a gray tint. Limestone textures are graded as:

- A—Statuary
- B—Select
- C—Standard
- D—Rustic
- E—Variegated
- F—Old Gothic

Grades A, B, C, and D come in buff or gray, and vary in grain from fine to coarse. Grade E is a mixture of buff and gray, and is of unselected grain size. Grade F is a mixture of D and E and includes stone with seams and markings.

Limestone is used as cut stone for veneer, caps, lintels, copings, sills, and moldings, and as ashlar with either rough or finished faces. Veneer panels or slabs may be sliced in thicknesses ranging from 1 in. to 6 in. and face sizes from 3 ft. by 5 ft. to 5 ft. by 14 ft. As panel size increases, panel thickness must increase as well. Collected and quarry rubble are often used as rustic veneers on residential and low-rise commercial buildings. Travertine is a porous limestone characterized by small pockets or voids. The pockets common to travertine may be filled to provide a consistent surface, prior to polishing. This natural and unusual texturing presents an attractive decorative surface highly suited to facing materials and veneer slabs.

MARBLE

Marble often has compressive strengths as high as 20,000 psi, and when used in dry climates or in areas protected from precipitation, the stone is quite durable. Some varieties, however, deteriorate by weathering or exposure to industrial fumes and are suitable only for interior work. ASTM C503, "Standard Specification for Marble Dimension Stone (Exterior)" covers four marble classifications, each with a minimum required compressive strength of 7500 psi: I, Calcite; II, Dolomite; III, Serpentine; and IV, Travertine. More than 200 imported and domestic marbles are available in the United States. Each has properties and characteristics that make it suitable for different types of construction.

Marbles are classified as A, B, C, or D on the basis of working qualities, uniformity, flaws, and imperfections. For exterior applications, only group A, highest-quality materials should be used. The other groups are less durable and therefore less suitable for use in exterior unprotected areas. Group B marbles have less favorable working properties than Group A, and will have occasional natural faults requiring limited repair. Group C marbles have uncertain variations in working qualities; contain flaws, voids, veins, and lines of separation; and will always require some repair (known as sticking, waxing, filling, and reinforcing). Group D marbles have an even higher proportion of natural structural variations requiring repair, and have great variation in working qualities.

Marble is available as rough or finished dimension stone, as thin veneer slabs for wall and column facings, flooring, partitions, tiles, and other decorative surface work. Veneer slabs may be cut in thicknesses from 3/4 in. to 2 in. Light transmission and translucence diminish as thickness increases.

SLATE

It is characterized by distinct cleavage planes, permitting easy splitting of the stone into slabs 1/4 in. or more in thickness. Used in this form, slate provides an extremely durable material for flooring, roofing, sills, stair treads, and facings. ASTM C629, "Standard Specification for Slate Dimension Stone" requires that both Type I exterior and Type II interior slate have a minimum modulus of rupture of 9000 psi across the grain, and 7200 psi along the grain.

Small quantities of other mineral ingredients give color to the various slates. Carbonaceous materials or iron sulfides produce dark colors such as black, blue, and gray; iron oxide produces red and purple; and chlorite produces green tints. "Select" slate is uniform in color and more costly than "ribbon" slate, which contains stripes of darker colors.

SANDSTONE

Sandstone can be categorized by grain size and cementing agent. Siliceous sandstone is cemented together with silica. Many siliceous sandstones contain iron, which is oxidized by acidic pollutants (or acidic cleaners), which turn the stone brown. Ferruginous sandstone is cemented together with iron oxide, so it is naturally red to deep brown in color. Calcareous sandstone is cemented together with calcium carbonate, which is sensitive to acids and can deteriorate rapidly in a polluted environment. Dolomitic sandstone is cemented together with dolomite, which is more resistant to acid. Argillaceous sandstone contains large amounts of clay, which can quickly deteriorate simply from exposure to rain.

ASTM C616, "Standard Specification for Quartz-Based Dimension Stone" includes three stone classifications. Type I, sandstone, is characterized by a minimum of 60 percent free silica content; Type II, quartzite sandstone, by 90 percent free silica; and Type III, quartzite, by 95 percent free silica content. As a reflection of these varying compositions, minimum compressive strengths are 2000 psi, 10,000 psi, and 20,000 psi, respectively. Absorption characteristics also differ significantly, ranging from 20 percent for Type I to 3 percent for Type II and 1 percent for Type III. When first taken from the ground, sandstone contains large quantities of water, which make it easy to cut. As the moisture evaporates, the stone becomes considerably harder.

Sandstones vary in color from buff, pink, and crimson to greenish brown, cream, and blue-gray. Both fine and coarse textures are found, some of which are highly porous and therefore low in durability. The structure of sandstone lends itself to smooth and textured finishes for cut stone typically used in veneers, moldings, sills, and copings. Sandstone is also available in rubble masonry.

FINISHES

Much of the stone that is produced for building construction has a sawn finish, but stone may also be further dressed with hand or machine tools for hammered finishes, polished finishes, and honed or rubbed finishes. Honing is accomplished by rubbing the stone surface with an abrasive after it has been planed. Larger surfaces are done by machine, smaller surfaces and moldings by hand. Polished surfaces require repeated rubbing with increasingly finer abrasives. Only granite, marble, and some very dense limestones will take and hold a high polish. Power-driven lathes have been developed for turning columns, balusters, and other members that are round in section.

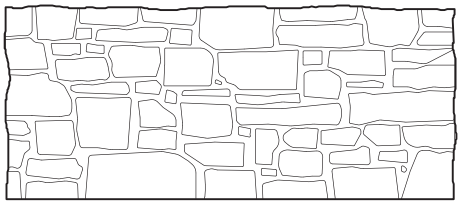
Hand-tooling is the oldest method of stone dressing. Working with pick, hammer, and chisels, the mason dresses each successive face of a stone, giving it the desired finish and texture. Hand-applied finishes include the bush-hammered, patent-hammered, pick-pointed, crandalled, and peen-hammered surface. Many of these finishes are now applied with pneumatic rather than hand tools, resulting in a more uniform surface. Ornate carving is still done by hand, both for new construction and for restoration and rehabilitation projects, although it is sometimes aided by pneumatic chisels.

STONE MASONRY PATTERNS AND VENEER

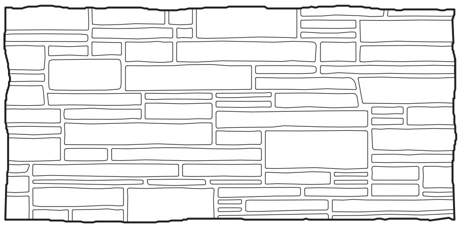
NOTES

- Structural bond refers to the physical tying together of load-bearing and veneer portions of a composite wall. Structural bond can be accomplished with metal ties or with stone units set as headers into the backup.
- Ties and anchors must be made of noncorrosive material. Chromium-nickel stainless steel types 302 and 304 and erado alloy zinc are the most resistant to corrosion and staining. Use stainless steel type 316 in highly corrosive environments. Copper, brass, and bronze will stain under some conditions. Local building codes often govern the types of metal that may be used for stone anchors.
- Nonstaining cement mortar should be used on porous and light-colored stones. At corners use extra ties and, when possible, larger stones. Joints for rough work are usually 1/2 to 1—1/2 in. and 3/8 to 3/4 in. for ashlar. Prevent electrochemical reaction between different metals combined in the same assembly by properly isolating or coating them.

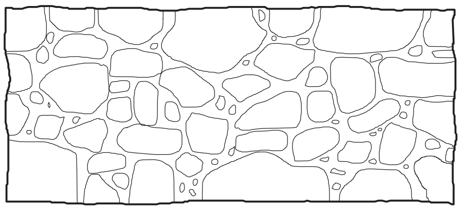
RUBBLE STONE MASONRY PATTERNS—ELEVATIONS
6.11



UNCOURSED ROUGHLY SQUARE PATTERN

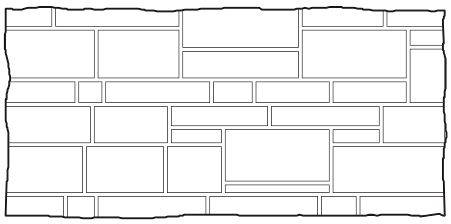


UNCOURSED LEDGE ROCK PATTERN

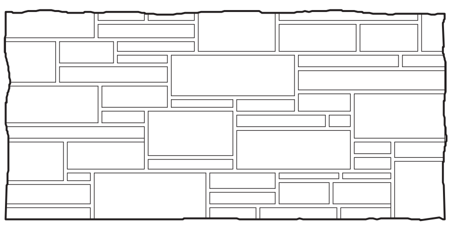


UNCOURSED FIELDSTONE PATTERN

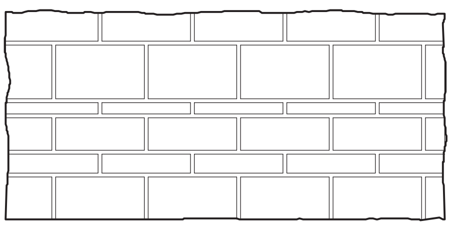
CUT STONE MASONRY PATTERNS—ELEVATIONS
6.12



RANDOM COURSED ASHLAR

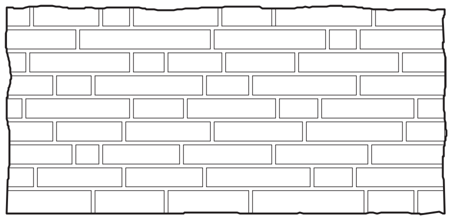


RANDOM BROKEN COURSED ASHLAR

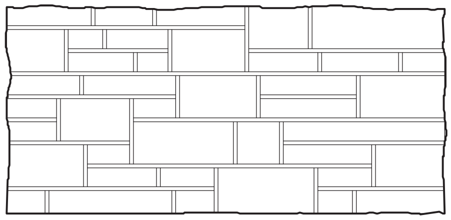


COURSED ASHLAR - RUNNING BOND

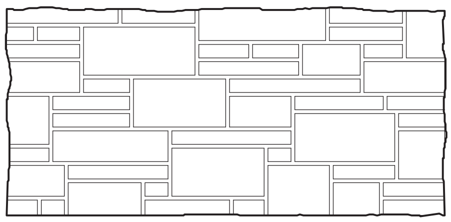
CUT STONE MASONRY HEIGHT PATTERNS—ELEVATIONS
6.13



ONE-HEIGHT PATTERN (SINGLE RISE)

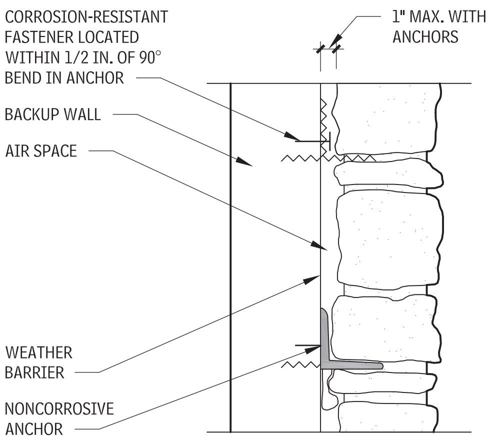


TWO-HEIGHT PATTERN (40% AT 2-1/4 IN.; 60% AT 5 IN.)

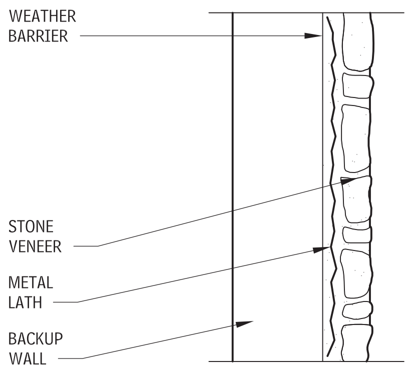


THREE-HEIGHT PATTERN (15% AT 2-1/4 IN.; 40% AT 5 IN.; 45% AT 7-3/4 IN.)

TYPICAL STONE VENEER SECTIONS
6.15

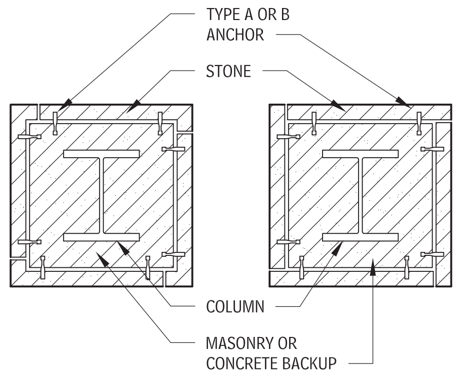


CAVITY WALL

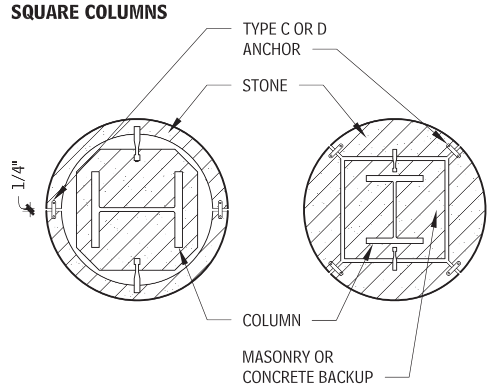


THIN VENEERED MASONRY ON METAL LATH

INSTALLATION DETAILS
6.14



SQUARE COLUMNS

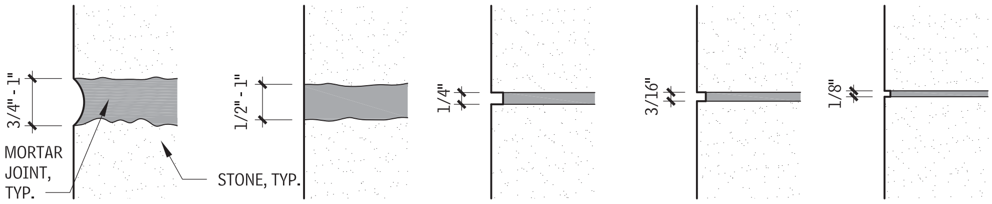


ROUND/QUADRANT COLUMNS

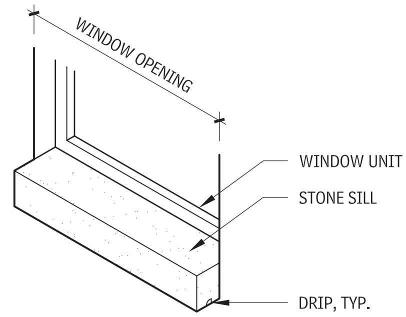
Contributors:
George M. Whiteside, III, AIA, and James D. Lloyd, Kennett Square, Pennsylvania; Building Stone Institute, New York, New York; Alexander Keyes, Rippeteau Architects, PC, Washington, DC; Christine Beall, NCARB, CCS, Austin, Texas.

STONE DETAILS

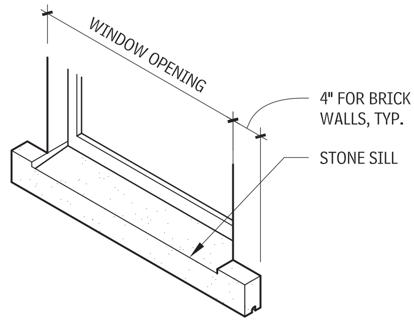
TYPICAL STONE JOINT DIMENSIONS
6.16



STONE SILL TYPES
6.17



SLIP SILL



LUG SILL

MASONRY MORTARING AND GROUTING

MORTAR AND GROUT

ASTM SPECIFICATIONS

ASTM C 270, "MORTAR FOR UNIT MASONRY"

ASTM C 270 standard specification addresses four types of mortar in two types of specifications: proportion specifications and property specifications.

Mortar conforming to the property specifications must be established by tests of laboratory-prepared mortar, which should be mixed from the mortar materials to be used in the masonry structure. Figure 6.18 provides the property requirements for Types M, S, N, and O mortars.

Although ASTM C 270 uses the same letters to designate mortar type under both the proportion and property specifications, the properties of these mortar types are not equivalent. A mortar mixed to the Type N proportion specification will have a laboratory-prepared compressive strength that is significantly higher than that of a Type N mortar required by the property specifications. Mortars may be made with either portland cement, mortar cement, or masonry cement.

ASTM C 476, "GROUT FOR MASONRY"

ASTM C 476 is the standard specification governing grout for reinforced and non-reinforced masonry assemblies. Two types of grout, fine and coarse, are specified by proportions of ingredients. Both types should be proportioned within the limits given in Figure 6.19.

Grout consists of cementitious materials and aggregate thoroughly mixed with sufficient water to attain the desired consistency. Grout should be wet enough to pour without segregation of the constituents. Grout can be used to bond two wythes of masonry, to provide additional material to resist load, or to bond steel reinforcement to masonry so the two materials exert common action under load.

MORTAR PROPERTY SPECIFICATION REQUIREMENTS[a]
6.18

MORTAR	TYPE	AVERAGE COMPRESSIVE STRENGTH AT 28 DAYS MIN. PSI	WATER RETENTION, MIN. PERCENTAGE	AIR CONTENT, MAX. PERCENTAGE	AGGREGATE RATIO (MEASURED IN DAMP, LOOSE CONDITIONS)
Cement-lime	M	2500	75	12	Not less than 2–1/4 and not more than 3–1/2 times the sum of the separate volumes of cementitious materials
	S	1800	75	12	
	N	750	75	14[b]	
	O	350	75	14[b]	
Mortar cement	M	2500	75	12	
	S	1800	75	12	
	N	750	75	14[b]	
	O	350	75	14[b]	
Masonry cement	M	2500	75	18	
	S	1800	75	18	
	N	750	75	18[c]	
	O	350	75	18[c]	

NOTES

6.18 a. Laboratory-prepared mortar only, with a quantity of water to produce a flow of 110 plus or minus 5 percent. Quality control of field-prepared mortar uses ASTM C780.
b. When structural reinforcement is incorporated in cement-lime mortar, the maximum air content shall be 12 percent.
c. When structural reinforcement is incorporated in masonry cement mortar, the maximum air content shall be 18 percent.

Contributor:
Christine Beall, NCARB, CCS, Austin, Texas.

GROUT PROPORTIONS BY VOLUME
6.19

TYPE	PARTS BY VOLUME OF PORTLAND CEMENT OR BLENDED CEMENT	PARTS BY VOLUME OF HYDRATED LIME OR LIME PUTTY	AGGREGATE (MEASURED IN A DAMP, LOOSE CONDITION)	
			FINE	COARSE
Fine grout	1	0 to 1/10	2–1/4 to 3 times the sum of the volumes of cementitious materials	—
Coarse grout	1	0 to 1/10	2–1/4 to 3 times the sum of the volumes of cementitious materials	1 to 2 times the sum of the volumes of cementitious materials

MATERIALS

PORTLAND CEMENT
Portland cement, a hydraulic cement, is the principal cementitious ingredient of mortar and grout. Three types of portland cement, covered by ASTM C 150, "Standard Specification for Portland Cement," are recommended: Types I, II, and III.

The allowable stresses for the structural design of masonry are based on the results of tests in which only portland cements were used. The use of blended hydraulic cements and natural cements is not recommended unless the strength of the masonry is first established by appropriate tests. For nonstructural masonry, such cements may be substituted for regular portland cement without testing.

HYDRATED LIME
Hydrated lime, a dry powder, is made by adding water to quicklime, thus converting the calcium oxide into calcium hydroxide. Hydrated lime can be used without extra preparation and thus is more convenient to use than quicklime. ASTM C 207, "Hydrated Lime for Masonry Purposes" designates four types of hydrated lime: S, SA, N, and NA. Because non-hydrated oxides and plasticity are not controlled in Types N or NA, only type S hydrated lime should be used for masonry mortar and grout.

MASONRY CEMENT
These proprietary mortar mixes are widely used in mortar because of their convenience and good workability. Masonry cements, however, should not be used in grout. The requirements for masonry cement are covered in ASTM C 91, "Standard Specification for Masonry Cement." Masonry cements are packaged as Type M, S, or N mortar mixes.

MORTAR CEMENT
Mortar cements are hydraulic cements, consisting of a mixture of portland cement, plasticizing components such as limestone, hydrated or hydraulic lime, and other materials intended to enhance the properties of the mortar. In this respect, mortar cement is similar to masonry cement. However, ASTM C 1329, "Specification for Mortar Cement" includes requirements for maximum air content and minimum flexural bond strength that are not found in the masonry cement specification. Three types of mortar cements are specified in ASTM C 1329: Types M, S, and N. Because of the strict controls on air content and the minimum strength requirement, mortar cement and portland cement mortars are treated similarly in ACI 530/ASCE 5/TMS 402, "Building Code Requirements for Masonry Structures."

AGGREGATE
Either natural or manufactured aggregate may be used. Gradation limits are given in ASTM C 144 and C 404 for aggregate used in mortar and grout. Only fine aggregate may be used in mortar; fine and coarse aggregate may be used in grout. Gradation can be easily altered by adding fine or coarse sands. Only clean sand is recommended for use in masonry mortar and grout.

WATER
Clean, potable water that is free of deleterious acids, alkalies, or organic materials is suitable for masonry mortar and grout.

COLOR AND OTHER ADMIXTURES
Many different types of admixtures can be added to mortar and grouts. Admixtures are used in mortar to provide color, enhance workability, reduce water penetration, reduce freezing, accelerate curing, and substitute for conventional materials. Admixtures are used in grout to increase fluidity, accelerate curing, and decrease shrinkage. Admixtures containing chlorides should never be used because they tend to corrode metal.

Air entrainment has the detrimental effect of reducing the bond between mortar, masonry units, and reinforcement. The use of air-entraining portland cements (Types IA, IIA, or IIIA) and air-entrained lime (Types SA and NA) for masonry mortar and grout may not be appropriate. Two different air-entraining agents should not be used in the same mortar or grout. Air-entraining admixtures should not be used in structural masonry. Building codes mandate lower allowable flexural tension stresses when air-entrained cements or lime are used in mortar.

RECOMMENDED TYPES

MORTAR
No single type of mortar is best suited for all purposes, but there are several rules for selecting mortar type:

Never use a mortar that is stronger in compression than needed by the structural requirements.

Always select the mortar weakest in compression that is consistent with the performance requirements of the project. However, this guideline should be coupled with good engineering judgment. For example, it would be uneconomical and unwise to change mortar types in various parts of a structure.

If mortar is used with reinforcement in a collar joint or in a cell of a hollow unit, then the air content must be less than 12 percent for portland cement–lime mortars and 18 percent for masonry cements.

The use of mortar is recommended only in non-reinforced collar joints of 3/4 in. (19 mm) or less.

Following are the recommended uses for different types of mortar:

- Type N mortar: General all-purpose mortar with good bonding capabilities and workability
- Type S mortar: High flexural bond strength
- Type M mortar: High compressive strength, but not very workable.
- Type O mortar: Low strength, mostly used for interior applications

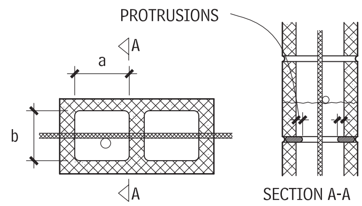
GUIDE FOR THE SELECTION OF MASONRY MORTAR[a]
6.20

LOCATION	BUILDING SEGMENT	MORTAR TYPE	
		RECOMMENDED	ALTERNATIVE
Exterior, above grade	Load-bearing wall	N	S or M
	Non-load-bearing wall	O[b]	N or S
	Parapet wall	N	S
Exterior, at or below grade	Foundation wall, retaining wall, man-holes, sewers, pavements, walks, and patios	S[c]	M or N3
Interior	Load-bearing wall	N	S or M
Nonbearing partitions		O	N

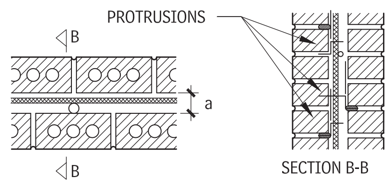
GROUT
Grout should be mixed thoroughly in a plastic mix suitable for placement without separation of the constituents. Add enough water to achieve a slump of 8 to 11 in. The compressive strength of the grout should match that of the masonry but must have a minimum compressive strength of 2000 psi.

- Fine grout: Can be used for grouting interior vertical spaces between two wythes of masonry, or aligned, unobstructed vertical spaces in hollow masonry units.
- Coarse grout: May be used when the grout space exceeds 2 in. in width. If the minimum grout space dimension exceeds 6 in., a larger aggregate size may be specified.

GROUT SPACE DIAGRAM
6.21



a MINIMUM GROUT SPACE DIMENSION
b MINIMUM GROUT SPACE DIMENSION PLUS HORIZONTAL BAR DIAMETER PLUS HORIZONTAL PROTRUSIONS (SEE GROUT PLACING REQUIREMENTS TABLE 6.22)



a MINIMUM GROUT SPACE DIMENSION PLUS HORIZONTAL BAR DIAMETER PLUS HORIZONTAL PROTRUSIONS (SEE GROUT PLACING REQUIREMENTS TABLE 6.22)

NOTES

6.20 a. This figure does not include many specialized mortar uses, such as chimney-reinforced masonry and acid-resistant mortar.
b. Type O mortar is recommended for use where the masonry is unlikely to be frozen when saturated, or unlikely to be subjected to high winds or other significant lateral loads. Types N or S mortar should be used in other cases.
c. Masonry exposed to weather in a nominally horizontal surface is extremely vulnerable to weathering. Mortar for such masonry should be selected with due caution.

Figure 6.22 provides dimensional requirements for placing of coarse and fine grout between wythes of masonry and also within hollow masonry cores. Figure 6.21 illustrates minimum width of grout space between wythes and minimum space requirements for grouting cells of hollow units.

GROUT PLACING REQUIREMENTS
6.22

SPECIFIED GROUT TYPE	MAXIMUM GROUT POUR HEIGHT (FT)	MINIMUM WIDTH OF GROUT SPACE (IN.)	MINIMUM GROUT SPACE DIMENSIONS FOR GROUTING CELLS OF HOLLOW UNITS (IN. × IN.)
Fine	1	3/4	1–1/2 × 2
	5	2	2 × 3
	12	2–1/2	2–1/2 × 3
	24	3	3 × 3
Coarse	1	1/2	1–1/2 × 3
	5	2	2–1/2 × 3
	12	2–1/2	3 × 3
	24	3	3 × 4

TYPES OF JOINTS

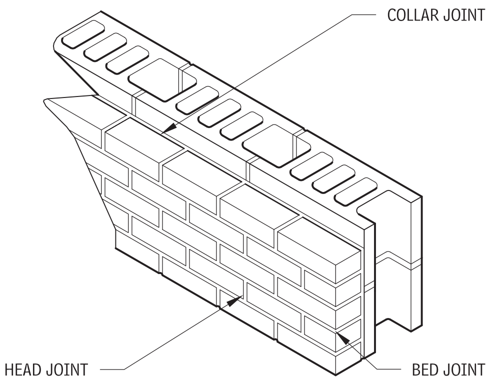
Mortar serves multiple functions:

- Joins and seals masonry, allowing for dimensional variations in masonry units
- Affects overall appearance of wall color, texture, and patterns
- Bonds reinforcing steel to masonry, creating composite assembly

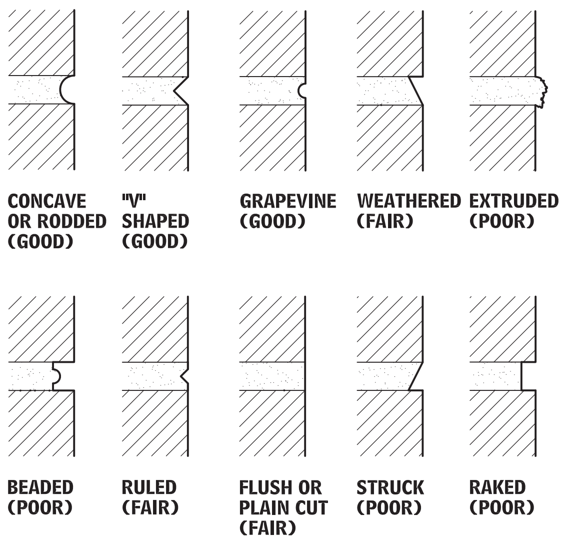
MORTAR JOINT FINISH METHODS

- Troweled: Excess mortar is struck off. The trowel is the only tool used for shaping and finishing.
- Tooled: A special tool is used to compress and shape mortar in the joint.

MORTAR JOINTS
6.23



TERMS APPLIED TO JOINTS



TYPES OF JOINTS (WEATHERABILITY)

MASONRY ANCHORAGE, REINFORCING, AND ACCESSORIES

MASONRY ANCHORAGE AND REINFORCING

GENERAL

Masonry construction has not always required the inclusion of metal components. Historically, composite masonry construction consisted of multiple wythes of masonry bonded together by headers. However, contemporary masonry walls require ties between the inner and outer wythes, which are then anchored to the structural frame. Many design professionals use the terms "wall tie" and "anchor" interchangeably. In practice, "ties" are of a lighter gauge material than anchors. Both ties and anchors transfer load to structural framing or other structural members.

Anchors and ties with flexible components may accommodate limited differential movement between the structural frame and the masonry wall by allowing for in-plane movement.

CORROSION PROTECTION

The durability of any metal component is usually based on its ability to resist corrosion. Since masonry walls are often subject to moisture, metal must be protected, either by galvanizing or by use of corrosion-resistant metals. The following ASTM standards apply to corrosion protection of carbon steel components.

- ASTM A 123, "Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products"
- ASTM A 153, "Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware"
- ASTM A 641, "Standard Specification for Zinc-Coated Carbon Steel Wire"
- ASTM A 653, "Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process"

Corrosion protection is also provided by stainless steel anchors and ties conforming to ASTM A 580, for Type 304.

ANCHORS AND REINFORCEMENT

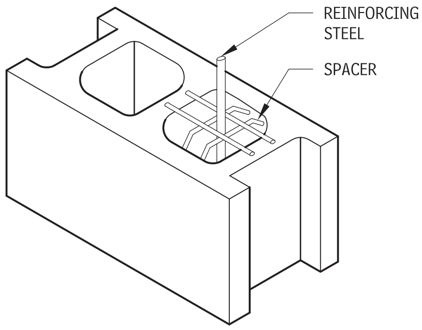
Selection of anchors and reinforcement is determined by the relationship of the masonry element to the structural support. Reinforcing bars may be placed horizontally and vertically in masonry. The reinforcement may be placed in the cores or cells of masonry units or between wythes of masonry. Figure 5.29 includes

NOTES

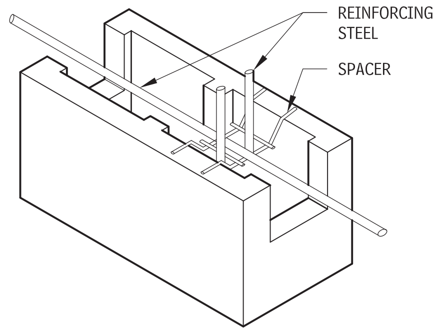
6.22. Grout space dimension is the clear dimension between any masonry protrusion and shall be increased by the diameters of the horizontal bars within the cross section of the grout space.
b. Area of vertical reinforcement should not exceed 6 percent of the area of the grout space.
c. When the following conditions are met, grout can be placed in lifts up to 12.67 ft.: the masonry has cured for 4 hours; the grout slump is maintained between 10 and 11 in.; and no intermediate bond beams interfere with the grouting operation.

Contributors:
Grace S. Lee, Rippeteau Architects, PC, Washington, DC; Brian E. Trimble, Brick Institute of America, Reston, Virginia; Stephen S. Szoke, PE, National Concrete Masonry Association, Herndon, Virginia.

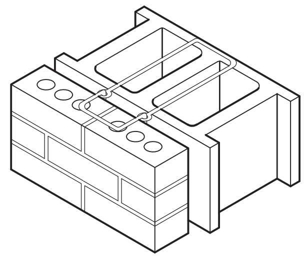
CMU REINFORCING BAR
6.24



CMU SPACER



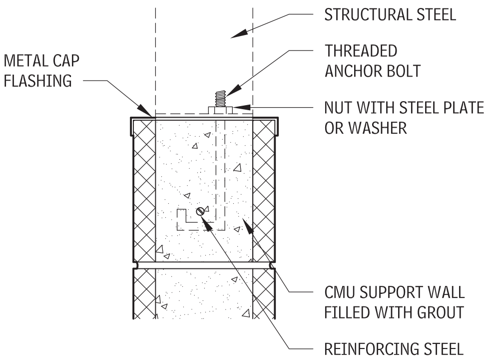
CMU BOND BEAM



TIE DETAIL

the cross-sectional areas and bar diameters. The use of dovetail slots welded on steel or concrete columns requires coordination during the steel or concrete fabrication stage. The type of anchor specified, including its size, diameter, and spacing, should be called out on the contract documents.

ANCHOR BOLT EMBEDMENT
6.25



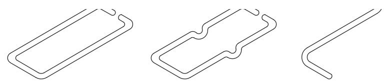
MASONRY TIES

Masonry ties perform one or more functions:

- Provide a connection
- Transfer lateral loads
- Permit in-plane movement to accommodate differential movements
- May act as horizontal structural reinforcement

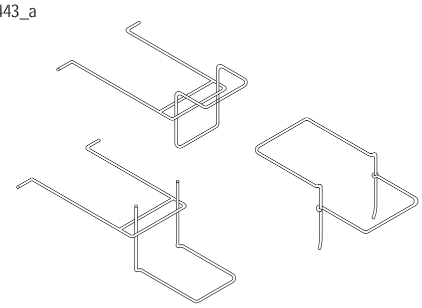
Masonry ties include unit ties, adjustable unit ties, adjustable joint reinforcement, and joint reinforcement.

UNIT TIES FOR MASONRY BACKUP
6.26



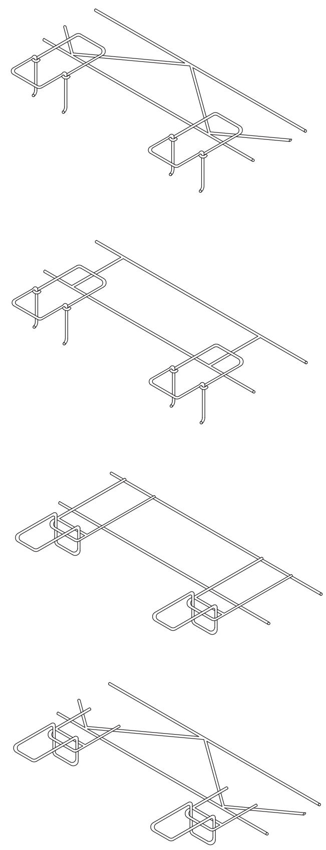
NIT TIES

L443_a

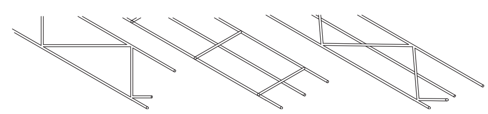


ADJUSTABLE UNIT TIES

JOINT REINFORCEMENT FOR MASONRY BACKUP
6.27



ADJUSTABLE JOINT REINFORCEMENT



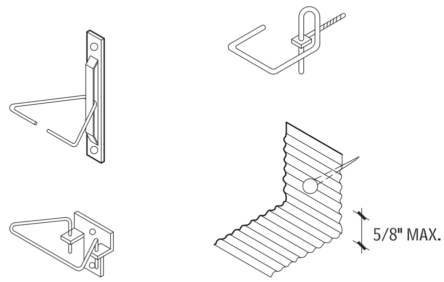
TRUSS TYPE **LONGITUDINAL WIRE LADDER TYPE** **LONGITUDINAL TRUSS TYPE**

NOTES

6.26 a. Z-ties can be used only with solid masonry veneer units.
b. Tie must extend a minimum of 1–1/2 in. onto solid masonry units and be fully embedded in mortar on the outer face shell of hollow masonry units.

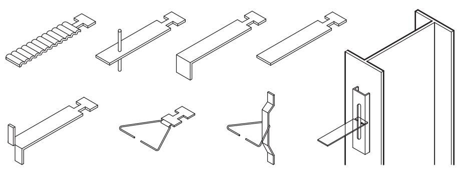
Contributors:
Grace S. Lee, Rippeteau Architects, PC, Washington, DC; Brian E. Trimble, Brick Institute of America, Reston, Virginia; Stephen S. Szoke, PE, National Concrete Masonry Association, Herndon, Virginia.

ADJUSTABLE UNIT TIE FOR FRAMING BACKUP
6.28



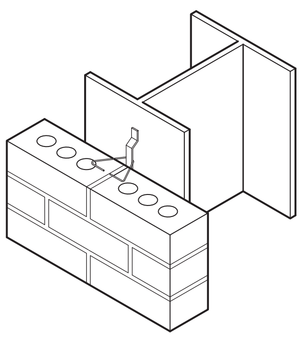
ADJUSTABLE UNIT TIES – STUD

ADJUSTABLE UNIT TIE FOR STRUCTURAL STEEL BACKUP
6.29



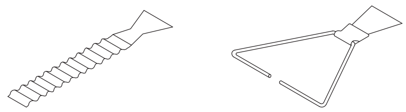
UNIT TIES – STEEL FRAME

WELD-ON TYPE CHANNEL SLOT (ANCHOR SHOWN)

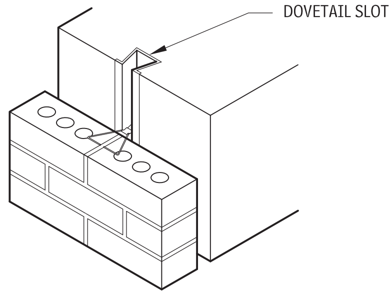


TIE DETAIL

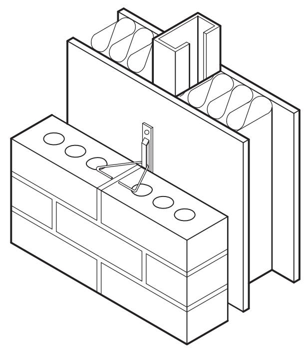
ADJUSTABLE UNIT TIE FOR CONCRETE BACKUP
6.30



UNIT TIES – CONCRETE



TIE DETAIL



TIE DETAIL

Masonry tie spacing recommendations are included Figure 6.31. The ties should be staggered in alternate rows, and only one row of ties should be located in the same bed joint to allow proper embedment in the mortar.

In wall construction in which masonry wythes are built up together and the joints align, a single anchor is laid over both wythes. Where one wythe of masonry is laid up before the other wythe, or when joints do not align, adjustable ties may be necessary.

AMASONRY TIE SPACING RECOMMENDATIONS
6.31

WALL TYPE	TIE AND GAUGE	MAXIMUM AREA PER TIE (SQ FT)	MAXIMUM VERTICAL SPACING (IN.)	MAXIMUM HORIZONTAL SPACING (IN.)
Multiwythe walls	W 1.7 (9 gauge)	2–2/3	24	36
	W 2.8 (3/16 in. dia.)	4-1/2	24	36
Cavity walls	W 1.7 (9 gauge)	2–2/3	24	36
	W 2.8 (3/16 in. dia.)	4-1/2	24	36
	Adjustable W 2.8 (3/16 in. dia.)	1.77	16	16
Veneer	Wire tie	3-1/2	18	32
	Corrugated	2–2/3	18	32

RECOMMENDED MINIMUM TIE DIAMETERS AND GAUGES
6.32

			MINIMUM DIMENSION	
MASONRY TIES			DIAMETER (IN.)	GAUGE
Standard Ties	Unit	Rectangular and Z-tie	3/16	—
		Corrugated	—	22
	Joint reinforcement	Ladder and truss	—	9
		Tab	—	9
Adjustable Ties	Unit	Rectangular and Z-tie	3/16	—
	Dovetail/channel slot	Wire	3/16	—
		Corrugated	—	16
		Connector slot	—	22
	Slotted plate	Wire	3/16	—
		Slot plate	—	14
		Backer plate	–	14
	Joint reinforcement	Standard section	—	9
		Tabs	3/16	—

NOTES

6.28 Differential movement must always be considered for wall framing with adjustable ties.
6.31 Consult applicable building codes for spacing requirements and for allowable tie types for various construction projects. Corrugated ties may not be allowed by code.
6.32 Thicker diameters and gauges are available.

Contributor:
Brian E. Trimble, Brick Institute of America, Reston, Virginia.

MASONRY ACCESSORIES

MASONRY CAVITY DRAINAGE, WEEPHOLES, AND VENTS

With proper design and installation, weepholes and vents discharge moisture trapped within the wall cavity. Weepholes are required in the head joint of the course of masonry immediately above all embedded flashing, and should be installed at all horizontal interruptions in the wall. Weepholes should never be located below grade and should be small enough to keep out rodents. Weepholes may be open head joints, holes formed with nylon rope or oiled rods, plastic or metal tubes, fibrous rope, cotton sash cord, or cellular material. Open head joints are often fitted with vents or screens to keep out insects or rodents. Formed and tube weepholes should have a minimum diameter of 1/4 in., though it is important to take into consideration the type of weephole used in conjunction with the climate. Open head joints are a preferred type of weephole, occurring no more than 32 in. on center, although in clay unit masonry they should be spaced no more than 24 in. on center. If cord or rope is used, the material should be at least 16 in. long. Weepholes other than open head joints should be spaced no more than 16 in. on center.

MASONRY EMBEDDED FLASHING

Flashing in masonry construction is necessary to collect moisture that enters the wall system and to channel it to the exterior through weepholes. Moisture enters masonry walls through condensation, penetration of wind-driven rains, failed sealant joints, interfaces with other components, or other components themselves, such as windows or roofs.

There are two types of flashing. Exposed flashings can be applied to all masonry construction, while use of embedded flashing is usually limited to drainage-type walls. Masonry is a durable, long-lasting construction material. Thus, the flashing materials selected should also be durable and have a long life, especially embedded flashing materials, which are difficult to replace.

MATERIALS

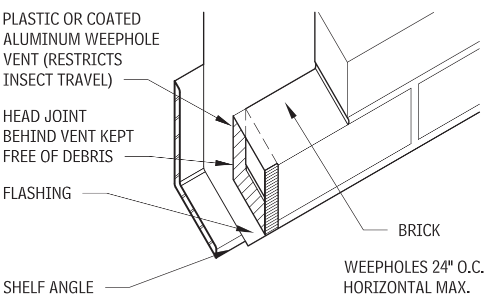
Flashing may be made of sheet metal (copper, lead, stainless steel, galvanized steel, or aluminum), plastic or composite materials (usually paper-backed, coated, metallic sheet, or fibrous glass mesh). When selecting flashing materials, avoid those that would have cathodic reactions with mortar, other metals, or other construction materials. The thickness of the flashing material specified should take into account the span between embedment, bends, or connections. Copper may cause a patina, which may be desirable. Lead and galvanized metal may result in some white staining, but this may be minimal if coated materials are used. Choose aluminum as an embedded flashing only if it is properly coated, so it will not react with the mortar. Polyethylene should not be used as flashing unless it has been chemically stabilized so it will not deteriorate when exposed to sunlight (ultraviolet radiation). Asphalt-impregnated building paper (building felt) is not an acceptable flashing material. Adhered flashings must be held back from the face of the wall to avoid deterioration and staining caused by high temperatures.

INSTALLATION

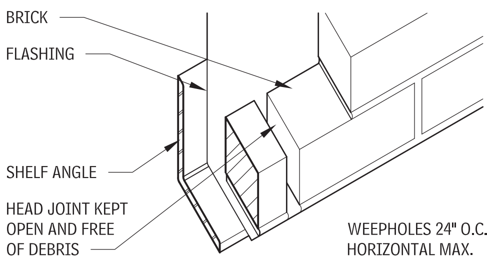
Embedded flashing is typically used in drainage walls at the base, above all openings, at sills and shelf angles, and under copings. Continuous embedded flashing should be lapped at least 6 in. and sealed with an appropriate sealer. Discontinuous flashing should have the ends turned up at least 1 in. to form a dam. Dams prevent water collected on the flashing from draining off the ends of the flashing back into the wall system or into framing or mullions.

Embedded flashing should extend at least 8 in. vertically within the wall system; it should extend at least 1–1/2 in. into the interior wythe and through the exterior wythe at least 1/4 in. to form a drip. The drip minimizes possible staining. Sometimes, it may be necessary to avoid the drip, as with rough textured units and ribbed, scored, or fluted masonry units. The flashing must be carefully brought to the surface of the recessed portion of the masonry. Plastic flashing is often exposed and cut off flush with the face of the masonry. If the flashing is recessed and does not reach the surface, water collected on it may be channeled by mortar under the flashing and back into the wall system.

WEEPHOLE DETAILS
6.33



WEEPHOLE VENT



OPEN HEAD JOINT WEEPHOLE

MASONRY MOVEMENT JOINTS

GENERAL

The various materials and elements used to construct a building are in constant motion. All building materials change in volume in response to internal or external stimuli, such as temperature changes, moisture expansion, and elastic deformation due to loads or creep. Restraining such movements may cause stresses within the building elements, which in turn may result in cracks.

To avoid cracks, the building design should minimize volume change, prevent movement, or accommodate differential movement between materials and assemblies. Masonry control and expansion joints are types of movement joints that minimize cracks in masonry construction. Design of joints should take into consideration the magnitude of each type of movement that may occur in masonry and other building materials.

MOVEMENTS OF CONSTRUCTION MATERIALS

The design and construction of most buildings do not allow precise movement prediction of building materials. Changes depend on material properties, therefore are highly variable. Material age and temperature at installation are two conditions that may also influence movement. When mean values of material properties are used in design, the actual movement may be underestimated or overestimated. Design professionals should use discretion when selecting the applicable values. Figure 6.35 indicates the type of movement that affects common building materials.

MOVEMENT JOINTS

There are various types of movement joints in buildings: expansion joints, control joints, separation joints, and construction joints. Each type of movement joint is designed to perform a specific task; they should not be used interchangeably.

Control joints are used to separate masonry into segments to minimize cracking due to changes in temperature, moisture expansion, elastic deformation due to loads, and shrinkage and creep in concrete framed buildings. Control joints may be horizontal or vertical. They are formed of elastomeric materials placed in a continuous, unobstructed opening through the masonry wythe. This construction allows the joint to compress with movement of materials. Control joints must be located so the structural integrity of the masonry is not compromised.

Expansion (isolation) joints are used to separate a building into discrete structural sections so that stresses developed in one section will not affect the integrity of the entire structure. The expansion joint is a through-the-building joint, including the roof assembly.

Separation joints are joints between dissimilar materials such as openings and adjacent masonry construction. These joints accommodate differential movement in building materials.

A construction (cold) joint is used primarily in concrete construction when construction work is interrupted. Construction joints are located where they will least impair the strength of the structure.

GALVANIC CORROSION (ELECTROLYSIS) POTENTIAL BETWEEN COMMON FLASHING MATERIALS AND SELECTED CONSTRUCTION MATERIALS
6.34

FLASHING MATERIALS	COPPER	ALUMINUM	STAINLESS STEEL	GALVANIZED STEEL	ZINC	LEAD	BRASS	BRONZE	MONEL	UNCURED MORTAR OR CEMENT	WOODS WITH ACID (REDWOOD AND RED CEDAR)	IRON/STEEL
Copper		●	●	◍	●	◍	◍	◍	◍	○	○	●
Aluminum			○	○	○	◍	●	●	○	●	●	◍
Stainless steel				◍	●	◍	●	●	●	○	○	◍
Galvanized steel					○	○	◍	◍	◍	○	◍	◍
Zinc alloy						○	●	●	●	○	●	●
Lead							◍	◍	◍	●	○	○

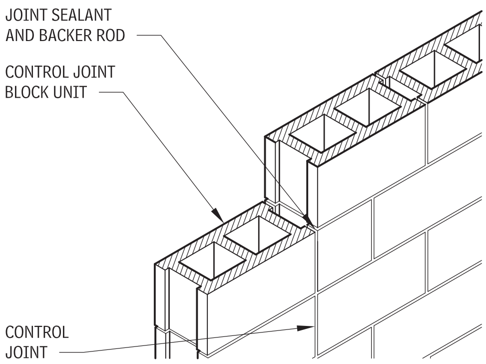
NOTES

6.34 a. Galvanic action will occur, hence direct contact should be avoided. Galvanic action may occur under certain circumstances and/or over a period of time. Galvanic action is insignificant; metals may come into direct contact under normal circumstances.
b. Galvanic corrosion is apt to occur when water runoff from one material comes in contact with a potentially reactive material.

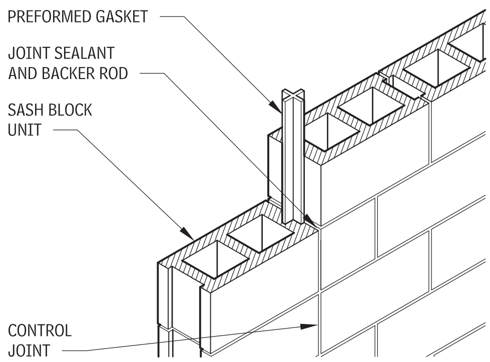
MOVEMENT OF BUILDING MATERIALS
6.35

BUILDING MATERIAL	THERMAL	REVERSIBLE MOISTURE	IRREVERSIBLE MOISTURE	ELASTIC DEFORMATION	CREEP
Brick masonry	X	—	x	x	x
Concrete masonry	X	X	—	x	x
Concrete	X	X	—	x	x
Steel	X	—	—	x	—
Wood	X	X	—	x	x

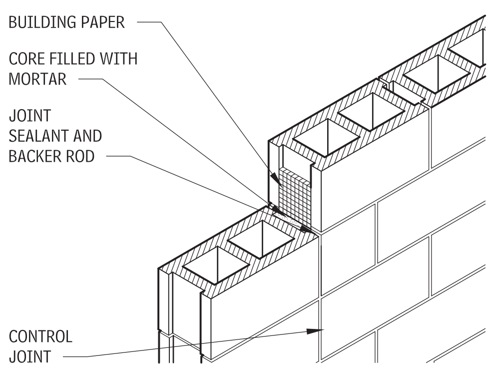
CONCRETE UNIT MASONRY CONTROL JOINTS
6.36



CONTROL BLOCK

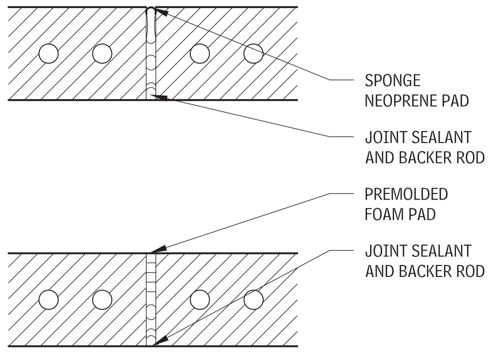


GASKET TYPE

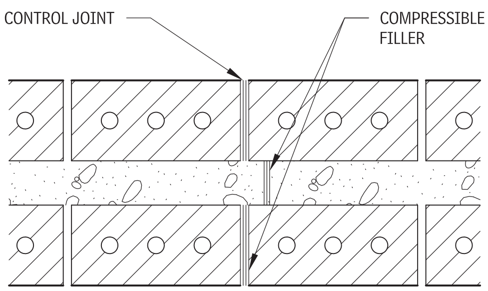


OUT-OF-PLANE RESTRAINT

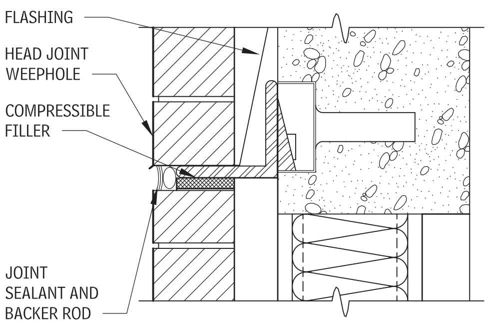
CLAY UNIT MASONRY CONTROL JOINTS
6.37



VERTICAL CONTROL JOINTS

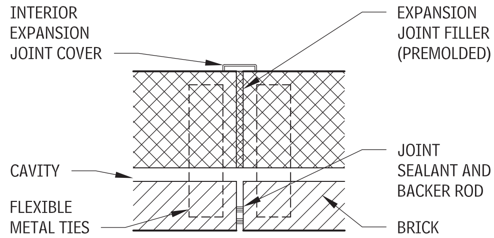


GROUTED MULTIPLE-WYTHE MASONRY

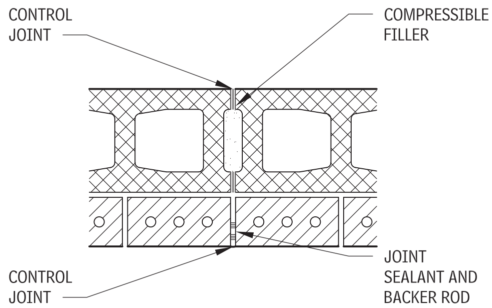


HORIZONTAL EXPANSION JOINT

MASONRY CONTROL AND EXPANSION JOINTS
6.38



EXPANSION JOINT AT MASONRY CAVITY WALL



DOUBLE WYTHE MASONRY

SPACING OF MASONRY CONTROL AND EXPANSION JOINTS

No single recommendation on the positioning and spacing of control and expansion joints can be applicable to all structures. Each building should be analyzed to determine the extent of movement expected within that particular structure. Provisions should be made to accommodate these movements and their associated stresses with a series of control and expansion joints.

Generally, spacing of control joints is determined by considering the amount of expected wall movement and the size of the control joint. Recommended spacing of control joints in concrete unit masonry is addressed in Figure 6.39. Control joints are often sized to resemble a mortar joint, usually 3/8 in. to 1/2 in.

Expansion joints may use sealant or preformed filler. Maximum sealant joint size is approximately 2 in. with 50 percent movement, thus when expansion joints are over 3 in. in width, preformed fillers are common.

Control and expansion joints do not have to be aligned in cavity walls; however, they should be aligned in multiwythe walls.

CONTROL JOINT SPACING FOR CONCRETE MASONRY UNITS
6.39

RECOMMENDED SPACING OF CONTROL JOINTS	VERTICAL SPACING OF JOINT REINFORCEMENT			
	NONE	24"	16"	8"
Expressed as ratio of panel length to height (L/H)	2	2–1/2	3	4
Panel length (L) not to exceed (regardless of height [H])	40’	45’	50’	60’

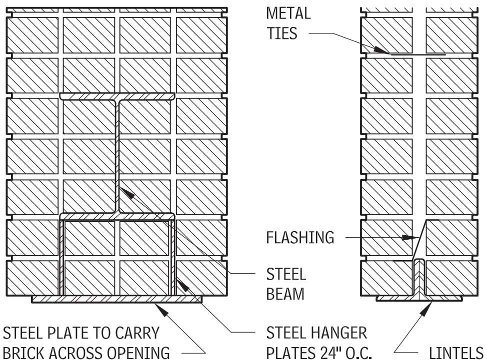
Contributors:
Grace S. Lee and A. Harris Lokmanhakim, AIA, Rippeteau Architects, PC, Washington, DC; Brian E. Trimble, Brick Institute of America, Reston, Virginia; Stephen S. Szoke, PE, National Concrete Masonry Association, Herndon, Virginia.

INSTALLATION GUIDELINES AND CONSTRUCTION TOLERANCES

LINTELS

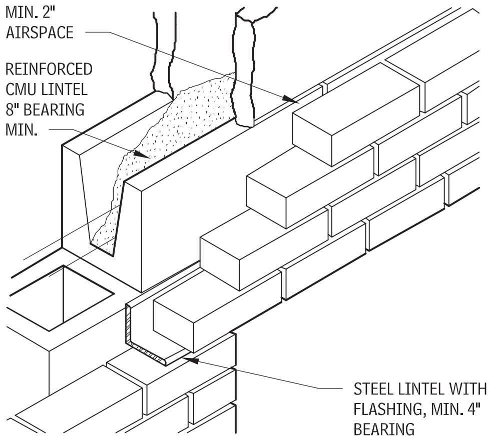
A lintel is a horizontal structural member above an opening to support the weight of the wall above the opening. Structural steel, concrete masonry, and precast concrete lintels are provided.

STEEL LINTEL DETAILS
6.40

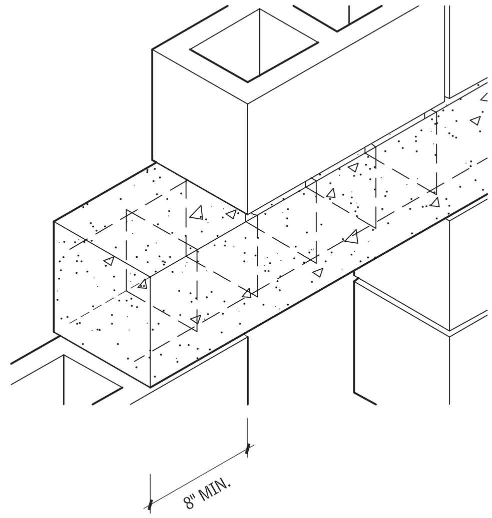


SOLID MASONRY WALL **CAVITY WALL**

MASONRY LINTEL DETAIL
6.41



PRECAST CONCRETE LINTEL DETAIL
6.42



STEEL ANGLE LINTEL SIZING CHART
6.43

HORIZONTAL LEG	ANGLE SIZE	WEIGHT PER FT (LB)	SPAN (FT) (CENTER TO CENTER OF REQUIRED BEARING)									
			3	4	5	6	7	8	9	10	11	12
3–1/2	3 × 3–1/2 × 1/4	5. 4	956	517	262	149	91	59				
	× 5/16	6.6	1166	637	323	184	113	73				
	3–1/2 × 3–1/2 × 1/4	5.8	1281	718	406	232	144	94	65			
	× 5/16	7.2	1589	891	507	290	179	118	80			
	4 × 3–1/2 × 1/4	6.2	1622	910	580	338	210	139	95	68		
	× 5/16	7.7	2110	1184	734	421	262	173	119	85	62	
	× 3/8	9.1	2434	1365	855	490	305	201	138	98	71	
	× 7/16	10.6	2760	1548	978	561	349	230	158	113	82	60
	5 × 3–1/2 × 1/4	7.0	2600	1460	932	636	398	264	184	132	97	73
	× 5/16	8.7	3087	1733	1106	765	486	323	224	161	119	89
	× 7/16	12.0	4224	2371	1513	1047	655	435	302	217	160	120
	6 × 3–1/2 × 1/4	7.9	3577	2009	1283	888	650	439	306	221	164	124
	× 5/16	9.8	4390	2465	1574	1090	798	538	375	271	201	151
	× 3/8	11.7	5200	2922	1865	1291	945	636	443	320	237	179

NOTES

6.40 Steel members to be designed by structural engineer. Flashing details must be designed to suit job conditions.
6.43 Allowable loads to the left of the heavy line are governed by moment, and to the right by deflection. Fy = 36,000 psi. Maximum deflection 1/600. Consult structural engineer for long spans. Allowable uniform loads indicated in pounds per linear foot.

REQUIRED REINFORCING FOR SIMPLY SUPPORTED REINFORCED CONCRETE MASONRY LINTELS
6.44

TYPE OF LOAD	LINTEL SECTION NOMINAL SIZE (IN.)	REQUIRED REINFORCING CLEAR SPAN							
		3'-4"	4'-0"	4'-8"	5'-4"	6'-0"	6'-8"	7'-4"	8-0"
Wall loads	6 × 8	1—#3	1—#4	1—#4	2—#4	2—#5			
	6 × 16					1—#4	1—#4	1—#4	1—#4
Floor and roof loads	6 × 16	1—#4	1—#4	2—#3	1—#5	2—#4	2—#4	2—#5	2—#5
Wall loads	8 × 8	1—#3	2—#3	2—#3	2—#4	2—#4	2—#5	2—#6	
	8 × 16							2—#5	2—#5
Floor and roof loads	8 × 8	2—#4							
	8 × 16	2—#3	2—#3	2—#3	2—#4	2—#4	2—#4	2—#5	2—#5

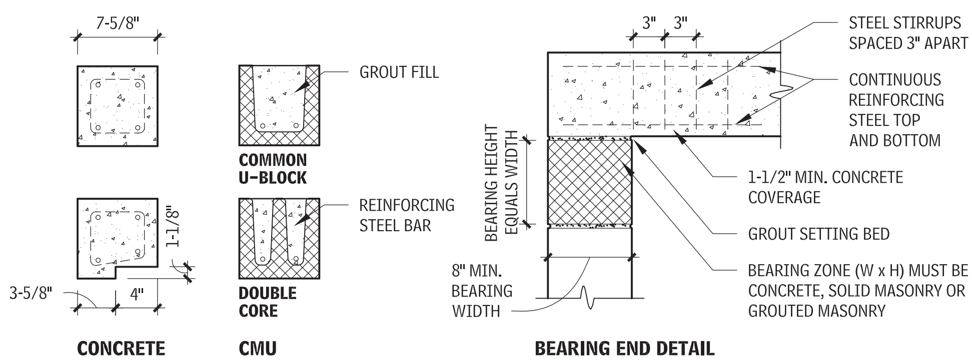
LINTEL REINFORCING REQUIREMENTS
6.48

LINTEL TYPE	CLEAR SPAN (MAX.)	8-IN. BRICK WALL (80 LB/SQ FT)	8-IN. CMU WALL (50 LB/SQ FT)
Reinforced concrete (7–5/8" square section)	4'-0"	4—#3	4—#3
	6'-0"	4—#4	4—#3
	8'-0"	4—#5	4—#4
Concrete masonry unit (7–5/8" square section) nominal 8 × 8 × 16 unit	4'-0"	2—#4	2—#3
	6'-0"	2—#5	2—#4
	8'-0"	2—#6	2—#5

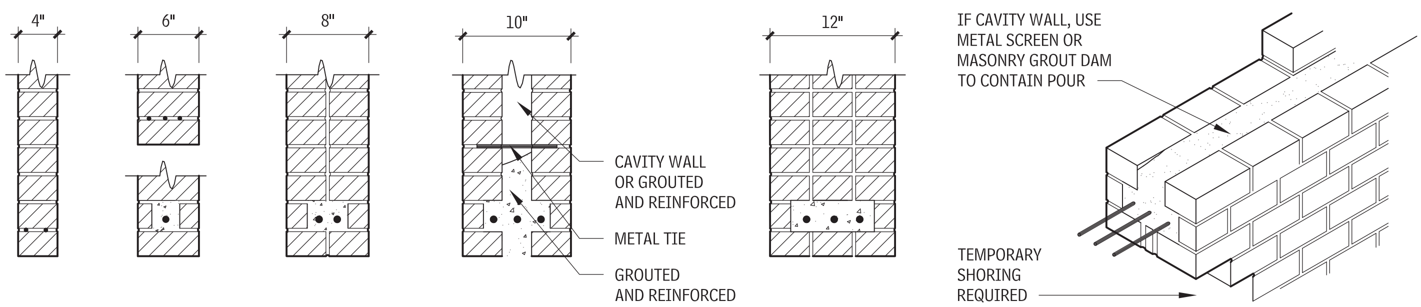
MAXIMUM DESIGN LOADS FOR PRECAST CONCRETE LINTELS (LB/LINEAR FT)
6.45

REINFORCEMENT	CLEAR SPAN										
	3′-4″	4′-0″	4′-8″	5′-4″	6′-0″	6′-8″	7′-4″	8′-0″	8′-8″	9′-4″	10′-0″	10′-8″
2—#3	1585	1150	850	625	475	365	285	225	180	145	115	90
2—#4	1855	1300	910	665	500	380	300	235	185	150	120	95
2—#5	1825	1410	1005	725	535	410	315	250	195	155	125	100

PRECAST CONCRETE AND CMU BEAMS OR LINTELS
6.46



REINFORCED BRICK BEAMS OR LINTELS
6.47



NOTES

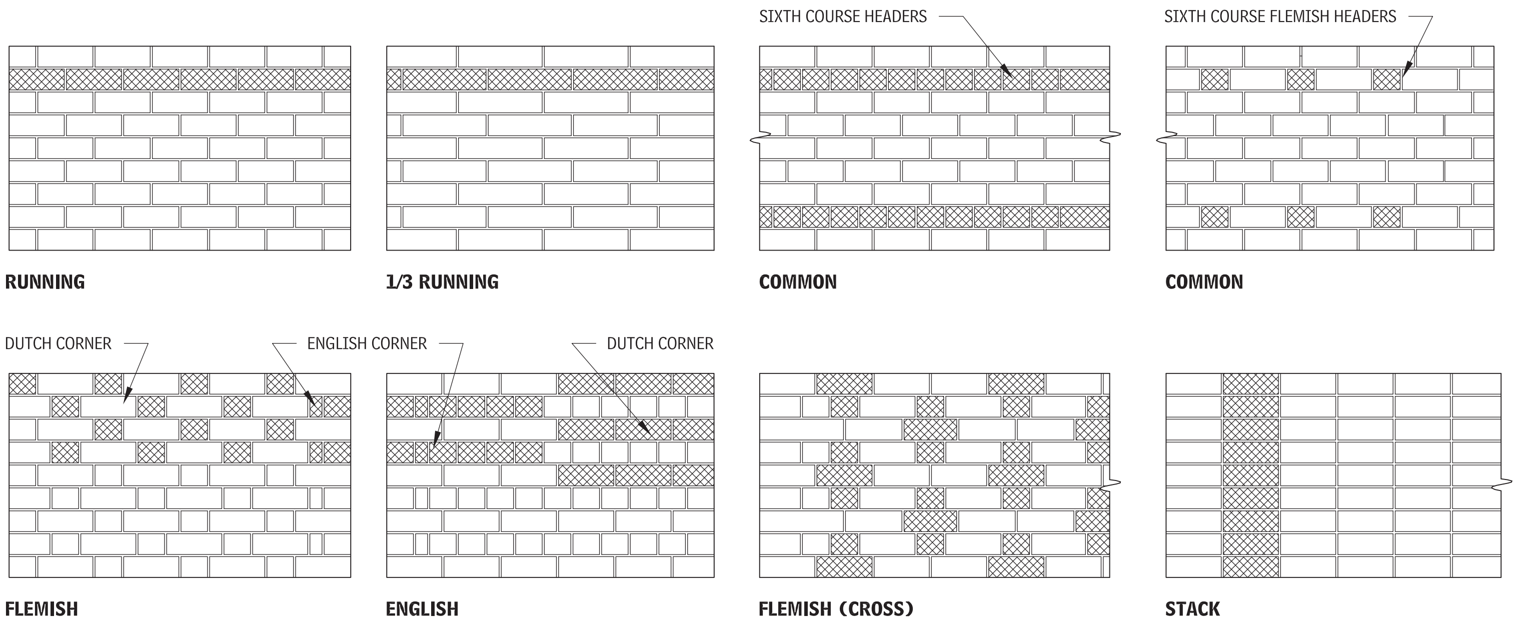
6.44 a. Includes weight of lintel.
b. Wall loads assumed to be 300 lb./linear ft.
c. Floor and roof loads including wall loads assumed to be 1000 lb./linear ft.
d. Eight-inch lintels assumed to weigh 50 lb./ft.
e. Sixteen-inch lintels assumed to weigh 100 lb./ft.
6.48. For precast concrete and reinforced concrete masonry unit lintels with no superimposed loads.
b. f'c= 3000 psi concrete and grout; fy = 60,000 psi.

Contributors:
Grace S. Lee, Rippeteau Architects, PC, Washington, DC; Brian E. Trimble, Brick Institute of America, Reston, Virginia; Stephen S. Szoke, PE, National Concrete Masonry Association, Herndon, Virginia.

UNIT MASONRY

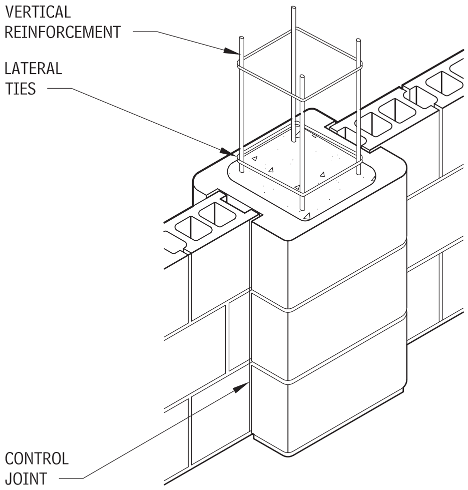
There are various types of bonding patterns that may be used when laying masonry. The most common bond pattern is the running bond for both exposed and unexposed masonry. Combination of various bond patterns produce more aesthetically interesting construction and may be combined with various types, textures, and colors of masonry. Many of the most common bond patterns are indicated in Figure 6.49.

COMMON BOND PATTERNS
6.49

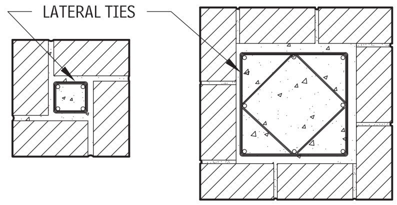


COLUMNS AND PILASTERS

TYPICAL SPECIAL PILASTER UNIT FOR USE WITH CONTROL JOINTS
6.50



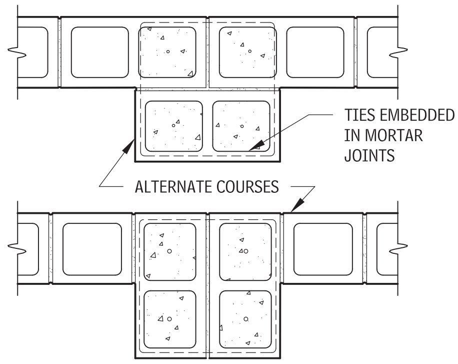
REINFORCED BRICK COLUMNS
6.51



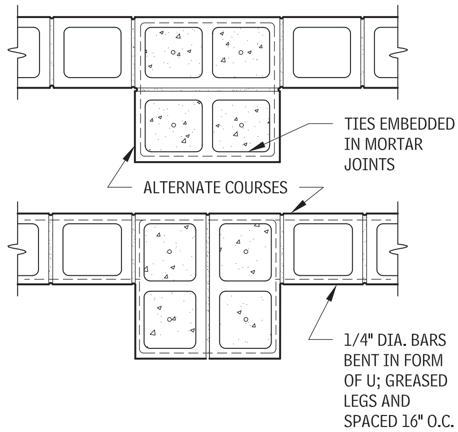
12-IN. SQUARE BRICK COLUMN

20-IN. SQUARE BRICK COLUMN

CMU PILASTER AND EMBEDDED COLUMN
6.52



CMU PILASTER

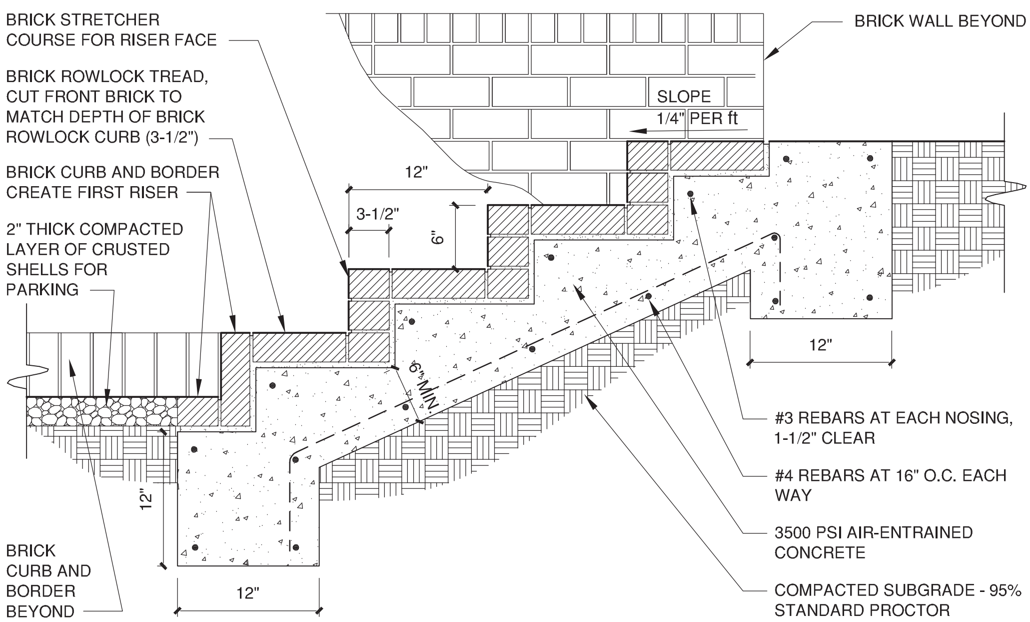


CMU EMBEDDED COLUMN

01571

MASONRY STAIRS

BRICK STAIRS CHEEKWALL
6.53



BRICK STAIRS WITH CHEEKWALL (CONDITION #1)

Contributors:
Grace S. Lee, Rippeteau Architects, PC, Washington, DC; Brian E. Trimble, Brick Institute of America, Reston, Virginia; Stephen S. Szoke, PE, National Concrete Masonry Association, Herndon, Virginia.

METALS

7

COMMON CHARACTERISTICS, STANDARDS, AND PRACTICES

PROPERTIES OF METALS

Metals and their alloys are classified in two broad categories: ferrous and nonferrous. Ferrous metals' main component is iron, and nonferrous metal alloys normally do not contain iron.

FERROUS METALS

Iron, steel, and their alloys are usually the most cost-effective metal choice for structural applications.

Iron that contains no trace of carbon is soft, ductile, and easily worked, but it rusts in a relatively short period of time and is susceptible to corrosion by most acids.

The characteristics of cast iron vary widely among the six basic types: gray, malleable, ductile, white, compacted graphite, and high-alloy iron. All cast irons have high compressive strengths, but tensile and yield strengths vary widely depending on basic type. Cast iron is relatively corrosion-resistant but cannot be hammered or beaten into shapes.

Gray irons are rather brittle because they have a high carbon and silicon content. However, castings of gray iron are excellent for damping purposes (i.e., absorbing vibrations). They are produced in eight ASTM classes or grades, with tensile-strength ratings from 20,000 to 60,000 psi. Applications include decorative shapes, such as fences and posts, gratings, and stair components, as well as utility uses such as manhole covers and fire hydrants.

Malleable iron, which is more expensive than gray iron, has been used for decades in applications that require durability and high ductility. This low-carbon white iron is cast, reheated, and slowly cooled, or annealed, to improve its workability.

Ductile iron is made by adding magnesium to molten iron shortly before the metal is poured into molds. The magnesium alters the surface-tension mechanism of the molten iron and precipitates the carbon out as small spheres, instead of flakes, which make the iron casting more ductile. Ductile iron is less brittle, stiffer, stronger, and more shock-resistant than gray iron. Ductile iron castings are more expensive than gray iron but usually less than malleable iron. Ductile iron is the fastest-growing segment of the metal casting industry.

Ductile irons are produced in strength ratings from 55,000 to 130,000 psi. Ductile castings using a special austempering heat-treating process offer much higher tensile strengths, ranging from 125,000 to 230,000 psi. Called ADI castings, they rival or surpass certain alloy steel castings in tensile and yield strengths.

White iron castings, which are extremely hard and brittle, are used primarily in industrial machinery parts that experience high wear and require abrasion resistance.

The characteristics of compacted graphite iron fall between those of gray and ductile iron. The properties of this metal are so difficult to control during production that very few metal casters manufacture it.

High-alloy irons are gray, ductile, or white irons with an alloy content of 3 percent to more than 30 percent. Their properties are significantly different from those of unalloyed irons.

Wrought iron or steel is relatively soft, corrosion- and fatigue-resistant, and machinable. It is easily worked, making it ideal for railings, grilles, fences, screens, and various types of decorative metal. It is commercially available in bars, rods, tubing, sheets, and plates.

Carbon steel is iron that contains low to medium amounts of carbon. Higher carbon content increases metal strength and hardness but reduces its ductility and weldability. The corrosion resistance of carbon steels is improved by galvanizing, which is a hot-zinc dipping process, or applying an organic coating. Some architectural uses include structural shapes such as welded fabrications or castings, metal framing and joists, fasteners, wall grilles, and ceiling suspension grids.

High-strength low-alloy (HSLA) steels have better corrosion resistance than carbon steels, and they are chosen when weight is a consideration and higher strength is specified. Low-alloy steels are seldom used in exterior architectural applications that involve water runoff because adjacent materials could become stained with rust.

Typical elements used to modify steel include the following:

- Aluminum, for surface hardening
- Chromium, for corrosion resistance
- Copper, for atmospheric corrosion resistance
- Manganese in small amounts, for additional hardening; in larger amounts, for better wear resistance
- Molybdenum, combined with other metals such as chromium and nickel, to increase corrosion resistance and raise tensile strength without reducing ductility
- Nickel, to increase tensile strength without reducing ductility; in high concentrations, nickel improves corrosion resistance.
- Silicon, to strengthen low-alloy steels and improve oxidation resistance; larger amounts produce hard, brittle castings that are resistant to corrosive chemicals.
- Sulfur, for free machining
- Titanium, to prevent intergranular corrosion of stainless steels
- Tungsten, vanadium, and cobalt for hardness and corrosion resistance

Stainless steels are at least 11.5 percent chromium. Nickel is added to boost atmospheric corrosion resistance; molybdenum is added when maximum corrosion resistance is needed, such as when iron will come into contact with saltwater. Stainless steel is used in construction for flashing, coping, fasciae, wall panels, floor plates, gratings, handrails, hardware, fasteners, and anchors. Decorative shapes and statuary can be cast in stainless steel.

NONFERROUS METALS

Nonferrous metals and their alloys can be categorized into seven major groups for architectural applications: those based on aluminum, copper (pure copper, brasses, and bronzes), lead, zinc, tin, nickel, and magnesium. Another approach is to divide nonferrous alloys into two groups: heavy metals (copper-, zinc-, lead-, and nickel-based) and light metals (aluminum- and magnesium-based).

ALUMINUM

The nonferrous metal workhorse for architectural applications is aluminum. It has good forming and casting characteristics and offers good corrosion resistance. When exposed to air, aluminum does not oxidize progressively because a hard, thin oxide coating forms on the surface and seals the metal from its environment.

Aluminum and its alloys, numbering in the hundreds, are widely available in common commercial forms. Aluminum alloy sheets can be formed, drawn, stamped, or spun. Many wrought or cast aluminum alloys can be welded, brazed, or soldered, and aluminum surfaces readily accept a wide variety of finishes, both mechanical and chemical.

Although it is light in weight, commercially pure aluminum has a tensile strength of about 13,000 psi. Most aluminum alloys lose strength at elevated temperatures. At subzero temperatures, on the other hand, aluminum is stronger than at room temperature but no less ductile. Cold-forming the metal may nearly double its tensile strength. Aluminum can be further strengthened by alloying it with other elements such as manganese, silicon, copper, magnesium, zinc, or lithium. The manganese-based aluminum alloy 3003 is used for roofing, sheet metal, siding, and electrical conduit.

BRASS, COPPER, AND BRONZE

Good thermal and electrical conductivity, corrosion resistance, and easy forming and joining make copper and its alloys useful in construction. However, copper and many of its alloys have relatively low strength-to-weight ratios, and their strength is even further reduced at elevated temperatures. These metals are offered in rod, plate, strip, sheet, and tube shapes; forgings; castings; and electrical wire.

These metals can be grouped according to composition in several general categories: copper, high-copper alloys, and many types of brass and bronze. Monel metal is a copper-nickel alloy that offers excellent corrosion resistance, and is often used for corrosion-resistant fasteners.

Bronze was originally a copper-tin alloy, but today aluminum bronzes, silicon bronzes, and leaded phosphor bronzes are more common. Phosphor bronze is a copper-tin-phosphorus alloy; and leaded phosphor bronze is composed of copper, lead, tin, and phosphorus.

Brass is copper with zinc as its principal alloying element. It is important to know that some brass alloys may be called bronzes even though they have little or no tin in them. Some common non-bronze brass alloys are commercial bronze (90 percent copper, 10 percent zinc), naval brass (60 percent copper, 29 percent zinc, and 1 percent tin), Muntz metal (60 percent copper, 40 percent zinc), and manganese bronze (58 percent copper, 39 percent zinc, and 1 percent tin and iron). When a metal is identified as bronze, the alloy may not contain zinc or nickel; if it does, it is probably brass. Architectural brasses and bronzes are actually all brasses; they are used for doors, windows, door and window frames, railings, trim and grilles, and finish hardware. Muntz metal, also called malleable brass, is a bronze alloy resembling extruded architectural bronze in color. It is available in sheet and strip and is used in flat surfaces in architectural compositions in connection with extruded architectural bronze.

Copper-based alloys characteristically form adherent films that are relatively impervious to corrosion and protect the base metal from further attack. In exterior applications certain alloys darken rather rapidly, from brown to black. Under most outdoor weather conditions, however, copper surfaces, such as roofs or statuary, develop a blue-green patina. Lacquer coatings can help retain the original alloy color.

LEAD

An extremely dense metal, lead is corrosion-resistant and easily worked. Alloys are added to it to improve properties such as hardness and strength. Typical applications of lead include roof and wall accessories, sound and vibration control, and radiation protection. It can be combined with tin alloy to plate iron or steel, which is commonly called terneplate.

It is important to note that lead vapors and dust are toxic if ingested, so care must be taken regarding how and where this metal is used.

ZINC

Although it is corrosion-resistant in water and air, zinc is brittle and low in strength. Its major use is in galvanizing (dipping hot iron or steel in molten zinc), although zinc is also used to create sand-cast or die-cast components. Major building industry uses are roofing, flashing, nails, plumbing hardware, galvanizing structural components, and decorative shapes.

WEIGHTS OF METALS FOR BUILDINGS
7.1

MATERIAL	SPECIFIC GRAVITY	DENSITY (LB/CU FT)	DENSITY (LB/CU IN.)
Aluminum	2.77	173	0.100
Zinc	7.14	446	0.258
Cast iron	7.22	450	0.260
Wrought iron	7.70	480	0.278
Steel	7.85	490	0.283
Brass	8.47	529	0.306
Copper and bronze	8.92	556	0.322
Lead	11.35	708	0.410

METAL CORROSION

Corrosion, which is caused by galvanic action, occurs between dissimilar metals or between metals and other materials when sufficient moisture is present to carry an electrical current. The galvanic series shown in Figure 7.3 is a useful indicator of corrosion susceptibility caused by galvanic action. The metals listed are arranged in order from the least noble (most reactive to corrosion) to the most noble (least reactive to corrosion). The farther apart two metals are on the list, the greater the deterioration of the less noble metal will be if the two come in contact under adverse conditions.

Metal deterioration also occurs when metal comes in contact with chemically active materials, particularly when moisture is present. For example, aluminum corrodes when in direct contact with concrete or mortar, and steel corrodes when in contact with certain treated woods.

Pitting and concentration cell corrosion are other types of metal deterioration. Pitting takes place when particles or bubbles of gas are deposited on a metal surface. Oxygen deficiency under these deposits sets up anodic areas, which cause pitting. Concentration cell corrosion is similar to galvanic corrosion; the difference is in the electrolytes. Concentration cell corrosion can be produced by differences in ion concentration, oxygen concentration, or foreign matter adhering to the surface.

THE GALVANIC SERIES
7.2

Anode (least noble) +	Magnesium, magnesium alloys
	Zinc
	Aluminum 1100
	Cadmium
	Aluminum 2024-T4
	Steel or iron, cast iron
	Chromium iron (active)
	Ni-Resist
	Type 304, 316 stainless (active)
	Hastelloy "C"
	Lead, tin
Electric current flows from positive (+) to negative (–)	Nickel (active)
	Hastelloy "B"
	Brasses, copper, bronzes, copper-nickel alloys, monel
	Silver solder
	Nickel (passive)
	Chromium iron (passive)
	Type 304, 316 stainless (passive)
	Silver
	Titanium
Cathode (most noble) –	Graphite, gold, platinum

Hot-dip galvanized steel is well suited for use in a variety of environments and fabrications, and sometimes is placed in contact with different metals including, among others, stainless steel, aluminum, copper and weathering steel.

Metals near each other in the galvanic series have little effect on each other. Generally, as the separation between metals in the series increases, the corroding effect on the metal higher in the series increases as well.

SHAPING AND FABRICATION OF METALS

Many different manufacturing processes are applied to metal to produce structural forms and shapes required in the construction and ornamentation of buildings.

Rolling hot or cold metal between pressurized rollers produces most of the readily available, standard construction material shapes. Baked enamel-coated aluminum is cold rolled to make siding and gutters.

In the extruding process, heated metal ingots or bars are pushed through a die orifice to produce a wide variety of simple and complex shapes. Sizes are limited only by the size or capacity of the die.

Casting is a process in which molten metal is poured into molds or forced into dies and allowed to solidify in the shape of the mold or die. The casting process is used with virtually all metals; however, surface quality and physical characteristics are greatly affected by the metal alloy and casting process selected. Almost all metals can be cast in sand molds. Only aluminum, zinc, and magnesium are ordinarily cast in metal dies in what is called either a die-casting or permanent-mold process. Round, hollow building products such as cast-iron pipe for plumbing and sewer applications are made by centrifugal casting machines.

In the drawing process, either hot or cold metal is pulled through dies that alter or reduce its cross-sectional shape to produce architectural product configurations. Common drawn products are sheets, tubes, pipes, rods, bars, and wires. Drawing can be used with all metals except iron.

Forging is the process of hammering hot metal or pressing cold metal to a desired shape in dies of a harder metal. The process usually improves the strength and surface characteristics of the metal. Aluminum, copper, and steel can be forged.

Machining is used to finish areas of castings or forgings that require highly precise fits or contours. Shapes can also be machined from heavy plate or solid blocks of metal.

Bending produces curved shapes in tubing, pipe, and extrusions.

Brake forming of metal plate or sheet metal is a process of successive pressings to achieve shapes with straight-line angles.

In the spinning process, ductile types of sheet metal (usually copper or aluminum) are shaped with tools while being spun on an axis.

Embossing and coining stamps metal with textured or raised patterns.

Blanking shears, saws, or cuts metal sheets with a punch press to achieve a desired configuration.

Perforating punches or drills holes through flat plate or sheet metal.

Piercing punches holes through metal without removing any of the metal.

Fusion welding is used to join metal pieces by melting filler metal (welding rod) and the adjacent edges briefly with a torch and then allowing the molten metal to solidify. Two common types of fusion welding are electric-arc and gas. Electric-arc or metallic-arc welding normally uses metal welding rods as electrodes in the welding tool.

Gas welding is also known as oxyacetylene welding because it uses a mixture of oxygen and acetylene to fuel the flames produced by the blowtorch. Oxyacetylene blowtorches are widely used in construction work to cut through metal structural beams and metal plates.

Soldering is a metal joining process that uses either hard or soft solder. The metal pieces being joined together do not melt as they do in the welding process because solders melt at much lower temperatures. Soft solders consist of tin with a high percentage of lead, and melt at temperatures of 360° to 370°F. Hard solders are composed of tin and a low content of antimony or silver, and melt at temperatures ranging from 430° to 460°F.

Brazing, which is sometimes called hard soldering, also joins two pieces of metal together by torch melting a filler rod material between them. The filler has a high content of copper and melts between 800° and 900°F.

Contributors:
Robert C. Rodgers, PE, Richmond Heights, Ohio; Edward R. Estes, Jr., PE, Norfolk, Virginia.

MELTING TEMPERATURES OF METALS
7.3

BASE METAL	MELTING TEMPERATURES DEGREES CELSIUS	DEGREES FAHRENHEIT
Aluminum	660	1220
Antimony	631	1168
Cadmium	321	610
Chromium	1857	3375
Cobalt	1495	2723
Copper	1083	1981
Gold	1064	1947
Iron	1535	2795
Lead	328	622
Magnesium	649	1200
Manganese	1244	2271
Nickel	1453	2647
Silver	962	1764
Tin	232	450
Zinc	420	788
Zirconium	1852	3366

CNC MACHINING FOR METALWORK

CNC (Computer Numerical Control) machining starts with a block of raw stock metal. Computer-controlled machining centers that have the combined capabilities of lathes, mills, routers, and/or grinders use rotating tools to create parts. The tools follow toolpaths generated by computers. Some CNC machine centers can turn and rotate the original work piece so that material can be removed from all six sides of a bar or block of metal. And parts can be machined out of both hard metals (steel and stainless steel) and soft metals (aluminum, brass, and copper).

There is no need to make a mold, enabling CNC machining to be cost effective and have the fastest lead times for low volumes for metal prototypes and parts. And because molds are not needed, draft and other moldability features are eliminated. Plus, CNC can easily create undercut features without affecting costs as significantly as it does with molding. CNC works with a wide variety of metals, giving designers flexibility and options. For example, if a part needs to resist corrosion, the part can be CNC machined out of stainless steel or aluminum. If lightweight is a goal, CNC parts can be machined out of aluminum or magnesium. Parts can also be precisely formed, with tolerances of +/− 0.005 and surface finishes that are superior to other rapid prototyping methods.

CNC machining is widely used by nearly all manufacturing industries—especially medical, computer/electronics, automotive, and aerospace. Aerospace engineers, for example, use it because it is well suited to making parts with strength and light weight but are only needed in low volumes. And biomedical engineers specify machined metal parts for a wide variety of devices including surgical tools and diagnostic equipment.

FINISHES ON METALS

GENERAL

The finishes commonly used on architectural metals fall into three categories:

- Mechanical finishes are the result of physically changing the surface of the metal through mechanical means. The forming process itself or a subsequent procedure is performed either before or after the metal is fabricated into an end-use product.
- Chemical finishes are achieved by means of chemicals, which may or may not have a physical effect on the surface of the metal.
- Coatings are applied as finishes, either to the metal stock or the fabricated product. These coatings either change the metal itself, through a process of chemical or electrochemical conversion, or they are simply applied to the metal surface.

Application environments, service requirements, and aesthetics together determine which metal finish or coating is best to specify. Finishes are usually selected for both appearance and function; chromium plating on metal bathroom water faucets and handles, or baked enamel on sheet metal lighting fixtures, for example, must be attractive as well as functionally protective.

For structural and exterior metal building products, such as structural metal framing, steel siding, and exterior lighting, function and operating environments are more important criteria. From a design standpoint, it is important to recognize how finishes and coatings resist wear and corrosion. To choose the right coating or finish, design professionals must understand which material or process is best suited for a specific application.

MECHANICAL FINISHES

Mechanical finishes fall into the following five categories:

As-fabricated finishes are the texture and surface appearance given to a metal by the fabrication process.

Buffed finishes are produced by successive polishing and buffing operations using fine abrasives, lubricants, and soft fabric wheels. Polishing and buffing improve edge and surface finishes and render many types of cast parts more durable, efficient, and safe.

Patterned finishes are available in various textures and designs. They are produced by passing an as-fabricated sheet between two matched-design rollers, embossing patterns on both sides of the sheet, or between a smooth roller and a design roller, embossing or coining on one side of the sheet only.

Directional textured finishes are produced by making tiny parallel scratches on the metal surface using a belt or wheel and fine abrasive, or by hand-rubbing with steel wool. Metal treated this way has a smooth, satin sheen.

Peened finishes are achieved by firing a stream of small steel shot at a metal surface at high velocity. The primary aim of shot-peening is to increase the fatigue strength of the component; the decorative finish is a by-product. Other nondirectional textured finishes are produced by blasting metal, under controlled conditions, with silica sand, glass beads, and aluminum oxide.

CHEMICAL FINISHES

Chemical finishes are produced in four ways.

Chemical cleaning cleanses the metal surface without affecting it in any other way. This finish is achieved with chlorinated and hydrocarbon solvents and inhibited chemical cleaners or solvents (for aluminum and copper) and pickling, chlorinated, and alkaline solutions (for iron and steel).

Etched finishes produce a matte, frosted surface with varying degrees of roughness by treating the metal with an acid (sulfuric and nitric acid) or alkali solution.

The bright finish process, not widely used, involves chemical or electrolytic brightening of a metal surface, typically aluminum.

Conversion coating is usually categorized as a chemical finish, but since a layer or coating is produced by a chemical reaction, it could be considered a coating. Conversion coatings typically prepare the surface of a metal for painting or for receiving another type of finish, but they are also used to produce a patina or statuary finish. A component is treated with a diluted solution of phosphoric acid or sulfuric acid and other chemicals that convert the surface of the metal to an integral, mildly protective layer of insoluble crystalline phosphate or sulphate. Such coatings can be applied by either spray or immersion and provide temporary resistance in a mildly corrosive environment. They can be used for gray, ductile, and malleable iron castings as well as steel castings, forgings, or weldments, such as railings and outdoor furniture.

COATINGS

Organic coatings on metal can provide protection and may also be decorative. When protection is the sole purpose, primers or undercoats, pigmented topcoats in hidden areas, and clear finishes are used. Organic coatings used for decorative and protective applications include pigmented coatings, clear finishes used for gloss, and transparent or translucent clear finishes with dyes added.

Organic coatings usually fall under the general categories of paints, varnishes, enamels, lacquers, plastisols, organisols, and powders. Hundreds of different organic coating formulations offer an almost unlimited range of properties.

Many organic coatings are applied with brushes and rollers, but dipping and spraying of coatings account for most industrial and commercial building projects. Dipping is useful for coating complex metal parts, but spraying is used for most architectural applications. Spraying is fast and inexpensive, and new computer-controlled applicators can follow even complex curvatures. Conventional sspraying, however, has two disadvantages. First, there is no easy, inexpensive way to collect and reuse the coating material. Second, when solvent-based coatings are used, environmental restrictions need to be taken into consideration.

Electrodeposition, an increasingly popular alternative to spraying, is similar to electroplating, except that organic resins are deposited instead of metal. Electrodeposition is based on the principles of electrophoresis—the movement of charged particles in a liquid under the influence of an applied electrical charge. Electrodeposition offers several advantages: The coating builds up to a uniform thickness without runs or sags; very little paint is wasted; low levels of volatile organic compounds (VOCs) are emitted; and coatings can be deposited even into deeply recessed areas of a complex shape. Electrodeposition also has disadvantages: Coating thickness is limited, and because only one coat can be applied this way, subsequent coats must be sprayed.

Powder coating is perhaps the best-known environmentally acceptable painting process. It offers three major advantages. One, because the paints are solventless, they are safer and sustainable; two, the paints cost less; and, three, they are more durable.

Powdered paints are formulated in much the same way as solvent-based paints, with the same pigments, fillers, and extenders, but are dry at room temperatures. Heat-reactive or "heat-latent" hardeners, catalysts, or cross-linking components are used as curing agents.

Powder coatings are either thermoplastic or thermosetting. Thermoplastic coatings (e.g., vinyl, polyethylene, and certain polyesters), as the term implies, are melted by heat during application. Before such coatings are applied, the surface must be primed to ensure adhesion. Thermosetting paints undergo a chemical change; they cannot be remelted by heat. Thermosets do not require a primer. Coating powders include epoxies, polyurethanes, acrylics, and polyesters.

Contributor:
Robert C. Rodgers, PE, Richmond Heights, Ohio.

COMPARATIVE APPLICABILITY OF VARIOUS FINISHES FOR ARCHITECTURAL APPLICATIONS
7.4

TYPE OF FINISH OR TREATMENT	METAL			
	ALUMINUM	COPPER ALLOYS	STAINLESS STEEL	CARBON STEEL AND IRON
MECHANICAL FINISHES				
As-fabricated	Common to all of the metals (produced by hot rolling, extruding, or casting)			
Bright rolled	Commonly used (produced by cold rolling)			Not used
Directional grit textured	Commonly used (produced by polishing, buffing, hand-rubbing, brushing, or cold rolling)			Rarely used
Nondirectional matte textured	Commonly used (produced by sandblasting or shot blasting)			Rarely used
Bright polished	Commonly used (produced by polishing and buffing)			Not used
Patterned	Available in light sheet gauges of all metals			
CHEMICAL FINISHES				
Nonetch cleaning	Commonly used on all of the metals			
Matte finish	Etched finishes widely used	Seldom used	Not used	Not used
Bright finish	Limited uses	Rarely used	Not used	Not used
Conversion coatings	Widely used as pretreatment for painting	Widely used to provide added color variation	Not used	Widely used as pretreatment for painting
COATINGS				
Organic	Widely used	Opaque types rarely used; transparent types common	Sometimes used	Most important type of finish
Anodic	Most important type of finish	Not used	Not used	Not used
Vitreous	Widely used	Limited use	Not used	Widely used
Metallic	Rarely used	Limited use	Limited use	Widely used
Laminated	Substantial uses	Limited use	Not used	Substantial uses

The two most common methods of applying powdered finishes to metal are spraying and dipping, the same as those used for solvent-based paint. Electrostatic spraying is used to apply powder films 1 to 5 mil in thickness. A mixture of air and powder moves from a hopper to a spray applicator. The mixture is charged electrostatically as it passes through the applicator, causing it to stick to any grounded metal object. Powder that falls to the floor is recycled.

For coatings thicker than 5 mil, fluidized-bed dipping is used. The powder is placed in a special tank into which air is blown, turning the powder into a fluidlike mass. Objects are dipped in the "fluid" and then baked to cure the finish.

Anodic coatings in the form of oxides are widely used to protect aluminum and many of its alloys from corrosion. When the metal is anodized in one of a variety of acids, a protective oxide is formed on the surface. Depending on the acid, the oxide may range from thin and nonporous to thick and porous. Three types of anodizing are used for aluminum: chromic, sulfuric, and hardcoat.

- Chromic anodizing, which results in a relatively soft coating, is the least used of the three types, but offers three important advantages. One, it has excellent corrosion resistance, so rinsing is not as important. Two, it is suitable for complex cast objects; and, three, it offers a coating of the most uniform thickness and the most enduring fatigue strength.
- Sulfuric anodizing, the most widely used method, produces a harder coating than chromic anodizing, but it can be scratched. It offers a pleasing appearance and can be dyed in several colors. Corrosion resistance is good.
- Hardcoat anodizing produces a relatively thick, extremely hard coating that can be dyed in a range of colors. Corrosion resistance is good. Hardcoats are porous, making them suitable as a base for paints and adhesives.

Because all anodic processes produce porous aluminum-oxide coatings, sealing is usually desirable. The coating is immersed in hot water, the oxide is hydrated, and the pores swell shut. Several manufacturers claim that their sealing agents do the same thing through catalytic action at lower temperatures. Chromic- and sulfuric-anodized coatings almost always are sealed, but hardcoats are not.

Vitreous coatings are composed of inorganic glossy materials (glass). Porcelain enamels are the most commonly used vitreous coating for architectural applications. Although one of the hardest and most durable finishes, they are brittle. Deformation of metal surfaces can cause cracking and splitting. Porcelain enamel coatings come in a wide range of colors and finishes and are typically applied to steel and aluminum (bathtubs, sinks, column covers). Embossed patterns and textures may be applied by altering the metal backing surface or the coating itself.

Hot dipping of ferrous metal objects consists of immersing clean parts into a molten bath of the desired coating metal. In general, molten aluminum, lead, zinc, and some alloys can be applied as hot-dip coatings to irons. Each offers specific advantages. Hot-dip coatings are particularly suitable for intricately shaped cast ferrous items such as metal roofing components and nails and other fasteners.

Metallic plating is achieved by electroplating. In electrodeposition, an electrical current is carried across an electrolyte, and an organic resin is deposited on an electrode (the metal object being painted). In electroplating, the metal, such as chromium, is an electrolyte. Water usually serves as the solvent in the electrolyte. Although chromium is commonly used for plating, many metals can be deposited on the substrate.

Similarly, a wide range of plating quality is possible. For example, a thin coating of zinc will protect a metal component from rust or corrosion for a short time. Chromium plating, on the other hand, protects longer and is more attractive.

Materials widely used to plate complex metal components include bronze, brass, chromium, cadmium, chromates, copper, lead, lead-tin, nickel, phosphates, silver, tin-nickel, and tin-zinc. Not all of these materials can be deposited on all metal substrates. For example, zinc electroplate can be used on steel but not on cast iron. Therefore, coating/substrate compatibility is a crucial consideration in matching coating performance to application requirements. Typical applications for plating include food servicing areas, plumbing fixtures, exterior metal, and architectural products.

NOTE

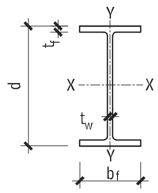
7.4 For more information, see the *Metal Finishes Manual for Architectural and Metal Products*, published by the Architectural Metal Products Division of the National Association of Architectural Metal Manufacturers.

TYPICAL METAL PRODUCTS

STRUCTURAL METAL FRAMING

W STEEL SHAPES

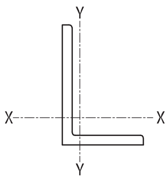
W SHAPES—DIMENSIONS FOR DETAILING
7.5



d = DEPTH
b_f = WIDTH
t_f = FLANGE THICKNESS
t_w = WEB THICKNESS

DESIGNATION		DEPTH (IN.)	FLANGE WIDTH (IN.)	FLANGE THICKNESS (IN.)	WEB THICKNESS (IN.)
W 36	× 302	37-3/8	16-5/8	1-11/16	15/16
	× 282	37-1/8	16-5/8	1-9/16	7/8
	× 262	36-7/8	16-1/2	1-7/16	13/16
	× 247	36-5/8	16-1/2	1-3/8	13/16
	× 231	36-1/2	16-1/2	1-1/4	3/4
W 36	× 210	36-3/4	12-1/8	1-3/8	13/16
	× 194	36-1/2	12-1/8	1-1/4	3/4
	× 182	36-3/8	12-1/8	1-3/16	3/4
	× 170	36-1/8	12	1-1/8	11/16
	× 160	36	12	1	5/8
	× 150	35-7/8	12	15/16	5/8
	× 135	35 1/2	12	13/16	5/8
W 33	× 241	34-1/8	15-7/8	1-3/8	13/16
	× 221	33-7/8	15-3/4	1-1/4	3/4
	× 201	33-5/8	15-3/4	1-1/8	11/16
W 33	× 152	33-1/2	11-5/8	1-1/16	5/8
	× 141	33-1/4	11-1/2	5/16	5/8
	× 130	33-1/8	11-1/2	7/8	9/16
	× 118	32-7/8	11-1/2	3/4	9/16
W 30	× 211	31	15-1/8	1-5/16	3/4
	× 191	30-5/8	15	1-3/16	11/16
	× 173	30-1/2	15	1-1/16	5/8
W 30	× 132	30-1/4	10-1/2	1	5/8
	× 124	30-1/8	10-1/2	15/16	9/16
	× 116	30	10-1/2	7/8	9/16
	× 108	29-7/8	10-1/2	3/4	9/16
	× 99	29-5/8	10-1/2	11/16	1/2
W 27	× 178	27-3/4	14-1/8	1-3/16	3/4
	× 161	27-5/8	14	1-1/16	11/16
	× 146	27-3/8	14	1	5/8
W 27	× 114	27-1/4	10-1/8	15/16	9/16
	× 102	27-1/8	10	13/16	1/2
	× 94	26-7/8	10	3/4	1/2
	× 84	26-3/4	10	5/8	7/16
W 24	× 162	25	13	1-1/4	11/16
	× 146	24-3/4	12-7/8	1-1/16	5/8
	× 131	24-1/2	12-7/8	15/16	5/8
	× 117	24-1/4	12-3/4	7/8	9/16
	× 104	24	12-3/4	3/4	1/2
W 24	× 94	24-1/4	9-1/8	7/8	1/2
	× 84	24-1/8	9	3/4	1/2
	× 76	23-7/8	9	11/16	7/16
	× 68	23-3/4	9	9/16	7/16
W 24	× 62	23-3/4	7	9/16	7/16
	× 55	23-5/8	7	1/2	3/8
W 21	× 147	22	12-1/2	1-1/8	3/4
	× 132	21-7/8	12-1/2	1-1/16	5/8
	× 122	21-5/8	12-3/8	15/16	5/8
	× 111	21-1/2	12-3/8	7/8	9/16
	× 101	21-3/8	12-1/4	13/16	1/2
W 21	× 93	21-5/8	8-3/8	15/16	9/16
	× 83	21-3/8	8-3/8	13/16	1/2
	× 73	21-1/4	8-1/4	3/4	7/16
	× 68	21-1/8	8-1/4	11/16	7/16
	× 62	21	8-1/4	5/8	3/8
W 21	× 57	21	6-1/2	5/8	3/8
	× 50	20-7/8	6-1/2	9/16	3/8
	× 44	20-5/8	6-1/2	7/16	3/8
W 18	× 119	19	11-1/4	1-1/16	5/8
	× 106	18-3/4	11-1/4	15/16	9/16
	× 97	18-5/8	11-1/8	7/8	9/16
	× 86	18-3/8	11-1/8	3/4	1/2
	× 76	18-1/4	11	11/16	7/16
W 18	× 71	18-1/2	7-5/8	13/16	1/2
	× 65	18-3/8	7-5/8	3/4	7/16
	× 60	18-1/4	7-1/2	11/16	7/16
	× 55	18-1/8	7-1/2	5/8	3/8
	× 50	18	7-1/2	9/16	3/8
W 18	× 46	18	6	5/8	3/8
	× 40	17-7/8	6	1/2	5/16
	× 35	17-3/4	6	7/16	5/16
W 16	× 100	17	10-3/8	1	9/16
	× 89	16-3/4	10-3/8	7/8	1/2
	× 77	16-1/2	10-1/4	3/4	7/16
	× 67	16-3/8	10-1/4	11/16	3/8
W 16	× 57	16-3/8	7-1/8	11/16	7/16
	× 50	16-1/4	7-1/8	5/8	3/8
	× 45	16-1/8	7	9/16	3/8
	× 40	16	7	1/2	5/16
	× 36	15-7/8	7	7/16	5/16
W 16	× 31	15-7/8	5-1/2	7/16	1/4
	× 26	15-3/4	5-1/2	3/8	1/4
W 14	× 730	22-3/8	17-7/8	4-15/16	1/16
	× 665	21-5/8	17 5/8	4-1/2	13/16
	× 605	20-7/8	17-3/8	4-3/16	5/8
	× 550	20-1/4	17-1/4	3-13/16	3/8
	× 500	19-5/8	17	3-1/2	3/16
	× 455	19	16-7/8	3-3/16	
W 14	× 426	18-5/8	16-3/4	3-1/16	7/8
	× 398	18-1/4	16-5/8	2-7/8	3/4
	× 370	17-7/8	16-1/2	2-11/16	5/8
	× 342	17-1/2	16-3/8	2-1/2	9/16
	× 311	17-1/8	16-1/4	2-1/4	7/16
	× 283	16-3/4	16-1/8	2-1/16	5/16
	× 257	16-3/8	16	1-7/8	3/16
	× 233	16	15-7/8	1-3/4	1/16
	× 211	15-3/4	15-3/4	1-9/16	
	× 193	15-1/2	15-3/4	1-7/16	7/8
	× 176	15-1/4	15-5/8	1-5/16	13/16
	× 159	15	15 5/8	1-3/16	3/4
	× 145	14-3/4	15-1/2	1-1/16	11/16
W 14	× 132	14-5/8	14-3/4	1	5/8
	× 120	14-1/2	14-5/8	15/16	9/16
	× 109	14-3/8	14-5/8	7/8	1/2
	× 99	14-1/8	14-5/8	3/4	1/2
	× 90	14	14-1/2	11/16	7/16
W 14	× 82	14-1/4	10-1/8	7/8	1/2
	× 74	14-1/8	10-1/8	13/16	7/16
	× 68	14	10	3/4	7/16
	× 61	13-7/8	10	5/8	3/8
W 14	× 53	13-7/8	8	11/16	3/8
	× 48	13-3/4	8	5/8	5/16
	× 43	13-5/8	8	1/2	5/16
W 14	× 38	14-1/8	6-3/4	1/2	5/16
	× 34	14	6-3/4	7/16	5/16
	× 30	13-7/8	6-3/4	3/8	1/4
W 14	× 26	13-7/8	5	7/16	1/4
	× 22	13-3/4	5	5/16	1/4
W 12	× 336	16-7/8	13-3/8	2-15/16	3/4
	× 305	16-3/8	13-1/4	2-11/16	5/8
	× 279	15-7/8	13-1/8	2-1/2	1/2
	× 252	15-3/8	13	2-1/4	3/8
	× 230	15	12-7/8	2-1/16	5/16
	× 210	14-3/4	12-3/4	1-7/8	3/16
W 12	× 190	14-3/8	12-5/8	1-3/4	1/16
	× 170	14	12-5/8	1-9/16	15/16
	× 152	13-3/4	12-1/2	1-3/8	7/8
	× 136	13-3/8	12-3/8	1-1/4	13/16
	× 120	13-1/8	12-3/8	1-1/8	11/16
	× 106	12-7/8	12-1/4	1	5/8
	× 96	12-3/4	12-1/8	7/8	9/16
	× 87	12-1/2	12-1/8	13/16	1/2
	× 79	12-3/8	12-1/8	3/4	1/2
	× 72	12-1/4	12	11/16	7/16
	× 65	12-1/8	12	5/8	3/8
W 12	× 58	12-1/4	10	5/8	3/8
	× 53	12	10	9/16	3/8
W 12	× 50	12-1/4	8-1/8	3/8	5/8
	× 45	12	8	5/16	9/16
	× 40	12	8	5/16	1/2
W 12	× 35	12-1/2	6-1/2	5/16	1/2
	× 30	12-3/8	6-1/2	1/4	7/16
	× 26	12-1/4	6-1/2	1/4	3/8
W 12	× 22	12-1/4	4	7/16	1/4
	× 19	12-1/8	4	3/8	1/4
	× 16	12	4	1/4	1/4
	× 14	11-7/8	4	1/4	3/16
W 10	× 112	11-3/8	10-3/8	1-1/4	3/4
	× 100	11-1/8	10-3/8	1-1/8	11/16
	× 88	10-7/8	10-1/4	1	5/8
	× 77	10-5/8	10-1/4	7/8	1/2
	× 68	10-3/8	10-1/8	3/4	1/2
	× 60	10-1/4	10-1/8	11/16	7/16
	× 54	10-1/8	10	5/8	3/8
	× 49	10	10	9/16	5/16
W 10	× 45	10-1/8	8	5/8	3/8
	× 49	9-7/8	8	1/2	5/16
	× 33	9-3/4	8	7/16	5/16
W 10	× 30	10-1/2	5-3/4	1/2	5/16
	× 26	10-3/8	5 3/4	7/16	1/4
	× 22	10-1/8	5-3/4	3/8	1/4
W 10	× 19	10-1/4	4	3/8	1/4
	× 17	10-1/8	4	5/16	1/4
	× 15	10	4	1/4	1/4
	× 12	9-7/8	4	3/16	3/16
W 8	× 67	9	8-1/4	15/16	3/16
	× 58	8-3/4	8-1/4	13/16	1/2
	× 48	8-1/2	8-1/8	11/16	3/8
	× 40	8-1/4	8-1/8	9/16	3/8
	× 35	8-1/8	8	1/2	5/16
	× 31	8	8	7/16	5/16

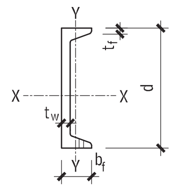
ANGLES—DIMENSIONS FOR DETAILING
7.6



SIZE AND THICKNESS (IN.)		WEIGHT PER FT (LB)	SIZE AND THICKNESS (IN.)		WEIGHT PER FT (LB)
L8 × 8 ×	1-1/8	57.2	L4 × 4 ×	3/4	18.5
	1	51.3		5/8	15.7
	7/8	45.3		1/2	12.8
	3/4	389.2		7/16	11.3
	5/8	33.0		3/8	9.8
	9/16	29.8		5/16	8.2
	1/2	26.7		1/4	6.6
L8 × 6 ×	1	44.4	L4 × 3-1/2 ×	1/2	11.9
	7/8	39.3		7/16	10.6
	3/4	34		3/8	9.1
	5/8	28.6		5/16	7.7
	9/16	25.9		1/4	6.2
	1/2	23.2	L4 × 3 ×	1/2	11.1
	7/16	20.4		7/16	9.8
L8 × 4 ×	1	37.6		3/8	8.5
	3/4	28.9		5/16	7.2
	9/16	22.1		1/4	5.8
	1/2	19.7	L3-1/2 × 3-1/2 ×	1/2	11.1
L7 × 4 ×	3/4	26.2		7/16	9.8
	5/8	22.1		3/8	8.5
	1/2	17.9		5/16	7.2
	3/8	13.6		1/4	5.8

SIZE AND THICKNESS (IN.)		WEIGHT PER FT (LB)	SIZE AND THICKNESS (IN.)		WEIGHT PER FT (LB)
L6 × 6 ×	1	37.5	L3-1/2 × 3 ×	1/2	10.2
	7/8	33.2		7/16	9.1
	3/4	28.8		3/8	7.9
	5/8	24.3		5/16	6.6
	9/16	22		1/4	5.4
	1/2	19.6	L3-1/2 × 2-1/2 ×	1/2	9.4
	7/16	17.3		7/8	8.3
	3/8	14.9		3/8	7.2
	5/16	12.5		5/16	6.1
L6 × 4 ×	7/8	27.1		1/4	4.9
	3/4	23.5	L3 × 3 ×	1/2	9.4
	5/8	19.8		7/16	8.3
	9/16	17.9		3/8	7.2
	1/2	16		5/16	6.1
	7/16	14.1		1/4	4.9
	3/8	12.2		3/16	3.71
	5/16	10.2	L3 × 2-1/2 ×	1/2	8.5
L6 × 3-1/2 ×	1/2	15.3		7/16	7.6
	3/8	11.6		3/8	6.6
	5/16	9.72		5/16	5.6
L5 × 5 ×	7/8	27.3		1/4	4.5
	3/4	23.7		3/16	3.39
	5/8	20.1	L3 × 2 ×	1/2	7.7
	1/2	16.3		7/16	6.8
	7/16	14.4		3/8	5.9
	3/8	12.4		5/16	5.0
	5/16	10.4		1/4	4.1
L5 × 3-1/2 ×	3/4	19.8		3/16	3.07
	5/8	16.8	L2-1/2 × 2-1/2 ×	1/2	7.7
	1/2	13.6		3/8	5.9
	7/16	12.0		5/16	5.0
	3/8	10.4		1/4	4.1
	5/16	8.7		3/16	3.07
	1/4	7.0	L2-1/2 × 2 ×	3/8	5.3
L5 × 3 ×	5/8	15.7		5/16	4.5
	1/2	12.8		1/4	3.62
	7/16	11.3		3/16	2.75
	3/8	9.8	L2 × 2 ×	3/8	4.7
	5/16	8.19		5/16	3.92

AMERICAN STANDARD CHANNELS—DIMENSIONS FOR DETAILING
7.7



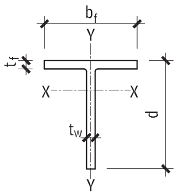
d = DEPTH
b_f = WIDTH
t_f = FLANGE THICKNESS
t_w = WEB THICKNESS

DESIGNATION		DEPTH (IN.)	FLANGE		WEB
			WIDTH (IN.)	AVERGE THICK-NESS (IN.)	THICK-NESS (IN.)
C 15	× 50	15	3-3/4	5/8	11/16
	× 40	15	3-1/2	5/8	1/2
	× 33.9	15	3-3/8	5/8	3/8
C 12	× 30	12	3	1/2	1/2
	× 25	12	3	1/2	3/8
	× 20.7	12	3	1/2	5/16
C 10	× 30	10	3	7/16	11/16
	× 25	10	2-7/8	7/16	1/2
	× 20	10	2-3/4	7/16	3/8
	× 15.3	10	2-5/8	7/16	1/4
C 9	× 20	9	2-5/8	7/16	7/16
	× 15	9	2-1/2	7/16	5/16
	× 13.4	9	2-3/8	7/16	1/4
C 8	× 18.75	8	2-1/2	3/8	1/2
	× 13.75	8	2-3/8	3/8	5/16
	× 11.5	8	2-1/4	3/8	1/4
C 7	× 14.75	7	2-1/4	3/8	7/16
	× 12.25	7	2-1/4	3/8	5/16
	× 9.8	7	2-1/8	3/8	3/16
C 6	× 13	6	2-1/8	5/16	7/16
	× 10.5	6	2	5/16	5/16
	× 8.2	6	1-7/8	5/16	3/16
C 5	× 9	5	1-7/8	5/16	5/16
	× 6.7	5	1-3/4	5/16	3/16

Contributor:
American Institute of Steel Construction, Chicago, Illinois.

STRUCTURAL TEES CUT FROM W AND S SHAPES

STRUCTURAL TEES CUT FROM W SHAPES—DIMENSIONS FOR DETAILING
7.8



d = DEPTH

b_f = WIDTH

t_f = FLANGE THICKNESS

t_w = WEB THICKNESS

DESIGNATION		DEPTH OF TEE (IN.)	FLANGE		STEM
			WIDTH (IN.)	THICKNESS (IN.)	THICKNESS (IN.)
WT 16.5	× 177	17-3/4	16-1/8	2-1/16	1-3/16
	× 159	17-5/8	16	1-7/8	1-1/16
	× 145.5	17-3/8	15-7/8	1-3/4	15/16
	× 131.5	17-1/4	15-3/4	1-9/16	7/8
	× 120.5	17-1/8	15-7/8	1-3/8	13/16
	× 110.5	17	15-3/4	1-1/4	3/4
	× 100.5	16-7/8	15-3/4	1-1/8	11/16
WT 16.5	× 84.5	16-7/8	11-1/2	1-1/4	11/16
	× 76	16-3/4	11-5/8	1-1/16	5/8
	× 70.5	16-5/8	11-1/2	15/16	5/8
	× 65	16-1/2	11-1/2	7/8	9/16
	× 59	16-3/8	11-1/2	3/4	9/16
WT 15	× 117.5	15-5/8	15	1-1/2	13/16
	× 105.5	15-1/2	15-1/8	1-5/16	3/4
	× 95.5	15-3/8	15	1-3/16	11/16
	× 86.5	15-1/4	15	1-1/16	5/8
WT 15	× 74	15-5/16	10-1/2	1-3/16	5/8
	× 66	15-1/8	10-1/2	1	5/8
	× 62	15-1/8	10-1/2	15/16	9/16
	× 58	15	10-1/2	7/8	9/16
	× 54	14-7/8	10-1/2	3/4	9/16
	× 49.5	14-7/8	10-1/2	11/16	1/2
WT 13.5	× 108.5	14-3/16	14-1/8	1-1/2	13/16
	× 97	14-1/16	14	1-5/16	3/4
	× 89	13-7/8	14-1/8	1-3/16	3/4
	× 80.5	13-3/4	14	1-1/16	11/16
	× 73	13-3/4	14	1	5/8
WT 13.5	× 64.5	13-13/16	10	1-1/8	5/8
	× 57	13-5/8	10-1/8	15/16	9/16
	× 51	13-1/2	10	13/16	1/2
	× 47	13-1/2	10	3/4	1/2
	× 42	13-3/8	10	5/8	7/16
WT 12	× 88	12-5/8	12-7/8	1-5/16	3/4
	× 81	12-1/2	13	1-1/4	11/16
	× 73	12-3/8	12-7/8	1-1/16	5/8
	× 65.5	12-1/4	12-7/8	15/16	5/8
	× 58.5	12-1/8	12-3/4	7/8	9/16
	× 52	12	12-3/4	3/4	1/2
WT 12	× 51.5	12-1/4	9	1	9/16
	× 47	12-1/8	9-1/8	7/8	1/2
	× 42	12	9	3/4	1/2
	× 38	12	9	11/16	7/16
	× 34	11-7/8	9	9/16	7/16
WT 12	× 31	11-7/8	7	9/16	7/16
	× 27.5	11-3/4	7	1/2	3/8

STRUCTURAL TEES CUT FROM W SHAPES—DIMENSIONS FOR DETAILING (continued)
7.9

DESIGNATION		DEPTH OF TEE (IN.)	FLANGE		STEM
			WIDTH (IN.)	THICKNESS (IN.)	THICKNESS (IN.)
WT 10.5	× 83	11-1/4	12-3/8	1-3/8	3/4
	× 73.5	11	12-1/2	1-1/8	3/4
	× 66	10-7/8	12-1/2	1-1/16	5/8
	× 61	10-7/8	12-3/8	15/16	5/8
	× 55.5	10-3/4	12-3/8	7/8	9/16
	× 50.5	10-5/8	12-1/4	13/16	1/2
WT 10.5	× 46.5	10-3/4	8-3/8	15/16	9/16
	× 41.5	10-3/4	8-3/8	13/16	1/2
	× 36.5	10-5/8	8-1/4	3/4	7/16
	× 34	10-5/8	8-1/4	11/16	7/16
	× 31	10-1/2	8-1/4	5/8	3/8
WT 10.5	× 28.5	10-1/2	6-1/2	5/8	3/8
	× 25	10-3/8	6-1/2	9/16	3/8
	× 22	10-3/8	6-1/2	7/16	3/8
WT 9	× 71.5	9-3/4	11-1/4	1-5/16	3/4
	× 65	9-5/8	11-1/8	1-3/16	11/16
	× 59.5	9-1/2	11-1/4	1-1/16	5/8
	× 53	9-3/8	11-1/4	15/16	9/16
	× 48.5	9-1/4	11-1/8	7/8	9/16
	× 43	9-1/4	11-1/8	3/4	1/2
	× 38	9-1/8	11	11/16	7/16
WT 9	× 35.5	9-1/4	7-5/8	13/16	1/2
	× 32.5	9-1/8	7-5/8	3/4	7/16
	× 30	9-1/8	7-1/2	11/16	7/16
	× 27.5	9	7-1/2	5/8	3/8
	× 25	9	7-1/2	9/16	3/8
WT 9	× 23	9	6	5/8	3/8
	× 20	9	6	1/2	5/16
	× 17.5	8-7/8	6	7/16	5/16
WT 8	× 50	8-1/2	10-3/8	1	9/16
	× 44.5	8-3/8	10-3/8	7/8	1/2
	× 38.5	8-1/4	10-1/4	3/4	7/16
	× 33.5	8-1/8	10-1/4	11/16	3/8
WT 8	× 28.5	8-1/4	7-1/8	11/16	7/16
	× 25	8-1/8	7-1/8	5/8	3/8
	× 22.5	8-1/8	7	9/16	3/8
	× 20	8	7	1/2	5/16
	× 18	7-7/8	7	7/16	5/16
WT 8	× 15.5	8	5-1/2	7/16	1/4
	× 13	7-7/8	5-1/2	3/8	1/4
WT 7	× 365	11-1/4	17-7/8	4-15/16	3-1/16
	× 332.5	10-7/8	17-5/8	4-1/2	2-13/16
	× 302.5	10-1/2	17-3/8	4-3/16	2-5/8
	× 275	10-1/8	17-1/4	3-3/16	2-3/8
	× 250	9-3/4	17	3-1/2	2-3/16
	× 227.5	9-1/2	16-7/8	3-13/16	2
	× 213	9-3/8	16-3/4	3-1/16	1-7/8
	× 199	9-1/8	16-5/8	2-7/8	1-3/4
	× 185	9	16-1/2	2-11/16	1-5/8
	× 171	8-3/4	16-3/8	2-1/2	1-9/16
	× 155.5	8-1/2	16-1/4	2-1/4	1-7/16
	× 141.5	8-3/8	16-1/8	2-1/16	1-5/16
	× 128.5	8-1/4	16	1-7/8	1-13/16
	× 116.5	8	15-7/8	1-3/4	1-1/16
	× 105.5	7-7/8	15-3/4	1-9/16	1
	× 96.5	7-3/4	15-3/4	1-7/16	7/8
	× 88	7-5/8	15-5/8	1-5/16	13/16
	× 79.5	7-1/2	15-5/8	1-3/16	3/4
	× 72.5	7-3/8	15-1/2	1-1/16	11/16

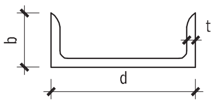
DESIGNATION		DEPTH OF TEE (IN.)	FLANGE		STEM
			WIDTH (IN.)	THICKNESS (IN.)	THICKNESS (IN.)
WT 7	× 66	7-3/8	14-3/4	1	5/8
	× 60	7-1/4	14-5/8	15/16	9/16
	× 54.5	7-1/8	14-5/8	7/8	1/2
	× 49.5	7-1/8	14-5/8	3/4	1/2
	× 45	7	14-1/2	11/16	7/16
WT 7	× 41	7-1/8	10-1/8	7/8	1/2
	× 37	7-1/8	10-1/8	13/16	7/16
	× 34	7	10	3/4	7/16
	× 30.5	7	10	5/8	3/8
WT 7	× 26.5	7	8	11/16	3/8
	× 24	6-7/8	8	5/8	5/16
	× 21.5	6-7/8	8	1/2	5/16
WT 7	× 19	7	6-3/4	1/2	5/16
	× 17	7	6-3/4	7/16	5/16
WT 7	× 13	7	5	7/16	1/4
	× 11	6-7/8	5	5/16	1/4
WT 6	× 168	8-3/8	13-3/8	2-15/16	3/4
	× 152.5	8-1/8	13-1/4	2-11/16	1-5/8
	× 139.5	7-7/8	13-1/8	2-1/2	1-1/2
	× 126	7-3/4	13	2-1/4	1-3/8
	× 115	7-1/2	12-7/8	2-1/16	1-5/16
	× 105	7-3/8	12-3/4	1-7/8	1-3/16
	× 95	7-1/4	12-5/8	1-3/4	1-1/16
	× 85	7	12-5/8	1-9/16	15/16
	× 76	6-7/8	12-1/2	1-3/8	7/8
	× 68	6-3/4	12-3/8	1-1/4	13/16
	× 60	6-1/2	12-3/8	1-1/8	11/16
	× 53	6-1/2	12-1/4	1	5/8
	× 48	6-3/8	12-1/8	7/8	9/16
	× 43.5	6-1/4	12-1/8	13/16	1/2
	× 39.5	6-1/4	12-1/8	3/4	1/2
	× 36	6-1/8	12	11/16	7/16
	× 32.5	6	12	5/8	3/8
WT 6	× 29	6-1/8	10	5/8	3/8
	× 26.5	6	10	9/16	3/8
WT 6	× 25	6-1/8	8-1/8	5/8	3/8
	× 22.5	6	8	9/16	5/16
	× 20	6	8	1/2	5/16
WT 6	× 17.5	6-1/4	6-1/2	1/2	5/16
	× 15	6-1/8	6-1/2	7/16	1/4
	× 13	6-1/8	6-1/2	3/8	1/4
WT 6	× 11	6-1/8	4	7/16	1/4
	× 9.5	6-1/8	4	3/8	1/4
	× 8	6	4	1/4	1/4
	× 7	6	4	1/4	3/16
WT 5	× 56	5-5/8	10-3/8	1-1/4	3/4
	× 50	5-1/2	10-3/8	1-1/8	11/16
	× 44	5-3/8	10-1/4	1	5/8
	× 38.5	5-1/4	10-1/4	7/8	1/2
	× 34	5-1/4	10-1/8	3/8	1/2
	× 30	5-1/8	10-1/8	11/16	7/16
	× 27	5	10	5/8	3/8
	× 24.5	5	10	9/16	5/16
WT 5	× 22.5	5	8	5/8	3/8
	× 19.5	5	8	1/2	5/16
	× 16.5	4-7/8	8	7/16	5/16
WT 5	× 15	5-1/4	5-3/4	1/2	5/16
	× 13	5-1/8	5-3/4	7/16	1/4
	× 11	5-1/8	5-3/4	3/8	1/4

MISCELLANEOUS METAL ANGLES, TEES, ZEES, AND CHANNELS

The following figures show sizes and shapes usually stocked or readily available. Manufacturers' data should be checked for availability of sizes other than those listed in these figures. Where necessary, and where extra cost is warranted, other sections may be produced by welding, cutting, or other methods.

STEEL CHANNELS—BAR SIZE (IN.)
7.10

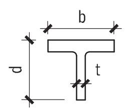
STEEL CHANNEL



d × b × t	d × b × t	d × b × t
3/4 × 3/8 × 1/8	1-1/2 × 1/2 × 1/8	2 × 5/8 × 1/4
1 × 3/8 × 1/8	1-1/2 × 9/16 × 3/16	2 × 1 × 1/8
1 × 1/2 × 1/8	1-1/2 × 3/4 × 1/8	2 × 1 × 3/16
1-1/8 × 9/16 × 3/16	2 × 1/2 × 1/8	2-1/2 × 5/8 × 3/16
1-1/4 × 1/2 × 1/8	2 × 9/16 × 3/16	

STEEL TEES—BAR SIZE (IN.)
7.11

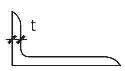
STEEL TEES



b × d × t
1-1/2 × 1-1/2 × 3/16
1-1/2 × 1-1/2 × 1/4
1-3/4 × 1-3/4 × 3/16
2 × 2 × 1/4
2-1/2 × 2-1/2 ×1/4

STEEL ANGLES, UNEQUAL LEGS—BAR SIZE (IN.)
7.12

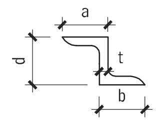
STEEL ANGLES UNEQUAL LEGS



SIZE × t	SIZE × t	SIZE × t
1 × 3/8 × 1/8	1-3/4 × 1-1/4 × 1/4	2-1$_2$ × 1-1/2 × 3/16
1 × 3/4 × 1/8	2 × 1-1/4 × 3/16	2-1/2 × 1-1/2 × 1/4
1-3/8 × 7/8 × 1/8	2 × 1-1/4 × 1/4	2-1/2 × 1-1/2 × 5/16
1-3/8 × 7/8 × 3/16	2 × 1-1/2 × 1/8	2-1/2 × 2 × 3/16
1-1/2 × 1-1/4 × 3/16	2 × 1-1/2 × 3/16	2-1/2 × 2 × 1$_4$
1-3/4 × 1-1/4 × 1/8	2 × 1-1/2 × 1/4	2-1/2 × 2 × 5/16
1-3/4 × 1-1/4 × 3/16	2-1/4 × 1-1/2 × 3/16	2-1/2 × 2 × 3/8

STEEL ZEES—BAR SIZE (IN.)
7.13

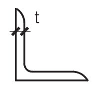
STEEL ZEES



d × a × b × t	d × a × b × t
1 × 1/2 × 5/8 × 1/8	1-3/8 × 3/4 × 1-3/16 × 1/8
1-3/16 × 5/8 × 3/4 × 1/8	1-3/4 × 1-1/4 × 3/4 × 3/16
STRUCTURAL	
3 × 2-11/16 × 2-11/16 × 1/4	4-1/8 × 3-3/16 × 3-3/16 × 3/8
3 × 2-11/16 × 2-11/16 × 3/8	5 × 3-1/4 × 3-1/4 × 5/16
3 × 2-11/16 × 2-11/16 × 1/2	5 × 3-1/4 × 3-1/4 × 1/2
4 × 3-1/16 × 3-1/16 × 1/4	5-1/16 × 3-5/16 × 3-5/16 × 3/8
4-1/16 × 3-1/8 × 3-1/8 × 5/16	6 × 3-1/2 × 3-1/2 × 3/8

STEEL ANGLES, EQUAL LEGS—BAR SIZE (IN.)
7.14

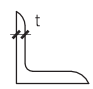
STEEL ANGLES EQUAL LEGS



SIZE × t	SIZE × t	SIZE × t
1/2 × 1/2 × 1/8	1-1/4 × 1-1/4 × 3/16	2 × 2 × 1/8
5/8 × 5/8 × 1/8	1-1/4 × 1-1/4 × 1/4	2 × 2 × 3/16
3/4 × 3/4 × 1/8	1-1/2 × 1-1/2 × 1/8	2 × 2 × 1/4
7/8 × 7/8 × 1/8	1-1/2 × 1-1/2 × 3/16	2 × 2 × 5/16
1 × 1 × 1/8	1-1/2 × 1-1/2 × 1/4	2 × 2 × 3/8
1 × 1 × 3/16	1-1/2 × 1-1/2 × 3/8	2-1/2 × 2-1/2 × 3/16
1 × 1 × 1/4	1-3/4 × 1-3/4 × 1/8	2-1/2 × 2-1/2 × 1/4
1-1/8 × 1-1/8 × 1/8	1-3/4 × 1-3/4 × 3/16	2-1/2 × 2-1/2 × 5/16
1-1/4 × 1-1/4 × 1/8	1-3/4 × 1-3/4 × 1/4	2-1/2 × 2-1/2 × 3/8
		2-1/2 × 2-1/2 × 1/2

STAINLESS STEEL ANGLES (IN.)
7.15

STAINLESS STEEL ANGLES



SIZE × t	SIZE × t	SIZE × t
3/4 × 3/4 × 1/8	1-1/2 × 1-1/2 × 1/8	2-1/2 × 2-1/2 × 3/16
1 × 1 × 1/8	1-1/2 × 1-1/2 × 3/16	2-1/2 × 2-1/2 × 1/4
1 × 1 × 3/16	1-1/2 × 1-1/2 × 1/4	3 × 3 × 1/4
1-1/4 × 1-1/4 × 1/8	2 × 2 × 1/8	3 × 3 × 5/16
1-1/4 × 1-1/4 × 3/16	2 × 2 × 3/16	3 × 3 × 3/8
1-1/4 × 1-1/4 ×1/4	2 × 2 × 1/4	

METAL TUBING AND PIPES

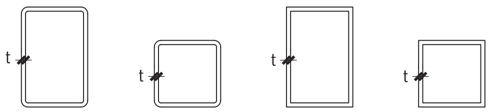
RECTANGULAR TUBING—STEEL
7.16

SIZE (IN.)	T = WALL THICKNESS (BW GAUGE OR IN.)						
1 × 1/2	18	16					
1-1/2 × 3/4	16	14	11				
1-1/2 × 1	16	14	11				
2 × 1	18	16	15	14	12	11	11
2 × 1-1/4	14						
2 × 1-1/2	14	11					
2-1/2 × 1	14						
2-1/2 × 1-1/4	14						
2-1/2 × 1-1/2	14	11	1/8″	9/16″	1/4″		
3 × 1	16	14					
3 × 1-1/2	14	13	12	11	1/8″	3/16″	1/4″
3 × 2	16	14	11	1/8″	3/16″	1/4″	5/16″
4 × 2	14	11	1/8″	3/16″	1/4″	5/16″	3/8″
4 × 2-1/2	1/8″						
4 × 3	11	1/8″	3/16″	1/4″	5/16″	3/8″	
5 × 2	11	1/8″	10	1/4″	5/16″		
5 × 2-1/2	1/8″	3/16″					
5 × 3	11	1/8″	1/4″	5/16″	3/8″	1/2″	
6 × 2	11	1/8″	1/4″	5/16″	3/8″		
6 × 3	11	1/8″	1/4″	5/16″	3/8″	1/2″	
6 × 4	1/8″	3/16″	1/4″	5/16″	3/8″	1/2″	
7 × 3	3/16″	1/4″	3/8″				
7 × 4	3/16″	1/4″	3/8″				
7 × 5	3/16″	1/4″	5/16″	3/8″	1/2″	3/8″	1/2″
8 × 2	3/16″	1/4″	3/8″				
8 × 3	3/16″	1/4″	5/16″	3/8″	1/2″		
8 × 4	3/16″	1/4″	5/16″	3/8″	1/2″		
8 × 6	3/16″	1/4″	5/16″	3/8″	1/2″		
9 × 5	3/8″						
9 × 7	1/4″	5/16″					
10 × 2	3/16″	1/4″					
10 × 4	3/16″	1/4″	5/16″	3/8″	1/2″		
10 × 5	1/4″						
10 × 6	1/4″	3/16″	5/16″	3/8″	1/2″		
10 × 8	1/4″	3/8″	1/2″				
12 × 2	3/16″	1/4″					
12 × 4	3/16″	1/4″	5/16″	3/8″	1/2″		
12 × 6	1/4″	5/16″	3/8″	1/2″			
12 × 8	1/4″	3/8″	1/2″				
ALUMINUM							
1 × 1-1/2	0.125″						
1 × 2	0.125″						
1-1/2 × 2	0.125″						
1-1/2 × 2-1/2	0.125″						
1-1/2 × 3	0.125″	0.188					
1-3/4 × 2-1/4	0.125″						
1-3/4 × 3	0.125″						
1-3/4 × 3-1/2	0.125″						
1-3/4 × 4	0.125″						
1-3/4 × 4-1/2	0.125″						
1-3/4 × 5	0.125″						
2 × 3	0.125″						
2 × 4	0.125″						
2 × 5	0.125″						
2 × 6	0.125″	0.250					
2 × 8	0.125″						
STAINLESS STEEL							
1 × 1-1/2	11						
1 × 2	11	16					
2 × 3	11	7					
2 × 4	11	7	1/4″				

NOTES

7.10 For structural channel sizes (d = 3 in. and larger), see figures for dimension for detailing of miscellaneous and American Standard channels.
7.12 For structural angle sizes (3 × 2 × 3/16 in. and larger), see Angles—Dimensions for Detailing.
7.14 For structural angle sizes (3 × 3 × 3/16 in. and larger), see Angles—Dimensions for Detailing.

RECTANGULAR AND SQUARE TUBING
7.17



STEEL ALUMINUM

RECTANGULAR ALUMINUM TUBING (IN.)
7.18

SIZE × t	SIZE × t	SIZE × t
1-1/2 × 1-1/2 × 1/8	1-3/4 × 3-1/2 × 1/8	2 × 4 × 1/8
1 × 2 × 1/8	1-3/4 × 4 × 1/8	2 × 5 × 1/8
1-1/2 × 2-1/2 × 1/8	1-3/4 × 4-1/2 × 1/8	3 × 5 × 1/8
1-3/4 × 2-1/4 × 1/8	1-3/4 × 5 × 1/8	
1-3/4 × 3 × 1/8	2 × 3 × 1/8	

SQUARE ALUMINUM TUBING (IN.)
7.19

SIZE × t	SIZE × t	SIZE × t
1/2 × 1/2 × 1/8	1-1/2 × 1-1/2 × 1/8	3 × 3 × 1/4
3/4 × 3/4 × 1/8	1-3/4 × 1-3/4 × 1/8	4 × 4 × 1/8
1 × 1 × 1/16	2 × 2 × 1/8	4 × 4 × 1/4
1-1/4 × 1- 1/4 × 1/8	2 × 2 × 1/4	
1-1/2 × 1-1/2 × 5/64	3 × 3 × 1/8	

ROUND PIPE—STEEL
7.20

SIZE (IN.) NOMINAL INSIDE DIAMETER	OUTSIDE DIAMETER (IN.)	INSIDE DIAMETER (IN.)		
		STANDARD	EXTRA-STRONG	DOUBLE-EXTRA-STRONG
1/8	0.405	0.269	0.215	
1/4	0.540	0.364	0.302	
3/8	0.675	0.493	0.423	
1/2	0.840	0.622	0.546	
3/4	1.050	0.824	0.742	
1	1.315	1.049	0.957	
1-1/4	1.660	1.380	1.278	
1-1/2	1.900	1.610	1.500	
2	2.375	2.067	1.939	1.503
2-1/2	2.875	2.469	2.323	1.771
3	3.500	3.068	2.900	2.300
3-1/2	4.000	3.548	3.364	
4	4.500	4.026	3.826	3.152
5	5.563	5.047	4.813	4.063
6	6.625	6.065	5.761	4.897
8	8.625	7.981	7.625	6.875
10	10.750	10.020	9.750	
12	12.750	12.000	11.750	

SQUARE TUBING—STEEL
7.21

SIZE (IN.)	WALL THICKNESS (BW GAUGE OR IN.)												
1/2 × 1/2	20	18		16									
5/8 × 5/8	20		16										
3/4 × 3/4	20	18		16	13	11							
7/8 × 7/8	18	16	14	13									
1 × 1	20	18		16	15		14	13	12	11			
1-1/8 × 1-1/8	18	16											
1-1/4 × 1-1/4	18		16		14	13	12	11	0.135	3/16″			
1-1/2 × 1-1/2	18		16	15	14	13	12	11	0.145	3/16″	1/4″		
1-3/4 ×1-3/4	16	14	13	11									
2 × 2	18		16	15	14	13	12	11	1/8″	10	0.145	3/16″	1/4″
2-1/4 × 2-1/4	16	0.109	1/4″										
2-1/2 × 2-1/2	16	12	1/8″	10		3/16″	0.238	1/4″					
3 × 3	14	0.109	11	1/8″		3/16″	1/4″	5/16″	3/8″				
3-1/2 × 3-1/2	1/8″		3/16″	1/4″	5/16″								
4 × 4	11	1/8″		3/16″	1/4″	5/16″	3/8″	1/2″					
4-1/2 × 4-1/2	3/16″	1/4″											
5 × 5	11	1/8″	7	3/16″	1/4″	5/16″	3/8″	1/2″					
6 × 6		3/16″	1/4″	5/16″	3/8″	1/2″							
7 × 7	3/16″	1/4″	5/16″	3/8″	1/2″								
8 × 8		3/16″	1/4″	5/16″	3/8″	1/2″	5/8″						
10 × 10	1/4″	5/16″	3/8″	1/2″	5/8″								
12 × 12	1/4″	5/16″	3/8″	1/2″									
14 × 14	3/8″	1/2″											
16 × 16	1/2″												

SIZE (IN.)	WALL THICKNESS (BW GAUGE OR IN.)				
ALUMINUM (IN.)					
3/4 × 3/4	0.125				
1 × 1	0.125				
1-1/4 × 1-1/4	0.125				
1-1/2 × 1-1/2	0.125				
1-3/4 ×1-3/4	0.125				
2 × 2	0.125	0.250			
2-1/2 × 2-1/2	0.125				
3 × 3	0.125	0.250			
4 × 49	0.250				
STAINLESS STEEL					
1 × 1	18	16	11		
1-1/4 × 1-1/4	16	14	11		
1-1/2 × 1-1/2	16	14	11	7	
2 × 2	16	14	11	7	1/4″
2-1/2 × 2-1/2		7			
3 × 3	14	11	7	1/4″	3/16″
4 × 4	11	7	3/16″		

NOTES

7.19 Rectangular and square tubing with sharp corners are usually used for metal specialties.
Round tubing is available in steel, aluminum, copper, stainless steel, and other metals. Consult manufacturers for availability of materials and sizes.
7.20 Round pipe is made primarily in three weights: standard, extra-strong (or extra-heavy), and double-extra-strong (or double-extra-heavy). Outside diameters of the three weights of pipe in each size are always the same: extra wall thickness is always on the inside, and therefore reduces the inside diameter of the heavier pipe. All sizes are specified by what is known as the "nominal inside diameter." Round pipe is also available in aluminum and stainless steel. Consult manufacturer for sizes.

DECORATIVE METAL

DECORATIVE METAL DETAILING

GENERAL

Wrought iron is a form of iron with a relatively soft and malleable fibrous structure. The term *wrought*, which means "worked" iron, is widely associated with decorative metal. Wrought iron is relatively pure iron with low carbon content. Iron with such low carbon content is scarce today, so most fabricators use steels containing combinations of iron with a higher percentage of carbon for ornamental details. Low carbon steel or mild steel is the most desirable of these.

Steel and iron are the metals most frequently used for decorative metal work. Other popular metals are aluminum (favored for its light weight and rust resistance), polished bronze, brass, and copper. Blacksmiths primarily produce custom work today; a smaller proportion of their work is restoration.

Working with iron is a craft not easily mastered and many may not be qualified to deliver a high-quality product. Check references for similar types of work on previous projects. Consult the National Ornamental and Miscellaneous Metal Association (NOMMA) and the Artists-Blacksmiths Association of North America for more information on references and lists of blacksmith shops in the United States.

NOMMA publishes voluntary guidelines for joint finishes in decorative work. They are:

Finish #1: no evidence of a welded joint

Finish #2: completely sanded joint, some undercutting and pinholes

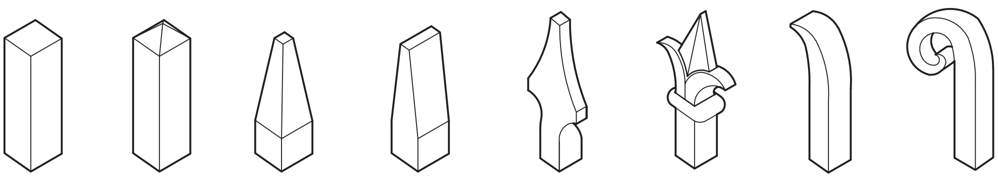
Finish #3: partially dressed weld with splatter removed

Finish #4: good quality, uniform undressed weld with minimal splatter

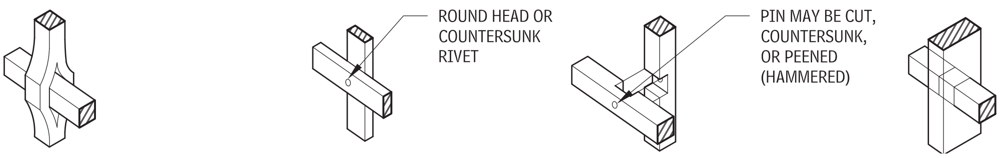
TYPICAL SIZES AND WEIGHTS (LB PER FT) FOR SOLID IRON AND CARBON STEEL BARS
7.22

DIAMETER OR THICKNESS (IN.)			1/8	3/16	1/4	5/16	3/8	7/16	1/2	5/8	3/4	7/8	1	1-1/4	1-1/2
ROUNDS (DIAMETER IN.)			.042	.094	.167	.261	.376	.511	.668	1.04	1.50	2.04	2.67	4.17	6.01
FLAT BARS (WIDTH)	1/8	IN.	0.053												
	3/16	IN.	0.080	0.120											
	1/4	IN.	0.106	0.160	0.213										
	5/16	IN.	0.133	0.200	0.266	0.322									
	3/8	IN.	0.159	0.239	0.399	0.398	0.478								
	7/16	IN.	0.186	0.279	0.372	0.464	0.558	0.651							
	1/2	IN.	0.212	0.319	0.425	0.531	0.637	0.744	0.850						
	5/8	IN.	0.266	0.398	0.531	0.664	0.797	0.930	1.062	1.328					
	3/4	IN.	0.319	0.478	0.637	0.797	0.956	1.116	1.275	1.594	1.912				
	7/8	IN.	0.372	0.558	0.748	0.930	1.116	1.302	1.487	1.859	2.231	2.603			
	1	IN.	0.425	0.637	0.850	1.062	1.275	1.487	1.700	2.125	2.550	2.975	3.400		
	1-1/4	IN.	0.531	0.797	1.062	1.328	1.594	1.859	2.125	2.656	3.187	3.719	4.250	5.312	
	1-1/2	IN.	0.638	0.956	1.275	1.594	1.913	2.231	2.550	3.188	3.825	4.463	5.100	6.375	7.650
	1-3/4	IN.	0.744	1.116	1.488	1.859	2.231	2.603	2.975	3.719	4.463	5.206	5.950	7.438	8.925
	2	IN.	0.850	1.275	1.700	2.125	2.550	2.975	3.400	4.250	5.100	5.950	6.800	8.500	10.200
	2-1/2	IN.	1.063	1.594	2.125	2.656	3.188	3.719	4.250	5.313	6.375	7.438	8.500	10.625	12.750

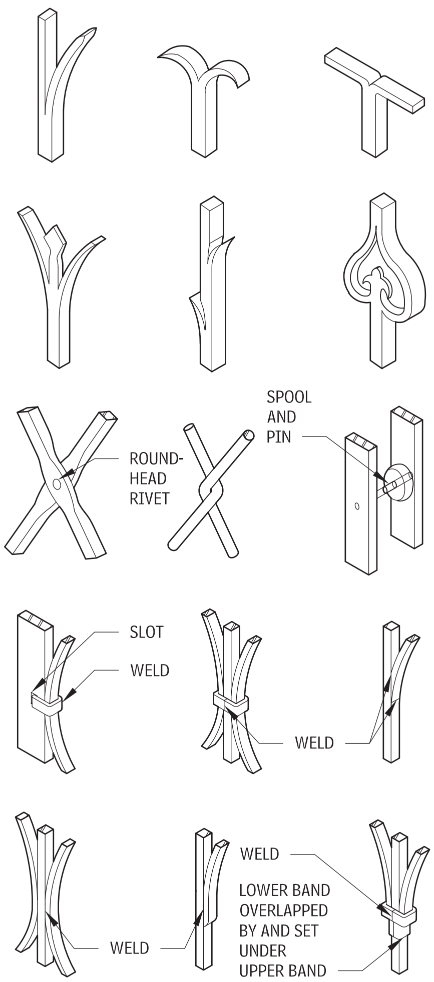
BAR ENDS
7.23



INTERSECTING MEMBERS
7.24



MISCELLANEOUS CONNECTIONS
7.25



ROUND HOLES
7.26

IPA NUMBERS	PERFORATIONS (IN.)	CENTERS (IN.)	HOLES PER SQ IN.	PERCENT OF OPEN AREA	LINE	S*/S, STRENGTH WIDTH DIRECTION	LENGTH DIRECTION
					Staggered	.530	.465
101	.023		576	24	Straight		
102	.027		400	23	Straight		
103	.032		324	26	Straight		
104	.040		225	30	Straight		
105	.045		224	37	Straight		
106	1/16	1/8		23	Staggered	.500	.435
107	5/64	7/64		46	Staggered	.286	.225
108	5/64	1/8		36	Staggered	.375	.310
109	3/32	5/32		32	Staggered	.400	.334
110	3/32	3/16		23	Staggered	.500	.435
111	3/32	1/4		12	Staggered		
112	1/10	5/32		36	Staggered	.360	.296
113	1/8	3/16		40	Staggered	.333	.270
114	1/8	7/32		29	Staggered	.428	.363
115	1/8	1/4		23	Staggered	.500	.435
116	5/32	7/32		46	Staggered	.288	.225
117	5/32	1/4		36	Staggered	.375	.310
118	3/16	1/4		51	Staggered	.250	.192
119	3/16	5/16		33	Staggered	.400	.334
120	1/4	5/16		58	Staggered	.200	.147
121	1/4	3/8		40	Staggered	.333	.270
122	1/4	7/16		30	Staggered	.428	.363
123	1/4	1/2		23	Staggered	.500	.435
124	3/8	1/2		51	Staggered	.250	.192
125	3/8	9/16		40	Staggered	.333	.270
126	3/8	5/8		33	Staggered	.400	.334
127	7/16	5/8		45	Staggered	.300	.239
128	1/2	11/16		47	Staggered	.273	.214
129	9/16	3/4		51	Staggered	.250	.192
130	5/8	13/16		53	Staggered	.231	.175
131	3/4	1		51	Staggered	.250	.192

S* = yield strength of perforated material
S = yield strength of unperforated material (strength for 60° standard staggered pattern)
Length direction = parallel to straight row of holes
Width direction = direction of stagger

PERFORATED METALS

GENERAL

Perforated metals were created to fulfill industrial needs such as minimizing the weight of a particular component or controlling the passage of fluids or gasses. As an architectural component, perforated metals can be used as control devices or simply as decoration. Perforated metal panels are considered acoustically transparent and may be visually solid depending on the size of the perforations. Perforated metals retain a great deal of their strength and ventilate well, so they are often employed in furniture and other designs. Because they can bend and interrupt wavelengths of many types, perforated metals are used to contain microwave radiation and the Electromagnetic Interference (EMI) or Radio Frequency Interference (RFI) radiation emitted by electrical devices. Metal is typically perforated with hole-punching machines, which work best on sheets .008 in. to .75 in. thick. Specialized equipment is available for thicker metal. The intended use of the perforated metal sheet determines the size, shape, and pattern of the holes punched. The strength and stiffness required vary according to use.

Perforated materials can be used in different applications involving a wide range of geometries, materials, and loading conditions, therefore design data are given in very general form. The large number of perforating patterns possible with round, square, slot, and other special perforation shapes make it impractical to list every pattern combination. The numbered perforations listed by the Industrial Perforators Association (IPA) are considered standard. (For design and tolerances of perforated metals, consult the IPA.)

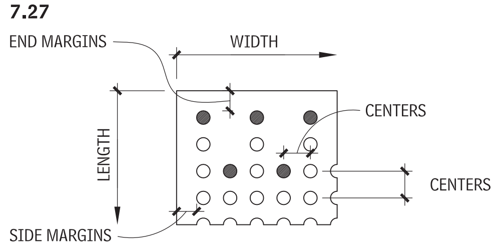
Round holes from .020 in. to more than 6 in. in diameter make up the majority of all perforated metal sheets produced. This is because round holes can be produced with greater efficiency and less expense and are generally stronger than other hole shapes.

Nonstandard end patterns may require special dies. Unperforated borders may cause distortions of the finished sheet. Roller leveling may be used to correct some of these distortions but may not always work.

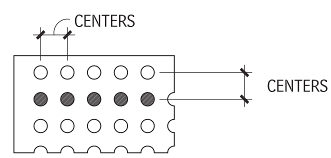
Common finishes for perforated material include

- Powder coat or wet paint on carbon steel
- Brush-finished, anodized, or painted on aluminum
- Brite, brushed, or electropolished on stainless steel and brass

STRAIGHT-LINE ROUND-HOLE PATTERN
7.27



OPEN PUNCH



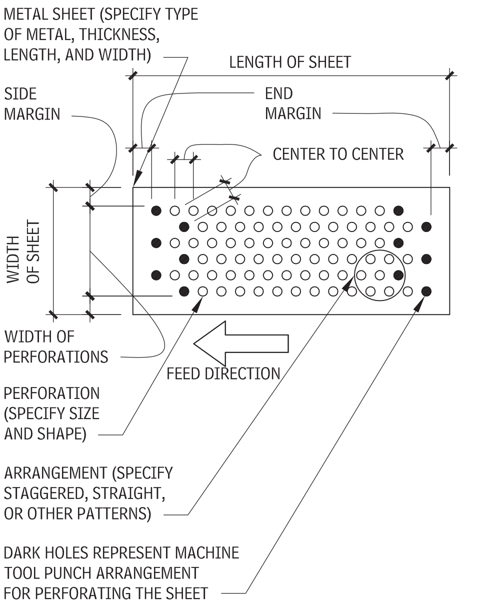
CLOSED PUNCH

NOTE

7.27 A straight-line pattern of holes is weaker than a staggered arrangement and can stretch the material more. The dark holes in the figure indicate the punch patterns.

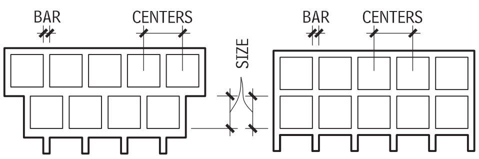
Contributors:
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland; Edward R. Estes, Jr., PE, Norfolk, Virginia.

TYPICAL TERMS FOR SPECIFYING PERFORATED METAL
7.28



PERFORATED AND SHEET METALS

SQUARE-HOLE OPEN AREAS
7.29

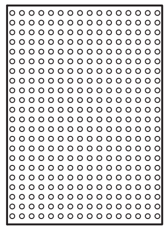


SQUARE PERFORATIONS STAGGERED

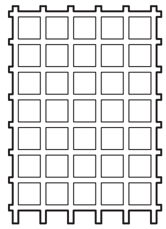
SQUARE PERFORATIONS STRAIGHT LINES

IPA NUMBER	PERFORA-TIONS (IN.)	CENTERS (IN.)	OPEN AREA (%)	LINE
200	2/10	1/4	64	Straight
201	1/4	3/8		
202	3/8	1/2	56	Straight
203	1/2	11/16	53	Straight
204	3/4	1	56	Straight
205	1	1 1/4		Straight
206	1	1 3/8		Straight

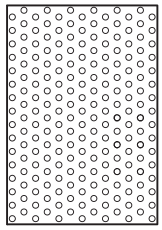
STANDARD PERFORATION PATTERNS
7.30



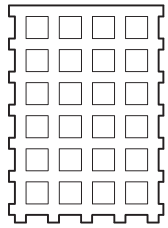
NO. 105, .045" DIA., 37% OPEN AREA



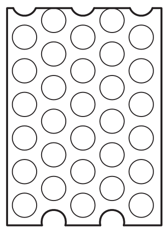
NO. 200, 1/5", 64% OPEN AREA



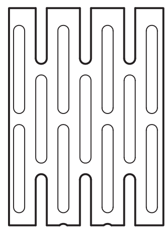
NO. 108, 5/64" DIA., 36% OPEN AREA



NO. 201, 1/4" OPENING

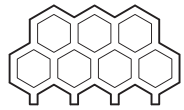


NO. 120, 1/4" DIA., 58% OPEN AREA

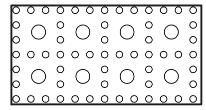


NO. 208, 1/8" x 1" OPENING, 43% OPEN AREA

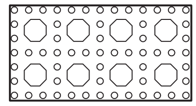
NONSTANDARD PERFORATION PATTERNS
7.31



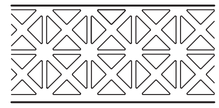
HEXAGONAL HOLES



ROUND CANE



OCTAGONAL CANE



GRECIAN

NOTES

7.28 Spacing can be specified as a center-to-center dimension, a percentage of open area, or holes per square inch.

7.29 Square holes, principally used for grilles and machine guards, offer optimal visibility and free area. Typically punched in a straight line, in either straight or staggered patterns, square holes make for weaker perforated sheets than round-hole patterns and are generally more expensive. Sharp corners make square-hole tooling wear out faster than round-hole tooling.

7.31 A broad assortment of nonstandard perforation shapes and patterns are available; consult metal perforators. Also available are indented holes, collared holes, and louvered holes.

INSTALLATION GUIDELINES AND CONSTRUCTION TOLERANCES

METAL FASTENINGS

STRUCTURAL WELDS

STRUCTURAL WELDING

Welds can be placed using various welding processes. The most common processes are forms of metal arc or resistance welding. Common welding processes include:

- SMAW: Shielded Metal Arc Welding
- GTAW: Gas Tungsten Arc Welding
- GMAW: Gas Metal Arc Welding
- FCAW: Flux Core Arc Welding
- SAW: Submerged Arc Welding
- ESW: Electroslag Welding
- EGW: Electrogas Welding

These processes are designed to fuse metal. Only in rare occasions does the design professional indicate which process is to be used to make the weld; but the type and size of weld should be indicated. The process is typically left up to the welder.

The two most common types of welds used in structural assemblies are fillet welds and groove welds. Plug and slot welds and back welds are additional types but are limited in application.

FILLET WELD

Fillet welds join two surfaces approximately at right angles to each other in lap, tee, and corner configurations. They may also be used in combination with groove welds as reinforcement in corner joints and T-joints. The cross section of a fillet weld is roughly triangular with equal legs. The length of a fillet weld is the distance from end to end of the full-size fillet, measured parallel to the root. For curved fillet welds the effective length is equal to the throat length, measured along a line bisecting the throat area.

The cross section of a fillet weld may differ from the right triangle model. The angle of the weld may vary from 60° to 135°. The angle could be less than 60°, with an acute angle heel test used to prove throat size to qualify; it may be greater than 135° if on the opposite side of a 135° intersection is a fillet with a 45° included angle that can be welded. Unequal leg welds may be used. When unequal leg welds are used, the use of the normal throat size as the effective size in weld strength calculations will, in most cases, be conservative. However, when the included angle of the weld deposit is substantially greater than 90°, the effective throat size should be determined from the actual dimensions of the weld, according to the American Welding Society (AWS) specifications.

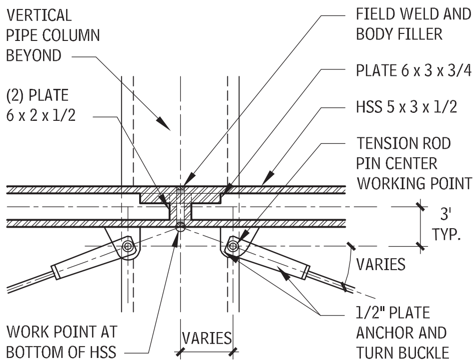
GROOVE WELDS

Groove welds are made in a groove between adjacent ends, edges, or surfaces of two parts to be joined in a butt, tee, or corner joint.

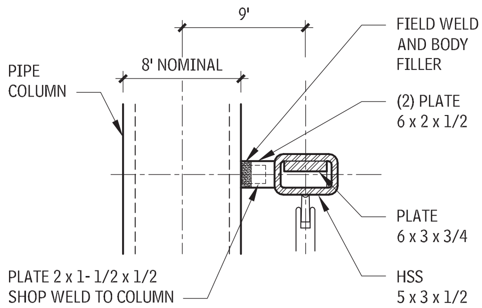
The edge or ends of objects to be groove welded are usually prepared by flame cutting, arc air gouging, or edge planing, to provide square, vee, bevel, U- or J-shaped grooves that are straight and true to dimension. The preparation is done to ensure that the base metal is welded evenly through the joint. With thicker metal, preparation of the objects is required to open the joint area for welding. Relatively thin material may be groove welded with square cut edges.

Groove welds will be complete penetration or partial penetration welds. The design professional should indicate the penetration type. A complete penetration weld achieves fusion of weld and base metal throughout the depth of the joint. It is accomplished by welding from both sides of the joint, from one side to a backing bar, or back welding the first weld.

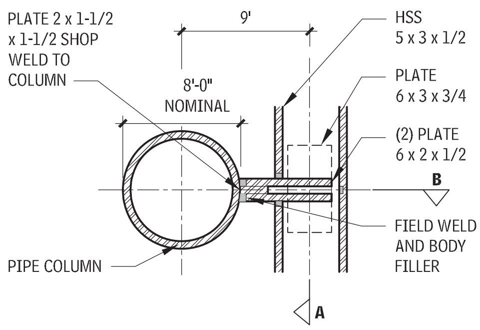
AESS CONNECTION
7.32



SECTION DETAIL



SECTION DETAIL

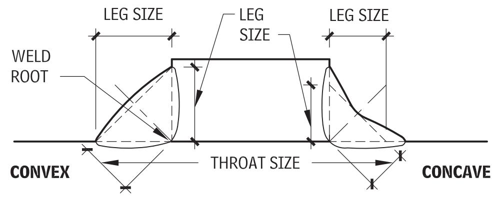


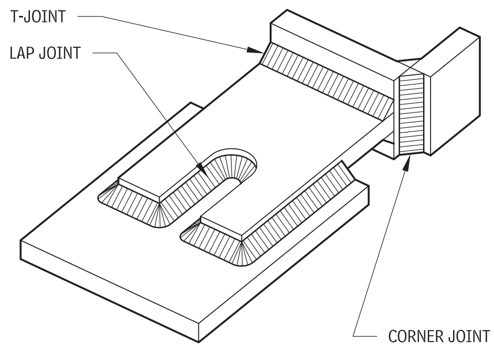
PLAN DETAIL

Except when backing bars are used, specifications require that the weld roots generally must be chipped or gouged to sound metal before applying the second weld. For purposes of stress calculation, the weld-size dimension of a full penetration groove weld is considered to be the full thickness of the thinner object joined.

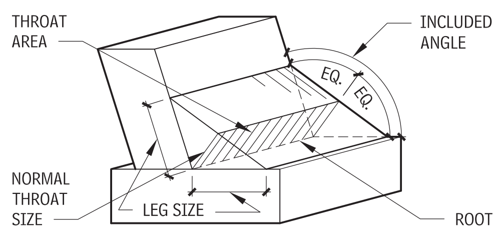
Partial penetration groove welds are used when stresses to be transferred do not require full penetration, or when welding must be performed from one side of a joint and it is not possible to use backing bars or to gouge weld roots for back welds. The application of partial penetration groove welds is governed by specifications and may limit the effective weld size or the thickness of the material on which they are to be used.

FILLET WELDS
7.33





FILLET WELD JOINTS



Edge preparation of base material for partial penetration welds is similar to that for full penetration groove welds, but will typically cover less than the full thickness of the objects. The effective weld size and, hence, the weld strength of partial penetration groove welds is normally limited to less than the full joint thickness.

The use of partial penetration welds is subject to AWS code and other recommendations. It is important to keep the stress in the root of a partial penetration weld low, especially if fatigue is in the equation. Localized unit stress in the root of a partial penetration weld can get to the point of rupture, before the calculated dead load on a weld will cause failure.

JOINT PREQUALIFICATION

The structural code contains prequalified joint details and prequalified welding procedure specifications (WPS). And though ESW and EGW processes are considered code-approved processes, they still require qualification of welding procedure specifications.

NOTE

7.32 Locate HSS seam away from line of sight, or grind smooth.

For additional information refer to ANSI/AWS D1.1, "Structural Welding Code-Steel."

WELDS AND WELDING SYMBOLS

BASIC WELDING SYMBOLS

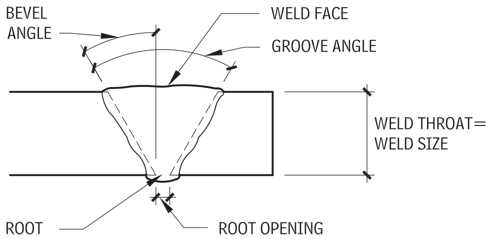
A weld symbol is composed of three elements: an arrow pointing to the joint, a reference line upon which the dimensional data is placed, and a weld symbol indicating the weld type required. The tail of the welding symbol is necessary only to indicate additional information, such as specification, process, or detail references.

The arrow indicates the joint where the weld is to be made. The basic weld symbol indicates the type of joint preparation, for example: fillet, U-groove, bevel, or plug. The position of the basic weld symbol indicates which side of the joint is to be welded. The bottom side of the reference line is designated as the arrow side, meaning any welding operation shown on this side of the reference line is to be performed on the same side of the joint as the arrow. When an operation is shown on the top side of the reference line, it is to be performed on the joint side opposite the arrow. Unless indicated differently, welds on both the arrow side and the other side are of the same size. Fillet welds must be shown on both sides of the symbol.

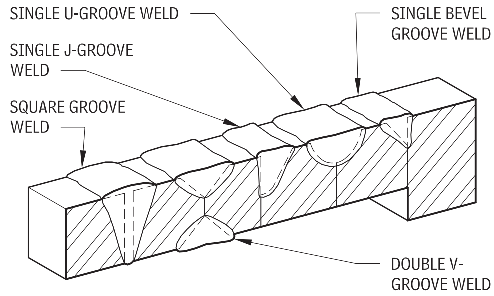
Weld dimensions—which may include size, length, and pitch—are placed on the reference line next to the weld symbol. These dimensions read from left to right regardless of which side the arrow is on. The perpendicular leg of fillet, bevel, J-groove, and flare-bevel weld symbols must be at the left. The point of the field weld symbol must point toward the symbol tail. Symbols apply between abrupt changes in direction of welding unless governed by the all-around symbol or otherwise dimensioned.

Weld symbols indicated in the figures and tables of this standard do not explicitly provide for the case that frequently occurs in structural work, where duplicate material, such as stiffeners, occur on the far side of a web or gusset plate. The fabricating industry has adopted the following convention: when a detail discloses the existing dimensions of a member on the far side as well as on the near side, the welding shown for the near side shall be duplicated on the far side.

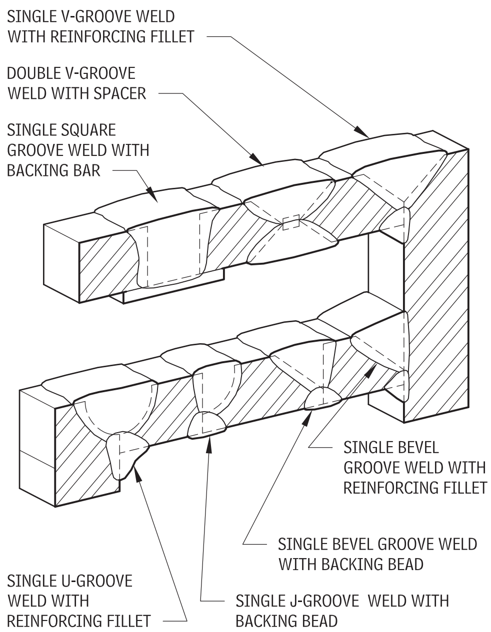
GROOVE WELDS
7.34



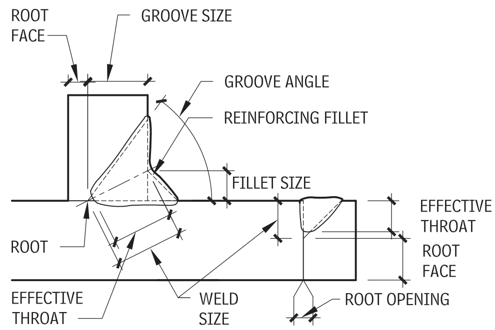
FULL PENETRATION GROOVE WELD



EXAMPLES OF PARTIAL-PENETRATION GROOVE WELDS



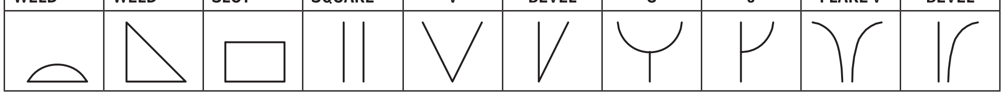
EXAMPLES OF COMPLETE PENETRATION GROOVE WELDS



PARTIAL PENETRATION GROOVE WELD

BASIC WELD SYMBOLS
7.35

BACK WELD	FILLET WELD	PLUG OR SLOT	GROOVE SQUARE	OR BUTT JOINTS					
				V	BEVEL	U	J	FLARE V	FLARE BEVEL



SUPPLEMENTARY WELD SYMBOLS
7.36

BACKING	SPACER	WELD ALL- AROUND	FIELD-WELD	FLUSH	CONVEX
M	M				

SUPPLEMENTARY WELD SYMBOLS

In addition to the basic weld symbols, standard supplementary weld symbols are used to provide additional information to the user. These symbols include information about requirements of backing and spacers or if the weld is to be all around.

The flush and convex symbols are used to modify the shape of the weld face. The flush weld symbol is used if the top of the weld is to be leveled off. Contour symbols are placed over the weld symbol.

Most of the basic weld symbols can be combined with each other and with the spacer, backing bar, back weld, and contour symbols to create many different welds. For additional basic and supplementary weld symbols refer the American Welding Society publication A2.4, "Standard Symbols for Welding, Brazing and Nondestructive Examination."

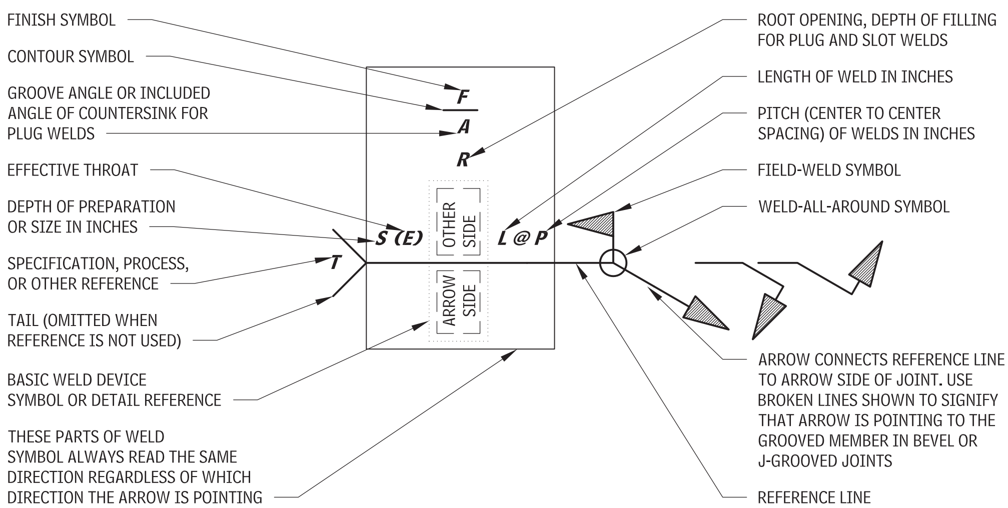
FILLET WELD SYMBOLS

The dimensions required for fillet welds include weld size and length; intermittent fillet welds should also include pitch. The weld size is equal to the weld leg size, assuming that the legs are equal. In the rare instance that the legs are not equal, the size is not given in the welding symbol; instead, the weld legs are dimensioned in the drawing to avoid confusion. If there is a typical weld size for a particular drawing, the size may be listed in the notes and left off of the symbol. If the joint is to be welded on both sides, then both sides must be dimensioned, even if they are the same.

If the length of a fillet weld is omitted, it is understood that the weld is to extend the full distance between abrupt changes in the object of the joint outline specified by the weld symbol arrow. If the same size fillet is required for the full length of all sides of a particular joint, regardless of abrupt changes in its direction, the weld-all-around symbol can be used to simplify the drawing.

Pitch is used with intermittent fillet welds to give the center-to-center dimension between welded sections. When using pitch, length is the dimension of the individual welds.

STANDARD LOCATION OF ELEMENTS OF A WELDING SYMBOL
7.37



WOOD

8

COMMON CHARACTERISTICS, STANDARDS, AND PRACTICES

WOOD MATERIALS

TYPES OF WOOD CONSTRUCTION

Building codes generally categorize wood construction into two distinct types: heavy timber (Type IV) and light wood-frame (Type V).

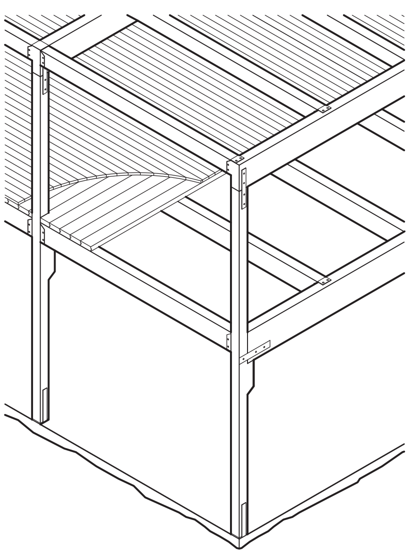
Heavy timber construction, consisting of exposed columns, girders, beams, and decking large enough to be slow to catch fire and burn, is permitted for use in relatively large buildings across a broad spectrum of uses. Its large member dimensions and spans make heavy timber construction best suited to buildings with regular, repetitive bays. Heavy timber buildings are engineered in accordance with the National Design Specification for Wood Construction, published by the American Forest and Paper Associations of the American Wood Council (www.awc.org).

Wood frame construction is made up of nominal 2-in. framing members spaced closely together and normally concealed by interior finish materials such as gypsum board or wood paneling. Wood frame construction, with its small members and close member spacings, adapts readily to even the most intricate spaces and architectural forms. However, because such construction is less resistant to fire than heavy timber construction, building codes limit the heights and areas of wood framed buildings. The maximum height generally permitted in residential wood frame buildings is three stories, although four or more stories are possible if an approved sprinkler system is installed. Under many conditions wood frame construction can use the International Code Council (ICC) International Residential Code, which has been widely adopted by states and municipalities.

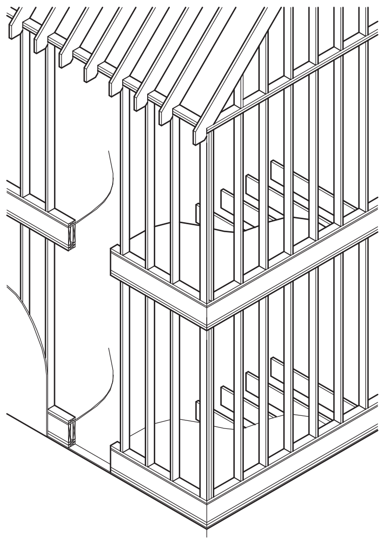
WOOD AS A STRUCTURAL MATERIAL

On the basis of performance per unit weight, typical construction lumber is at least as strong and stiff as structural steel. Because of its microstructure of longitudinal cells, wood has different structural properties in its two principal directions: parallel to the grain, wood is strong and stiff; perpendicular to the grain, it is weak and deformable. The strength of wood varies with the duration of the load. For short-term loads, such as those from snow, wind, and impact, allowable stress values are 15 to 100 percent higher than those allowed for normal-term loads. Under very long-term loading, however, wood has a tendency to creep, and reduced stress values must be used.

HEAVY TIMBER CONSTRUCTION
8.1



WOOD FRAME CONSTRUCTION
8.2



WOOD AS A FINISH MATERIAL

Wood is used as a finish material in buildings of every kind. Even in the most fire-resistant types of construction, limited quantities of wood finish may be used. With proper protection from fire, water, and sunlight, wood can serve as a durable exterior material for cladding, trim, and even roofing. For interior finishes, despite recent concerns regarding the depletion of rare or old-growth species, woods of many types remain commonly available in solid or veneer forms and exhibit a variety of properties including hardness, grain, color, suitability for different finishes, and cost. Finish woods are readily available in many preformed shapes and are also easily shaped and cut in the field. Wood and wood products may be finished with transparent or opaque coatings or serve as a base for applied plastic laminates.

SELECTION OF INTERIOR FINISH WOOD MATERIALS

The major factors that influence lumber selection for finish wood applications, as specified by the Architectural Woodwork Institute (AWI) are:

- *Aesthetic characteristics*: Different species exhibit a variety of colors, grains (open or close grain), and figures (grain patterns) that are further distinguished by the sawing method (plain-sawn, quarter sawn, rift-sawn) and finishing characteristics (receptivity to finish processes, such as fillers, stains, etc.).
- *Availability*: The availability of particular species varies by season and popularity.
- *Size limitations*: Some species produce longer and/or wider members.
- *Strength, hardiness, and density*: The ability of selected lumber to sustain stress; resist indentation, abuse, and wear; and carry its anticipated load contributes to its suitability for particular uses.
- *Dimensional stability*: Swelling and shrinking due to relative humidity and moisture content changes vary according to the species and product type.
- *Adaptability for exterior use*: Certain species are more durable for use in exterior applications. Heartwood of all species is more resistant to damage by the elements than sapwood. The following species are rot-resistant and acceptable for exterior use: Eastern and Western red cedar, redwood, mahogany, and teak. For more information, see the section "Wood Treatment" in this chapter.
- *Fire retardance*: Natural fire-retardant qualities and acceptability of treatment vary with species. Flame spread classification is the generally accepted measurement for fire rating of materials. Fire-retardant treatments and buildup of members can be used to improve the fire resistance rating of wood materials.
- *Preservative treatments*: Certain species used for architectural woodwork can be treated with preservative compounds to extend their life when exposed to the elements.

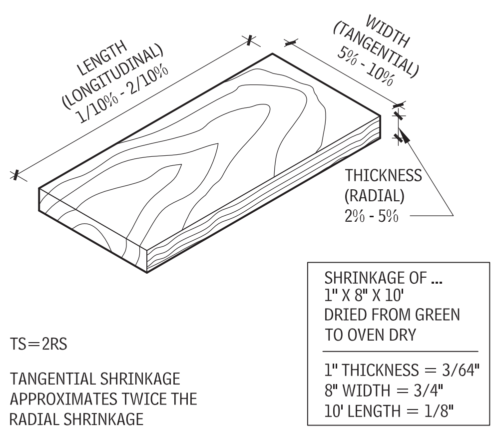
LUMBER PRODUCTION

Commercially marketed lumber includes trees of dozens of species roughly divided into softwoods, which are the evergreen species, and hardwoods, those species that drop their leaves in the fall. The majority of framing lumber comes from the comparatively plentiful softwoods. Hardwoods, with their greater range of colors and grain figures, are used primarily for interior finishes, flooring, cabinets, and furniture.

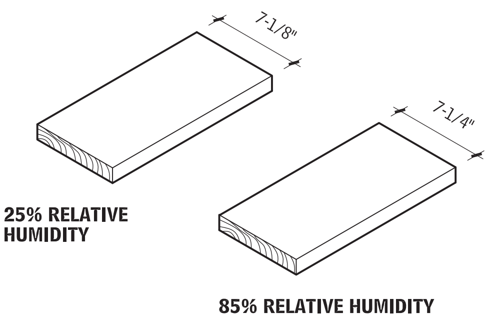
When examined under a low-power magnifier, wood is made up primarily of hollow tubular cells of cellulose that run parallel to the long axis of the tree trunk. When the tree is harvested, both the hollows and the walls of these tubes are full of watery sap. The tree is sawed into rough lumber while in this saturated, or "green," condition. Finish lumber is seasoned (dried of much of its moisture), either by stacking it in the open air for a period of months or, more commonly, by heating it in a kiln for a period of days. During seasoning, moisture evaporates first from the hollows of the tubes, and then from the cellulose walls of the tubes, causing the lumber to shrink. By the time the lumber leaves the kiln, it is considerably smaller. Further shrinkage usually occurs after the lumber has been incorporated into a building, as the moisture content in the wood comes gradually to equilibrium with the moisture content of the surrounding air. Wood absorbs moisture during damp weather and gives it off during dry weather in a never-ending cycle of swelling and shrinking, a fact that must be taken into account when detailing wood components of buildings.

Most lumber is surfaced after seasoning to reduce it to its final dimensions and give it smooth faces.

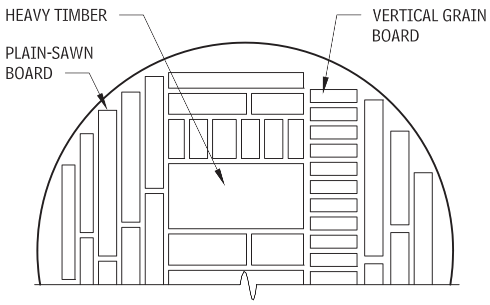
SHRINKAGE DUE TO DRYING
8.3



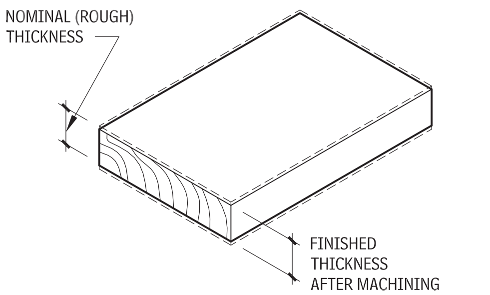
EXPANSION DUE TO MOISTURE IN THE AIR
8.4



TYPICAL SAWING OF A LARGE LOG
8.5



LUMBER THICKNESS
8.6



BEFORE MACHINING		AFTER MACHINING
NOMINAL (ROUGH) THICKNESS		FINISHED THICKNESS
INCHES	QUARTERS	HARDWOODS AND SOFTWOODS (IN.)
1	4/4	3/4
1–1/4	5/4	1
1–1/2	6/4	1–1/4
2	8/4	1–1/2
2–1/2	10/4	2
3	12/4	2–1/2

LUMBER GRADING

As a natural product wood varies greatly in appearance and structural properties. Consequently, elaborate systems of grading have been established to indicate the quality of each piece of lumber. Within each species of wood there are two grading systems, one based on structural strength and stiffness, the other on appearance. Appearance is graded visually. Structural grading is based either on visual inspection, the sizes and positions of knots and other defects, or structural properties as measured by machines that analyze each piece of lumber.

Strength and stiffness of wood varies considerably from one species and grade to another. When designing a wood structure, it is necessary to know which species and grade will be used. If in doubt, base structural calculations on the weakest species, and base grade on a locally available species.

JOINING WOOD

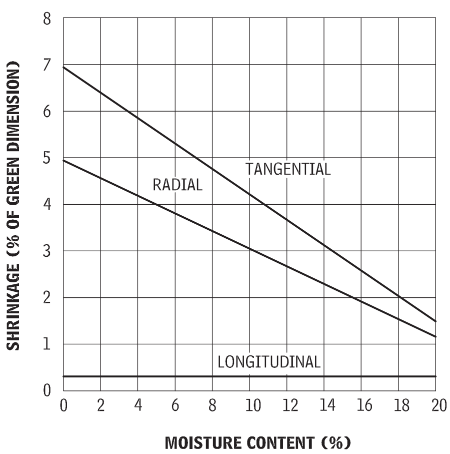
Nailing is the most common method of joining wood framing. Nails are inexpensive to buy and install and may be driven by hand or with pneumatic equipment. When applied in proper size, number, and spacing, they form a strong, resilient joint. Sheet metal straps, anchors, and brackets can be nailed to connections where greater resistance to tension or shear is necessary. Detailed nailing requirements for wood frame construction are included in building codes. Heavy timber construction typically relies on bolts and lag screws, together with metal connecting devices.

MOISTURE MOVEMENT IN WOOD

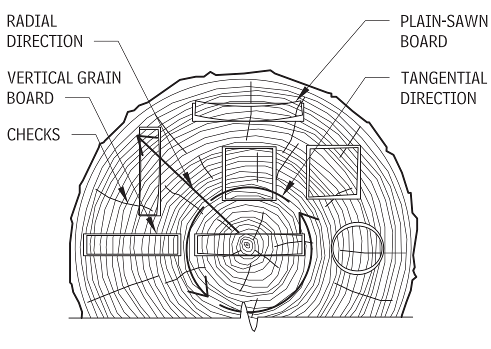
The shrinkage of wood as it dries is not uniform. Wood shrinks very little along the length of the grain, somewhat in the radial direction of a cylindrical log, and more in the tangential direction of the log, as shown in Figure 8.7. One consequence of the difference between the radial and tangential shrinkage is that radial splits, called checks, form during seasoning, especially in lumber of larger dimensions. In addition, pieces of lumber distort noticeably in accordance with their original positions in the tree trunk.

For pieces of lumber that must stay flat, such as flooring, outdoor decking, baseboards, casings, and paneling, vertical-grain lumber, which is sawn so the annual growth rings are more or less perpendicular to the broad face of the board, is desirable. One particular sawing pattern that produces vertical-grain lumber is called quarter-sawn. For ordinary framing, seasoning distortions are of little consequence, so plain-sawn boards are used.

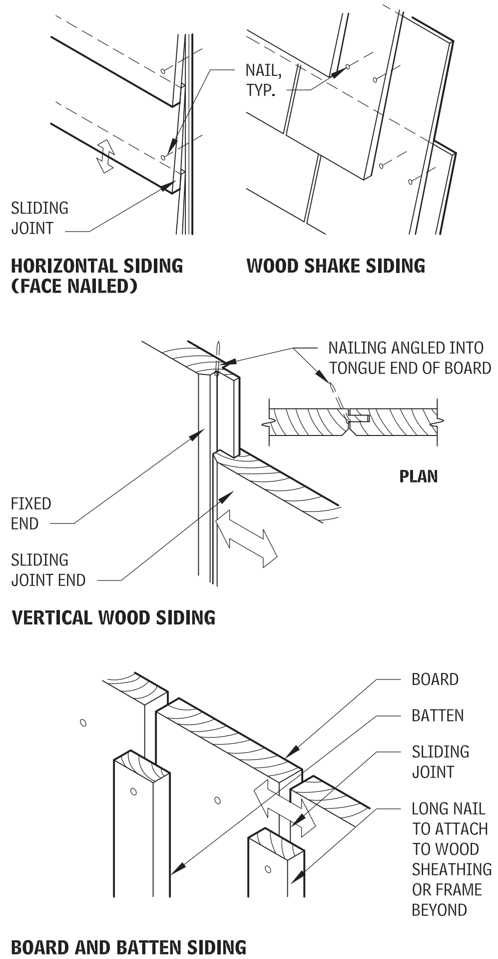
MOISTURE SHRINKAGE OF TYPICAL SOFTWOOD
8.7



SHRINKAGE DISTORTIONS BY POSITION IN LOG
8.8



SLIDING JOINTS IN WOOD SIDING
8.9



A number of accepted wood detailing practices have been developed in response to the moisture movement that occurs in wood and the distortions that result from the differing rates of shrinkage along the three axes of the grain. In applying wood siding, it is necessary to use nailing patterns that do not restrain the cross-grain seasonal shrinking and swelling of the wood as indicated in Figure 8.9. Horizontal bevel siding is nailed so that each board is fastened by one row of nails only, creating a sliding joint at each overlapping edge to allow for movement. Tongue-and-groove siding boards are nailed at the tongue edge only, the other edge being restrained by the tongue of the adjacent board sliding freely in its groove. Vertical board-and-batten siding is nailed only at the centers of the boards and battens, allowing for free expansion and contraction of the wood.

Because wood shrinkage is so much greater in the tangential direction than in the radial, plain-sawn boards tend to cup noticeably in a direction similar to the curvature of the annual rings. Therefore, plain-sawn decking and flooring should be laid with the "bark side" of each board facing up, to reduce the raising of edges. On outdoor decks, this practice will also minimize puddling of water on the boards. Vertical-grain flooring and deck boards are preferable to plain-sawn boards, not only because they minimize cupping but also because the tighter grain pattern wears better.

Contributors:
Edward Allen, AIA, South Natick, Massachusetts; Joseph Iano, Architect, Mercer Island, Washington; Greg Heuer, Architectural Woodwork Institute, Potomac Falls, Virginia; John Showalter, PE, American Wood Council, Washington, DC.

WOOD CLASSIFICATION

WOOD CLASSIFICATION—SOFTWOOD AND HARDWOOD

Tree species are divided into two classes—softwood and hardwood—but these terms do not describe a wood's hardness or density. Basswood, for example, is classified as a hardwood but is actually relatively easy to cut or scratch. Softwoods are defined as coniferous trees, evergreens that have needles instead of leaves. Softwoods, by far the more widely used type of wood, are used as framing lumber and in decorative moldings. Hardwoods are from deciduous trees, which have broad leaves that are shed each winter; these include fruit and nut trees. Hardwoods are often used as flooring and furniture components.

HARDWOODS AND SOFTWOODS
8.10

SPECIES	SOFTWOOD (S) OR HARDWOOD (H)	HARDNESS
Ash	H	Hard
Basswood	H	Soft
Beech	H	Hard
Birch, yellow	H	Hard
Cedar, western red	S	Soft
Cherry, American black	H	Hard
Fir, Douglas	S	Medium
Hickory	H	Very hard
Maple, hard	H	Very hard
Maple, soft—"natural"	H	Medium
Oak, English brown	H	Hard
Oak, red	H	Hard
Oak, white	H	Hard
Pecan	H	Hard
Pine, ponderosa	S	Medium
Pine, southern yellow	S	Medium
Redwood	S	Soft
Teak	H	Hard
Walnut, American Black	H	Hard

Source: Adapted from AWI, Architectural Woodwork Institute, Reston, Virginia.

WOOD SOURCES

To conserve and preserve wood resources, choose certified wood, where possible. Composite and engineered wood salvaged from lumber production make use of otherwise wasted materials. Reclaimed woods can replace imported exotic hardwoods from unregulated sources and markets. Less wood can be used by minimizing job-site waste and with careful detailing.

FOREST CERTIFICATION

Wood in North America is increasingly available from certified forests. Major programs certifying forestland as sustainably and responsibly managed include:

- *Forest Stewardship Council (FSC):* International organization that requires documentation of the chain of custody of wood products as well as product labeling. The FSC sanctions third-party certifiers.
- *Sustainable Forestry Initiative (SFI):* Certification program run by the American Forest and Paper Association (AF&PA).
- *American Tree Farm System:* Certification program for smaller, nonindustrial forest landowners.
- *Sustainable Forest Management Program:* Developed by the Canadian Standards Association (CSA).

RECLAIMED WOOD

Reclaimed wood can be uniquely beautiful as well as environmentally friendly. Sources for reclaimed wood include:

- Demolition of old buildings
- Dead, fallen, diseased, or nuisance trees in urban and suburban areas
- Orchard trees cut for replacement
- Careful reclamation of fallen trees from lakes and rivers
- Usable wood safely reclaimed from demolition landfills
- Wood by-products from secondary manufacturers

WOOD TREATMENT

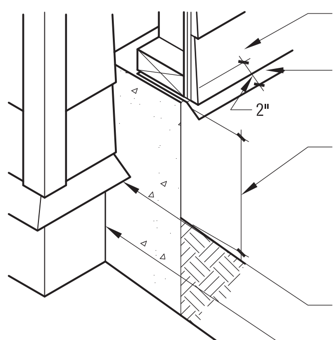
WOOD PRESERVATIVES

GENERAL

Wood may be destroyed by decay caused by fungi, by insects such as carpenter ants and termites, and by marine borers in saltwater exposures. Four conditions must exist before many of these organisms can destroy wood: (1) a free oxygen supply; (2) a moisture content in the wood above the fiber saturation point (20 percent); (3) a temperature in the range of 50 to 90°F; and (4) the presence of a food source, in this case, the wood. Some insects, such as drywood termites and carpenter ants, are able to destroy wood that has very low moisture content.

In most indoor environments, where relative humidity levels are generally low, wood will last for a very long time. In certain indoor environments, however, and in many exterior environments, wood cannot be kept dry or out of the proximity of moisture. Most building codes recognize this by requiring the use of preservative wood treatment or naturally resistant wood species in building components that come into contact with concrete, masonry, or exposed soil. This requirement also covers floor joists and crawl space support members within 12 to 18 in. of exposed soil.

TERMITE SHIELD DETAIL
8.11



REMOVE TREE STUMPS, ROOTS, WOOD SCRAPS, ETC. FROM BUILDING SITE TO DISCOURAGE TERMITES

DECAY-RESISTANT WOOD

When specifying a wood that will resist decay, the choice is between naturally decay-resistant wood and wood treated with preservatives. The first requires use of the heartwood of naturally decay-resistant woods such as western red cedar, bald cypress, redwood, and others that contain natural poisons called extractives, which are not palatable to decay-causing organisms. However, not all grades or species of these woods are suitable for some structural situations. The process for treating wood with preservatives is to impregnate the wood with chemicals through a pressure treatment process. Nonpressure treatments, such as spraying, dipping, and brushing, are commonly used for the treatment of millwork components during manufacture, field treatment of wood during construction, or remedial treatment of existing wood that is already in service.

PRESSURE-TREATED WOOD

Several processes are commonly used for pressure treating wood, including the full-cell, modified-full-cell, and empty-cell processes. The method chosen depends on the desired amount of preservative retention. During pressure treatment, the wood is placed in a

Contributors:
Edward Allen, AIA, South Natick, Massachusetts; Joseph Iano, Architect, Mercer Island, Washington; Greg Heuer, Architectural Woodwork Institute, Potomac Falls, Virginia; John Showalter, PE, American Wood Council, Washington, DC.

large, cylindrical pressure vessel and, depending on the process, a vacuum or low pressure is applied. The preservative is pumped into the cylinder and forced under pressure into the wood cells. After the proper amount of preservative has been injected, the preservative is pumped out of the cylinder and, in most cases, a vacuum is applied to remove excess preservative. Regardless of which process is used, the wood is generally dried prior to treatment to a moisture content that will permit the specified penetration and retention of the preservative.

PENETRATION AND RETENTION OF PRESERVATIVES

Penetration and retention are the two measures that define the effectiveness of preservation methods. Penetration depends on the species of wood, the type of preservative, and the size of the lumber member being treated. Some species that resist preservative penetration, such as Douglas fir, are usually incised with small slits to make treatment more effective. Others, such as Southern pine, are easily treated without incisions. While the sapwood of some species is readily penetrated, the heartwood of most resists penetration (although the heartwood of all species naturally resists decay to varying degrees).

Penetration and retention are determined by using a hollow drill bit to remove a "core" from a representative sample of wood treated in each batch. Penetration is determined by visual examination of each core, and retention is determined through chemical analysis of the core. Penetration and retention standards are established by the American Wood Preservers' Association (AWPA) in an open, consensus-based process; these standards are enforced by an independent third-party agency approved by the American Lumber Standard Committee (ALSC). A quality mark outlining pertinent information can be found on complying wood stock.

RELATIVE HEARTWOOD DECAY RESISTANCE OF NATURALLY RESISTANT UNTREATED WOODS 8.12

RESISTANT OR VERY RESISTANT	MODERATELY RESISTANT	SLIGHTLY OR NONRESISTANT
Bald cypress (old-growth), cedar, white oak, redwood	Bald cypress (new-growth), Douglas fir, Western larch, old-growth longleaf, slash, and Eastern white pines, tamarack	Pines other than those listed under "Moderately Resistant," spruces, true firs

PRESERVATIVE TYPES

Two primary classes of preservatives are in use today: oil-borne (organic and organometallic) and waterborne (inorganic).

OIL-BORNE PRESERVATIVES

Organic and organometallic oil-borne preservatives either are used alone or are carried in hydrocarbon solvents such as mineral spirits or fuel oil, and are used to treat most softwoods and hardwoods. Some of the more common oil-borne preservatives include creosote, pentachlorophenol (penta), copper naphthenate, and copper 8-quinolinolate.

Creosote-treated wood is often used for industrial products such as railroad crossties, piling, utility poles, and heavy timbers in exterior applications. Creosote is especially effective in deterring the attack of marine borers when used to treat piles and timbers that will be immersed in salt or brackish water. Wood treated with creosote is colored dark brown to black, and usually has a strong mothball odor when freshly treated. Due to the oily residue sometimes found on the surface of creosote-treated wood, paint may not adhere satisfactorily. Also, creosote contains volatile organic compounds (VOCs) and, as such, should not be specified for interior locations without adequate ventilation.

Penta-treated wood is primarily used for utility poles, heavy timbers, and glue-laminated timbers. For these applications, penta is dissolved in a heavy hydrocarbon solvent, which leaves the wood with an oily surface until the solvent evaporates, at which time it is possible to paint the wood—although oils may bleed through the paint at a later date. When penta is dissolved in a light hydrocarbon solvent and is used to treat millwork items, oil-based paints and primers may adhere adequately after all of the solvents have evaporated from the wood. The color of penta-treated wood depends on the color of the hydrocarbon solvent. Lighter oils darken the wood slightly, while darker oils make the wood very dark in color.

WATERBORNE PRESERVATIVES

Inorganic waterborne preservatives are the most popular and commonly available types of preservatives used for treating wood. They include alkaline copper quaternary (ACQ), both copper boron azole Type A (CBA-A) and copper azole Type B (CA-B), chromated copper arsenate (CCA), ammoniacal copper zinc arsenate (ACZA), and inorganic boron (SBX). All of these preservatives are dissolved in water, so after the wood is permitted to dry, the surface readily accepts paints and stains.

ACQ (Types A, B, C, and D) are composed of copper and a quaternary ammonium compound dissolved in an aqueous solution of ammonia and/or ethanolamine.

FINISHING OF PRESERVATIVE TREATED WOOD

Waterborne preservatives are recommended when clean, odorless, and paintable wood products are required. Wood treated with such preservatives may be used indoors if sawdust and construction debris are cleaned up. Painting wood treated with oil-borne preservatives is not recommended, as it is difficult to use, requiring extensive care and an aluminum-based paint. For certain interior applications in commercial, industrial, or farm buildings, creosote- or penta-treated wood may be used if exposed surfaces are sealed with two coats of urethane or epoxy paint or shellac. Guidelines for precautions in these cases are outlined in an EPA-approved consumer information sheet for each preservative treatment.

FASTENING PRESERVATIVE TREATED WOOD

Wood treated with most waterborne preservatives can be corrosive to metal fasteners and connectors. For aboveground construction, hot-dip galvanized steel and stainless steel fasteners are typically recommended. Joist hangers and framing anchors should also be hot-dip galvanized steel or stainless steel. For below-grade construction, such as treated wood foundation systems, Types 304 and 316 stainless steel Type H silicon bronze, ETP copper, and monel fasteners are required. Adhesives work well with wood treated with waterborne preservatives. Phenolresorcinol, resorcinol, and melemine-formaldehyde structural adhesives are used in glulam beams made from treated wood members. On job sites, use adhesives recommended for use with treated wood.

Other issues important to design professionals:

- Never mix galvanized steel with stainless steel in the same connection. When these dissimilar metals are in physical contact with each other, galvanic action will increase the corrosion rate of the galvanized part (the zinc will migrate off the galvanized part onto the stainless part at a faster rate). Refer to Figure 7.3 in Chapter 7, Metals.
- Galvanizing provides a sacrificial layer to protect the steel connector or fastener. Greater thicknesses (coating weights) generally provide longer protection in corrosive environments.
- Most commonly available electrogalvanized fasteners do not have a sufficient coating of zinc for these new chemicals.
- Aluminum should not be used in direct contact with CCA, ACQ, copper azole, or ACZA.

PRECAUTIONS FOR USE AND HANDLING

The chemical formulations used for preservative treatment of wood are registered with the EPA, which has approved certain uses for various types of pressure-treated wood to ensure safe handling and avoid environmental or other health hazards. Some guidelines for use and handling follow:

- Dispose of treated wood by ordinary trash collection or burial. Never burn treated wood in open fires or in stoves, fireplaces, or residential boilers.
- Avoid frequent inhalation of sawdust from treated wood. Whenever possible, perform sawing and machining of treated wood outdoors.
- Avoid frequent or prolonged skin contact with penta- or creosote-treated wood.
- After handling treated wood products, wash skin thoroughly before eating or drinking.

SPECIFICATION OF TREATED WOOD

Most building codes require the use of preservative treated wood in certain applications. AWPA has established a use category system and has published these standards in a document entitled *U1—Use Category System: User Specification for Treated Wood.* Wood processing and treatment is regulated by a number of organizations and not all regulatory bodies recognize or permit the use of the particular preservatives, processes, or the wood species listed in the standard. The following is a summary of the AWPA—U1categories:

- *Use Category UC1:* Wood used in interior construction, not in contact with the ground or foundations, and protected from water.
- *Use Category UC2:* Wood used in interior construction not in contact with ground, but may be subject to occasional dampness.
- *Use Category UC3:* Wood used in exterior construction, not in contact with ground. UC3 can be divided into two subcategories: UC3A is wood that is coated and used in a way that permits water to quickly drain from the surface, typically used in vertical applications and UC3B is wood that is not coated (except for aesthetic purposes) and may be used in either vertical or horizontal applications.
- *Use Category UC4:* Wood used in exterior construction and in contact with the ground or other conditions that support potential deterioration. UC4 can be divided into three subcategories: UC4A is wood used in ground- or freshwater contact; UC4B is wood used in contact with the ground in severe environments or as critically important structural components; and UC4C is wood used in contact with the ground in extremely severe environments or climates with an extremely high potential for deterioration.
- *Use Category UC5:* Wood exposed to saltwater and wood with brackish water exposure. UC5 is divided into three subcategories, which depend on the types of marine borers present in various areas in North America: UC5A is for wood exposed to waters north of New Jersey or north of San Francisco; UC5B is for wood exposed to waters south of San Francisco or from New Jersey south to Georgia; UC5C is for waters south of Georgia, the Gulf Coast, Puerto Rico, and Hawaii. Prior to specifying a UC5 subcategory, it is necessary to determine which marine borers are present in the area before consulting AWPA Standard U1.

Once the use category for each component has been determined, the specifier should consult the tables found in commodity specification for the type of component, to determine the appropriate species and preservative and retention combinations for that component. Figure 8.13 provides examples of applications from AWPA Standard U1.

NOTE

8.12 Source: *Wood Handbook*: *Wood as an Engineering Material*, developed by the USDA Forest Products Laboratory.

Contributors:
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland; American Plywood Association, Tacoma, Washington; Colin McCown, American Wood Preservers' Association, Selma, Alabama; John Showalter, PE, American Wood Council, Washington, DC.

EXAMPLES OF APPLICATIONS AND PRESERVATIVE RETENTION VALUES FROM AWPA STANDARD U1
8.13

APPLICATION	USE CATEGORY	COMMODITY SPECIFICATION	SPECIES	PRESERVATIVE	RETENTION (PCF)
Residential decks	UC3B	A	Southern pine	ACQ	0.25
			Douglas fir	CBA-A	0.21
Fascia boards	UC3A	A	Ponderosa pine	ACQ	0.25
			Southern pine	CA-B	0.10
Glulam beams, interior	UC2	F	Southern pine	ACQ	0.25
Glulam beams, exterior	UC4A	F	Douglas fir	Penta	0.30
Molding	UC1	A	Spruce pine fir	SBX	0.17
Permanent wood foundation	UC4B	A	Southern pine	CCA	0.60
			Douglas fir	ACZA	0.60
Piles, foundation	UC4C	E	Southern pine	Creosote	12.0
Piles, marine	UC5B	G	Douglas fir	ACZA	2.5 outer
					1.5 inner
Plywood subfloor	UC2	F	Southern pine	CCA	0.25
			Southern pine	SBX	0.17
Poles, building and utility	UC4B	D	Western red cedar	Penta	1.0
			Southern pine	CCA	0.60
Posts, fence, round	UC4A	B	Jack pine	CCA	0.40
Sill plates	UC2	A	Southern pine	SBX	0.17
			Douglas fir	ACQ	0.25

TYPICAL QUALITY MARK FOR TREATED LUMBER
8.14

A: Trademark of inspection agency certified by the American Lumber Standard Committee (ALSC). Contact the Southern Pine Council (SPC) or the ALSC for a list of certified inspection agencies.

B: Applicable American Wood Preservers' Association (AWPA) standard

C: Year of treatment

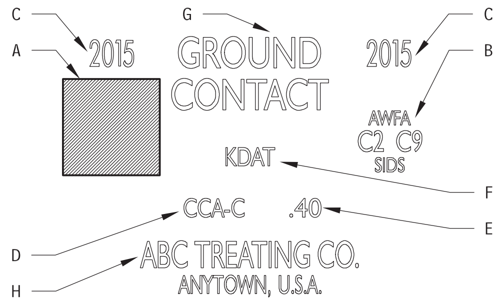
D: Preservative used for treatment

E: Retention level

F: Dry or KDAT (kiln-dried after treatment), if applicable

G: Proper exposure conditions

H: Treating company and location



FIRE-RESISTANT CONSTRUCTION

GENERAL

Building construction materials are tested for four criteria related to performance during a fire: fire resistance, flame spread, fuel contributed, and smoke developed.

Fire resistance is the material's ability to resist burning while retaining its structural integrity.

Flame spread measures the rate at which flames travel along the surface of a material.

Fuel contributed is a measure of how much combustible matter a material furnishes to a fire.

Smoke developed is a measure of the surface-burning characteristics of a material.

How fire spreads through wood structures depends on the size and arrangement of wood members and the details that restrict or encourage air movement around them. Larger cross sections take longer to burn. As wood burns, it develops an outer layer of charcoal, which insulates the wood beneath and slows burning. This "char" layer proceeds through the burning wood at an average rate of 1–1/2 in. per hour. Various design strategies can be used to resist fire damage to a wood structure and its spread to adjacent areas, but the most important is to protect the wood members by means of coverings, coatings, or treatments.

FIRE-RETARDANT WOOD TREATMENT

Modern fire-retardant treatment (FRT) of wood consists of pressure treatment with aqueous solutions of various organic and inorganic chemicals, followed by kiln drying to reduce moisture content to 19 percent or less for lumber under 2 in. thick, and 15 percent or less for plywood. All proprietary FRTs must conform to Underwriters Laboratory (UL) classifications. FRT wood is commonly used in plywood sheathing, roof trusses, rafters, floor joists, studs, staging, and shingles and shakes. Fire-retardant chemical combinations include zinc chloride, ammonium sulfates, borax or boric acid, and smaller amounts of sodium dichromate. Ammonium phosphates are no longer used because they cause rapid disintegration of wood.

Fire retardants work when fire-retardant chemicals react with the tars and gases normally produced by burning wood. The resultant carbon char acts as thermal insulation (greater than on untreated wood), slowing the rate of burning. Gases released from the FRT wood are diluted with carbon dioxide and water vapor, lessening the chance of flashover, in which wood gases are ignited by high temperatures and then explode.

FRT STANDARDS AND CLASSIFICATIONS

Interior fire retardants meet Class I ratings, which are required by code for vertical exits and special areas. Class II ratings are required for horizontal exits, but this rating is rarely reached with untreated wood. FRT lumber and plywood are recognized substitutes for noncombustible materials for insurance purposes. Many codes allow FRT wood products for a variety of applications.

Both the flame spread index and smoke developed index give numerical scales for a material's fire classification. The flame spread index is the primary test for fire performance, according to ASTM E-84. In the International Building Codes, flame spread ratings are classified as 0–25 (Class I or A), 26–75 (Class II or B), and 76–200 (Class III or C).

A smoke developed index of 450 or less is permitted for FRT wood used for interior wall and ceiling finishes. The UL FR-S listing applies only to treated products with a UL-723 (ASTM E-84) flame and smoke classification not exceeding 25 in a 30-minute test. The classification applies to the species tested and does not pertain to the structures in which the materials are installed.

Fire retardants come in interior and exterior types. Interior fire retardants are used on wood trusses and studs; exterior retardants protect exterior lumber, siding, roof shakes and shingles, and scaffold planking. The latter type offers durable, nonleachable,

NOTE

8.13 Many other species and preservative combinations are available for each application; the listing here is intended only as a sample from AWPA Standard U1. For more information on the AWPA's Use Category System visit www.awpa.com.

Contributors:
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland; Southern Pine Council, Kenner, Louisiana; Colin McCown, American Wood Preservers' Association, Selma, Alabama; American Plywood Association, Tacoma, Washington.

long-term fire protection in outdoor or moist (relative humidity of 95 percent or greater) conditions.

Class C or Class B FRT shingles and shakes may be considered as noncombustible materials. For wood exposed to the weather, specify exterior-type retardants that retain their protective properties under the standard rain test.

Interior Type A wood is appropriate for interior and weather-protected applications with less than 95 percent relative humidity. In rare instances, when relative humidity is less than 75 percent, Type B can be specified. Interior Type A is used when a wood with low hygroscopicity (the rate at which the chemical draws moisture from the air) is required.

FRT INTERIOR WOODWORK

Instead of solid lumber, it is often desirable to build members of treated cores clad with untreated veneers 1/28-in. thick or less. Most codes discount this narrow finishing in determining the flame spread index of the wood, permitting use of untreated wood in about 10 percent of the combined wall and ceiling surface area. Sizes and species currently being treated (flame spread index less than 25) include red oak and Western red cedar up to 4/4 and yellow poplar up to 8/4. Color and finishes are affected by FRTs.

FINISHING AND FINISHES

FRT lumber and plywood can be lightly sanded for cosmetic cleaning after treatment. Painting and staining are possible but not always successful, particularly with transparent finishes. Test finishes for compatibility before application.

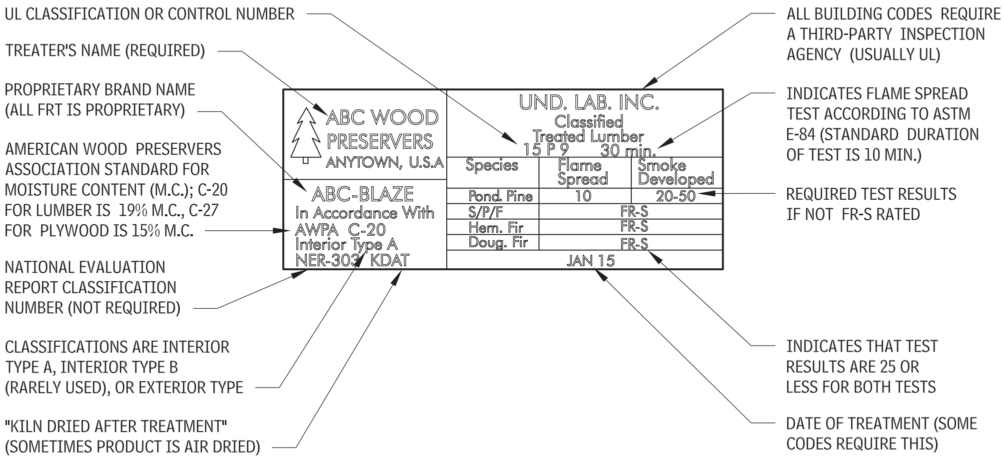
Treated lumber may be end-cut, but ripping and extensive surfacing will normally void the UL label. To the extent possible, materials should be precut before treatment, otherwise a wood treater should be consulted. Treated plywood can be cut in either direction without loss of fire protection.

Intumescent coatings are sometimes used to reduce flammability of wood surfaces in both opaque and transparent finishes. Under high heat, these coatings expand or foam, creating an insulating effect that reduces flame spread. Check local codes before specifying these coatings because they tend to be less durable, softer, and more hygroscopic than standard finishes.

FRT FACTS

- These standards apply to FRT wood: ASTM E-84, ASTM D-2898, ASTM D-3201, ASTM E-108, AWPA C-20, AWPA C-27, and the *ULI Building Materials Directory* (current edition). For more information, contact the American Wood Preservers' Association (AWPA), American Wood Preservers' Institute, USDA Forest Service, Southern Forest Products Association, Western Wood Preservers' Institute, and American Forest and Paper Association.
- FRT wood has increased weight and decreased strength. Consult a structural engineer and the wood treater for actual design values for structural applications.
- FRT wood fasteners must be hot-dipped, zinc-coated galvanized stainless steel, silicon bronze, or copper; other materials deteriorate upon contact with FRT chemicals.

TYPICAL FIRE-RETARDANT TREATED WOOD IDENTIFICATION MARK
8.15



FLAME SPREAD INDEX
8.16

MATERIAL[a]		ASTM E-84 FLAME SPREAD	SOURCE[b]
Lumber	Birch, yellow	105–110	UL
	Cedar, Western red	70	HPMA
	Douglas fir	70–100	UL
	Maple (flooring)	104	CWC
	Oak, red or white	100	UL
	Pine, Ponderosa	105–230[c]	UL
	Pine, Southern yellow	130–195	UL
	Poplar	170–185	UL
	Redwood	65	CRA
	Spruce, Northern	65	UL
Softwood plywood (exterior glue)	Douglas fir, 1/4″	118	CWC
	Douglas fir, 5/8″	95	APA
	Southern pine, 1/4″	95–110	APA
Hardwood plywood	Lauan, 1/4″	150	HPMA
Particleboard	1/2″, 47 lb./cu ft.	156	NBS
	5/8″, 44 lb./cu ft.	153	NBS
Flakeboard	Red oak, 1/2″, 42–47 lb./cu ft. (four types)	71–189	FPL
Shakes	Western red cedar, 1/2″	69	HPMA
Shingles	Western red cedar, 1/2″	49	HPMA

FLAME SPREAD INDEX OF FACTORY-FINISHED PRODUCTS
8.17

MATERIAL			ASTM E-84 FLAME SPREAD
Particleboard	1/32″	Factory finish printed	118–178
	1/2″	Paper overlay	175
	5/8″	Vinyl overlay	100
Medium-density fiberboard (MDF)	3/16″	Factory finish printed	167
Hardboard	1/8″	Factory finish printed	158–194
		Paper overlay	155–166
Flakeboard	Aromatic cedar, 3/16″		156
Hardwood plywood	Aspen, 1/4″	Factory finished	196
	Birch, 5/32″	Factory finished	160–195
	Cherry, 1/4″	Factory finished	160
	Hickory, 1/4″	Factory finished	140
	Lauan, 1/4″	Factory finish printed	99–141
	Maple, 1/4″	Factory finished	155
	Oak, 1/4″	Factory finished	125–185
	Pine, 1/4″	Factory finished	120–140
	Walnut, 1/4″	Factory finished	138–160

NOTES

8.15 Wood shakes and shingles are further classified as Class B or C. Rather than stamp each piece, each bundle is tagged with an identification mark.

8.16 a. Unless indicated, thickness of material is 1 in. nominal.

b. Sources: American Plywood Association (APA), California Redwood Association (CRA), Canadian Wood Council (CWC), USDA Forest Products Laboratory (FPL), Hardwood Plywood Manufacturers Association (HPMA), National Bureau of Standards (NBS), Underwriters Laboratories (UL).

c. Average of 18 tests was 154 with three values over 200.

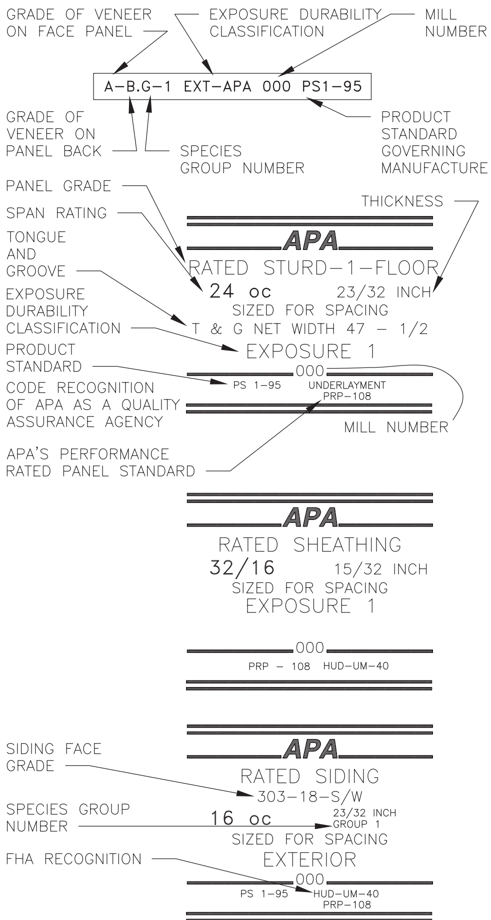
8.17 Hardwood Plywood Manufacturers Association test records.

Contributors:
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland; Colin McCown, American Wood Preservers' Association, Selma, Alabama.

TYPICAL WOOD AND COMPOSITE PRODUCTS

PLYWOOD DESIGN DATA

APA TRADEMARKS
8.18



GRADE DESIGNATIONS

Structural panel grades are generally identified in terms of the veneer grade used on the face and back of the panel (e.g., A-B, B-C, etc.) or rated by a name suggesting the panel's intended end use (e.g., APA Rated Sheathing, APA Rated Sturd-I-Floor, etc.).

VENEER GRADES

Veneer grades define veneer appearance in terms of natural unrepaired growth characteristics and the number and size of repairs allowable during manufacture. The highest quality veneer grades are N and A. The minimum grade of veneer permitted in exterior plywood is C-grade. D-grade veneer is used only for backs and inner plies of panels intended for interior use or applications protected from exposure to permanent or severe moisture.

- N—Smooth surface "natural finish" veneer. Select all heartwood or all sapwood. Free of open defects. Allows not more than six repairs, wood only, per 4 by 8 panel, made parallel to grain and well matched for grain and color.
- A—Smooth, paintable. Not more than 18 neatly made repairs; boat, sled, or router type; parallel to grain permitted. May be used for natural finish in less demanding applications. Synthetic repairs permitted.
- B—Solid surface. Shims, circular repair plugs, and tight knots to 1 in. across grain permitted. Some minor splits and synthetic repairs permitted.
- C—Plugged, improved. C-grade veneer with splits limited to 1/8-in. width; knotholes and borer holes limited to 1/4 by 1/2 in. Admits some broken grain. Synthetic repairs permitted.
- C—Tight knots to 1–1/2 in. Knotholes to 1 in. across grain and some to 1–1/2 in., if total width of knots and knotholes is within specified limits. Synthetic or wood repairs. Discoloration and sanding defects that do not impair strength permitted. Limited splits allowed. Stitching permitted.
- D—Knots and knotholes to 2–1/2 in. width across grain and 1/2 in. larger within specified limits. Limited splits allowed. Stitching permitted. Limited to interior and Exposure 1 panels.

SPAN RATINGS

APA Rated Sheathing, APA Rated Sturd-I-Floor, and APA Rated Siding carry numbers in their trademarks called span ratings. These denote the maximum recommended center-to-center spacing, in inches, of supports for the panels in construction applications. Except for APA Rated Siding panels, the span rating in the trademark applies when the long panel dimension is across supports, unless the strength axis is otherwise identified. The span rating in the trademark of rated siding panels applies when installed vertically.

The span rating in APA Rated Sheathing trademarks appears as two numbers separated by a slash, such as 32/16 and 48/24. The Span Rating for APA Rated Siding panels is for vertical installation; for lap siding, the rating applies with the long dimension across supports. An exception is APA Rated Sheathing intended for use on walls only. The trademarks for these contain a single number, similar to the span rating for APA Rated Siding. The left-hand number denotes the maximum recommended spacing of supports when the panel is used for roof sheathing, with the long dimension or strength axis of the panel across three or more supports. The right-hand number indicates the maximum recommended spacing of supports when the panel is used for subflooring, with the long dimension or strength axis of the panel across three or more supports. A panel marked 32/16, for example, may be used for roof decking over supports 32 in. o.c. or for subflooring over supports 16 in. o.c.

The span ratings in the trademarks on APA Rated Sturd-I-Floor and Siding panels appear as a single number. APA Rated Sturd-I-Floor panels are designed specifically for single-floor (combined subfloor underlayment) applications under carpet and pad and are manufactured with span ratings of 16, 20, 24, 32, and 48 in. The span ratings for APA Rated Sturd-I-Floor panels, like those for APA Rated Sheathing, are based on application of the panel, with the long dimension or strength axis across three or more supports.

APA Rated Siding is available with span ratings of 16 and 24 in. Span-rated panels and lap siding may be applied directly to studs, over nonstructural wall sheathing (Sturd-I-Wall construction), or over nailable panel or lumber sheathing (double wall construction). Panels and lap siding with a span rating of 16 o.c. may be applied directly to studs spaced 16 in. o.c and similarly with 24 in. o.c for panel and span rating of 24. All rated siding panels may be applied horizontally direct to studs 16 or 24 in. o.c., provided horizontal joints are blocked. When used over nailable structural sheathing, the span rating of rated siding panels refers to the maximum recommended spacing of vertical rows of nails, rather than to stud spacing.

BOND CLASSIFICATIONS

APA-trademarked panels may be produced in three bond classifications: Exterior, Exposure 1, and Interior. (Note: All-veneer APA Rated Sheathing, Exposure 1, commonly called CDX in the trade, is frequently mistaken as an Exterior panel and is erroneously used in applications for which it does not possess the required resistance to weather. CDX should only be used for applications as outlined under Exposure 1, below. For sheathing grade panels that will be exposed permanently to the weather, specify APA Rated Sheathing Exterior (C-C Exterior under Product Standard PS-1 for manufacturing.)

Exterior panels have a fully waterproof bond and are designed for applications subject to permanent exposure to the weather.

Exposure 1 panels have a fully waterproof bond and are designed for applications where long construction time may delay permanent protection or where high moisture conditions may be encountered in service. Exposure 1 panels are made with the same adhesives used in Exterior panels. However, because other compositional factors may affect bond performance, only Exterior panels should be used for permanent exposure to the weather.

Interior panels that lack further glueline information in their trademarks are manufactured with interior glue and are intended for interior applications only.

SANDED, UNSANDED, AND TOUCH-SANDED PANELS

Panels with B-grade or better veneer faces are sanded smooth in manufacture to fulfill the requirements of their intended applications (cabinets, shelving, furniture, built-ins, etc.). APA Rated Sheathing panels are unsanded because a smooth surface is not required for their intended use. Other APA panels—Underlayment, Rated Sturd-I-Floor, C-D Plugged, and C-C Plugged—require only touch-sanding for "sizing," to make the panel thickness more uniform.

Unsanded and touch-sanded panels and panels with B-grade or better veneer on one side only usually carry the APA trademark on the panel back. Panels with both sides of B-grade or better veneer, or with special overlaid surfaces (such as medium-density overlay), carry the APA trademark on the panel edge.

GROUP NUMBER

Plywood can be manufactured from more than 70 species of wood. These species are divided, on the basis of bending strength and stiffness, into five groups under U.S. Product Standard PS 1. The strongest species are in Group 1, the next strongest in Group 2, and so on. The group number that appears in the trademark on some APA-trademarked panels—primarily sanded grades—is based on the species of face and back veneers. Where face and back veneers are not from the same species group, the higher group number is used, except for sanded and decorative panels 3/8 in. thick or less. These are identified by face species because they are chosen primarily for appearance and used in applications where structural integrity is not critical. Sanded panels greater than 3/8 in. are identified by face species if C or D grade backs are at least 1/8 in. and are no more than one species group number larger. Some species are used widely in plywood manufacture, others rarely. Check local availability before specifying if a particular species is desired.

CLASSIFICATION OF SPECIES
8.19

GROUP 1		GROUP 2				GROUP 3		GROUP 4		GROUP 5
Apitong[a, b]		Cedar, Port Orford		Maple, Black		Alder, Red		Aspen		Basswood
Beech, American		Cypress		Mengkulang[a]		Birch, Paper			Bigtooth	Poplar, Balsam
Birch		Douglas fir, No. 2[c]		Meranti, Red[a, d]		Cedar, Alaska			Quaking	
	Sweet	Fir		Mersaw[a]		Fir, subal-pine		Cativo		
	Yellow		Balsam	Pine		Hemlock, Eastern		Cedar		
Douglas fir, No. 1[c]			California Red		Pond	Maple, Bigleaf			Incense	
Kapur[a]			Grand		Red	Pine			Western red	
Keruing[a, b]			Noble		Virginia		Jack	Cottonwood		
Larch, Western			Pacific Silver		Western White		Lodgepole		Eastern	
Maple, Sugar			White	Spruce			Ponderosa		Black (Western poplar)	
Pine		Hemlock, Western			Black		Spruce	Pine		
	Caribbean	Lauan			Red	Redwood			Eastern White	
	Ocote		Almon		Sitka	Spruce			Sugar	
Pine, Southern			Bagtikan	Sweetgum			Engelmann			
	Loblolly		Mayapis	Tamarack			White			
	Longleaf		Red Lauan	Yellow Poplar						
	Shortleaf		Tangile							
	Slash		White Lauan							
Tanoak										

303-PLYWOOD SIDING GRADES
8.20

CLASS	GRADE[a]	WOOD PATCHES	SYNTHETIC PATCHES
Special Series 303	303-OC[b, c]	Not permitted	Not permitted
	303-OL[d]	Not applicable for over-lays	
	303-NR[e]	Not permitted	Not permitted
	303-SR[f]	Not permitted	Permitted as natural defect shape only
303–6	303–6-W	Limit 6	Not permitted
	303–6-S	Not permitted	Limit 6
	303–6-S/W	Limit 6, any combination	
303–18	303–18-W	Limit 18	Not permitted
	303–18-S	Not permitted	Limit 18
	303–18-S/W	Limit 18, any combination	
303–30	303–30-W	Limit 30	Not permitted
	303–30-S	Not permitted	Limit 30
	303–30-S/W	Limit 30, any combination	

PLYWOOD PANEL TYPES

APA RATED SIDING PANELS

APA Rated Siding Panels can be used for exterior siding, fencing, and other external applications. They can be manufactured as conventional veneered plywood or as an overlaid oriented strand board siding. Both panel and lap siding are available. They are intended for use with a special surface treatment such as V-groove, shallow channel groove, deep groove (such as APA Texture 1–11), kerfed groove, brushed, rough-sawn, and texture-embossed medium density overlay (MDO). Span Rating (stud spacing for siding qualified for APA Sturd-I-Wall applications) and face grade classification (for veneer-faced siding) are indicated in the trademark. Bond Classification: Exterior. Common thicknesses are 11/32, 3/8, 15/32, 1/2, 19/32, and 5/8 in.

SPECIALTY SIDING

APA publishes minimum requirements that plywood panels must meet to qualify for classification as Specialty Siding. APA classifies materials that meet the requirements as APA 303 Series Specialty Siding. These materials must meet requirements related to gluebond, veneer grade, workmanship, panel thickness, number of plies and layers, as well as type and number of repair patches. Figure 8.22 indicates the allowable patches for various types of specialty siding.

Texture 1–11 is a groove detail for 303 Special Siding panel. Texture 1–11 pattern details include: 1/4 in. deep groove, 3/8 in. wide, spaced 4 or 8 in. o.c., overall panel thickness is limited to five-plies with a minimum nominal thickness of 19/32 in.

MARINE-GRADE PLYWOOD

Ideal for boat hulls. Made only with Douglas fir or Western larch. Special solid-jointed core construction for water resistance. Subject to special limitations on core gaps and face repairs. Also available with high-density overlay (HDO) or MDO faces. Bond Classification: Exterior. Common thicknesses: 1/4, 3/8, 1/2, 5/8, and 3/4 in. A common misconception involves the use of marine-grade plywood in place of exterior panels. Marine-grade plywood is uniquely situated for marine applications and is not treated to enhance its resistance to decay. Marine-grade plywood and exterior panels have the same APA Exterior Exposure Durability, and both are designed for extended exposure to weather and moisture. Marine-Grade plywood has a sanded face and will not be as visually acceptable after weathering.

APA RATED STURD-I-FLOOR 48 OC (2–4–1)

For combination subfloor underlayment on 32- and 48-in. spans and for heavy timber roof construction. Manufactured only as conventional veneered plywood. Available square-edged or tongue-and-grooved. Bond Classifications: Exposure 1. Thickness: 1–1/8 in.

NOTES FOR SANDED AND PERFORMANCE-RATED PANELS

- Specify performance-rated panels by thickness and span rating. Span ratings are based on panel strength and stiffness. These properties are a function of panel composition and configuration as well as thickness, therefore the same span rating may appear on panels of different thicknesses. Conversely, panels of the same thickness may be marked with different span ratings.
- All plies in Structural I panels are limited to Group 1 species. Structural II panels are seldom available.
- Exterior sanded panels, C-C Plugged, C-D Plugged, and Underlayment grades can also be manufactured in Structural I (all plies limited to Group 1 species).
- Some manufacturers also produce panels with premium N-grade veneer on one or both faces. They are available only by special order.
- Available in thicknesses of 11/32, 15/32, 19/32, and 23/32 in.

NOTES

8.19 a. Each of these names represents a trade group of woods consisting of a number of closely related species.
b. Species from the genus *Dipterocarpus* are marketed collectively: Apitong if originating in the Philippines, Keruing if originating in Malaysia or Indonesia.
c. Douglas fir from trees grown in the states of Washington, Oregon, California, Idaho, Montana, and Wyoming, and the Canadian provinces of Alberta and British Columbia are classed as Douglas fir No. 1. Douglas fir from trees grown in the states of Nevada, Utah, Colorado, Arizona, and New Mexico are classed as Douglas fir No. 2.
d. Red Meranti is limited to species having a specific gravity of 0.41 or more, based on green volume and oven-dry weight.
8.20 a. Limitations on grade characteristics are based on 4 by 8 ft. panel size. Limits on other sizes vary in proportion. All panels except 303-NR allow restricted minor repairs such as shims. These and other face appearance characteristics such as knots, knotholes, and splits, are limited by both size and number, in accordance with panel grades; 303 OC is the most restrictive and 303–30 the least. Multiple repairs are permitted only on 303–18 and 303–30 panels. Patch size is restricted on all panel grades. For additional information, including finishing recommendations, refer to the APA Product Guide: 303 Plywood Siding, E300.
b. Check local availability.
c. Clear.
d. Overlaid (e.g., medium-density overlay siding).
e. Natural rustic.
f. Synthetic rustic.

Contributors:
Bloodgood, Sharp, Buster Architects and Planners, Des Moines, Iowa;
APA—The Engineered Wood Association, Tacoma, Washington.

PLYWOOD USES

EXTERIOR-TYPE PANELS
8.21

APPEARANCE[a]		VENEER			THICKNESS (IN.)					
GRADE[b]	COMMON USES	F	M	B	1/4	5/16	11/32 3/8	15/32 1/2	19/32 5/8	23/32 3/4
A-A Ext	For use where appearance of both sides is important for exterior applications such as fences, signs, boats, shipping containers, tanks, ducts, etc.	A	C	A	•		•	•	•	•
A-B Ext	For use where appearance of one side is less important but where two solid surfaces are necessary	A	C	B	•		•	•	•	•
A-C Ext	For use where appearance of only one side is important in exterior applications, e.g., soffits, fences, structural uses, boxcar and truck linings, farm buildings, tanks, trays, commercial refrigerators, etc.	A	C	C	•		•	•	•	•
B-B Ext	Utility panels with two solid sides; for protected applications	B	C	B	•		•	•	•	•
B-C Ext	Utility panel for farm service and work buildings, boxcar and truck linings, containers, tanks, agricultural equipment, as a base for exterior coatings and other exterior uses	B	C	C	•		•	•	•	•
HDO Ext	Has a hard semi-opaque resin-fiber overlay on both sides; abrasion-resistant. For concrete forms, cabinets, countertops, signs, tanks. Suitable for permanent exterior exposure without further finishing. Also available with skid-resistant screen-grid surface.	A B	C	A B			•	•	•	•
MDO Ext	Medium-density overlay with smooth, opaque, resin-fiber overlay, one or both sides. Recommended for siding and other outdoor applications. Ideal base for paint—indoors and outdoors. Available as a 303 Siding.	B	C	B C			•	•	•	•
Panel Siding Ext[c]	Special surface treatment, such as V-groove, channel groove, striated, brushed, rough sawn	C	C			•	•	•		
T1–11 Ext[c]	Special 303 panel having grooves 1/4 in. deep, 3/8 in. wide, spaced 4 or 8 in. o.c.; other spacing optional. Edges shiplapped. Available unsanded, textured, and medium-density overlay.	A B C	C	C				•		
Plyron Ext	Hardboard face on both sides. Faces tempered, untempered, smooth, or screened. For countertops, shelving, cabinet doors, flooring, etc.	HB	C	HB				•	•	•
Underlayment C-C Plugged Ext	For application over structural subfloor. Provides smooth surface for application of carpet and pad. Touch-sanded.	C	C	C			•	•	•	•
C-C Plugged Ext	For use as underlayment over structural subfloor, in severe moisture conditions, including refrigerated or controlled atmosphere storage rooms, pallet bins, tanks, truck floors, linings, and other exterior applications. Touch-sanded.	C-Plugged	C	C			•	•	•	•
B-B Plyform Class I and Class II Ext[d]	Concrete form grades with high reuse factor. Sanded both sides and mill-oiled, unless otherwise specified. Special restrictions on species. Class I panels are stiffest, strongest, and most commonly available. Also available in HDO for very smooth concrete finish, in Structural I (all plies limited to Group 1 species), and with special overlays.	B	C	B					•	•
PERFORMANCE RATED[a]		**VENEER**			**THICKNESS**					
GRADE	**COMMON USES**	**F**	**M**	**B**	**1/4**	**5/16**	**11/32 3/8**	**15/32 1/2**	**19/32 5/8**	**23/32 3/4**
Sheathing Ext	Specially designed for subflooring and wall and roof sheathing, and siding on service and farm buildings. Also good for a broad range of other construction and industrial applications. Can be manufactured as a conventional veneered plywood, as a composite, or as a nonveneered panel. For special engineered applications, veneered panels conforming to PS 1 may be required.	C	C	C		•	•	•	•	•
Structural I and II Sheathing Ext	Unsanded all-veneer PS 1 or PS 2 plywood grades are used where strength is of maximum importance; for example, for box beams, gusset plates, stressed-skin panels, containers, and pallet bins. Structural I is more commonly available. For engineered applications in construction and industry where full exterior-type panels are required. Unsanded.	C	C	C		•	•	•	•	•
Sturdi-I-Floor Ext	Specially designed as combination subfloor underlayment, where severe moisture conditions exist (e.g., balcony decks). Provides smooth surface for application of carpet and pad, and possesses high concentrated and load-impact resistance. Can be manufactured as a nonveneered panel. Available square-edged or tongue-and-grooved. Touch-sanded.	C	C[e]	C					•	•

INTERIOR TYPE PANELS
8.22

APPEARANCE[a]			VENEER			THICKNESS (IN.)					
GRADE[b,f]	COMMON USES		F	M	B	1/4	5/16	11/32 3/8	15/32 1/2	19/32 5/8	23/32 3/4
A-A Int	Use where appearance of both sides is important for interior applications, such as built-ins, cabinets, furniture, partitions. Smooth surfaces suitable for painting.		A	D	A	•		•	•	•	•
A-B Int	For use where appearance of one side is less important but where two solid surfaces are necessary.		A	D	B	•		•	•	•	•
A-D Int	For use where appearance of only one side is important in interior applications, e.g., paneling, built-ins, shelving, partitions, etc.	Interior Exposure 1	A	D	D	•		•	•	•	•
B-B Int	Utility panels with two solid sides.		B	D	B	•		•	•	•	•
B-D Int	Utility panel for backing, sides of built-ins, industry shelving, slip sheets, separator boards, bins, and other interior or protected applications.		B	D	D	•		•	•	•	•
Decorative Panels-Int	Rough-sawn, brushed, grooved, or other faces. For paneling, interior accent walls, built-ins, counter facing, and exhibit displays. Can also be made by some manufacturers in Exterior for siding, gable ends, fences, etc. Use recommendations for exterior panels vary with the particular product; check with manufacturer.		A B C	D	D		•	•	•	•	
Plyron-Int	Hardboard face on both sides. Faces tempered, untempered, smooth, or screened. For countertops, shelving, cabinet doors, flooring, etc.		HB	C	HB				•	•	•
			D								
Underlayment-Int	For application over structural subfloor. Provides smooth surface for application of carpet and pad, and has high concentrated and impact-load resistance. Touch-sanded. Also available with exterior glue.		C	C	D			•	•	•	•
			D								
C-D Plugged Int	For open soffits, built-ins, wall and ceiling tile backing, cable reels, walkways, separator boards, and other interior or protected applications. Not a substitute for underlayment or APA Rated Sturd-I-Floor, as it lacks puncture resistance. Touch-sanded. Also made with exterior glue.		C	D	D			•	•	•	•
PERFORMANCE RATED[a,g]			**VENEER[h]**			**THICKNESS**					
GRADE	**COMMON USES**		**F**	**M**	**B**	**1/4**	**5/16**	**11/32 3/8**	**15/32 1/2**	**19/32 5/8**	**23/32 3/4**
Sheathing Exp 1	Specially designed for subflooring and wall and roof sheathing. Also good for broad range of other construction and industrial applications. Can be manufactured as a conventional veneered plywood, as a composite, or as a nonveneered panel. For special engineered applications, veneered panels conforming to PS 1 may be required. Commonly available with exterior glue for sheathing and subflooring. Specify Exposure 1 treated wood foundations.		C	D	D		•	•	•	•	•
Structural 1 and II Sheathing Exp 1	Unsanded all-veneer PS 1 or PS 2 plywood grades for use where strength is of maximum importance; for example, box beams, gusset plates, stressed-skin panels, containers, pallet bins. Structural I is more commonly available. Made only with exterior glue for beams, gusset plates, and stressed-skin panels.		C[g]	D[g]	D[g]					•	•
Floor Exp 1	For combination subfloor and underlayment under carpet and pad. Specify Exposure 1 where moisture is present. Available in tongue-and-groove.		C D[e]	C	D					•	•
Floor 48 in. o.c. Exp 1	Combination subfloor underlayment on 32- and 48-in. spans and for heavy timber roofs. Touch-sanded or fully sanded.		C D	C	D					1–1/8	

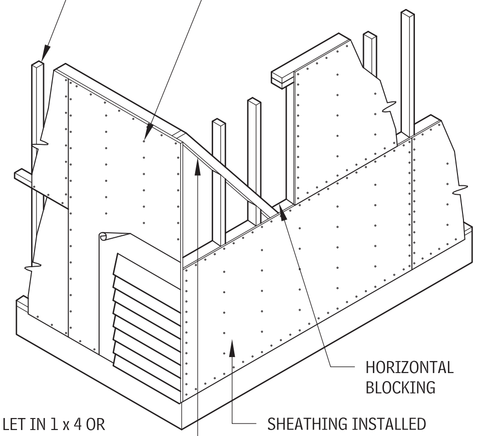
NOTES

8.21 and 8.22
a. Standard 4 by 8 panel sizes; other sizes available.
b. Available in Group 1, 2, 3, 4, or 5, unless otherwise noted.
c. Maximum recommended support spacing for roofs and floors is indicated in sheathing and single-layer floor trademarks. Wall span ratings are included in rated siding panels.
d. Also available in Structural I.
e. Special construction to resist indentation from concentrated loads.
f. Interior type panels with exterior glue are identified as Exposure I.
g. Special improved grade for structural panels.
h. Also available as nonveneer panels.

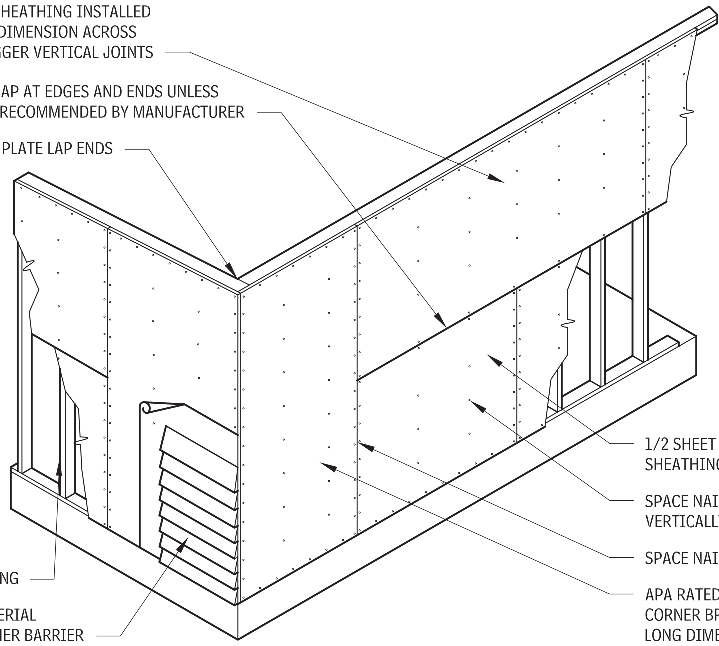
Contributor:
David S. Collins, FAIA, Preview Group, Inc., Cincinnati, Ohio.

WALL AND ROOF SHEATHING

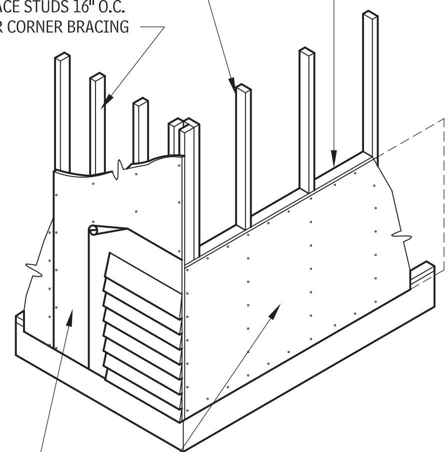
FIBERBOARD SHEATHING
8.23



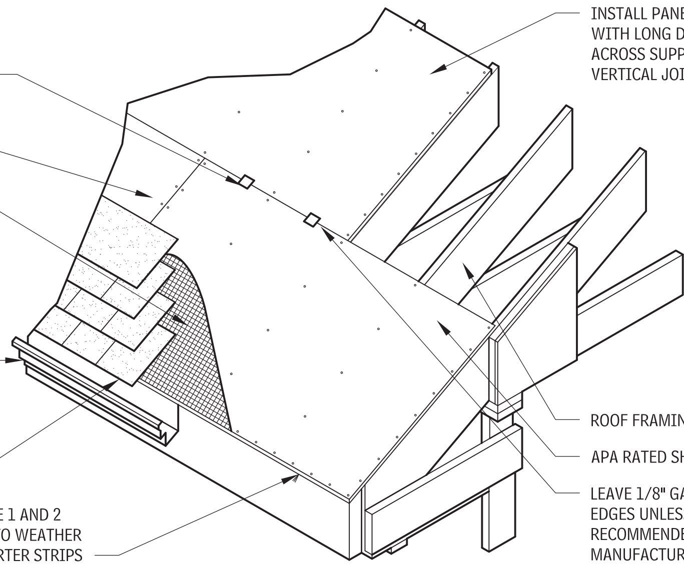
STRUCTURAL WALL SHEATHING
8.24



GYPSUM BOARD SHEATHING
8.25



STRUCTURAL ROOF SHEATHING
8.26



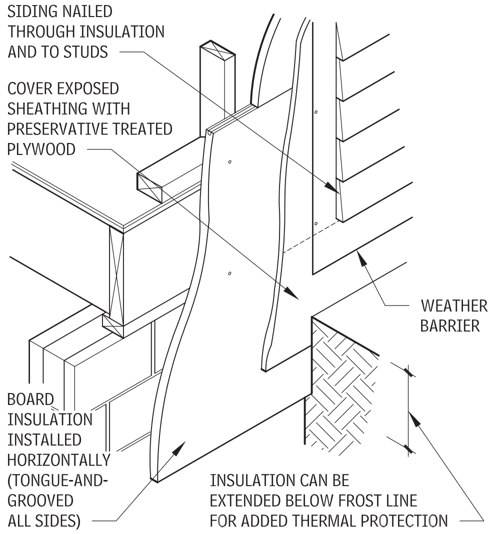
NOTES

8.25 Nail siding through gypsum board to studs; refer to manufacturer's recommendations for specific installation instructions.
8.26 Before roofing is applied cover roof sheathing as soon as possible with roofing felt for protection from moisture.

SHEATHING MATERIALS
8.27

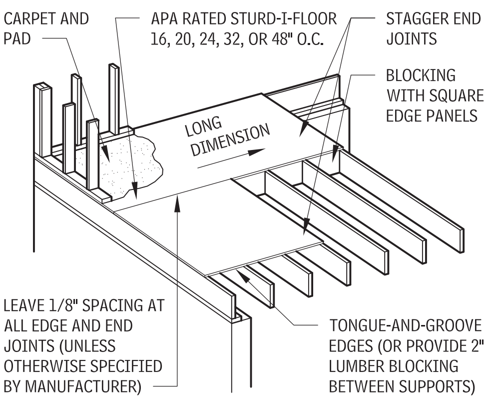
CHARACTERISTICS	STRUCTURAL SHEATHING	GYPSUM	FIBERBOARD
Nailable base	Yes	No	Only high-density
Vapor retardant	No	No	If asphalt-treated
Insulation R-value (1/2-in. thickness)	1.2	0.7	2.6
Corner bracing provided	Yes	Yes (see manufacturer's recommendations)	Only high-density
Panel sizes (in.)	48 × 96, 48 × 108, 48 × 120	24 × 96, 48 × 96, 48 × 120, 48 × 144, 48 × 168	48 × 96, 48 × 108, 48 × 120, 48 × 144
Panel thickness (in.)	5/16, 3/8, 7/16, 15/32, 1/2, 19/32, 5/8, 23/32, 3/4, 7/8, 1, 1–1/8	1/4, 3/8, 1/2, 5/8	1/2, 25/32
Other remarks	Plywood grades commonly used for roof and wall sheathing have span ratings of 12/0, 16/0, 20/0, 24/0, 24/16, 32/16, 40/20, and 48/24; exposure durability classifications are Exposure 1 and Exterior. For unsupported edges, refer to manufacturer's recommendations.	Fire-rated panels are available in 1/2- and 5/8-in. thicknesses.	Also called insulation board. Can be treated or impregnated with asphalt. Available in regular and high-density panels.

RIGID INSULATION SHEATHING
8.28



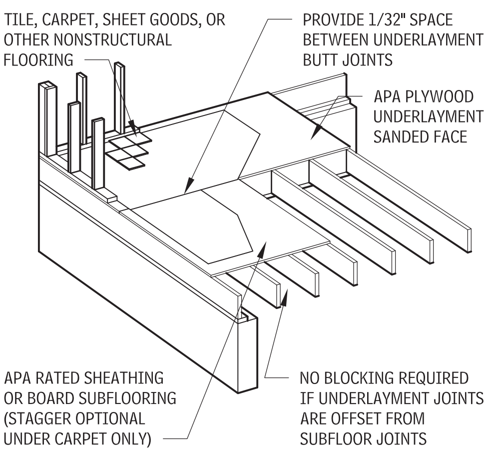
PLYWOOD SUBFLOORING ON WOOD FRAMING

APA RATED STURD-I-FLOOR
8.29



SPAN RATING (MAXIMUM JOIST SPACING, IN.)	PANEL THICKNESS (IN.)	NAIL SIZE AND TYPE	FASTENING			
			PANEL EDGE		INTERMEDIATE	
			SPACING (IN.)			
			GLUE/NAILED	NAILED ONLY	GLUE/NAILED	NAILED ONLY
16	19/32, 5/8, 21/32	6d ring or screw shank[c]	12	6	12	12
20	19/32, 5/8, 23/32, 3/4	6d ring or screw shank[c]	12	6	12	12
24	11/16, 23/32, 3/4	6d ring or screw shank[c]	12	6	12	12
	7/8, 1	8d ring or screw shank[c]	12	3	12	12
48	1–1/8	8d ring or screw shank[d]	6	6		

PLYWOOD UNDERLAYMENT
8.30



PLYWOOD GRADES AND SPECIES GROUP	APPLICATION	MINIMUM PLYWOOD THICKNESS (IN.)
Groups 1, 2, 3, 4, and 5 Underlayment Int-APA (with interior or exterior glue), or Underlayment Ext-APA (C-C Plugged) Ext	Over smooth subfloor	1/4
	Over lumber subfloor or other uneven surfaces	11/32
Same grades as above, but Group 1 only	Over lumber floor up to 4 in. wide. Face grain must be perpendicular to boards.	1/4

UNDERLAYMENT NAILING SCHEDULE

Use 3d ring shank nails for underlayment up to 1/2-in. thickness, 4d for 19/32 in. and thicker. Use 16-gauge staples; however, 18-gauge may be used with 1/4-in.-thick underlayment. Crown width should be 3/8 in. for 16-gauge staples, and 3/16 in. for 18-gauge. Length should be sufficient to penetrate subflooring at least 5/8 in. or extend completely through. Space fasteners at 3 in. along panel edges and 6 in. each way in the panel interior, except for 11/32 in. or thicker underlayment applied with ring shank nails; in this case, use 6-in. spacing along edges and 8-in. spacing each way in the panel interior. Unless subfloor and joists are of thoroughly seasoned material and have remained dry during construction, countersink nail heads below surface of the underlayment just prior to laying finish floors, to avoid nail popping. Joints should be 1/32 in. wide to allow for expansion and contraction. If thin, resilient flooring is to be used to cover underlayment, fill and thoroughly sand joints.

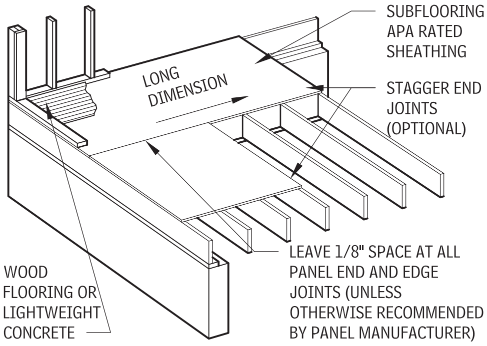
NOTES

8.29 a. For conditions not listed, see APA literature.
b. Use only APA Specification AFG-01 adhesives, properly applied. Use only solvent-based glues on nonveneered panels with sealed surfaces and edges.
c. If ring or screw-shank nails are not available, 8d common nails may be substituted.
d. If supports are well seasoned, 10d common nails may be substituted with 1–1/8-in. panels.
e. Space nails 6 in. for 48-in. spans and 12 in. for 32-in. spans.

8.30 a. For carpeting, sheet goods, or other nonstructural flooring (consult the Tile Council of America for recommendations regarding ceramic tile).
b. Where floors may be subject to unusual moisture conditions, use panels with exterior glue (Exposure 1) or Underlayment C-C Plugged EXT-APA. C-D Plugged is not an adequate substitute for underlayment grade, since it does not ensure equivalent dent resistance.
c. Recommended grades have a solid surface backed with a special inner-ply construction that resists punch-through and dents from concentrated loads.

Contributor:
David S. Collins, FAIA Preview Group, Inc., Cincinnati, Ohio.

APA PANEL SUBFLOORING[a]
8.31



PANEL SPAN RATING (OR GROUP NUMBER)	PANEL THICKNESS (IN.)	MAXIMUM SPACING[b,c,e] (IN.)
24/16	7/16, 1/2	16
32/16	15/32, 1/2, 5/8, 23/32	16[d]
40/20	19/32, 5/8, 23/32, 3/4	20[d]
48/24	23/32, 3/4, 7/8	24
1–1/8 in., Groups 1 and 2	1–1/8	48

SUBFLOORING NAILING SCHEDULE

For 7/16-in. panel, use 6d common nails at 6 in. o.c. at panel edges and 12 in. o.c. at intermediate supports. For 15/32- to 7/8-in. panels, use 8d common nails at 6 in. o.c. at panel edges and 12 in. o.c. at intermediate supports. For 1–1/8- and 1–1/4-in. panels up to 48-in. span, use 10d common nails 6 in. o.c. at panel edges and 6 in. o.c. at intermediate supports.

GLUED FLOOR SYSTEM

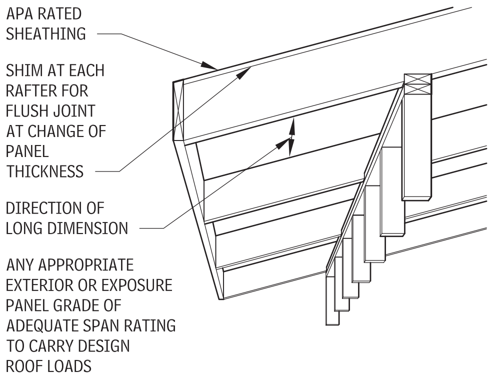
- For complete information on glued floors, including joist span tables (based on building code criteria and lumber sizes), application sequence, and a list of recommended adhesives, contact the American Plywood Association.
- Place APA Sturd-I-Floor tongue-and-groove (T&G) across the joists with end joints staggered. Leave 1/8 in. space at all end and edge joints.
- Although T&G is used more often, square edge panels may be used if 2 by 4 blocking is placed under panel edge joints between joists.
- Based on live load of 40 psf and total load of 50 psf, deflection is limited to 1/360 at 40 psf.
- Glue to joists and at T&G joints. If square edge panels are used, block panel edges and glue between panels and between panels and blocking.

GLUED FLOOR NAILING SCHEDULE

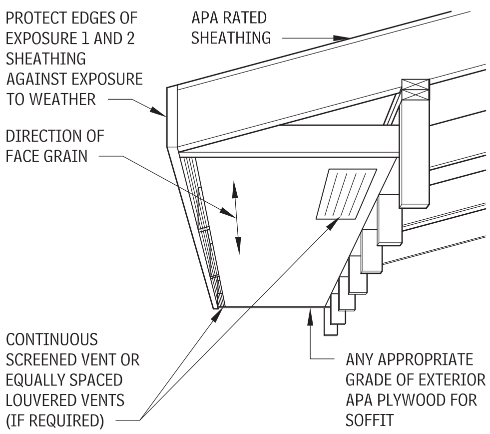
Panels should be secured with power-driven fasteners or nailed per APA Sturd-I-Floor Figure 8.29.

PLYWOOD SHEATHING FOR ROOFS AND SOFFITS

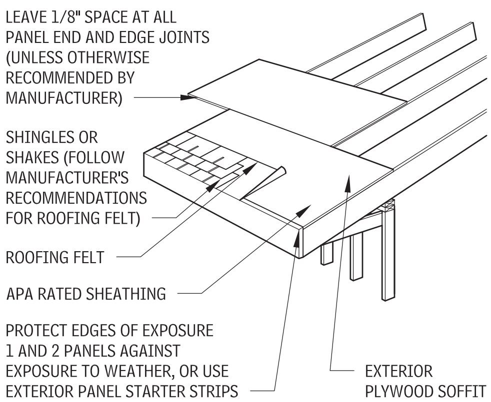
OPEN SOFFIT
8.32



CLOSED SOFFIT
8.33



GABLE ROOF
8.34



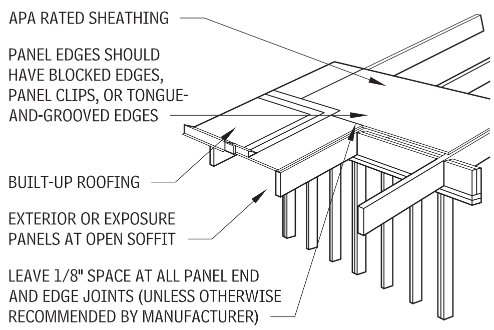
EXTERIOR OPEN SOFFITS/COMBINED CEILING DECKING[a]
8.35

PANEL DESCRIPTIONS, MINIMUM RECOMMENDATIONS	GROUP	MAXIMUM SPAN (IN.)
15/32″ APA 303 siding	1, 2, 3, 4	16
15/32″ APA sanded and MDO	1, 2, 3, 4	
15/32″ APA 303 siding	1	24
15/32″ APA sanded and MDO	1, 2, 3	
19/32″ APA 303 siding	1, 2, 3, 4	32[b]
19/32″ APA sanded and MDO	1, 2, 3, 4	
19/32″ APA 303 siding	1	
19/32″ APA sanded and MDO	1	
23/32″ APA 303 siding	1, 2, 3, 4	
23/32″ APA sanded and MDO	1, 2, 3, 4	
1 1/8″ APA textured	1, 2, 3, 4	48[b]

EXTERIOR CLOSED PLYWOOD SOFFITS
8.36

NOMINAL PLYWOOD THICKNESS	GROUP	MAXIMUM SPAN (IN.) ALL EDGES SUPPORTED
11/32″ APA 303 siding or APA sanded	All species groups	24
15/32″ APA 303 siding or APA sanded		32
19/32″ APA 303 siding or APA sanded		48

FLAT LOW-PITCHED ROOF
8.37



NOTES

8.31 a. Applies to APA Rated Sheathing grades only.
b. The spans assume plywood is continuous over two or more spans, with the long dimension across supports.
c. In some nonresidential buildings, special conditions may require construction in excess of minimums given.
d. May be 24 in. if 3/4-in. wood strip flooring is installed at right angles to joists.
e. Spans are limited to the values shown because of the possible effect of concentrated loads.

8.35 a. Plywood is assumed to be continuous across two or more spans with face grain across supports.
b. In open soffit construction, for spans of 32 or 48 in., provide adequate blocking, tongue-and-groove edges, or other support such as panel clips. Minimum loads are at least 30 psf live load, plus 10 psf dead load.
8.36 Plywood is assumed to be continuous across two or more spans with face grain across supports.

Contributors:
Bloodgood, Sharp, Buster Architects and Planners, Des Moines, Iowa; APA—The Engineered Wood Association, Tacoma, Washington.

APA PANEL ROOF SHEATHING
8.38

		MAXIMUM SPAN (IN.)		NAIL SPACING (IN.)		
PANEL SPAN RATING	PANEL THICKNESS (IN.)	WITH EDGE SUPPORT	WITHOUT EDGE SUPPORT	NAIL SIZE AND TYPE	PANEL EDGES	INTERMEDIATE
12/0	5/16	12	12	6d common	6	12
16/0	5/16, 3/8	16	16			
20/0	5/16, 3/8	20	20			
24/0	3/8, 7/16, 15/32, 1/2	24	20			
24/16	7/16, 15/32, 1/2	24	24			
32/16	15/32, 1/2	32	28			
32/16	19/32, 5/8	32	28	8d common		
40/20	19/32, 5/8, 23/32, 3/4, 7/8	40	32			
40/24	23/32, 3/4, 7/8	48	36			
				STAPLING SPACES (IN.)		
				LEG LENGTH	PANEL EDGES	INTERMEDIATE
(See above)	5/16	(See above)		1–1/4″	4	8
	3/8			1–3/8″		
	7/16, 15/32, 1/2			1–1/2″		

NAILING SCHEDULE

For closed soffits, use nonstaining box or casing nails: 6d for 11/32-in. and 15/32-in. panels, and 8d for 19/32-in. panels. Space nails 6 in. at panel edges and 12 in. along intermediate supports for spans less than 48 in.; 6 in. at all supports for 48-in. spans.

Use 6d common smooth, ring shank, or spiral thread nails for plywood 1/2-in. thick or thinner and 8d for plywood to 1-in. thick. Use 8d ring shank or spiral thread or 10d common smooth for 2–4–1 and 1–1/8-in. panels. Space nails 6 in. at panel edges and 12 in. at intermediate supports, except for 48-in. or longer spans where nails should be spaced 6 in. at all supports.

ORIENTED STRAND BOARD

GENERAL

Oriented strand board (OSB) is manufactured from rectangular-shaped wood strands that are oriented lengthwise and then arranged in layers at right angles to one another, laid up into mats, and bonded together with waterproof, heat-cured adhesives. This results in a structural engineered wood product that shares many of the strength and performance characteristics of plywood.

In the first phase of OSB manufacture, logs are debarked and cut to a uniform length. The logs are then turned into strands or wafers. The strands are dried with heat in a large rotating drum, which is screened to grade for strands that are the correct size. The dried strands are sprayed with liquid or powder resin and then transported in layers on a conveyer system to a forming line, where the layers are cross-oriented into mats. For face layers, the strands generally run along the panel; for core layers, the strands are randomly oriented or run across the panel. The mats are trimmed to a workable size and then moved to a press where the wood strands and glue are bonded together under heat and pressure to create a structural panel. Finally, the panels are cut to size. Panels can be manufactured in many sizes simply by altering the cutting pattern.

OSB uses the wood resource very efficiently, in part because sheathing panels can be made using smaller, younger fast-growing tree species such as aspen and Southern yellow pine. Plus, about 85 to 90 percent of a log can be used to make high-quality structural panels, and the remainder—bark, saw trim, and sawdust—can be converted into energy, pulp chips, or bark dust.

OSB is most commonly used for traditional applications such as sheathing for roofs and walls, subfloors, and single-layer flooring. Its superior performance has allowed OSB to gain popularity in a variety of other areas, including structural insulated panels, webs for wood I-joists, materials-handling applications, furniture, and a variety of do-it-yourself projects.

COMMON SIZES

OSB panels manufactured in North America are typically 4 by 8 ft. in size. Panels for use as exterior siding are also available in narrow lap widths of 6 or 8 in. and 16-ft lengths. Because OSB is typically manufactured in large sizes, many manufacturers can custom-make panels in almost any size simply by altering the cutting pattern. Most OSB manufacturers make oversized panels, up to 8 by 24 ft., which are typically used for panelized roof systems or modular floors. In operations where oversized panels can be handled, they provide the advantage of reducing the total number of panels required to do a job, and thus speed installation time and cost.

OSB can be manufactured with square edges or with T&G edges. Panel surface treatments may include texturing or sanding. Overlaid OSB for use as exterior siding also may be surface textured or grooved.

APA PANEL GRADE AND THICKNESS

Two common panel grades for OSB are APA Rated Sheathing and APA Rated Sturd-I-Floor. OSB APA Rated Sheathing is intended for subflooring, wall sheathing, and roof sheathing. APA Rated Sheathing/Ceiling Deck can also be made using OSB; it is made so that one surface has an overlay, texturing, or grooving. Common thicknesses for sheathing panels are: 5/16, 3/8, 7/16, 15/32, 1/2, 19/32, 5/8, 23/32, and 3/4 in.

OSB APA Rated Sturd-I-Floor is intended for single-layer flooring under carpet and pad. APA Rated Sturd-I-Floor panels often have tongue-and-groove edges. Common thicknesses for flooring panels are: 19/32, 5/8, 23/32, 3/4, 7/8, 1, and 1–1/8 in.

BOND CLASSIFICATION OF OSB

APA Performance—Rated OSB panels have a designated bond classification, which identifies the panel's resistance to moisture exposure. Panels are classified into the following two groups:

Exterior panels have a fully waterproof bond and are designed for applications subject to permanent exposure to the weather or to moisture.

Exposure 1 panels have a fully waterproof bond and are designed for applications where long construction delays may be expected prior to providing protection. Approximately 95 percent of Performance Rated Panels are manufactured with this designation.

APA'S PERFORMANCE RATED PANEL STANDARD FOR OSB

OSB panels that bear the APA trademark are manufactured under APA's rigorous quality assurance program and are recognized by the major U.S. and Canadian building codes, as well as many international building codes. Each panel is "performance rated," which means the panel meets the performance requirements necessary for its end-use application.

Most North American OSB panels are manufactured in conformance with Voluntary Product Standard PS-2 or APA PRP-108 performance standards. Panel applications described in PS-2 and APA PRP-108 include floors, walls, and roofs. These standards are recognized by the building codes in the United States, including the International Building Code and International Residential Code, and by National Evaluation Service Report NER-108.

PANEL PRODUCTS AND WOOD VENEERS

GENERAL

Architectural wood panels are made from wood material that is cut or formed into sheet products that are referred to as the "panel core." These sheets are used alone (with or without a finish) or laminated together with other veneer products to make plywood. A wide variety of panels are manufactured using different core materials and adhesives or binders and various forming techniques and surface treatments. The characteristics of the panels vary with these differences in material and construction.

PANEL CORE TYPES

Panel cores, which serve as the substrate for laminates and veneers on the outer surface, are classified by products and methods of manufacture. The types of panel cores described below are suitable for architectural use.

INDUSTRIAL-GRADE PARTICLEBOARD CORE

This core type is made by using heat and pressure to bond together synthetic resin or binder and wood particles of various sizes. Employed in a wide variety of architectural woodwork applications, industrial-grade particleboard is especially well suited as a substrate for high-quality veneers and decorative laminates. When used as panels without any surface layers, the product is called particleboard; when used with wood veneer on the surface, the panels are referred to as particle-core plywood. Particleboard core is classified into three densities, dependent on weight per cubic ft.:

- Low-density: less than 40 lb. per cubic ft.
- Medium-density: 40 to 50 lb. per cubic ft.
- High-density: more than 50 lb. per cubic ft.

MOISTURE-RESISTANT PARTICLEBOARD CORE

Some medium-density industrial particleboard is bonded with resins more resistant to swelling when exposed to moisture. The most common grades are Type M-2-Exterior Glue and M-3-Exterior Glue in accordance with ANSI 208.1.

FIRE-RETARDANT PARTICLEBOARD CORE

Medium-density industrial particleboard may be treated during manufacture to carry a UL Class A fire rating stamp (flame spread, 20; smoke developed, 25). This material can be used as a substrate for paneling, requiring a Class A rating.

MEDIUM-DENSITY FIBERBOARD (MDF) CORE

MDF is made from wood particles reduced to fibers in a moderate-pressure steam vessel, combined with resin, and bonded together under heat and pressure. The surface is flat, smooth, uniform, dense, and free of knots or grain pattern. MDF is useful as a substrate for paint, thin overlay materials, veneers, and decorative laminates. The homogeneous edge allows machining and paint

NOTE

8.38 Applicable to APA Rated Panel Sheathing.
All panels will support at least 30 psf live load plus 10 psf dead load at maximum span. Uniform load deflection limit is 1/180 span under live load plus dead load, or 1/240 under live load only.
Special conditions may require construction in excess of the given minimums.
Panel is assumed to be continuous across two or more spans, with long dimension across supports.

finishes. MDF is one of the most stable mat-formed panel products and is widely used as an architectural panel.

MOISTURE-RESISTANT MDF CORE

Some MDF is bonded with a moisture-resistant resin to produce a water-resistant product.

VENEER CORE (PLYWOOD)

This panel product is made up of alternating layers of thin veneer. Adhesive is placed between the layers, and the panels are pressed until the adhesive is set; heat is often used to speed the cure. The two outside layers, often selected for species, grain, and appearance, are called the face veneers.

HARDBOARD CORE

Hardboard is made of interfelted fibers consolidated under heat and pressure to a density of 31 lb. per cubic ft. or more. Available with either one side (S1S) or two sides (S2S) smooth, hardboard is often used for casework backs, drawer bottoms, and divider panels. Architectural woodworkers typically use two types of hardboard core: standard (untempered) and tempered, which is standard hardboard that has been subjected to a curing treatment to increase its stiffness, hardness, and weight.

CHARACTERISTICS OF CORE MATERIAL

Characteristics of core material performance are influenced by the grade and thickness of the core and specific gravity of the core species. Visual Edge Quality is rated before treatment with edge bands or fillers and, for lumber core, assumes the use of "clear edge" grade. Surface uniformity is directly related to the performance of fine veneers placed over the surface. Dimensional stability is usually related to exposure to wide variations in relative humidity. Screw-holding and bending strength are influenced by proper design and engineering.

PLYWOOD

The term "plywood" is defined as a panel consisting of three or more layers (plies) of wood or wood products (veneers or overlays and/or core materials) generally laminated into a single sheet (panel). Plywood is separated into two groups, according to materials and manufacturing:

- Hardwood plywood panels are made from hardwood or decorative softwood veneers over a core material such as medium-density particleboard, medium-density fiberboard, low-density lumber and other veneers.
- Softwood plywood panels are made with softwood face veneers, and are seldom incorporated into finished architectural woodworking projects because of the instability of the core material and core voids.

TYPES OF FACING MATERIAL

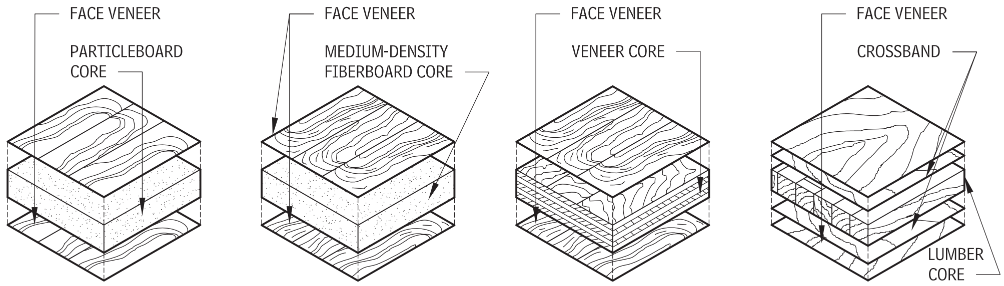
Wood product substrates are classified in two main facing material categories: decorative laminates/overlays and wood veneers.

DECORATIVE LAMINATES, OVERLAYS, AND PREFINISHED PANEL PRODUCTS

This finish surface category can be broken down into the following broad groups:

High-pressure decorative laminates are formed under heat and pressure from resin-impregnated kraft paper substrates with decorative plastic face materials and a clear protective top sheet. This assembly, commonly called plastic laminate, offers resistance to wear and many stains and chemicals. Common uses include casework exteriors, countertops, and wall paneling.

HARDWOOD PLYWOOD CORE TYPES
8.39



CHARACTERISTICS OF CORE MATERIAL PERFORMANCE
8.40

PANEL CORE TYPE	FLATNESS	VISUAL EDGE QUALITY	SURFACE UNIFORMITY	DIMENSIONAL STABILITY	SCREW-HOLDING	BENDING STRENGTH	AVAILABILITY
Industrial Particleboard (medium)	Excellent	Good	Excellent	Fair	Fair	Good	Readily
Medium-Density Fiberboard (MDF)	Excellent	Excellent	Excellent	Fair	Good	Good	Readily
Veneer	Fair	Good	Fair	Excellent	Excellent	Excellent	Readily
Lumber	Good	Good	Good	Good	Excellent	Excellent	Limited
Combination Core with Composite Crossbands	Excellent	Good	Excellent	Good	Excellent	Excellent	Limited
Combination Core with Composite Innerply	Good	Fair	Good	Good	Good	Good	Limited
Moisture-Resistant Particleboard	Excellent	Good	Good	Fair	Fair	Good	Limited
Moisture-Resistant MDF	Excellent	Excellent	Excellent	Fair	Good	Good	Limited
Fire-Rated Particleboard	Excellent	Fair	Good	Fair	Fair	Good	Limited

Refer to *Architectural Woodwork Quality Standards Illustrated* for additional information.

Thermally fused decorative panels are flat-pressed from a thermoset polyester or melamine resin-impregnated web, and most have been laminated to industrial particleboard or medium-density fiberboard substrates when they arrive at the woodwork fabricator. Performance is similar to that of high-pressure decorative laminates. Common uses include casework interiors, furniture, shelving, display materials, and decorative paneling.

Thermoplastic sheets are semi-rigid sheets or rolls, stock-extruded from a nonporous acrylic/polyvinyl chloride (PVC) alloy. The materials are impact resistant and minor scratches and gouges are less conspicuous due to the through-color property.

Medium-density overlays are made from pressed resin-impregnated paper overlays, and are highly resistant to moisture. They are available applied to cores suitable for both interior and exterior uses. The seamless panel face and uniform density offer a sound base for opaque finishes and paint.

Vinyl films, foils, and low-basis weight papers are decorative facing materials that, although they have limited use in custom architectural woodworking, are suitable for some installations.

WOOD VENEERS

Wood veneers are produced in a variety of industry standard thicknesses. The slicing process is controlled by a number of variables, but the thickness of the veneer has little bearing on the quality of the end product.

There are two types of veneers, hardwood and softwood. Hardwood veneers are available in many domestic and imported wood species and are normally plain-sliced, but certain species can be rift-sliced, quarter-sliced, or rotary-cut. Softwood veneers are usually sliced from Douglas fir, but pine and other softwoods are available. Most softwood veneer is rotary cut. Plain-sliced and quarter-sliced (vertical grain) softwoods may be obtained by special order.

Most veneers are taken from large trees, but some are sliced from fast-growing trees, dyed, and re-glued in molds to create "grain" patterns. The color of these reconstituted veneers is established during manufacture because the high percentage of glue line resists staining.

The manner in which a log segment is cut with relation to the annual rings of the tree determines the appearance of the veneer. Individual pieces of veneer, referred to as "leaves," are kept in the order in which they were sliced for reference during installation. The group of leaves from one slicing is called a "flitch" and is identified by a number and the gross square feet it contains. The faces of the leaves with relation to their position in the log are identified as the "tight face" (toward the outside of the log) and the "loose face" (toward the inside, or heart, of the log).

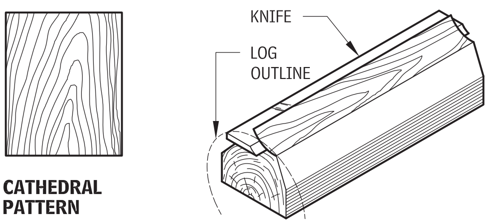
NOTES

- To achieve balanced construction, panel products should be absolutely symmetrical from the centerline. Materials used on either side should contract and expand or exhibit moisture permeability at the same rate.
- In panel construction, the thinner the facing material, the less force it can generate to cause warping. The thicker the substrate, the more it can resist a warping movement or force.
- Wood veneer standards: For hardwood plywood, the face veneer characteristics of the Hardwood Plywood and Veneer Association (HPVA) have generally been adapted for use. These face grades apply to custom architectural woodwork.

TYPES OF VENEER CUTS

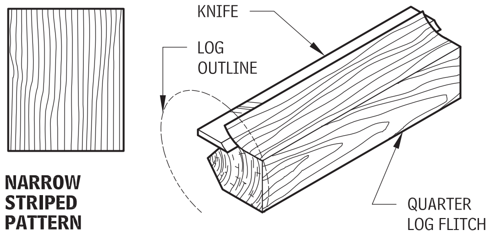
The plain or flat slicing method is most often used to produce veneers for high-quality architectural woodwork. Slicing is done parallel to a line through the center of the log. A combination of cathedral and straight-grain patterns results, with a natural progression of pattern from leaf to leaf.

PLAIN-SLICED (FLAT-SLICED) VENEER
8.41



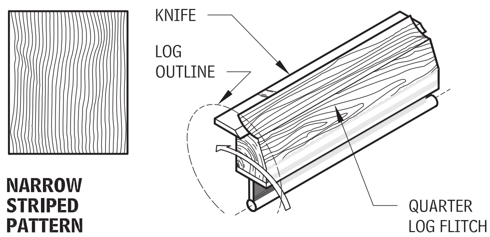
Quarter-slicing, roughly parallel to a radius line through the log segment, simulates the quarter-sawing process used with solid lumber. In many species, the individual leaves are narrow as a result. A series of stripes is produced, varying in density and thickness among species. In red and white oak, "fleck" (sometimes called flake) is a characteristic of this slicing method.

QUARTER-SLICED VENEER
8.42



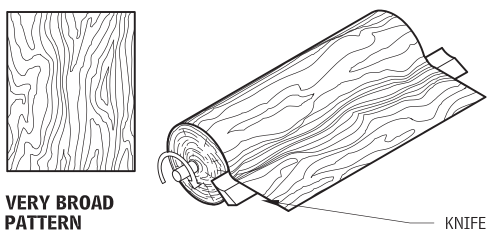
Rift-cut veneers are produced most often in red and white oak, rarely in other species. Note that rift veneers and rift-sawn solid lumber are produced so differently that a "match" between them is highly unlikely. In both cases the cutting is done slightly off the radius lines, minimizing the "fleck" (sometimes called flake) associated with quarter-slicing.

RIFT-SLICED (RIFT-CUT) VENEER
8.43



To create rotary-cut veneers, the log is center-mounted on a lathe and "peeled" along the path of the growth rings, like unwinding a roll of paper. This provides a bold, random appearance. Rotary veneers vary in width, so matching at veneer joints is extremely difficult. Most softwood veneers are cut this way. Rotary-cut veneers are the least useful in fine architectural woodwork.

ROTARY VENEER
8.44



MATCHING BETWEEN ADJACENT VENEER LEAVES

It is possible to achieve certain visual effects by the manner in which the veneer leaves are arranged. Rotary-cut veneers are difficult to match, therefore most matching is done with sliced veneers. Matching of adjacent veneer leaves must be specified. Consult the AWI woodworker for choices.

BOOK MATCH

Book matching is the most commonly used match in the industry. In it, every other piece of veneer is reversed so adjacent pieces (leaves) are "opened" like the pages of a book. Because the "tight" and "loose" faces alternate in adjacent leaves, they reflect light and accept stain differently. The veneer joints match, creating a symmetrical pattern that yields maximum continuity of grain.

SLIP MATCH

In this match method, adjoining leaves are placed (slipped out) in sequence without being turned, thus all the same face sides are exposed. The grain figure repeats but joints do not show grain match.

RANDOM MATCH

In random matching, veneer leaves are placed next to each other in a random order and orientation, producing a casual board-by-board effect in many species. Conscious effort is made to mismatch the grain at joints.

END MATCH

End matching is often used to extend the apparent length of available veneers for high wall panels and long conference tables. End matching occurs in two types:

- *Architectural end match*: Leaves are individually book or slip matched, alternating end to end and side to side. Architectural end matching yields the best continuous grain patterns for length as well as width.
- *Panel end match*: Leaves are book or slip matched on panel subassemblies, with sequenced subassemblies end matched, resulting in some modest cost savings on projects, where applicable. For most species, panel end matching yields a pleasing, blended appearance and grain continuity.

RUNNING MATCH

Using this method, each panel face is assembled from as many veneer leaves as necessary. This often results in an asymmetrical appearance, with some veneer leaves of unequal width.

BALANCE MATCH

In balance matching, each panel face is assembled from an odd or even number of veneer leaves of uniform width before edge trimming.

BALANCE AND CENTER MATCH

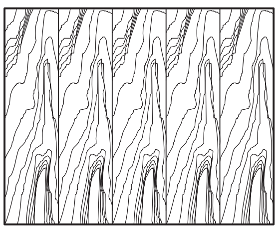
Using this method, each panel face is assembled from an even number of veneer leaves of uniform width before edge trimming. Thus, there is a veneer joint in the center of the panel, producing horizontal symmetry.

Contributors:
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland; Greg Heuer, Architectural Woodwork Institute, Potomac Falls, Virginia.

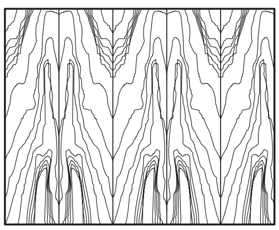
GENERAL CHARACTERISTICS OF SELECTED WOOD VENEER SPECIES
8.45

SPECIES		WIDTH TO (IN.)	LENGTH (FT)	FLITCH SIZE	COST[a]	AVAILABILITY
Mahogany	Plain-Sliced Honduras Mahogany	18	12	Large	Moderate	Good
	Quartered Honduras Mahogany	12	12	Large	High	Moderate
	Plain-Sliced African Mahogany	18	12	Large	Moderate	Moderate
	Quartered African Mahogany	12	12	Large	High	Good
Ash	Plain-Sliced American White Ash	12	10	Medium	Moderate	Good
	Quartered American White Ash	8	12	Small	High	Good
	Quartered or Plain-Sliced European Ash	10[d]	10	Medium	High	Limited
Anegre	Quartered or Plain-Sliced Anegre	12[d]	12	Large	High	Good
Avodire	Quartered Avodire	10	10	Large	High	Limited
Cherry	Plain-Sliced American Cherry	12	11	Medium	Moderate	Good
	Quartered American Cherry	4	10	Very small	High	Moderate
Birch	Rotary-Cut Birch (Natural)	48	10	Large	Low	Good
	Rotary-Cut Birch (Select Red or White)	36	10	Medium	Moderate	Moderate
	Plain-Sliced Birch (natural)	10	10	Small	Moderate	Limited
	Plain-Sliced Birch (Select Red or White)	5	10	Small	High	Limited
Butternut	Plain-Sliced Butternut	12	10	Medium	High	Limited
Makore	Quartered or Plain-Sliced Makore	12[d]	12	Large	High	Good
Maple	Plain-Sliced (Half-Round) American Maple	12	10	Medium	Moderate	Good[b]
	Rotary Birdseye Maple	20	10	Medium	Very high	Good
Oak	Plain-Sliced English Brown Oak	12	10	Medium	Very high	Limited
	Quartered English Brown Oak	10	10	Medium	Very high	Limited
	Plain-Sliced American Red Oak	16	12	Large	Moderate	Good
	Quartered American Red Oak	8	10	Small	Moderate	Good
	Rift-Sliced American Red Oak	10	10	Medium	Moderate	Good
	Comb Grain Rift American Red Oak	8	10	Small	Very high	Limited
	Plain-Sliced American White Oak	12	12	Medium	Moderate	Good
	Quartered American White Oak	8	10	Small	Moderate	Good
	Rift-Sliced American White Oak	8	10	Medium	High	Good
	Comb Grain Rift American White Oak	8	10	Small	Very high	Limited
Hickory or Pecan	Plain-Sliced American Hickory or Pecan	12	10	Small	Moderate	Good
Sapele	Quartered or Plain-Sliced Sapele	12[d]	12	Large	High	Good
Sycamore	Plain-Sliced English Sycamore	10	10	Medium	Very high	Limited
	Quartered English Sycamore	6	10	Medium	Very high	Limited
Teak	Plain-Sliced Teak	12	12	Large	Very high	Limited[c]
	Quartered Teak	12	12	Medium	Very high	Limited[c]
Walnut	Plain-Sliced American Walnut	12	12	Medium	Moderate	Good
	Quarter-Sliced American Walnut	6	10	Very small	High	Rare

VENEER MATCH TYPES
8.46

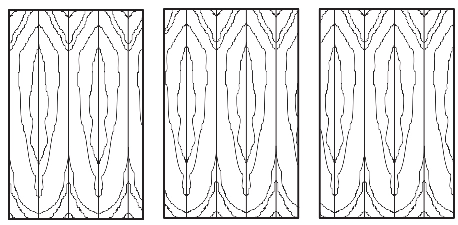


SLIP MATCH

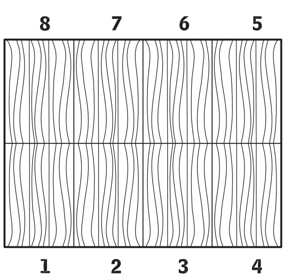


BOOK MATCH

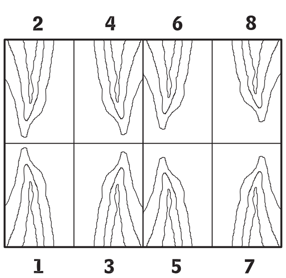
RANDOM MATCH



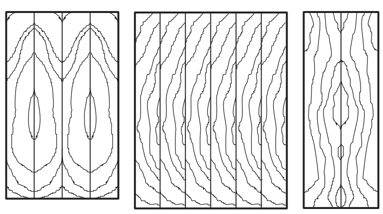
RUNNING MATCH



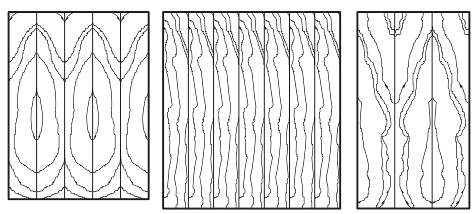
SLIP, CENTER, BOOK MATCH



ARCHITECTURAL END OR BUTT MATCH



BALANCE AND CENTER MATCH



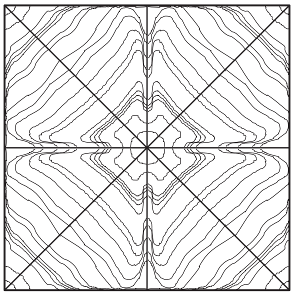
BALANCE MATCH

NOTES

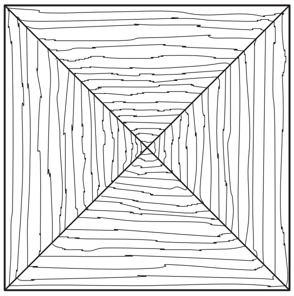
8.45 a. Cost reflects raw veneer costs weighted for waste or yield characteristics and degree of labor difficulty.
b. Seasonal factors may affect availability.
c. Availability of blond teak is very rare.
d. When quartered or plain-sliced are listed on the same line, the width dimensions are listed with quartered first and plain-sliced second.

Contributors:
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland; Architectural Woodwork Institute, Potomac Falls, Virginia.

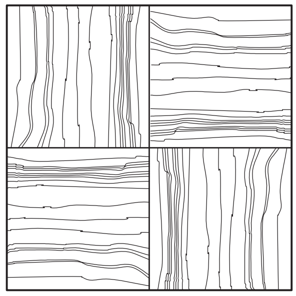
SPECIAL WOOD VENEER MATCHING OPTIONS
8.47



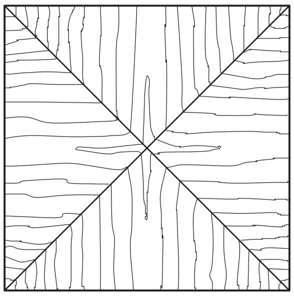
8-PIECE SUNBURST MATCH



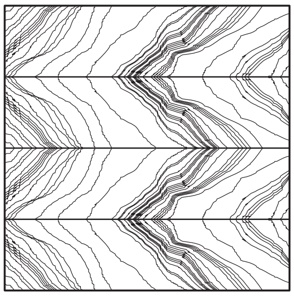
BOX MATCH



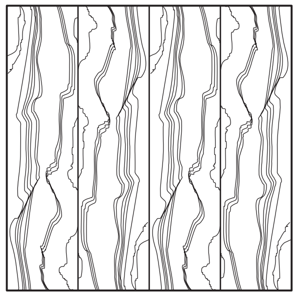
PARQUET MATCH



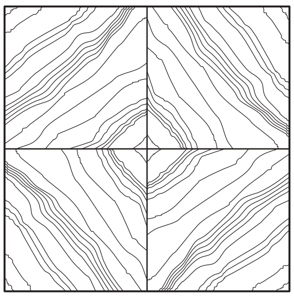
REVERSE OR END GRAIN BOX MATCH



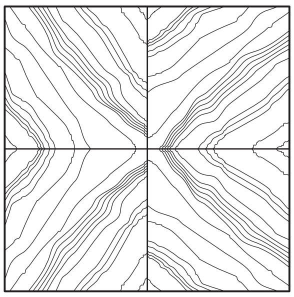
HERRINGBONE OR BOOK MATCH



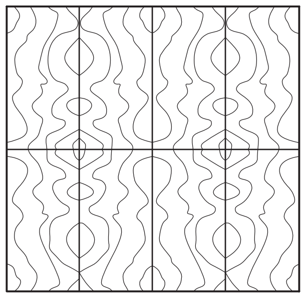
SWING MATCH



DIAMOND MATCH



REVERSE DIAMOND MATCH



BOOK AND BUTT MATCH

INSTALLATION GUIDELINES AND CONSTRUCTION TOLERANCES

WOOD ADHESIVES

GENERAL

Adhesives have been used for bonding wood for centuries, but until the 1930s they were limited to only a few naturally derived substances—those based on animal or vegetable proteins, gums, or resins. It wasn't until World War II that stepped-up materials research efforts spurred the development of synthetic adhesives for bonding metals, concrete, glass, rubber, plastics, and wood. Many of these synthetic adhesives are used to manufacture products such as plywood, oriented strand board, and laminated timbers. They can also be used during construction to attach plywood subfloors to floor joists, adhere ceramic tiles to floors or walls, attach gypsum board, and other construction products. In addition to their structural use, adhesives also can be used to eliminate squeaks in floors and for some mechanical fastening.

Adhesives are composed of a base component, dispersion medium, and various additives that impart specific properties. The elastomeric base of a construction-type adhesive accounts for 30 to 50 percent of its weight. Depending on its intended application, this base is made of natural rubber (isoprene) or synthetic rubbers such as neoprene, butyl, polyurethane, polysulfide, nitrile, styrene-butadiene, or butadiene acrylonitrile. Additives include tackifiers, flow and extrusion modifiers, curing agents, antioxidants, and fillers. Together, the base and the additives are dispersed (or dissolved) in a liquid, typically an organic solvent or water.

Currently, most adhesives use organic solvents, but water-based adhesives are gaining in popularity because they do not emit harmful vapors, are easy to clean up, and can be discarded as regular trash. The design professional should consider requirements for disposal of the containers containing organic solvents. Many jurisdictions are enacting clean air statutes that, among other things, target organic solvents as air pollutants. Organic solvents also can have adverse effects on the workers who apply them, as well as on future building occupants. One drawback to most water-based adhesives, however, is that they tend only to resist water, whereas the solvent-based adhesives are waterproof.

CONSTRUCTION ADHESIVES

Construction adhesives are defined as elastomer-based extrudable mastics, which means that the main adhesive component is elastic and will continue to maintain some of its flexibility indefinitely.

Contributors:
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland;
Architectural Woodwork Institute, Potomac Falls, Virginia.

Mastics are a type of adhesive with high viscosity, or resistance to flow. A construction adhesive is a substance capable of holding materials together by surface attachment.

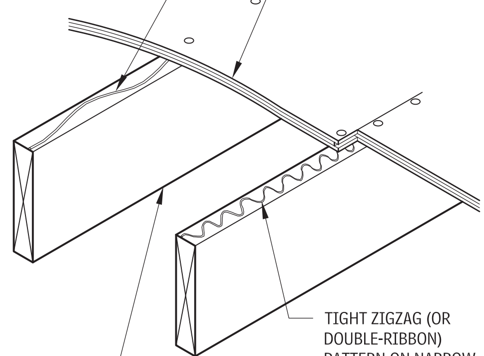
Adhesives used for building have been formulated to tolerate many of the often-adverse conditions that exist at most job sites, such as extreme temperatures and temperature fluctuations. They are excellent for filling gaps, and thus work on both smooth and rough surfaces. The degree of adhesion depends on the surface conditions of the materials; ice, dirt, grease, or other contaminants will all have a negative effect.

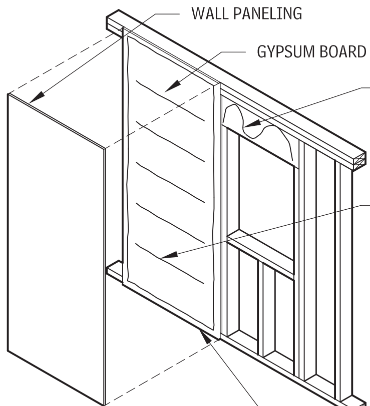
Many of the characteristics of modern adhesives are described in Figure 8.48. Note that most adhere to wood, but performance depends on careful consideration of the physical and chemical compatibility of glue and wood, processing requirements, mechanical properties, and durability under design conditions.

ADHESIVE SUMMARY[a]
8.48

CLASS	FORM	PROPERTIES	TYPICAL USES
Urea resin	Dry powders or liquids; may be blended with melamine or other resins	High strength under both wet and dry conditions; moderately durable under damp conditions; moderate to low resistance to temperatures above 120°F; white or tan color	Hardwood plywood for interior use and furniture; interior particleboard; flush doors; furniture core stock
Phenol resin[a]	Dry powders or liquids	High strength under both wet and dry conditions; very resistant to moisture and damp conditions; dark red in color	Primary adhesive for exterior softwood plywood and flakeboard
Resorcinol resin and phenol-resorcinol resins	Liquid; hardener supplied separately	High strength under both wet and dry conditions; very resistant to moisture and damp conditions; dark red color	Primary adhesive for laminated timbers and assembly joints, to withstand severe service conditions
Polyvinyl acetate resin emulsions	Liquid; ready to use	Generally high strength in dry conditions; low resistance to moisture and elevated temperatures; joints tend to yield under continued stress; white or yellow color	Furniture assembly, flush doors, bonding of plastic laminates, architectural woodworking
Cross-linkable polyvinyl acetate resin emulsions	Similar to polyvinyl acetate resin emulsions but includes a resin capable of forming linkage	Improved resistance to moisture and elevated temperatures; improved long-term performance in moist or wet environment; color varies	Interior and exterior doors, molding and architectural woodworking
Contact adhesives	Typically an elastomer base in organic solvents or water emulsion	Initial joint strength develops immediately upon pressing, increases slowly over a period of weeks; dry strength generally lower than those of conventional woodworking glues; water resistance and resistance to severe conditions variable; color varies	For some nonstructural bonds; high-pressure decorative laminates to substrates; useful for low-strength metal and some plastic bonding
Mastics (elastomeric construction adhesives)	Puttylike consistency; synthetic or natural elastomer base, usually in organic solvents	Gap filling; develops strength slowly over several weeks; water resistance and resistance for severe conditions vary; color varies	Lumber and plywood to joists and studs; gypsum board; styrene and urethane foams
Thermoplastic synthetic resins (hot melts)	Solid chunks, pellets, ribbons, rods, or films; solvent-free	Rapid bonding; gap filling; lower strength than conventional woodworking adhesives; minimal penetration; moisture resistant; white to tan color	Edge banding of panels; films and paper overlays
Epoxy resins	Chemical polymers, usually in two parts, both liquid; completely reactive; no solvents	Good adhesion to metals, glass, certain plastics, and wood products; permanence in wood joints not adequately established; gap-filling	Used in combination with other resins for bonding metals, plastics, and materials other than wood; fabrication of cold-molded wood panels
Protein glues (casein and hide)	Dry powders or reconstituted liquid	Bonds extremely well to wood; moisture resistant	Interior applications; laminating beam

RECOMMENDED ADHESIVE BEAD PATTERNS
8.49





NOTES

8.48 a. Most types of resin used in the United States are alkaline-catalyzed. The general statements refer to this type.
Data adapted from *Architectural Woodwork Quality Standards*.
8.49 Adhesive is applied to one surface only.

Contributor:
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland.

NAILS

GENERAL

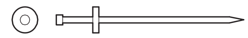
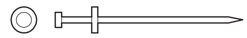
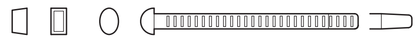
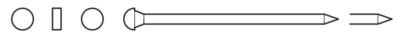
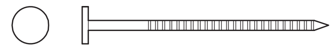
Nails are made of many types of metal for diverse uses. When selecting nails, follow the recommendations of the manufacturer of the material to be fastened, as well as applicable building codes. General guidelines include:

- Select nails so as to avoid galvanic action between the nail and the nailed material.
- Select nail head size according to the strength and area of the material to be held.
- In wood framing use the correct size and number of nails to withstand stress. Procedures for calculating nailed connections can be found in the *National Design Specifications for Wood Construction*.
- Base nail selection on the type(s) of wood or other materials to be assembled, joined, or connected.
- Be aware that nails with serrated or helically threaded shanks have increased holding power, but such nails are difficult to remove without destroying the surrounding material.
- Where nails are exposed to moisture or weather—for example, in exterior stucco lath—use nonferrous (aluminum) or zinc-coated nails.
- Choose nails for automatic nailing equipment specifically for the equipment used. See ANSI's "Safety Requirements for Power-Actuated Fastening Systems," and OSHA regulations.

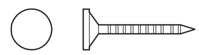
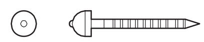
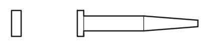
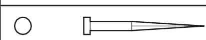
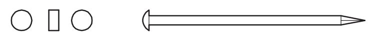
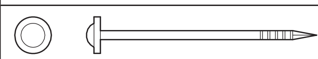
COMMON NAIL SIZES
8.50

LENGTH	PENNY (D)	GAUGE	DIAMETER OF HEAD (IN.)	NAILS/LB
1	2	15	11/64	847
1–1/4	3	14	13/64	543
1–1/2	4	12–1/2	1/4	296
1–3/4	5	12–1/2	1/4	254
2	6	11–1/2	17/64	167
2–1/4	7	11–1/2	17/64	150
2–1/2	8	10–1/4	9/32	101
2–3/4	9	10–1/4	9/32	92.1
3	10	9	5/16	66
3–1/4	12	9	5/16	66.1
3–1/2	16	8	11/32	47.4
4	20	6	13/32	29.7
4–1/2	30	5	7/16	22.7
5	40	4	15/32	17.3
5–1/2	50	3	1/2	13.5
6	60	2	17/32	10.7

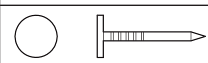
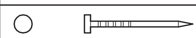
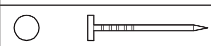
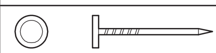
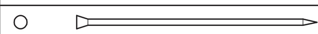
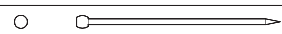
NAILS FOR ROUGH CARPENTRY
8.51

NAME	SHAPE	MATERIAL	FINISH
Common		Steel or aluminum	Smooth
Annular		Steel, hardened steel, copper, brass, bronze, silicon bronze, nickel silver, aluminum, monel, or stainless steel	Bright, hardened
Helical		Steel, hardened steel, copper, brass, bronze, silicon bronze, nickel silver, aluminum, monel, or stainless steel	Bright, hardened
Common Cut Strike		Steel or iron	Bright or zinc-coated
Double-Headed		Steel	Bright or zinc-coated
		Aluminum	Bright
Square		Steel	Smooth, bright, zinc-coated
Round Wire		Steel	Smooth, bright, zinc-coated
Annular		Aluminum	Bright or hard

ROOFING NAILS
8.52

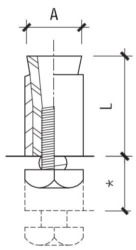
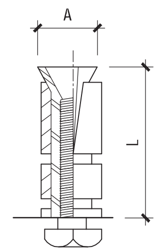
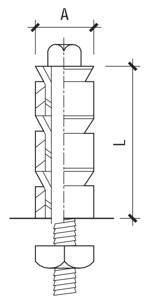
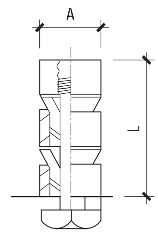
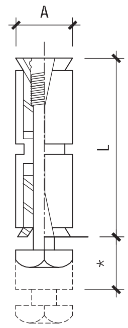
NAME	SHAPE	MATERIAL	FINISH
Siding and Shingle		Steel, copper, or aluminum	Smooth, bright, zinc- or cement-coated
Roofing (Barbed)		Steel or aluminum	Smooth, bright, zinc- or cement-coated
Roofing		Steel	Bright or zinc-coated
Nonleaking		Steel	Bright or zinc-coated
Shingle Nail		Steel or cut iron	Plain or zinc-coated
Cut Slating (Nonferrous)		Copper, muntz metal, or zinc	Plain or zinc-coated
Gutter Spike (Round)		Steel	Bright or zinc-coated
Gutter Spike (Annular)		Copper	Bright

NAILS FOR FINISH WORK
8.53

NAME	SHAPE	MATERIAL	FINISH
Wallboard		Steel or aluminum	Smooth, bright, blued, or cement-coated
Fine Nail		Steel	Bright
Lath		Steel	Blued or cement-coated
Lath		Steel or aluminum	Smooth, bright, blued, or cement-coated
Casing or Brad		Steel or aluminum	Bright or cement-coated
Finishing		Steel	Smooth

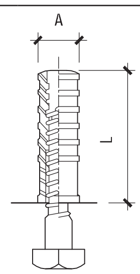
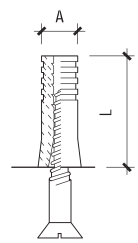
SHIELDS AND ANCHORS

MACHINE BOLT ANCHORS AND SHIELDS (IN.)
8.54

														
NOMINAL SIZE OR BASIC DIAMETER	THREADS PER INCH	DECIMAL EQUIVALENT	SINGLE EXPANDING ANCHOR (CAULKING)		SINGLE EXPANDING ANCHOR (NONCAULKING)		MULTIPLE EXPANDING ANCHOR (PLAIN STYLE)			MULTIPLE EXPANDING ANCHOR (THREADED STYLE)			DOUBLE-ACTING SHIELD	
								L UNITS			L UNITS			
			A	L	A	L	A	2	3	A	2	3	A	L
6	32	.138	5/16	1/2										
8	32	.164	5/16	1/2										
10	24	.190	3/8	5/8										
12	24	.216	1/2	7/8										
1/4"	20	.250	1/2	7/8	1/2	1–3/8	1/2	1–1/8		1/2	1		1/2	1–1/4
5/16"	18	.312	5/8	1	5/8	1–5/8							5/8	1–1/2
3/8"	16	.375	3/4	1–1/4	5/8	1–5/8	3/4	1–1/2		3/4	1–1/2		3/4	1–3/4
1/2"	13	.500	7/8	1–1/2	7/8	2–1/2	1	1–3/4	2–3/8	1	1–3/4	2–1/4	7/8	2–1/4
5/8"	11	.625	1–1/8	2	1	2–3/4	1–1/8	*	2–5/8	1–1/8	*	2–1/2	1	2–1/2
3/4"	10	.750	1–1/4	2–1/4	1–1/4	2–7/8	1–3/8	*	3	1–3/8	*	3–1/8	1–1/4	3–1/2
7/8"	9	.875					1–1/2	*	3–1/2	1–1/2	*	3 5/8	1–5/8	4
1"	8	1.00					1–5/8	*	3–7/8	1–5/8	*	3–3/4	1–3/4	4–1/4

*Use of three units in these diameters is recommended.

SHIELDS FOR LAG BOLTS AND WOOD SCREWS (IN.)
8.55

							
			LAG BOLT EXPANSION SHIELD			LEAD SHIELD FOR LAG BOLT OR WOOD SCREW	
				L			
LAG SCREW DIAMETER	WOOD SCREW SIZES	DECIMAL EQUIVALENT	A	SHORT	LONG	A	L
	6	.138				1/4	3/4 to 1–1/2
	8	.164				1/4	3/4 to 1–1/2
	10	.190				5/16	1 to 1–1/2
	12	.216				5/16	1 to 1–1/2
1/4	14	.250	1/2	1	1–1/2	5/16	1 to 1–1/2
	16	.268				3/8	1–1/2
	18	.294				3/8	1–1/2
5/16	20	.320	1/2	1–1/4	1–3/4	7/16	1–3/4
3/8	24	.372	5/8	1–3/4	2–1/2	7/16	1–3/4
1/2		.500	3/4	2	3		
5/8		.625	7/8	2	3–1/2		
3/4		.750	1	2	3–1/2		

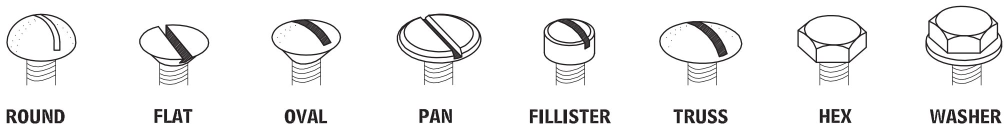
NOTE

8.54 Extension sleeve may be used for deep setting.
Expansion shields and anchors shown are representative of many types, some of which may be used in single or multiple units.
Many are threaded for use with the head of the screw outside, some with the head inside, and some types require setting tools to install.

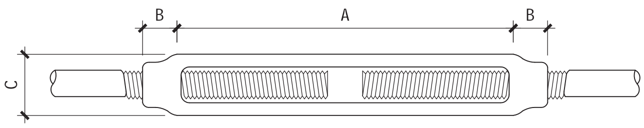
SCREW AND BOLT LENGTHS (IN.)
8.56

DIAMETER	CAP SCREWS				BOLTS		
	BUTTON HEAD	FLAT HEAD	HEXAGON HEAD	FILLISTER HEAD	MACHINE BOLT	CARRIAGE BOLT	LAG BOLT
1/4	1/2 to 2-1/4		1/2 to 3–1/2	3/4 to 3	1/2 to 8	3/4 to 8	1 to 6
5/16	1/2 to 2-3/4		1/2 to 3–1/2	3/4 to 3–3/4	1/2 to 8	3/4 to 8	1 to 10
3/8	5/8 to 3		1/2 to 4	3/4 to 3–1/2	3/4 to 12	3/4 to 12	1 to 12
7/16	3/4 to 3		3/4 to 4	3/4 to 3–3/4	3/4 to 12	1 to 12	1 to 12
1/2	3/4 to 4		3/4 to 4–1/2	3/4 to 4	3/4 to 24	1 to 20	1 to 12
9/16	1 to 4		1 to 4–1/2	1 to 4	1 to 30	1 to 20	
5/8	1 to 4		1 to 5	1–1/4 to 4 1/2	1 to 30	1 to 20	1–1/2 to 16
3/4	1 to 4		1–1/4 to 5	1–1/2 to 4–1/2	1 to 30	1 to 20	1–1/2 to 16
7/8			2 to 6	1–3/4 to 5	1–1/2 to 30		2 to 16
1			2 to 6	2 to 5	1–1/2 to 30		2 to 16
Length intervals = 1/8-in. increments up to 1 in.; 1/4-in. increments from 1–1/4 in. to 4 in.; 1/2-in. increments from 4–1/2 in. to 6 in.					Length intervals = 1/4-in. increments up to 6 in.; 1/2-in. increments from 6–1/2 in. to 12 in.; 1-in. increments over 12 in.		Length intervals = 1/2-in. increments up to 8 in.; 1-in. increments over 8 in.

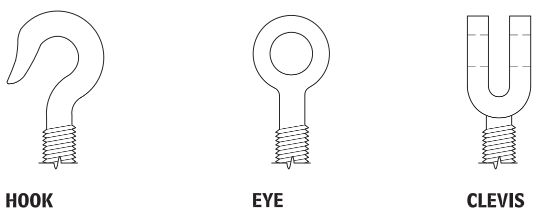
HEAD TYPES
8.57



TURNBUCKLES (IN.)
8.58

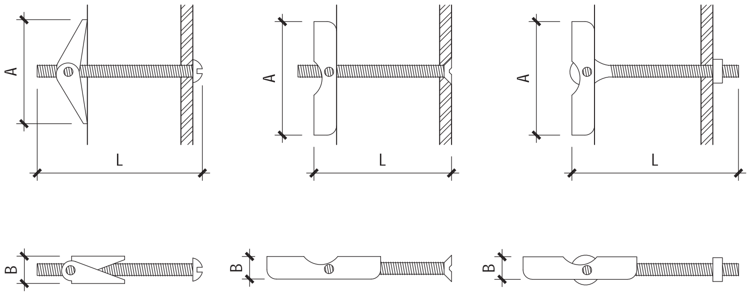


TURNBUCKLE WITH STUB ENDS



DIAMETER	1/4	5/16	3/8	1/2	5/8	3/4	7/8	1
DECIMAL EQUIVALENT	.250	.313	.375	.500	.625	.750	.875	1.00
A	4	4–1/2	6	6	6"	6	6	6
				9	9	9		
				12	12	12	12	12
B	7/16	1/2	9/16	3/4	29/32	1–1/16	1–7/32	1–3/8
C	3/4	7/8	31/32	1–7/32	1–1/2	1–23/32	1–7/8	2–1/32

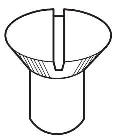
TOGGLE BOLTS (IN.)
8.59



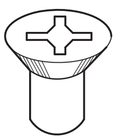
SPRING WING **TUMBLE** **RIVETED TUMBLE**

DIAMETER		1/8	5/32	3/16	1/4	5/16	3/8	1/2
DECIMAL EQUIVALENT		.138	.164	.190	.250	.313	.375	.50
SPRING WING	A	1.438	1.875	1.875	2.063	2.750	2.875	4.625
	B	.375	.500	.500	.688	.875	1.000	1.250
	L	2 to 4	2–1/2 to 4	2 to 6	2–1/2 to 6	3 to 6	3 to 6	4 to 6
TUMBLE	A	1.250	2.000	2.000	2.250	2.750	2.750	
	B	.375	.500	.500	.688	.875	.875	
	L	2 to 4	2–1/2 to 4	3 to 6	3 to 6	3 to 6	3 to 6	
RIVETED TUMBLE	A		2.000	2.000	2.250	2.750	2.750	3.375
	B		.375	.375	.500	.625	.688	.875
	L		2–1/2 to 4	3 to 6	3 to 6	3 to 6	3 to 6	3 to 6

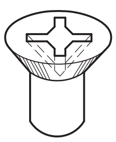
WOOD SCREWS (IN.)
8.60



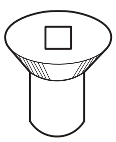
SLOTTED



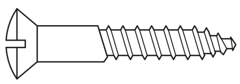
PHILLIPS



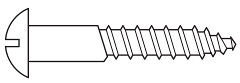
FREARSON



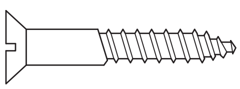
ROBERTSON



OVAL HEAD



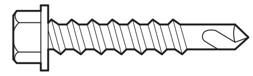
ROUND HEAD



FLAT HEAD

WOOD SCREW SIZES	DECIMAL EQUIVALENT	LENGTH
0	.060	1/4 to 3/8
1	.073	1/4 to 1/2
2	.086	1/4 to 3/4
3	.099	1/4 to 1
4	.112	1/4 to 1–1/2
5	.125	3/8 to 1–1/2
6	.138	3/8 to 2–1/2
7	.151	3/8 to 2–1/2
8	.164	3/8 to 3
9	.177	1/2 to 3
10	.190	1/2 to 3–1/2
11	.203	5/8 to 3–1/2
12	.216	5/8 to 4
14	.242	3/4 to 5
16	.268	1 to 5
18	.294	1–1/4 to 5
20	.320	1–1/2 to 5
24	.372	3 to 5

SELF-DRILLING FASTENERS
8.61



Self-drilling fasteners are used to attach metal to metal, wood, and concrete. Consult manufacturer for sizes and drilling capabilities.

Contributor:
Timothy B. McDonald; Washington, DC.

GLASS

9

COMMON CHARACTERISTICS, STANDARDS, AND PRACTICES

GLASS PRODUCTS

Glass is a hard, brittle, amorphous substance made by melting silica (sometimes combined with oxides of boron or phosphorus) with certain basic oxides (notably sodium, potassium, calcium, magnesium, and lead) to produce annealed flat glass by a controlled cooling process. Most glasses soften at 932°F to 2012°F (500°C to 1100°C). The brittleness of glass is such that minute surface scratches in manufacturing greatly reduce its strength.

INDUSTRY-QUALITY STANDARDS

A number of industry-quality standards apply to glass products:

- Glazing Association of North America (GANA) Glazing Manual
- ASTM Standard C1036, "Specification for Flat Glass"
- ASTM Standard C1048, "Specification for Heat-Treated Flat Glass—Kind HS, Kind FT Coated and Uncoated"
- UL Standard 752, "Bullet-Resisting Equipment"
- UL Standard 752, "Bullet-Resisting Glazing Material"
- AAMA Curtain Wall and Storefront Publications: Glass and Glazing
- ASTM Standard E1300, "Practice for Determining Load Resistance of Glass in Buildings"
- CPSC Standard 16CFR 1201, "Safety Standard for Architectural Glazing Materials"
- ANSI Z97.1: Safety Glazing Materials Used in Buildings—Safety Performance Specification and Methods of Test
- ASTM C1172, "Specification for Laminated Architectural Flat Glass"

More information can also be found in these two books: *Glass in Building*, by David Button and Brian Pye (Pilkington, with Butterworth Architecture, 1993); and *Glass in Architecture*, by Michael Wiggington (Phaidon Press Ltd., 1996). Also, be sure to consult glass manufacturers for current information because processes, qualities, finishes, colors, sizes, thicknesses, and limitations are continually revised. The information presented here represents one or more manufacturers' guidelines.

BASIC TYPES OF CLEAR GLASS

The following are basic types of clear glass:

- *Sheet glass:* Sheet glass is manufactured by a horizontal flat or vertical draw process, and then annealed slowly to produce a natural flat-fired, high-gloss surface. It generally is used in residential and industrial applications. Because it is not mechanically polished, inherent surface waves are noticeable in sizes larger than 4 sq. ft. For minimum distortion, larger sizes are installed with the wave running horizontally. The width is listed first when specifying. For architectural applications, sheet glass is either single-strength (0.101 in. thick) or double-strength (0.134 in. thick). Very little glass is produced in the United States by this process; almost all sheet glass is produced by the float process.
- *Float glass:* Generally accepted as the successor to polished plate glass, float glass has become the quality standard of the glass industry. It is manufactured by floating molten glass on a surface of molten tin, then annealing it slowly to produce a transparent flat glass, thus eliminating grinding and polishing. This process produces a glass with very uniform thickness and flatness, making it suitable for applications requiring excellent optical properties, such as architectural windows, mirrors, and specialty applications. It is available in thicknesses ranging from 1/8 to 7/8 in. Float glass is made to the specification requirements of ASTM C1036, and its minimum thickness to resist wind load is established using ASTM E1300.
- *Plate glass:* Transparent flat glass is ground and polished after rolling to make plate glass. Cylindrical and conical shapes can be bent to a desired curvature (within limits). Only glass for specialty applications is produced by this method; it is not produced for widespread use in architectural applications.

VARIATIONS OF BASIC GLASS TYPES

Several variations of the basic glass types are in use today.

- *Patterned glass:* Patterned glass is known also as *rolled* or *figured glass*. It is made by passing molten glass through rollers that are etched to produce the design. Designs include flutes, ribs, grids, and other regular and random patterns, which provide translucency and a degree of obscurity. Usually, only one side of the glass is imprinted with a pattern. Patterned glass is available in thicknesses of 1/8, 3/16, and 7/32 in.
- *Wire glass:* Wire glass is available as clear polished glass or in various patterns such as square-welded mesh, diamond-welded mesh, and linear parallel wires. Some distortion, wire discoloration, and misalignment are inherent. Some 1/4-in. wired glass products are recognized as certified safety glazing materials for use in hazardous locations (e.g., fire-rated windows, doors, and skylights). For applicable fire and safety codes that govern their use, refer to ANSI Z97.1. Note that wire glass is no longer exempt from regulations for locations requiring safety glass (i.e., doors and sidelights). Therefore, it is better to avoid wire glass entirely. Consider using other laminated and specialty fire-rated and safety-rated products. If wire glass must be used, ensure that the submitted product complies with the indicated requirement for special wire glass that does comply with safety regulations. Verify application of patterned wire glass to avoid applications requiring safety glazing.
- *Obscure glass:* Obscure glass is used to obscure a view or create a design. The entire surface on one or both sides of the glass can be sandblasted, acid-etched, or both. When a glass surface is altered by any of these methods, the glass is weakened, and may be difficult to clean.

STRENGTHENED GLASS

Glass can be strengthened either by a controlled heating and cooling process, or by immersion in a chemical bath. Both processes have glass thickness, size, and use restrictions that should be verified.

HEAT-TREATED GLASS

Heat-strengthened (Kind HS) and tempered (Kind FT) glass are produced by reheating annealed float glass close to its softening point and then rapidly quenching (cooling) it with high-velocity blasts of air. Both types have greatly increased mechanical strength and resistance to thermal stresses. Before it is heat-treated, the glass must be fabricated to its exact size and shape (including any holes), because neither type of glass can be altered after heat treatment.

Most manufacturers heat-treat the glass using a horizontal process that can introduce warpage, kinks, and bowing into the finished product, which may create aesthetic or technical concerns. A vertical process may still be available that produces tong marks or depressions into the glass surface near the suspended edge. Vertical processing may produce large amounts of warping and distortion. The heat treatment quenching pattern on the surface of the glass can become visible as a pattern of light and dark areas at certain oblique viewing angles and with polarized light. This effect can be more pronounced with thicker glass and may be an aesthetic consideration. Refer to ASTM C1048 for allowable tolerances and other properties.

Heat-strengthened glass is generally two to three times stronger than annealed glass. It cannot be cut, drilled, or altered after fabrication. Unlike tempered glass, it breaks into large, sharp shards similar to broken annealed glass. Heat-strengthened glass is not acceptable for safety glazing applications.

TEMPERED GLASS

Tempered glass is generally four to five times stronger than annealed glass. It breaks into innumerable small, cube-shaped fragments. It cannot be cut, drilled, or altered after fabrication; the precise size required and any special features (such as notches, holes, edge treatments, and so on) must be specified when ordering.

Tempered glass can be used as a safety glazing material provided it complies with the ANSI and CPSC references listed in the "Laminated Glass" section, below. Tempered glass can be used in insulating and laminated assemblies and in wired, patterned, and coated processes. All float and sheet glass 1/8 in. or thicker may be tempered.

ULTRACLEAR GLASS

The high clarity and high visible light transmittance that characterize ultraclear glass come from the special soda lime mixture it is made from, which minimizes the iron content that normally gives a slight greenish color to clear flat glass. Ultraclear glass is generally available in thicknesses from 1/8 to 3/4 in. It can be heat-strengthened, tempered, sandblasted, etched, or assembled into laminated glass. Ultraclear glass is used for commercial display cases, museum cases, display windows, frit-coated spandrel glass, aquariums, mirrors, shelving, security glass, and other uses in which clarity and better color transmittance are required.

HEAT-ABSORBING OR TINTED GLASS

This type of float glass was developed to help control solar heat and glare in large areas of glass. It is available in blue, bronze, gray, or green, and in thicknesses ranging from 1/8 to 1/2 in. The glass absorbs a portion of the sun's energy because of its admixture contents and thickness; it then dissipates the heat to both the exterior and interior. The exterior glass surface rejects some heat, depending on the sun's position. Heat-absorbing glass has a higher temperature than clear glass when exposed to the sun; thus, the central area expands more than the cooler, shaded edges, causing edge tensile stress buildup. When designing heat-absorbing or tinted glass windows, consider the following:

- To minimize shading problems and tensile stress buildup at the edges, provide conditions in which glass edges warm as rapidly as the exposed glass.
- The thicker the glass, the greater the solar energy absorption.
- Indoor shading devices such as blinds and draperies reflect energy back through the glass, thus increasing the temperature of the glass. Spaces between indoor shading devices and the glass, including ceiling pockets, should be vented adequately. Heating elements always should be located on the interior side of shading devices, directing warm air away from the glass.
- The glass can be heat-treated to increase its strength and resistance to edge tensile stress buildup.

INSULATING GLASS

Insulated glass is constructed from two or more panes of glass separated by spacer bars to form a hermetically sealed void between the panes. This arrangement greatly enhances the insulating, thermal, and acoustic properties of the glass unit. The most common insulated units are filled with air, and employ a hollow spacer bar containing a desiccant to absorb moisture vapor inside the unit. The void can be filled with an inert gas such as argon, and the spacer can be changed to a "warm edge" type to further improve the insulating value of the unit. The spacer bar is sealed to the glass with a continuous joint sealant (typically, butyl or silicone) forming an airtight seal. Structural joint sealant, usually silicone or polyurethane, is applied outboard of the spacer bar to hold the panes of glass together, especially during transport and handling. For coastal environments, in structural silicone glazing systems and when otherwise recommended by the manufacturer, the architect may limit both sealants to the silicone type. By varying the makeup of the individual panes of glass in the insulating unit, its insulating, shading, and visual characteristics can be greatly enhanced.

Durability for insulating glass is established through ASTM E 774, "Standard Specification for the Durability of Sealed Insulated Glass Units," for Class C, CB, or CBA. Class CBA is the most durable and is typically selected for most commercial and institutional work.

SOUND CONTROL GLASS

Laminated, insulating, laminated insulating, and double-laminated insulating glass products commonly are used for sound control. STC ratings from 31 to 51 are available, depending on glass thicknesses, airspace size, polyvinyl butyral film thickness, and the number of laminated units used in insulating products.

SPANDREL GLASS

Spandrel glass is an opaque glass and available tinted or with a variety of coatings, including reflective, ceramic frit (patterned and solid colors), and direct-to-glass polyvinylidene fluoride (PVDF) coatings. It can be heat-treated or laminated, and is available as insulating glass units. Insulation and vapor retarders can be added to spandrel glass. Consult with spandrel glass manufacturers for guidelines.

SECURITY GLASS

Security glass is composed of multiple layers of glass and/or polycarbonate plastic that are laminated together under heat and pressure with a polyvinyl butyral (for glass) or polyurethane plastic (for polycarbonate) film. It is available in multilayer laminated glass, insulating, laminated insulating, and double-laminated insulating or spaced configurations, generally in thicknesses from 3/8 in. to 2–1/2 in. as a laminated product and up to about 4–3/4 in. for insulating and spaced construction products. Bullet-resistant glass should be tested to UL 752, and burglar-resistant to UL 972. Consult manufacturers for blast-resistant glass. Security glass products, depending on type, are subject to size limitations, and some are not recommended for exterior applications. Consult with the manufacturer for glazing requirements and restrictions on use.

COATED GLASS

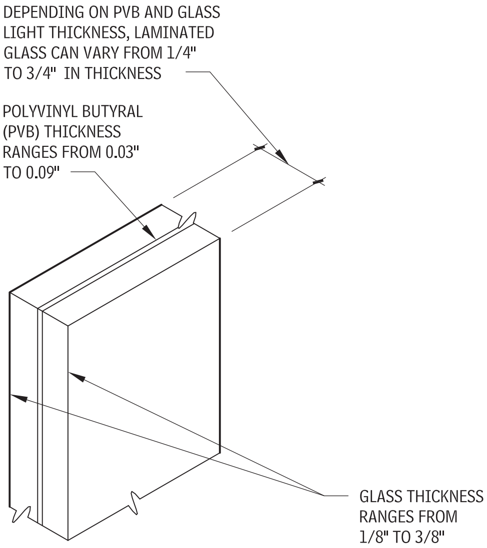
A reflective or low-emissivity coating can be applied to the surface of monolithic glass. Generally, only pyrolitically applied "hard" coatings (which have scratch resistance) are used on exposed glass surfaces. During glass manufacture, pyrolitic coatings are sprayed onto the glass before it cools, which integrates them with the glass surface. Magnetically sputtered or "soft" coatings can also be applied to the glass surface, but they must be protected from the elements as part of an insulating or laminated glass product. The range of coating types, aesthetic appearances, and thermal performance available for pyrolitic coatings is generally less than for sputtered coatings.

LAMINATED GLASS

To produce laminated glass, a tough, clear plastic polyvinyl butyral (PVB) sheet (interlayered), ranging in thickness from 0.03 to 0.09 in., is sandwiched, under heat and pressure, between lights of sheet, plate, float, wired, heat-absorbing, tinted, reflective, low-emissivity, or heat-treated glass, or combinations of each. When laminated glass breaks, the particles tend to adhere to the plastic film.

Laminated glass is manufactured to the specification requirements of ASTM C1172. Laminated safety glass should be manufactured to comply with ANSI Z97.1 and CPSC 16CFR 1201.

LAMINATED GLASS PROFILE
9.1



BENT GLASS

Clear, tinted, ceramic frit-coated spandrel, pyrolitically coated, patterned, laminated, and wire glass are among glass types that can be bent in thicknesses to about 1 in. and to a minimum radius of about 4 in. Sharp angle bends to 90°, edgework, pattern cutting, and tempering (meeting safety glazing standards), and heat-strengthening are also available. Bent glass can be fabricated into insulating glass units. Bent glass tolerances must be compatible with the glazing system. Size, configuration, and product availability vary by fabricator.

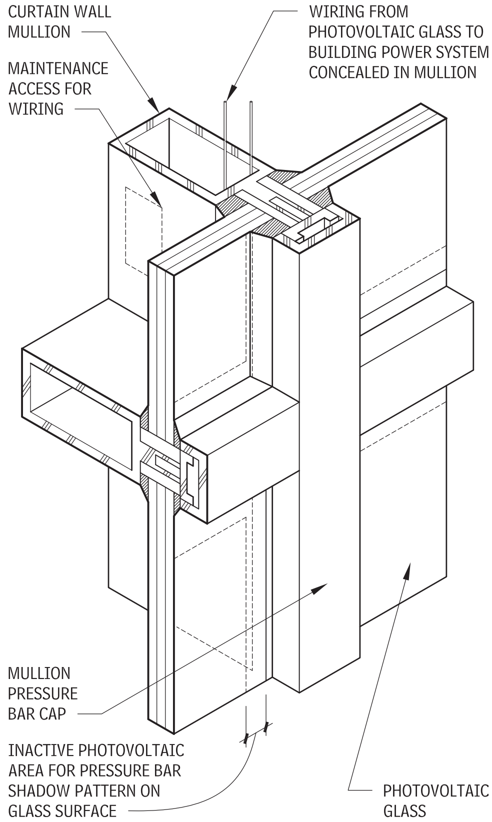
STRUCTURAL GLASS

Structural glass facades are as much about the expression of elegant and minimalist structural systems as they are about facade transparency. The use of tensile elements in the form of steel cables and rods is a primary design strategy to dematerialize the structure and enhance the transparency of a facade design. Compression elements are frequently minimized or eliminated, and where present are crafted from cast and machined components in an elegant expression of exposed structure.

PHOTOVOLTAIC GLASS

There are two types of photovoltaic (PV) glass: crystalline silicon (sandwiched between two lights of glass) and thin-film amorphous silicon (applied to an interior-facing glass surface). When these arrangements are exposed to sunlight, they generate either DC or AC power, which is transferred by concealed wiring to the building's power system. Pressure bar or structural silicone flush-glazed curtain walls and skylights, awnings, sunshades, light shelves, and roof panels are some of the systems that can incorporate PV glass. For curtain walls and skylights, the pressure bar type allows easy concealment of the wiring. Shadow patterns from the cap on the PV glass surface must be considered in system design. Flush-glazed systems have no shadow patterns, but wiring concealment is more difficult and the PV module on the glass must be kept from reacting with the structural silicone sealant. Both types of PV glass are used for opaque curtain-wall spandrel panels and can be used for curtain-wall or skylight vision glass if the quality of daylighting and visibility is acceptable. Consult PV glass and metal-framing system manufacturers to determine availability, suitability, and cost for a particular application.

PHOTOVOLTAIC GLASS (IN A PRESSURE BAR FRAMING SYSTEM)
9.2



DECORATIVE SILK-SCREENED (OR FRIT) GLASS

Annealed clear or tinted glass is washed and ceramic frit paint (in standard or custom color) silk-screened on its surface in a standard or custom pattern or design (such as dots, holes, lines, or a logo) and then dried in an oven. The frit-coated glass is then subjected to very high temperatures in a tempering furnace to fire the ceramic frit permanently to the glass surface. As a result, silk-screened glass will be either heat-strengthened or tempered after firing. Reflective and low-emissivity coatings can also be applied to the glass surface. Silk-screened glass can be used monolithically or for insulating or laminated glass products.

OUTSIDE PROTECTION GLASS

Properly made decorative glass does not necessarily need additional glazing to make it waterproof, but it is valuable for insulating purposes and to afford some protection from external damage. Frames should be designed with a 3/4-in. ventilated space between glass, and should be arranged for the protection glass to be installed from the exterior, and the decorative glass from the interior. Clear glass or textured glass 3/16 to 1/4 in. thick is most successful.

GLAZING SEALANTS

Exterior decorative glass must be pressed into a deep back bed of mastic compound or glazing tape. When outside protection glass is used, a watertight seal is not required, and foam tape compressed between the glazing bead and glass may suffice.

Contributors:
Thomas F. O'Connor, AIA, FASTM, Smith, Hinchman & Grylls, Detroit, Michigan; Randall S. Lindstrom, AIA, Ware Associates, Inc., Chicago, Illinois; Joseph A. Wilkes, FAIA, Annapolis, Maryland; Bobbie Burnett Studio, Annapolis, Maryland; Cline McGee, AIA, Charlotte, NC.

AVERAGE PERFORMANCE VALUES OF 1/4-IN. UNCOATED GLASS
9.3

	PERCENT TRANSMITTANCE				
GLASS TYPE	AVERAGE DAYLIGHT	TOTAL SOLAR	ULTRAVIOLET	PERCENT REFLECTANCE AVERAGE DAYLIGHT	SHADING COEFFICIENT
Ultraclear	91	89	85	8	1.04
Clear	89–88	78–76	71–62	9–8	0.95–0.94
Clear Laminated	86–84	67–64	<1	8–7	0.86–0.83
Green	77–75	47–42	42–30	8–7	0.70–0.67
Blue-Green	75–71	49–35	32–28	7	0.72–0.60
Blue	55	47	41	6	0.70
Bronze	55–51	51–48	31–23	6	0.74–0.71
Gray	46–43	49–42	32–25	6–5	0.72–0.66

SIZE LIMITATIONS

Decorative glass panels should not exceed 12 sq. ft., making it necessary to divide larger openings with metal division bars: tee bars for single glazed windows, and special channel bars for windows with outside protection glass.

GLASS COLORS

Machine-made and blown glass from the United States, England, France, and Germany are available in most solid colors, as well as mixed colors and textures. Uniformity of color will vary from glass of different batches. Special colors are derived by "sumping," or kiln firing.

FACETED STAINED GLASS

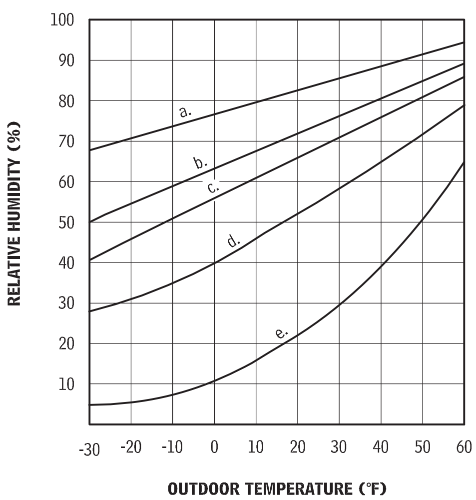
A twentieth-century development in the art of stained glass introduced the use of glass dalles, 8 by 12 by 1 in., cast in hundreds of different colors. These can be cut to any shape and used in combination with an opaque matrix of epoxy resin or reinforced concrete 5/8 to 1 in. in thickness, to create translucent windows and walls of great beauty. Sizes are limited, and an outer protection glass is required.

Further information is available from the Stained Glass Association of America.

CONDENSATION POTENTIAL

Figure 9.4 shows the potential for condensation on glazing (at the center of the glass) at various outdoor temperatures and indoor relative humidity conditions. Condensation can occur at any point on or above the curves. (Note: All airspaces are 1/2 in.; all coatings are E = 0.10.)

CONDITIONS THAT LEAD TO CONDENSATION ON WINDOWS
9.4



For example, at 20°F (–7°C) outside, condensation will form on the inner surface of double glazing when the indoor relative humidity is 52 percent or higher. It will form at an indoor relative humidity of 70 percent or higher if a double-pane window with a low-E coating and argon fill is used.

THERMAL RESISTANCE VALUES OF GLAZING MATERIALS

The thermal conductivity of glass is relatively high (k = 7.5); and for single glazing, most of the thermal resistance is imposed at the indoor and outdoor surfaces. Indoors, approximately two-thirds of the heat flows by radiation to the room surfaces; only one-third flows by convection. This can be materially affected by the use of forced airflow from induction units, for example. The inner surface coefficient of heat transfer, h_i, can be substantially reduced by applying a low-emittance metallic film to the glass.

For glazing with airspaces, the U-value can be reduced to a marked degree by the use of low-emittance films. This process imparts a variable degree of reflectance to the glass, thereby reducing its shading coefficient.

Manufacturers' literature should be consulted for more details on this important subject. Also consult Chapter 27 of the 1981 ASHRAE *Handbook of Fundamentals*.

SOLAR GAIN THROUGH FENESTRATION SYSTEMS

Heat gains through sunlit fenestration constitute major sources of cooling load in summer. In winter, discomfort is often caused by excessive amounts of solar radiation entering through south-facing windows. By contrast, passive solar design depends largely on admission and storage of the radiant energy falling on south-facing and horizontal surfaces. Admission takes place both by transmission through glazing and by inward flow of absorbed energy. With or without the sun, heat flows through glazing, either inwardly or outwardly, whenever there is a temperature difference between the indoor and outdoor air. These heat flows may be calculated in the following manner.

The solar heat gain is estimated by a two-step process. The first step is to find, either from tabulated data or by calculation, the rate at which solar heat would be admitted under the designated conditions through a single square foot of double strength (1/8-in.) clear sheet glass. This quantity, called the solar heat gain factor (SHGF), is set by (a) the local latitude; (b) the date, hence the declination; (c) the time of day (solar time should be used); (d) the orientation of the window. Tabulated values of SHGF are given in the *ASHRAE Handbook of Fundamentals* (1981), Chapter 27, for latitudes from 0° (the equator) to 64° N by 8° increments and for orientations around the compass from N to NNW, by 22.5° increments. Selected values from the 40° table are given in an adjacent column.

Each individual fenestration system, consisting of glazing and shading devices, has a unique capability to admit solar heat. This property is evaluated in terms of its shading coefficient (SC), which is the ratio of the amount of solar heat admitted by the system under consideration to the solar heat gain factor for the same conditions. In equation form, this becomes:

$$\text{Solar heat gain (Btu/sq. ft. * hr)} = SC \times SHGF$$

Values of the shading coefficient also are given in the *ASHRAE Handbook of Fundamentals* (1981), Chapter 27, for the most widely used glazing materials alone and in combination with internal and external shading devices. Selected values for single and double glazing are given in Figure 9.6.

For combinations of glazing and shading devices, also refer to Chapter 27 of the *ASHRAE Handbook of Fundamentals*.

The heat flow caused by temperature difference is found by multiplying the U-value for the specified fenestration system by the area involved and by the applicable temperature difference:

$$Q = A \times [SC \times SHGF + U \times (t_0 - t_1)]$$

GLASS THERMAL RESISTANCE VALUES
9.5

MATERIAL AND DESCRIPTION	OVERALL HEAT TRANSMISSION COEFFICIENT (U)	SEASONS	RESISTANCE (R)
VERTICAL PANELS—EXTERIOR			
Flat Glass			
Single glass	1.10	Winter	0.91
	1.04	Summer	0.96
Insulating glass: two lights of glass, 3/16″ airspace	0.62	Winter	1.61
	0.65	Summer	1.54
1/4″ airspace	0.58	Winter	1.72
	0.61	Summer	1.64
1/2″ airspace	0.49	Winter	2.04
	0.56	Summer	1.79
Insulating glass: three lights of glass, 1/4″ airspace	0.39	Winter	2.56
	0.44	Summer	2.22
1/2″ airspace	0.31	Winter	3.23
	0.39	Summer	2.56
1/2″ airspace; low-emittance coating E = 0.20	0.32	Winter	3.13
	0.38	Summer	2.63
E = 0.40	0.38	Winter	2.63
	0.45	Summer	2.22
E = 0.60	0.43	Winter	2.33
	0.51	Summer	1.96
Storm windows: 1/4″ airspace	0.50	Winter	2.00
	0.50	Summer	2.00
Single Plastic Sheet:			
1/8″ thick (nominal)	1.06	Winter	0.94
	0.98	Summer	1.02
1/4″ thick (nominal)	0.96	Winter	1.04
	0.89	Summer	1.12
HORIZONTAL PANELS—EXTERIOR			
Flat glass: single glass	1.23	Winter	0.81
	0.83	Summer	1.20
Insulating glass: two lights of glass, 3/16″ airspace	0.70	Winter	1.43
	0.57	Summer	1.75
1/4″ airspace	0.65	Winter	1.54
	0.54	Summer	1.85
1/2″ airspace	0.59	Winter	1.69
	0.49	Summer	2.04

NOTES

9.4 a. Triple-glazed windows with two low-E coatings and argon gas fill.
b. Double-glazed windows with a low-E coating and argon gas fill.
c. Double-glazed windows with a low-E coating.
d. Double-glazed windows.
e. Single-glazed windows.
9.5 a. Resistances are representative values for dry materials and are intended as design (not specification) values for materials in normal use. Unless shown otherwise in descriptions of materials, all values are for 167°F mean temperature.
b. Includes paper backing and facing, if any. In cases where insulation forms a boundary (highly reflective or otherwise) of an airspace, refer to the appropriate table for the insulating value of the airspace. Some manufacturers of batt and blanket insulation mark their products with an R-value, but they can ensure only the quality of the material as shipped.
c. Average values only are given, as variations depend on density of the board and on the type, size, and depth of perforations.
d. Thicknesses supplied by different manufacturers may vary, depending on the particular material.
e. Values will vary if density varies from that listed.
f. Thermal resistance of metals is so low that in building constructions it is usually ignored. Values shown emphasize relatively easy flow of heat along or through metals so that they are usually heat leaks, inward or outward.
g. Spaces of uniform thickness are bounded by moderately smooth surfaces.
h. Values shown are not applicable to interior installations of materials listed.
i. Winter is heat flow up; summer is heat flow down, based on area of opening, not on total surface area. Derived from data from *ASHRAE Handbook of Fundamentals* (1977), Chapter 22.

Contributors:
Thomas F. O'Connor, AIA, FASTM, Smith, Hinchman & Grylls, Detroit, Michigan; John I. Yellott, PE, College of Architecture, Arizona State University, Tempe, Arizona.

SHADING COEFFICIENT FOR SELECTED GLAZING SYSTEMS
9.6

TYPE OF GLASS	SOLAR TRANSMISSION	SHADING COEFFICIENT
Clear		
1/8″	0.86	1.00
1/4″	0.78	0.94
Heat-absorbing		
1/8″	0.64	0.83
1/4″	0.46	0.69
Insulating glass: clear both lights		
1/8 + 1/8″	0.71	0.88
1/4 + 1/4″	0.61	0.81
Heat-absorbing out		
Clear in, 1/4″	0.36	0.55

SOLAR INTENSITY AND SOLAR HEAT GAIN FACTORS FOR 40°N LATITUDE
9.7

DATE	SOLAR TIME (A.M.)	DIRECT NORMAL (BTUH/SQ FT)	SOLAR HEAT GAIN FACTORS (BTUH/SQ FT)					SOLAR TIME (P.M.)
			N	E	S	W	HOR	
Jan 21	8	142	5	111	75	5	14	4
	10	274	16	124	213	16	96	2
	12	294	20	21	254	21	133	12
Feb 21	8	219	10	183	94	10	43	4
	10	294	21	143	203	21	143	2
	12	307	24	25	241	25	180	12
Mar 21	8	250	16	218	74	16	85	4
	10	297	25	153	171	25	186	2
	12	307	29	31	206	31	223	12
Apr 21	6	89	11	88	5	5	11	6
	8	252	22	224	41	21	123	4
	10	286	31	152	121	31	217	2
	12	293	34	36	154	36	252	12
May 21	6	144	36	141	10	10	31	6
	8	250	27	220	29	25	146	4
	10	277	34	148	83	34	234	2
	12	284	37	40	113	40	265	12
June 21	6	155	48	151	13	13	40	6
	8	246	30	216	29	27	153	4
	10	272	35	145	69	35	238	2
	12	279	38	41	95	41	267	12
Jul 21	6	138	37	137	11	11	32	6
	8	241	28	216	30	26	145	4
	10	269	35	146	81	35	231	2
	12	276	38	41	109	41	262	12
Aug 21	6	81	12	82	6	5	12	6
	8	237	24	216	41	23	122	4
	10	272	32	150	116	32	214	2
	12	280	35	38	149	38	247	12
Sep 21	8	230	17	205	71	17	82	4
	10	280	27	148	165	27	180	2
	12	290	30	32	200	32	215	12
Oct 21	8	204	11	173	89	11	43	4
	10	280	21	139	196	21	140	2
	12	294	25	27	234	27	177	12
Nov 21	8	136 8	5	108	72	5	14	4
	10	268	16	122	209	16	96	2
	12	28	20	21	250	21	132	12
Dec 21	8	89	3	67	50	3	6	4
	10	261	14	113	146	14	77	2
	12	285	18	19	253	19	113	12

The same equation is used for both summer and winter, with appropriate U-values, but in winter the conduction heat flow is usually outward because the outdoor air is colder than the indoor air.

As an example, find the total heat gain, in Btu/sq. ft. * hr, for 1000 sq. ft. of unshaded 1/4-in. heat-absorbing single glass, facing west, in Denver, Colorado (40°N latitude) at 4:00 P.M. solar time on October 21. Indoor air temperature is 70°F; outdoor air temperature is 40°F.

From Figure 9.12, for 4:00 P.M. on October 21, find the SHGF for west-facing fenestration on October 21 to be 173 Btu/sq. ft. * hr. For 1/4-in. heat-absorbing glass, SC = 0.69, and U for winter conditions is 1.10 Btu/sq. ft. * hr * °F.

$$Q = 1000 \times [0.69 \times 173 + 1.10 \times (40 - 70)]$$
$$= 1000 \times (119.4 - 33.0) = 86{,}400 \text{ Btu/hr}$$

Even though the outdoor air is 30° cooler than the indoor air, the net heat gain through the window in question would be equivalent to 7.2 tons of refrigeration.

For the same window area in summer, on August 21 at 4:00 P.M. solar time, SHGF = 216, and the air temperatures may be taken as 95°F outdoors and 78°F indoors. The total heat gain will be:

$$Q = 1000 \times [0.69 \times 216 + 1.04 \times (95 - 78)]$$
$$= 1000 \times (149.0 + 17.7) = 166{,}700 \text{ Btu/hr}$$
$$= 13.9 \text{ tons of refrigeration}$$

The cooling load can be reduced by selecting a fenestration system with a lower shading coefficient and U-value. Under the same conditions, a double-glazed window with two lights of 1/4-in. clear glass and a highly reflective translucent inner shading device would have U = 0.52 and SC = 0.37. The cooling load would then be reduced to 88,760 Btu/hr, or 7.4 tons of refrigeration.

SOL-AIR TEMPERATURE

When the opaque surfaces of a structure are struck by solar radiation, much of the energy is absorbed by the irradiated surface, raising its temperature and increasing the rate of heat flow into the roof or wall. The time lag between the onset of irradiation and the resulting rise in the indoor surface temperature depends on the thickness and mass per unit area of the building element and on the thermal conductivity, specific heat, and density of the materials. The time lag is negligible for an uninsulated metal roof, but it can be a matter of hours for a massive concrete or masonry wall.

Heat flow through sunlit opaque building elements is estimated by using the sol-air temperature, t_{sa}, defined as an imaginary outdoor temperature that, in the absence of sunshine, would give the same rate of heat flow as actually exists at the specified time under the combined influence of the incident solar radiation and the ambient air temperature.

$$t_{sa} = I \times \text{Abs.}/h_o$$

where I = solar irradiance (Btu/sq. ft. * hr)

Abs. = surface absorptance, dimensionless
h_o = outer surface coefficient (Btu/sq. ft. * hr * °F)

Surface absorptances range from as low as 0.30 for a white surface to 0.95 for a black built-up roof. Values of h_o range from the conventional 4.0 for summer with an assumed wind speed of 7.5 mph to a still air value of 3.0.

For example, find the rate of heat flow through a 1000 sq. ft. uninsulated black built-up roof, U = 0.3, under strong summer sunshine, I = 300 Btu/sq. ft. * hr, still air with 100°F outdoors, 78°F indoors. The sol-air temperature is found from:

$$t_{sa} = 300 \times (0.95/3.0) + 100 = 195°\text{F}$$

The rate of heat flow, neglecting the time lag, is:

$$Q = 1000 \times 0.3 \times (195 - 78) = 35{,}100 \text{ Btu/hr}$$

With no sunshine on the roof, the heat flow is

$$\text{heat flow} = 1000 \times 0.3 \times (100 - 78) = 6600 \text{ Btu/hr}$$

The effect of the solar radiation is thus to increase the heat flow rate by 88 percent. A more massive roof with a lower U-value would show considerably less effect of the incoming solar radiation.

ENERGY PERFORMANCE OF GLAZING ASSEMBLIES

The National Fenestration Rating Council (NFRC) has developed a fenestration energy rating system based on whole-product

Contributor:
John I. Yellott, PE, College of Architecture, Arizona State University, Tempe, Arizona.

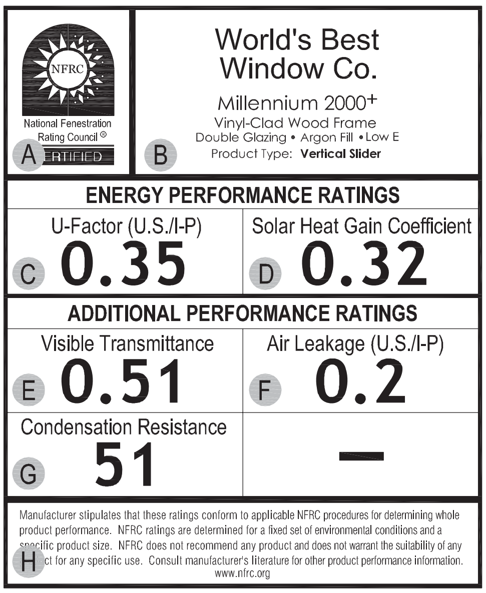
performance. The system accurately accounts for the energy-related effects of all of a product's component parts and prevents misleading comparisons of information about a single component with whole-product properties. At this time, NFRC labels on window units give ratings for U-value, solar heat gain coefficient, and visible light transmittance. Soon, labels will include air infiltration rates and an annual fenestration heating and cooling rating. The initial development of the NFRC rating system has focused on window units manufactured mainly for residential applications. In the future, the NFRC will adapt the rating system to commercial glazing and curtain wall systems.

Manufacturers of modern fenestration products want to take credit for the technological advances and increasing complexity of their products, but these are not easily visually verified. Thus, in 1989, the NFRC was established to develop a fair, accurate, and credible rating system for these products. State energy codes began to incorporate NFRC procedures in 1992, and the National Energy Policy Act provided for the development of a national rating system. The U.S. Department of Energy has certified the NFRC procedures as the national rating system, and they are now referenced in and being incorporated into the Model Energy Code and ASHRAE Standards 90.1 and 90.2.

Note that the total window U-factor takes into account the glass (edge of glass and center of glass) and the frame in a vertical position. Changing the mounting angle can affect the U-factor of a window.

NFRC ratings are determined for a fixed set of environmental conditions and specific product sizes and may not be appropriate for directly determining seasonal energy performance.

NFRC WINDOW PRODUCT IDENTIFICATION MARK 9.8



AAA WINDOW COMPANY			
Manufacturer stipulates that these ratings were determined in accordance with applicable NFRC procedures			
Energy Rating Factors	Ratings Residential		Product Description
U-factor	0.40	0.38	Model 1000 Casement Low-E = 0.2 0.5″ gap Argon-filled
Solar heat gain coefficient	0.65	0.66	
Visible light transmittance	0.71	0.71	
Air leakage	0.20	0.20	

PROPERTIES OF GLAZING MATERIALS USED IN MANUFACTURED WINDOW UNITS

Three things happen to solar radiation as it passes through a glazing material: some is transmitted, some is reflected, and the rest is absorbed. These three components determine many of the other energy-performance properties of a glazing material. Manipulating the proportion of transmittance, reflectance, and absorptance for different wavelengths of solar radiation has been the source of much recent innovation in window energy performance. The four basic properties of glazing that affect radiant energy transfer are transmittance, reflectance, absorptance, and emittance.

Before the recent innovations in the technology of glass, the primary property of glass was its capability to transmit visible light, and its quality was judged by how clear it was. However, as attention focused on improving the total energy performance of glass, it became clear that transparency to visible light is only part of the picture.

Visible light is a small portion of the electromagnetic spectrum. Beyond the blues and purples lie ultraviolet radiation and other higher-energy short wavelengths, from X-rays to gamma rays. Beyond red light are the near-infrared, given off by very hot objects, the far-infrared, given off by warm room-temperature objects, and the longer microwaves and radio waves.

Glazing types vary in their transparency to different parts of the spectrum. On the simplest level, a glass that appears to be tinted green as you look through it toward the outside will transmit more sunlight from the green portion of the visible spectrum and reflect/absorb more of the other colors. Similarly, bronze-tinted glass will absorb the blues and greens and transmit the warmer colors. Neutral gray tints absorb most colors equally.

This same principle applies outside the visible spectrum. Most glass is partially transparent to at least some ultraviolet radiation, whereas plastics are commonly more opaque to ultraviolet. Glass is opaque to far-infrared radiation but generally transparent to near-infrared.

With the recent advances in glazing technology, manufacturers can control how glazing materials behave in different areas of the spectrum. The basic properties of the substrate material (glass or plastic) can be altered, and coatings can be added to the surfaces of the substrates. For example, a window optimized for daylighting and for reducing solar heat gain should transmit adequate light in the visible portion of the spectrum but exclude unnecessary heat gain from the near-infrared part of the solar spectrum. On the other hand, a window optimized for collecting solar heat gain in winter should transmit the maximum amount of visible light as well as heat from the near-infrared wavelengths in the solar spectrum, while blocking the lower-energy radiant heat in the far-infrared range (an important heat-loss component). These are the strategies of spectrally selective and low-emittance coatings, respectively.

PERFORMANCE OF COMMON GLAZING TYPES

The graphics in Figure 9.10 illustrate the solar heat gain and visible light transmittance for common glazing types used in windows and curtain walls in commercial buildings. The graphics are for the center of the glass only; the characteristics of the frame must

CHARACTERISTICS OF SELECTED WINDOW TYPES 9.9

CHARACTERISTIC	EXAMPLE 1	EXAMPLE 2	EXAMPLE 3	EXAMPLE 4	EXAMPLE 5	EXAMPLE 6	EXAMPLE 7	EXAMPLE 8
General Glazing Description	Single-Glazed Clear	Double-Glazed Clear	Double-Glazed Bronze	Double-Glazed Clear	Double-Glazed Low-E	Double-Glazed Spectrally Selective	Triple-Glazed Clear	Triple-Glazed low-E superwindow
Layers of glazing and spaces (outside to inside)	1/8″ clear	1/8″ clear	1/8″ bronze	1/8″ clear	1/8″ clear	1/8″ low-E (0.04)	1/8″ clear	low-E (0.08) on 1/8″ clear
		1/2″ air	1/2″ air	1/2″ air	1/2″ argon	1/2″ argon	1/2″ air	1/2″ krypton
		1/8″ clear	1/8″ clear	1/8″ clear	low-E (0.20) on 1/8″ clear	1/8″ clear	1/8″ clear	1/8″ clear
							1/2″ air	1/2″ krypton
							1/8″ clear	low-E (0.08) on 1/8″ clear
Center of glass								
U-factor	1.11	0.49	0.49	0.49	0.30	0.24	0.31	0.11
Solar heat gain coefficient	0.86	0.76	0.62	0.76	0.74	0.41	0.69	0.49
Shading coefficient	1.00	0.89	0.72	0.89	0.86	0.47	0.81	0.57
Visible transmittance	0.90	0.81	0.61	0.81	0.74	0.72	0.75	0.68
Frame								
Type	Aluminum, no thermal break	Aluminum, thermal break	Aluminum, thermal break	Wood or vinyl	Wood or vinyl	Wood or vinyl	Wood or vinyl	Insulated vinyl
U-factor	1.90	1.00	1.00	0.40	0.30	0.30	0.30	0.20
Spacer	—	Aluminum	Aluminum	Aluminum	Stainless steel	Stainless steel	Stainless steel	Insulated
Total window								
U-factor	1.30	0.64	0.64	0.49	0.33	0.29	0.34	0.15
Solar heat gain coefficient	0.79	0.65	0.55	0.58	0.55	0.31	0.52	0.37
Visible transmittance	0.69	0.62	0.47	0.57	0.52	0.51	0.53	0.48
Air leakage								
Cu ft./minimum per linear foot of crack	0.65	0.37	0.37	0.37	0.10	0.10	0.10	0.05
Cu ft./minimum per sq. ft. of unit	0.98	0.56	0.56	0.56	0.15	0.15	0.15	0.08

NOTES

9.8 a. Ratings of the basic thermal and optical properties of all fenestration products (windows, doors, skylights) must include the effects of the glass, the sash, and the frame, and be in accordance with the appropriate National Fenestration Rating Council (NFRC) standard. Products must be labeled with ratings for these properties, and the manufacturer must certify they are in accordance with the NFRC Product Certification Program.

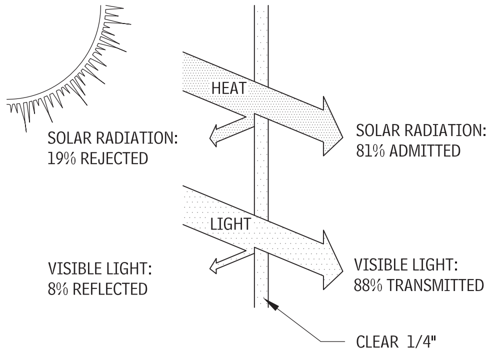
b. The NFRC standards for the basic thermal and optical properties of fenestration products are as follows: NFRC 100 for the U-factor, NFRC 200 for the solar heat gain coefficient (SHGC), NFRC 300 for visible light transmittance, and NFRC 400 for air leakage.

9.9 Source: Carmody, Selkowitz, and Heschong, Residential Windows—New Technologies and Energy Performance, 1996.

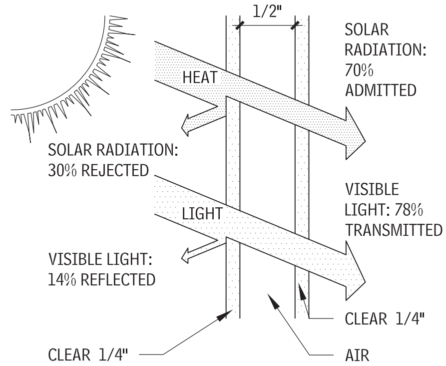
Units for all U-factors are Btu/hr-sq. ft.-F. All values for total window are based on a 2- by 4-ft. casement window.

Contributors:
John Carmody, University of Minnesota, Minneapolis, Minnesota; Stephen Selkowitz, Lawrence Berkeley National Laboratories, Berkeley, California.

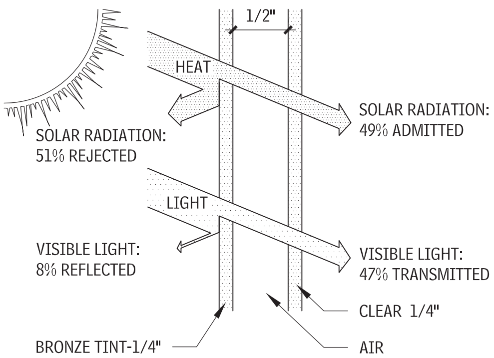
PERFORMANCE OF 1/4-IN.-THICK GLASS IN WINDOWS AND CURTAIN WALLS FOR COMMERCIAL BUILDINGS
9.10



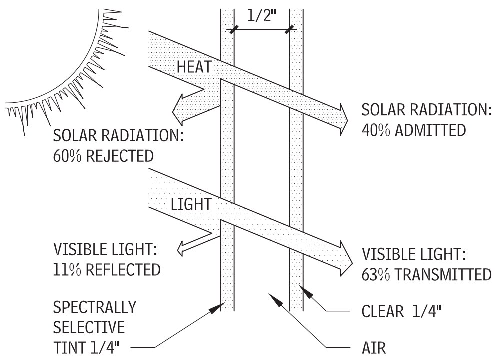
SINGLE GLAZING–CLEAR GLASS[a]



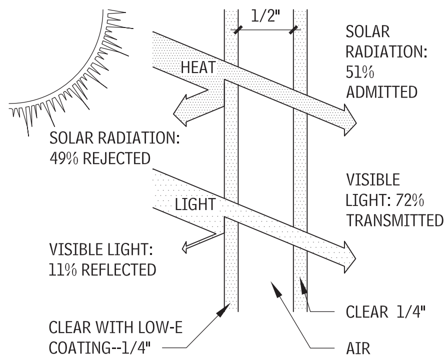
DOUBLE GLAZING–CLEAR GLASS[b]



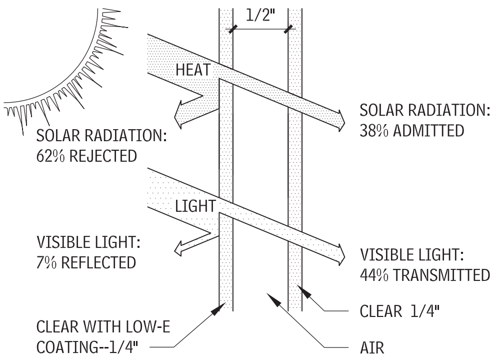
DOUBLE GLAZING–BRONZE TINT[c]



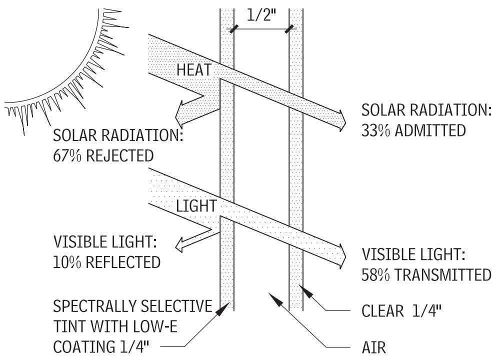
DOUBLE GLAZING–SPECTRALLY[d]
SELECTIVE TINT



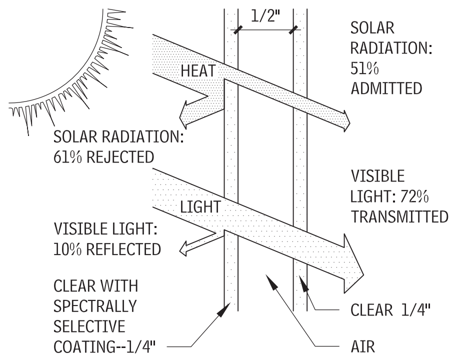
DOUBLE GLAZING–CLEAR GLASS[e]
WITH LOW–E COATING



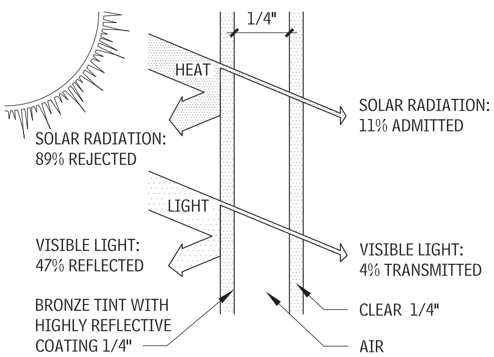
DOUBLE GLAZING–BRONZE[f]
TINT WITH LOW–E COATING



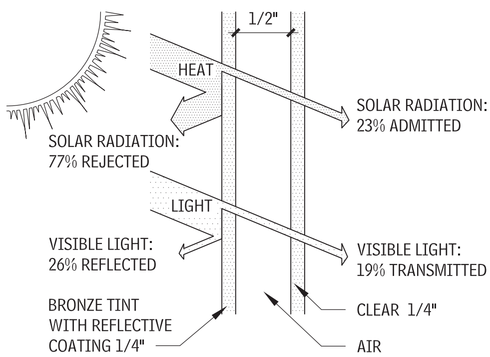
DOUBLE GLAZING–SPECTRALLY[g]
SELECTIVE TINT AND LOW–E COATING



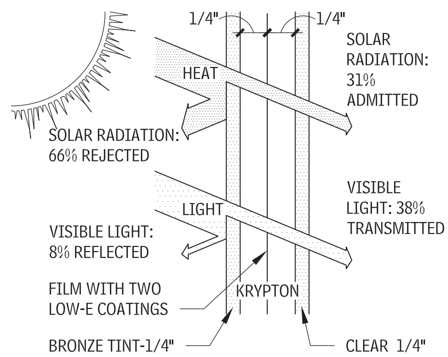
DOUBLE GLAZING–CLEAR GLASS[h]
WITH SPECTRALLY SELECTIVE COATING



DOUBLE GLAZING–BRONZE TINT[i]
WITH HIGHLY REFLECTIVE COATING



DOUBLE GLAZING–BRONZE TINT[j]
WITH REFLECTIVE COATING



DOUBLE GLAZING–BRONZE TINT AND TWO[k]
LOW–E COATINGS ON FILM + CLEAR

ABBREVIATIONS
SHGC: solar heat gain coefficient; SC: shading coefficient; VT: visible transmittance

NOTES

9.10 a. U-value = 1.09; SHGC = 0.81; SC = 0.94; VT=0.88
b. U-value = 0.45; SHGC = 0.70; SC = 0.81; VT = 0.78
c. U-value = 0.48; SHGC = 0.49; SC = 0.57; VT = 0.47
d. U-value = 0.48; SHGC = 0.40; SC = 0.46; VT = 0.63
e. U-value = 0.31; SHGC = 0.51; SC = 0.59; VT = 0.72
f. U-value = 0.31; SHGC = 0.38; SC = 0.44; VT = 0.44
g. U-value = 0.31; SHGC = 0.34; SC = 0.39; VT = 0.58
h. U-value = 0.29; SHGC = 0.39; SC = 0.46; VT = 0.69
i. U-value = 0.48; SHGC = 0.11; SC = 0.13; VT = 0.04
j. U-value = 0.48; SHGC = 0.23; SC = 0.27; VT = 0.19
k. U-value = 0.14; SHGC = 0.31; SC = 0.36; VT = 0.38

Contributors:
John Carmody, University of Minnesota, Minneapolis, Minnesota; Stephen Selkowitz, Lawrence Berkeley National Laboratory, Berkeley, California.

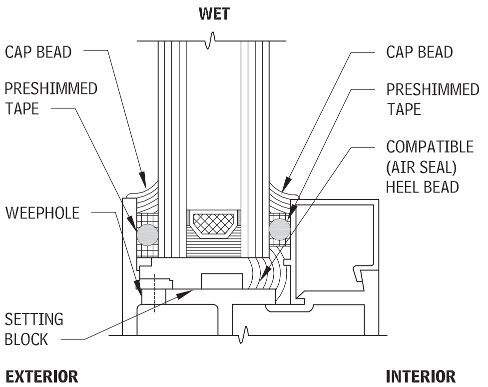
be included to obtain performance information on the whole window assembly. The darker arrows indicate the total admitted and total rejected solar energy. The lighter arrows indicate the amount of transmitted and reflected daylight. Daylight that is neither transmitted nor reflected is absorbed.

INSTALLATION GUIDELINES, DETAILS, AND CONSTRUCTION TOLERANCES

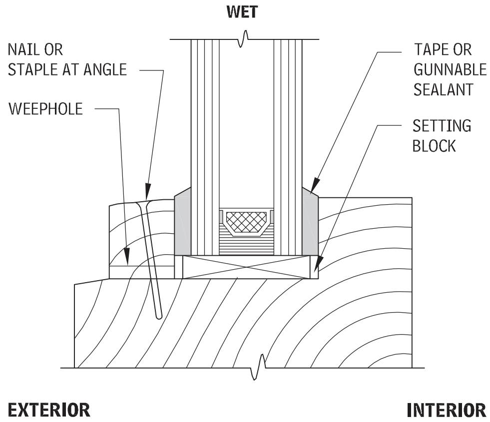
Important window glazing considerations are as follows:

- Dry glazing methods are generally less expensive than wet methods.
- Cap beads make glazing watertight and weathertight and are required for face-sealed glazing systems. Cap beads can also be used to increase the performance of existing windows.
- Two-sided structural silicone glazing usually has the other two sides either pressure plate–glazed or wet/dry glazed.
- Heel beads can be added at the bottom edge and turned up 6 to 8 in. to protect against water leaks caused by differential pressures between the interior and exterior.
- Heel beads at the full perimeter may be required to provide a continuous air barrier in a pressure-equalized rainscreen curtain-wall system.
- Skylights generally use wet glazing methods, cap beads, or structural silicone glazing.

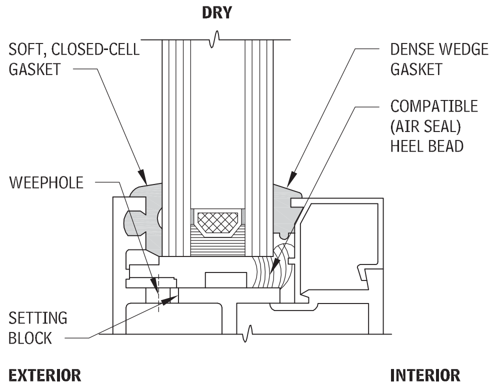
WET GLAZING
9.11



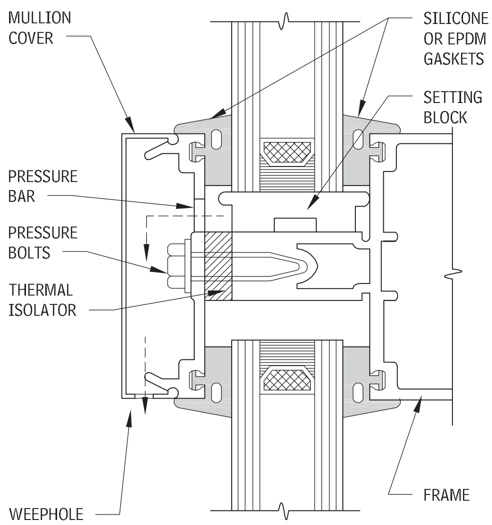
INSULATING GLASS IN WOOD SASH
9.12



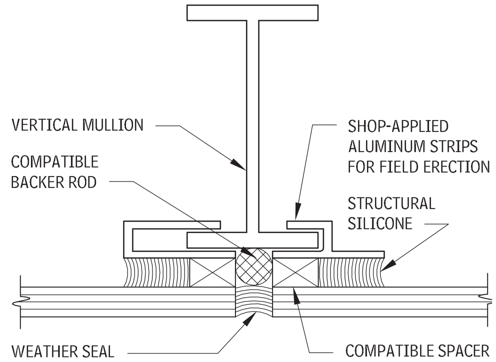
DRY GLAZING
9.13



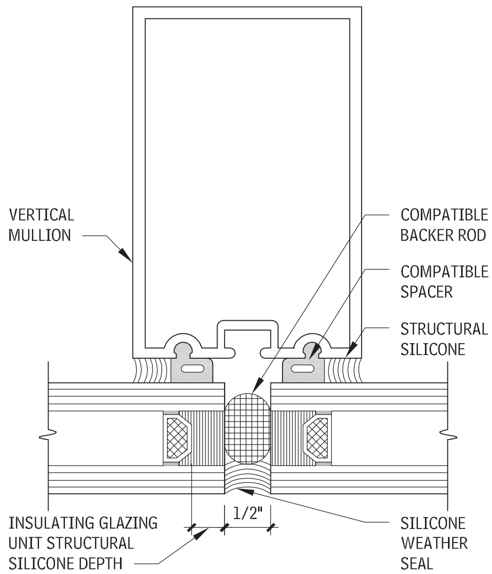
PRESSURE-GLAZED SYSTEM
9.14



STRUCTURAL SILICONE GLAZING
9.15



STRUCTURAL SILICONE GLAZING—TYPICAL VERTICAL MULLION FOR TWO-SIDED SYSTEM
9.16



SECTION 3

BUILDING ELEMENTS

ELEMENT A: SUBSTRUCTURE

10

SOILS AND SOILS EXPLORATIONS

Bringing together project team design professionals, including geotechnical engineers, structural engineers, and architects to discuss the matter of soils and foundations is fundamental to ensure that the foundation selected satisfies the constraints of the project budget as well as the functionality of the structure.

Understanding the vocabulary of geotechnical science (for example, the difference between "cohesive" and "cohesionless" soils) is the first step toward fostering collaborative communication, which becomes increasingly important as the process continues. What should be tested, what the test should be, why it is important, and what are the limitations of the test must be addressed. Likewise, identifying foundation and ground modification alternatives (as well as their pros and cons) will aid in the preliminary design phase, when the building foundations are being developed.

Understanding the geotechnical investigation report and geographical variations such as climate and seismic conditions will assist the design professionals in discussing important foundation issues.

SOILS DEFINITIONS: TERMS AND CLASSIFICATIONS

It is critical that geotechnical and structural engineering information be understood properly; to that end, the following definitions of common soils and other terms are included below for reference:

- *Clay:* Determined by the size of particles and composition, clays are chemically different from their parent materials as a result of weathering. Clays are typically inorganic and have grain sizes less than 0.0002 in. in diameter. This material contains charged particles and has an affinity for water. Because of their size and chemical composition, clays exhibit cohesion and plasticity. Clays can be classified as stiff, medium, or soft, depending on the moisture content, with drier clays typically being stiffer. Clays make a satisfactory bearing material under some conditions. Long-term settlement can sometimes control the allowable bearing pressure. Because of the cohesive nature of clay, excavations can have steep slopes for short periods of time.
- *Silt:* Silt consists of inorganic particles between 0.003 in. and 0.0002 in. in diameter. These fine-grained particles are similar in composition to the rocks from which they are derived, and are not plastic in nature. Organic silt is found on the bottom of lakes and river deltas.
- *Sand:* Classifications of sand vary from fine to coarse; these rock particles range in size from 0.003 in. to 0.079 in. in diameter. Adequately compacted, sand makes an ideal bearing material. The coarser the sand, the higher the allowable bearing pressures. Fine sands are susceptible to becoming quick when subjected to unbalanced hydrostatic pressures, and may liquefy when they are loose, saturated, or subjected to seismic forces. Settlement is usually immediate, with little long-term settlement.
- *Gravel:* Classifications of gravel vary from fine to coarse, and these unconsolidated rock fragments range from .75 in. to about 3 in. in size. Except for gravels composed of shale, this material makes a good foundation material. Depending on the compactness and the underlying material, very high bearing pressures are allowed by some building codes.
- *Cobbles:* Ranging in size from about 3 in. to about 10 in., these rock fragments can make reliable foundation-bearing materials, but can be difficult to properly compact, when used for fill. Cobble-sized materials can interfere with pile driving and drilled-pier construction causing significant problems.
- *Boulders:* Typically classified as rock fragments greater than 10 in., boulders can be used as part of a fill mass if the voids between the boulders are filled with finer-grained sands and silts. These materials are generally not considered suitable for direct foundation support because of their size and shape, and the difficulty in excavating the material to desired shapes. As with cobbles, boulders can cause significant problems during construction.
- *Bedrock:* Unbroken hard rock that is not over any other material is considered bedrock. Depending upon its composition, it can be capable of withstanding extremely high bearing pressure, and is desirable for foundations supporting high loads. If the rock has been weathered or is cracked, its bearing capacity may be compromised. Settlement of buildings on bedrock is primarily limited to the elastic settlement of the foundation.
- *Residuum:* Residuum consists of soil derived from the in-place decomposition of bedrock materials. In general, these soils are more weathered near the surface, and gradually transition to a more rocklike material with depth. Where residual soils reveal evidence of the stratification and structure of the parent rock, they are known as *saprolitic* materials.
- *Alluvial soils:* As materials are eroded, transported, and deposited through the action of flowing water, these soils are typically loose and saturated, hence often are unsuitable for support of structures or pavements.
- *Colluvial soils:* As materials are transported by gravity, typically associated with landslides, these soils are generally irregular in composition and loose. They require improvement prior to being used to support buildings and pavements.
- *Aeolian soils*: These soils are transported and deposited by the wind. Typically, they consist of silt or sand-sized soils. Loess, one of the more common types of aeolian soils, is comprised of fine cemented silt. While this material may be competent in-place, it loses much of its strength when disturbed or recompacted.
- *Till:* Till is a mixture of clay, silt, sand, gravel, and boulders deposited by glaciers. Consolidated tills that are well graded (indicated by a uniform distribution of particle size) are exceptionally strong and make excellent foundation strata. Loose tills can cause differential settlements if used as a bearing material.
- *Loam:* This organic material, made up of humus and sand, silt, or clay, provides excellent material for agriculture, but should not be used for foundations. Organic materials will settle a great deal over time, and even lightly loaded slabs on grade will settle if bearing on loam.
- *Cohesionless soils:* These types of soils consist of cobbles, gravels, sands, and nonplastic silts. They are generally formed from the mechanical weathering of bedrock brought about by water, ice, heat, and cold. They are typically composed of the same minerals as the parent rock. The strength of cohesionless materials is derived primarily from interparticle friction.
- *Cohesive soils:* These types of soils contain clay minerals with an unbalanced chemical charge. As a result, they tend to attract water and bond together. The strength of cohesive materials is derived from a combination of these chemical bonds and from interparticle friction.
- *Consolidation:* When soils are subjected to loads, water within the void spaces initially supports the change in stress through an increase in pressure. Excess pressures gradually dissipate in proportion to the permeability of the soil. Coarse-grained materials drain rapidly, while finer-grained silts and clays drain more slowly. As the excess pore pressures dissipate, the void spaces compress and transfer the loads to the soil grains. The resulting reduction in volume over time is known as *consolidation*.
- *Underconsolidated soils:* Soils that have built up in river deltas and other water bodies are deposited in a very loose state. These soils are often underconsolidated, in that they have never experienced stresses equal to or greater than current overburden stresses. These materials tend to consolidate under their own weight over time, until all excess pore pressures have been dissipated and the soils become "normally consolidated." Foundations bearing on underconsolidated soils can typically expect large short- and long-term settlement.
- *Overconsolidated soils:* Unlike many other types of materials, soils are not elastic. When stresses are applied to soils, they compress. However, when the same stress is removed, they do not rebound to the same height. When reloaded, the soils "remember" previously loaded conditions and compress to their historical level of stress. Soils that have previously been loaded to stresses above those created by the current soil overburden are considered to be overconsolidated. Foundations bearing on overconsolidated soils can typically expect less short- and long-term settlements.
- *Desiccation:* All soils typically contain some moisture within the voids between soil particles. When soils are dried, capillary tension tends to pull the soil grains together, causing the soil to shrink and lose volume. This action can cause the soil to become overconsolidated, as the capillary tension results in stress.

SOIL CLASSIFICATIONS

The Unified Soil Classification system, as defined in ASTM D2487, is the classification system most commonly used by geotechnical engineers as a basis for defining the soils found in their tests. This system allows for reproducible and reliable understanding of soils found from the testing performed at the site. Because some of the testing is qualitative, it also provides a mechanism to correlate the soils.

SOIL STUDIES AND REPORTS

For a structure to perform properly, it is essential that it bear on a suitable foundation tailored to the specific subsurface conditions within the project site. While geologic conditions can be generally consistent within broad areas of the country, subsurface conditions can vary considerably within short horizontal distances caused by both natural and human-made factors. Consequently, geotechnical investigation must be performed for each new development to characterize site-specific conditions and to evaluate cost-effective and practical site preparation and foundation recommendations.

Two types of geotechnical investigations are often conducted. In a *preliminary study*, several sites may be considered for construction, and only a broad understanding of conditions may be required to find the parcel with the least cost of development. In a *final,*

SOIL TYPES AND THEIR PROPERTIES
10.1

DIVISION	SYMBOLS: LETTER	SYMBOLS: HATCHING	SYMBOLS: COLOR	SOIL DESCRIPTION	VALUE AS A FOUNDATION MATERIAL	DRAINAGE	FROST ACTION
Gravel and gravelly soils	GW		Red	Well-graded gravel, or gravel-sand mixture; little or no fines	Excellent	None	Excellent
	GP		Red	Poorly graded gravel, or gravel-sand mixtures; little or no fines	Good	None	Excellent
	GM		Yellow	Silty gravels, gravel sand-silt mixtures	Good	Slight	Poor
	GC		Yellow	Clayey gravels, gravel clay-sand mixtures	Good	Slight	Poor
Sand and sandy soils	SW		Red	Well-graded sands, or gravelly sands; little or no fines	Good	None	Excellent
	SP		Red	Poorly graded sands, or gravelly sands; little or no fines	Fair	None	Excellent
	SM		Yellow	Silty sands, sand-silt mixtures	Fair	Slight	Fair
	SC		Yellow	Clayey sands, sand-clay mixtures	Fair	Medium	Poor
Silts and clays—Liquid limit <50	ML		Green	Inorganic silt, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity	Fair	Very high	Poor
	CL		Green	Inorganic clays of low to medium plasticity, gravelly clays, silty clays, lean clays	Fair	Medium	Impervious
	OL		Green	Organic silt-clays of low plasticity	Poor	High	Impervious
Silts and clays—Liquid limit >50	MH		Blue	Inorganic silts, micaceous or diatamaceous fine sandy or silty soils, elastic silts	Poor	Very high	Poor
	CH		Blue	Inorganic clays of high plasticity, fat clays	Very poor	Medium	Impervious
	OH		Blue	Organic clays of medium to high plasticity, organic silts	Very poor	Medium	Impervious
Highly organic soils	Pt		Orange	Peat and other highly organic soils	Not suitable	Slight	Poor

design-level study, more detailed information is required to address a number of issues, including, but not limited to the following:

- *Geologic hazards:* (1) Is the site in an area prone to sinkholes, subsidence, expansive soils? (2) Are landslides prevalent? (3) Will soils in the area liquefy or rupture during a seismic event?
- *Historical issues:* (1) Was the site developed in the past? (2) Is existing fill present? (3) Was mining conducted within or beneath the site?
- *Excavation issues:* (1) What types of materials will need to be excavated as part of development? (2) Can excavations be sloped, or will they require shoring? (3) Will groundwater be encountered in excavations, and how may it be dealt with? (4) Can excavated materials be reused for fill? (5) What is the depth and type of topsoil, and can it be stripped, stockpiled, and reused?
- *Applicable foundations:* (1) Is the site compatible with shallow foundations, or can subsurface conditions be improved to support shallow foundations? (2) What types of deep foundations are most cost-effective? (3) What parameters should be used in the design of foundations? (4) What factors should be considered in foundation construction, given the nature of subsurface conditions? (5) What is the expected performance of the foundation?
- *Seismic issues:* (1) Is the site near a fault? (2) How will the site react to a seismic event? (3) What seismic building code parameters are applicable to the site? (4) Are there any local regulatory restrictions on construction?

Subsurface studies employ a broad array of investigative techniques that are often specific to an area of the country. Certainly, specific needs should be delineated by the project design team, but broad latitude should be given to the geotechnical engineer to define the scope of study required to properly assess subsurface conditions and to develop design recommendations for site preparation and substructures.

READING A SOILS REPORT

A geotechnical report helps the design team understand the site on which the structure is to be built. Most geotechnical reports contain the following information, based on the previously defined scope of exploration:

- Report summary
- Project information
- Exploration methods
- Description of soil and groundwater conditions
- Design recommendations
- Construction considerations
- Location diagram
- Soil boring or test pit logs
- Soil profiles
- Laboratory test results

The report summary provides the most salient information and recommendations of the report. Also included in the report would be project information describing the building and site characteristics such as number of stories, building construction materials, foundation loadings, basement data if applicable, and grades. The exploration section defines how the geotechnical engineer obtained the soil information required to describe the foundation—this would include number, location, and depth of soil borings and test pits, and laboratory and field-testing to be performed.

The general soil and groundwater conditions include a general overview of the results of the geotechnical engineer's tests. More detailed information is contained in the soil boring and test pit logs, which can be reviewed when required.

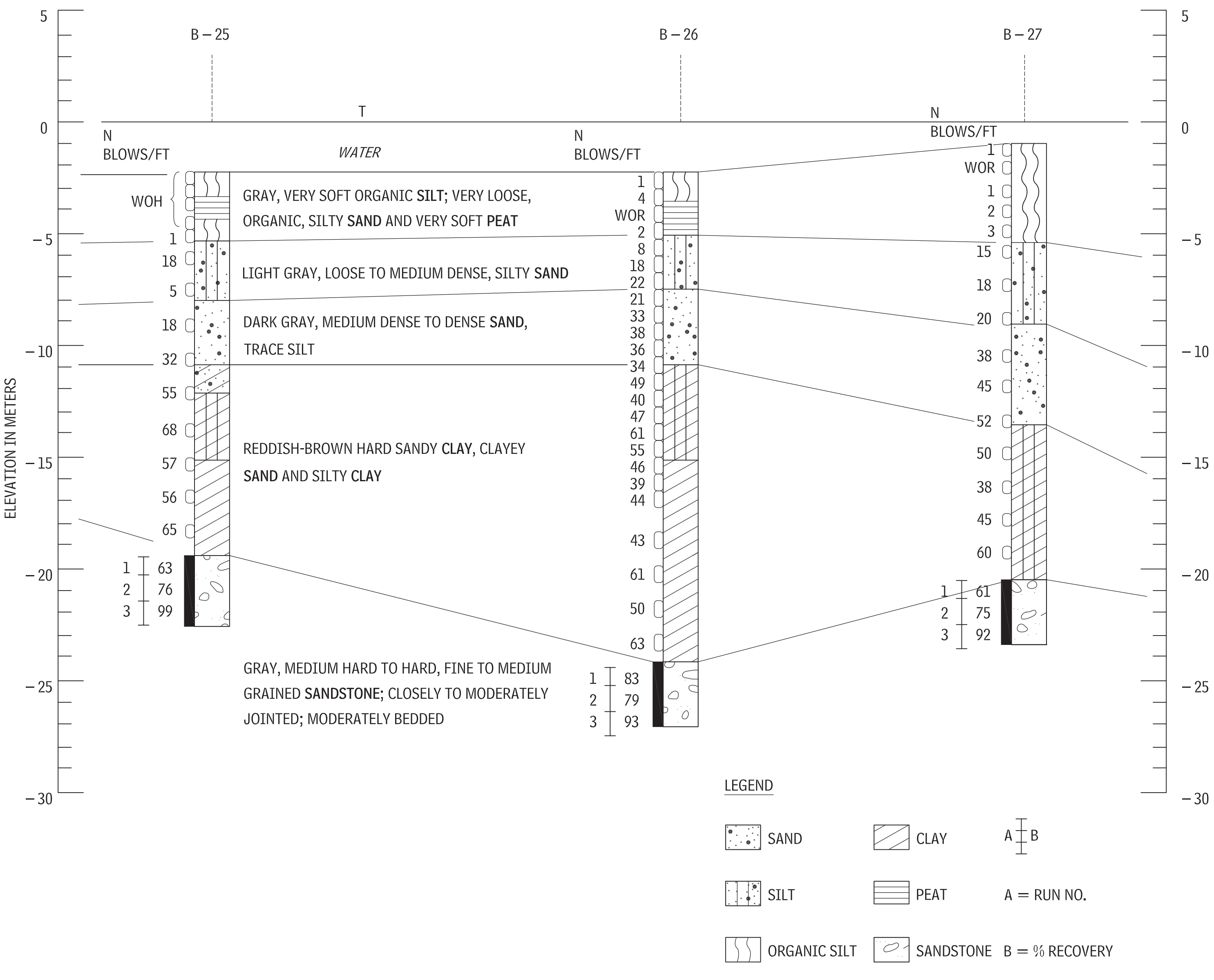
The design recommendations section makes specific recommendations concerning the design of foundations, grade slab, walls, drainage requirements, and other key building components. It should be read together with the section on construction considerations, which identifies potential problems during construction that can be avoided or minimized.

Often reports will provide a transverse section of the soil profile, combining the soil-boring information in a convenient picture. This will enable the reader to better understand approximately how the soil properties vary across the site.

READING A BORING LOG

A soil boring log, which is prepared by the geotechnical engineer, identifies the layers of soil found at specific depths beneath the surface and lists several measured characteristics of this soil, which could impact the design of any structure built upon it.

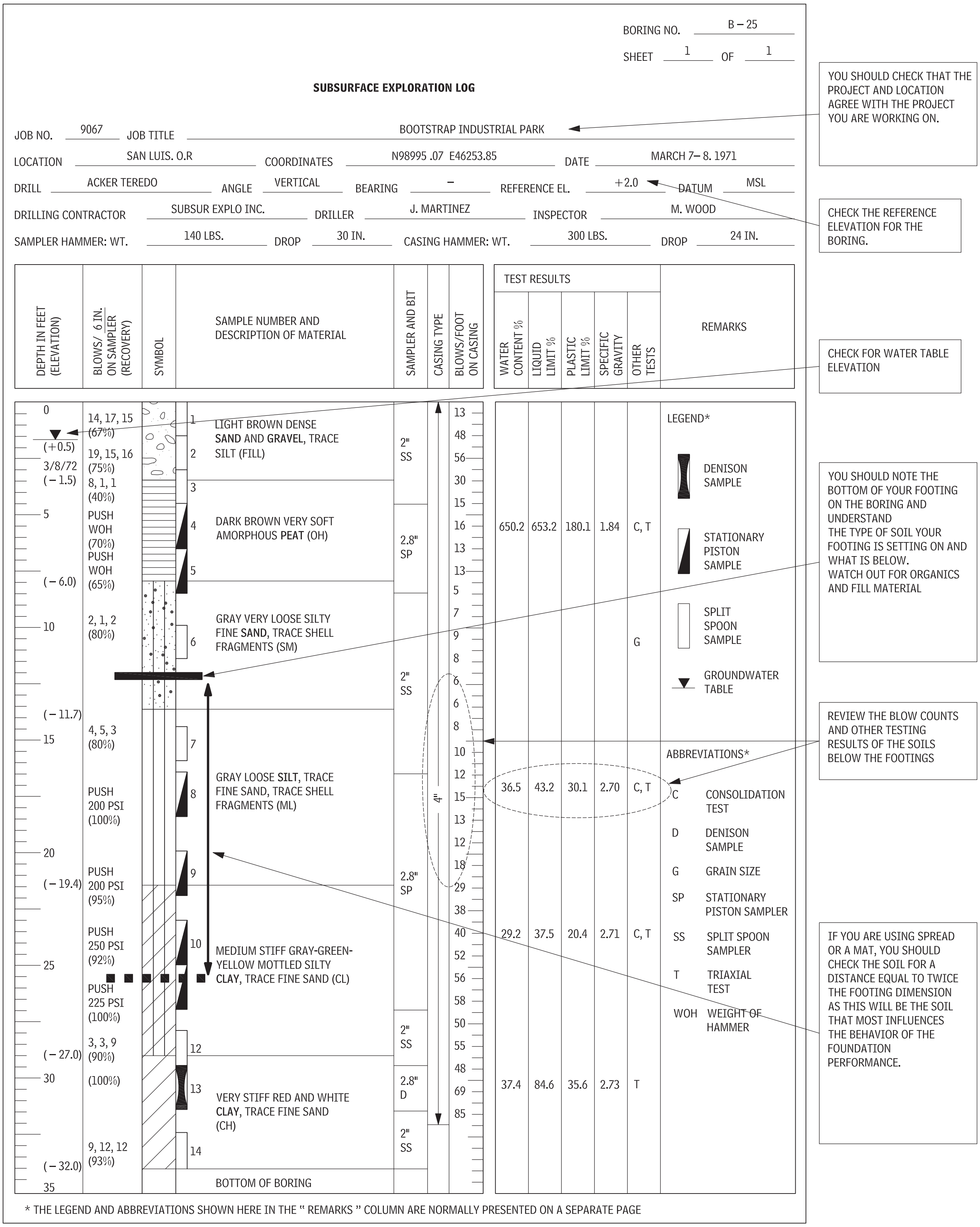
SITE SOIL PROFILE
10.2



NOTE

10.2 Source: Foundation Engineering Handbook, 2d edition, John Wiley & Sons, New York, 1991.

SOIL BORING LOG
10.3



NOTE

10.3 Source: Foundation Engineering Handbook, 2d edition, John Wiley & Sons, New York, 1991.

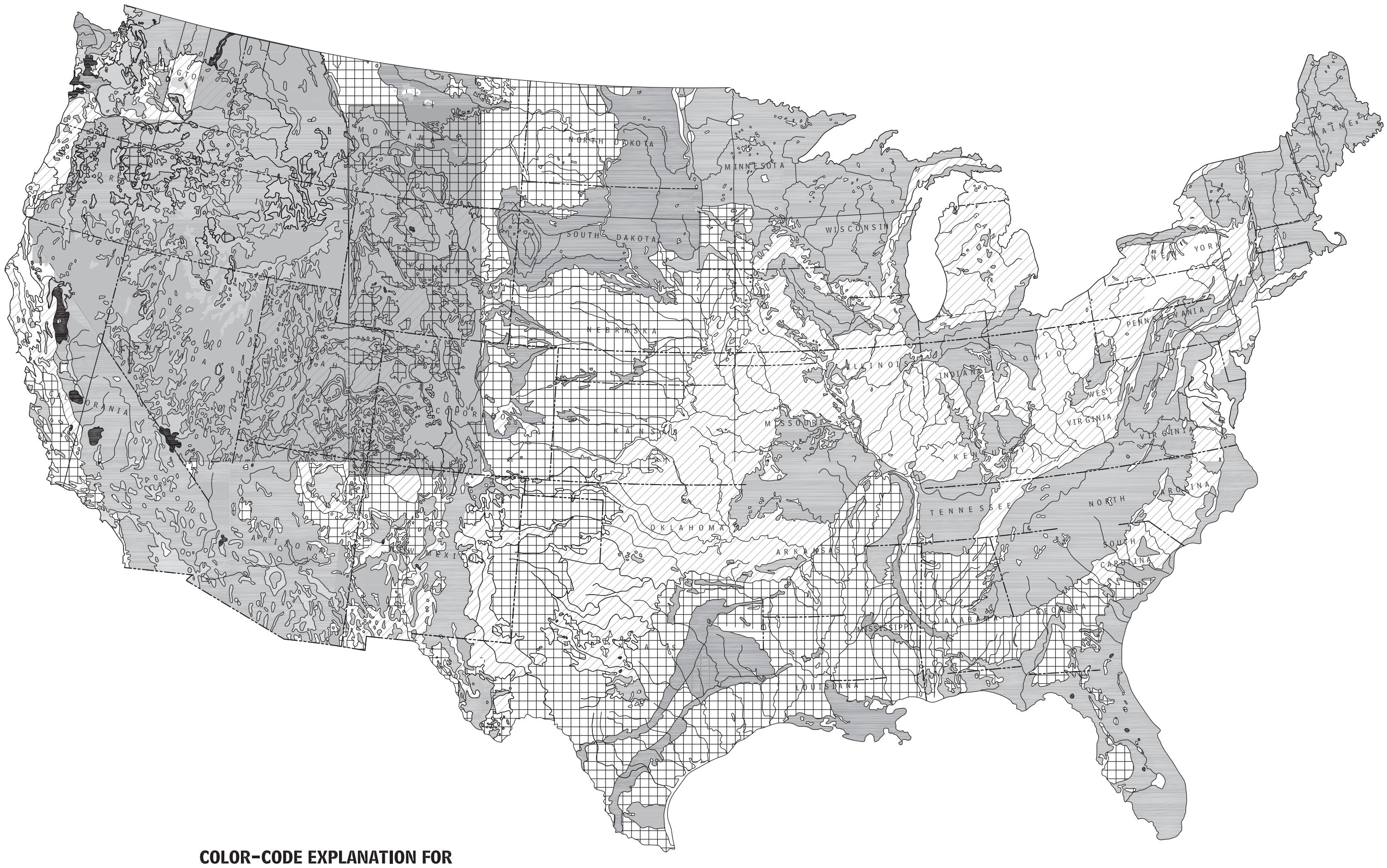
EXPANSIVE SOILS

Expansive soils contain clay minerals derived from volcanic ash and marine deposits that attract and readily absorb water. The water chemically bonds with the clay mineral and causes the soil to expand. It is not unusual for such materials to swell 5 to 10 percent upon wetting and to exert pressures of 10,000 psf or more. These soils are prevalent in the southwestern and western parts of the United States, but are present in limited areas of the South and Midwest. These soils need to be removed, treated, or bypassed through the use of deep foundations to prevent damage to structures.

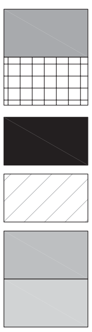
RADON IN SOILS

Radon, which comes from the natural decay of uranium in rocks and soil, is a gas which cannot be detected by our senses. It is harmless when present in outdoor air but can be a health threat when accumulated inside buildings. According to the World Health Organization, the decay product of radon can enter into the lungs and increase the risk of lung cancer. The EPA established that a concentration of 4.0 pCi/L (picocuries per liter) constitutes a potential hazard and recommends remediation action when 2 to 4 pCi/L are detected. The agency recommends that every home and workplace be tested for amount of radon in the air.

EXPANSIVE SOILS ACROSS THE UNITED STATES
10.4



COLOR-CODE EXPLANATION FOR SWELLING-CLAY MAP



UNIT CONTAINS ABUNDANT CLAY HAVING HIGH SWELLING POTENTIAL

PART OF UNIT, GENERALLY LESS THAN 50 PERCENT, CONSISTS OF CLAY HAVING HIGH SWELLING POTENTIAL

UNIT CONTAINS ABUNDANT CLAY HAVING SLIGHT TO MODERATE SWELLING POTENTIAL

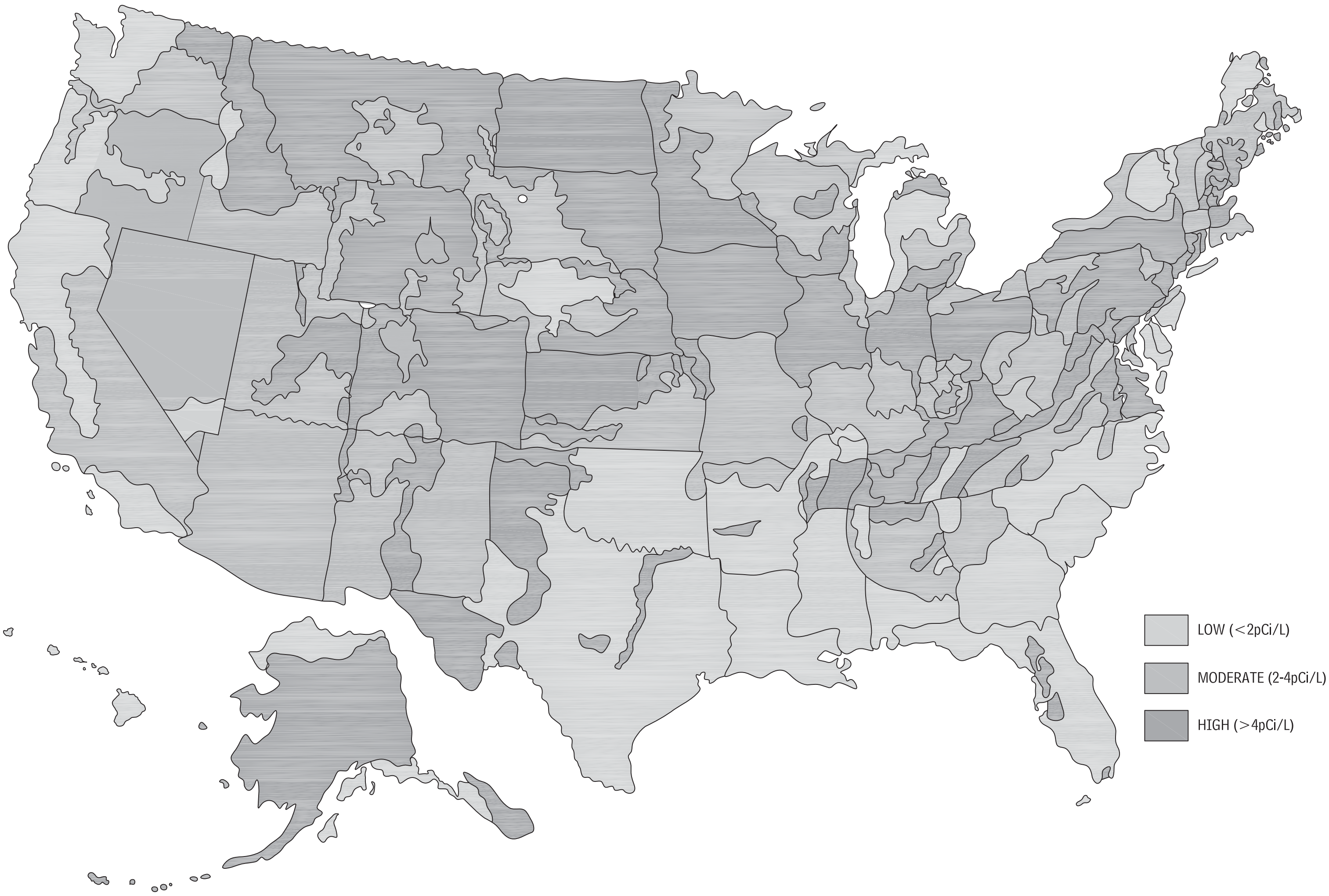
PART OF UNIT, GENERALLY LESS THAN 50 PERCENT, CONSISTS OF CLAY HAVING SLIGHT TO MODERATE SWELLING POTENTIAL

UNIT CONTAINS LITTLE OR NO SWELLING CLAY

DATA INSUFFICIENT TO INDICATE CLAY CONTENT OF UNIT AND (OR) SWELLING POTENTIAL OF CLAY. SHOWN IN WESTERNMOST STATES ONLY

Contributors:
James W. Niehoff, PE, Chief Engineer, PSI, Wheat Ridge, Colorado; Timothy H. Bedenis, PE, Chief Geotechnical Engineer, Soil and Materials Engineers, Inc., Plymouth, Michigan; John P. McCarthy, PE, SE, SmithGroup, Architecture, Engineering, Interiors, Planning, Detroit, Michigan.

RADON IN SOILS ACROSS THE UNITED STATES
10.5



DESIGNING FOR COLD AND PERMAFROST CLIMATES

Cold climates in North America are generally north of the 40th parallel. "Very cold" is identified by the southern boundary of the 32°F mean annual temperature, and includes most of Canada and Alaska, except along the Pacific Coast. Permafrost extends from below the Hudson Bay and just north of the southern coast of Alaska to the Arctic Ocean. The Arctic Circle designates the southernmost point where continuous daylight in summer and continuous darkness in winter exists. Foundations in these climates are extremely important, and technically challenging to design.

The danger for foundations in these climates is that the soil around and under the foundation might thaw and lose strength. There are several strategies for designing in these areas. Both self-contained convection (passive) and mechanically refrigerated (active) systems are used for new construction and stabilization of existing foundations, either directly as pipe piles or in smaller pipes (probes) that can be placed beside a pile or under a slab or foundation. Passive systems rely on natural convection of a liquid or gas medium to remove heat from the ground to keep it frozen; active systems use pumps and refrigeration technology. Recent concerns regarding global warming have caused renewed interest in the design parameters for passive systems.

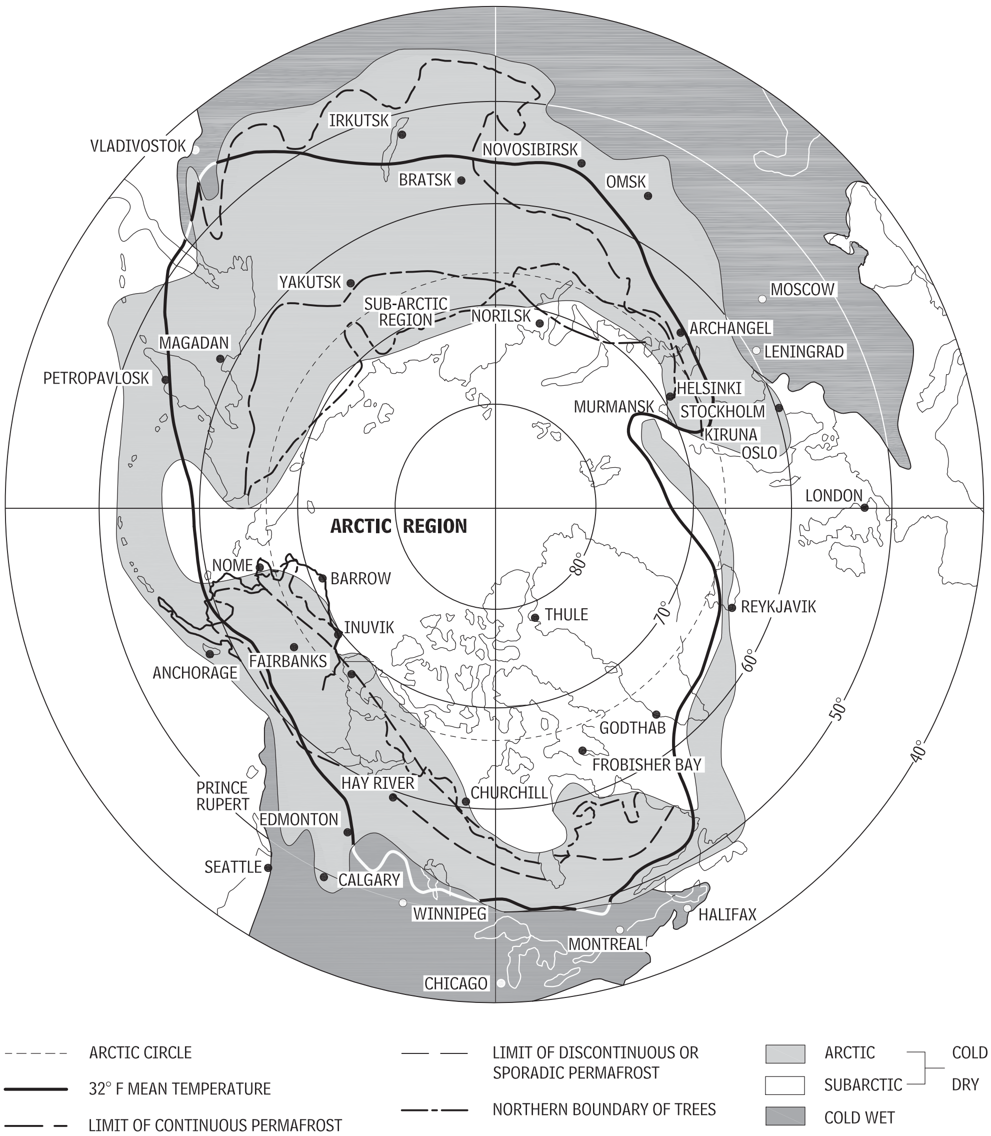
PERMAFROST, ICE WEDGES AND LENSES, AND FROST HEAVE

In the scope of climate issues, the following are important terms:

- *Permafrost:* Ground of any kind that stays colder than the freezing temperature of water throughout several years. Depth can extend to 2000 ft. below the active layer.
- *Active layer:* Top layer of ground subject to annual freezing and thawing. Can be up to 10 ft. or only 18 in. over some permafrost.
- *Frost heaving:* Lifting or heaving of soil surface created by the freezing of subsurface frost-susceptible material.
- *Frost-susceptible soil:* Soil that has enough permeability and capillary action (wickability) to allow ice lenses to form and expand upon freezing.
- *Ice lense (taber ice):* Subsurface pocket of ice in soil.
- *Ice wedge:* Wedge-shaped mass of ice within thaw zone. Wedges range up to 3 or 4 ft. wide and 10 ft. deep.
- *Pereletok:* Frozen layer at the base of the active layer that remains unthawed during some cold summers.
- *Residual thaw zone:* Layer of unfrozen ground between the permafrost and active layer. This layer does not exist when annual frost extends to the permafrost, but is present during some warm winters.

Contributor:
Hall Architects, Inc. Charlotte, North Carolina.

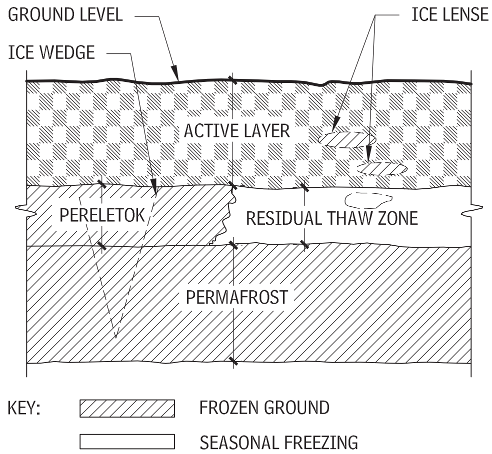
NORTHERN HEMISPHERE PERMAFROST LIMITS
10.6



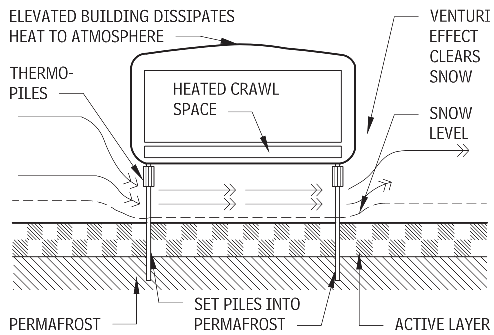
CONDITION OF BUILDINGS ON PERMAFROST

- *Condition 1:* Buildings elevated on piles allow the dispersion of building heat to prevent ground thaw and allow the wind to remove snow. Wooden piles, with low thermal conductivity, induce minimal heat into the frozen ground, while thermopiles can remove heat to retain frozen state.
- *Condition 2:* Buildings elevated on non-frost-susceptible gravel pads provide insulation in addition to existing ground cover. Rigid insulation adds to the protection from thaw of the permafrost. Thermopiles are used to refreeze fill and keep permafrost frozen.

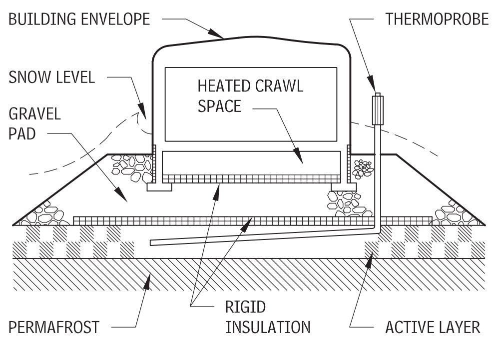
SOIL CROSS SECTION AT PERMAFROST ZONE
10.7



CONDITION 1: ELEVATED BUILDING ON PILES
10.8



CONDITION 2: BUILDING ON GRAVEL PAD
10.9



Contributors:
Edwin Crittenden, FAIA, and John Crittenden, AIA, Anchorage, Alaska; G. H. Johnston, *Permafrost Engineering, Design and Construction*, National Research Council of Canada, John Wiley & Sons, New York; Arvind Phukan, *Frozen Ground Engineering*, Prentice Hall, Englewood, New Jersey; and Eb Rice, *Building in the North*, Geophysical Institute, University of Alaska, Fairbanks, Alaska.

FOUNDATIONS

GENERAL

Foundations, because they are hidden below the surface, are often overlooked and their importance minimized by the design team. A great deal of scientifically guided creativity is often necessary to produce a foundation that supports the loads of the structure in such a way as to economically maintain the aesthetics and function of a facility. The wide variety of soil types and conditions across the United States—from the bedrock near the surface in New York to the sink holes and coral in Florida to the deep soft clays in the Midwest and South, and expansive soils in the Southwest to the seismically active areas of the country such as the West Coast—pose a challenge to the design team. The most popular and economical foundation solution is the spread footing. Spread footings are typically shallow, simple to design and construct, and perform well under many conditions. When properly designed, load is spread from a column to the soil at a bearing pressure that causes neither excessive settlement nor failure of the soil.

Should the soil conditions near the surface be weak, poorly compacted, filled with debris or organic material, or too compressible, deep foundations are warranted. The effect is to extend the foundation through the weak strata to a soil type that can withstand the loadings with tolerable settlement. Deep foundations come in several types and, depending on the soil conditions, may include driven piles, bored piles (bored, augered, or drilled) or caissons. Deep foundations resist imposed loads either by end bearing or side friction or some combination. It is not necessary to drive or drill a deep foundation to rock, only to the depth required to reach a suitable stratum.

A spread footing is not always appropriate, such as when the property line limits the extent of the foundation in one direction, or when the soil conditions are very weak and suitable soil strata too deep to reach with a deep foundation. In these cases, other types of special foundations (such as combined footings, strap footings, and raft foundations) are sometimes required.

Two basic criteria should be met for all foundations:

- *Soil strength (bearing capacity)*: The ability of a soil to support a load without experiencing failure is known as the bearing capacity and is a function of the foundation size as well as the inherent strength properties of the soil. If the pressures exerted by a foundation exceed the strength of a soil, the soil mass experiences a shear failure leading to gross movements of both the soil and the supporting foundation element.
- *Limitations of settlement*: Settlement can happen either immediately (foundations on sands), or over a period of time, short or long term (foundations on clays). Some settlement is expected, over various parts of the country; typical and acceptable settlement is usually less than 1 in. Settlement is not as important with a solitary structure, but becomes more important when: (1) buildings adjacent to an existing structure need to be interconnected; (2) long utility runs need to be connected to the structure; or (3) there is sensitive equipment in the building. Uniform settlement is somewhat better tolerated than differential settlement that is uneven across several columns. Differential settlement distorts the structure and causes cracking of the exterior skin and interior partitions, broken windows, and doors that don't open. Allowable differential settlement may be dependent on the material of the skin and structure; for example, brick and concrete masonry buildings tolerate less differential settlement than curtain-wall buildings. Differential settlement of 1/4 in. is typically considered tolerable for most building types.

The importance of proper foundation design and detailing cannot be overemphasized. Working with the geotechnical engineer, familiar with the soil conditions in the area, and a structural engineer, familiar with the proposed design and detailing of the foundation, will help ensure the building functions as intended for its lifecycle.

SETTLEMENT AND DIFFERENTIAL SETTLEMENT

Often, settlement governs the allowable bearing pressure, which is set at an intensity that will yield a settlement within tolerable levels for the building type. Allowable settlement is typically building and use specific. Total and differential settlement, as well as the time rate of the occurrence of the settlement, must be considered when evaluating whether the settlement is tolerable. For example, in the case of a conventional steel frame structure, in typical practice a total maximum settlement of 1 in. is usually acceptable, and differential settlement of one-half of the total settlement is also usually tolerable.

ANGULAR DISTORTION

Settlement tolerance is commonly referred to in terms of angular distortion in the building or settlement between columns. Typically, an angular distortion of 1:480 is used for conventional structures. This equates to 1 in. in 480 in., or 1 in. in 40 ft. Depending on the type of structure, the allowable angular distortion might vary from 1:240 for a flexible structure (such as a wood frame, single-story structure) to 1:1000 for a more "brittle" or sensitive structure.

EFFECTS OF SOIL TYPES

When load is applied to granular soils, the grains of soil are able to respond almost immediately, and they will densify as the packing of the grains becomes tighter.

Clay soils exhibit a time-dependent relationship associated with the consolidation of the clay soil. In order for the clay to consolidate, and the overlying soil or structure to settle, the excess pressures that are induced in the water in the clay must dissipate, and this takes time because of the low permeability of the clay. Depending on the drainage characteristics of the clay, the time required for 90 percent of the consolidation (and settlement) to occur may vary from a few months to several years. If there is a high frequency of sand layers or seams within the clay mass, then the consolidation will be quicker, because the excess pore water pressure can be dissipated faster.

Both sand and clay soils have a built-in "memory" that, in effect, remember the maximum load that was applied to the soil at some time in the past. This memory is referred to as the *preconsolidation pressure*. If 10 ft. of soil has been removed (by excavation or erosion) from a soil profile, then the equivalent weight of that 10 ft. of soil (approximately 1250 lbs per square foot) could be reapplied to the soil profile without the soil below sensing any difference. Depending on the process that deposited the soil—weathering processes, past climatological changes, or human activities—the preconsolidation pressure of the soil may be far in excess of the pressures induced by the current soil profile. When that is the case, settlement of conventional structures is rarely a significant concern. But when the soil has not been preconsolidated, the addition of any new load may result in excessive settlement.

SPECIAL TYPES OF SETTLEMENT

Three special types of settlement are sometimes of concern:

- *Elastic compression:* Soil is a viscoelastic material, which means that if a pressure is applied, the soil will deform elastically to a certain point. For instance, in excavating for a large basement, the weight of the soil removed will relieve pressure on the underlying soil, and the soil will immediately expand vertically upward in an elastic manner because of the stress relief. If the excavation is filled back in with soil or a building, the underlying soil will experience elastic recompression. Normally, the elastic heave and recompression are relatively minor, and are usually taken into consideration by the geotechnical engineer.
- *Lowering of the water table:* The lowering of a groundwater table can have significant settlement consequences if proper precautions are not taken. The lowering of the groundwater table can occur naturally by drought conditions or vegetation or by human activities. If a temporary dewatering system is installed in conjunction with a construction project, or if a permanent perimeter drain is constructed around a basement below the original groundwater table, then settlement of nearby structures can occur. The reason is that the clay soil that was previously below the groundwater table and is now above the groundwater table after dewatering has lost its buoyancy condition. This increases the effective stress and weight on the underlying soil. While a rather complicated process, the design professional should be aware that any significant lowering of the groundwater table could adversely affect adjoining property.
- *Vibration:* This type of special settlement problem occurs when granular soils (primarily sand and gravel) are subjected to vibrations. The vibrations can be from machinery installations, traffic, pile driving, other construction operations, or seismic events. When the vibrations encounter a granular soil deposit that is in a less-than-optimum dense condition, the vibration energy causes the particles to rearrange themselves. The soil settles into a denser condition and settlement results. Clay soils are not nearly as susceptible to densification by vibrations as are granular soils.

STANDARD FOUNDATIONS

GENERAL

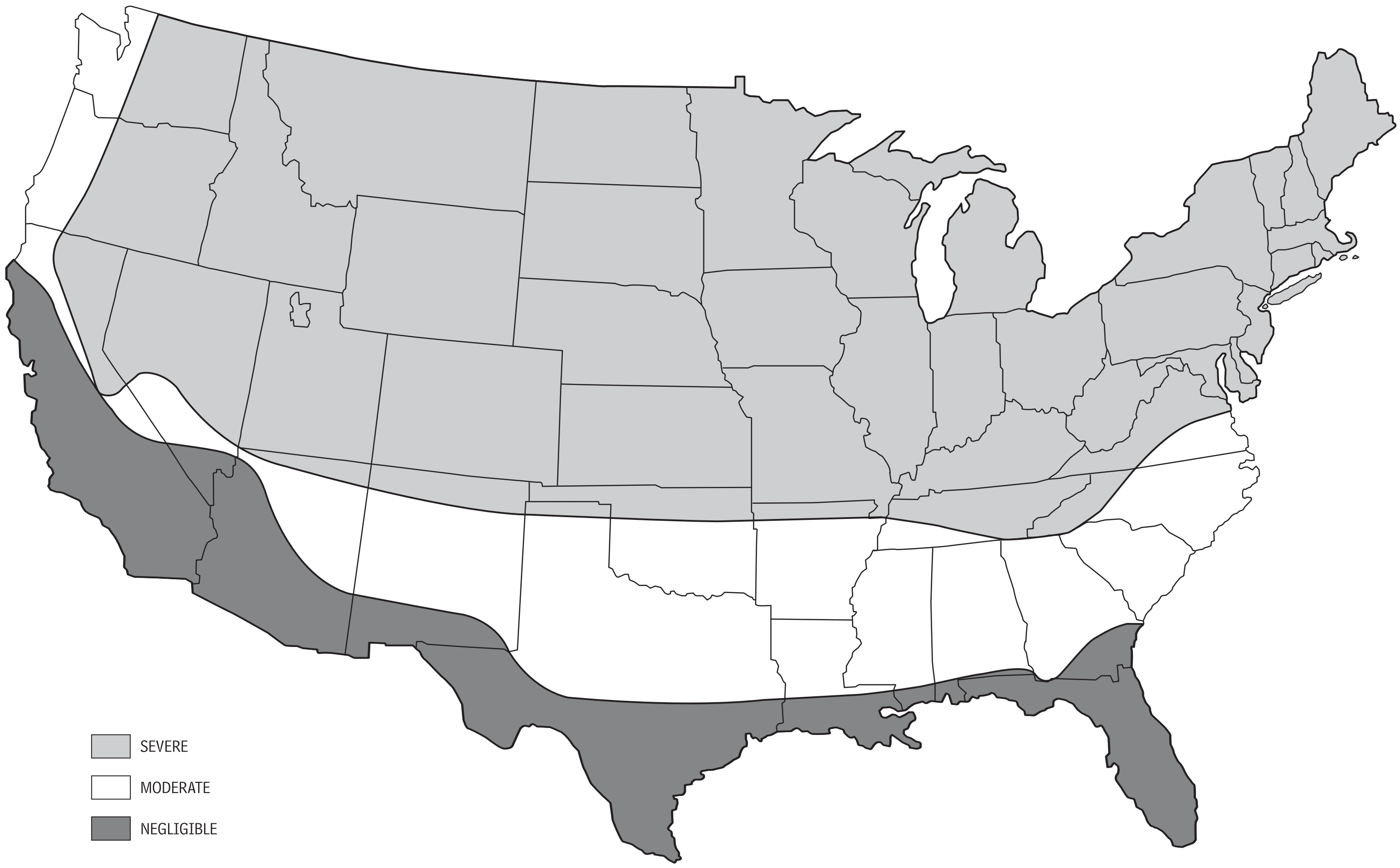
Footings lie under the basement, crawl space, or foundation walls, and transfer structural loads from the walls of the building to the supporting soil. Footings are typically cast-in-place concrete, extending beneath the frost depth to prevent damage and heaving caused by freezing of water in the soil.

The bottom surface of the footing should not exceed a slope of 1 in 10. The footing should rest on undisturbed native soil, unless this soil is unsuitable, in which case, the unsuitable soil should be removed and replaced with compacted fill material. Similarly, tree roots, construction debris, and ice should be removed prior to placing footings.

Footings should be carefully aligned so that the supported wall will be near the centerline of the footing. The top surface of cast-in-place concrete footings should be relatively level and generally should not be troweled smooth, as a slightly roughened surface enhances the bond between the wall and footing.

Building Code Requirements for Structural Concrete and Commentary, ACI 318, and Requirements for Residential Concrete Construction and Commentary, ACI 332 establish requirements for footing design which take into account the weathering probability, as indicated in Figure 10.10.

WEATHERING PROBABILITY MAP FOR CONCRETE
10.10



Source: Based on ACI 332-04 Requirements for Residential Concrete Construction and Commentary, Figure 4.1; reprinted with permission of the American Concrete Institute.

MINIMUM SPECIFIED COMPRESSIVE STRENGTH AT 28 DAYS F′C, AND MAXIMUM SLUMP OF CONCRETE
10.11

TYPE OR LOCATION OF CONCRETE CONSTRUCTION	WEATHERING PROBABILITY			MAXIMUM SLUMP (IN.)
	NEGLIGIBLE F′c psi	MODERATE F′c psi	SEVERE F′c psi	
Type 1: Walls and foundations not exposed to weather; interior slabs-on-ground, not including garage floor slabs	2,500	2,500	2,500	6
Type 2: Walls, foundations, and other concrete work exposed to weather, except as noted in Type 3	2,500	3,000	3,000	6
Type 3: Driveways, curbs, walkways, ramps, patios, porches, steps, and stairs exposed to weather and garage floors, slabs	2,500	3,500	4,500	5

Source: Based on ACI 332-04 Requirements for Residential Concrete Construction and Commentary, Table 4.1; reprinted with permission of the American Concrete Institute.

AIR CONTENT FOR TYPE 2 AND TYPE 3 CONCRETE UNDER MODERATE OR SEVERE WEATHERING PROBABILITY
10.12

NOMINAL MAXIMUM AGGREGATE SIZE (IN.)	AIR CONTENT (TOLERANCE ±0.015)	
	MODERATE	SEVERE
3/8	0.06	0.075
1/2	0.055	0.07
3/4	0.05	0.07
1	0.045	0.06
1–1/2	0.045	0.055

Source: Based on ACI 332-04 Requirements for Residential Concrete Construction and Commentary, Table 4.2; reprinted with permission of the American Concrete Institute.

NOTES

10.10 a. Lines defining areas are approximate only. Local areas can be more or less severe than indicated by the region classification.
b. A "severe" classification refers to weather conditions that encourage or require the use of deicing chemicals or where there is potential for continuous presence of moisture during frequent cycles of freezing and thawing. A "moderate" classification refers to weather conditions that occasionally expose concrete, in the presence of moisture, to freezing or thawing, but where deicing chemicals are not generally used. A "negligible" classification refers to weather conditions that rarely expose concrete, in the presence of moisture, to freezing and thawing.
c. Alaska and Hawaii are classified as severe and negligible, respectively.
d. Where deicing and anti-icing products are used the concrete composition and condition should be thoroughly investigated prior to their use. Products range from organic, anti-icing, deicing, environmentally friendly products, such as sand, that are less corrosive overall compared to rock salt, which is potentially damaging to concrete and reinforcing steel.

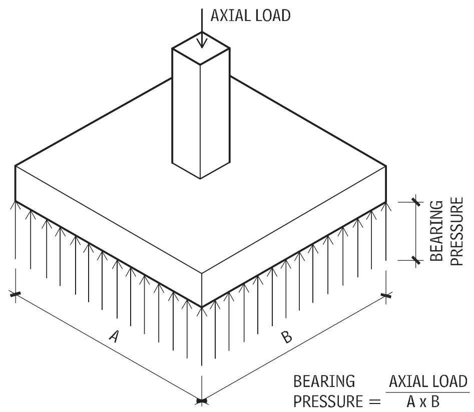
10.11 Maximum slump refers to the characteristics of the specified mixture proportion based on water cement ratio only. Midrange and high-range water-reducing admixtures can be used to increase the slump beyond these maximums.
10.12 American Concrete Institute (ACI) and International Building Code (IBC) have requirements for the minimum footing dimensions.

SHALLOW FOUNDATIONS

Shallow foundations are typically the most economical foundations to construct where soil and loading conditions permit. Coordination with local codes for frost depth and with the underground utilities is required. The thickness of the footing has to be coordinated with anchor bolt and dowel embedment. Typically, one layer of steel in the bottom of the footing is required to resist the bending of the footing caused by soil-bearing pressures.

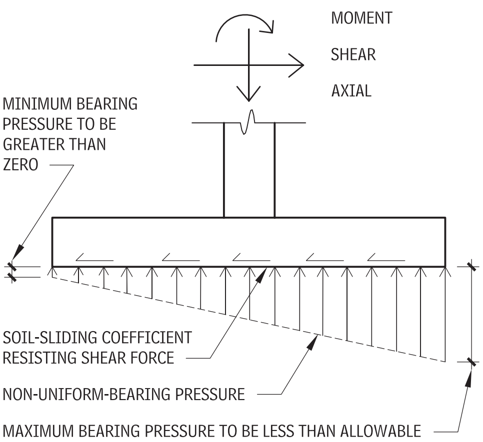
AXIALLY LOADED SPREAD FOOTING 10.13

Axial loads are distributed in a uniform manner under the footing. The allowable bearing pressure necessary to resist the load determines footing size.



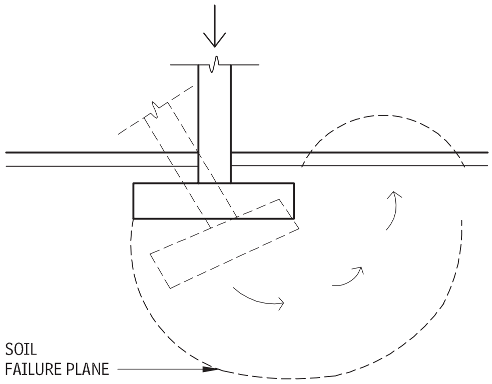
SPREAD FOOTING RESISTING MOMENT, SHEAR, AND AXIAL LOADS 10.14

Axial loads, combined with shear and overturning forces can be resisted by spread footings. The combination of axial load and moment forces on the foundation need to be balanced to keep the calculated loads on the footing less than the allowable bearing pressure of the soil as determined by the geotechnical engineer.

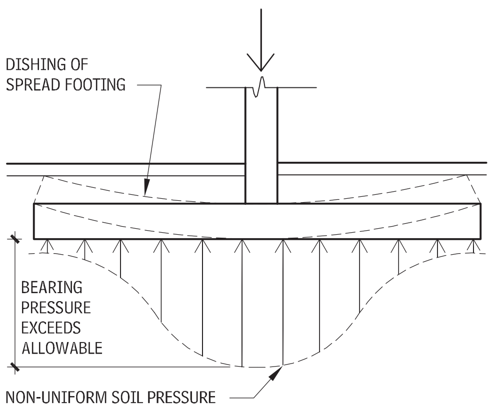


SPREAD FOOTING SIZE LIMITATIONS 10.15

Minimum sizes of spread footings are specified by the geotechnical engineer, to reduce the possibility of local soil failures by punching shear of an overall movement of soil mass. Maximum sizes of spread footings keep the non-uniform bearing pressure from becoming extreme and overstressing the soil.

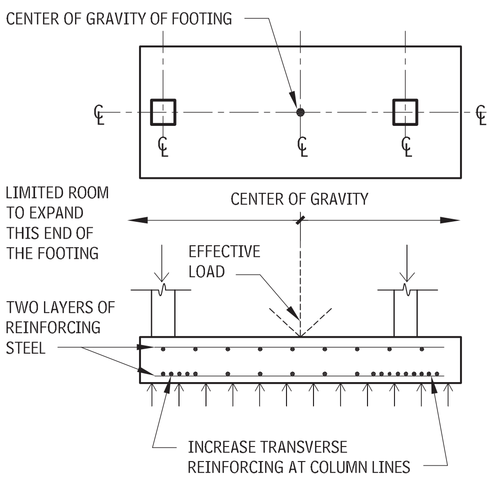


MINIMUM FOOTING WIDTHS TYPICALLY 3'–0" SQUARE

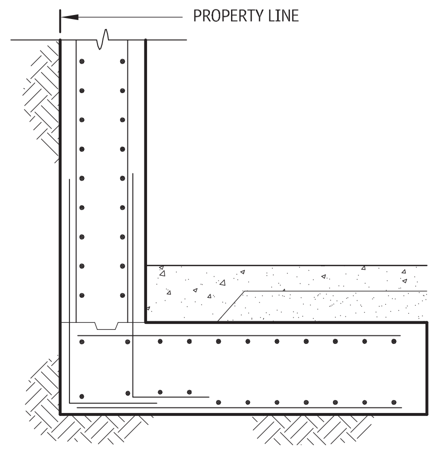


MAXIMUM FOOTING WIDTHS TYPICALLY 20'–0" SQUARE

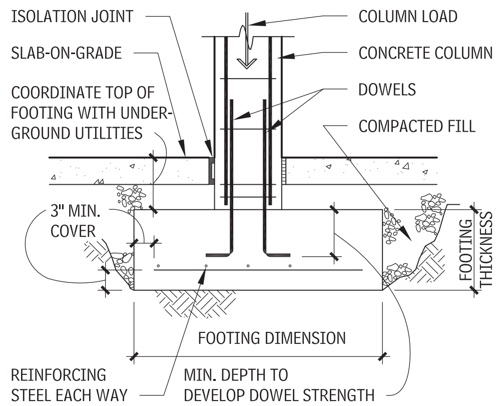
COMBINED FOOTING 10.16



FOOTING AT PROPERTY LINE 10.17



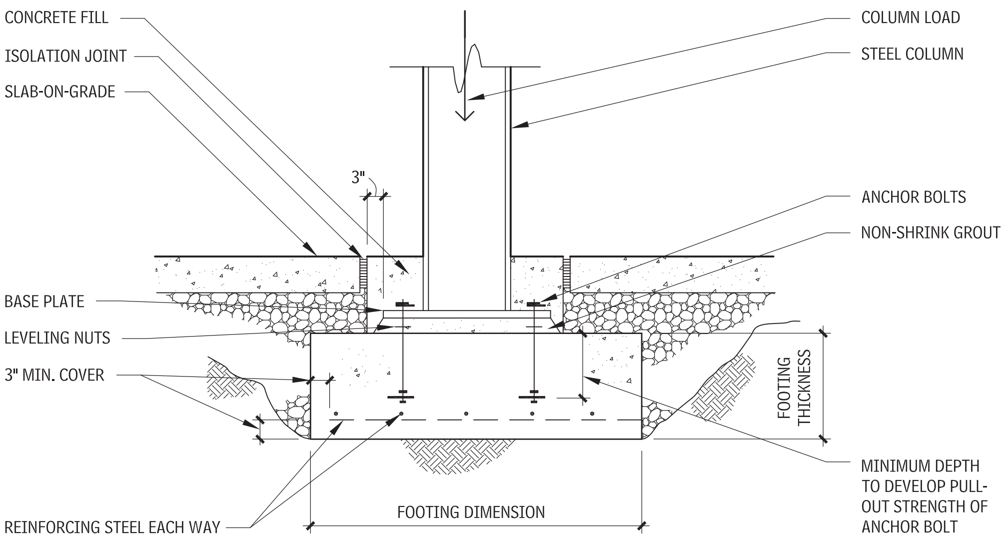
SPREAD FOOTING—CONCRETE COLUMN 10.18



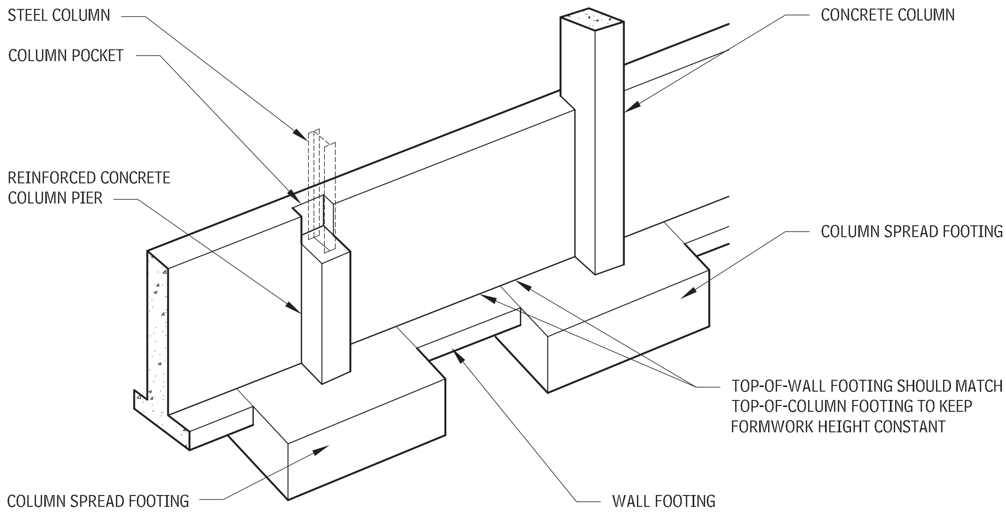
NOTES

10.16 These are highly loaded, closely spaced columns.
10.18 a. Soil below footing should not be disturbed after excavation.
b. Footing size based on allowable bearing pressure.
c. Thickness based on bending and shear requirements.
d. Reinforcing steel based on bending and minimum steel requirements.
e. Dowels as required to transfer load.

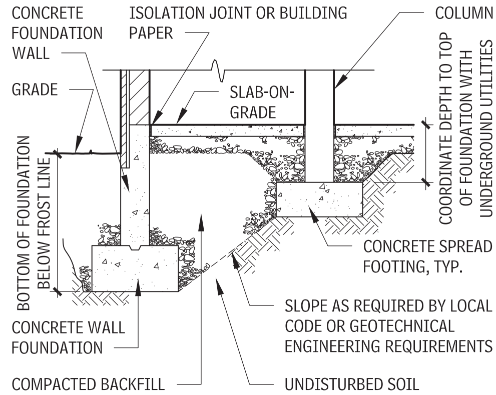
SPREAD FOOTING—STEEL COLUMN
10.19



TYPICAL FOUNDATION WALL AND SPREAD FOOTING DETAIL
10.20



FOUNDATIONS AT GRADE
10.21



FOUNDATION WALLS

Foundation walls are used where basements are not required and the need to support a limited load on firm soil exists. Typically, the excavation is to below frost depth or as required by the geotechnical engineer. The wall thickness is typically 8 in. but may be thicker if the wall it is supporting is thicker. Minimal amounts of reinforcing steel are required to limit cracking. Reinforcing requirements may increase as the height of the building wall increases.

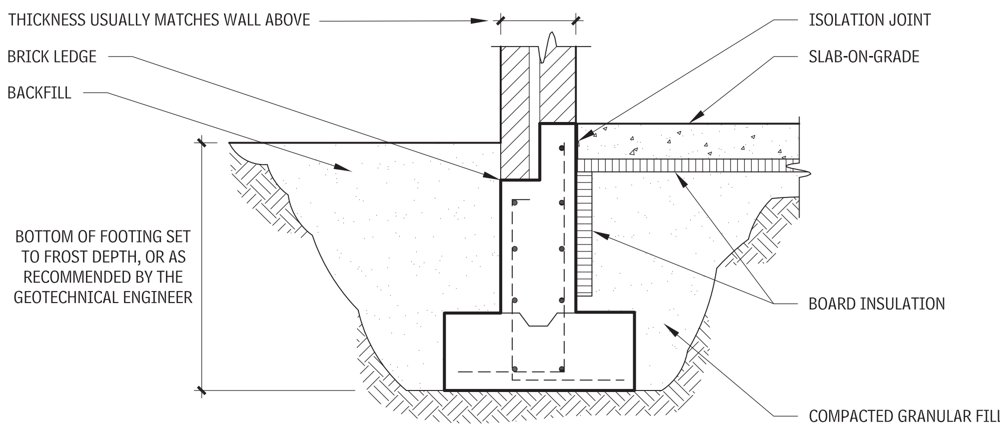
In colder climates, insulation is sometimes provided on the inside face of the foundation and under the slab to minimize the cold penetration to the interior.

When required, brick ledges need to be coordinated between grade elevation and desired brick coursing. Generally, an isolation joint is provided at the slab-wall interface to allow the slab and grade wall to settle independently.

Standard foundation walls may be constructed using concrete, masonry units, or wood.

Concrete unit masonry used in foundation wall construction should be laid on a clean footing. Mud, oil, dirt, ice, or other materials that reduce the bond should be removed prior to wall construction. To accommodate surface irregularities in the footing, set the first unit masonry course on a mortar bed ranging in thickness from 1/4 to 3/4 in. Fully bed the first course of unit masonry including webs;

CONCRETE FOUNDATION WALL
10.22



NOTES

10.19 a. Provide concrete fill after all dead load has been applied to column.
b. Thickness of non-shrink grout to accommodate unevenness of footing surface and leveling nuts.
c. Anchor bolts designed to resist moments and shears from axial loads, as well as lateral loads.

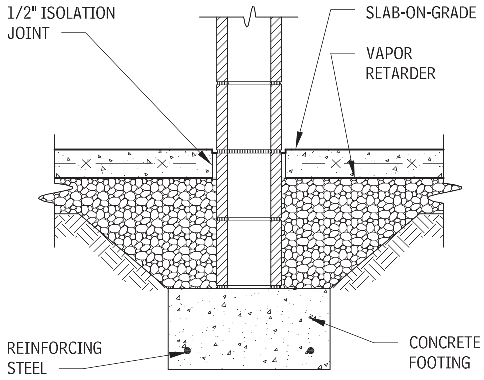
mortar should not protrude excessively into masonry cells that will be grouted. Many building codes require Type M or Type S mortar for use in foundation wall construction.

For reinforced construction, reinforcing steel must be properly located. In most cases, vertical reinforcing is positioned toward the interior face of below-grade walls to provide the greatest resistance to soil pressure.

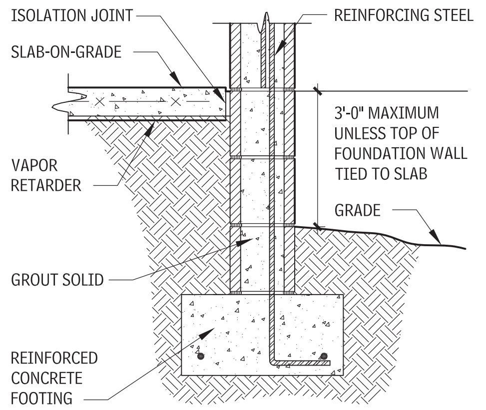
A solid top course on the below-grade concrete masonry wall spreads loads from the building above. Where only the top course is to be grouted, wire mesh or other equivalent grout stop material can be used to contain the grout.

For residential construction, anchor bolts are typically embedded 7 in. into the masonry, are 1/2 in. in diameter, and are spaced at a maximum of 6 ft. on center, to attach the home to the foundation. Wood in direct contact with masonry materials should be pressure-treated or naturally decay-resistant.

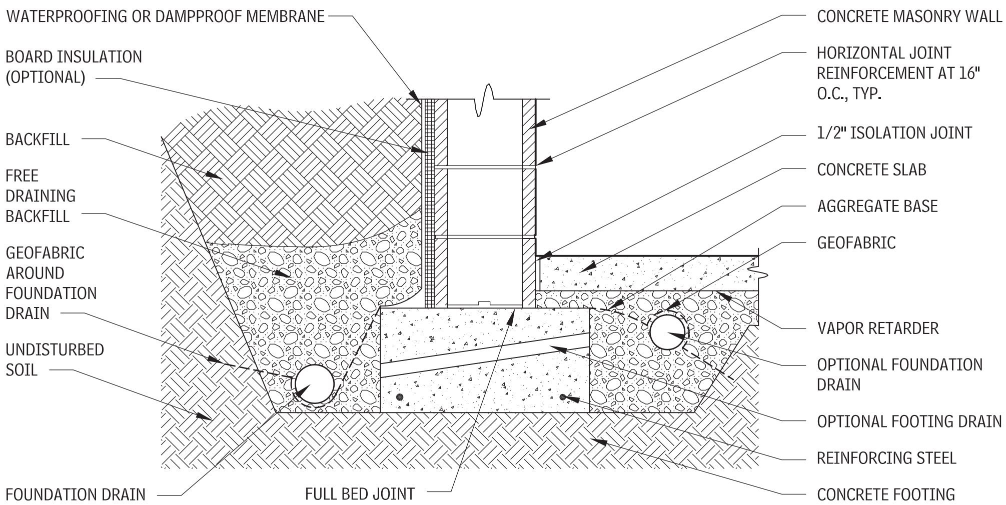
INTERIOR LOAD-BEARING CMU FOUNDATION WALL
10.25



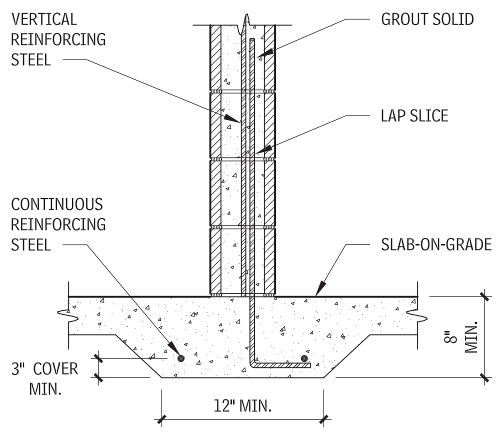
EXTERIOR LOAD-BEARING CMU FOUNDATION WALL
10.27



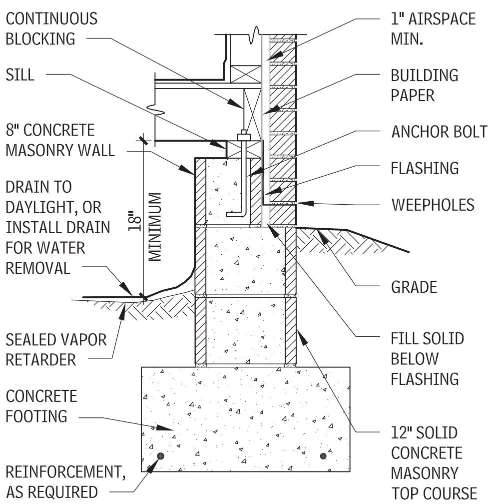
CMU FOUNDATION WALL AT BASEMENT
10.23



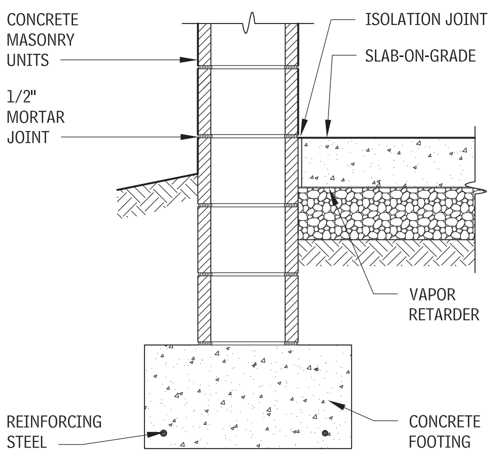
INTERIOR NON-LOAD-BEARING WALL
10.28



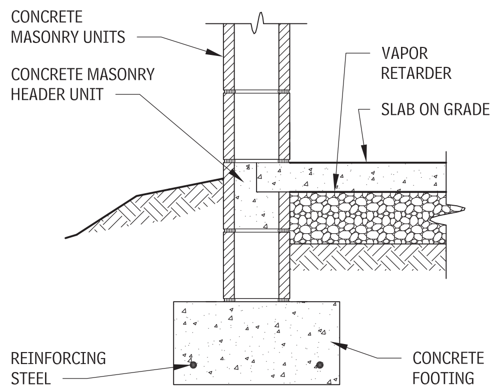
CMU FOUNDATION WALL AT CRAWL SPACE
10.24



FOUNDATION WALL DETAILS
10.26



FLOATING SLAB



SLAB–SUPPORTED ON HEADER BLOCK

NOTES

10.23 Based on NCMA Annotated Design and Construction Details for Concrete Masonry Figure 3E.1. Courtesy of National Concrete Masonry Association.
10.24 Based on NCMA Annotated Design and Construction Details for Concrete Masonry, Figure 3E.3. Courtesy of National Concrete Masonry Association.
10.25 Based on NCMA Annotated Design and Construction Details for Concrete Masonry Figure 3E.5. Courtesy of National Concrete Masonry Association.
10.26 Based on NCMA Annotated Design and Construction Details for Concrete Masonry, Figure 3E.7. Courtesy of National Concrete Masonry Association.
10.27 Based on NCMA Annotated Design and Construction Details for Concrete Masonry Figure 8B.1. Courtesy of National Concrete Masonry Association.
10.28 Based on NCMA Annotated Design and Construction Details for Concrete Masonry, Figure 8B.2. Courtesy of National Concrete Masonry Association.
a. Slab joints should be located away from thickened slab.
b. This detail is for relatively lightly loaded walls. Refer to Figure 10.38 for load-bearing interior foundation walls.

DEEP FOUNDATIONS

When the soil near the surface is not suitable to support the building loads, it is sometimes necessary to support the structure on deep foundations. There are several scenarios when a deep foundation makes more sense than a shallow foundation, including the following:

- If a suitable and reliable bearing stratum is at a much lower elevation.
- If scour from flowing water can occur at the surface.
- If the structure transmits great loads to the foundation.
- If the structure transmits tension loads to the foundation.
- If there are large horizontal loads transmitted to the foundation.
- If reducing settlement or differential settlement is crucial.

Deep foundations come in several types and, depending on the soil conditions, may include driven piles, bored piles (bored, augered, or drilled) or caissons.

DRIVEN PILES

Driven piles include concrete piles, steel piles, timber piles, and composite piles. The resistance to vertical compressive load typically results from friction along the sides and end bearing as these types of foundations are driven into the ground with a mechanical hammer. The geotechnical conditions that make driven piles advantageous include cohesionless soils with few boulders. Driven piles are selected over bored piles and caissons when groundwater or methane gas is present above the suitable bearing soil layer. These conditions make bored piles difficult and more costly than driven piles.

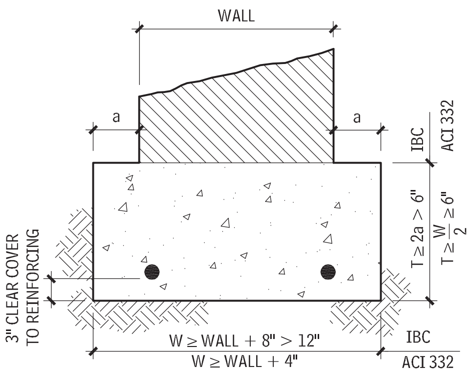
BORED PILES

Bored piles include auger cast grout piles, bored and socketed piles, bored concrete piles, drilled caissons, drilled concrete piers and shafts, and drilled micropiles. In a similar manner to driven piles, resistance to vertical loads typically results from a combination of end bearing and side friction. The geological conditions that make bored piles advantageous include: cohesive soils, obstructions that can be tolerated with the right size of drill, and a dense reliable bearing surface.

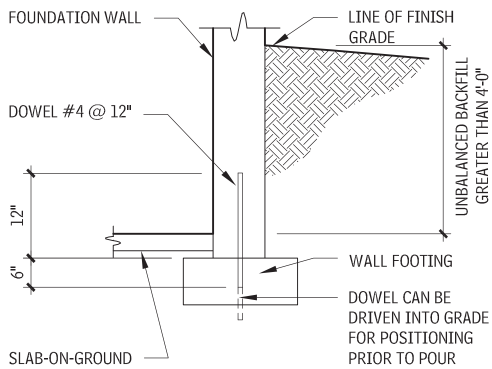
Bored piles are preferred over driven piles when:

- The loads are exceptionally high and the bearing surface reliable.
- Work is in close proximity to existing structures where vibration from driven piles may damage existing structures.
- Inspecting the bearing surface is important, and limited inspection of the bearing material is possible.

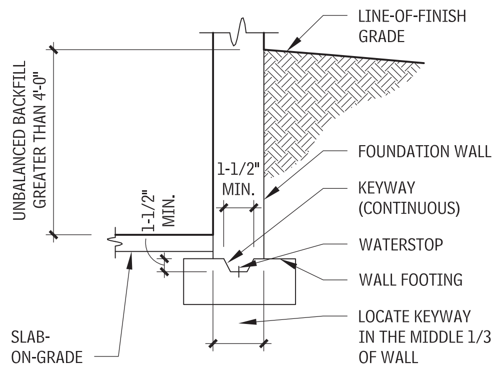
FOOTING MINIMUM DIMENSIONAL REQUIREMENTS
10.29



DOWEL AND KEYWAY REQUIREMENTS FOR FOOTINGS
10.30

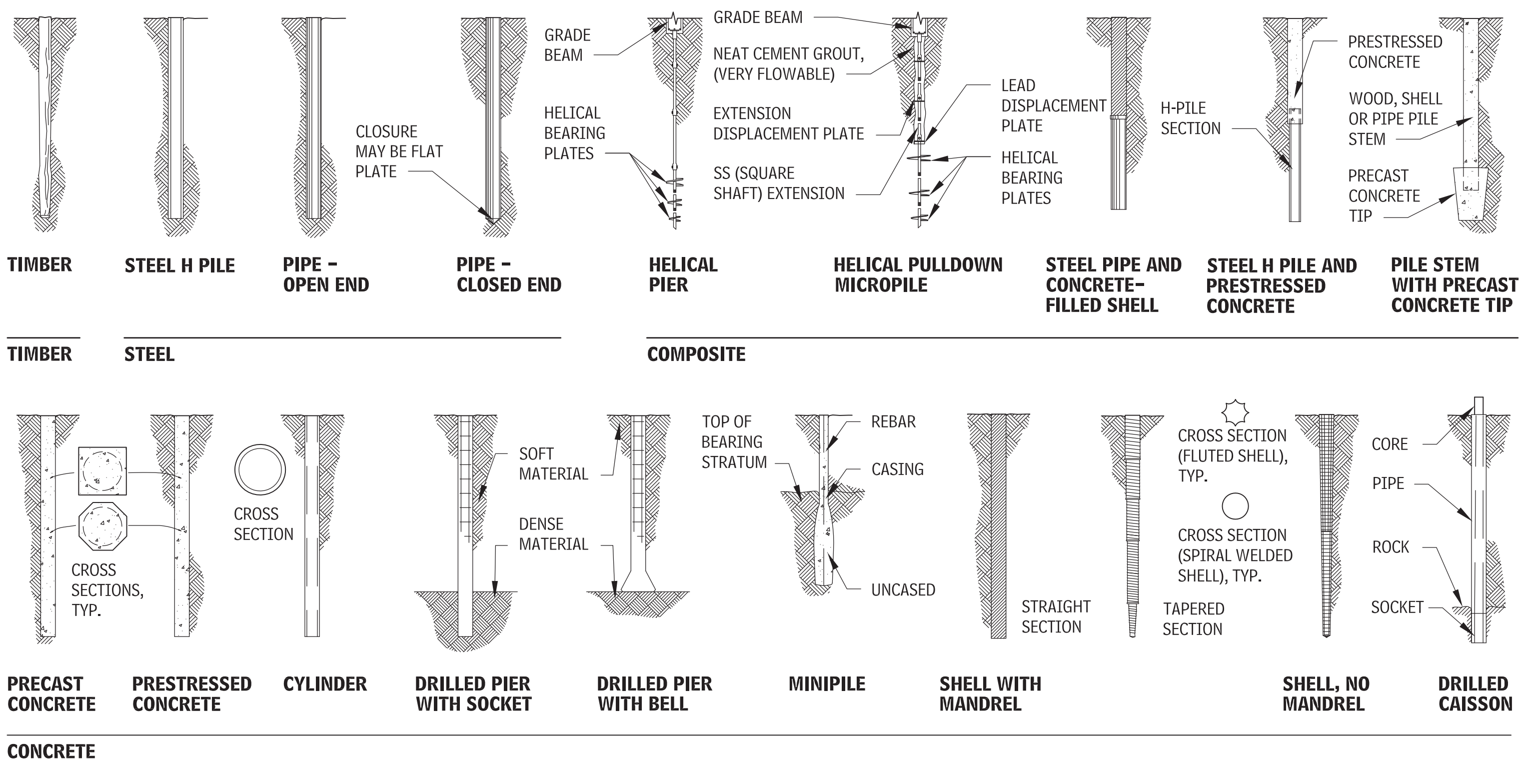


WALL-TO-FOOTING JOINT WITH DOWEL



WALL-TO-FOOTING JOINT WITH KEYWAY

PILE TYPES
10.31



NOTE

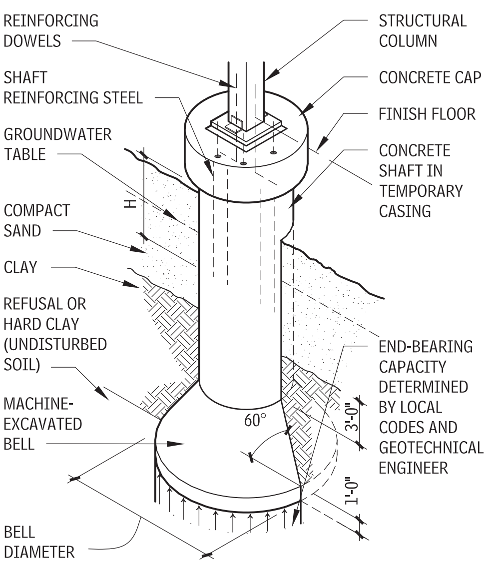
10.30 Based on ACI 332-04 Requirements for Residential Concrete Construction and Commentary, Figures R6.5 and R 6.6. Reprinted with permission of the American Concrete Institute.
10.31 Helical Pier and Helical Pulldown Micropile based on AB Chance, Centralia and Independence, Missouri.

GENERAL PILE DATA
10.32

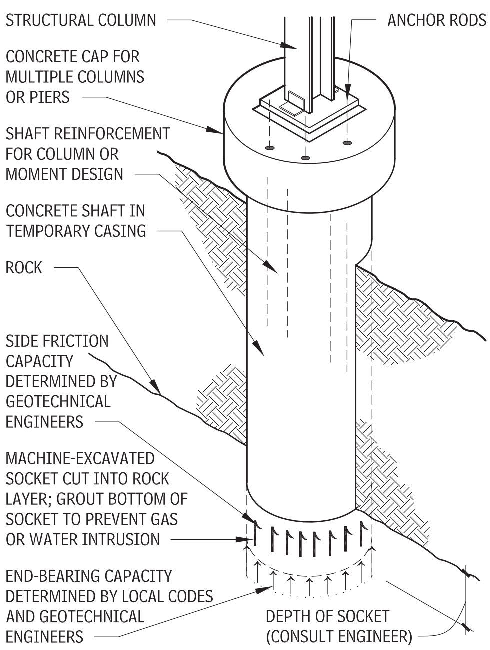
PILE TYPE	MAXIMUM LENGTH (FT)	OPTIMUM LENGTH (FT)	SIZE (IN.)	MAXIMUM CAPACITY (TONS)	OPTIMUM LOAD RANGE (TONS)	USUAL SPACING
TIMBER						
Timber	110	45–65	5–10 tip; 12–20 butt	40	15–25	2'–6" to 3'–0"
STEEL						
Steel H pile	250	40–150	8–14	200	50–200	2'–6" to 3'–6"
Pipe—open end, concrete-filled	200	40–120	7–36	250	50–200	3'–0" to 4'–0"
Pipe—closed end, concrete-filled	200	30–80	10–30	200	50–70	3'–0" to 4'–0"
Shell—mandrel, concrete-filled	100	40–80	8–18	75	40–60	3'–0" to 3'–6"
Shell—no mandrel, concrete-filled	150	30–80	8–18	80	30–60	3'–0" to 3'–6"
Drilled caisson, concrete-filled	250	60–120	24–48	3,500	1,000–2,000	6'–0" to 8'–0"
CONCRETE						
Precast concrete	100	40–50	10–24	100	40–60	3'–0"
Prestressed concrete	270	60–80	10–24	200	100–150	3'–0" to 3'–6"
Cylinder pile	220	60–80	36–54	500	250–400	6'–0" to 9'–0"
Drilled pier with socket	120	10–50	30–120	500	30–300	3'–0" to 8'–0"
Drilled pier with bell	120	25–50	30–120	500	30–200	6'–0"
Minipiles	200	25–70	2.5–7	100	5–40	2'–0" to 4'–0"
COMPOSITE						
Helical pier	120	20–70	1-1/2" sq. to 4-1/2 dia.	100	15–60	4'- 0" to 15'–0"
Helical pulldown micropile	100	20–70	4" dia. to 7" dia.	150	20–80	4'–0" to 15'–0"
Concrete—pipe	180	60–120	10–23	150	40–80	3'–0" to 4'–0"
Steel H–pile and prestressed concrete	200	100–150	20–24	200	120–150	3'–6" to 4'–0"
Pile stem with precast concrete tip	80	40	13–35 tip; 19–41 butt	180	30–150	4'–6"

Source: Helical Pier and Helical Pulldown Micropile information based on AB Chance, Centralia and Independence, Missouri.

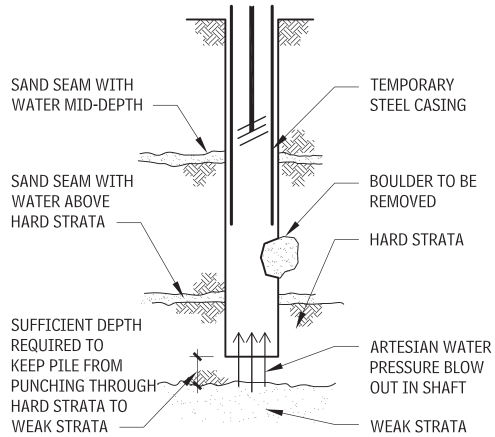
DRILLED PIER WITH BELL
10.33



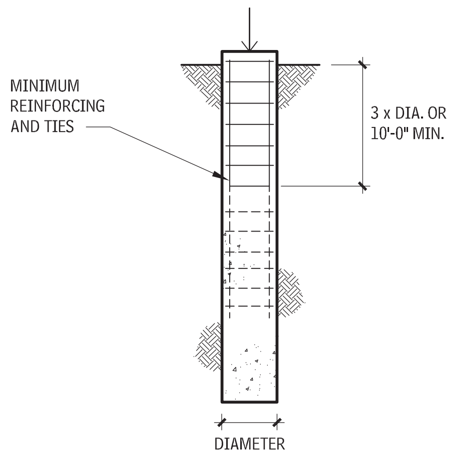
DRILLED PIER WITH SOCKET
10.34



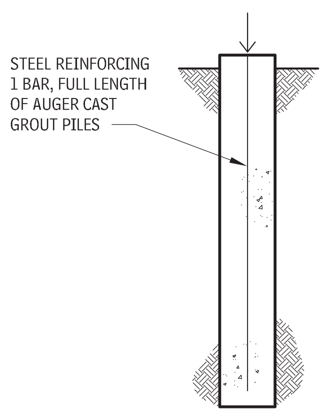
CONSTRUCTION ISSUES WITH DRILLED PIERS
10.35



REINFORCING AXIALLY LOADED DRILLED PIERS
10.36



DRILLED CONCRETE PIER



AUGER CAST GROUT PILE

NOTES

10.32 a. Applicable material specifications: Concrete ACI 318; Timber ASTM D25; Structural Sections ASTM A36, A572, and A690. For selection of type of pile, consult a geotechnical engineer.
b. A mandrel is a member inserted into a hollow pile to reinforce the pile shell while it is driven into the ground.
c. Timber piles must be treated with wood preservative when any portion is above the groundwater table.

10.33 a. Test soils to determine their allowable bearing capacity.
b. "H" (depth of shaft reinforcing, below concrete cap) is the function of the passive resistance of the soil, generated by the moment applied to the pier cap.
c. Piers may be used under grade beams or concrete walls. For very heavy loads, pier foundations may be more economical than piles.
10.34 a. Set pier into a socket in rock to transmit high compression or tension lads into rock by side friction and end bearing.
b. Pier shaft should be poured in dry conditions if possible, but tremie pours can be used.

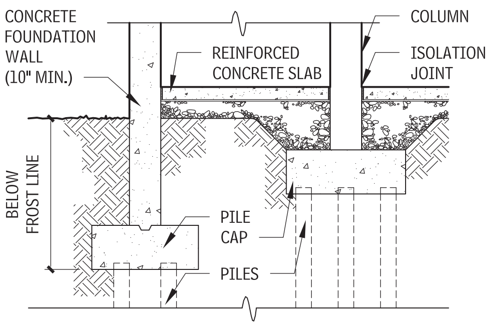
Contributors:
Mueser Rutledge Consulting Engineers, New York, New York; AB Chance/Atlas Systems, Centralia and Independence, Missouri; and John P. McCarthy, PE, SE, SmithGroup, Architects, Engineers, Interiors, Planners, Detroit, Michigan.

PILE CAPS

In most instances, more than one deep foundation element is required to resist the gravity and lateral loads. In order to distribute the loads from the single point column to the multiple foundation elements, a pile cap is required. Pile caps are thick, reinforced concrete blocks that distribute the load from the column to the foundations through a combination of flexure and shear.

Other applications of the pile caps include providing a method of connecting the columns to the foundations, and easing the construction tolerance issues that occur when installing deep foundations. These pile caps are designed and detailed to encase a small portion of the deep foundation, and transition to the column support elevation, thus providing a convenient location to position anchor bolts and column dowels.

PILE SUPPORTED FOUNDATIONS
10.37



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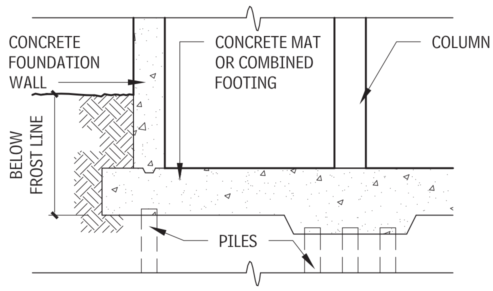

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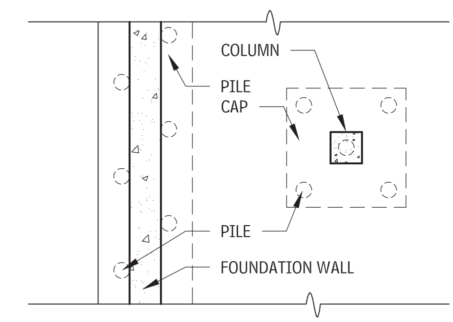
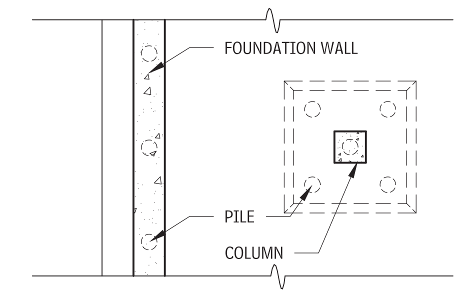
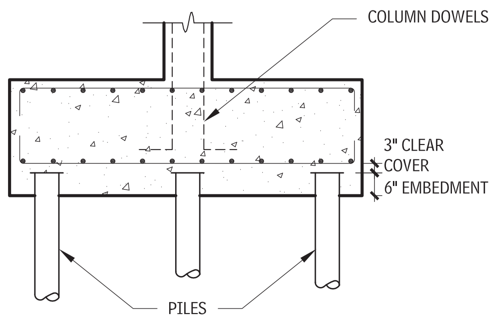


PLAN – INDIVIDUAL PILE CAPS



PLAN – MAT OR COMBINED FOOTING PILE CAPS

PILE CAP
10.38



DEEP FOUNDATION MEANS AND METHODS

DRIVEN PILES

Rams, called hammers, are used to drive piles to impart a vertical force to the top of the pile. Most hammers use a weight that is repeatedly lifted and dropped on top of the pile.

Several methods are used to lift the hammer or ram including mechanical, hydraulic, and pneumatic, driven devices. Vibratory hammers consist of eccentric weights that oscillate at a very high frequency, thus imparting a downward vibratory force to the pile. These are especially effective in granular soils. Vertical steel supports or leads are used to support the hammer and position the pile before and during driving. Crawler-type cranes are generally used to position the hammer leads over the pile locations.

BORED PILES

Bored piles use various types of boring equipment and tools to remove a cylindrical area of soil and replace it with a grout or concrete. The boring equipment is generally attached to a tracked or rubber-tired vehicle to allow easy access to the pile location. The drilling equipment uses a power source (gas engine, diesel engine, or electric motor) to turn either a continuous flight of augers or a short length of auger on the end of the steel shaft. The augers transport the soil to the ground surface, where the spoil is removed.

Cohesive soils generally allow an open excavation of a large drilled shaft without any additional support. In contrast, granular soils and some fill soils require the use of steel casings, or a drilling slurry for large shaft construction. Concrete or grout is placed in the excavated hole either by direct fall methods or by pumping or tremie methods.

DEEP FOUNDATION TESTING

Testing of deep foundations is conducted (and is often required) to verify the load capacity and structural integrity of deep foundation elements. Load testing of deep foundation shafts is sometimes done to provide greater design capacity than can be obtained with conventional analytical methods or with presumptive values commonly used in a particular region. Two common types of testing are:

- *Static load test:* This is the most common type of load test for a deep foundation. It consists of incrementally loading a pile with a static load at a specified rate, and measuring the movement of the pile. The pile is normally loaded to twice the design load of the pile, which will result in a minimum safety factor of 2. Compressive loading is the most common static load test, although tension and lateral load testing is sometimes performed if such loads are deemed critical to the structure.

- *Dynamic load test:* Piles can also be tested using dynamic loads. The pile dynamic analyzer (PDA) is a device that measures the response of a pile under a dynamic impact load such as the driving hammer. The results from the PDA are used to determine the most probable static load capacity for each strike of the hammer. A common analytical tool used to predict driven pile capacities is the wave equation. The hammer-pile-soil system is mathematically modeled in the computer program to simulate the driving of the pile. The output is the estimated ultimate capacity of the pile at various driving resistances, and the induced stresses in the pile at those resistances. This analytical tool is very useful for determining what size of pile, as well as what size and type of hammer, are required to achieve a desired capacity in the given soil profile.

RAFT FOUNDATIONS

MAT FOUNDATION

Mat foundations combine all the column loads and distribute them to the soil on a single large foundation. Mat foundations are used where the allowable soil-bearing pressures are low and the size of a single spread footing becomes excessive or overlaps adjacent footings. For structures that cannot tolerate differential settlement between columns, mat foundations become ideal. Structures that use mat foundations include chimneys, silos, and large pieces of equipment.

SEISMIC BASE ISOLATION

Base isolation of structures refers to the concept of detaching the structure from the foundation for the purpose of reducing the level of seismic forces imparted to the structure through horizontal ground-shaking by changing the dynamic characteristics of the structure. The separation of foundation and structure is accomplished by providing a flexible connection between the two that allows for horizontal movement of the foundation at a different frequency of that from the structure above. Energy-dissipating devices are used in conjunction with the isolators to control structural displacements.

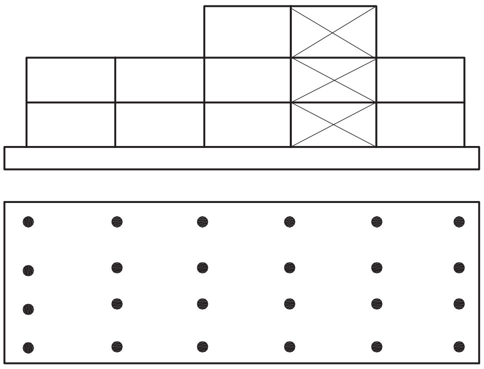
Reduced demands on the lateral force-resisting structural elements, including foundations, allows for a more economical design of these elements. By limiting the amount of force that is delivered to the structure, and by also limiting the amount of movement, damage to the structure, facade, and building contents is significantly lessened.

Base isolation of structures in high seismic regions is most appropriate for low- to midrise buildings, essential service buildings (such as hospitals and police and fire stations), and buildings with valuable contents (such as museums and scientific research facilities). Base isolation has been successfully used for both new and existing structures.

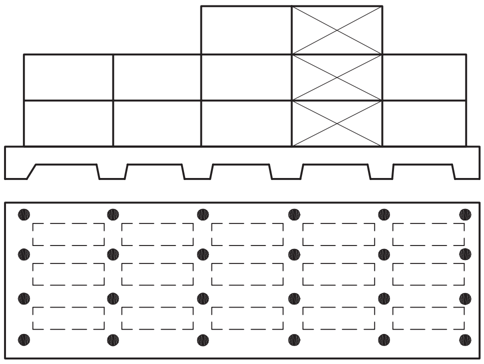
When using base isolation, it is important to ensure that the isolators are the only places where the building touches the surrounding earth. This is normally accomplished by positioning the building in a large, excavated area, and connecting the building to the surrounding ground with flexible "bridges." The base isolators are usually located in a subbasement dedicated to their use.

A recent variation of base isolation is offered by a family of devices that absorb or dissipate energy and change the response of a structure to seismic activity. These devices are most useful for retro existing structures without the need for an entirely new structural system.

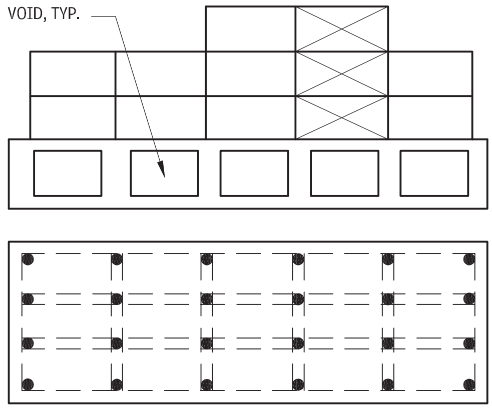
TYPICAL MAT FOUNDATIONS
10.39



FLAT PLATE

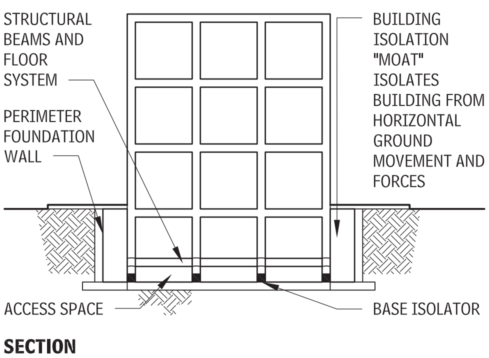


TWO WAY SLAB AND BEAM



CELLULAR

BASE ISOLATION
10.40



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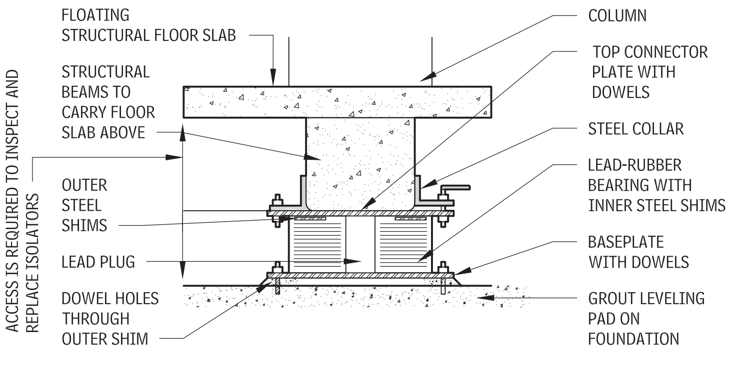


DETAIL

Contributors:
Sidney Freedman, Precast/Prestressed Concrete Institute, Chicago, Illinois; William W. Stewart, FAIA, Stewart-Schaberg Architects, Clayton, Missouri; James Kellogg, AIA, Senior Vice President, Best Practices Director, HOK, San Francisco, California; and SmithGroup, Architecture, Engineering, Interiors, Planning, Detroit, Michigan.

CAST-IN-PLACE CONCRETE SLAB

GENERAL

Factors to be considered in the design and construction of cast-in-place concrete slab, often known as slab-on-grade, include the intended use, base and subbase materials, concrete thickness, concrete compressive or flexural strength, concrete mix design, joint locations, reinforcement, surface finish and treatment, curing, and joint-filling materials and installation.

SUBGRADE

Slab-on-grade design should be based on adequate geotechnical information. The capability of a slab to support loads depends on the integrity of both slab and soil support. The common classifications

CLASSES OF FLOORS ON THE BASIS OF INTENDED USE AND SUGGESTED FINAL FINISH TECHNIQUE
10.41

CLASS	SLUMP[a]	CONCRETE STRENGTH[b]	ANTICIPATED TYPE OF TRAFFIC	USE	SPECIAL CONSIDERATIONS	FINAL FINISH
1. Single course	5”	3000 psi	Exposed surface—foot traffic	Offices, churches, commercial, institutional, multiunit residential	Uniform finish, nonslip aggregate in specific areas, curing	Normal steel-troweled finish, nonslip finish where required
				Decorative	Colored mineral aggregate, color pigment or exposed aggregate, stamped or inlaid patterns, artistic joint layout, curing	As required
2. Single course	5”	3000 psi	Covered surface—foot traffic	Offices, churches, commercial, multiunit residential, institutional with floor coverings	Flat and level slabs suitable for applied coverings, curing. Coordinate joints with applied coverings.	Light steel-troweled finish
3. Two-course	5”	3000 psi	Exposed or covered surface—foot traffic	Unbonded or bonded topping over base slab for commercial or non-industrial buildings where construction type or schedule dictates	Base slab—good uniform level surface tolerance; curing	Base slab—troweled finish under unbonded topping; clean, textured surface under bonded topping
					Unbonded topping—bond breaker on base slab, minimum thickness 3”, reinforced; curing	Topping—for exposed surface, normal steel-troweled finish; for covered surface, light steel-troweled finish
					Bonded topping—properly sized aggregate, 3/4” minimum thickness; curing	
4. Single course	5”	3500 psi	Exposed or covered surface— foot and light vehicular traffic	Institutional or commercial	Level and flat slab suitable for applied coverings; nonslip aggregate for specific areas; curing. Coordinate joints with applied coverings.	Normal steel-troweled finish
5. Single course	5”	3500 psi	Exposed surface—industrial vehicular traffic (i.e., pneumatic wheels and moderately soft solid wheels)	Industrial floors for manufacturing, processing, and warehousing	Good uniform subgrade, joint layout, abrasion resistance, curing	Hard steel-troweled finish
6. Single course	5”	3500 psi	Exposed surface— heavy-duty industrial vehicular traffic (i.e., hard wheels and heavy wheel loads)	Industrial floors subject to heavy traffic; may be subject to impact loads	Good uniform subgrade, joint layout, load transfer, abrasion resistance, curing	Special metallic or mineral aggregate surface hardener; repeated hard steel troweling
7. Two-course	5”	3500 psi	Exposed surface—heavy-duty industrial vehicular traffic (i.e., hard wheels and heavy wheel loads)	Bonded two-course floors subject to heavy traffic and impact	Base slab—good uniform subgrade, reinforcement, joint layout, level surface, curing	Clean, textured base slab surface suitable for subsequent bonded topping. Special power floats for topping are optional; hard steel-troweled finish
					Topping—composed of well-graded all-mineral or all-metallic aggregate; minimum thickness 3/4”. Mineral or metallic aggregate surface hardener applied to high-strength plain topping to toughen; curing	
8. Two-course	3”	4000 psi	As in Classes 4, 5, or 6	Unbonded topping—on new or old floors where construction sequence or schedule dictates	Bond breaker on base slab, minimum thickness 4”, abrasion resistance, curing	As in Classes 4, 5, or 6
9. Single course or topping	5”	4000 psi	Exposed surface—superflat or critical surface tolerance required. Special materials-handling vehicles or robotics requiring specific tolerances	Narrow-aisle, high-bay warehouses; television studios, ice rinks, or gymnasiums. Refer to ACI 36OR for design guidance	Varying concrete quality requirements. Special application procedures and strict attention to detail are recommended when shake-on hardeners are used. F_F 50 to F_F 125[C] (“superflat” floor); curing	Exposed surface—superflat or critical surface tolerance may be required Refer to ACI 302.1R Guide for concrete floor and slab construction Section 8.9.

Source: Based on ACI 302.1R-04 Guide for Concrete Floor Construction and Slab Construction, Table 2.1; reprinted with permission of the American Concrete Institute.

NOTES

10.41 a. Slump is assumed to be achieved using a Type A water-reducing admixture.
b. Compressive strength at 28.
c. F_F = floor flatness index.

encountered in slab-on-grade design delineate soil according to grain size, moisture content, plastic, and liquid limit. Atterberg plastic and liquid limits indicate the percentage of moisture where soil acts as a semisolid, or acts as a liquid, and will affect capacity and performance of the slab. Unified soil classifications are the most recognized and preferred by geotechnical firms. The base material should be compactable and well drained and provide uniform load-bearing support; coarse-grained materials are most likely to be specified for this application. Soil materials designated as fine-grained are generally associated with either a high degree of compressibility or instability resulting from volume changes, and may allow the floor slab to settle or sink over a long period. When fine-grained soils are encountered, input from the geotechnical engineer is advised.

CONCRETE MIX

The performance of concrete slabs depends on the specific characteristics of ingredients; therefore the concrete mix design must be reviewed for strength, shrinkage, finishability, and durability. The Portland cement content and the content of other cementitious products, if used, should be sufficient for finishability and durability, per ACI 301. The setting characteristics of concrete should be relatively predictable, and concrete should not experience excessive retardation and surface crusting. Concrete floors exposed to freezing and thawing should have water/cementitious ratios of no more than 0.5, and if subjected to deicing chemicals, of no more than 0.45. Concrete in these exposure conditions should also have air contents between 4 and 7 percent.

SLAB REINFORCEMENT

Reinforcement in slabs, including reinforcing bars, welded wire fabric, steel or synthetic fibers, is provided primarily to control the width of cracks caused by shrinkage. Only when reinforcing steel is properly sized and placed can the effect of shrinkage cracks be controlled. The best way to reduce or prevent shrinkage cracking is to pay close attention to the smoothness of the base, the quality of the concrete, the curing process, and the joint spacing and timing of the joint cutting.

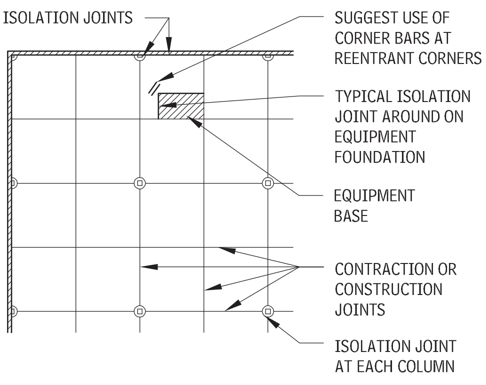
VAPOR RETARDERS

ACI 302 recommends a minimum of 10-mil thickness for vapor retarders. This material will limit vapor transmission from the soil support system through concrete slabs, which can adversely affect moisture-impermeable or moisture-sensitive floor finishes. ACI 302 recommendations regarding where to place the vapor retarder are governed by local conditions and construction sequences.

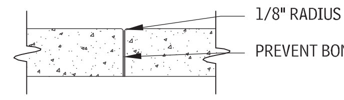
JOINTS

Joints in the concrete slab-on-grade are provided to reduce the frequency and width of random cracks caused by concrete shrinkage, or to allow for the practical limits of concrete placement.

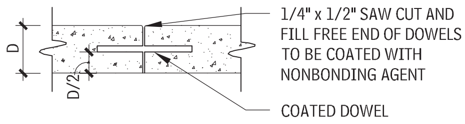
APPROPRIATE LOCATIONS FOR JOINTS
10.42



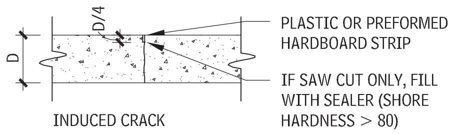
TYPICAL JOINT DETAILS
10.43



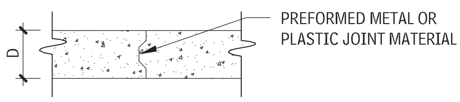
BUTT JOINT CONSTRUCTION JOINT



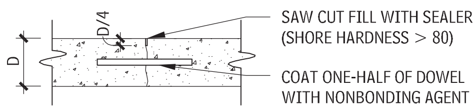
BUTT-TYPE CONSTRUCTION JOINT WITH DOWELS



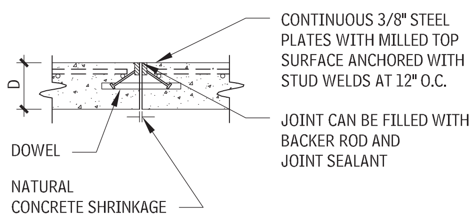
SAWED OR PREMOLDED CONTRACTION JOINT



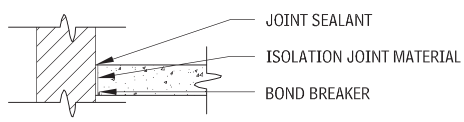
TONGUE-AND-GROOVE JOINT



CONTRACTION JOINT WITH DOWELS



TYPICAL ARMORED CONSTRUCTION JOINT DETAIL

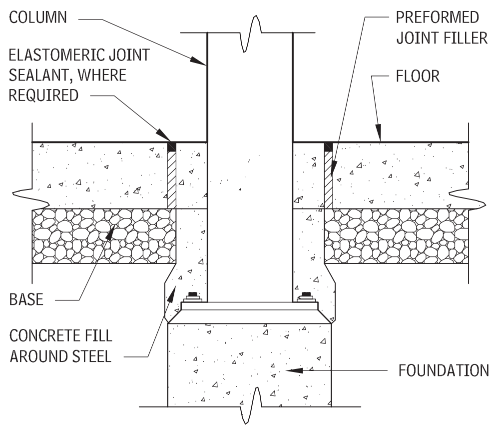


ISOLATION JOINT

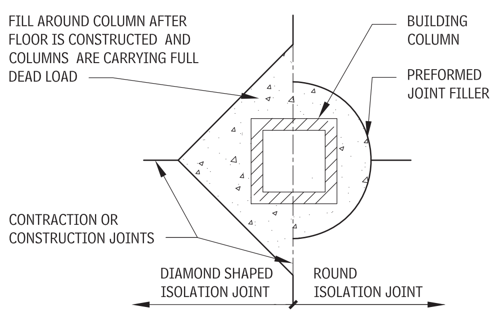
Expect some cracking in concrete construction. Generally, cracking is controlled with joints and reinforcement. However, not all cracks indicate errors or performance problems, and not all cracks need to be repaired. These types of joints are classified as one of the following:

- *Isolation joints:* Allow complete freedom of horizontal and vertical movement between the floor and adjoining walls not requiring lateral restraint from the slab, columns, equipment foundations, or other points of restraint (such as drains, manholes, sumps, and so on).
- *Construction joints:* Define the extent of the individual placement of concrete, generally in conformity with a predetermined joint layout. These can also function as contraction or isolation joints.
- *Contraction (control) joints:* Induce cracking at preselected locations, usually at column lines, with intermediate joints located at equal spaces between column lines. Spacing of contraction joints depends on the method of design, slab thickness, type and amount of reinforcement, base friction, layout of foundations, and curing, among other items. Saw-cut contraction joints should be made as early as practical after finishing the slab; and in areas with wet conditions, hygienic and dust control requirements, or where the floor is subjected to traffic by hard-wheeled vehicles such as forklifts, they should be filled. A semirigid filler with a Shore Hardness "A" of at least 80 should be used in joints supporting forklift traffic.

TYPICAL ISOLATION JOINTS AT TUBE COLUMNS
10.44



SECTION



PLAN

NOTES

10.42 Based on ACI 302.1R-04 Guide for Concrete Floor Construction and Slab Construction, Figure 3.2. Reprinted with permission of the American Concrete Institute.
10.43 Based on ACI 302.1R-04 Guide for Concrete Floor Construction and Slab Construction, Figure 3.15. Reprinted with permission of the American Concrete Institute.
10.44 Based on ACI 302.1R-04 Guide for Concrete Floor Construction and Slab Construction, Figure 3.3. Reprinted with permission of the American Concrete Institute.

FINISH AND FLOOR FLATNESS

In general, concrete floor slabs are monolithically finished by floating and troweling, to achieve a smooth and dense surface finish. ACI 302 provides guidance for appropriate finishing procedures to control achievable floor flatness. ACI 302, ACI 360, and ACI 117 provide guidance for flatness selection, as well as techniques by which flatness and levelness are produced and measured.

Floor finish tolerance is measured by placing a freestanding 10-ft straightedge on the slab surface, or by F-Numbers. The preferred method of measuring flatness and levelness is the F-Number System. Special finishes are available to improve appearance, as well as surface properties. These include sprinkled (shake) finishes or high-strength toppings, either as monolithic or separate surfaces.

TYPES OF SLABS-ON-GRADES

There are six identifiable slab types that are commonly used per ACI 360:

- *Type 1, Plain concrete slab:* This type contains no reinforcement or fibers. Joint spacings are 24 to 36 times the slab thickness. Up to a maximum of 18 ft. is recommended to reduce shrinkage cracking.
- *Type 2, Slab-reinforced for shrinkage:* Shrinkage cracking is controlled by a nominal amount of distributed reinforcement or steel fibers to hold tightly and prevent cracks that may develop between joints. Joint spacing is usually the same or slightly larger than Type 1 concrete slabs.
- *Type 3, Shrinkage-compensating concrete slab:* The shrinkage-compensating concrete used in this slab contains an expansive admixture or Type K concrete with reinforcing, which is placed in the upper half of the slab to limit the initial slab expansion and to restrain the slab's subsequent drying shrinkage. Joints can be spaced farther apart than in Type 1 or 2 slabs.
- *Type 4, Slab post-tensioned to offset shrinkage:* These slabs contain post-tensioning tendons intended for crack control. The prestressing force allows a wide spacing of construction joints with no intermediate contraction joints.
- *Type 5, Slab post-tensioned and/or reinforced with active prestress:* These slabs are designed following the Post-Tension Institute's procedures using active prestress, which permits thinner slabs. They are reinforced with post-tensioning tendons and mild steel reinforcement, and incorporate monolithic beams to increase the rigidity of the section. In addition, these slabs are designed to accept structural edge loading from building superstructures, as well as to resist the forces caused by swelling or shrinking of unsuitable soils.
- *Type 6, Structurally reinforced slabs:* These slabs are designed as reinforced concrete slabs to allow cracking at some predetermined level of loading.

SUBDRAINAGE

Subdrainage is a very different engineering design from surface drainage. Surface drainage intercepts and collects stormwater runoff and conveys it away from a building and site with the use of large inlets and storm drains. Subsurface drainage typically is smaller in size and capacity, designed to intercept the slower underground flows of a natural groundwater table, underground stream, or infiltration of soils from surface sources. Surface and subsurface drainage typically requires discharge either through a pumping station or by gravity.

Please see section Site Civil Utilities - Subsurface Drainage Systems, images 16.106 through 16.111 for perimeter building foundation drainage systems and details.

CRACKING IN CONCRETE CONSTRUCTION[a]
10.45

	SLABS ON GRADE				BEAMS, WALLS, COLUMNS, AND STRUCTURAL SLABS			
	SURFACE CRAZING	PLASTIC SHRINKAGE	EARLY CONCRETE VOLUME CHANGES (DRYNG SHRINKAGE)	OTHER CRACKING[b]		SETTLEMENT CRACKS		OTHER CRACKING[b]
Cause	Shrinkage of cement paste at exposed concrete surfaces due to concrete mix, too-wet excessive bleeding, overtroweling surface, or rapid drying of surface.	Water at the concrete surface evaporates too rapidly due to job-site conditions such as low humidity, high wind speeds, high concrete temperatures, or high to moderate air temperatures.	As concrete cools and hardens, concrete volume shrinks; cracking will occur if slab is restrained at any point.	Subgrade settlement	Premature excessive loading on slab	Same as for slabs on grade; also, heavier amounts of reinforcement and nature of formed or shored construction	Flexible forms and insufficient vibration can increase likelihood.	Subgrade or formwork settlement, early volume changes, construction overloads, errors in design and detailing
Effect	Unsightly crazing of surface layer, although surface is probably sound	Parallel cracking, fairly wide at the exposed surface but shallow; doesn't typically extend to slab edge. Crack spacing and length vary greatly.	Random or regularly spaced cracks, usually passing completely through slab; during saw cutting of joints, crack may jump ahead of saw cut	Slab will bend and crack	Punch-through at edge by heavy equipment, etc.	Longitudinal cracks develop over reinforcement bars; can cause reinforcement bar corrosion		General cracking
Preventive measures	Reduce amount and rate of shrinkage at concrete surface by avoiding wet mixes, limiting bleeding by increasing sand or air content, limiting troweling or not troweling too early, or curing as soon as possible.	Reduce rate at which surface moisture evaporates by erecting windbreaks or building walls before slab, avoiding wet mixes, dampening subgrade before concrete placement, curing as soon as possible, or avoiding vapor barrier under slab unless necessary.	Not always preventable; careful joint design or reinforcement may help. Other measures: tool or saw cut joints 1/4 of slab thickness, min.; time saw cut according to concrete curing rate; locate contraction joints at column lines, min.; for unreinforced slabs, space joints at 24 to 36 times slab thickness, max.; post-tension at slab; isolate slabs from adjoining structures with preformed joint filler or if continuity is required, increase slab reinforcement.	Compact subgrade well	Generally, curing periods of 4 to 7 days, followed by 1 to 2 days of drying	Proper form design and sufficient vibration or revibration: use lowest possible slump and increase concrete cover.		Consult with structural concrete engineer or consultant to prevent

NOTES

10.45 a. Expect some cracking in concrete construction. Generally, cracking is controlled with joints and reinforcement; however, not all cracks indicate errors or performance problems, and not all cracks need to be repaired.
b. Other causes for cracking include: thermal cracking, D-cracking, cracking due to ASR, or corrosion of reinforcement.

CRAWL SPACE CONSTRUCTION

CRAWL SPACE INSULATION AND VENTILATION

The best understanding of the interrelated issues surrounding control of heat, air, and moisture (HAM) inside crawl spaces and the transfer of HAM to the building interior suggests that it is preferable to treat the crawl space as part of the interior conditioned environment.

Arguments against ventilating crawl spaces include:

- Venting of a crawl space is meant to keep moisture within acceptable levels; pulling hot, humid air into the space is counterproductive, especially when it is likely that the ground surface temperatures may be below the dew point temperature.
- Insulated floor assemblies are rarely constructed airtight and allow air infiltration/exfiltration.
- Insulated floor assemblies are rarely as warm or as comfortable as floors with a conditioned environment on both sides.
- Conditioned spaces above hot, humid, ventilated crawl spaces create a vapor drive, which may result in excess load on the HVAC, uncontrolled condensation, and potentially rot and mold.
- Crawl spaces are frequently used for distribution of mechanical ductwork. The distribution ductwork is outside of the thermal envelope and, therefore, experiences greater loss than if interior to the thermal envelope. The penetrations required for the ductwork create more opportunities for air leakage between the conditioned and unconditioned space. In hot, humid conditions, there is a likelihood that the vapor retarder on the duct insulation will not be perfect, causing condensation on the ductwork to occur, thereby adding more moisture to an already damp environment.
- Sanitary sewer and domestic water supply lines likely pass through the unconditioned crawl space and may be susceptible to freezing and condensation.

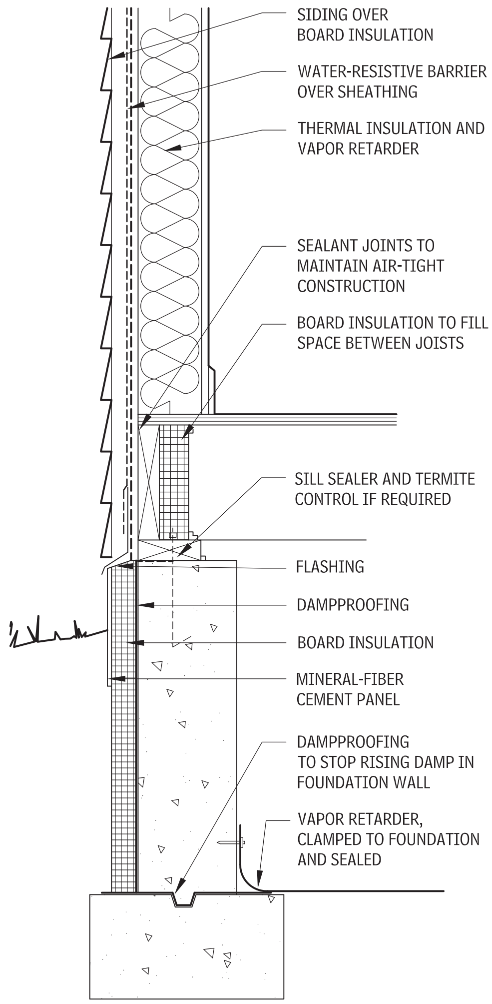
Recommendations for crawl spaces include the following:

- Codes generally require ventilation of crawl spaces; however, they also provide exemptions for a variety of conditions, specifically: "where warranted by climatic conditions," "where continuously operated mechanical ventilation is provided," and "when the perimeter walls are insulated." Most exemptions require the ground surface to be covered with a vapor retarder. Refer to the specific building codes in effect for all requirements.
- Cover the ground surface in the crawl space with a vapor retarder. Tape seams and seal penetrations. Consider protecting the vapor retarder with a rough concrete mud slab. Mechanically fasten the retarder to the foundation at the perimeter with a nailing strip. In cold climates, it may be desirable to insulate the entire ground surface.
- Insulate the crawl space walls as required by code. Follow recommendations for exterior walls regarding the permeability of insulation materials, air sealing, and the use of vapor retarders. Insulation may need to be fire-rated, especially board insulation; or use noncombustible-type insulation. If possible, locate insulation outside of the dampproofing on the foundation wall.
- Ventilate the crawl space, typically with a small supply duct at code-specified rate, normally 1 cfm for each 50 sq. ft., and provide connection to the return air plenum, either directly through the interior space above via transfer grilles. Locate the supply and return points to evenly mix and distribute the air
- Alternative crawl space drying methods include a permanent dehumidifier or exhaust fans controlled by humidistats, with makeup air from the interior and ducted to the exterior. However, this solution may use a large amount of energy.
- Pay attention to exterior wall detailing and proper drainage to keep water away from the crawl space.
- Crawl spaces used as the supply plenum to the remainder of the house require special treatment to maintain air quality.

Two primary difficulties encountered with the insulation of floor assemblies are providing a continuous vapor retarder on the warm side, and keeping the floor warm, even with insulation. In cold climates, the floor will be uncomfortable for any long-term occupancy. If possible, it is best to avoid insulation applied directly to the bottom of floor assemblies; instead, use an insulated soffit. If direct application is unavoidable, consider the following two methods:

- Board insulation is typically applied to the underside of the structure by impaling over adhesive-applied stickpins and crimped with large washers. Mineral wool insulation is a good choice because it is noncombustible and performs well even if it becomes slightly damp from condensation.
- Sprayed insulation can be cellulose-based, mineral-based, or foam. Closed-cell foam can eliminate the need for a separate vapor barrier.
- Consult the following reference: *www.buildingscience.com*.

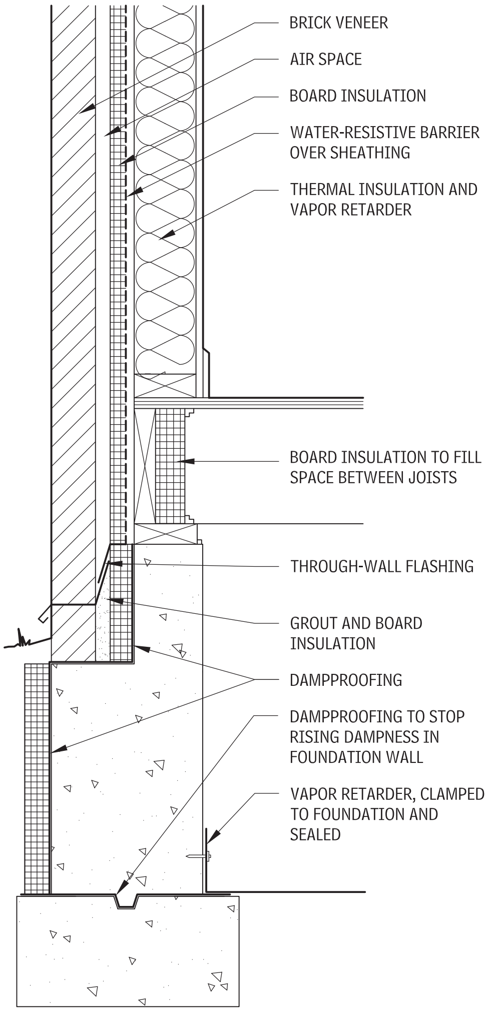
WOOD FRAME OVER CRAWL SPACE (COLD CLIMATE)
10.46



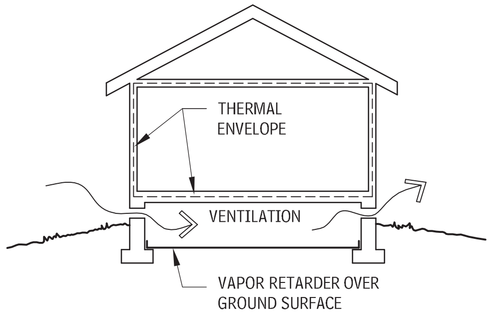
NOTE

10.46 These cementitious reinforced panels are most commonly used in noncombustible-type construction.

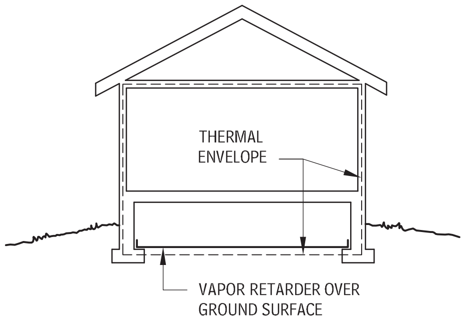
WOOD FRAME OVER CRAWL SPACE (MIXED CLIMATE)
10.47



VENTILATED CRAWL SPACE
10.48



CONDITIONED CRAWL SPACE
10.49



BASEMENT CONSTRUCTION

In residential construction, particularly in the colder climates, basements are inexpensive spaces, because the frost depths require excavations deep enough that a little more excavation can result in a habitable area, providing space for the utilities and warmth for the first floor.

In commercial construction, basements are sometimes provided for the mechanical and electrical facility services. Basements can also be economical if a relatively thin layer of poor soil is encountered. The cost of removing and replacing the poor soil can be offset by the excavation and installation of a basement.

BASEMENT WALLS

Basement walls may be constructed of various materials, including, concrete, masonry, and wood.

BASEMENT WALL CONSTRUCTION

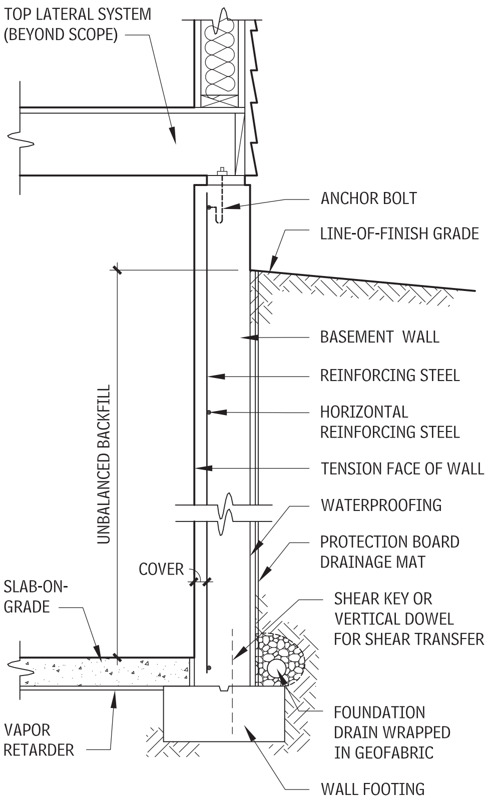
CONCRETE BASEMENT WALLS

Concrete basement walls may be either cast-in-place or precast. Cast-in-place concrete basement walls provide a cost-effective means of supporting a floor and resisting soil pressures. Commercial and residential applications of concrete basement walls are prevalent. Forms are easily placed in the excavation on the footings. Reinforcing steel may be tied on- or off-site, and is placed within the wall formwork. Depending on the soil and groundwater conditions, dampproofing should typically be used on foundation walls and waterproofing is generally required on basement walls prior to backfilling. Unless lateral bracing is utilized, the top of the basement wall must be supported by the first floor and the base of the wall by the footing or slab-on-grade before backfilling against the wall can begin. Keeping the wall heights uniform, as well as reducing the number of penetrations and maintaining a simple plan configuration, will help reduce the final cost of the wall.

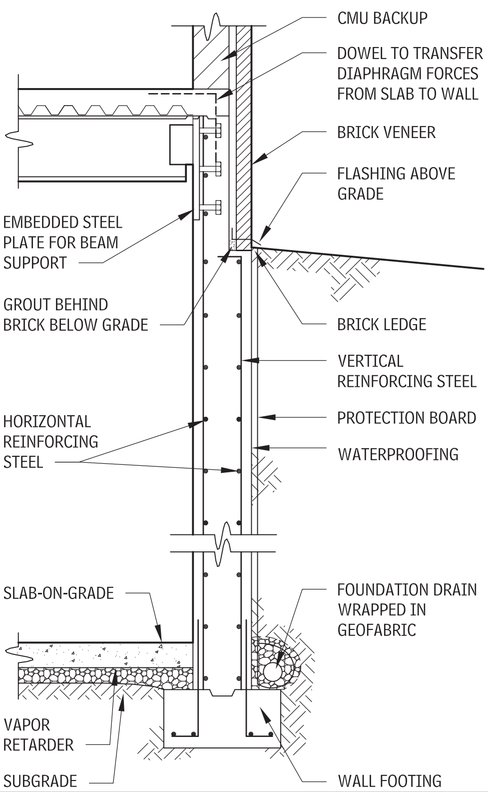
Precast concrete basement walls enable basement construction in less time than conventional cast-in-place concrete. In addition to time and construction methods other advantages of precast concrete include the ability of the precast supplier to utilize concrete admixtures that focus on ultimate strength, rather than cure time and temperature. Precast manufacturers are able to produce mixes that cure to 5000 psi, which is stronger than concrete unit masonry or cast-in-place concrete walls. Additionally, better control of the concrete mixture and curing environment allows the use of low water/cement ratios, which results in a dense material that reduces water penetration.

Contributors:
Joe Lstriburek, Building Sciences Corporation, Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland; Eric Gastier, Alexandria, Virginia.
American Concrete Institute; Grace S. Lee, Rippeteau Architects, PC, Washington, DC; Stephen S. Szoke, PE, National Concrete Masonry Association, Herndon, Virginia; Daniel Zechmeister, PE, Masonry Institute of Michigan, Livonia, Michigan; Paul Johnson, AIA, Senior Architect, SmithGroup, Detroit, Michigan.

CONCRETE BASEMENT WALLS - RESIDENTIAL CONSTRUCTION
10.50



CONCRETE BASEMENT WALLS - COMMERCIAL CONSTRUCTION
10.51



MASONRY BASEMENT WALLS

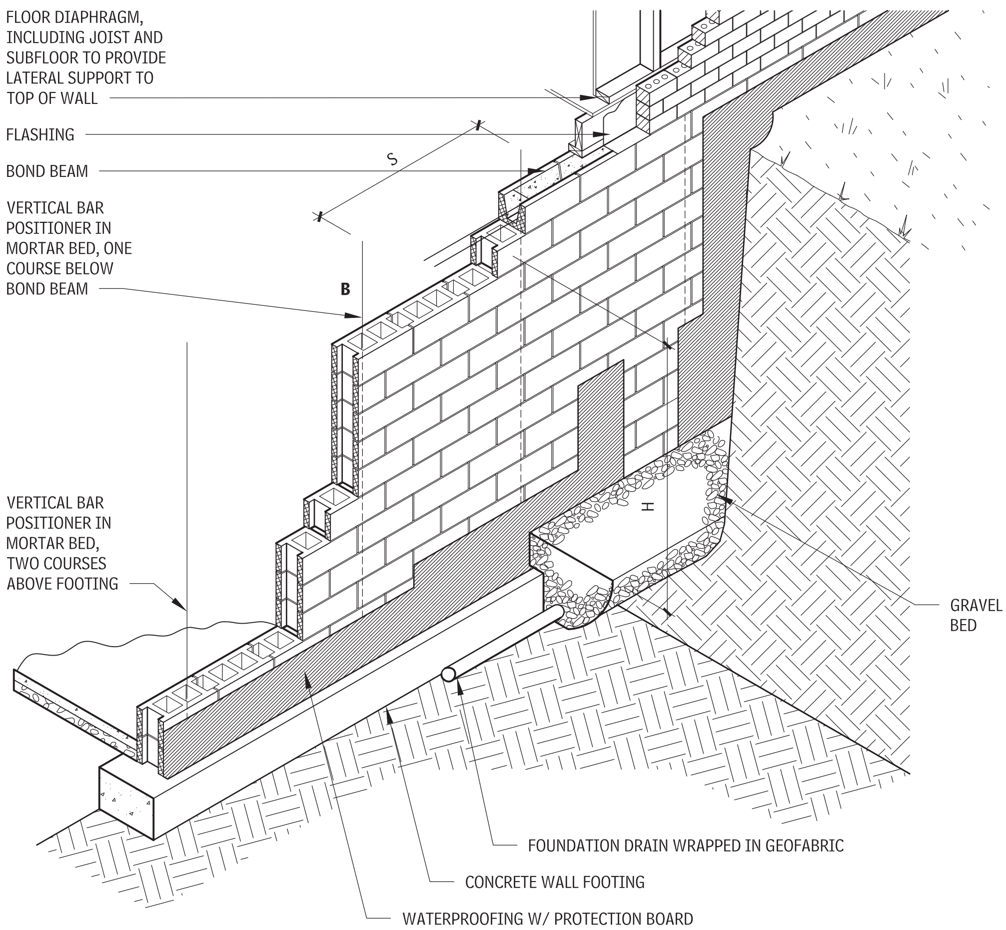
Masonry walls have long served as foundations for structures. Today, most masonry basement walls consist of a single wythe, hollow, or solid concrete masonry units, depending on the required bearing capacity. The walls are reinforced as necessary to resist lateral loads. Generally, such reinforcing should be held as close to the interior face shell as possible, to provide the maximum tensile strength.

THICKNESS OF CMU BASEMENT WALLS
10.52

BASEMENT WALL CONSTRUCTION	NOMINAL THICKNESS (IN.)	MAXIMUM DEPTH OF UNBALANCED FILL (FT)
CMU—hollow units, ungrouted	8	5
	10	6
	12	7
CMU—solid units	8	5
	10	7
	12	7
CMU—hollow or solid units, fully grouted	8	7
	10	8
	12	8

VERTICAL REINFORCEMENT SPACING
10.53

S = spacing of vertical reinforcing bars
B = bar size
H = height of backfill



Basement walls should protect against heat and cold, insect infestation (particularly termites), fire, and penetration of water and soil gases.

If radon is a major concern, the top course of the masonry and the course of masonry at or below the slab should be constructed of solid units or fully grouted hollow units. Foundation drain, used to collect and drain condensation moisture from basements, should be avoided in areas where soil-gas entry is a concern.

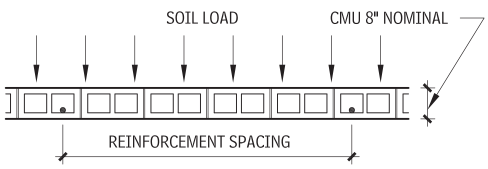
Architectural masonry units may be used to improve the appearance of the wall. Masonry units with architectural finishes facing the interior can be used for economical construction of finished basement space.

Masonry easily accommodates any floor plan, and returns and corners increase the structural performance of the wall for lateral load resistance.

NOTES

10.50 Reinforcing is based on unbraced backfill height, soil pressure, and groundwater conditions.
10.51 Based on ACI 332-04 Requirements for Residential Concrete Construction and Commentary, Figure R7.1; reprinted with permission of the American Concrete Institute.

CMU BASEMENT WALL REINFORCEMENT (BAR SIZE AND MAXIMUM BAR SPACING) 10.54



	HEIGHT OF BACKFILL, H				
	8′	7′	6′	5′	4′
Bar size, B	#6	#6	#5	#5	#4
Spacing, S	64″	56″	64″	72″	72″

CMU BASEMENT WALL: HORIZONTAL JOINT REINFORCEMENT 10.55

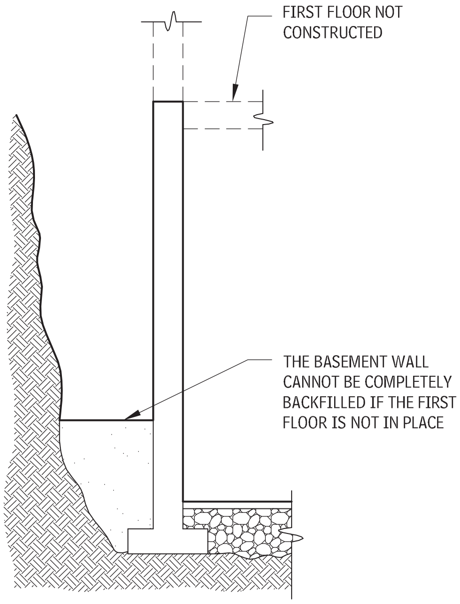
MORTAR JOINT	HEIGHT OF BACKFILL, H				
	8′	7′	6′	5′	4′
13	—	—	—	—	—
12	—	—	—	—	—
11	W2.1	W1.7	W1.7	W1.7	W1.7
10	—	—	—	—	—
9	W2.1	W1.7	W1.7	W1.7	—
8	—	—	—	—	W1.7
7	W2.1	W1.7	W1.7	W1.7	—
6	—	—	—	—	—
5	W2.1	W1.7	W1.7	W1.7	—
4	—	W1.7	W1.7	W1.7	W1.7
3	W2.1	W1.7	W1.7	W1.7	W1.7
2	—	—	—	—	—
1	—	—	—	—	—

BACKFILLING AGAINST BASEMENT WALLS

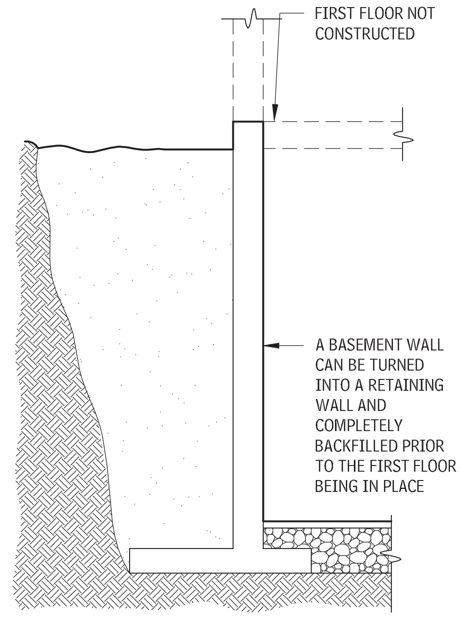
Backfilling against a basement wall is not appropriate, unless resistance to the overturning load has been provided. The most common approach is to construct the first-floor slab before backfilling. Alternate approaches include designing the wall as a freestanding retaining wall, or providing temporary lateral bracing for the basement wall. A retaining wall is either a freestanding or a laterally braced wall that bears against soil or other fill material that resists lateral forces from the material in contact with the face of the wall. Below-grade portions of basement walls are considered retaining walls.

By constructing a freestanding retaining wall or providing lateral bracing on the perimeter, backfilling operations can progress without the first floor being complete. An additional cost is involved in constructing the basement wall as a freestanding retaining wall, because more concrete, reinforcing, and excavation are required.

BACKFILLING AGAINST BASEMENT WALLS 10.56

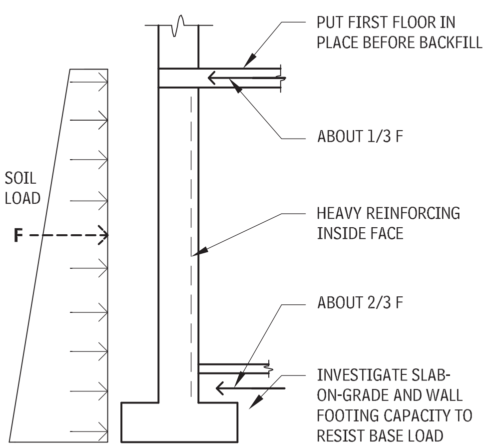


LATERALLY BRACED BASEMENT WALL

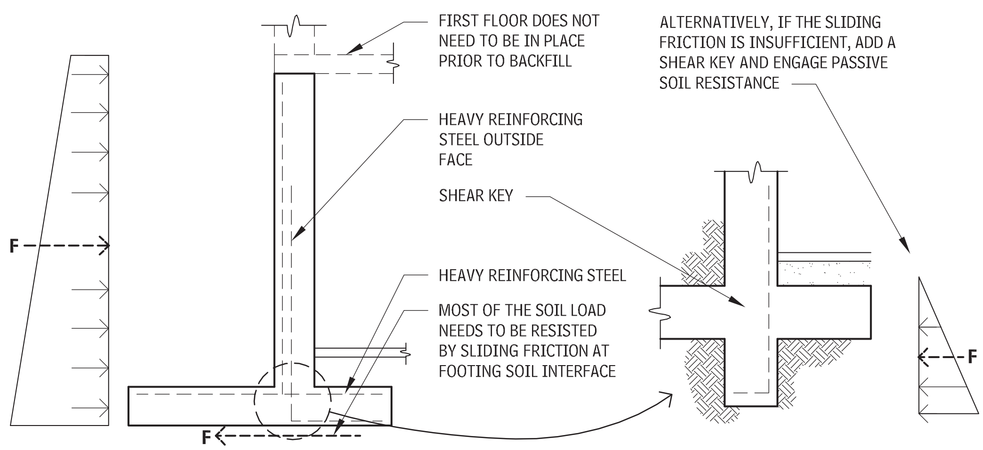


FREESTANDING BASEMENT WALL

BACKFILLING FORCES ON BASEMENT WALLS 10.57



LATERALLY BRACED BASEMENT WALL



FREESTANDING BASEMENT WALL

NOTES

10.55. The empirical design method of the Building Code Requirements for Masonry Structures, ACI 530/ASCE 5, Chapter 9, allows up to 5 ft. of backfill on an 8-in., non-reinforced concrete masonry wall.
b. As an alternate, W1.7 joint reinforcement placed in joint numbers 3, 4, 5, 7, 8, and 11 may be used.
c. Use of vapor retarders should be verified by proper analysis.
d. Backfill pressure on wall is assumed to be 30 psf/ft. of depth of wall. Soil pressures may be higher, and greater thicknesses required at a given location. Consult with local code officials or geotechnical engineers.

SOIL PRESSURE ON BASEMENT WALLS

Soil, similar to water, exerts pressure on the back face of basement walls. The pressure exerted by water is equal to the density of water times the depth. Soil also exerts pressure in proportion to the density of the soil times the depth of the wall. This proportion is based on an earth pressure coefficient, which is dependent on the type and magnitude of soil movement and flexibility of the wall. It is important to understand these influences before designing retaining walls.

Four types of soil pressure need to be understood and resisted by retaining walls: active, at-rest, passive, and surcharge.

ACTIVE SOIL PRESSURE

Active soil pressure exists when a wall moves inward and the soil fails (shears) in the zone right behind the wall. The active soil pressure is dependent on the shear resistance (i.e., strength) of the soil. The higher the strength of the soil the lower the active pressure on the wall. The retaining wall must be flexible to allow for enough movement to occur so the active pressure can develop. Unfortunately, most concrete basement walls do not behave flexibly enough to allow for the full active condition to develop; however, freestanding retaining walls rotate about the base to allow for active pressure to be used for design. An active earth pressure coefficient of typically around 0.30 to 0.35 is used for compacted sand wall backfill.

AT-REST SOIL PRESSURE

At-rest soil pressures occur when there is no wall movement (inward or outward) as a result of placement of soil against the wall. This condition most often occurs when backfilling against rigid or stiff walls which deflect very little under the lateral soil pressures. Since there is no soil movement, the soils do not shear and the pressures are transmitted elastically to the walls. Typical basement walls are considered rigid enough to resist the soil in an at-rest condition. The coefficient of at-rest soil pressure is typically around 0.50 to 0.55 for compacted sand wall backfill.

PASSIVE SOIL PRESSURE

Passive soil pressures occur when a foundation wall actually moves into the soil away from the wall due to an external force. This typically happens when the lateral loads on the structure are resisted by the foundation. Here, the soil is being pushed away from the wall with the pressure increasing with the amount of lateral wall movement until an ultimate (maximum) pressure occurs. The ultimate passive pressure is also based on the shearing resistance of the soil. Care must be taken to determine how much movement is anticipated for the level of passive resistance needed to resist the lateral loads from the structure. Typical values of ultimate passive soil coefficients can range around 2.0 to 5.0 for compacted sand wall backfill, but the movement required to obtain these values is greater than most structures can tolerate. Therefore, a lower "allowable" passive soil coefficient of around 1.0 to 1.5 is used for design, with the lateral movement required to achieve this passive resistance limited to between 1/4 and 1/2 in.

SURCHARGE SOIL LOADING

Surcharge loading is an often-overlooked load on a foundation wall, especially for construction surcharge loadings. Surcharge loads can be due to a number of sources; car, truck, or pedestrian traffic, storage of materials, landscaping berms, snow piles, etc. Additional lateral pressures on the walls occur due to the vertical surcharge loads applied at or near the surface. Uniform surcharge pressures are typically given in feet-of-soil equivalents (such as 1, 2, or 3 ft. of soil). This typically equates to 100, 200, or 300 psf of surcharge loading. The effective lateral load from the uniform surcharge is computed with the same earth pressure coefficient used in calculating the lateral load on the foundation wall: either the active or the at-rest coefficient.

Various types of surcharge loadings should be considered when designing the foundation walls. Construction loads are typically point loads, and transient. The lateral load distribution of concentrated-point loads is a bulb-type loading, and affects only a short length of the wall. The uniform load of storage material can exist over a great length of the wall, and can have a significant effect on the design of the wall. Because emergency equipment often must have close access to a building, foundation walls should be designed to resist the large concentrated loads of fire and emergency equipment.

BASEMENT—WATERPROOFING/ DAMPPROOFING/INSULATION

Consult a geotechnical engineer to determine soil types and groundwater levels, as well as their effect on drainage and waterproofing methods. Consult a waterproofing specialist to determine a specific design approach for problem soils and conditions. Sites may have groundwater contamination that will degrade the durability of the waterproofing materials. Generally, waterproofing will be necessary if a head of water is expected against the basement wall or under the slab. Because groundwater levels can vary with seasons, it is important to understand these seasonal fluctuations and design for the maximum expected head.

Foundation drainage is recommended when the groundwater level may rise above the top of the floor slab or when the foundation is subject to hydrostatic pressure after heavy rain. Geosynthetic drainage material conveys water to the drainage piping, thus reducing hydrostatic pressure. It is important to understand the hydrostatic pressures exerted on the floor slab and wall systems if the drainage system is not adequate to remove all the water.

Special negative-side coatings on the interior face of a foundation wall, such as metallic oxide, are recommended only when the exterior is not accessible (such as pits and trenches, and in particular, elevator pits).

BASEMENT WALL VERTICAL WATERPROOFING

Grading around the building is an important part of the overall water management plan. The backfilling operation usually results in a more porous material than the adjacent undisturbed soil, which makes it easier for water to collect next to the building. Finished grade should slope away from the building, and an impervious layer of soil placed on top of the backfill against the building. Drainage from downspouts should be diverted away from the foundations.

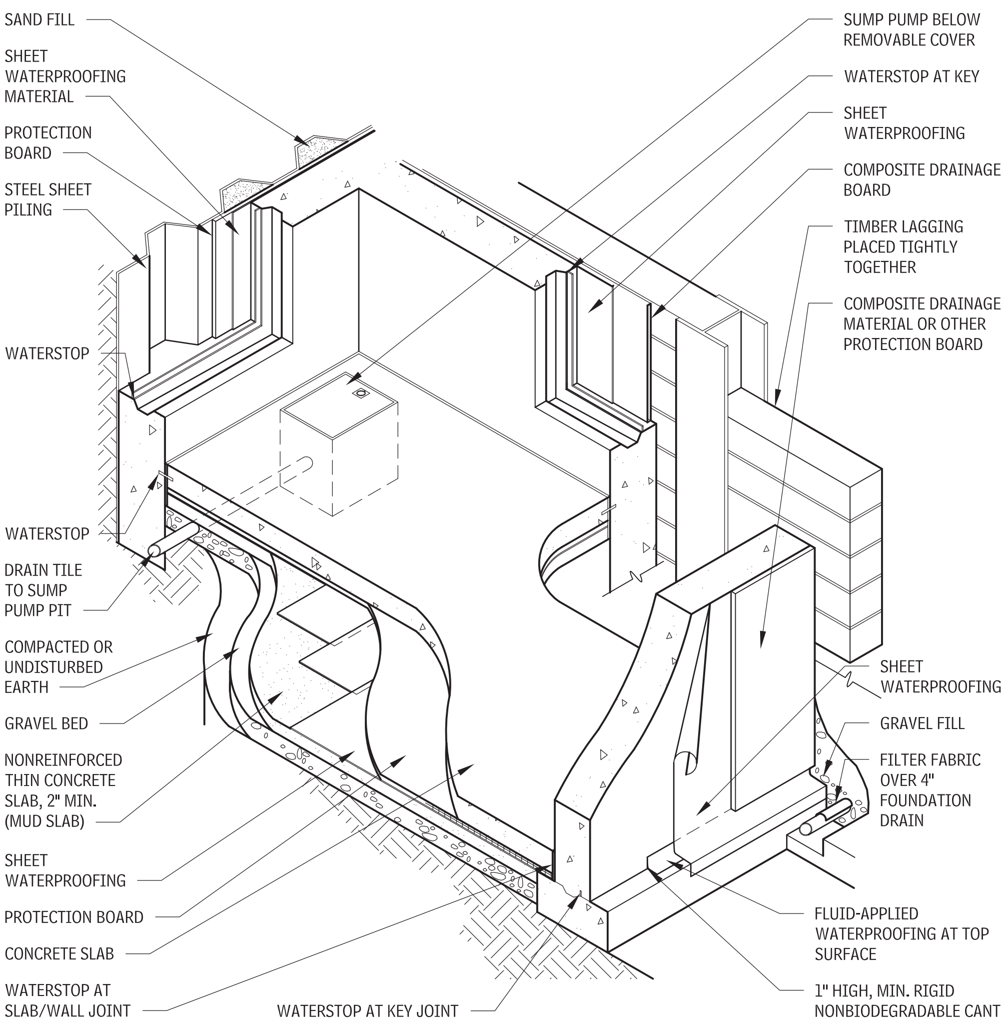
Types of waterproofing include built-up bituminous, sheet, fluid-applied, cementitious and reactive, and bentonite.

- *Built-up bituminous:* Composed of alternating layers of bituminous sheets and viscous bituminous coatings. Bituminous waterproofing includes built-up asphalt and cold-tar waterproofing systems.
- *Sheet waterproofing*: Formed with sheets of elastomeric, bituminous, modified bituminous or thermoplastic materials. Sheet waterproofing may be either mechanically attached or self-adhered. Sheet waterproofing provides an impermeable surface to water penetration.
- *Fluid-applied*: Applied in a hot or cold viscous state. Includes hot fluid-applied rubberized asphalt. As with sheet waterproofing, fluid-applied waterproofing will bridge minor cracks in a concrete surface.
- *Cementitious and reactive:* Types of waterproofing that achieve waterproof qualities through chemical reaction and include polymer modified cement, crystalline, and metal oxide waterproofing systems. Metal oxide is recommended for use when the exterior surface is not accessible, as in the case of an elevator pit.
- *Bentonite:* Formed from clay into panels and composite sheets. When moistened, the clay swells and takes on a gel-like consistency, forming an impermeable retarder when confined. Bentonite clay works well only when moistened. For applications where the water table fluctuates, there may be a time lag between the rising water table and when the bentonite takes effect, during which time there is the possibility of water infiltration. Therefore, when the water table varies, caution is in order when relying on bentonite clay for waterproofing. Proper coordination between the wall construction details and the waterproofing termination is required.

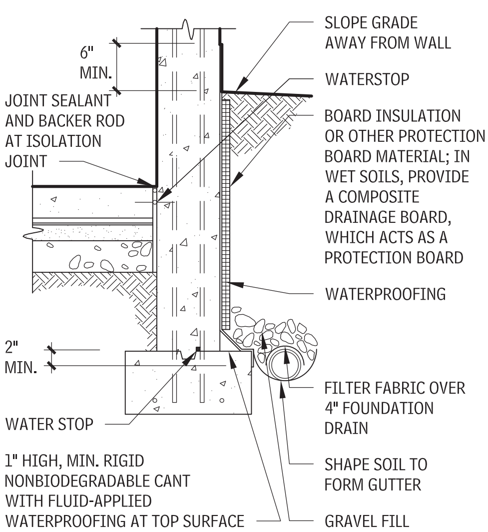
At the interface of the foundation wall and slab, waterstops are placed on top of the footing, at vertical concrete keyed wall joints.

Most waterproofing materials require a stable, rigid, and level substrate. Generally, a mud slab (subslab that is nonreinforced and nonstructural) is used when the waterproofing material is placed below the structural slab and/or when a solid working surface is needed on unstable soils. When waterproofing materials are placed on top of the structural slab, a protective cover, such as another concrete slab, is required.

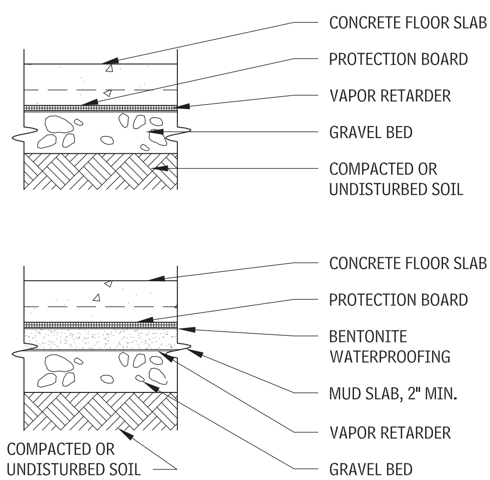
WATERPROOFING APPLICATIONS AT BASEMENT CONDITIONS
10.58



WATERPROOFING AT FOOTINGS
10.59



WATERPROOFING UNDERSLAB
10.60



Protection of waterproofing or coatings during construction and backfilling is essential. Protection materials should be selected according to soil, climate, and cost requirements. These materials include the following:

- *Composite drainage board*: Recommended when water is frequently present in soils surrounding foundations. Usually, this is made up of a rigid open-weave material, approximately 3/4 in. thick, covered on both sides by a geotextile filter fabric that prevents small stones or other materials from clogging the drainage route of water inside. Typically, the drainage material is terminated at drain tiles at the bottom of the foundation. This system has a higher in-place cost than other protection board materials.
- *Board insulation*: Used above the frost line or if ground temperatures are low. Rigid insulation boards are usually made of expanded or extruded polystyrene, with a minimum thickness of 1/4 in. when used as protection board only, and 1 in. or thicker if thermal insulation properties are desired.
- *Protection board*: Used only to protect waterproofing; it does not drain or insulate. Protection board is usually made of 1/8-in. asphalt-impregnated fiberboard or 1/4-in. extruded polystyrene. This is the least expensive material when protection of the waterproofing is the only requirement.
- *Grout*: Packed around pipes penetrating the foundation and other types of waterproofing, grout should contain a mixture of iron oxide, which chemically alters the grout to be more water-resistant.

BASEMENT WALL DAMPPROOFING

Dampproofing is generally provided to reduce or prohibit the absorption of condensation and high-humidity into below-grade concrete or masonry and to reduce the likelihood of water not under a head of pressure from moving through or up the construction. Examples of applications requiring dampproofing include on the back side of site retaining walls or at basement walls where there is no head of water.

Dampproofing is not "water-tight" and will not perform to the same levels as waterproofing, and so should not be used in applications that require waterproofing.

In addition to the desire to resist water intrusion through a wall, dampproofing has historically been utilized to prevent water intrusion into concrete or masonry below grade, as a means to limit or eliminate "rising damp"—that is, a condition in which moisture is absorbed into the subgrade construction and travels upward by capillary action to drier materials such as masonry or wood. Water infiltration of this type can lead to rotting of wood, efflorescence of masonry, or freeze-thaw masonry damage, as well as corrosion of unprotected or improperly protected metals (such as light-gauge steel framing). Note that this may not be a problem only at exterior walls but can also be problematic at foundations and piers (especially crawl spaces) and within the building interior if there are unfavorable water conditions.

Another appropriate use of dampproofing is at site-retaining walls that may have special finishes such as architectural precast concrete applied to a structural retaining wall. In this case, it would be highly desirable to prohibit excessive water penetration from the back side to be transmitted to the decorative finish. Waterproofing is sometimes not appropriate in these conditions; however, dampproofing often provides the correct level of protection in these cases.

Dampproofing is most often a spray-, roller-, or brush-applied bituminous material (asphalts), but may include cementitious and sheet materials. Fluid-applied and cementitious applications have little capability to bridge across cracks or discontinuities of the concrete or masonry wall to which they are applied, and have very limited capability to accept movement.

NOTE

10.58 Place 12-in. neoprene strips over joints in sheet piling.

THERMAL INSULATION

Insulation requirements are proportional to heating loads. The foundation is often underinsulated and can be a major source of heat loss. The desirable insulation level depends on the use of the basement space, basement temperature, and insulation levels in the rest of the building. An approximate thermal optimum is:

$$R_{ins} = \frac{(T_{bsmt} - T_0)}{(T_1 - T_0)} \times R_{ref} - R_{wall}$$

R_{ins} = R-value to be added to basement wall above grade

R_{ref} = R-value of superstructure wall

R_{wall} = R-value of uninsulated basement foundation wall

T_{bsmt} = Average seasonal temperature of basement

T_1 = Average seasonal temperature of living space

T_0 = Average seasonal outdoor temperature

The added foundation insulation above grade is R_{ins}. It should decrease with depth by R-2 per foot in ordinary soils and R-1.5 in wet soils. A horizontal skirt can be used to reduce floor perimeter losses. Exterior insulation keeps the wall warm and eliminates condensation and thermal bridges. As seasonal basement temperature decreases, losses to it from the superstructure increase, and basement ceiling R-values should increase. As a very rough rule, the basement ceiling R-value should be greater than ($R_{ref} - R_{ins}$).

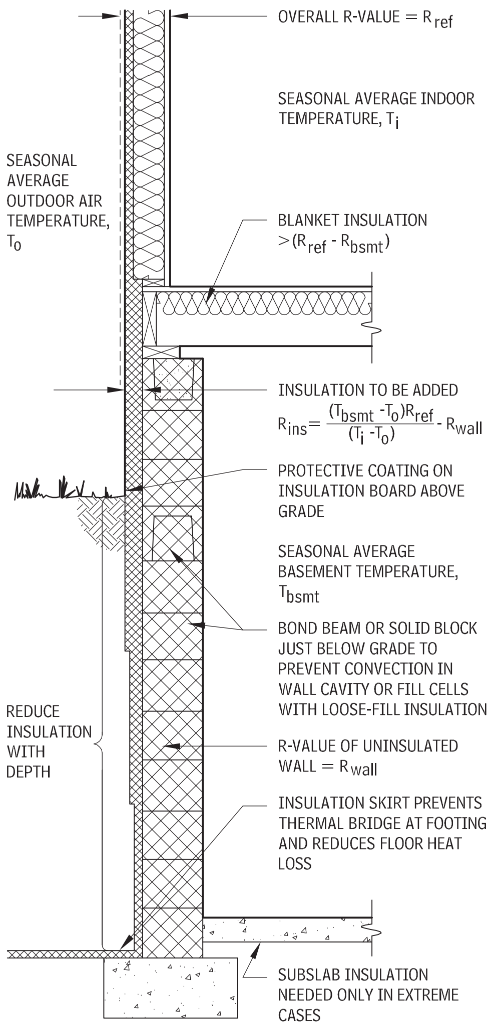
There are basically two insulation types used for foundations:

- *Expanded polystyrene*: Also known as "bead board," this is generally a low-density, low-compressive strength material that is supplied in sheet form, usually 2 to 4 ft. wide and 8 ft. long (2 in. is a typical thickness of insulation).
- *Extruded polystyrene*: This is a sheet material that is also used as masonry cavity wall insulation. This material can come in compressive strengths of 20 to 100 psi in sheets of 2 to 4 ft. wide and 8 ft. in length (2 in. is a fairly typical basement insulation thickness).

Both the extruded and expanded polystyrene insulations are susceptible to chemical reaction to direct contact with petroleum-based chemicals in the soil, or driven by percolation from the surface.

Expanded or cellular glass (also known as "stink board" because of the sulphur that is trapped within the closed cell-glass structure) is inert and may be the best insulation product in these situations. However, if cellular glass products are used in areas prone to freezing temperatures, special precautions are necessary, to prevent deterioration and damage to the insulation caused by freezing of water that gets into the open cells at the insulation edges. The edges of the board are cut and, therefore, have open cells along the edges. The edges of these sheets must be sealed when exposed to freezing temperatures.

BASEMENT FOUNDATION AND CEILING INSULATION
10.61



This insulation also comes in sheet form, 2 by 4 ft.; thicknesses can vary according to need. Cell-glass insulation may be appropriate for projects requiring foundation insulation adjoining vehicle maintenance and large-scale traffic circulation. The design should take into account control and filtering of storm and drainage water, to avoid percolation and potential contamination of adjoining soils.

It should be noted that the insulation sheets can also be used as a very effective protection board for waterproofing. Some waterproofing manufacturers have strong recommendations regarding the appropriate type of protection board.

REFERENCES

National Association of Home Builders Research Center, a wholly owned subsidiary of the National Association of Home Builders, is the research and development leader in the home-building industry. Government agencies, manufacturers, builders, and remodelers rely on the expertise and objectivity that are at the very heart of the research center and its activities.

National Institute of Building Sciences (NIBS) is a nonprofit, nongovernment organization that brings together representatives of government, the professions, industry, labor, and consumer interests to focus on the identification and resolution of problems and potential problems that hamper the construction of safe, affordable structures for housing, commerce, and industry throughout the United States.

National Roofing Contractors Association (NRCA) is one of the construction industry's oldest trade associations and the voice of professional roofing contractors worldwide.

NISTIR: Envelope Design Guidelines for Federal Office Buildings—Thermal Integrity and Airtightness. These guidelines are organized by envelope construction system and contain practical information on the avoidance of thermal performance problems such as thermal bridging, insulation system defects, moisture migration, and envelope air leakage.

Partnership for Advancing Technology in Housing (PATH) serves builders as a reliable source of information on new products or processes. It lists details on each technology and contact information for the manufacturers.

Sealant, Waterproofing and Restoration Institute (SWRI) provides a forum for those engaged in the application, design, and manufacture of sealant, waterproofing, and restoration products.

WALL SYSTEMS is a guide intended to facilitate a better understanding of the basic principles behind heat, air, and moisture transfer (including bulk rainwater penetration and precipitation management) through the exterior walls of a building or structure.

Whole Building Design Guide (WBDG) is a Web-based portal providing government and industry practitioners with one-stop access to up-to-date information on a wide range of building-related guidance, criteria, and technology from a "whole buildings" perspective.

Contributors:
Krommenhoek/McKeown & Associates, San Diego, California; Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland, in consultation with James B. Thompson, San Marino, California; James Kellogg AIA, Senior Vice President, Best Practices Director, HOK, San Francisco, California; and Paul Johnson, AIA, Senior Architect, SmithGroup, Detroit, Michigan.

ELEMENT B: SHELL

11

DESIGN CONSIDERATIONS

CLIMATE AND ENERGY

Of primary importance to the shell of a building is the mediation between the exterior and interior environment. Proper design and detailing of the building enclosure requires an understanding of the specific characteristics of both the desired interior environmental conditions and specific exterior environmental conditions, on both a macro and micro scale.

DEFINITIONS

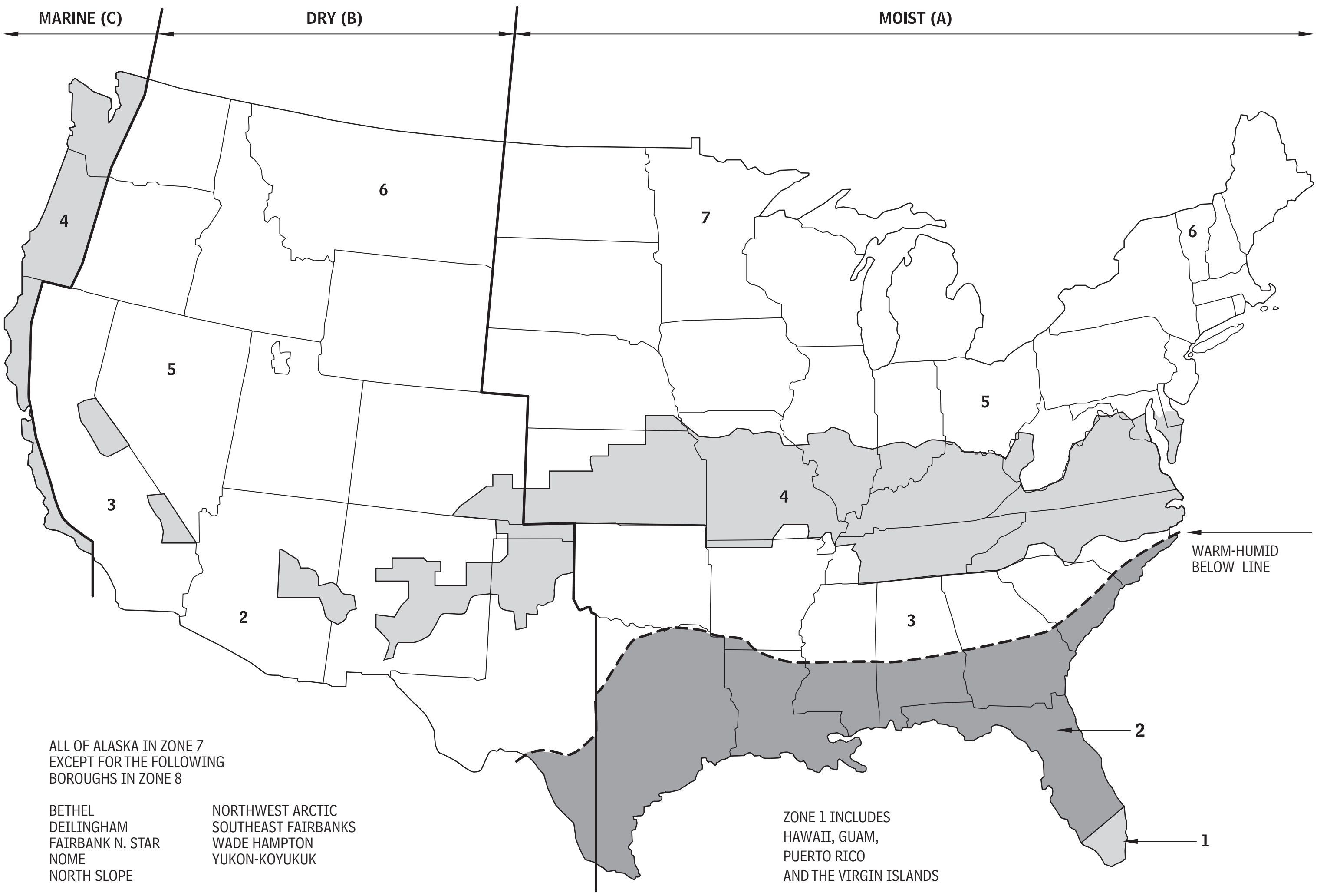
When reading the content of this chapter, keep in mind the following definitions of concepts and principles:

- *Air barriers:* Materials or combinations of materials that form a continuous envelope around all sides of the conditioned space to resist the passage of air. Joints, seams, transitions, penetrations, and gaps must be sealed. The air barrier must be capable of withstanding combined positive and negative wind load and fan and stack pressure without damage or displacement. The air barrier must be at least as durable as the overlying construction and be detailed to accommodate anticipated building movement. An air barrier may or may not be a vapor retarder.
- *Vapor barriers and retarders:* Without industrywide consensus, materials with a perm rating less than 1 are interchangeably called a vapor barrier or vapor retarder (IBC and IEC 2003 use vapor retarder). More important than the term is to understand a few basic principles:
  - Vapor diffusion through materials with perm ratings less than 1 is nearly inconsequential, but even small gaps or holes can easily transport many times as much water vapor.
  - All materials have some greater or lesser degree of resistance to diffusion, and their placement in an enclosure assembly, whether intended as a retarder or not, will affect wetting and, more importantly, drying of an assembly.
- *Insulation:* A material that slows the flow of heat through conduction.
- *Radiant barriers:* A material, usually metallic or shiny, that reflects radiant thermal energy.
- *Weather barrier (Water-resistant barrier):* A material that is resistant to the penetration of water in the liquid state, or is waterproof. It may or may not be an air barrier or vapor retarder. The face of the weather barrier is sometimes called the *drainage plane*.
- *Barrier wall:* A wall assembly that resists moisture with a continuous waterproof membrane, or with a plane of weather barrier material thick enough to prevent absorbed moisture from penetrating to the interior.
- *Drained cavity wall:* A wall assembly with an outer water-shedding layer over an air cavity, and with a weather barrier. The cavity is flashed and weeped to drain incidental water.
- *Drainage plane wall:* A wall assembly with a continuous water-resistant barrier under an outer water-shedding layer. The lack of a cavity limits the amount of water that can be quickly drained.
- *Pressure-equalized rainscreen wall:* A wall assembly that resists all the physical forces that can transport water across a joint in the outer or "rainscreen" layer. Kinetic energy forces are controlled by venting a cavity behind the rainscreen and, thus, allowing the pressure differential across the joint to be equalized. An air barrier and compartmentalization of the cavity are required to control the pressure equalization. The cavity is flashed and weeped to drain incidental moisture.

EXTERIOR CLIMATIC INFLUENCE

The United States has widely varying climates. More than the obvious extremes of Miami and Alaska are the subtler—and just as important—variations within the contingent states. The ANSI/

CLIMATE ZONES FOR U.S. LOCATIONS
11.1



ASHRAE/IESNA Standard 90.1, Map of Climate Zones for the United States reproduced herein dictates zones based on heating and cooling requirements. (Note: A simplified map of climatic zones can be found in *Moisture Control Handbook: Principles and Practices for Residential and Small Commercial Buildings,* by Joseph W. Lstiburek and John Carmody, 1996.) There are six zones within the continental states and Hawaii, plus two more for Alaska. Within these zones are subzones for moist, dry, marine, and warm-humid.

As this chapter will demonstrate, solutions appropriate for one zone may be totally unsuited for another. SEI/ASCE 7, "Minimum Design Loads for Buildings and Other Structures," and other similar standards establish the wind, snow, and seismic structural loads on buildings. Again, there is wide variation in wind speed, snowfall, and ground movement. In addition to the base loads, localized conditions such as surrounding topography and adjacent buildings can cause wide variances in the environmental influences. Figure 11.2 shows the annual precipitation for North America. Suggested types of exterior enclosure systems that will meet the minimum level of service and reliability are correlated to the rainfall levels.

ANNUAL PRECIPITATION IN NORTH AMERICA
11.2

EXPOSURE:

EXTREME	OVER 60" PRESSURE EQUALIZED RAINSCREEN/PRESSURE MODERATED SCREEN
HIGH	40" - 60" RAINSCREEN/VENTED CLADDING/VENTED DRAINAGE SPACE
MODERATE	20" - 40" DRAINAGE PLANE/DRAINAGE SPACE
LOW	UNDER 20" FACE SEAL

INTERIOR CLIMATIC INFLUENCE

Environmental conditions to be maintained within the building also influence the design of the shell. Buildings with requirements for high or low levels of humidity, tight temperature tolerances, pressure differentials to the exterior, high-reliability containment, acoustic isolation, protection from blast or forced entry, high indoor air quality, or other extraordinary requirements will require particular attention to system selection and detailing, in concert with consideration of the exterior climate.

HEAT, AIR, AND MOISTURE

In addition to the obvious structural loads, the building enclosure must resist the transfer of heat, air, and moisture (HAM). The laws of physics dictate that heat always flows from hot to cold. Air moves through building enclosures by passing through porous materials, or through holes and gaps in nonporous materials, based on differential air pressures. Moisture, as water in the liquid state (such as rain, snow, and groundwater), moves through enclosures by four methods: capillary action, surface tension, gravity, and kinetic energy (e.g., wind-driven rain). Moisture in the vapor state moves through enclosures from zones of higher to lower vapor pressures, by diffusion through solid materials or by air transport through holes.

CONTROL OF HAM

Control of the flow of HAM across the building enclosure is an interrelated problem, in that air movement can create the kinetic energy that pulls water through joints, dramatically reduce thermal insulation effectiveness, or cause massive vapor transport. Improper thermal insulation can cause condensation on uncontrolled surfaces.

To control HAM, three components must be considered separately: heat, air, and moisture.

Heat is most commonly controlled by thermal insulation. Keep in mind the following:

- Air movement around thermal insulation can seriously degrade its effectiveness, so avoid systems that ventilate the conditioned side of the thermal insulation.
- Radiant barriers may be effective, particularly in hot climates, but they must have an airspace on the warm side. Generally speaking, radiant barriers have virtually no insulating value and should not replace but, instead, enhance typical thermal insulation and conductive losses.
- Thermal short circuits can dramatically reduce the U-value of thermal insulation. The most common example is metal studs, which may reduce the effective value of thermal insulation between the studs by half.

Air transfer is controlled by a coordinated and continuous system of air barriers for all six sides of the enclosure (i.e., the lowest-grade level, foundation walls, exterior walls, and the roof).

- Common approaches to wall air barriers are continuous membranes applied to sheathing and sealed to windows, doors, and penetrations.
- Below-grade assemblies can utilize either the concrete walls and slabs or applied waterproofing membranes.
- Most typical low-slope roof membranes will provide an air barrier, except for mechanically fastened systems that may not be able to resist all of the required loads.
- It is possible to design the gypsum board as an air barrier, if all joints and cracks are sealed.
- Many air barrier systems require a combination of a membrane and a structural panel to resist loading, such as spun-bond polyolefin membranes stapled to sheathing or bituminous membranes adhered to CMU.

Moisture management consists of controlling moisture entry, moisture accumulation, and allowing for drying.

- Perfect barriers to moisture are virtually impossible to achieve, therefore it is important that measures taken to keep out moisture do not also trap moisture—for example, waterproofing membranes that trap thermal insulation between a vapor retarder.
- It is essential to maintain a balance of the moisture that is able to accumulate in an assembly between drying cycles. Accumulation

and drying are extremely dependent on the local climate. Some materials such as wood-framed walls and masonry have the capacity to absorb relatively large quantities of moisture and to then later dry out without damage or deterioration. Other systems such as gypsum board on metal studs have very little capacity for storage of moisture.
- The source of water is primarily rain, which should be limited by a reasonably detailed assembly based on the expected amount of precipitation. The precipitation map in Figure 11.2 shows recommended enclosure types along with the required performance to minimize water entry.
- Below grade, the primary source of moisture is through capillary action that can be controlled through membranes and capillary breaks.
- Sources of vapor may be from the interior or exterior environment. Vapor retarders have been the traditional method used to control vapor movement, but their use in mixed heating and cooling climates must be carefully evaluated to allow drying.
- Moisture control in the solid state (i.e., ice) depends on not letting liquid water freeze; or, if it does, allowing room for expansion. For example, cold roof surfaces that eliminate thawing also prevent ice buildup, and air-entrained concrete provides room for ice crystals to expand.

Figures 11.3 and 11.6 show details of wall assemblies that can be used for analysis of drying under various climatic conditions. The various assemblies are somewhat independent of the cladding type. Other wall assemblies, including face-sealed or massive barrier assemblies, should receive similar analysis of HAM control. Two useful tools for this purpose are:

- *Computerized modeling of wetting and drying of walls:* This is widely available and is very helpful in understanding moisture accumulation and drying. Analysis is recommended for large projects and any assembly that requires seasonal drying. Mixed climates may be the most difficult to predict by rule of thumb or empirical analysis. WUFI, developed by the Fraunhofer Institute for Building Physics in Germany with a North American version developed jointly with Oak Ridge National Laboratory (*www.ornl.gov*) is a widely recognized modeling tool. Similar software is available through *www.virtual-north.com/download/OrderForm.pdf* and *www.architects.org/emplibrary/HAMtoolbox.pdf*.
- *Manual analysis of simple two-dimensional diagrams of wall sections:* This involves using temperature gradients plotted against dew point temperature or vapor-pressure gradients plotted against saturation pressure. For instructions refer to "Design Tools," by Anton TenWolde (Chapter 11 in the manual *Moisture Control in Buildings* [MNL18], Heinz R. Trechsel, editor, published by ASTM, 1994).

CONSIDERATIONS FOR CLIMATE ZONES

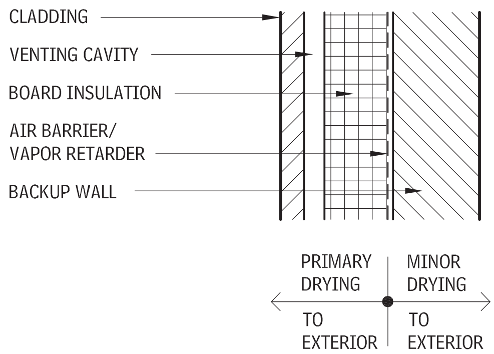
GENERAL

- Refer to specific details for each material for more information regarding selection criteria and proper detailing.
- Include only one vapor retarder in a wall assembly, and ensure that all other materials are increasingly permeable from the vapor retarder out.
- It is acceptable (and sometimes desirable) to provide more than one air barrier in a wall assembly.
- It is generally desirable to protect blanket insulation from air-washing with an air barrier on the cold side.

ALL CLIMATES

- Secure a highly reliable enclosure system to control HAM in all climate zones, without relying on building mechanical systems to dry interior air.
- Thermal insulation located outside of the structure and wall framing allows easy installation of continuous air barriers and vapor retarders.

ALL CLIMATES
11.3

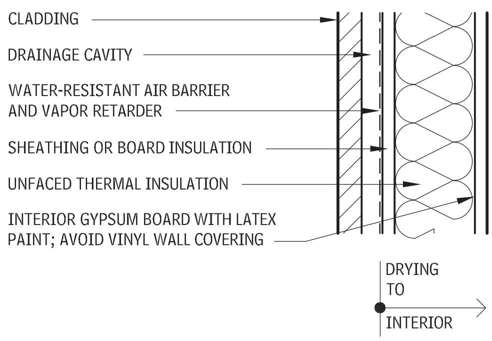


- Thermal insulation must be continuous to prevent the vapor retarder from reaching the dew point.
- Masonry veneer over CMU or metal stud backup systems is an excellent choice.
- If metal stud backup systems are used, do not place thermal insulation between the studs.
- Any paint or wall covering is allowed on the interior finish.

HOT CLIMATES (ZONES 1, 2, AND 3)

- The mechanical system must provide dehumidification of the interior air for drying.
- Avoid any vapor-impermeable interior finishes (e.g., a vinyl wall covering that will trap moisture).
- A radiant barrier may be incorporated into the cavity.
- Taped joints in sheathing, board insulation, or a combination may provide an air barrier.
- An air barrier is crucial to limit moisture transport through imperfections in the vapor retarder.

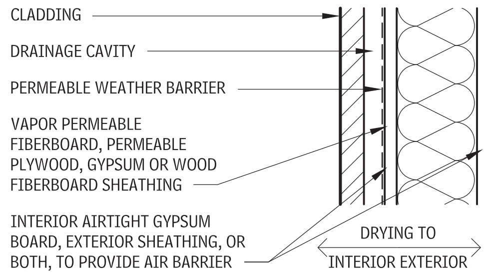
HOT, HUMID CLIMATES
11.4



MIXED CLIMATES (ZONES 3 AND 4)

- All materials must be relatively vapor-permeable to allow drying in both directions, because seasons change direction of heat flow and vapor drive.
- Detail system with interior and exterior side-permeable air barriers to limit moisture transport and infiltration/exfiltration.
- May be possible to use board insulation with taped joints as sheathing, which will form a vapor retarder if board and blanket insulation have approximately the same U-value.

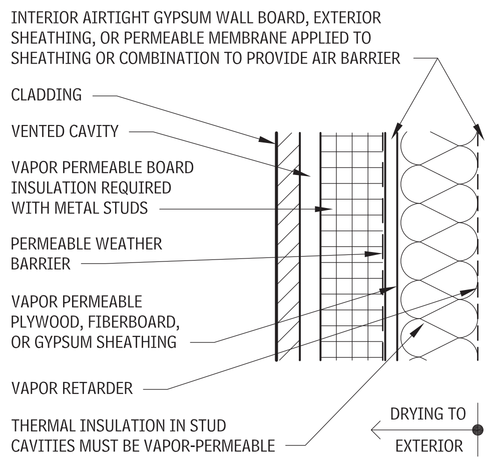
MIXED CLIMATES
11.5



COLD CLIMATES (ZONES 5 TO 8)

- Materials should be progressively more permeable, because they are located closer to the exterior face.
- Any paint or wall covering is allowed on the interior finish.
- A mechanical system is not required to dry the interior air.
- Failure of the building paper may allow moisture accumulation that cannot be overcome by drying.
- Elements penetrating thermal insulation (such as beams supporting a projecting canopy or the sump pan of roof drains) can cause condensation problems, unless they are insulated with closed-cell thermal insulation or a thermal insulation with a vapor retarder to keep moisture-laden air from getting to these surfaces. This is particularly true for occupancies with high humidity (including residences, hospitals, museums, swimming pools).

COLD CLIMATES
11.6



THERMAL MOVEMENT

Walls and other surfaces on or around buildings respond to ambient temperature change, solar radiation, wetting and drying effects from precipitation, and varying cloud cover by either increasing or decreasing in volume and therefore in linear dimension. The dimensional change of a material causes a change in the width of a sealant joint opening, producing movement in a sealant. Thermal movement is usually the predominate effect causing dimensional change. Thermal movement may need to be evaluated at different stages in a building's life; for example, expected temperature differentials may need to be considered for the building when it is: (1) under construction, (2) unoccupied and unconditioned, and (3) occupied and conditioned. Each of these stages will have different building interior environmental conditions, and depending on the building enclosure material or system being analyzed for movement, one of those stages may produce the maximum expected thermal movement. ASTM Guide C 1472 provides procedures to assist a joint designer in determining material or system minimum winter and maximum summer surface temperatures as well as information to assist in establishing joint opening installation temperature effects.

NOTES

11.3–11.6 Provide an air barrier in the assembly at one or more of the locations noted by properly detailing either the inner layer of gypsum board, the sheathing layer, or the permeable weather barrier. The inner gypsum board can be made an air barrier by sealing the perimeter, penetrations, and transitions to adjacent air barrier assemblies. The sheathing can be made an air barrier through similar means of sealing all joints, penetrations, and transitions. Using a membrane over the sheathering (either fluid-applied or sheet material) that is vapor permeable, weather-resistant, anmd airtight is extremely effective for providing an air barries with the added benefits of simple installation and inspection.

JOINT DESIGN

The industry standard is a 4:1 joint design factor, which accommodates thermal movement only, for most sealants. This design ratio reflects an absolute minimum. Construction, fabrication, and erection tolerances must be added to calculate the nominal joint size. The 4:1 joint design factor can be explained as follows:

Anticipated movement of joint: 1/8 in.

Apply the 4:1 joint design factor: 4 × 1/8 in. = 1/2-in. joint

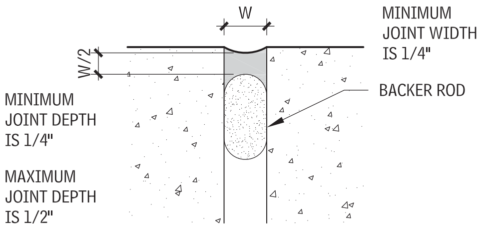
The maximum allowable joint size will vary depending on the sealant being applied. The minimum allowable caulking joint size configuration is set at 1/4 in. by 1/4 in. These dimensions are the limit in order to allow for adequate cleaning, priming, and application of the sealant in a dynamically moving joint.

The depth of the sealant should never exceed the width. If this is ignored the sealant will not be able to perform properly and withstand movement. A standard recommendation for joint width to depth is a ratio of 2:1. However, the depth of the sealant should be no more than a 1/2 in. to 5/8 in. for most standard caulking joints.

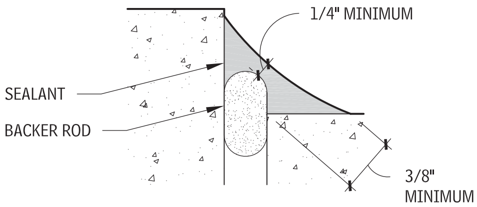
The following details illustrate the basic typical joints.

- *Butt joint:* Butt joints are the typical joint found in construction. They can be expansion joints in walls, floors, and floor perimeters.
- *Fillet or angle joint:* Fillet or angle joints are typically constructed where two substrates meet at a 90-degree angle. Applications around window and door perimeters are typical angle joints. If adequate space is not available to insert a backer rod, bond breaker tape is required to allow movement of the sealant. A 1/4-in. minimum sealant depth and a 3/8-in. sealant/surface contact are required.
- *Lap joint:* To seal metal to metal joinery, lap joints are usually constructed.

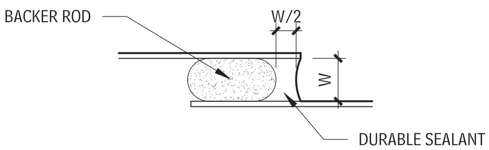
BUTT JOINT
11.7



FILLET OR ANGLE JOINT
11.8



LAP JOINT
11.9

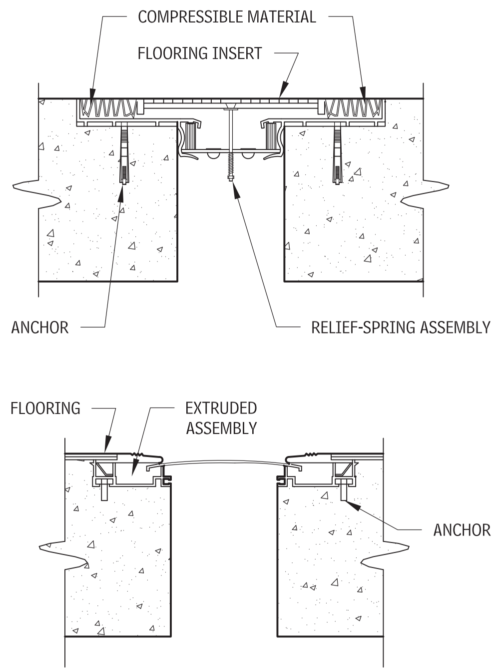


EXPANSION CONTROL

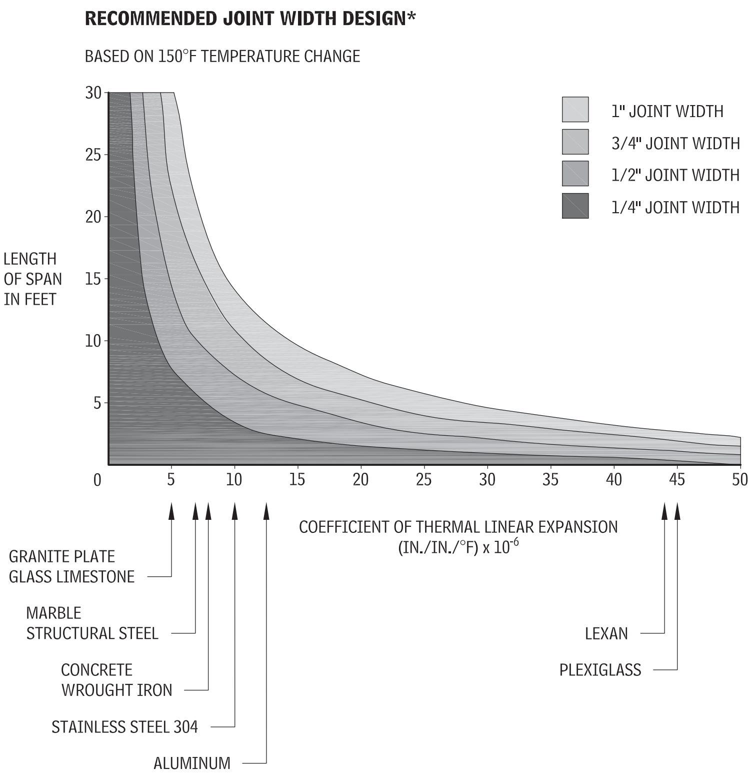
HORIZONTAL AND FLOOR CONSTRUCTION EXPANSION CONTROL

Expansion joint covers that will respond to differential movement, both laterally and horizontally, should be provided at joints in structure, located where seismic action may be expected or where differential settlement is anticipated.

SEISMIC JOINT COVERS WITH FLOORING INSERT
11.11



RECOMMENDED JOINT WIDTH DESIGN
11.10



COEFFICIENT OF THERMAL LINEAR EXPANSION – TYPICAL BUILDING MATERIALS

WROUGHT IRON	= 0.000008 IN./IN./°F
CONCRETE	= 0.000008 IN./IN./°F
ALUMINUM	= 0.000013 IN./IN./°F
PLATE GLASS	= 0.000005 IN./IN./°F
LEXAN	= 0.000044 IN./IN./°F
PLEXIGLASS	= 0.000045 IN./IN./°F
GRANITE	= 0.000005 IN./IN./°F
STRUCTURAL STEEL	= 0.000007 IN./IN./°F
LIMESTONE	= 0.000005 IN./IN./°F
MARBLE	= 0.000007 IN./IN./°F
STAINLESS STEEL "304"	= 0.000010 IN./IN./°F

SAMPLE CALCULATION

TEMPERATURE x COEF. OF THER. LIN. EXPANSION x SPAN LENGTH x DESIGN FACTOR = JOINT WIDTH

(150°F) x (0.000010 IN./IN./°F) x 12 IN./FT. x 10 FT. x 4 = JOINT WIDTH

10 FT. x 4 = JOINT WIDTH

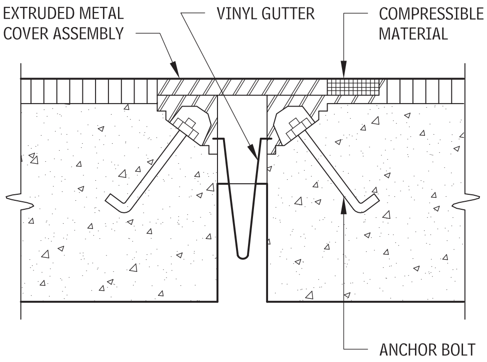
0.72 = JOINT WIDTH

3/4 INCH = JOINT WIDTH DESIGN

*IF LENGTH IS OFF CHART, USE EQUATION, AS ILLUSTRATED

Contributor:
ASTM C1193, Hall Architect, Inc.

JOINT COVER AT FLOOR
11.12



A large selection of prefabricated assemblies to cover interior expansion joints is available. Fire-rated barrier-type inserts are available and applicable to most assemblies.

VERTICAL EXPANSION CONTROL

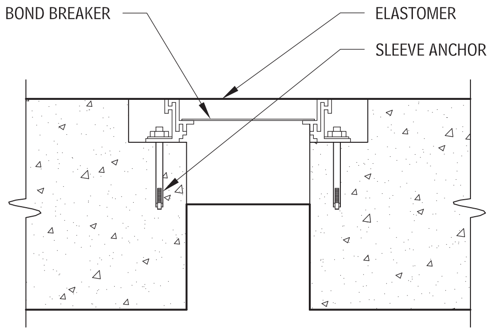
Expansion joints in the exterior enclosure need to be covered in a manner that allows for the anticipated movement and to ensure it remains weather tight. Continuity of the expansion joint cover from foundation up walls and across soffits, ledges, and other offsets up to the roofing expansion joint is crucial.

When expansion joints occur within pressure equalized rainscreen walls and drained cavity walls, both the outer layer and the inner air/vapor barrier must both be sealed. The outer layer is typically sealed with systems listed previously. The air/vapor barrier is generally sealed with a fold of flexible membrane; or an elastic bellows is commonly used for roofing expansion joints.

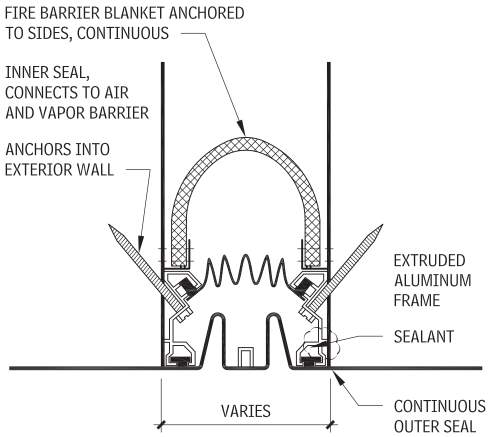
Types of exterior expansion joint covers include:

- *Metal-framed joint covers:* These are typically available with extruded aluminum, stainless steel, and brass or bronze frames, which retain a thermoplastic diaphragm. The diaphragm is available in a variety of colors, and joints are typically heat-welded in the field. These joint systems often come with a secondary inner seal. Widths between 2 and 12 in. are common. The diaphragm is available in lengths up to 50 ft., which are effective on tall, uninterrupted walls.
- *Gland-type joint covers:* These are thermoplastic glands of folded or multicelled cross section, typically with molded-in wings for grouting into a blockout (i.e., tee joint). These systems are most commonly used in parking garages and other horizontal surfaces.
- *Faced precompressed foam:* The same product listed for use as a sealant can be used for expansion joints. The faced materials are typically used to provide a finished appearance. These systems are relatively easy to install and to make complicated transitions, corners, and turns.
- *Sheet metal:* Sheet metal (preferably interlocking, but possibly just overlapping) can be used to form an expansion joint cover if a backup layer is provided. These may be preferred in metal panel systems or within a curtain wall.

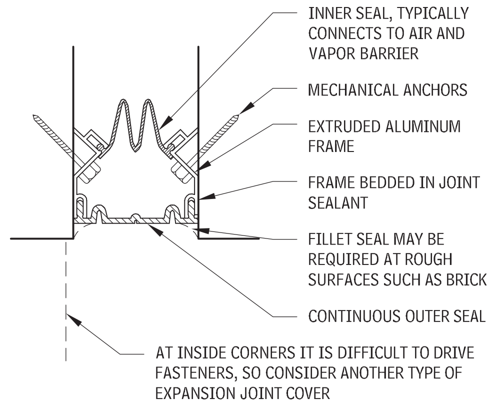
ELASTOMERIC JOINT COVER—REMOVABLE
11.13



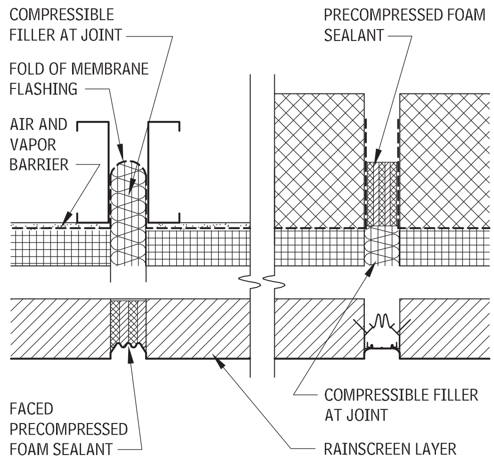
FIRE RATED JOINT COVER
11.15



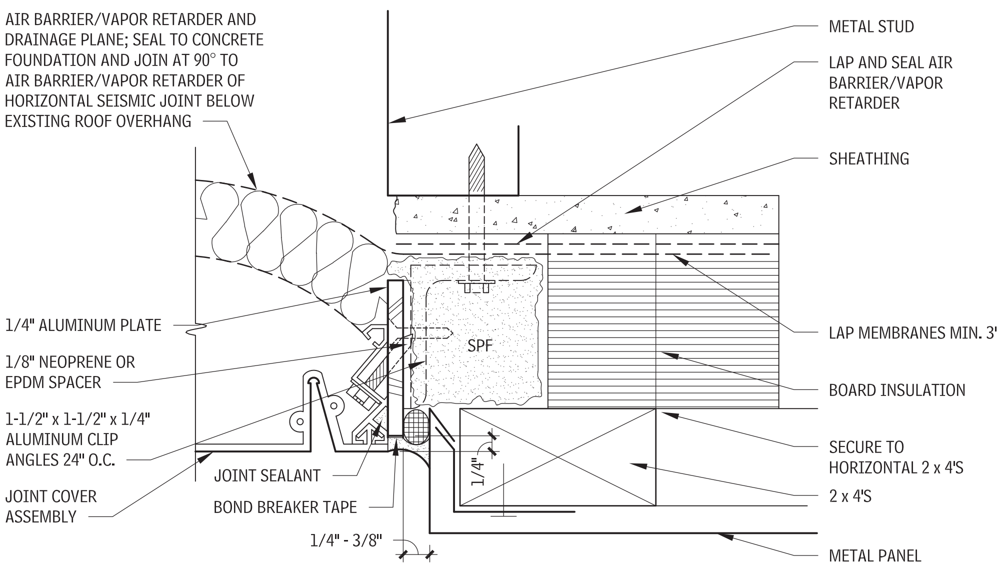
VERTICAL EXPANSION JOINT COVER
11.14



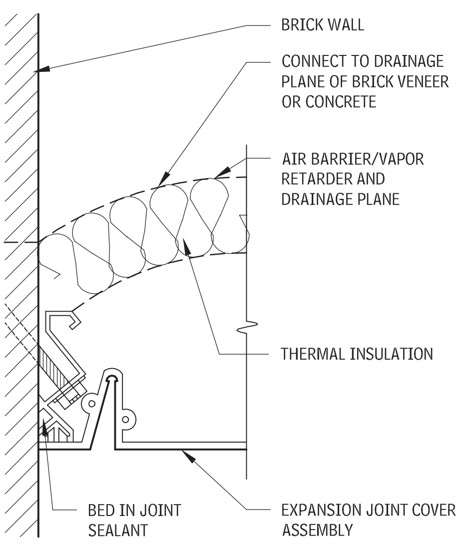
EXPANSION JOINT COVERS IN DRAINED CAVITY OF RAINSCREEN WALLS
11.16



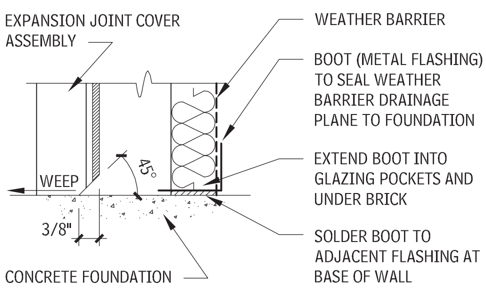
DUAL-LINE EXPANSION JOINT AT RAINSCREEN METAL PANEL
11.17



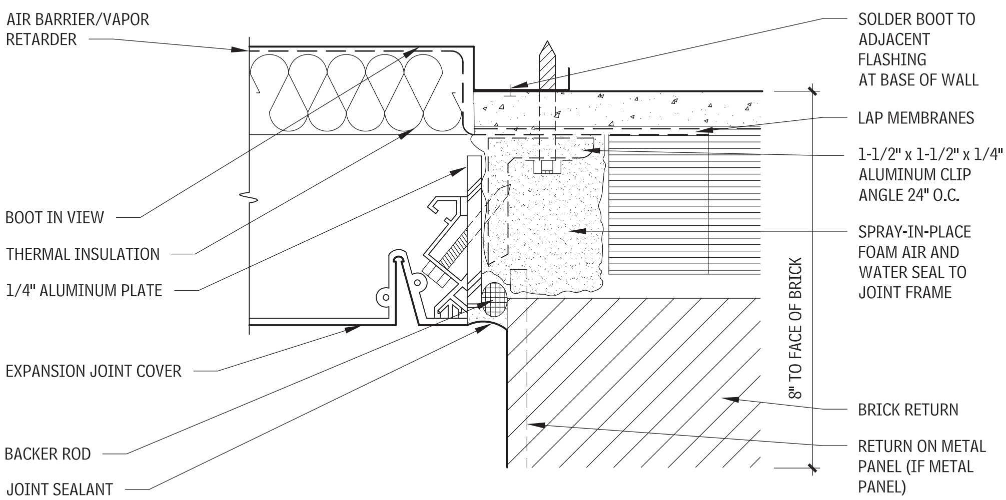
DUAL-LINE EXPANSION JOINT AT BRICK VENEER
11.18



DUAL-LINE EXPANSION JOINT TERMINATION AT FOUNDATION
11.19



DUAL-LINE EXPANSION JOINT IN NEW BRICK VENEER WALL
11.20



SUSTAINABILITY AND ENERGY

The building shell should be a major part of the sustainable strategy. At a minimum, the shell should:

- Contribute to minimizing energy use.
- Incorporate environmentally sensitive materials.
- Ensure good indoor air quality and occupant comfort.
- Be durable.

For high-performance building projects, the enclosure could help generate energy, return nutrients to the environment, and filter pollutants.

One area of special concern for the building shell is durability. The building superstructure and enclosure are frequently portions of the building that should last the longest and are the most difficult to repair or replace. Buildings that perform well for many years slow or reduce the consumption of resources and the waste stream. Failures of the enclosure can lead not only to water-damaged materials needing repair or replacement but also to unnecessary long-term energy consumption, toxic mold, and sick buildings.

Buildings are major consumers of energy, so the enclosures should be part of a strategy to reduce energy consumption. In fact, creating a well-performing enclosure is considered to be the first step in reducing energy use, ahead of other more sophisticated strategies, such as high-performance mechanical systems. A thorough understanding of the interior and exterior environments is paramount. For residential buildings in cold climates, heat loss through the enclosure may be the largest component of total energy consumption. For large commercial buildings in a moderate environment, daylighting schemes may save more energy, even as they may result in an enclosure with lower thermal resistance.

Most jurisdictions require compliance with an energy conservation code. ASHRAE 90.1 and the International Energy Conservation Code (in various editions) are common model codes. These are minimum standards and should be exceeded if possible.

Contributor:
Sealant, Waterproofing and Restoration Institute (SWRI), Kansas City, Missouri.

SUPERSTRUCTURE

LONG-SPAN AND TENSILE STRUCTURES

DESIGN CONSIDERATION FACTORS

Examples of long-span structures shown in Figure 11.21 are rated for their capability to address the following design factor conditions.

NATURAL CONDITIONS

Uneven or excessive snow and ice loads: Geometry, equipment, or surrounding structure may contribute to snow drifting or ice buildup.

Ponding: Provide positive drainage to remove water from the structure when roof drains clog.

Wind: Evaluate potential of wind-induced destructive vibration in members or connections.

Thermal: Daily and seasonal temperature cycles can cause significant changes in structural shape and member stresses, and may lead to fatigue failure.

Freeze/thaw cycles or corrosive atmosphere: Evaluate long-term effects on structural performance, particularly for exposed concrete structures.

PRIMARY STRESSES

Load paths: Two or more load paths for all loads should be provided wherever possible. The greater the area a single member supports, the greater should be its safety factor.

Compression failure: Resistance to lateral buckling of long members is crucial. Use members that ensure initial and verifiable alignment.

Tension failure: Dynamic stability under wind or other vibration loading should be carefully verified.

SECONDARY STRESSES

Deflection: Changes in orientation of members at joints can increase destructive stresses from loads.

Member interaction: Load flows through structures in such a way as to minimize strength. Check all possible load paths of complex geometric structures.

Nonstructural connections: Assemblies attached to a structure will influence structural load flow and even become part of the load flow if the attachment changes the deflected shape.

Scale: Most members have a span limit, beyond which weight of the member itself becomes a limiting factor.

Stress concentration: Check stresses at changes of cross sections, holes, and connections. High-strength materials are particularly sensitive.

LONG-SPAN COMPONENTS
11.21

COMPONENTS	MATERIAL (OR SHAPE)	ONE-WAY	TWO-WAY	FLAT SURFACE	PITCHED PLANE	CURVED PLANE	CURVED SURFACE	SPAN RANGE (FT) 50 100 150 300 600	SPAN/DEPTH RATIO (FT)
Joist	Steel	•		•	—				24
Truss	Steel	•		•	•	—			22
			•	•		—			20
	Wood	•		•	•	—			12
			•	•		—			12
Space frame	Steel	•	•	•					20
Stressed skin	Steel		•	•		—			18
Beam	Steel	•	—	•					22
	Wood	•		•					20
	Prestressed concrete	•	—	•					26
Rigid frame	Steel	•	—	•	—				20–24
	Wood	•		•	—				18–22
	Prestressed concrete	•	—	•	—				24–28
Cable-stayed									
Folded plate	Steel	•			•				22
	Wood	•			•				6
	Concrete	•			•				14
Cylindrical shell	Concrete	•				•			14
Vault	Concrete	•	•			•			10
Arch	Steel	•	•			•			8
	Wood	•	•			•			7
	Concrete	•	•			•			7
Dome	Radial steel		•				•		8
	Geodesic dome		•				•		5
	Radial wood		•				•		6
	Lamella wood		•				•		6
	Concrete		•				•		8
Pneumatics	Steel		•				•		7
Cable	Parallel	•				•			16
	Radial		•				•		12
	Hyperbolic		•				•		8
	Tent		•				•		6
Hyperbolic	Concrete		•				•		6

NOTES

11.21 a. Steel is A-36; wood is laminated, sometimes heavy timber; concrete is reinforced with steel; prestressed concrete is prestressed with steel.

b. Cable-stayed system can give auxiliary support to trusses, beams, or frames, greatly reducing span and member sizes, but providing additional tensional strength.

c. Lamella arches provide two-way arch structures and improve redundancy.

d. Domes may also be constructed of aluminum.

e. Pneumatics are fabric roofs, pressurized, and stabilized with steel cables.

f. For each system, the following notation applies: the bullet (•) indicates the typical configuration; the dash (—) indicates occasionally used.

Contributor:
William C. Bauman, Jr., University of Oklahoma, Norman, Oklahoma.

TOLERANCES

Erection alignment: True member length and spatial position are crucial for proper alignment and load flow.

Creep: Length changes over time will influence both primary and secondary stresses.

Supports and foundations: Supports must accept movements due to deflections from primary and secondary stresses and differential foundation settlement.

QUALITY CONTROL

Design: Engineering design must not be compromised by time, scheduling, design changes, or building codes.

Methods: Construction methods should be selected carefully to safely and accurately locate the structural components.

Site observation: Only when the structure is properly established in space should it be accepted. Changes in construction materials or methods should be carefully evaluated.

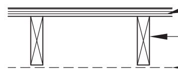
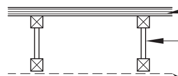
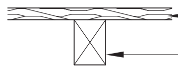
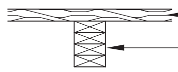
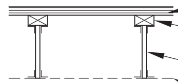
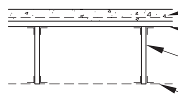
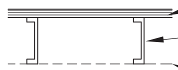
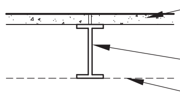
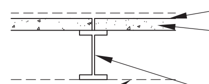
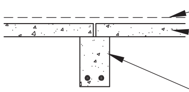
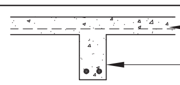
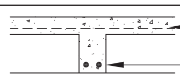
Structural building maintenance: Conditions and alignment of various members, especially crucial nonredundant members, should be verified on a regular schedule. Consider using equipment to detect excessive deflection.

Nonstructural building maintenance: The condition of building components should not adversely affect the structure (e.g., keep roof drains open, prevent excessive equipment vibration, and maintain expansion joints).

FLOOR ASSEMBLIES

This section examines common floor construction assemblies. Consult literature from manufacturers and trade associations for more details on the information presented in the accompanying tables.

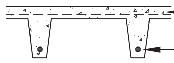
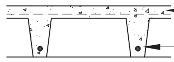
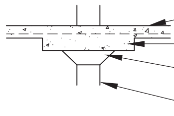
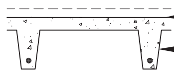
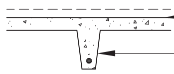
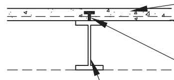
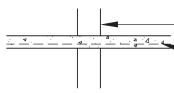
FLOOR STRUCTURE ASSEMBLIES
11.22

		DEPTH OF ASSEMBLY (IN.)	STANDARD MEMBER SIZES (IN.)	DEAD LOAD OF STRUCTURE (PSF)	SUITABLE LIVE LOAD RANGE (PSF)	SPAN RANGE (FT)	DIMENSIONAL STABILITY AFFECTED BY
Wood joist		7–13	Nominal joist 2 × 6, 8, 10, and 12	5–8	30–40	Up to 18	Deflection
Wood I-joists or shop-fabricated wood trusses		13–21	12, 14, 16, 18, and 20	6–12	30–40	12–30	Deflection
Wood beam and plank		10–22	Nominal plank 2, 3, and 4	6–16	30–40	10–22	—
Glue-laminated beam and plank		8–22	Nominal plank 2, 3, and 4	6–20	30–40	8–34	—
Steel joist		9–31	Steel joists 8–30	8–20	30–40	16–40	Deflection
Steel joist		11–75	Steel joists 8–72	30–110	30–100	16–60 (up to 130)	Deflection
Lightweight steel frame		7–12	Consult manufacturers' literature	6–20	30–60	10–22	—
Structural steel frame		9–15	—	35–60	30–100	16–35	Deflection
Structural steel frame		8–16	Precast structural concrete 16–48 W 4–12 D	40–75	60–150	Up to 50; generally below 35	Deflection and creep
Precast concrete		6–12	Precast structural concrete 16–48 W 4–12 D	40–75	60–150	Up to 60; generally below 35	Deflection and creep
One-way concrete slab		4–10	—	50–120	40–150	10–20; more with post-tensioning	—
Two-way concrete slab		4–10	—	50–120	40–250	10–30; more with post-tensioning	—

FLOOR STRUCTURE ASSEMBLIES (continued)
11.22

BAY SIZE CHARACTERISTICS	REQUIRES FINISHED FLOOR SURFACE	REQUIRES FINISHED CEILING SURFACE	SERVICE PLENUM	COMPARATIVE RESISTANCE TO SOUND TRANSMISSION		REMARKS
				IMPACT	AIRBORNE	
—	Yes	Visual or fire protection purposes	Between joists—one way	Poor	Fair	Economical, light, easy to construct; limited to low-rise construction
—	Yes	Visual for fire protection purposes	Between trusses and joists—two ways	Poor	Fair	Close dimensional tolerances; cutting holes through web permissible
Maximum beam spacing 8′-0″	Optional	No	Under structure—one way	Poor	Fair	Most efficient with planks continuous over more than one span
—	Optional	No	Under structure— one way	Poor	Fair	—
Light joists, 16″ to 30″ o.c.; heavy joists, 4′–12′ o.c.	Yes	Visual or fire protection purposes	Between joists—two ways	Poor	Poor	—
Light joists, 16″ to 30″ o.c.; heavy joists, 4′ –12′ o.c.	No	Visual or fire protection purposes	Between joists—two ways	Poor	Fair	Economical system; selective partition placement required; cantilevers difficult
—	Yes	Visual or fire protection purposes	Under structure	Poor	Poor	—
—	No	Visual or fire protection purposes	Under structure	Poor	Fair	—
—	Optional	Visual or fire protection purposes	Under structure	Fair	Fair	—
—	Optional	No	Under structure	Fair	Fair	—
—	No	No	Under structure	Good	Good	Restricted to short spans because of excessive dead load
$L \leq 1.33\ W$	No	No	Under structure	Good	Good	Suitable for concentrated loads; easy partition placement

FLOOR STRUCTURE ASSEMBLIES (continued)
11.22

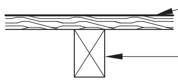
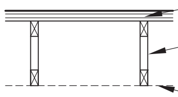
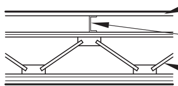
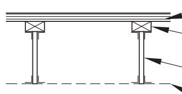
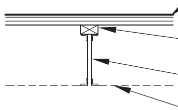
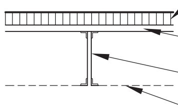
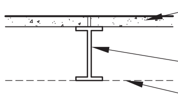
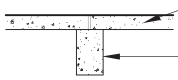
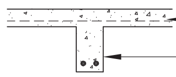
		DEPTH OF ASSEMBLY (IN.)	STANDARD MEMBER SIZES (IN.)	DEAD LOAD OF STRUCTURE (PSF)	SUITABLE LIVE LOAD RANGE (PSF)	SPAN RANGE (FT)	DIMENSIONAL STABILITY AFFECTED BY
One-way ribbed concrete slab		8–22	Standard pan forms 20 and 30 W, 6–20 D	40–90	40–150	15–50; more with post-tensioning	Creep
Two-way ribbed concrete slab		8–22	Standard dome forms 19 × 19, 30 ×30 6–20 D	75–105	60–200	25–60; more with post-tensioning	Creep
Concrete flat slab		6–16	Minimum slab thickness 5, without drop panel; 4 with drop panel	75–170	60–250	20–40; up to 70 with post-tensioning	Creep
Precast double tee		8–18	48, 60, 72, 96, and 120 W 6–16 D	50–80	40–150	20–50	Creep
Precast tee		18–38	16–36 D	50–90	40–150	25–65	Creep
Composite		4–6	—	35–70	60–200	Up to 35	Deflection
Concrete flat plate		5–14	—	60–175	60–200	18–35; more with post-tensioning	Creep

BAY SIZE CHARACTERISTICS	REQUIRES FINISHED FLOOR SURFACE	REQUIRES FINISHED CEILING SURFACE	SERVICE PLENUM	COMPARATIVE RESISTANCE TO SOUND TRANSMISSION		REMARKS
				IMPACT	AIRBORNE	
—	No	No	Between ribs—one way	Good	Good	Economy through reuse of forms; shear at supports controlling factor
L ≤ 1.33 W	No	No	Under structure	Good	Good	For heavy loads, columns should be equidistant; not good for cantilevers
L ≤ 1.33 W	No	No	Under structure	Good	Good	Drop panels against shear required for spans above 12'
—	Optional	Visual purposes; differential camber	Between ribs—one way	Fair	Good	Most widely used prestressed concrete product in the medium-span range
—	Optional	Visual purposes; differential camber	Between ribs—one way	Fair	Good	Easy construction; lacks continuity; poor earthquake resistance
—	No	Visual or fire protection purposes	Under structure	Good	Good	—
L ≤ 1.33 W	No	No	Under structure	Good	Good	Uniform slab thickness; economical to form; easy to cantilever

ROOF ASSEMBLIES

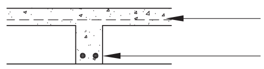
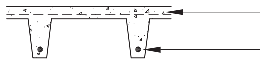
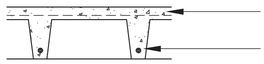
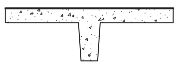
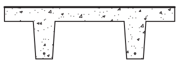
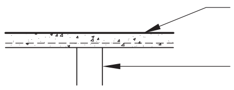
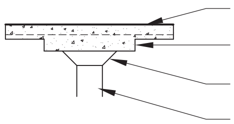
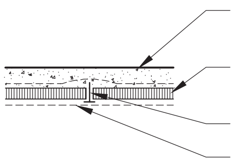
This section examines common systems used in roof construction. Consult literature from manufacturers and trade associations for more details on the information presented in the accompanying tables.

ROOF STRUCTURE ASSEMBLIES
11.23

		DEPTH OF SYSTEM (IN.)	STANDARD MEMBER SIZES (IN.)	DEAD LOAD OF STRUCTURE (PSF)	SUITABLE LIVE LOAD RANGE (PSF)	SPAN RANGE (FT)	BAY SIZE CHARACTER-ISTICS	DIMENSIONAL STABILITY AFFECTED BY
Wood rafter		5–13	Nominal rafters 2 × 4, 6, 8, 10, and 12	4–8	10–50	Up to 22	—	Deflection
Wood beam and plank		8–22	Nominal planks 2, 3, and 4	5–12	10–50	8–34	Maximum beam spacing 8′–0″	—
Stress skin panel		3-1/4 and 8-1/4	—	3–6	10–50	8–32	4′–0″ modules	—
Shop-fabricated wood truss		Varies12 – 120	—	5–15	10–50	30–50	2′–8′ between trusses	Deflection
Cold-formed metal truss		Varies	—	15–25	10–60	100–200	—	Deflection
Steel joist		11–75	Steel joists 8–72	10–28	10–50	Up to 96	Light joists 16″–30″ o.c.; heavy joists 4′–12′ o.c.	Deflection
Steel joist		10–32	Steel joists 8–30	8–20	10–50	Up to 96	Light joists 16″–30″ o.c.; heavy joists 4′–12′ o.c.	Deflection
Steel joist		11–75	Steel joists 8–72	6–24	10–50	Up to 96	—	Deflection
Steel frame		4–12, plus beam depth	Concrete plank 16–48 W, 4–12 D	40–75	30–70	20–60; generally below 35	—	Deflection and creep
Precast concrete		4–12, plus beam depth	Concrete plank 16–48 W, 4–12 D	40–75	30–70	20–60; generally below 35	—	Deflection and creep
One-way concrete slab		4–10 slab, plus beam depth	—	50–120	Up to 100	10–25; more with prestressing	—	—

SUITABLE FOR INCLINED ROOFS	REQUIRES FINISHED CEILING SURFACE	SERVICE PLENUM	RELATIVE THERMAL CAPACITY	COMPARATIVE RESISTANCE TO SOUND TRANSMISSION		REMARKS
				IMPACT	AIRBORNE	
Yes	For visual or fire protection purposes	Between rafters—one way	Low	Poor	Fair	
Yes	For fire protection purposes	Under structure—one way	Medium	Poor	Fair	
Yes	No	Under structure only	Low	Poor	Fair	
Yes	For visual or fire protection purposes	Between trusses	Low	Poor	Fair	Truss depth to span ratio 1:5 to 1:10
Yes; pitched trusses usually used for short spans	For visual or fire protection purposes	Between trusses	Low	Fair	Fair	Truss depth to span ratio 1:5 to 1:15
No	For visual or fire protection purposes	Between joists	Medium	Fair	Fair	
Yes	For visual or fire protection purposes	Between joists	Low	Poor	Fair	
Yes	For visual or fire protection purposes	Between joists	High	Excellent	Good	
Yes	For visual or fire protection purposes	Under structure	High	Fair	Fair	Easy to design; quick erection
Yes	No	Under structure	High	Fair	Fair	Provides finished flush ceiling; may be used with any framing system
No	No	Under structure	High	Good	Good	

ROOF STRUCTURE ASSEMBLIES (continued)
11.23

		DEPTH OF SYSTEM (IN.)	STANDARD MEMBER SIZES (IN.)	DEAD LOAD OF STRUCTURE (PSF)	SUITABLE LIVE LOAD RANGE (PSF)	SPAN RANGE (FT)	BAY SIZE CHARACTER-ISTICS	DIMENSIONAL STABILITY AFFECTED BY
Two- way concrete slab		4–10 slab, plus beam depth	—	50–120	Up to 100	10–30; more with prestressing	L ≤ 1.33 W	—
One-way ribbed concrete slab		8–22	Standard pan forms 20 and 30 W, 6–20 D	40–90	Up to 100	15–50; more with prestressing	—	Creep
Two-way ribbed concrete slab		8–24	Standard dome forms 19 × 19, 30 × 30 6–20 D	75–105	Up to 100	25–60; more with prestressing	L ≤ 1.33 W	Creep
Precast concrete single tee		16–36	16–36 D	65–85	20–80	30–100	—	Creep
Precast concrete double tee		6–16	48, 60, 72, 96 AND 120 W, 6–16 D	35–55	25–60	20–75	—	Creep
Concrete flat plate		4–14	—	50–160	Up to 100	Up to 35; more with prestressing	L ≤ 1.33 W	Creep
Concrete flat slab		5–16	Minimum slab thickness 5 without drop panel, 4 with drop panel	50–200	Up to 100	Up to 40; more with prestressing	L ≤ 1.33 W; equal column spacing required	Creep
Gypsum concrete roof deck		3–6	—	5–20	Up to 50	Up to 10	Up to 8′ between subpurlins	Deflection and creep

ROOF STRUCTURE ASSEMBLIES (continued)
11.23

SUITABLE FOR INCLINED ROOFS	REQUIRES FINISHED CEILING SURFACE	SERVICE PLENUM	RELATIVE THERMAL CAPACITY	COMPARATIVE RESISTANCE TO SOUND TRANSMISSION		REMARKS
				IMPACT	AIRBORNE	
No	No	Under structure	High	Good	Good	
No	For visual purposes	Between ribs—one way	High	Good	Good	
No	No	Under structure	High	Good	Good	Economy in forming; suitable for two-way cantilevering
Yes	For visual or fire protection purposes	Between ribs—one way	High	Fair	Good	Generally used for long spans
Yes	For visual or fire protection purposes	Between ribs—one way	High	Fair	Good	Most widely used prestressed concrete element
No	No	Under structure	High	Good	Good	Uniform slab thickness; easy to form; suitable for vertical expansion of building
No	No	Under structure	High	Good	Good	Suitable for heavy roof loads
No	For visual or fire protection purposes	Under structure	High	Good	Good	Provides resistance to wind and seismic loads

Contributors:
Stephan Pienkny, AIA and Cline McGee, AIA, Hall Architects, Inc.,
Charlotte, North Carolina.

COMPARISON OF SYSTEMS

STRUCTURAL USE COMPARISON
11.24

FRAME AND SUPPORT	ADVANTAGES	DISADVANTAGES	APPROPRIATE BUILDING TYPES	COMMENTS
Bearing walls	Eliminates use of steel or concrete columns and beam at exterior wall	Height of structure limitation	All building types with exception of mid- or high-rise structures	Economical construction and great choice of veneer materials for pleasing aesthetic appearance
	Bearing masonry itself can be used as exterior shell or can be clad in variety of veneer materials such as brick, CMU, and stone in a cavity wall	Requires sealing if used in unclad fashion		Durable and low-maintenance shell that ages well
	Can meet fire rating requirements and form fire walls	Requires added insulation for meeting current energy codes		
		Requires added interior finish if a natural masonry look is nondesirable		
Bearing walls with pilasters	Allows for thinner shell walls that results in increased net usable area	Height of structure limitation	All building types with exception of mid- or high-rise structures	Economical construction particularly for commercial structures
		Pilaster projection into floor space		Great choice of veneer materials for exterior cladding in a cavity wall
	Defines columns/piers for beams or joists supports	Requires sealing if used in unclad fashion		Durable and low maintenance shell that ages well
	Lower cost of foundations	Requires added insulation for meeting current energy codes		
	Can meet fire rating requirements	Requires added interior finish if a natural masonry look is nondesirable		
Concrete columns	Economical construction	Limited height; usually does not exceed two stories	All building types, but not commonly used in mid- or high-rise structures	Masonry columns are economical to construct whether with grout and steel reinforced core or multi-wythe fashion
	Eliminates use of steel columns	Uses more space than a steel column		Offers pleasing aesthetic appearance as part of exterior elevations or interiors with a rustic appearance
	Can be used as finished without enclosure or cladding	Rustic or rough finish of material may require additional finish		Durable and low maintenance
	Can meet fire rating requirements			
Precast walls	Modular construction of exterior shell	Panel size limited due to transportation requirement	All building types	Economical construction when masonry appearance is desired
	Great choice of materials for aesthetic appearance from brick to stone or tile	Requires crane		Construction time can be reduced since panels are shop produced
	Prefabricated	Requires joints		
	Reduced erection time			
Tilt-up	Allows for on-site construction	Less control of workmanship	Utilitarian buildings such as manufacturing plants and warehouses	Economical, fast construction
	Walls form structural support	In-shop production		
	Variety of finish materials from brick to stone	Height limitation usually to single story		

SELECTED FLOOR LOADS

LIVE LOAD

Live load is the weight superimposed by the use and occupancy of the building or other structure, not including environmental loads such as wind, snow, rain, flood, and seismic loads. The live loads to be assumed in the design of buildings and other structures will be the greatest loads that probably will be produced by the intended use or occupancy; but in no case will they be less than the minimum uniformly distributed unit load.

LIVE LOAD REDUCTION

In general, design live loads should not be in excess of 100 psf on any member, supporting an area of 150 sq. ft. or more, except for places of public assembly, storage, repair garages, parking structures, and roofs. The reduction must not exceed the value of R, from the following formulas:

$R = 0.08\ (A - 150)$
$R = 23\ (1 + D/L)$

where the following is true:

R = reduction (%)
D = dead load per square foot of area supported by the member
L = live load per square foot of area supported by the member
A = area supported by the member

In no case should the reduction exceed 60 percent for vertical members, or 40 percent for horizontal members.

For live loads in excess of 100 psf, some codes allow a live load reduction of 20 percent for columns only.

CODES AND STANDARDS

For specific uniformly distributed live loads, movable partition load, special and concentrated load requirements, refer to the applicable building code.

In addition to specific code requirements, the designer must consider the effects of special loading conditions such as moving loads, construction loads, rooftop planting loads, and concentrated loads from supported or hanging equipment (radiology, computer, heavy filing, or mechanical equipment).

The live loads given in Figure 11.25 are obtained by reference to ICC.

CONCENTRATED LOADS

Floors must be designed to safely support the uniformly distributed live load, or the concentrated load in pounds given, whichever produces the greater stresses. Unless otherwise specified, the indicated concentration is assumed to occupy an area of 2–1/2 ft. by 2–1/2 ft. (6.26 sq. ft.) and be located so as to produce the maximum load effects in the structural members.

PARTIAL LOADING

The full intensity of the appropriately reduced live loads applied only to a portion of the length of a structure or member will be considered if it produces a more unfavorable effect than the same intensity applied over the full length of the structure or member.

IMPACT LOADS

The live loads will be assumed to include adequate allowance for ordinary impact conditions. Provision will be made in structural design for uses and loads that involve unusual vibration and impact forces.

- *Elevators:* All elevator loads will be increased 100 percent for impact, and the structural supports will be designed within limits of deflection, as prescribed by the American Society of Mechanical Engineers Safety Code for Elevators and Escalators (ASME A17.1).
- *Machinery:* For the purpose of design, the weight of machinery and moving loads will be increased as follows to allow for impact:
  - Elevator machinery: 100 percent
  - Light machinery, shaft or motor driven: 20 percent
  - Reciprocating machinery or power driven units: 50 percent
  - Hangers for floors or balconies: 33 percent
  - Percentages to be increased if so recommended by the manufacturer.
- *Parking garage guardrails:* Guardrails and walls acting as impact rails in passenger vehicle parking structures will be designed for a single load of 6000 lb. applied 18 in. above the floor at any point of the guardrail.

MINIMUM UNIFORMLY DISTRIBUTED LIVE LOADS
11.25

OCCUPANCY OR USE	LIVE LOAD (PSF)	CONCENTRATED (LBS)
1. Access floor systems Office use Computer use	 50 100	 2000 2000
2. Armories and drill rooms	150	—
3. Assembly areas and theatres Fixed seats (fastened to floor) Follow spot projections and control rooms Lobbies Movable seats Stages and platforms	 60 50 100 100 125	—
4. Balconies On one- and two-family residences only, and not exceeding 100 sq. ft.	100 60	—
5. Bowling alleys	75	—
6. Catwalks	40	300
7. Dance halls and ballrooms	100	—
8. Decks	Same as occupancy served	—
9. Dining rooms and restaurants	100	—
10. Dwellings (see residential)	—	—
11. Cornices	60	—
12. Corridors, except as otherwise indicated	100	—
13. Elevator machine room grating (on area of 1 sq. in)	—	300
14. Finish light floorplate construction (on area of 1 sq. in)	—	200
15. Fire escapes On single-family dwellings only	100 40	—
16. Garages (passenger vehicles only)	40	Note[a]
17. Grandstands (see stadium and arena bleachers)	—	—
18. Gymnasiums, main floors and balconies	100	—
19. Hospitals Corridors above first floor Operating rooms, laboratories Patient rooms	 80 60 40	 1000 1000 1000
20. Libraries Corridors above first floor Reading rooms Stack rooms	 80 60 150[b]	 1000 1000 1000
21. Manufacturing Heavy Light	 250 125	 3000 2000
22. Marquees	75	—
23. Office buildings Corridors above first floor File and computer rooms shall be designed for heavier loads based on anticipated occupancy Lobbies and first-floor corridors Offices	 80 — 100 50	 2000 — 2000 2000
24. Penal institutions Cell blocks Corridors	40 100	—
25. Residential One- and two-family dwellings Uninhabitable attics without storage Uninhabitable attics with limited storage[i] Habitable attics and sleeping areas[i,j,k] All other areas except balconies and decks Hotels and multiple-family dwellings Private rooms and corridors serving them Public rooms and corridors serving them	 10 20 30 40 40 100	
26. Roofs All roof surfaces subject to maintenance workers Awnings and canopies Fabric construction supported by a lightweight rigid skeleton structure All other construction Ordinary flat, pitched, and curved roofs Primary roof members, exposed to a work floor Single panel point of lower chord of roof trusses or any point along primary structural members supporting roofs: Over manufacturing, storage warehouses, and repair garages All other occupancies Roofs used for other special purposes Roofs used for promenade purchases Roofs used for roof gardens or assembly purposes	 5 Nonreducable 20 20 Note l 60 100	300 2000 300 Note l
27. Schools Classrooms Corridors above first floor First-floor corridors	 40 80 100	 1000 1000 1000
28. Scuttles, skylight ribs, and accessible ceilings	—	200
29. Sidewalks, vehicular driveways and yards, subject to trucking	250[d]	8000[c]
30. Skating rinks	100	—
31. Stadiums and arenas Bleachers Fixed seats (fastened to floor)	 100[c] 60[c]	—
32. Stairs and exits One- and two-family dwellings All other	 40 100	Note[f]
33. Storage warehouses (shall be designed for heavier loads if required for anticipated storage) Heavy Light	 250 125	
34. Stores Retail First floor Upper floors Wholesale, all floors	 100 75 125	 1000 1000 1000
35. Walkways and elevated platforms (other than exitways)	60	—
36. Yard and terraces, pedestrians	100	—

Source: Adopted from 2006 International Building Code Council.

NOTES

11.25 a. Floors in garages or portions of buildings used for the storage of motor vehicles shall be designed for the uniformly distributed live loads of Table 11.27 or the following concentrated loads: (1) for garages restricted to vehicles accommodating not more than nine passengers, 3000 lb. acting on an area of 4.5 in. by 4.5 in.; (2) for mechanical parking structures without slab or deck which are used for storing passenger vehicles only, 2250 lb. per wheel.
b. The loading applies to stack room floors that support nonmobile, double-faced library bookstacks, subject to the following limitations:
1. The nominal bookstack unit height shall not exceed 90 in.;
2. The nominal shelf depth shall not exceed 12 in. for each face; and
3. Parallel rows of double-faced bookstacks shall be separated by aisles not less than 36 in. wide.
c. Design in accordance with the ICC Standard on Bleachers, Folding and Telescopic Seating and Grandstands.
d. Other uniform loads in accordance with an approved method which contains provisions for truck loadings shall also be considered where appropriate.
e. The concentrated wheel load shall be applied on an area of 20 sq. in.
f. Minimum concentrated load on stair treads (on area of 4 sq. in.) is 300 lb.
g. Where snow loads occur that are in excess of the design conditions, the structure shall be designed to support the loads due to the increased load caused by drift buildup or a greater snow design determined by the building official.
h. Not used.
i. Attics without storage are those where the maximum clear height between the joist and rafter is less than 42 in., or where there are not two or more adjacent trusses with the same web configuration capable

CONCRETE

CONCRETE CONSTRUCTION

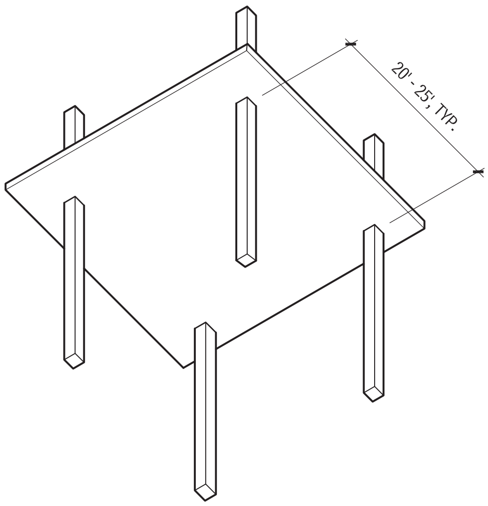
The information presented here is intended only as a preliminary design guide. All structural dimensions for slab thickness, beam and joint sizes, column sizes, should be calculated and analyzed for each project condition by a licensed professional engineer.

Spans shown in the accompanying figures are approximate and are based on use of mild reinforcing steel. For spans greater than 40 ft., consider post-tensioning.

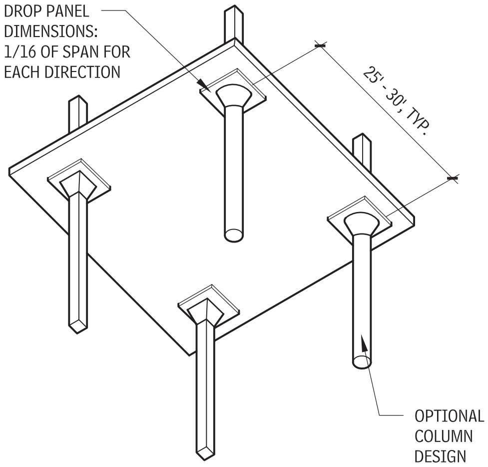
Consider embedded items such as conduits and penetrations for ducts and pipes when coordinating a structural system. Concrete floor construction may have less flexibility for locating large duct openings close to beam lines or small penetrations immediately adjacent to columns.

FLOOR AND BALCONY

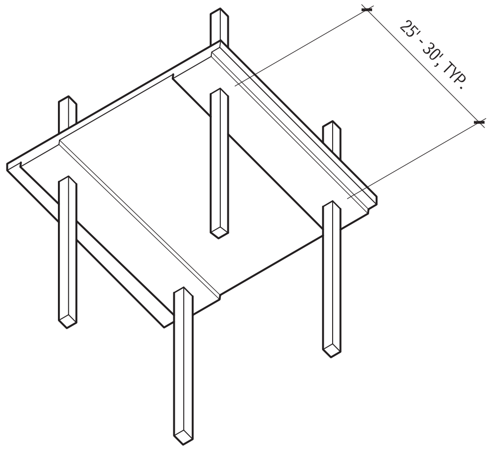
FLAT PLATE
11.26



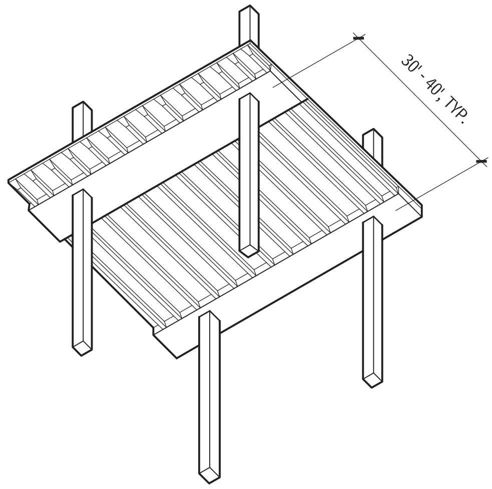
FLAT SLAB
11.27



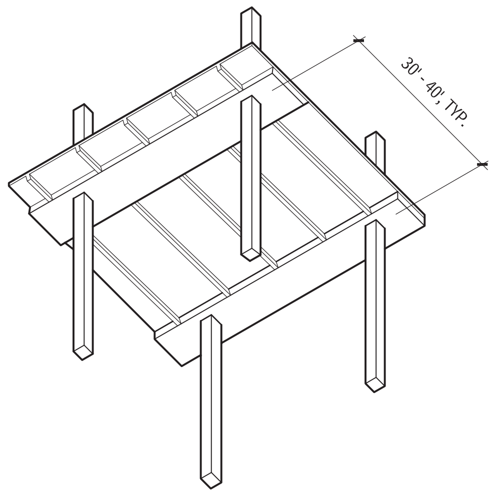
BANDED SLAB
11.28



JOIST SLAB
11.29



SKIP JOIST
11.30



of containing a rectangle 42 in. high by 2 ft. wide, or greater, located within the plane of the truss. For attics without storage, this live load need not be assumed to act concurrently with any other live load requirements.

j. For attics with limited storage and constructed with trusses, this live load need only be applied to those portions of the bottom chord where there are two or more adjacent trusses with the same web configuration capable of containing a rectangle 42 in. high by 2 ft. wide or greater, located within the plane of the truss. The rectangle shall fit between the top of the bottom chord and the bottom of any other truss member, provided that each of the following criteria is met:

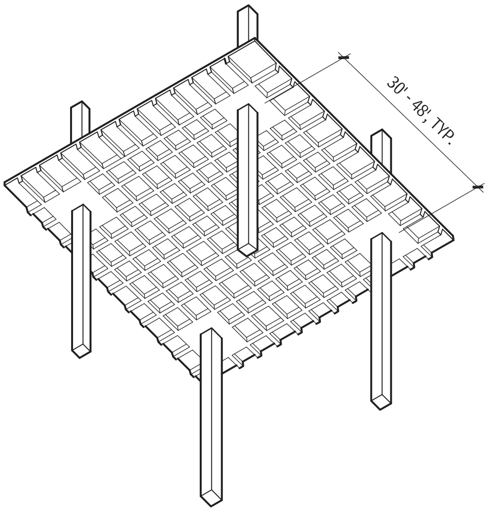
1. The attic area is accessible by a pull-down stairway or framed opening in accordance with Section 1209.2, ICC, and
2. The truss shall have a bottom chord pitch less than 2:12.
3. Bottom chords of trusses shall be designed for the greater of actual imposed dead load or 10 psf, uniformly distributed over the entire span.

k. Attic spaces served by a fixed stair shall be designed to support the minimum live load specified for habitable attics and sleeping rooms.

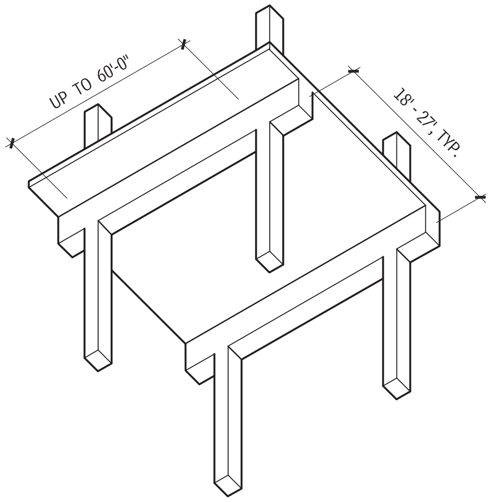
l. Roofs used for other special purposes shall be designed for appropriate loads as approved by the building official.

Contributor:
Charles W. Vanderlinden, PE, Hansen Lind Meyer, Inc., Orlando, Florida.

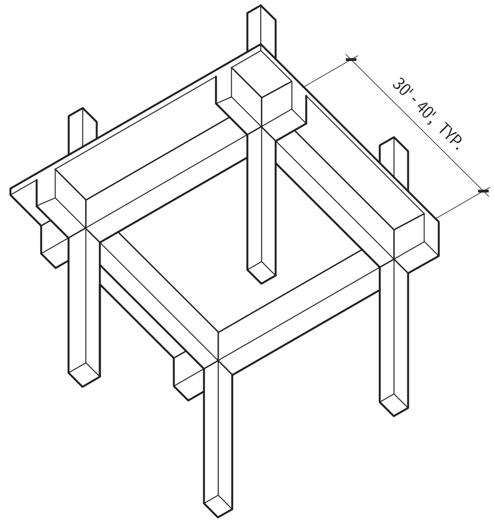
WAFFLE SLAB
11.31



ONE-WAY SLAB
11.32



TWO-WAY SLAB
11.33



CONCRETE FLOOR SYSTEM COMPARISON
11.34

FLOOR SYSTEM	ADVANTAGES	DISADVANTAGES	APPROPRIATE BUILDING TYPES	COMMENTS
Flat plate	Inexpensive formwork; ceilings may be exposed; minimum thickness; fast erection; flexible column location	Excess concrete for longer spans; low shear capacity; greater deflections	Hotels, motels, dormitories, condominiums, hospitals	A flat plate is best for moderate spans because it is the most economical floor system and has the lowest structural thickness. Avoid penetrations for piping and ductwork through the slab near the columns. Spandrel beams may be necessary.
Flat slab	Economical for design loads greater than 150 psf	Formwork is costly.	Warehouses, industrial structures, parking structures	Flat slabs are most commonly used today for buildings supporting very heavy loads. When live load exceeds 150 lb. per sq. ft., this scheme is by far the most economical.
Banded slab	Longer spans than flat plate; typically post-tensioned; minimum thickness	Must reuse formwork many times to be economical	High-rise buildings; same use as flat plates, if flying forms can be used more than 10 times	A banded slab has most of the advantages of a flat plate, but permits a longer span in one direction. It can resist greater lateral loads in the direction of the beams.
Joist slab	Minimum concrete and steel; minimum weight, hence reduced column and footing size; long spans in one direction; accommodates poke-through electrical systems	Unattractive for a ceiling; formwork may cost more than flat plate	Schools, offices, churches, hospitals, public and institutional buildings, buildings with moderate loadings and spans	This is the best scheme if slabs are too long for a flat plate and the structure is not exposed. The slab thickness between joints is determined by fire requirements. Joists are most economical if beams are the same depth as the joists. Orient joists in the same direction throughout the building and in the long direction of long rectangular bays.
Skip joist	Uses less concrete than joist slab; lower rebar placing costs; joist space used for mechanical systems; permits lights and equipment to be recessed between joists	Similar to joist slab; joists must be designed as beams; forms may require special order	Same as for joist slabs, especially for longer fire ratings	Ensure the availability of formwork before specifying skip joists. For larger projects, a skip joist slab should be less expensive than a joist slab, and it permits lights and equipment recessed between joists.
Waffle slab	Longer two-way spans; attractive exposed ceilings; heavy load capacity	Formwork costs more and uses more concrete and steel than a joist slab.	Prominent buildings with exposed ceiling structure; same types as are suitable for flat slab, but with longer spans	Column spacing should be multiples of span spacing to ensure uniformity of drop panels at each column. Drop panels can be diamond-shaped, square, or rectangular.
One-way slab	Long span in one direction	Beams interfere with mechanical services; more expensive forms than flat plate.	Parking garages, especially with post-tensioning	This scheme is most favored for parking garages, but the long span of about 60 ft. must be post-tensioned, unless beams are quite deep. Shallow beams will deflect excessively.
Two-way slab	Long span in two directions; small deflection; can carry concentrated loads	Same as for one-way beams, only more so	Portions of buildings in which two-way beam framing is needed for other reasons; industrial buildings with heavy concentrated loads	The high cost of the formwork and structural interference with mechanical systems make this scheme unattractive, unless heavy concentrated loads must be carried.

Contributor:
Russell S. Fling, P.E., Consulting Engineer, Columbus, Ohio.

PRESTRESSED AND POST-TENSIONED CONCRETE

Concrete by itself is inherently strong in tension and weak in compression. There are two procedures used for placing concrete in compression. Prestressing of the reinforcing steel occurs prior to placement of concrete and is used almost exclusively with precast concrete. Post-tensioning is the permanent tensioning of reinforcing steel for cast-in-place concrete.

- Concrete strength is usually 5000 psi at 28 days, and at least 3000 psi at the time of post-tensioning. Use hard-rock aggregate or lightweight concrete. Low-slump-controlled mix concrete is required to reduce shrinkage. Concrete shrinkage after post-tensioning decreases strength gains.
- Post-tensioning systems can be divided into three categories depending on whether the tendon is *wire*, *strand*, or *bar*. Wire systems use 0.25-in. diameter wires that have a minimum strength of 240,000 psi, and are usually cut to length in the shop. Strand systems use tendons (made of seven wires wrapped together) that have a minimum strength of 270,000 psi, and are cut in the field. Bar systems use bars ranging from 5/8- to 13/8-in. diameter, with a minimum strength of 145,000 psi, and may be smooth or deformed. The system used determines the type of anchorage used, which in turn affects the size of blockout required (in the edge of slab or beam) for the anchorage to be recessed.
- Grease and wrap tendons, or place in conduits, to reduce frictional losses during stressing operations. Limit the length of continuous tendons to about 10 ft. if stressed from one end. Long tendons require simultaneous stressing from both ends to reduce friction loss. Tendons may be grouted after stressing, or left unbonded. Bonded tendons have structural advantages that are more important for beams and primary structural members.
- Minimum average post-tensioning (net force per area of concrete) equals 150 to 250 psi for flat plates and 200 to 500 psi for beams. Exceeding these values by much causes excessive post-tension loss because of creep.
- Field inspection of post-tensioned concrete is critical to ensure proper size and location of tendons, and to monitor the tendon stress. Check tendon stress by measuring the elongation of the tendon and by monitoring gauge pressures on the stressing jack.
- Make provisions for the shortening of post-tensioned beams and slabs caused by elastic compression, shrinkage, and creep. After the post-tensioning is complete, build shear walls, curtain walls, or other stiff elements that adjoin post-tensioned members and isolate them with an expansion joint. Otherwise, additional post-tensioning force will be required to overcome the stiffness of the walls and prevent cracking.
- Fire tests have been conducted on prestressed beam and slab assemblies according to ASTM E119, "Standard Test Methods for Fire Tests of Building Construction and Material" test procedures. They compare favorably with reinforced cast-in-place concrete. There is little difference between beams using grouted tendons and those using ungrouted tendons.

Consult the following references:

- Post-Tensioning Institute, "Post-Tensioning Manual"
- Precast/Prestressed Concrete Institute, "PCI Design Handbook—Precast and Prestressed Concrete"
- "Design of Prestressed Concrete Structures," 1981, T.Y. Lin and Ned H. Burns, Wiley
- American Concrete Institute, "Building Code Requirements for Structural Concrete and Commentary" (ACI-318)

When working with a prestressed or post-tensioned beam, keep the following in mind:

- Prestressing force compresses the entire cross section of the beam, thereby reducing unwanted tension cracks.
- Permanent tension is introduced into the tendon and "locked in" with the stressing anchorage in one of two ways, though the principle in both cases is the same. In prestressed concrete, the tendon is elongated in a stressing bed before the concrete is poured. In post-tensioned concrete, the tendon is elongated after concrete has been poured and allowed to cure by means of hydraulic jacks pushing against the beam itself. Post-tensioned beams permit casting at the site for members too large or heavy for transporting from the factory to the site.
- Internal vertical forces within the beam are created by applying tension on the tendon, making the tendon begin to "straighten out." The tension reduces downward beam deflection and allows for shallower beams and longer spans than in conventionally reinforced beams.
- Auxiliary reinforcing steel provides additional strength and controls cracking and produces more ductile behavior.
- Use stirrups to provide additional shear strength in the beam and to support the tendons and longitudinal reinforcing steel. Stirrups should be open at the top to allow the reinforcing to be placed before the tendon is installed. After the tendons are placed, "hairpins" that close the stirrups may be used, when required.

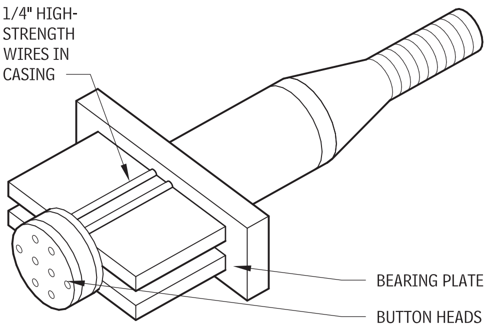
PRECAST CONCRETE FRAME

Precast concrete frame systems are ideal for highly repetitive structural frames such as parking garages and hotel/apartment/dormitory buildings. Precast members can be precast structural concrete or precast architectural concrete in exposed locations.

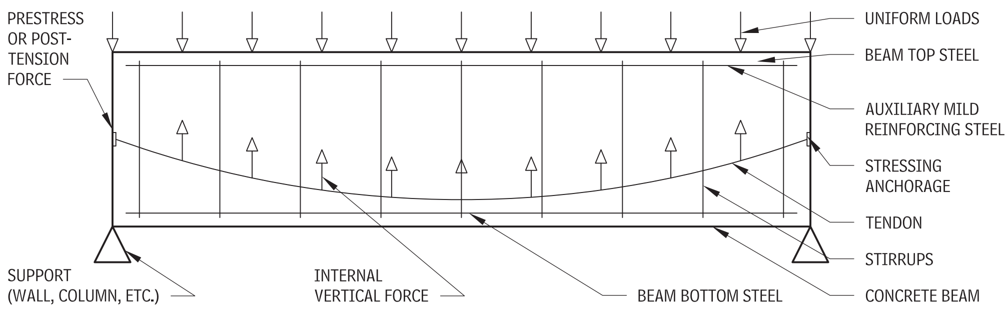
Detailing of connections for both aesthetics and to protect embedded steel members from corrosion is crucial. Typically, welded or bolted connections are grouted after final adjustment and anchorage.

Shear walls in both directions are the most common method to resist lateral loads. Stair/elevator cores and dwelling unit separation may also serve as shear walls.

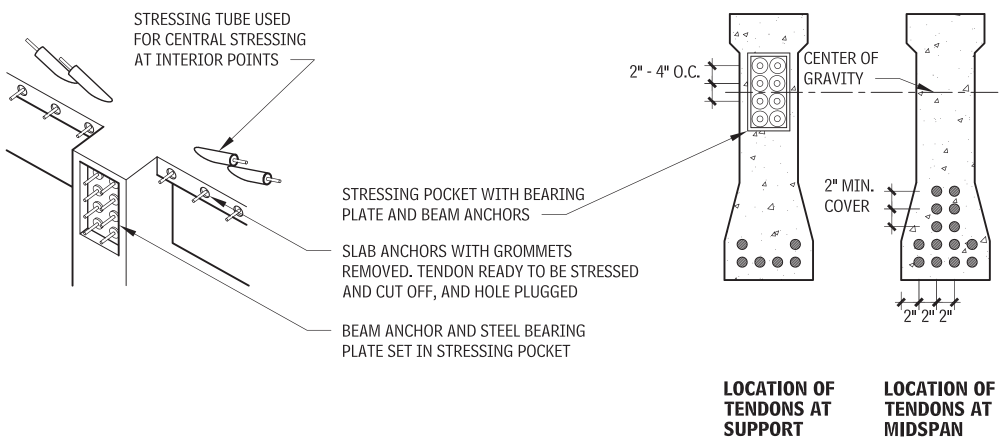
POST-TENSIONING ANCHOR
11.35



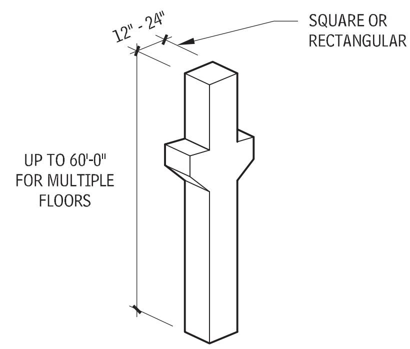
PRESTRESSED OR POST-TENSIONED BEAM
11.36



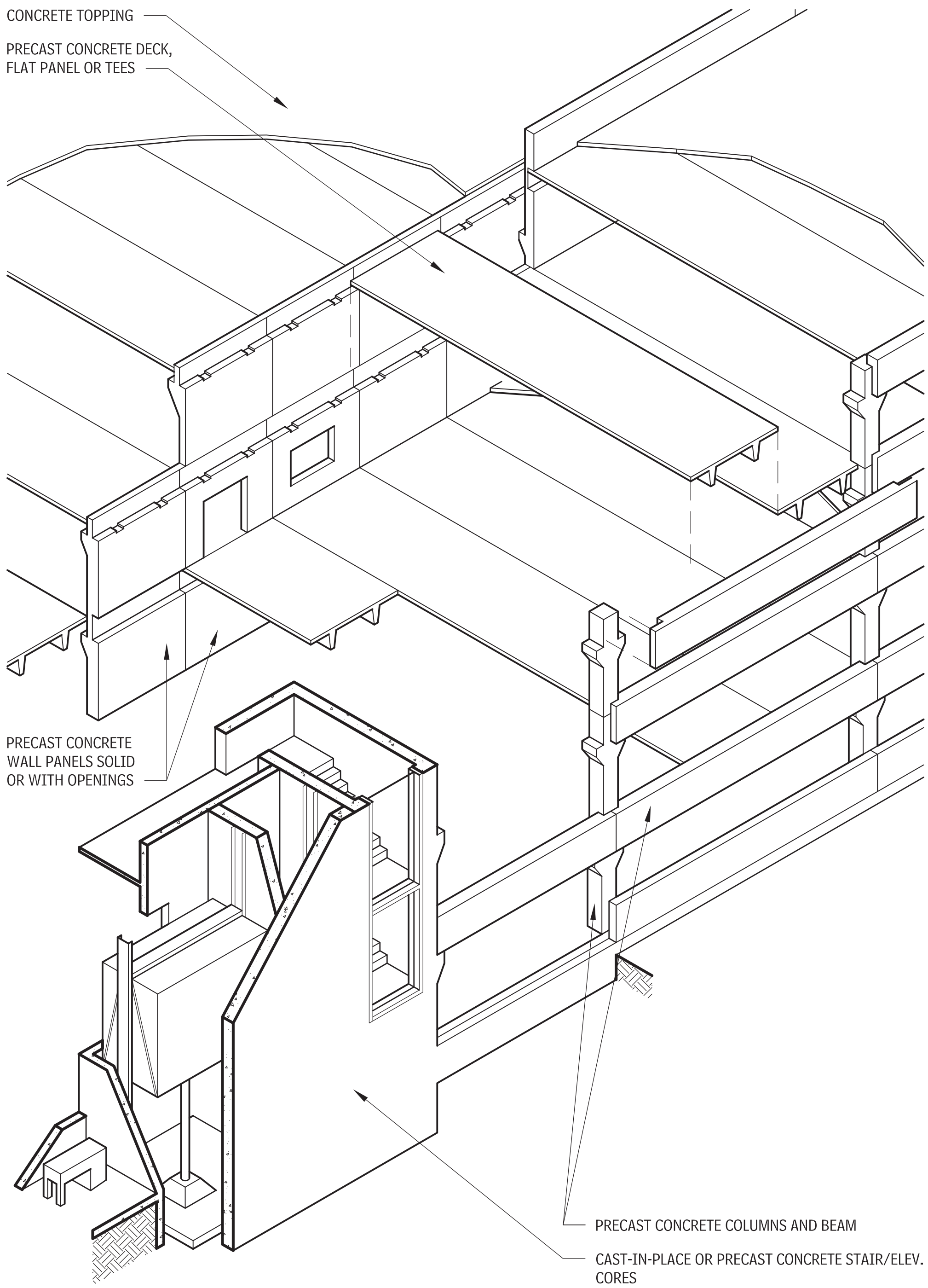
POST-TENSIONED BEAM AND SLAB
11.37



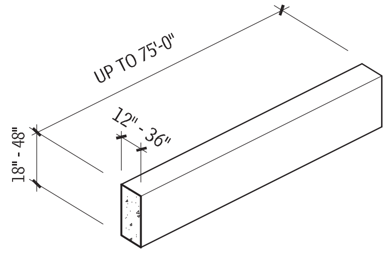
PRECAST CONCRETE COLUMN
11.38



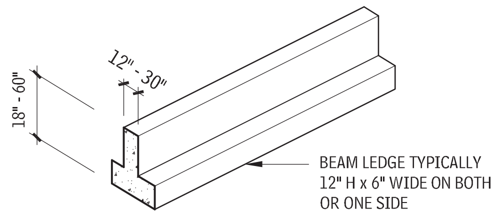
PRECAST CONCRETE FRAME
11.39



PRECAST CONCRETE BEAM AND GIRDER
11.40

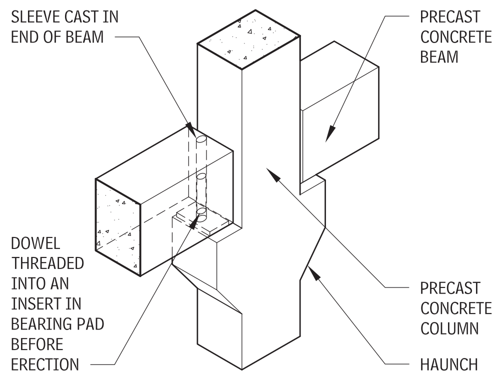


PRECAST CONCRETE BEAM



PRECAST CONCRETE GIRDER

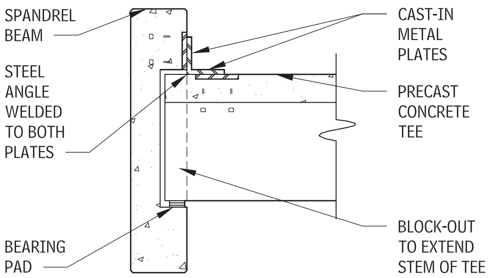
DOWELED BEAM-TO-COLUMN CONNECTION
11.41



NOTE

11.41 The beam sits on the bearing pad, which provides uniform bearing and accommodates small movements caused by shrinkage, creep, and temperature changes.

SPANDREL CONNECTION
11.42

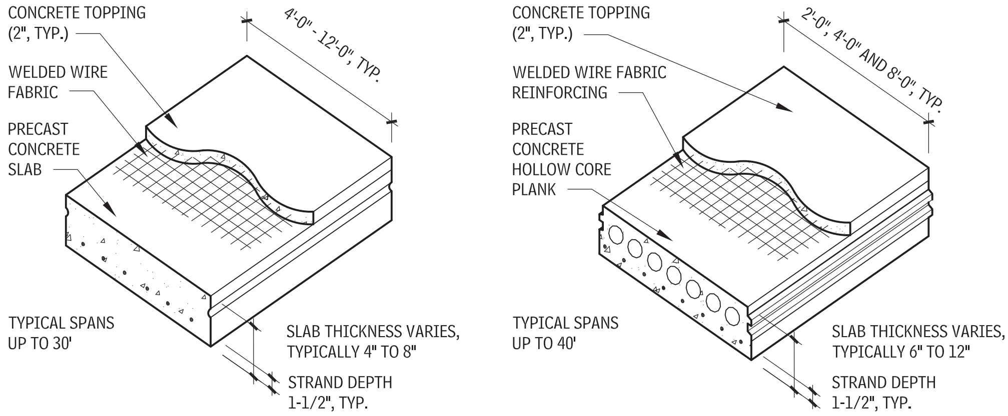


PRECAST CONCRETE DECKS AND SLABS

Normal weight (150 pcf) or lightweight concrete (115 pcf) is used in standard precast concrete slab construction. Concrete topping is usually normal-weight concrete with a cylinder strength of 3000 psi. All units are prestressed with strand release once concrete strength is 3500 psi. Strands are available in various sizes, strengths, and placements, according to individual manufacturers.

Camber varies substantially depending on slab design, span, and loading. Nonstructural components attached to members may be affected by camber variations. Calculations of topping quantities should recognize camber variations. Safe superimposed surface loads include a dead load of 10 psf for untopped concrete and 15 psf for topped concrete. The remainder is live load.

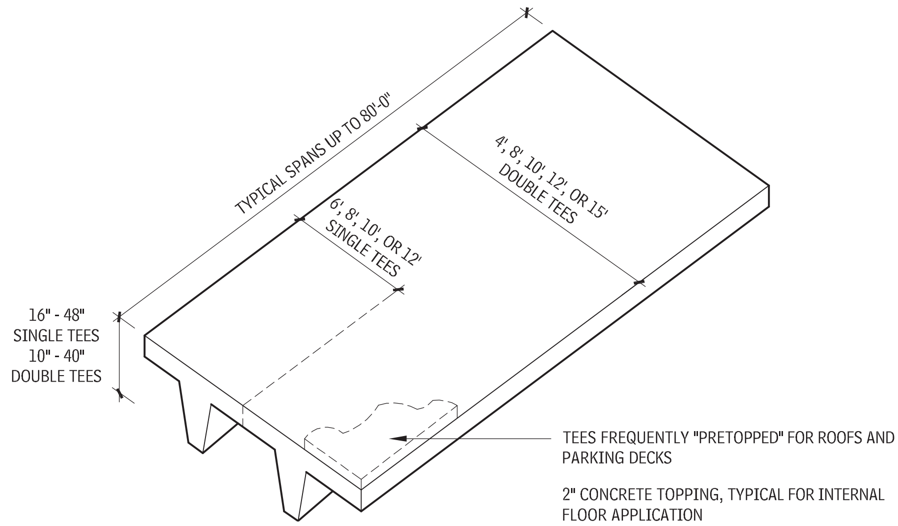
FLAT DECK MEMBERS
11.43



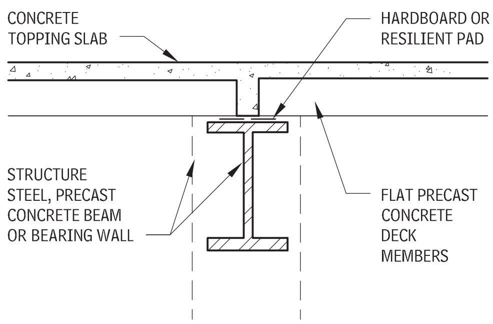
PRECAST CONCRETE SLAB

HOLLOW CORE PLANK

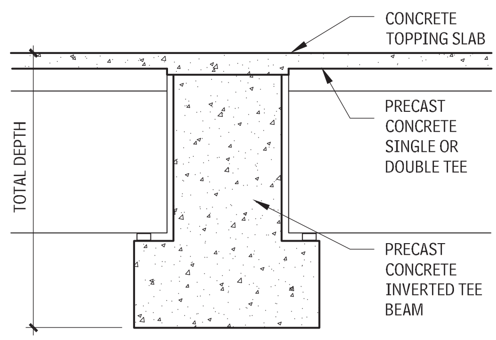
SINGLE OR DOUBLE TEE MEMBERS
11.44



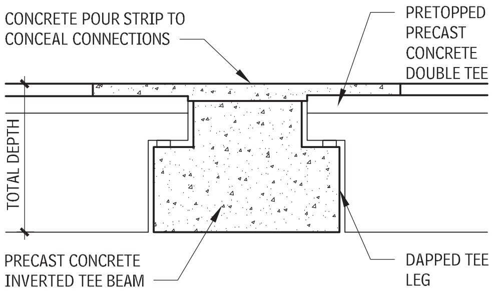
FLAT DECKS
11.45



TEE DECKS
11.46



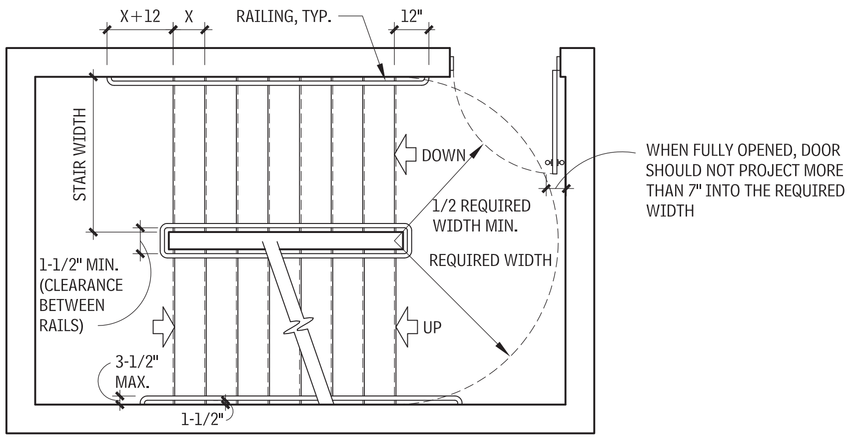
TEE DECKS DAPPED
11.47



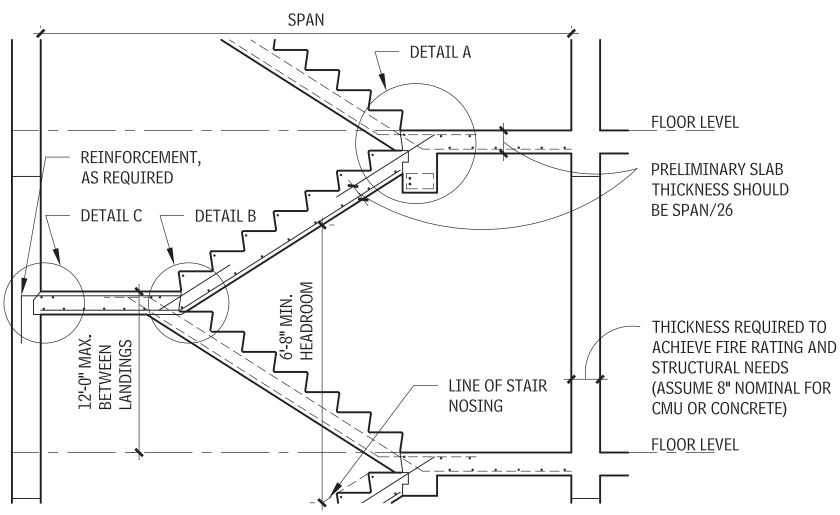
CONCRETE STAIRS

A common method of stair construction is the utilization of concrete, which can be cast-in-place or precast.

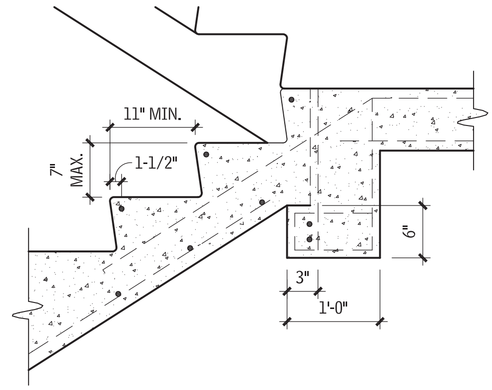
U–TYPE CONCRETE STAIRS
11.48



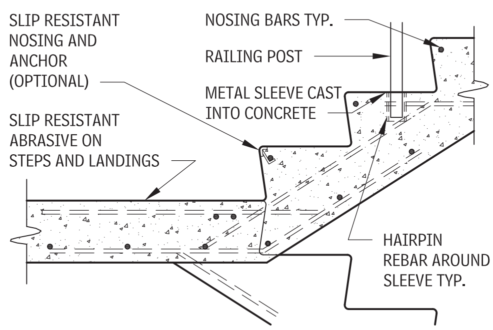
PLAN



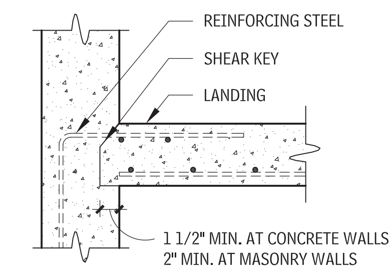
SECTION



DETAIL A



DETAIL B



DETAIL C

NOTES

11.48. a. Consult a structural engineer for reinforcing steel placement.
b. Verify required dimensions and clearances for code compliance.

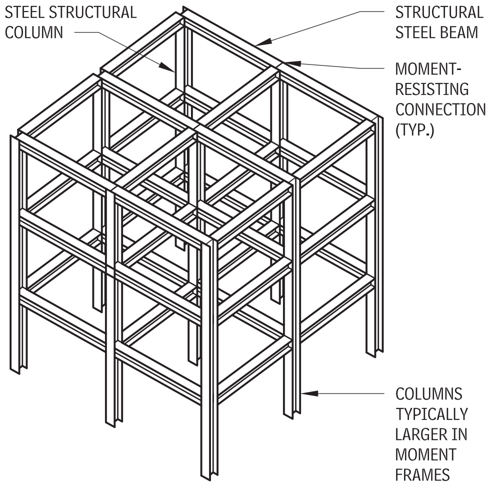
STRUCTURAL METAL

STRUCTURAL STEEL FRAMING

MOMENT-RESISTING FRAME

A moment-resisting frame's lateral stability and resistance to wind and seismic forces depend on a fixed connection of beams and columns. A moment-resisting connection is achieved when the top and bottom flanges of each beam are welded to the flanges of the connecting columns with full-depth welds. By directly welding the beam web to the column flange, the beam's horizontal reaction to wind forces is transferred to the column. (A connection using web angles and high-strength bolts is also permitted.) The building's floors are designed to act as diaphragms that connect all of the columns and beams, enabling the building to react as a unit.

MOMENT-RESISTING FRAME
11.49



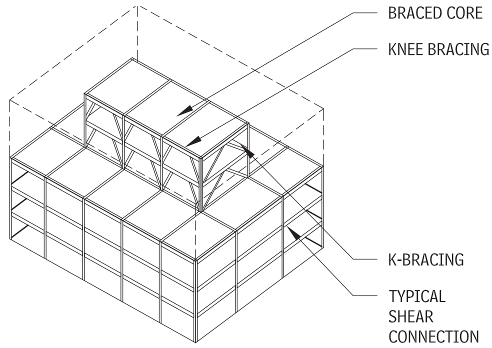
Moment-resisting frames are uneconomical in tall steel buildings because the larger lateral forces in such structures can be handled more efficiently by compression and tension diagonal members, as found in braced frames. To save costs, often the upper stories of a braced-frame building use moment-resisting beam-column connections to resist wind loads.

BRACED CORE

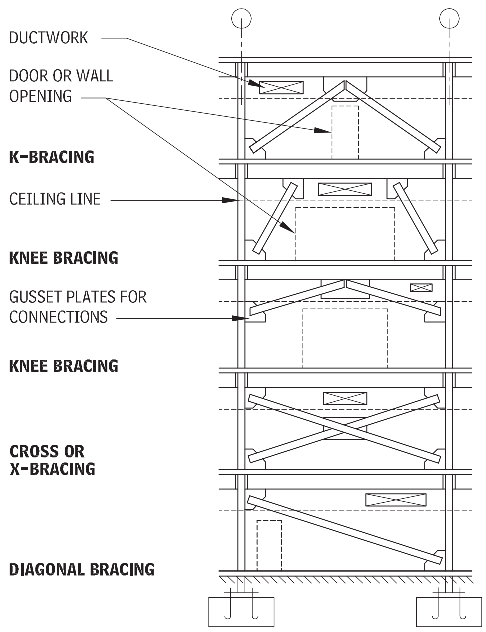
In the braced core system, walls around elevator shafts and stairwells are designed to act as vertical trusses that cantilever up from the foundation. The chords of each truss are building columns; the floor beams act as ties. Diagonals placed in a K-pattern (occasionally, in an X-pattern) complete the truss. A system employing knee braces is used in seismic areas because of its greater capability to dissipate earthquake energy.

Braced-core systems can be used efficiently in single-story buildings, as well as in buildings over 50 stories.

BRACED CORE
11.50



BRACING DIAGRAM
11.51



Following are characteristics and principles to keep in mind when working with structural steel framing:

- High strength of steel provides for economical construction of relatively large structural bays.
- Major framing elements are typically W-shaped sections, or round, square, and rectangular hollow structural sections. Angles or channels may be used for architectural expression.
- Building codes require protection of the steel from fire, except for small or low-rise structures in some low-hazard occupancies.
- Horizontal loads from wind and seismic events must be resisted, typically by diagonal bracing, moment connections, or shear walls.
- Moment frames allow maximum floor plan flexibility, but typically increase weight and cost of the structural steel framing.
- Braced frames are cost-effective, but disrupt the floor plan if not carefully located around typical core elements such as stairs, shafts, and toilet rooms. Bracing typically is provided by angles or W-shapes, as well as hollow structural shapes. Rods and cables may be used for architectural expression.
- Shear walls, typically around shafts for stairs, ducts, and elevators, can be an effective lateral load design option. Shear walls can be constructed of steel plate, concrete, or reinforced CMU. Minimize openings in shear walls for doors and services.
- It may be effective to mix different lateral restraint methods. For a long, narrow building, bracing in the short direction with moment frames in the long direction may be effective.
- The floor or roof deck typically is designed to act as a diaphragm to transmit loads to the lateral restraint elements. Structures without a deck capable of transmitting loads (such as bar grating or metal roofing) may require diagonal bracing in the floor or roof framing.
- Open-web steel joists may be used within a main frame of structural steel for economy.

For more information, refer to the *AISC Manual of Steel Construction.*

ARCHITECTURALLY EXPOSED STRUCTURAL STEEL FRAMING

The characteristics and principles to keep in mind when working with architecturally exposed structural steel (AESS) include the following:

- AESS is structural steel superstructure, supporting all or portions of a building, which is left exposed in the finished work. Through layout and detailing, AESS is meant to contribute to the architectural expression.
- The challenge to successful use of AESS is to clearly specify and detail the level of quality required, which is substantially beyond the requirements for normal structural steel. Primary areas of concern are the quality of finish of the individual members, the quality of the methods of joining members together (particularly of welds), and the tolerances of the finished work.
- AESS frequently incorporates a variety of tension members fabricated of stainless steel and proprietary fittings.
- AESS may need special fire protection, such as intumescent coating or deluge sprinkler systems.
- For economy, it is worthwhile to carefully identify which portions of the AESS will be viewed in close proximity versus those that are farther away. Locate defects, welds, and connections on the side of assembly away from view, for economy.

Refer to the "AESS Supplement" to *Modern Steel Construction* (May 2003), for an explanation of how to specify AESS.

STEEL JOIST FLOOR FRAMING

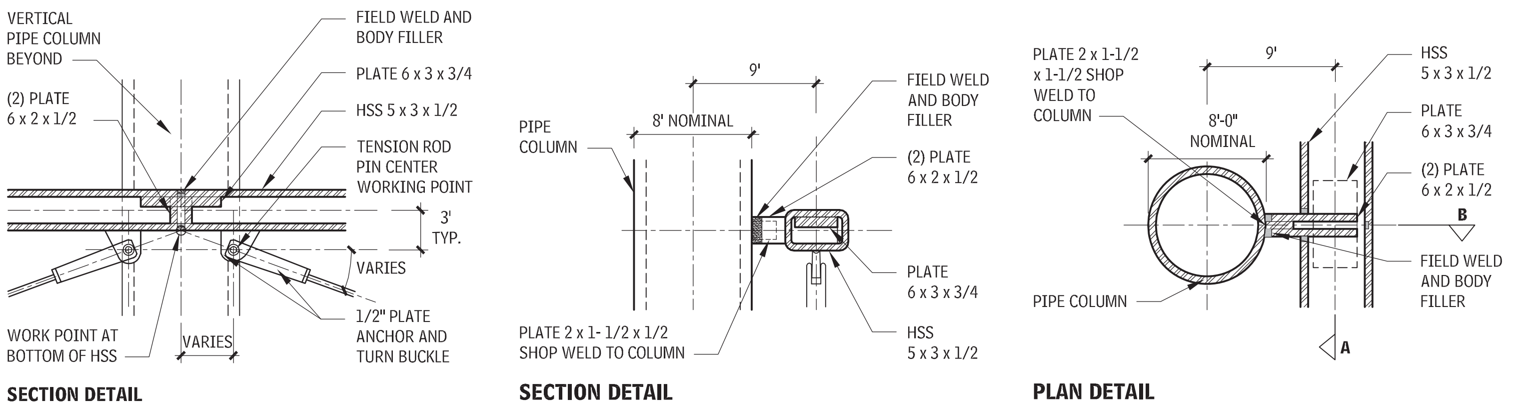
Design consideration of steel joist floor framing should include:

- *Ceilings:* Ceiling supports can be suspended from or mounted directly to the bottom chords of joists. Suspended systems are recommended, because of dimensional variations in actual joist depths.

NOTES

11.50. a. Knee bracing introduces bending into columns and beams and may increase their size, but allows for larger openings.
b. Cross or diagonal bracing is very efficient but limits opening location and size.

AESS CONNECTION
11.52



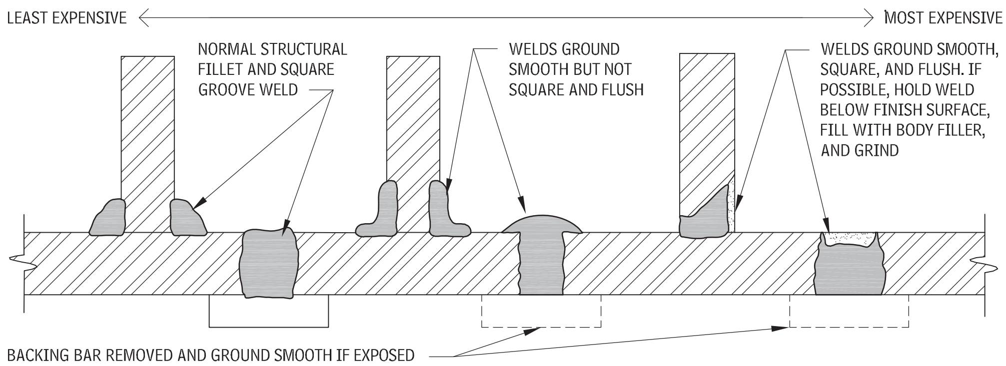
- *Floor construction:* Joists are usually covered by 2–1/2 to 3 in. of concrete on steel decking. Concrete thickness may be increased to accommodate electrical conduit or electrical/communications raceways. Precast concrete, gypsum planks, or plywood can also be used for the floor system.
- *Vibration:* Objectionable vibrations can occur in open web joist and 2–1/2-in. concrete slab designs for open floor areas at spans between 20 and 40 ft., in particular at 28 ft. When a floor area cannot have partitions, objectionable vibrations can be prevented or reduced by increasing slab thickness or modifying the joist span. Attention should also be given to support for framing beams, which can magnify a vibration problem when unsupported.
- *Openings in floor or roof systems:* Small openings between joists are framed with angles or channels supported on the adjoining two joists. Larger openings necessitating interruption of joists are framed with steel angle or channel headers.
- *Adaptability:* It is more difficult to alter joists, add openings, or change loading than with structural steel framing.
- *Fireproofing:* Applying fireproofing to joists is more difficult and expensive than to structural steel.

COLD-FORMED METAL FLOOR JOIST FRAMING

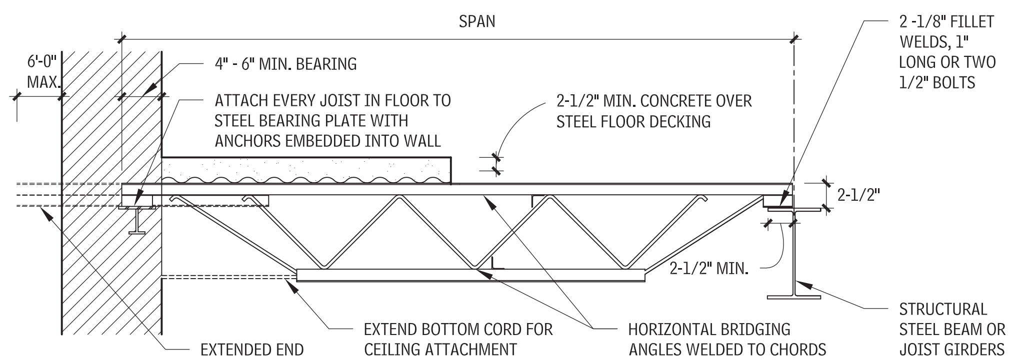
Cold-formed steel (CFS) floor framing uses C-shaped members that are cold-rolled from a steel sheet. CFS framing is laid out similar to traditional wood joist floor framing. Finishes may be hot-dipped-galvanized coating or shop primed. Fastening is typically self-drilling, self-tapping screws, or welded.

Final engineering of CFS framing is commonly provided by a structural engineer hired by the installing contractor, based on a performance specification prepared by the architect and project structural engineer. This delivery method, known as delegated design, allows an optimization of the design of the CFS system. CFS framing characteristics vary by manufacturer. Based on preliminary investigation and other project design requirements, the design professional may select certain characteristics of the joists, for example depth or minimum spacing. The installer's engineer will then select specific joists that conform to the design characteristics that also meet the structural performance criteria, including yield strength (33 or 50 ksi), joist gauge, and flange width. CFS rim joists, plates, and other framing may require continuous insulation outside of the CFS element, to reduce thermal bridging and to comply with energy code.

AESS WELDS
11.53



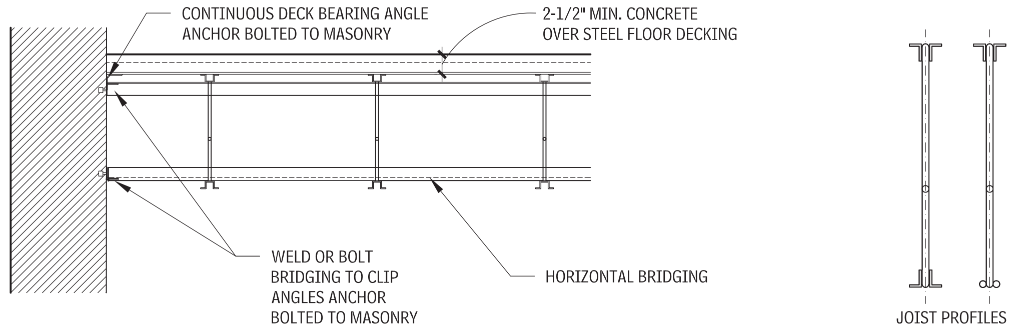
SECTION-THROUGH OPEN WEB STEEL JOIST BEARING
11.54



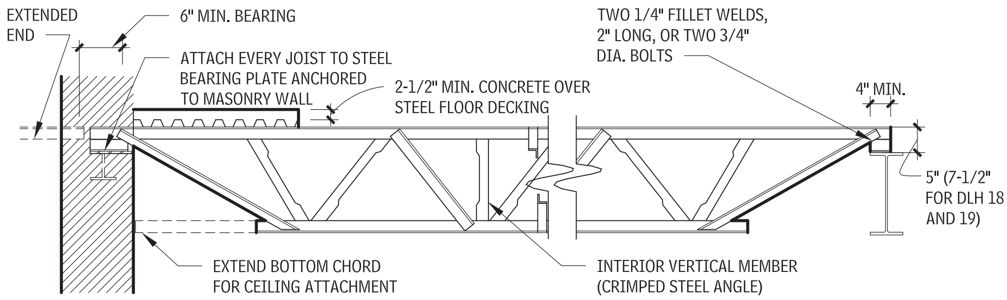
NOTE

11.52 HSS refers to *hollow structural section*. HSS members can be circular, square, or rectangular sections, although other shapes are available, such as elliptical. HSS is only composed of structural steel. Rectangular and square HSS are also commonly called *tube steel* or *structural tubing*. Locate HSS seam away from line of sight, or grind smooth.

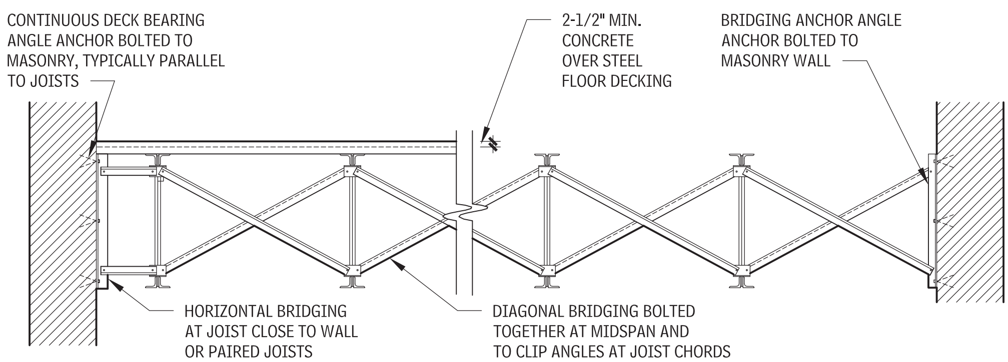
SECTION-THROUGH OPEN WEB STEEL JOISTS
11.55



SECTION-THROUGH LONG SPAN STEEL JOIST BEARING
11.56



SECTION-THROUGH LONG-SPAN STEEL JOIST
11.57



SPACE FRAMES

A space frame is a three-dimensional truss with linear members that form a series of triangulated polyhedrons. It can be seen as a plane of constant depth that can sustain fairly long spans and varied configurations of shape.

Space frames' prime attributes include:

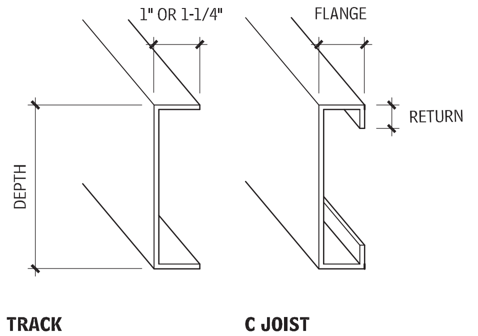
- Light weight
- Inherent rigidity
- Wide variety of form, size, and span
- Compatible interaction with services, primarily HVAC

Most space frames are designed for specific applications, and a structural engineer with specific experience should be consulted. Manufacturers can provide the full range of capabilities (loading, spans, shapes, specific details) for their products. Standardized structural assemblies in 4- and 5-ft. modules are available.

Metal space frames are classified as noncombustible construction, and can usually be exposed when 20 ft. above the floor. However, a fire suppression or a rated ceiling assembly may be required. Consult codes.

Common finishes include paint, thermoset polyester, galvanized, stainless steel, and metal plating.

COLD-FORMED METAL JOISTS
11.58

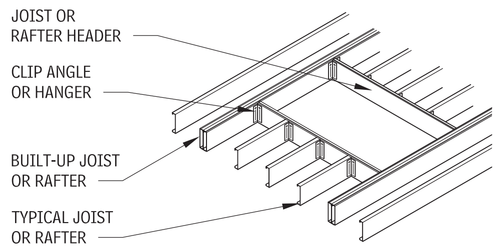


Common depths: 6, 7–1/4, 8, 9–1/4, 10, 11–1/2, 12, 14, and 16 in.; consult manufacturers for available sizes.

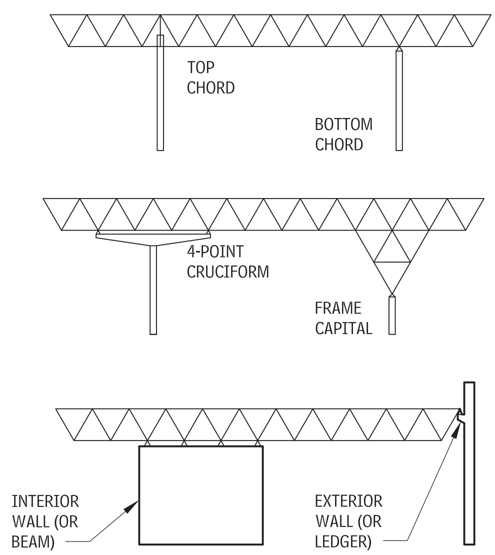
Lengths up to 60 ft.

FLANGE (IN.)	RETURN (IN.)
1–3/8	5/16 to 3/8
1–5/8	1/2 to 9/16
2 or 2–1/2	9/16 to 11/16
3 or 3–1/2	1

FRAMING OF FLOOR OPENING
11.59



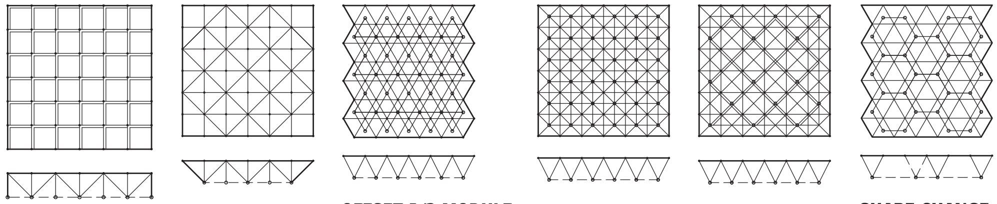
SUPPORT TYPES
11.60



NOTE

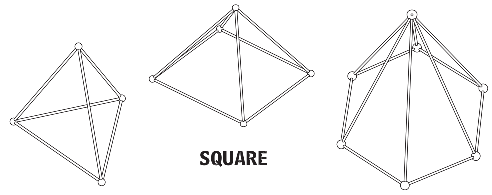
11.56 Web member type depends on span and load characteristics.

COMMON PATTERNS
11.61



DIRECT | **DIRECT SKEWED** | **OFFSET 1/3 MODULE** | **OFFSET 1/2 MODULE** | **OFFSET SKEWED** | **SHAPE CHANGE**

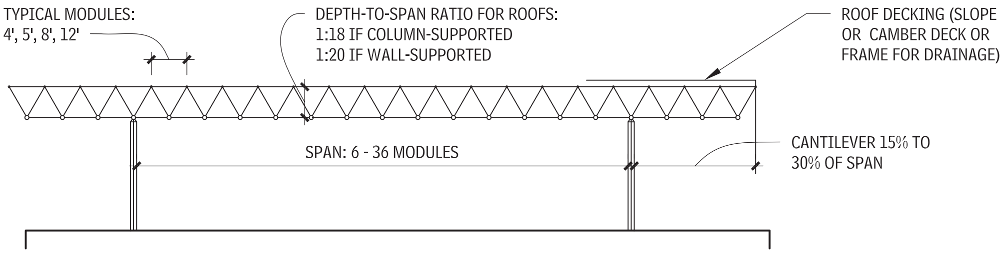
GRID SHAPES
11.66



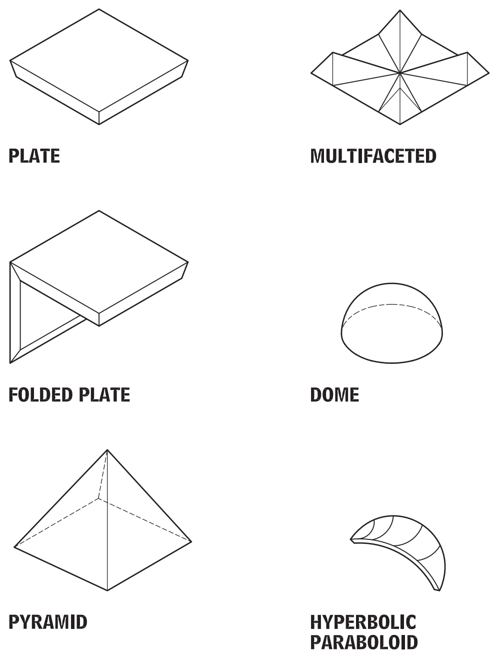
TETRAHEDRON | **HEXAGONAL**

MODULE SELECTION AND CHARACTERISTICS
11.62

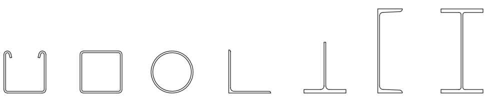
Select a space frame module that is compatible with the structural module in shape (e.g., a square module with orthogonal plan) and size (a multiple of the structural module), is consistent with the limitations of the interfacing systems (e.g., the maximum span of the roof deck or mullion spacing of the glazing system), and satisfies the spatial and aesthetic effects in scale and form.



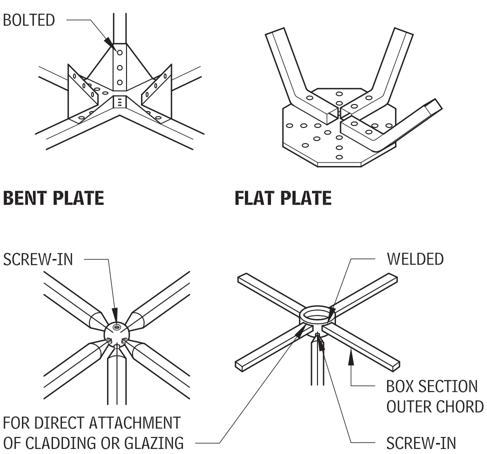
SPACE FRAME FORM TYPES
11.67



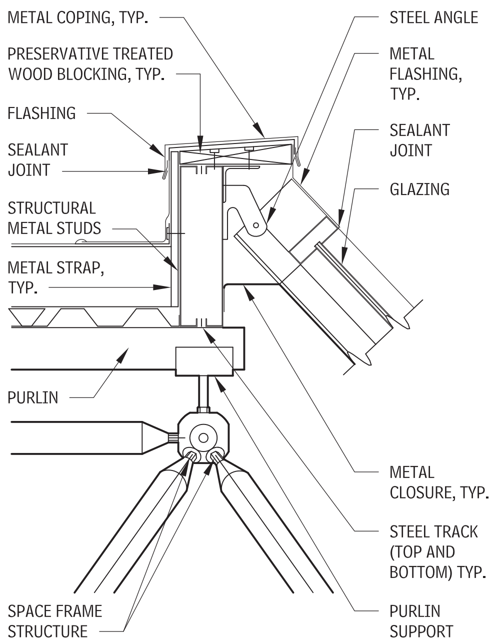
MEMBER SHAPES
11.63



NODE CONNECTIONS
11.64



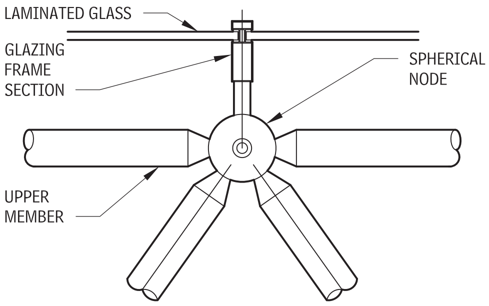
SLOPED GLAZING
11.65



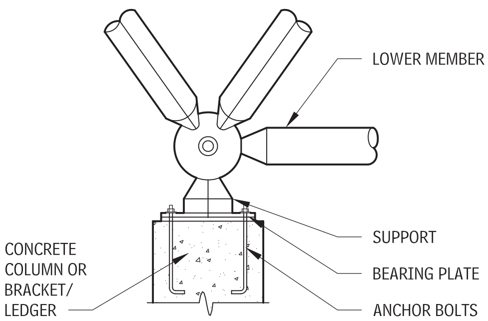
NOTES

11.61 Many proprietary node systems are available for specific applications and budgets. Keep field connections to a minimum; welded connections often eliminate joint pieces.
11.62 Square tubes or angles within their span range are often the most economical.
11.63 Space frame supports are at joints only, not along members.

ROOF AND FLOOR CONNECTIONS
11.68



GLAZING AT ROOF



BOTTOM SUPPORT

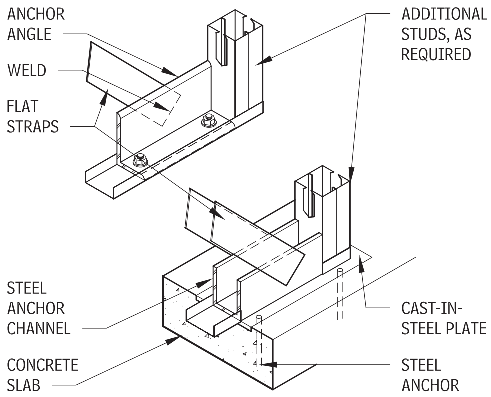
COLD-FORMED METAL FRAMING AND BRACING

Lightweight steel framing is cold-formed, which means the components are manufactured by brake forming and punching galvanized coil and sheet stock. Cold-formed framing members consist of two basic types of components that are C-shaped in section: one type has 1/4-in. flanges folded inward; the other has no flanges. Studs, joists, and rafters are made with flanges to stiffen them so they will more readily stand vertically. Components without flanges (called *tracks*) have unpunched solid webs. For added strength, tracks are sized slightly larger than the flanged members so the tracks will fit snugly inside them as sill or top plates or as part of posts or headers.

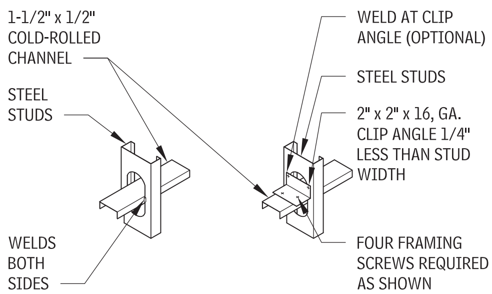
Cold-formed metal framing is strong and versatile. The strength and load-carrying capacity of a member can be increased simply by increasing the thickness, or gauge, of the metal; the dimensions of the member, or the spacing, do not necessarily have to be increased. There is little limitation on the length of steel framing members; joists or studs may be fabricated in lengths up to 40 ft. If handled with care, steel framing is straight and consistent; also, it is not affected by moisture content.

Disadvantages of cold-formed metal framing include lack of insulating qualities; difficulty in cutting, compared to wood; and dangerously sharp edges. Consult the American Iron and Steel Institute (AISI) for further information.

DIAGONAL STABILITY BRACING ANCHORAGE DETAILS
11.69



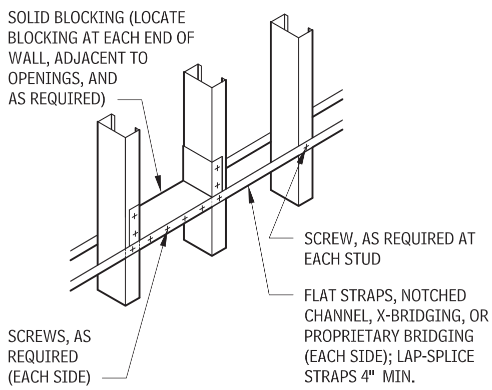
LATERAL BRACING ATTACHMENTS
11.70



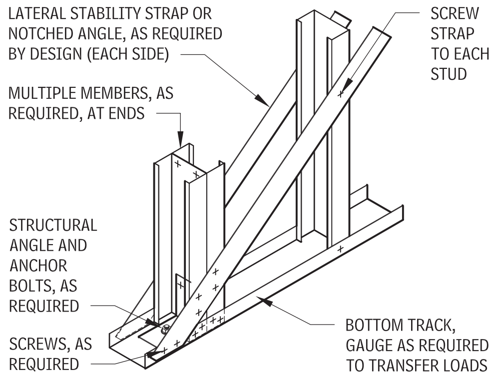
WELD ATTACHMENT (FOR 3-5/8" OR SMALLER STUDS; 16-GA. OR HEAVIER)

SCREW ATTACHMENT (FOR 3-5/8" TO 8" STUDS)

WALL BRIDGING
11.71

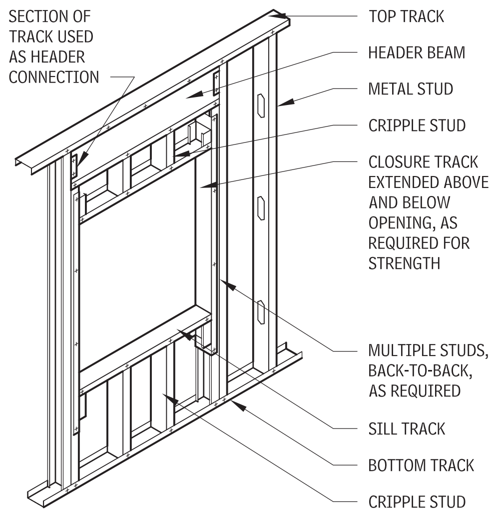


DIAGONAL STABILITY BRACING ANCHORAGE
11.72



COLD-FORMED METAL FRAMING—OPENING DETAILS

WINDOW OPENING
11.73



BRACING

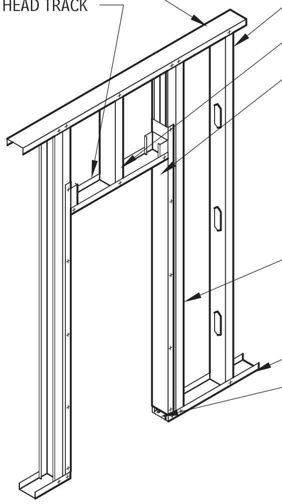
Buildings must be properly braced to resist racking under wind and seismic loads. Diagonal strap bracing is sloped to resist forces in tension, and fastened by screws or welds to studs and plates. Properly spaced lateral steel bracing resists stud rotation and minor axis bending under wind, seismic, and axial loads; this is especially critical during construction, before sheathing or finishes are installed.

NOTES

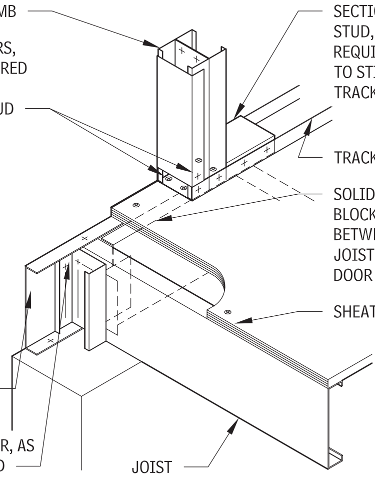
11.69 The top detail is for one- to two-story buildings; the bottom detail is for buildings more than two stories. Steel channel, plate, and anchor size depend on applied uplift and horizontal shear forces.
11.70 Channels should be spaced as required by design.
11.71 The number of required rows of bridging is dependent on the structural design.
11.72 Strap forces may require additional stiffening of the bottom track or structural angle.

Contributor:
Severud Associates, New York, New York.

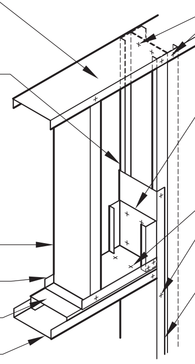
DOOR OPENING
11.74



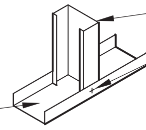
DOOR JAMB BASE AT FLOOR FRAMING
11.75



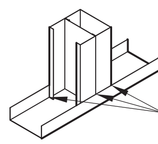
HEAD AT OPENING 4 FT WIDE OR WIDER IN LOAD-BEARING WALL CONDITION
11.76



STUD-TO-TRACK CONNECTION
11.79

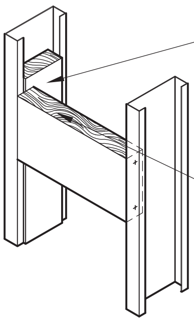


MECHANICAL FASTENERS

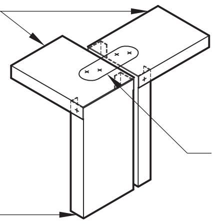


WELDED CONNECTION

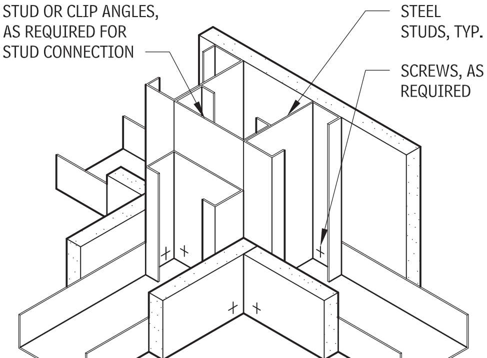
DETAILS FOR COLD-FORMED METAL FRAMING HEAVY FIXTURE ATTACHMENT
11.77



TOP PLATE INTERSECTION
11.78



WALL INTERSECTION FRAMING
11.80

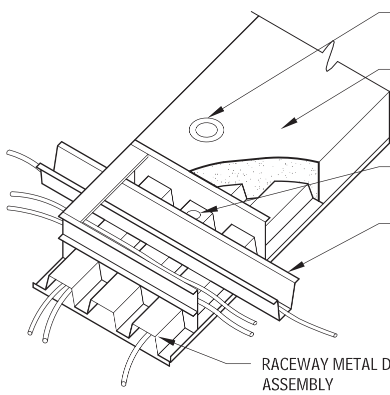


METAL FLOOR DECKING

When designing with metal decking, two guidelines are important to follow:

- When lightweight concrete is used in the construction, use galvanized deck material.
- In a fire-resistant assembly, ensure that metal components are unprimed.

ELECTRICAL TRENCH DUCT
11.81

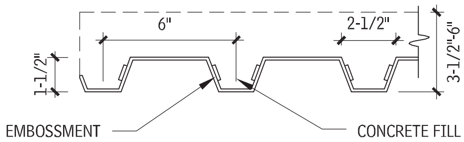
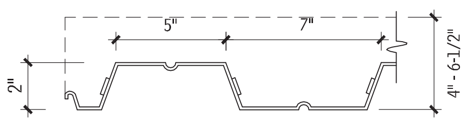
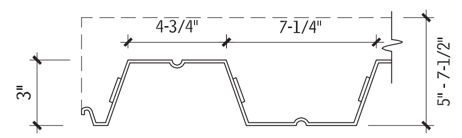


These are some advantages of metal floor decks:

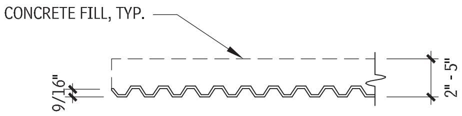
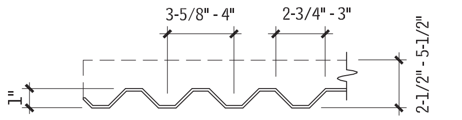
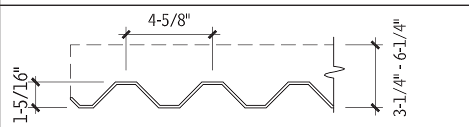
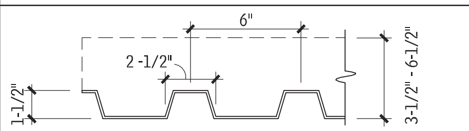
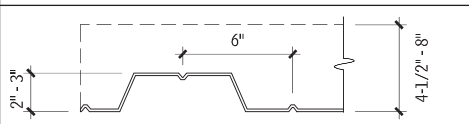
- They provide a working platform, eliminating temporary wood planking in high-rise use.
- Composite decks provide positive reinforcement for concrete slabs.
- Both noncomposite and composite decks serve as forms for concrete, eliminating the need for forming and stripping.
- Acoustic treatment is possible.
- Electric raceways may be built into the floor slab.
- Metal floor decking provides economical floor assemblies.

Consult the Underwriters Laboratories (UL) directory for specific fire-rating requirements.

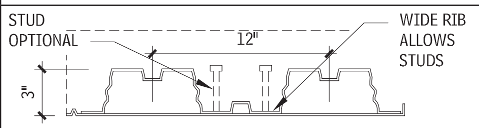
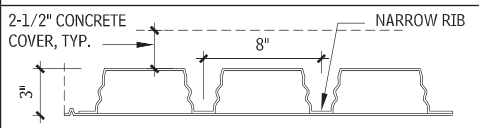
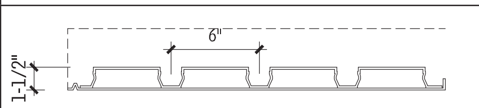
COMPOSITE FLOOR DECK WITH CONCRETE FILL
11.82

TYPE	PROFILE	REMARKS	SPAN	WIDTH	MAXIMUM LENGTH
Shallow deck		Convex embossments bond with concrete fill; reverse deck for concave embossments	5′-0″ to 12′-0″	36″	42′-0″
Intermediate deck		Convex embossments	6′-0″ to 13′-0″	24″ or 36″	42′-0″
Deep deck		Convex embossments	7′-0″ to 14′-0″	24″ or 36″	42′-0″

NONCOMPOSITE FLOOR DECK WITH CONCRETE FILL
11.83

TYPE	PROFILE	REMARKS	SPAN	WIDTH	MAXIMUM LENGTH
Shallow deck		Narrow rib	2′-0″ to 5′-6″	30″, 35″, 36″	42′-0″
Intermediate deck		Narrow rib	3′-0″ to 10′-0″	32″, 33″	42′-0″
Intermediate deck		Narrow rib	4′-0″ to 11′-0″	32″	42′-0″
Intermediate deck		Narrow rib	4′-0″ to 11′-0″	30″, 36″	42′-0″
Deep deck		Wide rib	5′-6″ to 14′-0″	24″, 36″	42′-0″

COMPOSITE AND NONCOMPOSITE CELLULAR FLOOR DECK WITH CONCRETE FILL
11.84

TYPE	PROFILE	SPAN	WIDTH	CELL CROSS-SECTIONAL AREA
3″ × 12″ cellular deck (for steel frames requiring studs)		12′-0″ to 15′-0″	24″, 36″	17.7 sq. in./cell (35 sq. in./sheet)
3″ × 8″ cellular deck (not suitable for structural studs)		12′-0″ to 15′-0″	24″	17.4 sq. in./cell (52.2 sq. in./sheet)
1.5″ × 6″ cellular deck (for thinner total slabs)		4′-0″ to 8′-0″	24″, 30″, 36″	6 sq. in./cell (24 sq. in./sheet)

NOTES

11.84. a. Electric raceways may be built into floor slabs by using cellular deck or special units that are blended with plain deck. Two-way distribution is achieved by using trench ducts that sit astride the cellular units at right angles.

b. Using trench ducts with composite floor deck may reduce or eliminate entirely the effectiveness of composite action at the trench duct. This is also true for composite action between steel floor beams and concrete fill. Trench duct locations must be taken into account in deciding whether composite action is possible.

COLD-FORMED METAL ROOF FRAMING

Cold-formed steel (CFS) framing members can be used to frame roofs in essentially the same manner as wood rafters or trusses. Note that thermal bridging can be a problem in cold climates when CFS members are not covered by continuous insulation.

Similar to cold-formed metal floor joist framing, including the use of delegated design, the following characteristics should be considered when utilizing CFS for roof framing:

- Cold-formed metal roof framing uses C-shaped members, in sizes approximating wood framing, with special details for sloped bearing conditions.
- CFS framing is laid out similar to traditional wood joist framing.
- CFS roof trusses are available in virtually all of the configurations available for wood trusses.
- Proprietary roof truss systems use various shapes for chords and webs designed to allow higher productivity in fabrication and optimization of structural performance. It is generally not advisable to design around any single system, but instead to provide a general shape that many fabricators can provide.
- For more information, consult the reference "Product Technical Information," Steel Stud Manufacturers Association; www.ssma.com.

METAL ROOF DECKING

Some of the many types of available metal roof decking include:

- Roof decking
- Composite deck
- Permanent forms for self-supporting concrete slabs
- Raceway (composite or noncomposite)
- Acoustic metal decking
- Acoustic cellular deck (composite or noncomposite)
- Vented roof deck (used with lightweight insulating concrete fill)

INSTALLATION AND DESIGN

Metal roof decks must be secured to supports, generally by means of welds made through the decking to supporting steel. Steel sheet lighter than 22 gauge should be secured by use of welding washers.

Side laps between adjacent sheets of deck must be secured by button-punching standing seams, welding, or screws, in accordance with the manufacturer's recommendations.

Decks used as lateral diaphragms must be welded to steel supports around their entire perimeter to ensure development of diaphragm action. More stringent requirements may govern the size and/or spacing of attachments to supports and side lap fasteners or welds.

Roof deck selection must consider construction and maintenance loads, as well as the capacity to support uniformly distributed live loads. Consult the Steel Deck Institute's recommendations and Factory Mutual Global's requirements.

Heavy roof-mounted mechanical equipment should not be placed directly on a metal roof deck. Equipment on curbs should be supported directly on main and supplementary structural members, and the deck must be supported along all free edges. Heavy items such as cooling towers that must be elevated should be supported directly onto structural members below the deck.

FIRE-RESISTANCE RATINGS

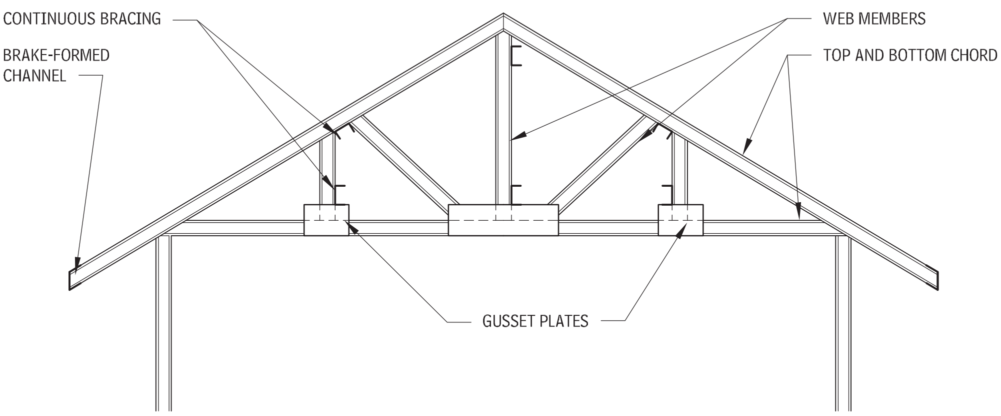
Fire-resistance ratings for roof assemblies are published by Code authorities, Underwriters Laboratories, and Factory Mutual. Fire-resistance ratings may be achieved by various methods including applied fireproofing, rated acoustic ceilings, and gypsum board enclosures.

ADVANTAGES OF METAL ROOF DECKS

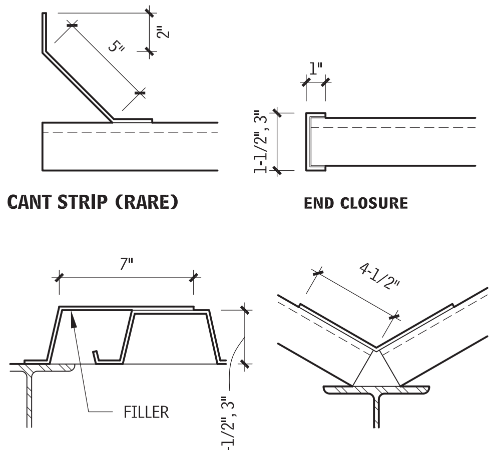
There are a number of advantages to using metal roof decks:

- A high strength-to-weight ratio reduces roof dead load.
- They can be erected in most weather conditions.
- A variety of depths and rib patterns are available.
- Acoustic treatment is possible.
- They can serve as the base for insulation and roofing.
- Fire ratings can be obtained with standard assemblies.
- They can provide a lateral diaphragm.
- They can be erected quickly and economically.
- Using them makes it easy and economical to create roof slopes for drainage when mounted over sloped structural steel.

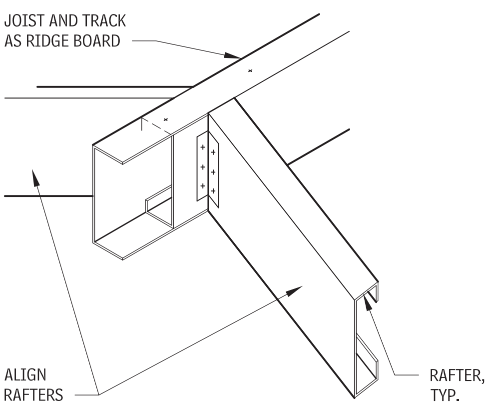
COLD-FORMED STEEL ROOF TRUSSES
11.85



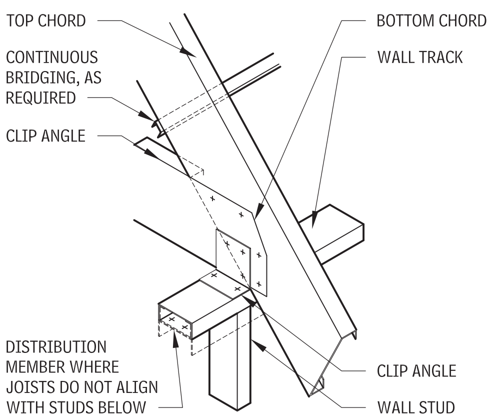
ROOF DECK ACCESSORIES
11.88



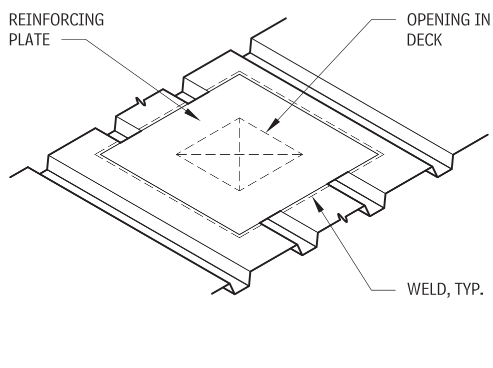
RIDGE BOARD
11.86



ROOF TRUSS EAVE DETAIL
11.87



OPENINGS IN DECK
11.89

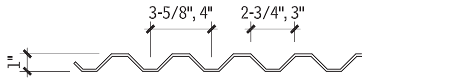
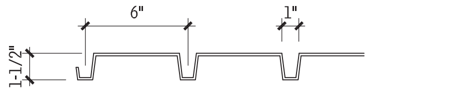
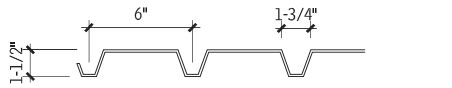
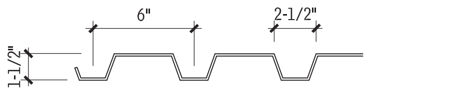
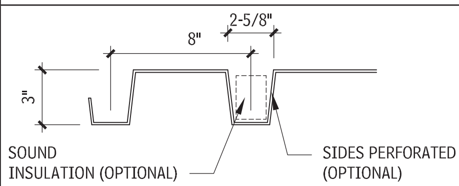
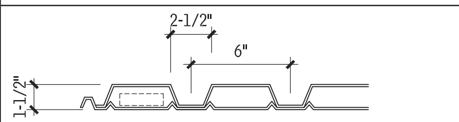
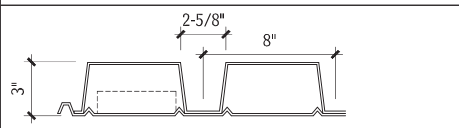
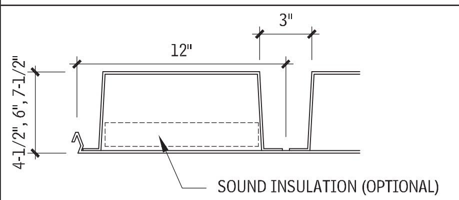


NOTES

11.85 a. Chords and webs can be typical CFS C-shapes or a variety of proprietary special shapes.
b. Bracing is typically channel or track.
c. Gusset plates are typically from flat plates or a section of a large C-shape.
11.89 a. Small openings (up to 6 in. by 6 in. or 6-in. diameter) usually may be cut in a roof or floor deck without reinforcing the deck.
b. Openings up to 10 in. by 10 in. or 10-in. diameter require reinforcing of the deck either by welding a reinforcing plate to the deck all around the openings or providing channel-shaped headers and/or supplementary reinforcing parallel to the deck span. Reinforcing plates should be 14-gauge sheets with a minimum projection of 6 in. beyond all sides of the opening, and they should be welded to each cell of the deck.
c. Larger openings should be framed with supplementary steel members so that all free edges of the deck are supported.

Contributor:
American Iron and Steel Institute, Washington, DC.

METAL ROOF DECK TYPES
11.90

TYPE	PROFILE	REMARKS	SPAN	WIDTH	MAXIMUM LENGTH
Economy		Most economical deck for shorter spans; use with 1″ or more insulation	2′-6″ to 8′-0″	32″ to 33″	42′-0″
Narrow rib (1″ wide)		Use with 1/2″ insulation; maximum surface area on top for adhering insulation	4′-0″ to 11′-0″	36″	42′-0″
Intermediate rib (1–3/4″ wide)		Use with 1″ insulation	4′-0″ to 11′-0″	36″	42′-0″
Wide rib (2–1/2″ wide)		Use with 1″ insulation	5′-0″ to 12′-0″	36″	42′-0″
Acoustic metal decking		Perforated type for sound absorption only	10′-0″ to 20′-0″	24″	42–0″
Raceway decking assemblies		For use as electrical raceway or as acoustic ceiling; bottom plate is perforated for sound absorption	9′-0″ to 12′-0″	24″	40′-0″
Raceway decking assemblies			10′-0″ to 13′-0″	24″	40′-0″
Raceway decking assemblies			20′-0″ to 30′-0″	24″	30′-0″

METAL STAIRS

Metal stairs are frequently constructed of steel, and fabricated in the shop to fit the required dimensions.

Treads and landings may be filled with 1–1/2 to 2 in. of concrete. Many finish materials can then be applied to the concrete. Balusters are anchored by welding, bolting, or screwing to the stringers. Glass balusters are often anchored into a special U-shaped channel, which is attached to the edge of the stringer. A similar detail can be used for glass railings.

DESIGN GUIDELINES FOR METAL STAIRS

General design guidelines for metal stairs are itemized in the following lists.

WIDTH OF STAIR

- Dwelling stairs: minimum 36-in. treads
- Public exit stairs: minimum 44-in. treads
- Rescue assistance area (ADA): 48 in. between handrails

TREADS

- Dwellings: 9 in. minimum (nosing to nosing)
- Other (ADA): 11 in. minimum (nosing to nosing)
- Uniform depth within one flight

RISERS

- Dwellings: 8–1/4 in. maximum
- Other: 4 in. minimum; 7 in. maximum
- Uniform height within one flight (with contrasting color on leading edge)

NOSING

- 1–1/2 in. maximum with 60° under nosing; $\frac{1}{2}$-in. maximum radius at edge
- Minimum: none required

STAIR RAILS

- Height in dwellings: 36 in.
- Height in exit stairs: 42 in.
- Arrange rails so that a sphere 4 in. in diameter cannot be passed through.
- Arrange rails to discourage climbing.
- Withstand concentrated load of 200 lb. of force nonconcurrently applied to the top rail in vertical downward and/or horizontal direction. The test loads are applicable for railings with supports not more than 8 ft. apart.

HANDRAILS

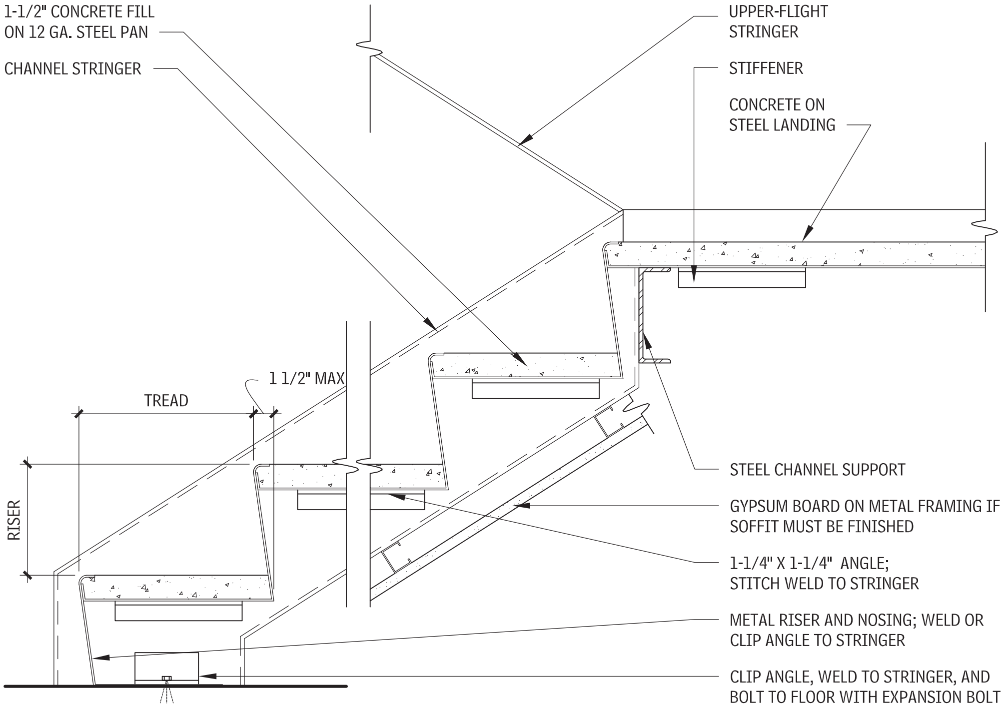
- Dwellings: required on one side only
- Other: required on both sides
- Height: 34 to 38 in.
- Grip surface: 1–1/4 to 1–1/2 in.
- Clearance at wall: 1–1/2 in.
- Projecting or recessed
- Extension at top of run: 12 in.
- Extension at bottom of run: 12 in., plus depth of tread
- When a guardrail more than 38 in. high is used, a separate handrail should be installed.
- Nothing should interrupt the continuous sliding of hands.

REGULATORS AND STANDARDS

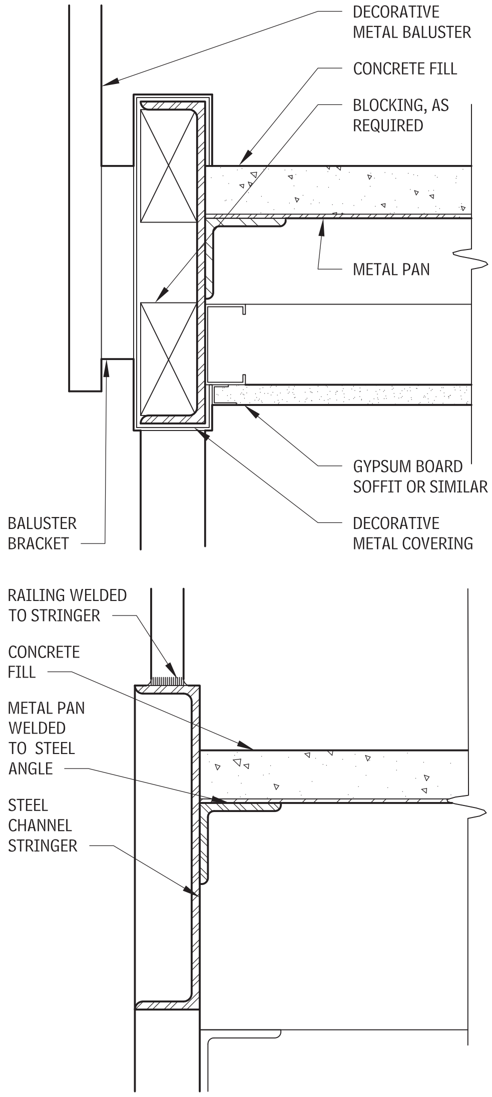
- Building codes: ADA-ABA ASTM, ANSI, NFPA, and OSHA

Contributors:
Donald Neubauer, P.E., Neubauer Consulting Engineers, Potomac, Maryland; Walter D. Shapiro, P.E., Tor, Shapiro & Associates, New York, New York.

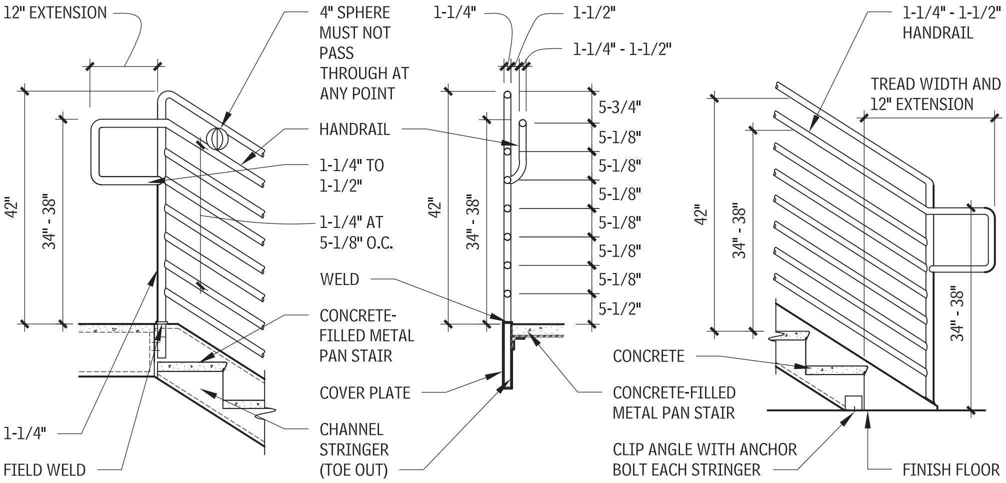
METAL STAIR SECTION
11.91



STRINGER DETAILS
11.92



STAIR RAILS
11.93

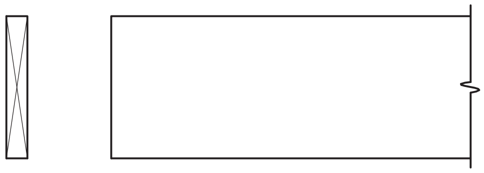


WOOD FRAMING

This section examines the use of wood in floor, roof, and stair framing assemblies.

WOOD FLOOR FRAMING MEMBERS
11.94

SHORT SPAN, LESS THAN 24'



DIMENSION LUMBER

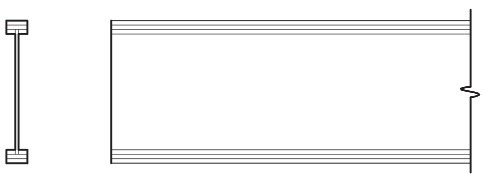
DIMENSIONAL LUMBER 2 x 8, 2 x 10, 2 x 12

SMALL TO MEDIUM, 16' TO 30'

LAMINATED VENEER LUMBER

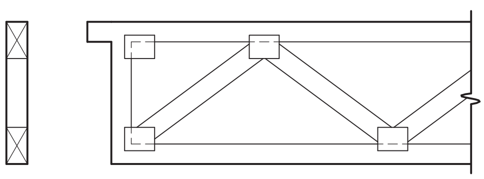
1-3/4" THICK LAMINATED JOISTS

SMALL TO MEDIUM, 20' TO 60'



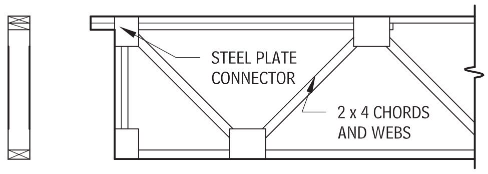
WOOD I-JOISTS

LIGHTWEIGHT 3/8" LAMINATED STRAND LUMBER, OSB, OR PLYWOOD WEB 1-1/2", 2" OR 3" WIDE LVL OR LUMBER FLANGE



SHOP-FABRICATED WOOD TRUSSES

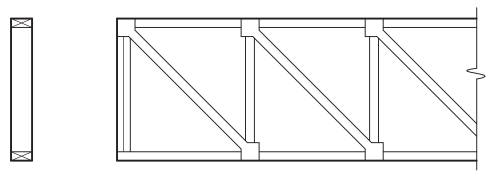
MEDIUM, SPAN 40' TO 60'



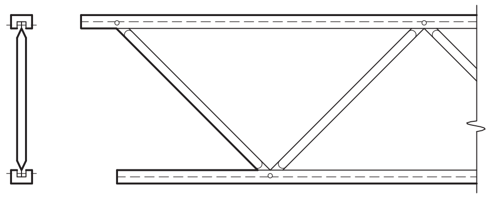
SHOP-FABRICATED WOOD TRUSSES

WOOD CHORDS AND WEBS, STEEL PLATE CONNECTORS

MEDIUM TO LONG, SPAN 40' TO 60'

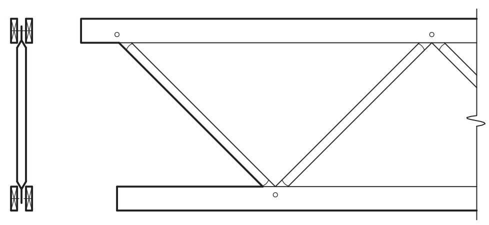


WOOD CHORDS, 20-GA. STEEL WEBS



WOOD CHORDS, 1" TO 1-1/2" DIA. TUBING WEBS; DEPTHS TO 40"

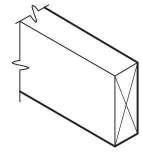
LONG TO VERY LONG SPAN, 60' TO 100'



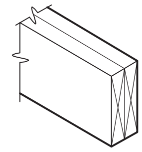
DOUBLE 2 x 6 CHORDS, 2" DIA. WEBS; DEPTHS TO 63"

METAL-WEB WOOD JOISTS

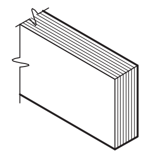
FLOOR FRAMING WOOD BEAMS
11.95



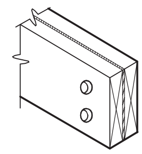
HEAVY TIMBER BEAM



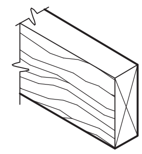
BUILT-UP BEAM



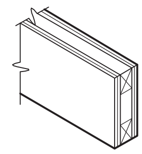
LAMINATED VENEER LUMBER (LVL) BEAM



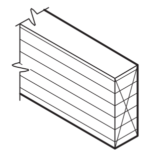
FLITCH BEAM



PARALLEL STRAND LUMBER (PSL) BEAM



BOX BEAM



GLUE-LAMINATED BEAM

NOTES

11.95 a. *Heavy timber beam:* Timber beams are available in a variety of species and grades; Douglas fir is the strongest. Heavy timber uses rectangular solid-wood framing members that are nominally a minimum of 5 in., in both dimensions.
b. *Laminated veneer lumber (LVL) beam:* Vertical factory-laminated sections are glued together. Actual widths are multiples of 1–3/4 in. (two pieces match thickness of 2 × 4 wall). Actual heights range from 5–1/2 to 18 in.
c. *Parallel strand lumber (PSL) beam:* Factory-glued composite beam made with long narrow strips of veneer, oriented along beam length. Actual widths are 3–1/2, 5–1/4, and 7 in. Heights range from 9–1/4 to 18 in.
d. *Glue-laminated beam:* Horizontal factory-glued laminations make a knot-free and very stable beam. Actual widths are 3–1/8, 5–1/8, 7–1/8 in., and so on. Heights are in multiples of 1–1/2 in.
e. *Built-up beam:* Dimension lumber is nailed together to form a single beam (four pieces maximum). Widths are multiples of 1–1/2 in. Height follows dimension lumber.
f. *Flitch beam:* A steel plate sandwiched between two pieces of lumber adds strength without substantially increasing the beam size. The lumber prevents buckling of the steel and provides a nailing surface. Widths are 3 to 3–1/2 in. Heights follow dimension lumber.
g. *Box beam:* 2 × 4 lumber is sandwiched between two plywood skins. Plywood is both nailed and glued to 2 × 4s and at all edges. Plywood joints must be offset.

WESTERN OR PLATFORM WOOD FRAMING

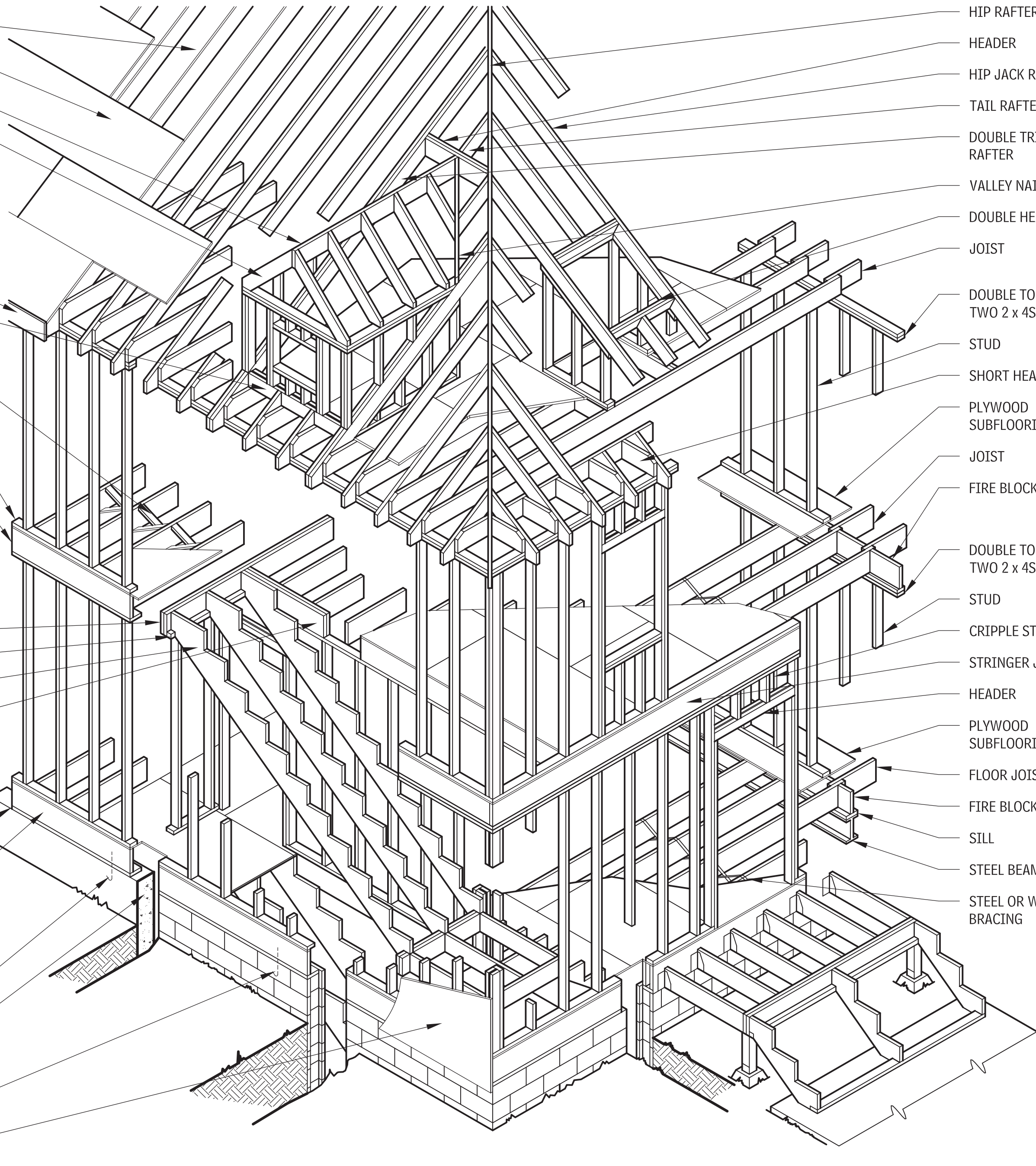
Before any of the superstructure is erected, the first-floor framing and subflooring is put down, making a platform on which the walls and partitions can be assembled and tilted into place. Because floor framing and wall frames do not interlock, adequate sheathing must act as bracing and provide the necessary lateral resistance. Where required for additional stiffness or bracing, metal strapping or a 1 by 4 may be let into outer face of studs at 45° angles, secured at the top, bottom, and to the studs. The process is repeated for each story of the building.

Bridging may be omitted when flooring is nailed adequately to the joist. However, where nominal depth-to-thickness ratio of joists exceeds 6, bridging would be installed at 8-ft-0-in. intervals. Building codes may allow omission of bridging under certain conditions. Steel bridging is available. Some types do not require nails.

For firestopping, all concealed spaces in framing, with the exception of areas around flues and chimneys, are to be fitted with 2-in. blocking arranged to prevent drafts between spaces.

Platform framing has essentially replaced balloon framing. Balloon framing with studs continuous from wood sill to top plate is rarely used, except at special locations (such as two-story spaces, at parapets, and similar situations where a structural cantilever of the wall is required).

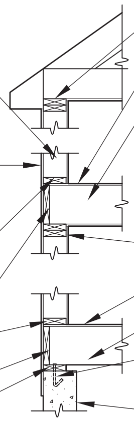
PLATFORM FRAMING
11.96



NOTES

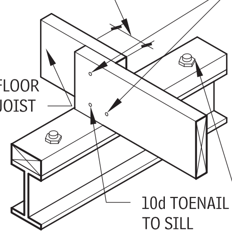
11.96 a. Roof framing may be level, I-joist, or trusses, shown in Figure 11.85.
b. Floor joists may be any of the framing members shown in Figure 11.95.

PLATFORM FRAMING SECTION
11.97

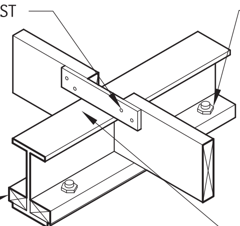


FRAMING DETAILS FOR JOISTS AND SILLS

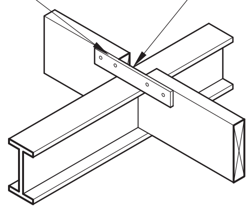
WOOD JOISTS SUPPORTED ON STEEL BEAM
11.98



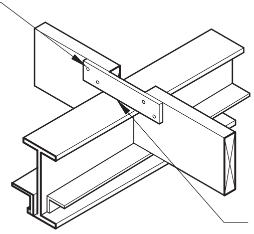
LAPPED OVER WOOD SILL



ON WOOD LEDGER

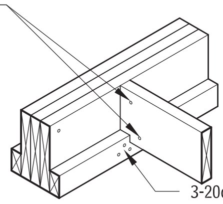


ON LOWER FLANGE

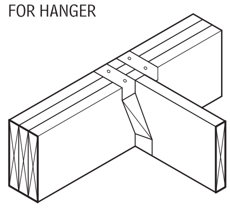


ON STEEL ANGLES

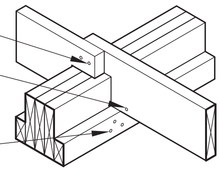
WOOD JOISTS SUPPORTED ON WOOD BEAM
11.100



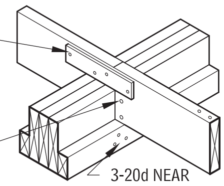
JOIST NOTCHED OVER LEDGER STRIP



JOIST IN JOIST HANGER

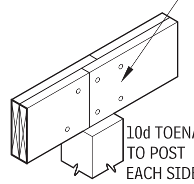


OVERLAPPING JOISTS NOTCHED OVER BEAM

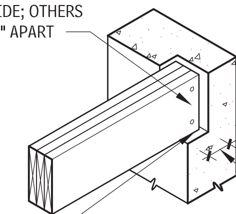


JOISTS NOTCHED OVER BEAM

BEAMS
11.101

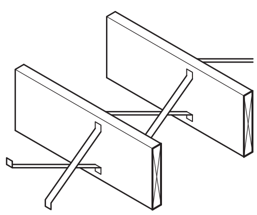


TWO-PIECE BUILT-UP BEAM

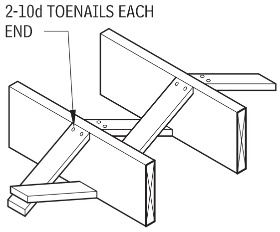


THREE-PIECE BUILT-UP BEAM

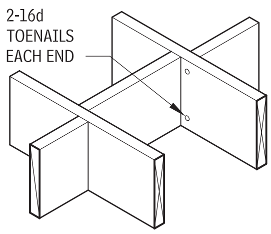
BRIDGING
11.99



STEEL BRIDGING

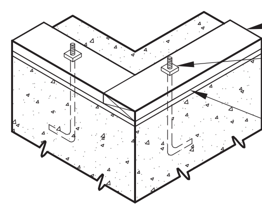


1 x 3 CROSS BRIDGING



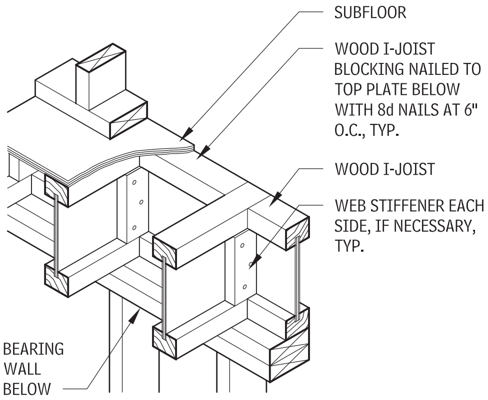
SOLID BRIDGING

SILL FOR PLATFORM FRAMING
11.102

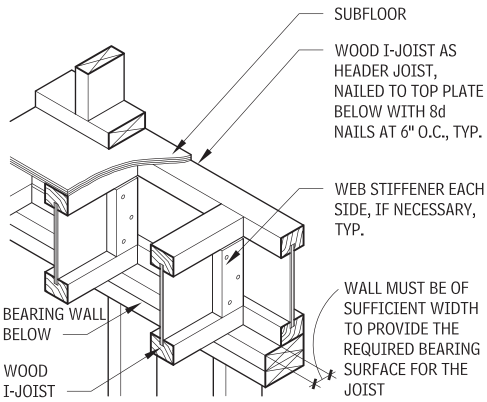


2 x 6 SILL

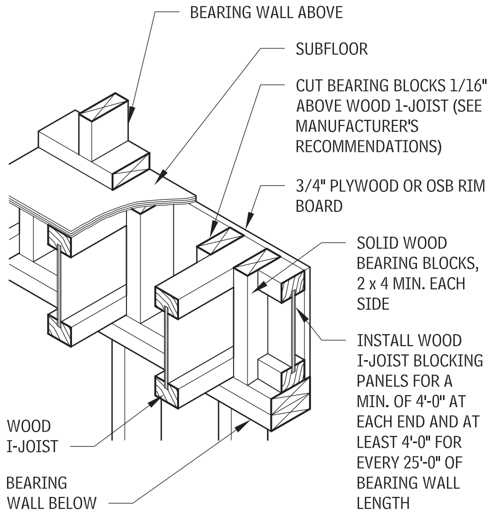
WOOD I-JOIST FLOOR FRAMING DETAILS
11.103



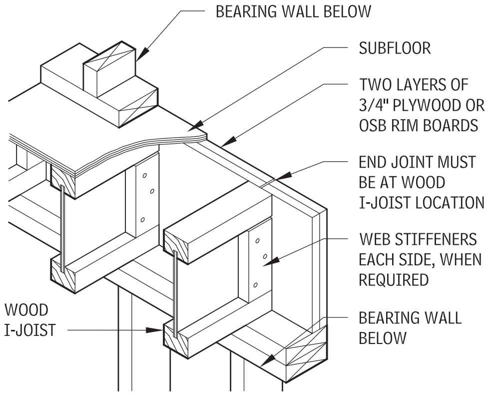
WOOD I-JOIST BLOCKING



WOOD I-JOIST AS HEADER JOIST

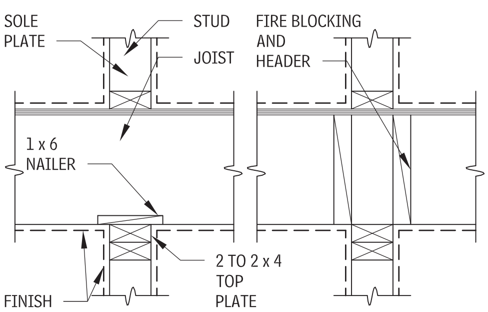


BEARING BLOCKS

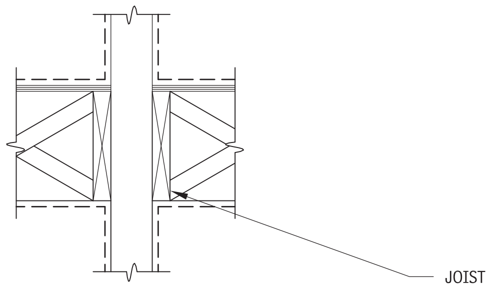


STANDARD 2X RIM BOARDS

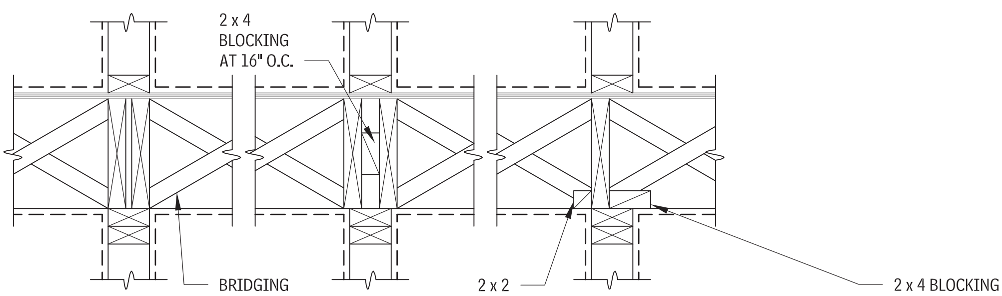
FLOOR DETAILS AT BEARING INTERIOR PARTITIONS
11.104



PARTITIONS PERPENDICULAR TO JOISTS

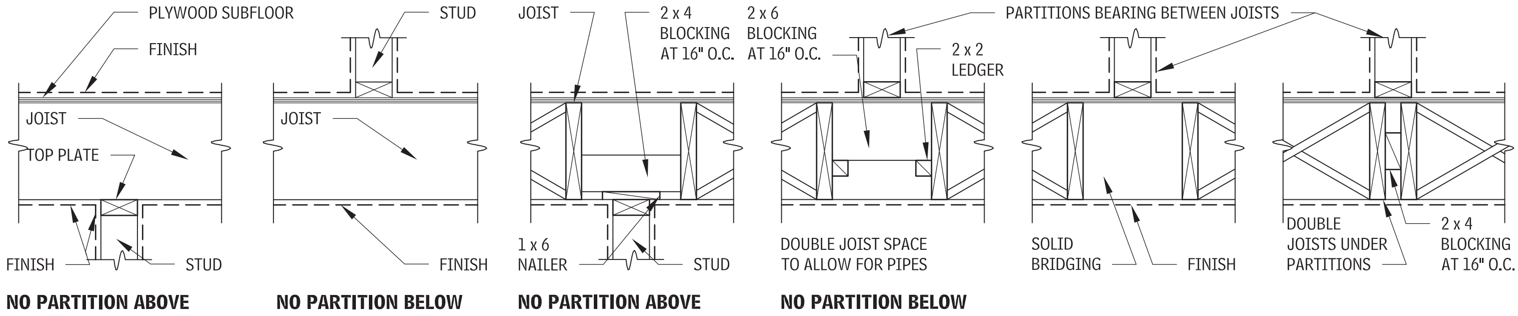


BALLOON AND BRACED



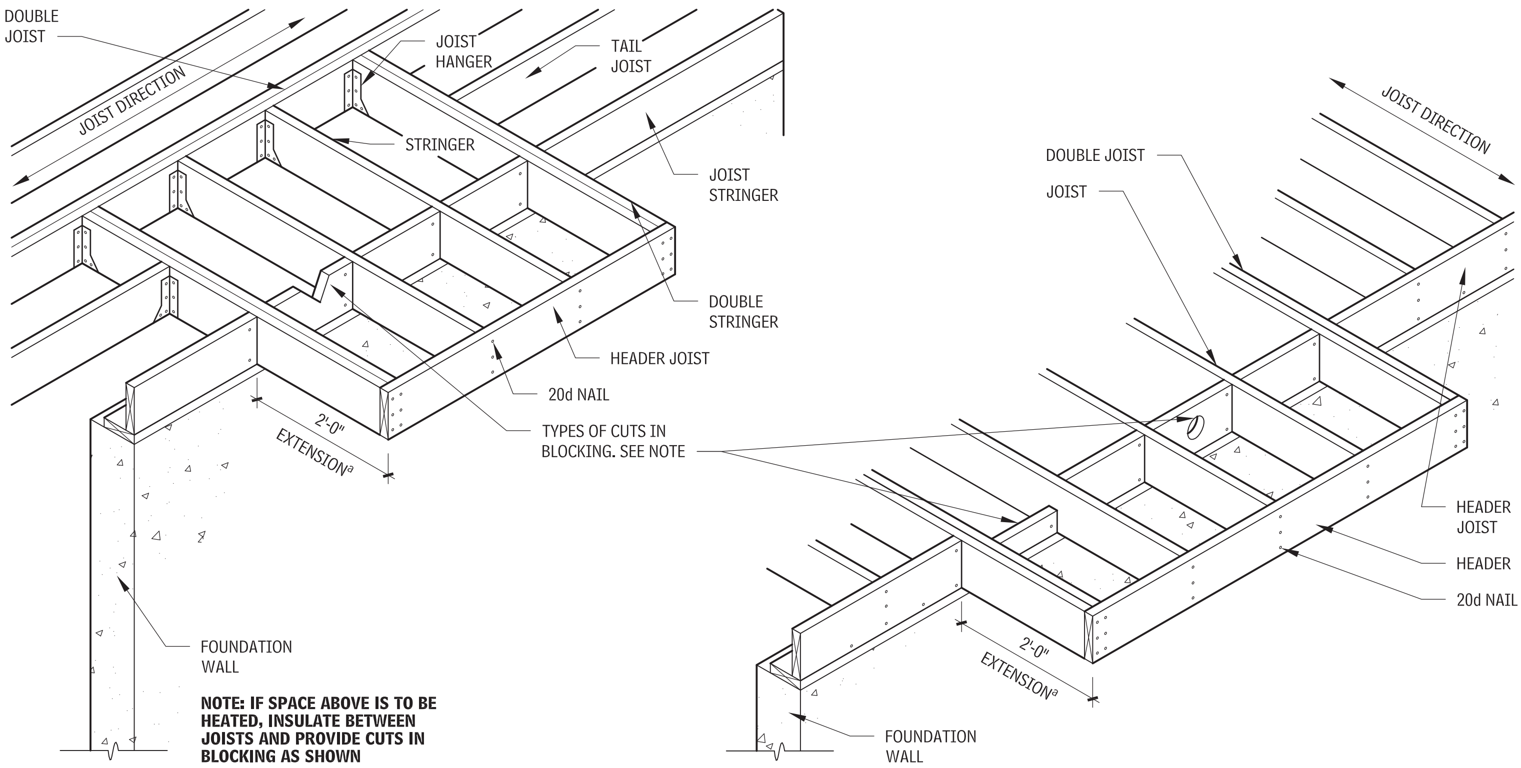
PARTITIONS PARALLEL TO JOISTS

FLOOR DETAILS AT NONBEARING INTERIOR PARTITIONS
11.105



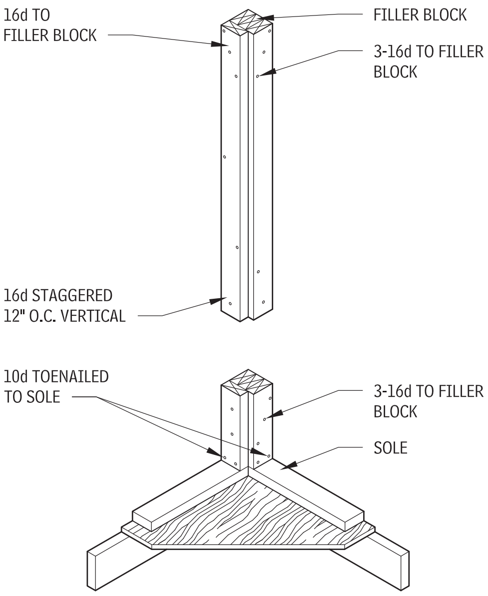
PARTITIONS PERPENDICULAR TO JOISTS **PARTITIONS PARALLEL TO JOISTS**

FLOOR CANTILEVERS
11.106

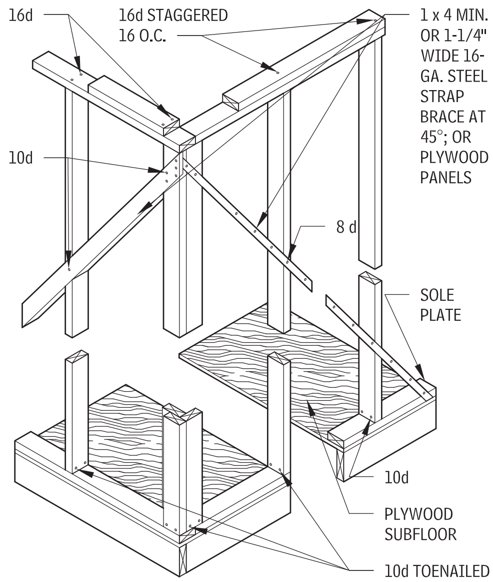


PERPENDICULAR TO JOISTS **PARALLEL TO JOISTS**

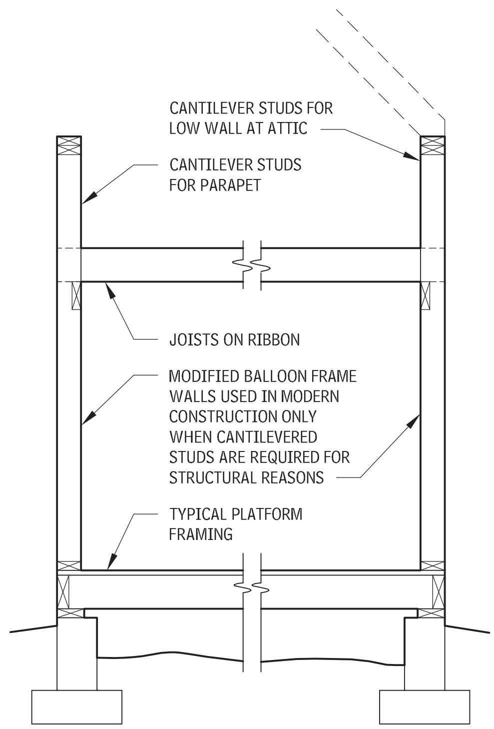
CORNER POST
11.107



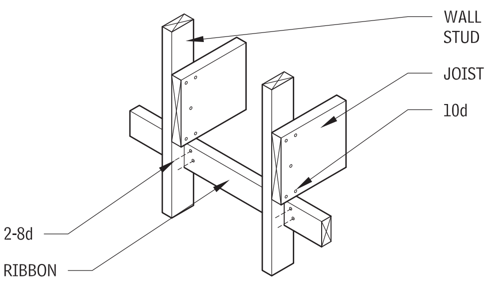
TOP PLATE AND BRACING
11.108



BALLOON FRAMING
11.109



JOISTS BEARING ON RIBBON
11.110

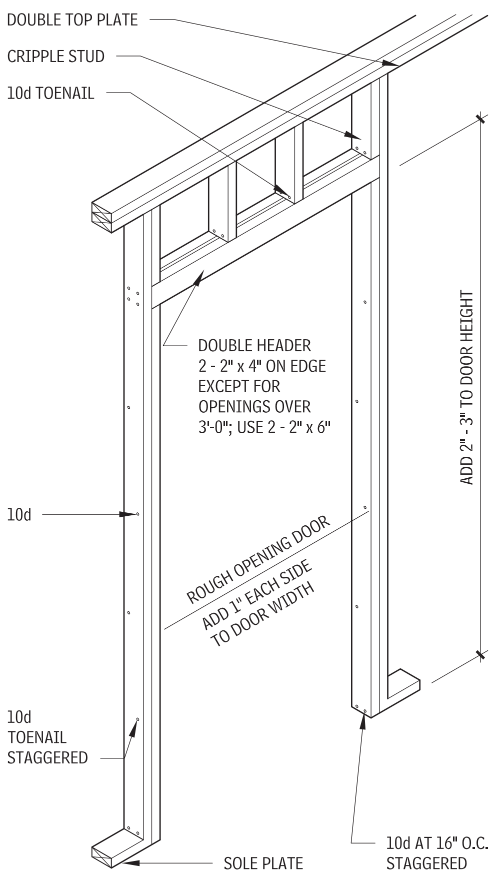


FRAMING DETAILS FOR OPENINGS

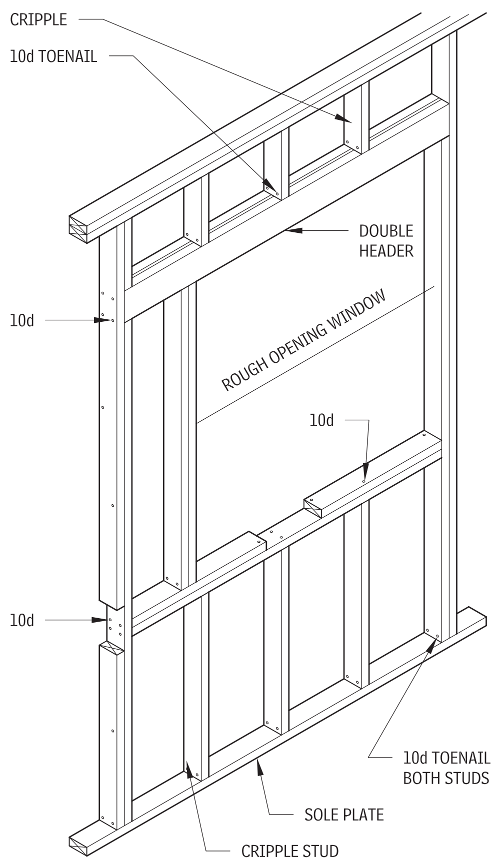
Steel lintels are selected from steel beam design tables on the basis of floor, wall, and roof openings. Wood lintels over openings in bearing walls may be engineered as beams. Composite beams, such as glued-laminated beams, also are appropriate in some applications. Plywood box beams are used for garage doors. Steel flitch plates can add strength without adding extra width to a composite beam.

Check with local codes and standards for fire-resistance requirements.

DOOR OPENING
11.111



WINDOW OPENING
11.112

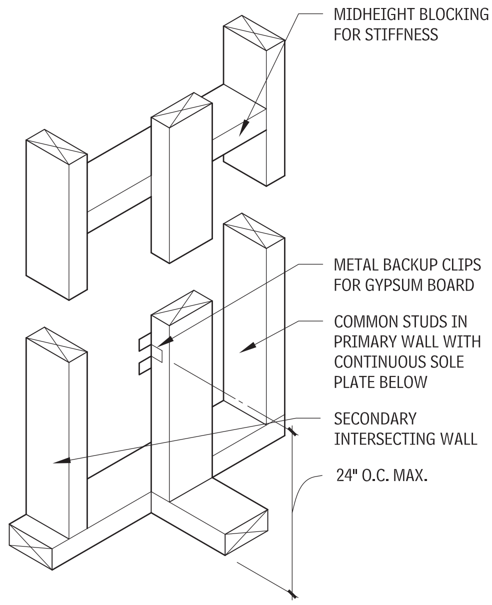


NOTE

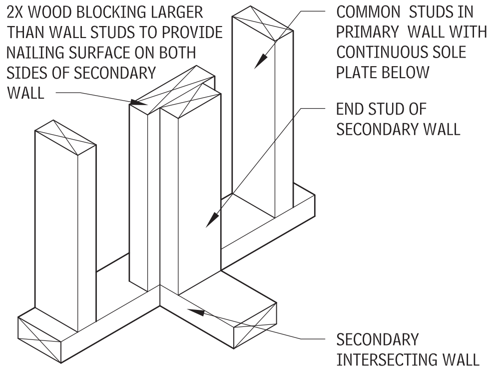
11.109 Two nails on each joist are sufficient if full story exists above ribbon.

Contributors:
American Iron and Steel Institute, Washington, DC; Joseph A. Wilkes, FAIA, Wilkes and Faulkner, Washington, DC; Joseph A. Wilkes, FAIA, Wilkes and Faulkner, Washington, DC.

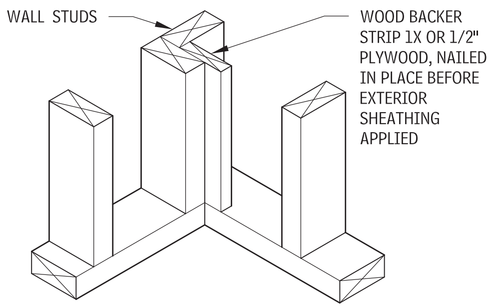
INTERSECTING WALL DETAILS
11.113



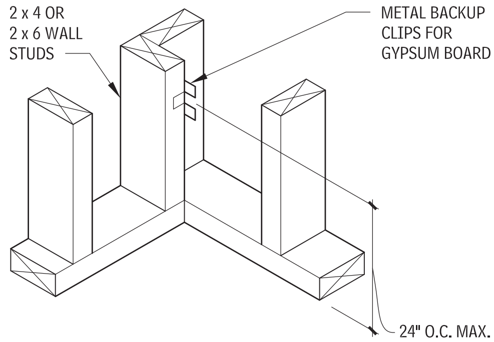
INTERSECTING WALLS WITH METAL GYPSUM BOARD CLIPS



INTERSECTING WALLS WITH BLOCKING

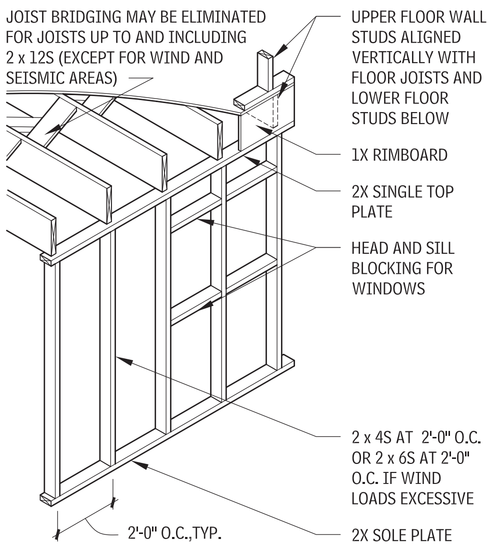


CORNER BLOCKING DETAIL

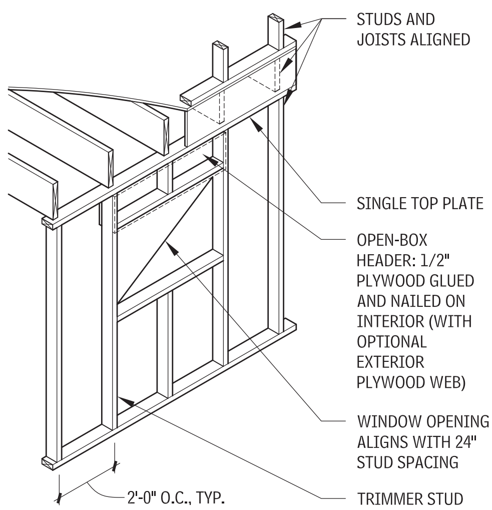


WALL CORNER WITH METAL GYPSUM BOARD CLIPS

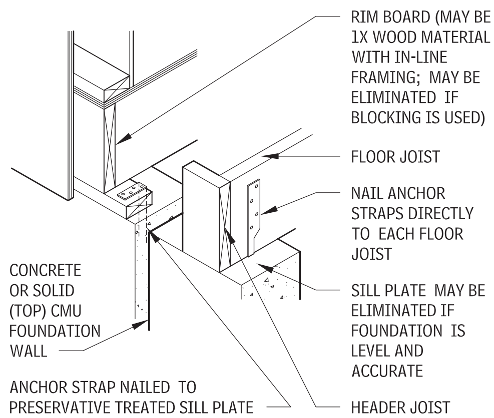
REDUCED WOOD FRAMING DETAILS
11.114



IN-LINE FRAMING



IN-LINE FRAMING WITH WIDE OPENING



NOTES

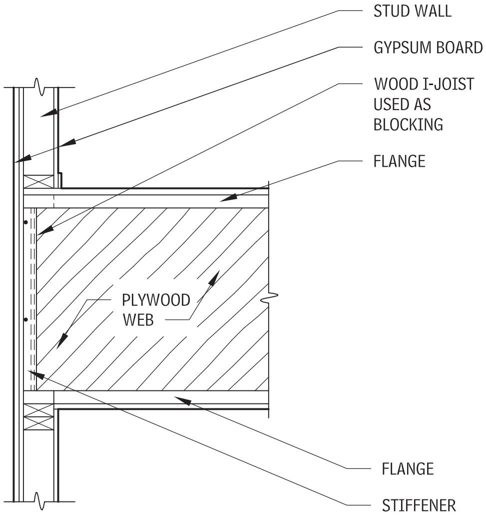
11.114 a. Some framing details rely on techniques that reduce the amount of lumber in wood construction. Among these are in-line framing details and corner details with metal framing clips for gypsum board. These types of details were developed to conserve wood resources, reduce material cost and job-site waste, and enhance energy efficiency by reducing thermal bridging across wall systems and increasing insulation cavities. When wood levels are to be reduced, a structural engineer should first be consulted.

b. Gypsum board installed at inside corners with metal clips or wood backers does not get fastened to either. The sheet resting against the backer or clips is installed first so the second sheet (which is nailed to the stud) will lock the first sheet in place. The "floating joint" that results is recommended, to reduce cracks in the corner.

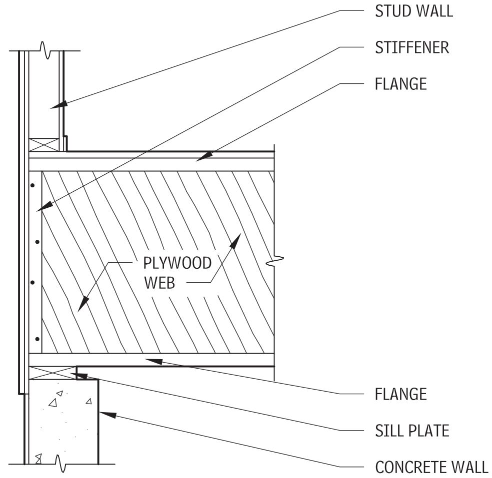
Contributor:
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland.

SHOP-FABRICATED STRUCTURAL WOOD

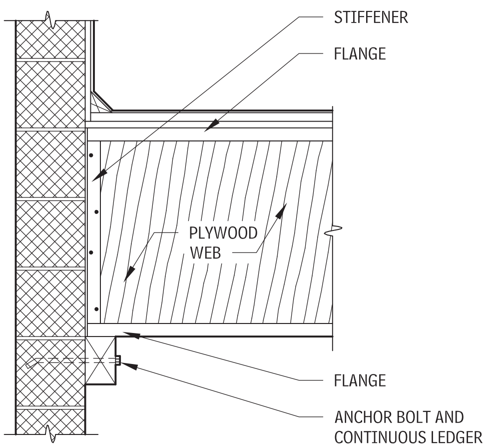
WOOD I-JOISTS 11.115



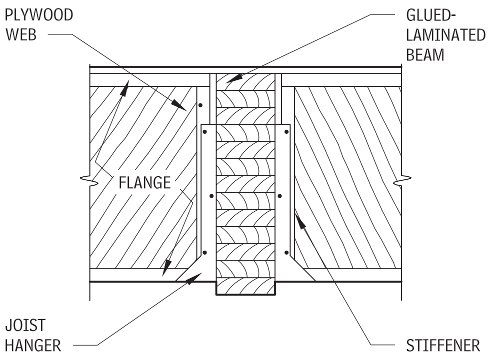
BEARING ON STUD WALL



FOUNDATION

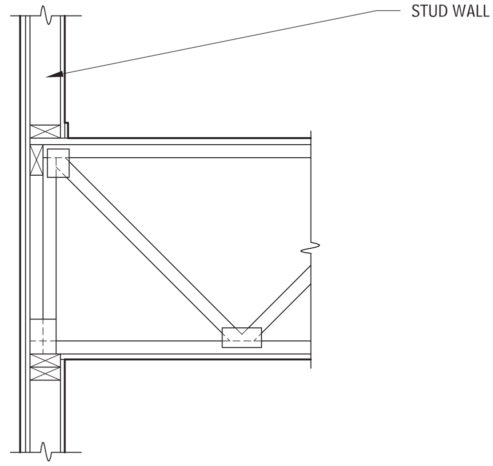


BEARING ON LEDGER

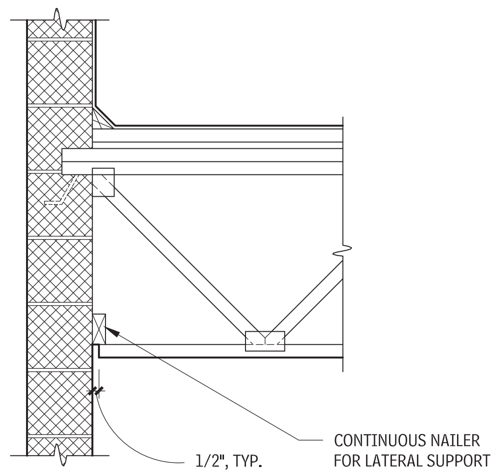


BOTTOM CHORD BEAM

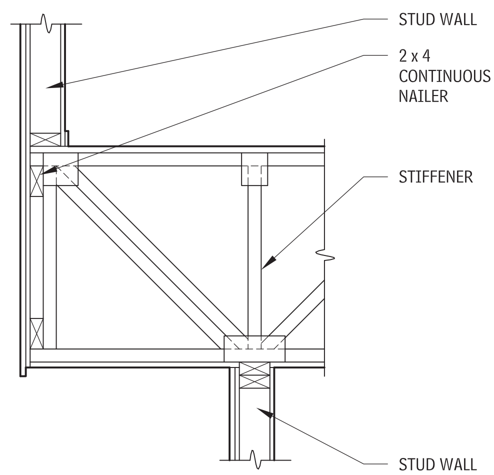
SHOP-FABRICATED WOOD TRUSSES 11.116



BOTTOM CHORD BEARING ON STUD WALL



TOP CHORD BEARING ON MASONRY WALL



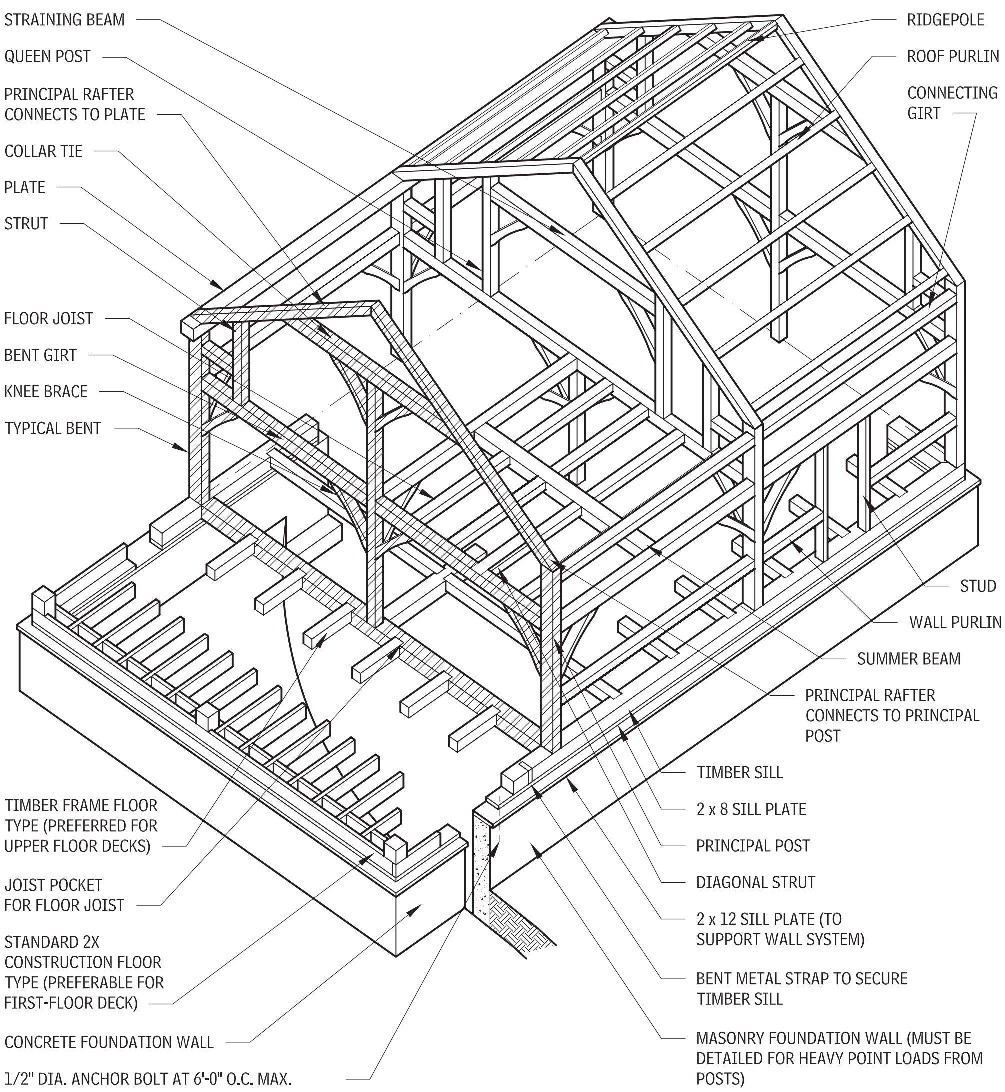
CANTILEVERED FLOOR TRUSS

HEAVY TIMBER CONSTRUCTION

Heavy timber construction is characterized by large, exposed timber columns, beams, and other structural members, joined together by traditional pegged mortise-and-tenon or similar joints. Heavy timber uses rectangular solid-wood framing members that are nominally a minimum of 5 in., in both dimensions. Heavy timber fabricated timber frame modules are called bents. Bents run perpendicular to the ridge, and include the primary columns, beams, girders, and rafters, and knee braces. Bents are typically spaced 10 to 16 ft. on center. Note that alternate framing methods running parallel to the ridge, or utilizing systems similar in concept to platform framing, are available from some timber framers. Knee braces typically provide bracing against lateral loads.

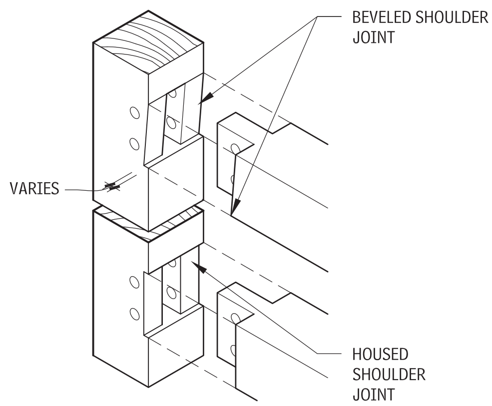
Heavy timber structures are typically enclosed with stressed-skin insulated panels, leaving the frame totally exposed on the interior. Heavy timber construction is being updated with modern materials such as glulam members and proprietary concealed metal connections.

TYPICAL TIMBER FRAME (SHOWING TWO-ROOF AND FLOOR TYPES)
11.117



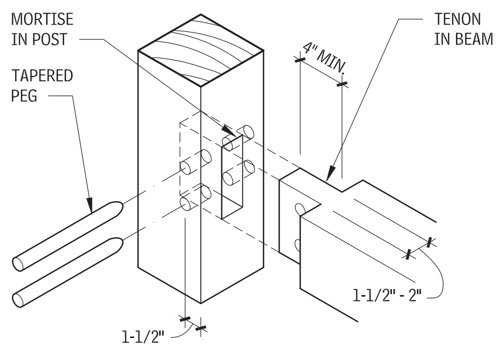
SHOULDERED MORTISE-AND-TENON JOINT
11.118

A beveled shoulder or housed joint is used to connect all load-bearing beams (such as bent and connecting girts and summer beams) to posts. Angled variations can be used when principal rafters join to posts or for diagonal braces. The depth of the shoulder depends on loading, torsion, other joinery in the area, and wood species.

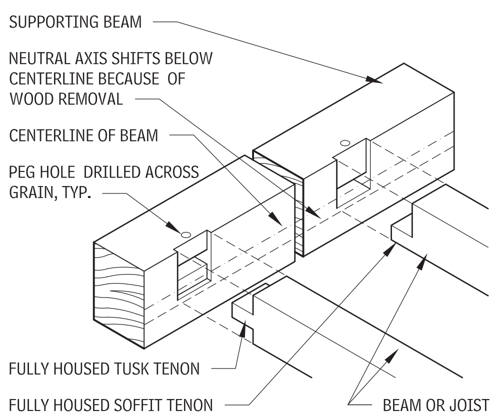


BASIC MORTISE-AND-TENON JOINT
11.119

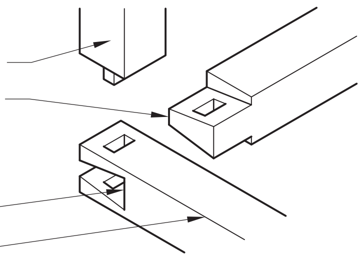
The basic mortise-and-tenon joint can be very effective in resisting both tension and compression forces. To increase tensile strength, increase the depth and thickness of the tenon and use additional pegs if the width and length of the tenon allow.



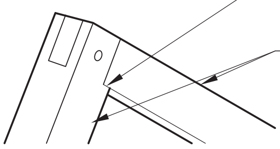
TUSK AND SOFFIT TENON JOINT
11.120



OPEN MORTISE-AND-TENON JOINTS
11.121

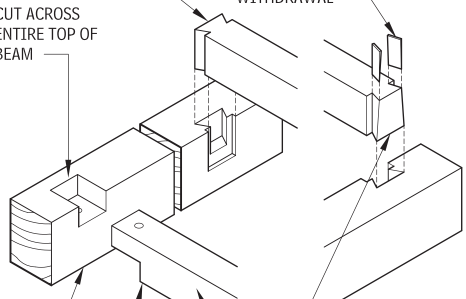


DOVETAIL MORTISE-AND-TENON JOINT



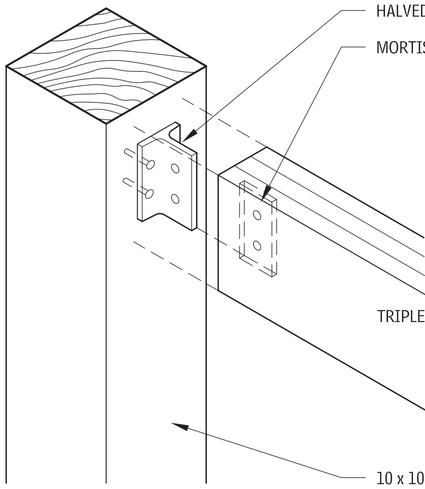
RAFTER JOINT

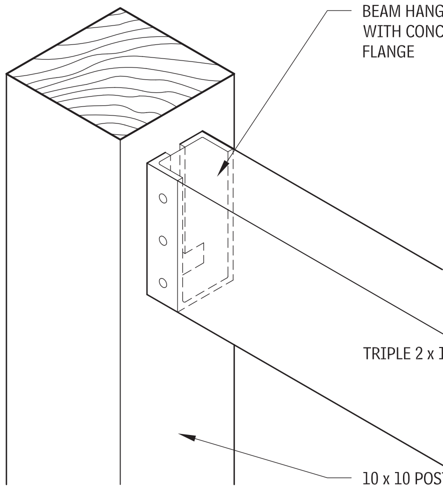
LAP JOINTS
11.122



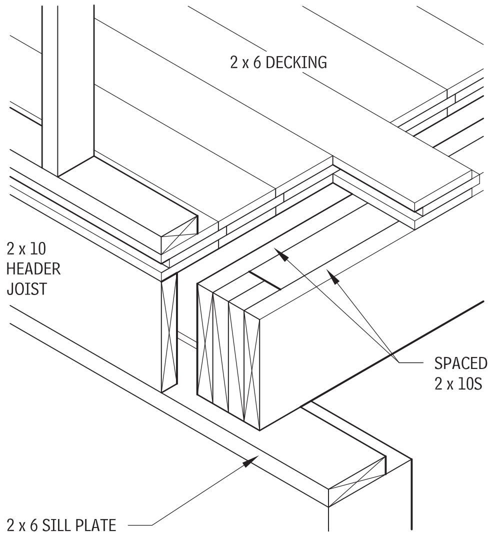
POST AND BEAM CONSTRUCTION

POST AND CONNECTIONS
11.123

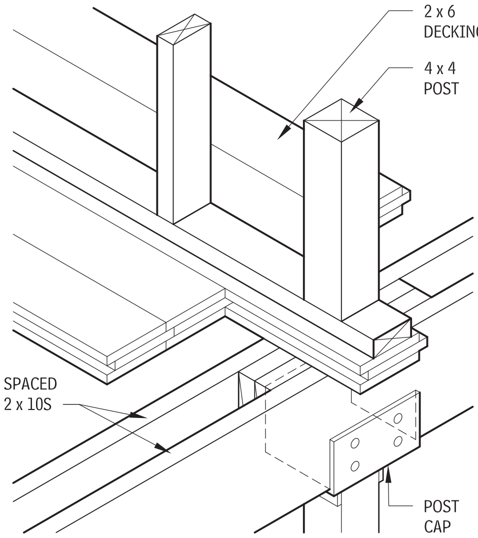




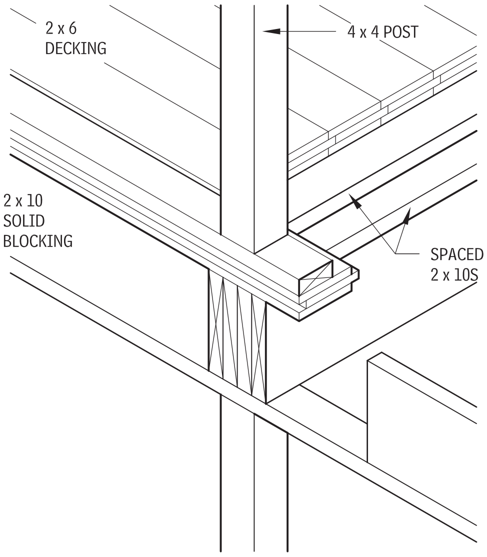
SPACED BEAM AT FOUNDATION
11.124



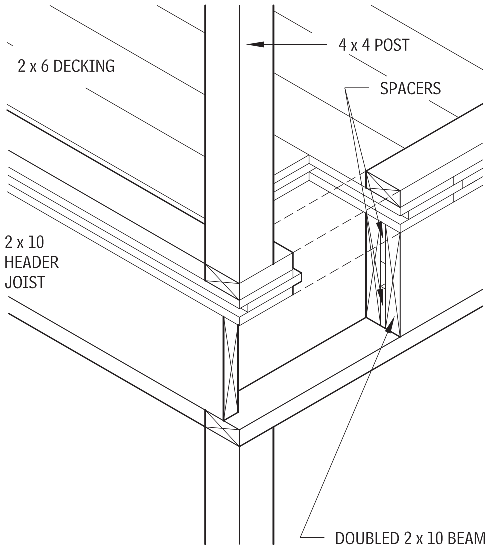
SPACED BEAM BEARING ON INTERIOR COLUMN
11.125



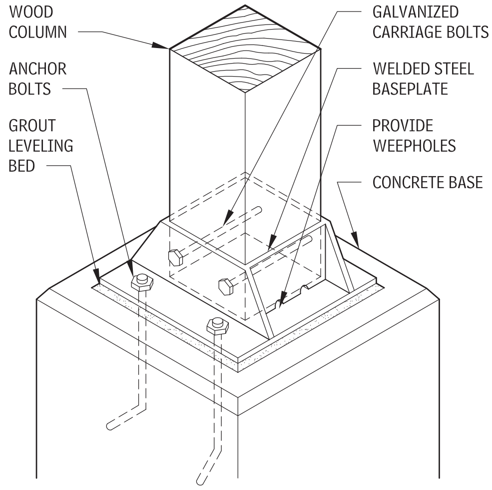
SPACED BEAM BEARING AT EXTERIOR WALL
11.126



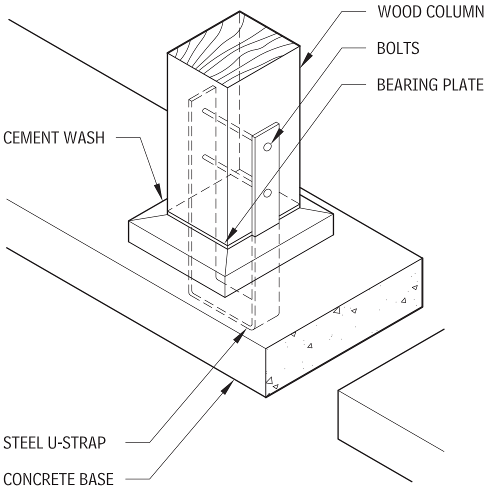
CORNER CONNECTION
11.127



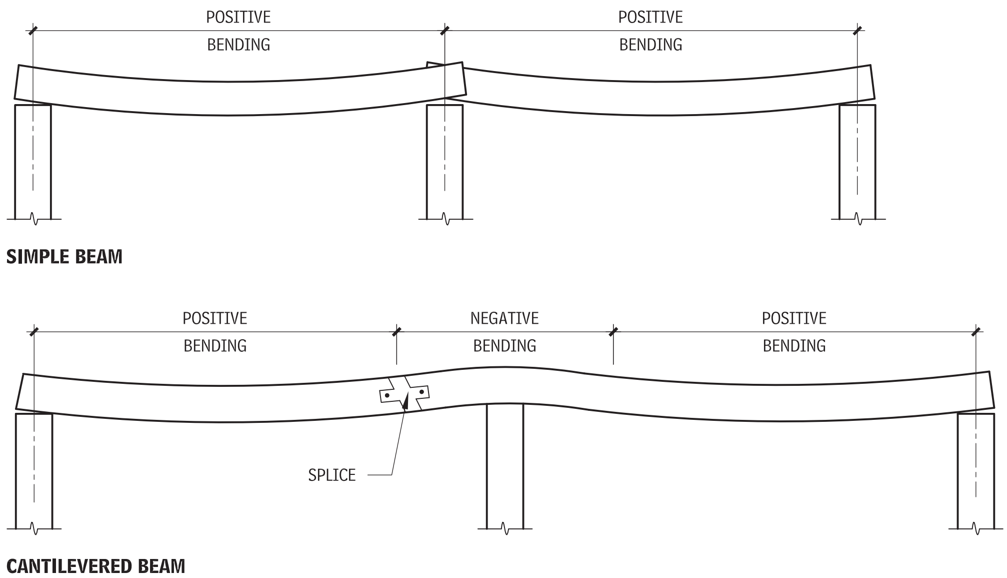
WOOD COLUMN ANCHORED WITH STEEL BASEPLATE
11.128



U-STRAP COLUMN ANCHORAGE TO CONCRETE BASE
11.129



SIMPLE AND CANTILEVERED FRAMING
11.130



Note in simple framing, shown in Figure 11.130, the "positive," or downward, bending that occurs in conventional framing with simple spans. Note also in cantilevered framing the combination of "positive" (downward) and "negative" (upward) bending that occurs with beams spliced at quarter point, producing supported beam and cantilevered beam. The two types of bending counterbalance each other, which produces more uniform stresses and uses material more efficiently.

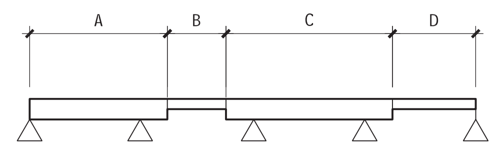
Moment splice occurs when compression stress is taken in bearing on the wood through a steel compression plate. Tension is taken across the splice by means of steel straps and shear plates. Side plates and straps are used to hold sides and tops of members in position. Shear is taken by shear plates in end grain. Bolts and shear plates may be used as design and construction considerations require.

CANTILEVERED AND CONTINUOUS SPAN

Cantilever beam systems may be composed of any of the various types and combinations of beams shown in the figures in this section. Cantilever systems generally permit longer spans or larger loads per size member than do simple span systems.

For economy, the negative bending moment at the support of a cantilevered beam should be equal in magnitude to the positive moment.

CANTILEVERED AND CONTINUOUS SPAN
11.131



A: SINGLE CANTILEVER
B: SUSPENDED
C: DOUBLE CANTILEVER
D: SINGLE END SUSPENDED

NOTE

11.129 Recommended for industrial buildings and warehouses to resist both horizontal forces and uplift. Moisture barrier is recommended. It may be used with shear plates.

Contributor:
Timothy B. McDonald, Washington, DC.

GLUED-LAMINATED CONSTRUCTION

The term *glued-laminated construction* refers to an engineered, stress-rated product made of wood laminations bonded with adhesives, with the grain approximately parallel lengthwise. Laminated pieces can be end-joined to form any length, be glued edge to edge to make wider pieces, or be of bent pieces curved during the laminating process.

STANDARD DEPTHS

Dimension lumber surfaced to 1–1/2 in. is used to laminate straight members and members that have a curvature within the bending radius limitations for the species. Boards surfaced to 3/4 in. are recommended for laminating curved members when the bending radius is too short to permit the use of dimension lumber, provided that the bending radius limitations for the species are observed. Other lamination thicknesses may be used to meet special requirements.

STANDARD WIDTHS
11.132

NOMINAL WIDTH (IN.)	NET FINISHED WIDTH (IN.)
3	2–1/8
4	3–1/8*
6	5–1/8*
8	6–3/4
10	8–3/4*
12	10–3/4*
14	12–1/4
16	14–1/4

CONNECTION DESIGN

The design of connections for glued-laminated construction is similar to the design of connections for dimension lumber. Since glued-laminated members often are much larger than dimension lumber, and the loads transferred are larger, the effect of increased size should be taken into account in the design of connections. In addition to being designed for strength to transfer loads, connections also should be designed to avoid splitting of the member, as well as to accommodate swelling and shrinking of the wood.

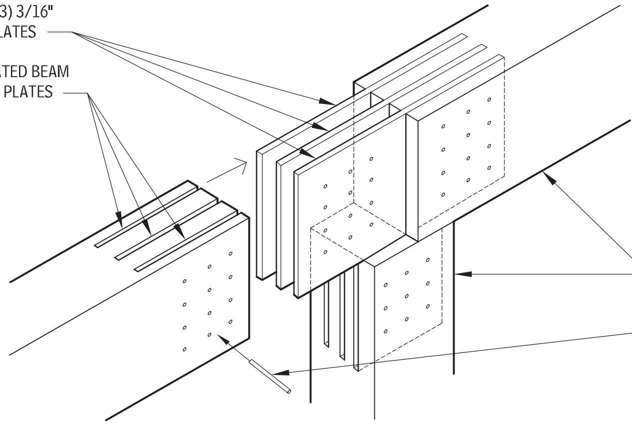
FIRE SAFETY

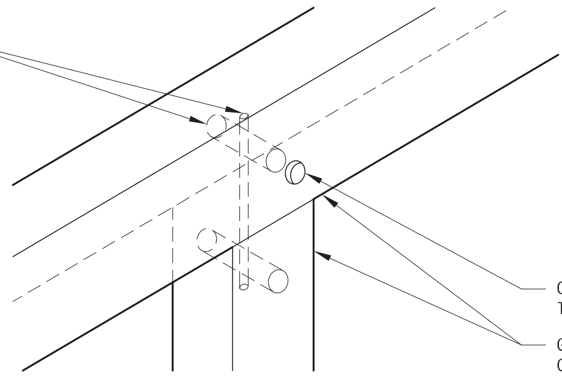
Similar in nature to heavy timber, the self-insulating qualities of glued-laminated construction cause the members to burn slowly. Good structural details, elimination of concealed spaces, and use of vertical fireblocking contribute to its fire-resistance and ability to retain its strength longer than unprotected metals.

Therefore, building codes generally classify glued-laminated construction as heavy timber construction if certain minimum dimensional requirements are met. Codes also allow for calculation of one-hour fire ratings for exposed glued-laminated members.

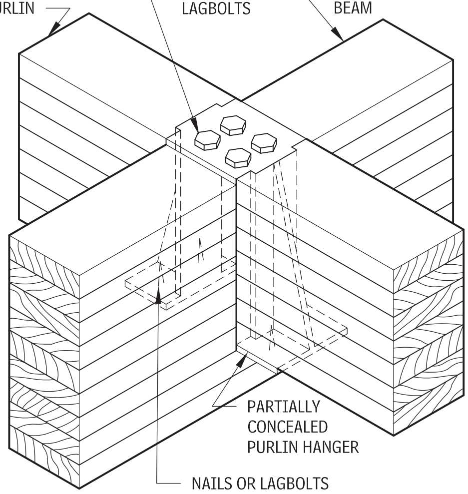
It is not recommended that fire-retardant treatments be applied to glued-laminated members because they do not substantially increase the fire resistance. In considering fire-retardant treatments, it is essential to investigate the following: reduction of strength related to type and penetration of treatment, compatibility of treatment and adhesive, use of special gluing methods, difficulty of application, and effect on wood color and fabrication process.

PROPRIETARY CONNECTIONS
11.133

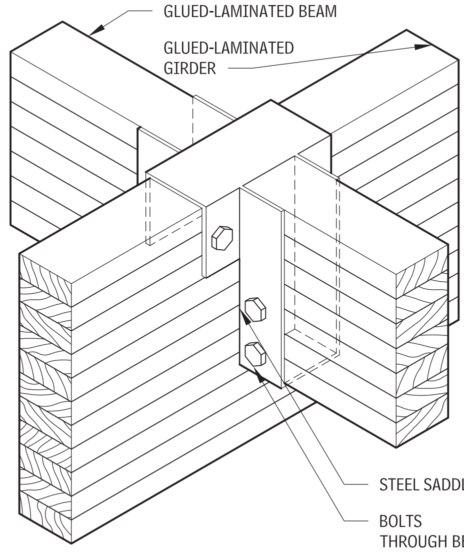




PURLIN-TO-BEAM CONNECTION
11.134



BEAM-TO-GIRDER CONNECTION
11.135



NOTES

11.132 Widths are 3, 5, 8–1/2, and 10–1/2 in. for southern pine.
11.133 a. Most typical connections can be accomplished with concealed or semiconcealed fasteners.
b. Final engineering is by manufacturer.

WOOD DECKING

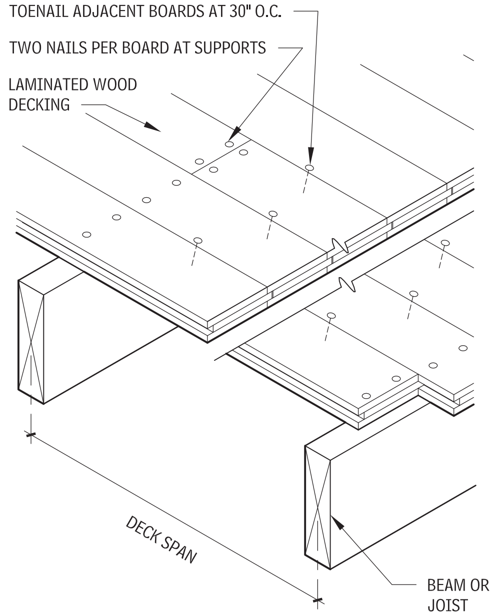
WOOD SELECTION

When it comes to selecting wood for decking, characteristics should include effective resistance to decay, nonsplintering, stiffness, strength, hardness, and warp resistance. Species selection will vary according to local climate and structure.

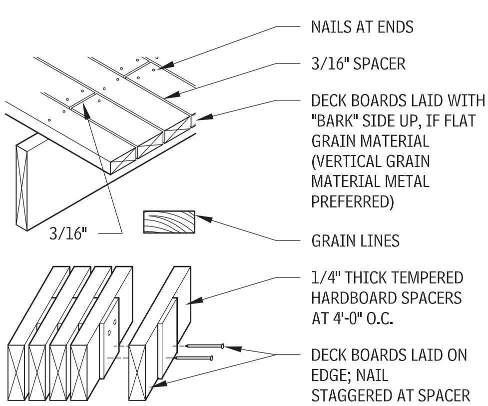
RELATIVE COMPARISON OF VARIOUS QUALITIES OF WOOD USED IN DECK CONSTRUCTION[a]
11.136

	DOUGLAS FIR LARCH[b]	SOUTHERN PINE[b]	HEMLOCK FIR[b,c]	SOFT PINE[b,d]	WESTERN RED CEDAR	REDWOOD	SPRUCE	CYPRESS	IPE[e]
Hardness	Fair	Fair	Poor	Poor	Poor	Fair	Poor	Fair	Good
Warp resistance	Fair	Fair	Fair	Good	Good	Good	Fair	Fair	Good
Ease of working	Poor	Fair	Fair	Good	Good	Fair	Fair	Fair	Difficult
Paint holding	Poor	Poor	Poor	Good	Good	Good	Fair	Good	—
Stain acceptance	Fair	Fair	Fair	Fair	Good	Good	Fair	Fair	Good
Nail holding	Good	Good	Poor	Poor	Poor	Fair	Fair	Fair	—
Heartwood decay resistance	Fair	Fair	Poor	Poor	Good	Good	Poor	Good	Excellent
Proportion of heartwood	Good	Poor	Poor	Fair	Good	Good	Poor	Good	Excellent
Bending strength	Good	Good	Fair	Poor	Poor	Fair	Fair	Fair	Good
Stiffness	Good	Good	Good	Poor	Poor	Fair	Fair	Fair	Good
Strength as a post	Good	Good	Fair	Poor	Fair	Good	Fair	Fair	—
Freedom from pitch	Fair	Poor	Good	Fair	Good	Good	Good	Good	Good

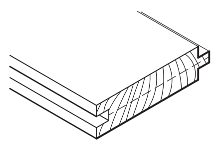
LAMINATED DECKING
11.139



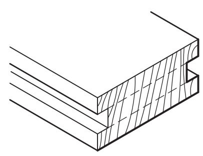
DECKING APPLICATIONS
11.137



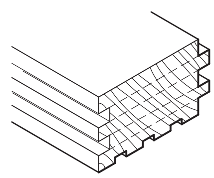
MACHINE-SHAPED DECKING TYPES
11.138



SINGLE TONGUE-AND-GROOVE



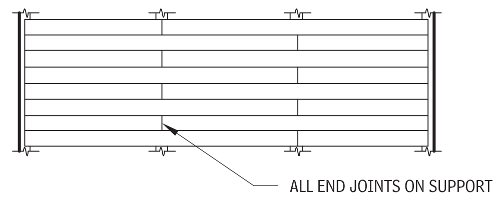
SPLINE



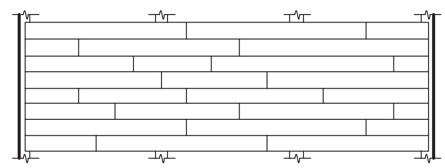
PATTERNED

SIZES				
THICKNESSES		WIDTH		MAXIMUM SPAN
NOMINAL (IN.)	ACTUAL (IN.)	NOMINAL (IN.)	ACTUAL (IN.)	TYPICAL (FT)
2	1–1/2	5, 6, 8, 10, 12	4, 5, 6–3/4, 8–3/4, 10–3/4	8
3	2–1/2	6	5–1/4, 7–1/8	12
4	3–1/2	6	5–1/4, 7–1/8	16

WOOD DECKING JOINT PATTERNS
11.140

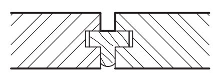


SIMPLE SPAN

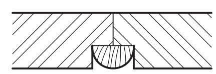


CONTINUOUS SPAN WITH RANDOM LENGTHS

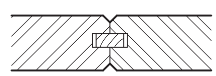
DECKING JOINTS
11.141



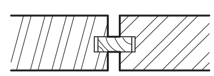
GROOVED PLANK MOLDED SPLINE



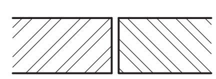
RABBETED PLANK BATTEN INSERT



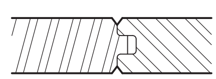
GROOVED PLANK WITH SPLINE



GROOVED PLANK WITH EXPOSED SPLINE



SQUARE EDGE

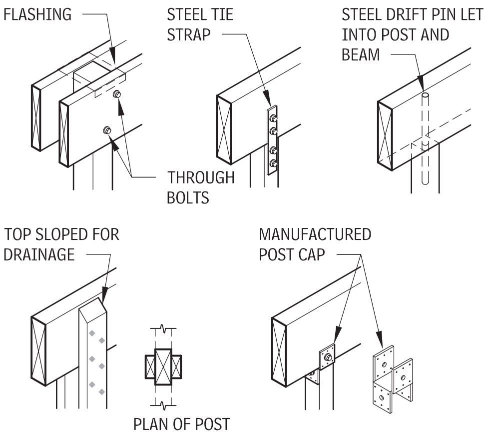


TONGUE-AND-GROOVE (MOST COMMON)

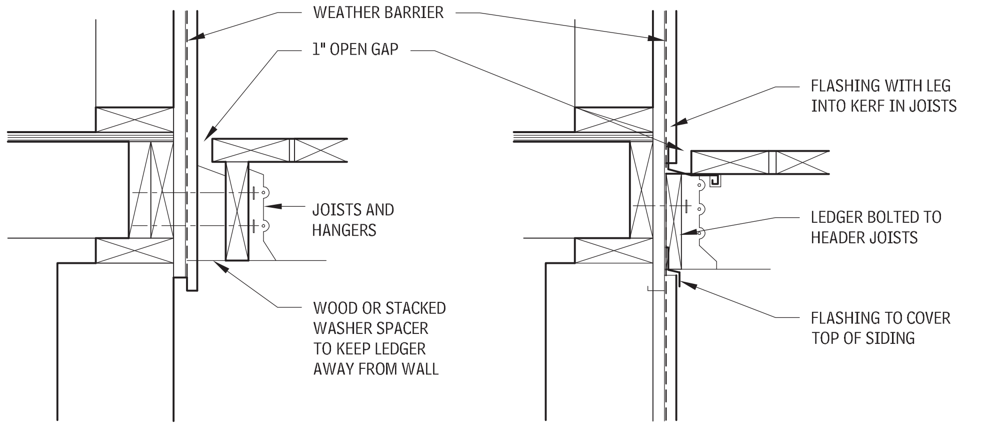
NOTES

11.136 a. Categories refer to semitransparent oil-base stain.
b. Use pressure-preservative-treated material only. All materials below deck surfaces should be pressure-treated.
c. Includes West Coast and eastern hemlocks.
d. Includes western and northeastern pines.
e. Ipe used typically for decking only, not framing.
11.137 Spacing of 1/4 in. is not recommended for walking surfaces where high heels are anticipated.

POST AND BEAM CONNECTIONS
11.142

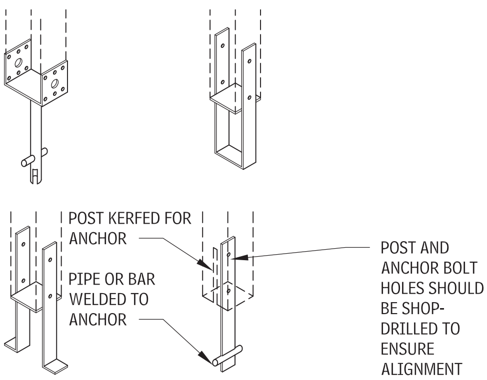


CONNECTIONS AT BUILDING
11.143

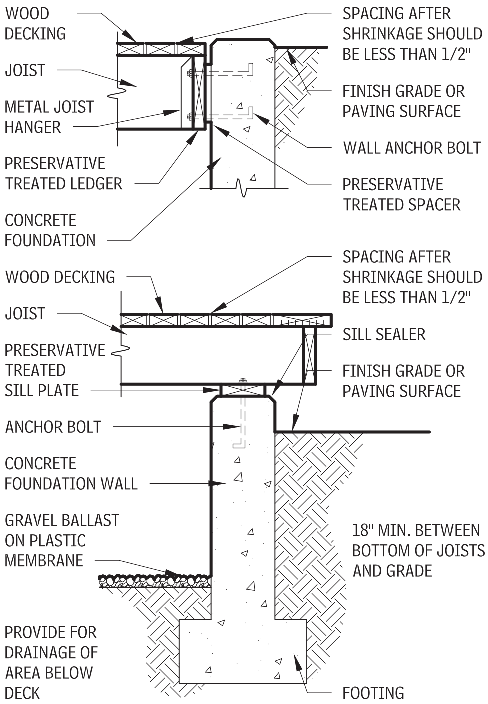


CONNECTIONS AT BUILDING

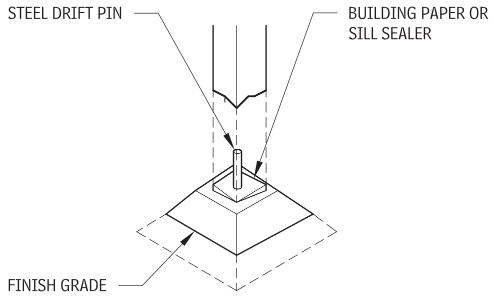
POST BASES
11.144



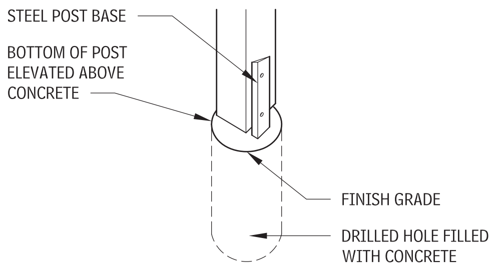
DECK EDGES
11.145



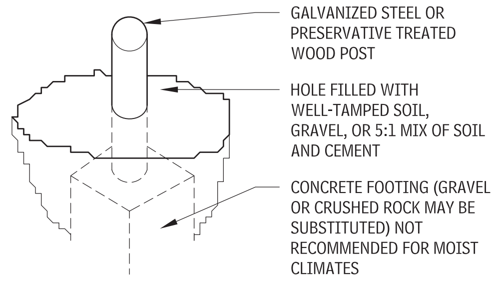
POSTS AND FOOTINGS
11.146



PRECAST CONCRETE PLINTH/PRESERVATIVE TREATED WOOD POST



POURED FOOTING/PRESERVATIVE TREATED WOOD POST



POURED OR PRECAST CONCRETE FOOTING/PRESERVATIVE TREATED WOOD POST

Contributors:
The Bumgardner Architects, Seattle, Washington; Mark J. Mazz, AIA, CEA, Inc., Hyattsville, Maryland; The Bumgardner Architects, Seattle, Washington.

FASTENERS

Guidelines for selecting fasteners include:

- Use hot-dipped galvanized fasteners to avoid corrosion and staining.
- Preservative treated wood requires stainless steel fasteners or special heavy galvanized coating recommended by the treatment manufacturer.
- To reduce board splitting by nailing, do the following: blunt nail points, predrill (3/4 of nail diameter), stagger nailing, and place nails no closer to the edge than one-half of board thickness.
- Avoid end-grain nailing and toenailing, if possible.
- Use flat washers under heads of lag screws and bolts, and under nuts.

In addition, note that hot-dipped galvanized casing nails or stainless steel deck screws are typically the best type of decking fasteners, and plated ring shank or spiral groove shank nails are suitable for arid climates.

PRESERVATIVE WOOD TREATMENT

To protect wood decking from moisture, follow these guidelines:

- Protect wood members from weather by preservative wood treatment.
- Treat wood in direct contact with soil or concrete with preservative.
- Ensure that the bottoms of posts on piers are 6 in. above grade.
- Sterilize or cover soil with membrane to keep plant growth away from wood members, to minimize moisture exchange.
- Treat ends, cuts, and holes, with preservative before placement.
- Kerf decking and flat-trim boards, 2 in. by 6 in. and wider, on the underside with 3/4-in.-deep saw cuts at 1 in. o.c., to prevent cupping.
- Avoid horizontal exposure of end grain, or provide adequate protection by flashing or sealing. Avoid or minimize joint conditions where moisture may be trapped by using spacers and/or flashing, caulking, sealant, or plastic roofing cement.

BRACING

On large decks or decks where post heights exceed 5 ft., lateral stability should be achieved with horizontal bracing (metal or wood diagonal ties on top or bottom of joists or diagonal application of decking), in combination with vertical bracing (rigid bolted or gusseted connections at tops of posts, knee bracing, or cross-bracing between posts), and/or connection to a braced building wall. Lateral stability should be assessed by a structural engineer.

COMPOSITE DECKING

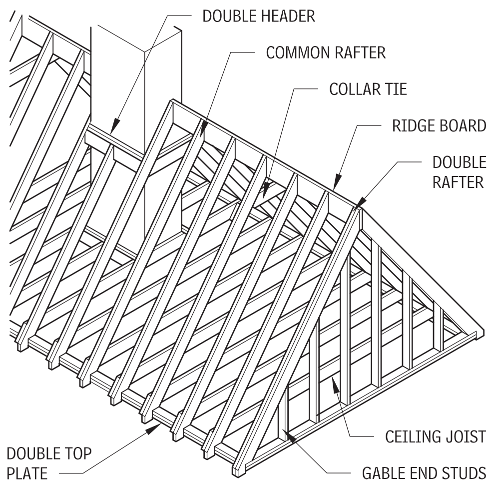
Composite decking is composed of various plastics with wood, glass, or carbon fibers, as well as other additives. Typically a portion of the plastic is recycled material. Composite decking may be solid, similar to wood, or extruded hollow shapes. Many assemblies are designed to utilize concealed fasteners.

Composite decking typically is more consistent in appearance and more durable than wood, but initially costs more, may not look natural, and may become very hot in direct sun.

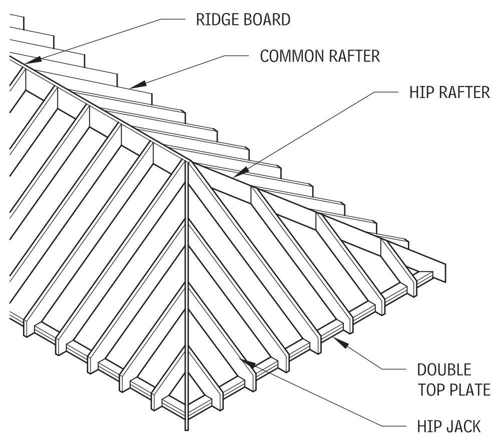
FRAMING DETAILS FOR ROOFS

These figures illustrate details of common types of roof framing.

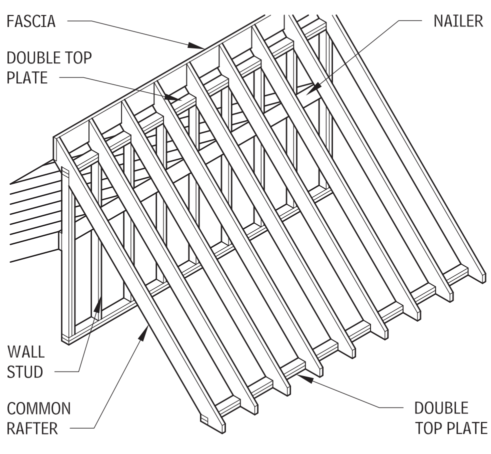
GABLE ROOF
11.147



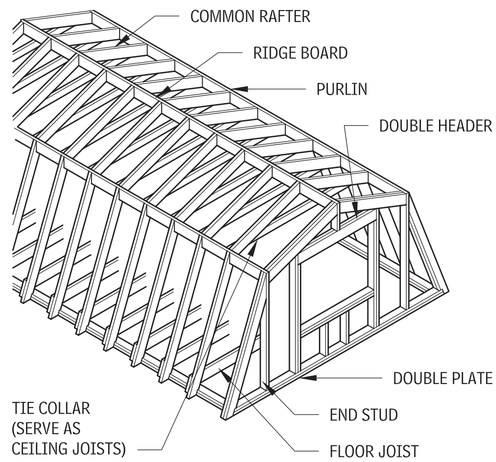
HIP ROOF
11.149



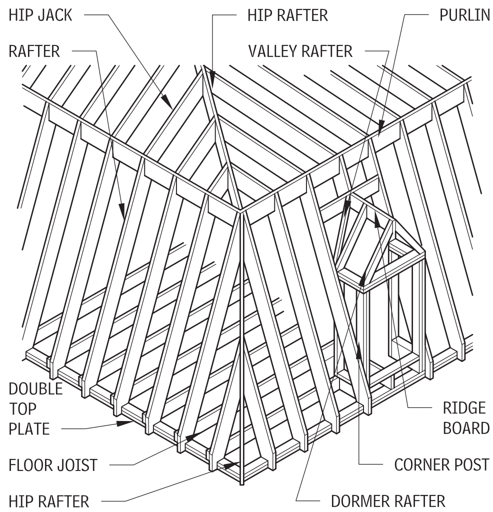
SHED ROOF
11.151



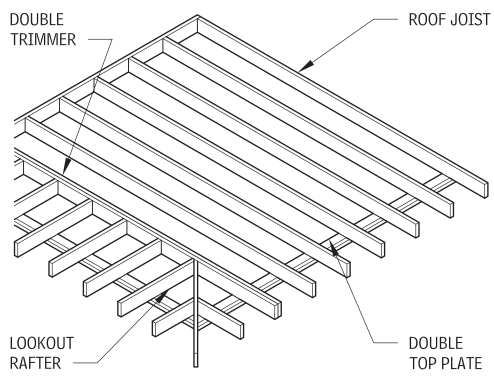
GAMBREL ROOF
11.148



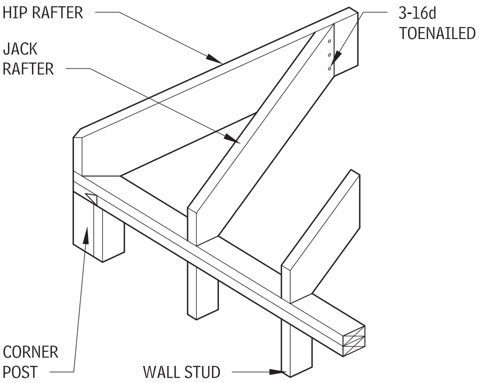
MANSARD ROOF
11.150



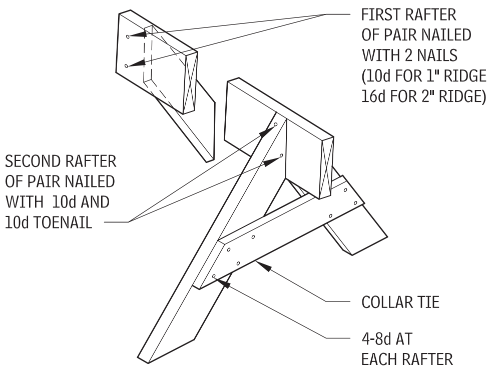
FLAT ROOF
11.152



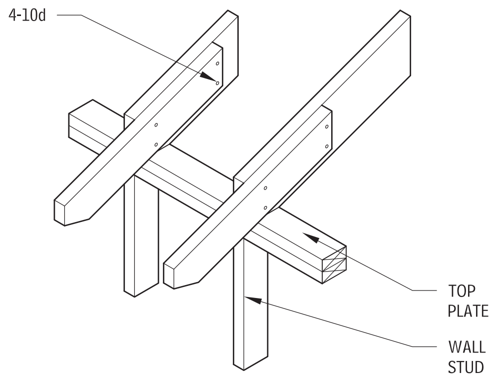
JACK RAFTERS
11.153



ROOF PEAK
11.154

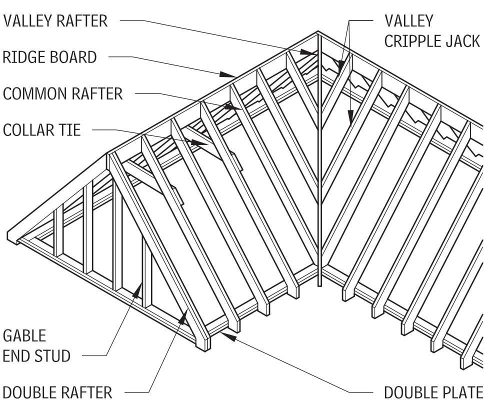


RAFTER TAILS
11.155

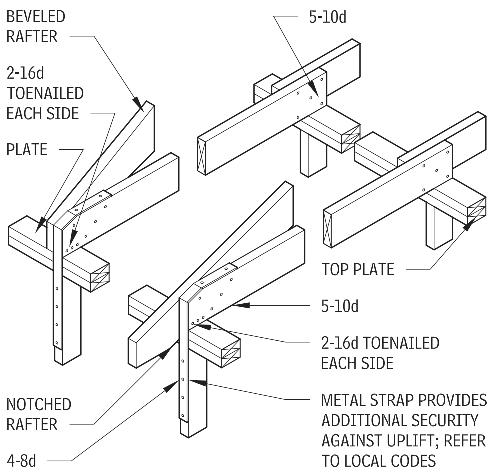


RAFTER ENDS

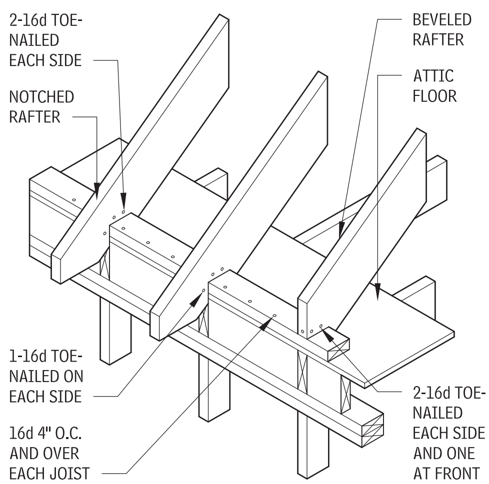
INTERSECTING ROOF
11.156



RAFTERS AND CEILING JOISTS RESTING ON WALL PLATES
11.157

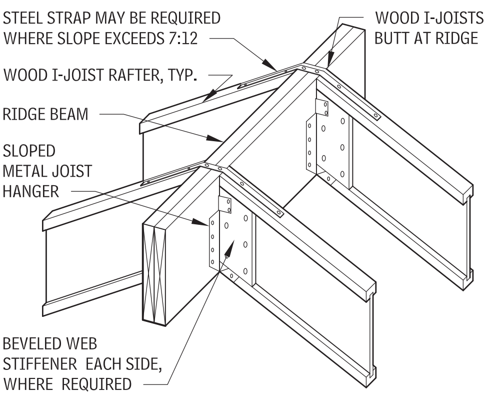


NOTCHED OR BEVELED RAFTERS RESTING ON PLATE
11.158

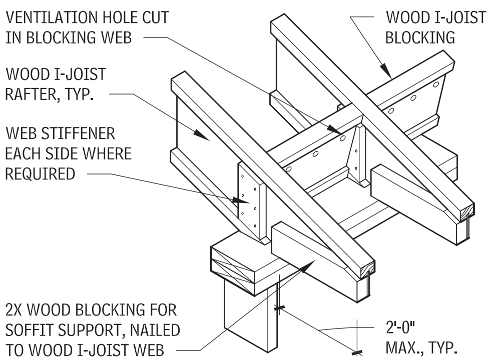


WOOD I-JOIST CONSTRUCTION DETAILS

WOOD I-JOIST RAFTER AT RIDGE BEAM DETAIL
11.159



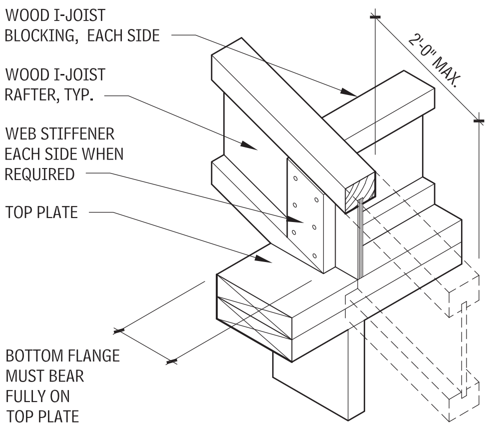
WOOD I-JOIST RAFTER AT OVERHANG
11.160



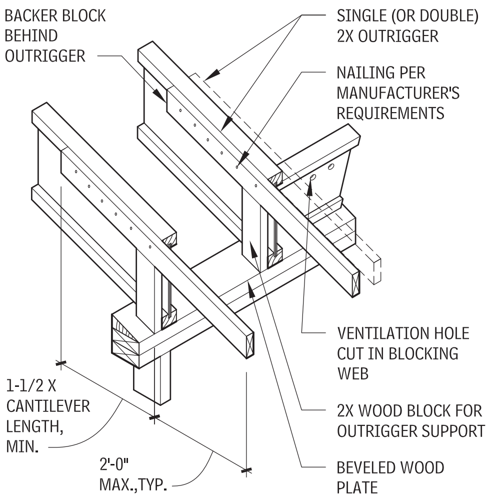
NOTES

11.159 Uplift connections may be required.
11.160 Uplift connections may be required.

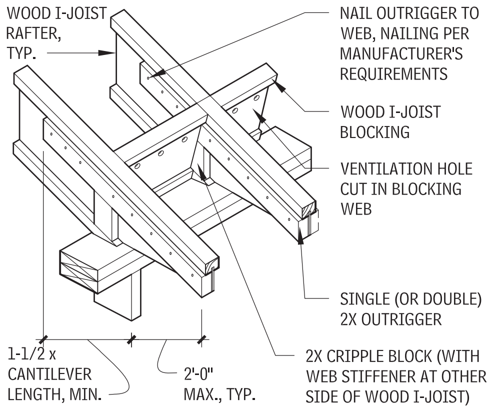
TYPICAL BIRD'S MOUTH I-JOIST CUT DETAIL
11.161



WOOD I-JOIST RAFTER WITH OUTRIGGER
11.162



WOOD I-JOIST RAFTER AT OUTRIGGER
11.163



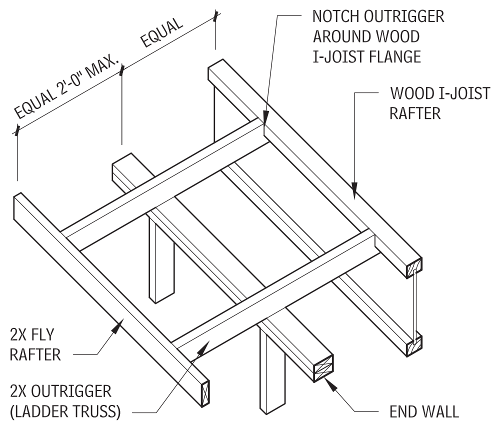
SHOP-FABRICATED WOOD TRUSSES

Shop-fabricated wood trusses have been used in building construction since 1953, when the metal connector plate was invented. Metal plates are available in a range of styles and tooth orientations. The metal plates are punched with barbs that grab onto the wood truss, thus reducing the hand-nailing required to fabricate a structure. Plate size for a given truss is based on a combination of the tooth withdrawal strength of the plate, the tensile and shear strength of the steel, and the net sectional area of the lumber.

This system is primarily used for roofs with either pitched or parallel chord trusses. It is occasionally employed for floors with parallel chord trusses. Individual trusses are cut from 2-by-4-in. or 2-by-6-in. dimension lumber and can be spaced 24 in. or 48 in. o.c. For typical residential construction, 24 in. o.c. is used. Exceptionally long spans are possible with shop-fabricated wood trusses, allowing the large, unencumbered interior spaces often required in commercial, agricultural, and other nonresidential building types.

Camber is designed for dead load only: Camber (in.) = Length (ft.)/60

FLY RAFTER DETAIL
11.164

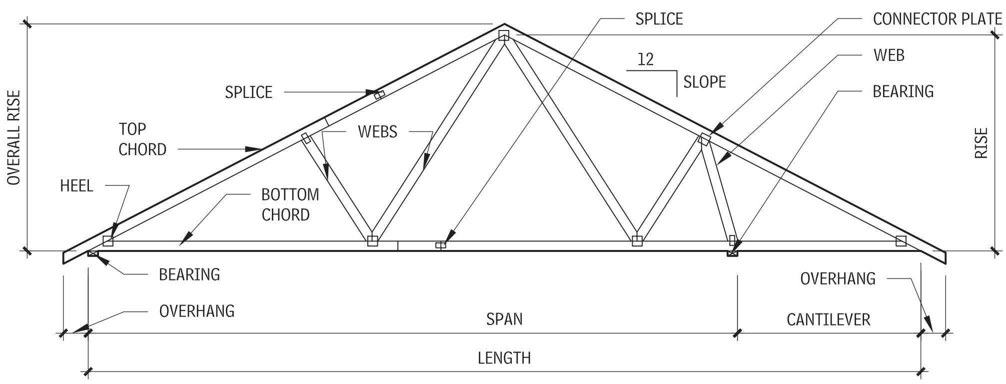


BRACING

Providing adequate bracing for trusses is essential, both during installation and as a component of the overall roof design. Truss members must be held in place with supports that meet them at right angles. Truss chords and web members are placed in a vertical, plumb position, and maintain that position, resisting applied design loads throughout the life of the structure. Permanent bracing and anchorage are expected to be an integral part of construction, and strongbacks are often used for this purpose.

Movement by crane can damage trusses. Crane spreader bars are used to avoid this "out-of-plane" buckling. Special stiffening may be applied to trusses during erection.

TYPICAL PITCHED CHORD ROOF TRUSS
11.165

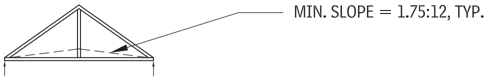


NOTES

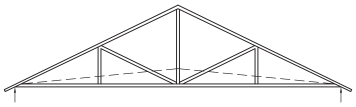
11.161 Uplift connections may be required.
11.162 Uplift connections may be required.

Contributor:
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland.

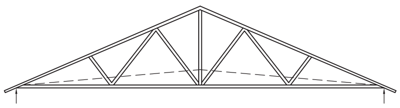
PITCHED CHORD TRUSSES
11.166



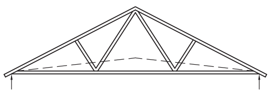
KING POST (TYP. MAX. SPAN = 37' APPROX.)



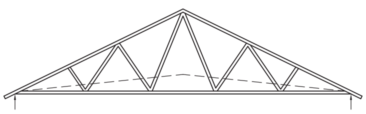
HOWE (TYP. MAX. SPAN = 37' APPROX.)



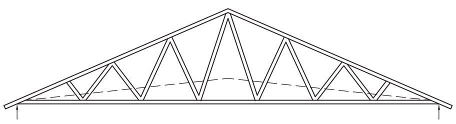
MODIFIED QUEEN POST (TYP. MAX. SPAN = 47' APPROX.)



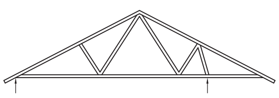
FINK (TYP. MAX. SPAN = 27' APPROX.)



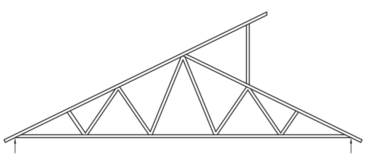
DOUBLE FINK (TYP. MAX. SPAN = 37' APPROX.)



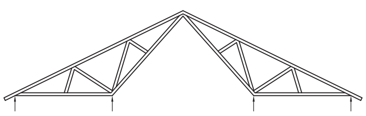
DOUBLE FINK (TYP. MAX. SPAN = 37' APPROX.)



CANTILEVER (TYP. MAX. SPAN = 20' APPROX.)

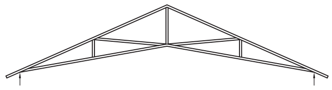


CLERESTORY (TYP. MAX. SPAN = 37' APPROX.)

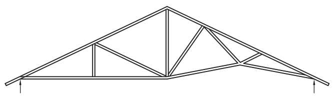


INVERTED (TYP. MAX. SPAN = 37' APPROX.)

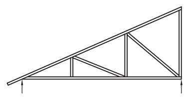
PITCHED TRUSSES
11.167



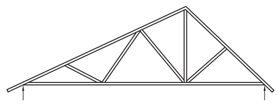
SCISSORS (TYP. MAX. SPAN = 45'-0" APPROX.)



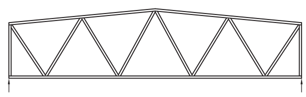
VAULTED CEILING (TYP. MAX. SPAN = 42'-0" APPROX.)



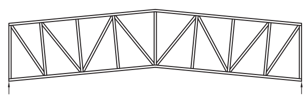
MONO-PITCH (TYP. MAX. SPAN = 23'-0" APPROX.)



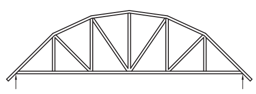
DUAL PITCH (TYP. MAX. SPAN = 32'-0" APPROX.)



PITCHED WARREN (TYP. MAX. SPAN = 42'-0" APPROX.)

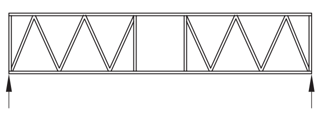


SCISSORED WARREN (TYP. MAX. SPAN = 42'-0" APPROX.)

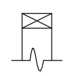


BOWSTRING (TYP. MAX. SPAN = 30'-0" APPROX.)

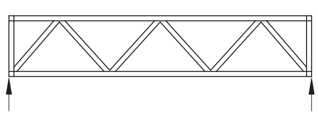
PARALLEL TRUSSES
11.168



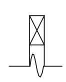
4 x 2 TRUSS (FLOOR)



CHORD/WEB ORIENTATION

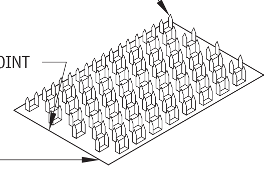


2 x 4 TRUSS (ROOF)

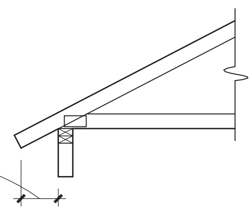


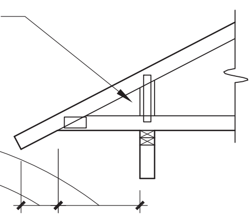
CHORD/WEB ORIENTATION

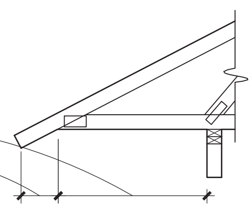
TYPICAL METAL PLATE CONNECTOR
11.169

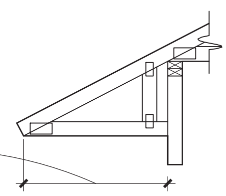


OVERHANG DETAILS
11.170





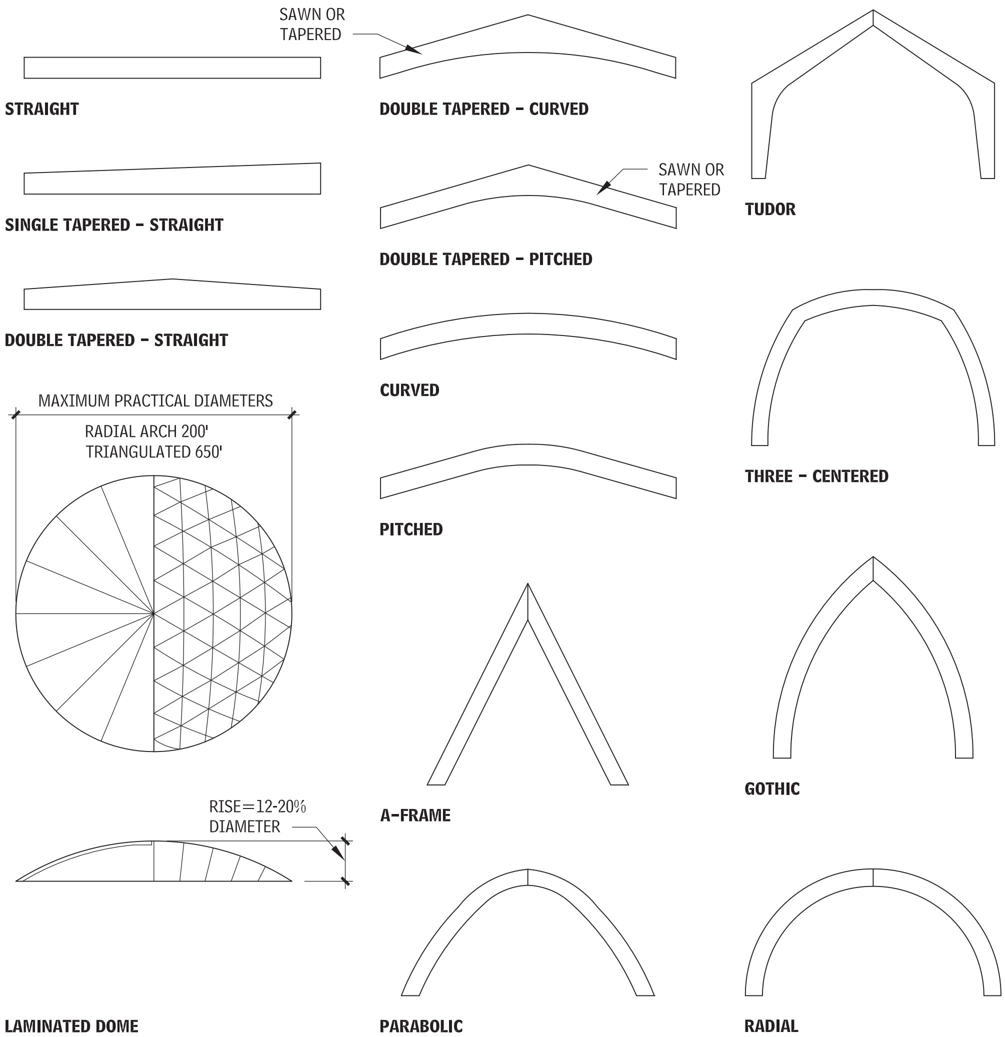




NOTES

11.166 a. The average spacing for light trusses (trussed rafters) is 2 ft. o.c.; but it varies, up to 4 ft. The average combined dead and live loads is 45 lb./sq. ft. Spans are usually between 20 and 32 ft., but can be as much as 50 ft.
b. Early in the design process, consult an engineer or truss supplier for preengineered truss designs to establish the most economical and efficient truss proportions. The supplier may provide final truss engineering design.
c. Permanent and temporary erection bracing must be installed as specified to prevent failure of properly designed trusses.
d. Some locales require an engineer's stamp when prefab trusses are used. Check local codes.
e. Member forces in a truss rise rapidly as the lower chord is raised above the horizontal.

STRUCTURAL GLUED-LAMINATED SHAPES
11.171

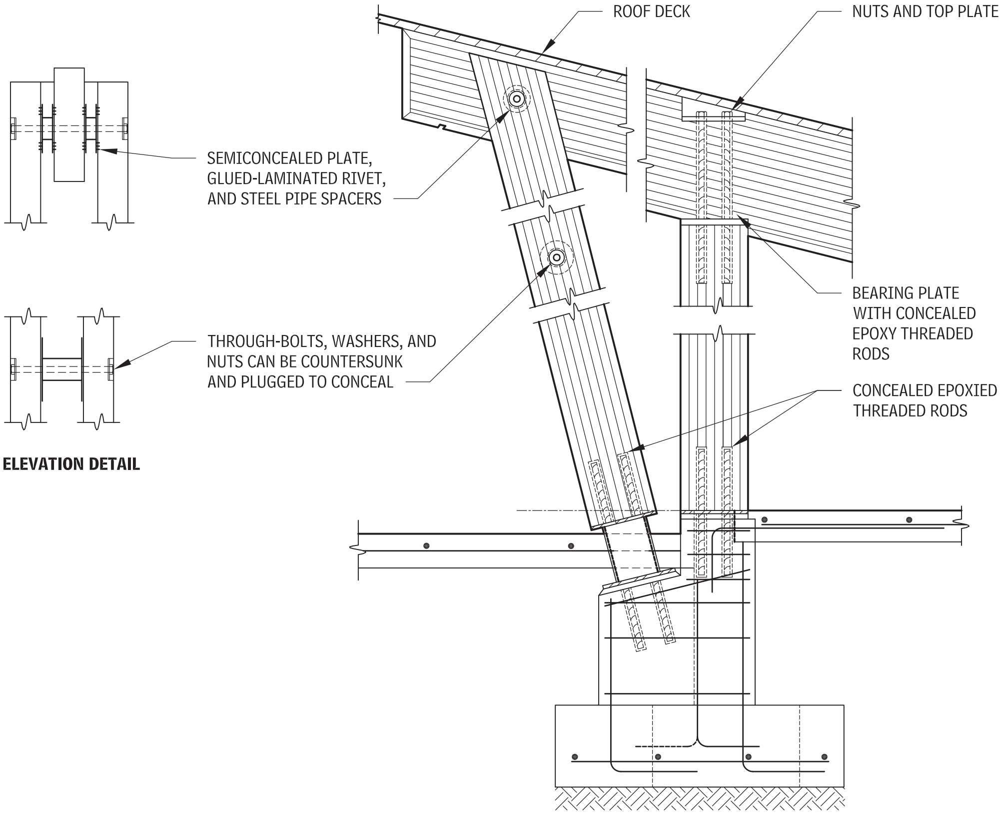


GLUED-LAMINATED SHAPES

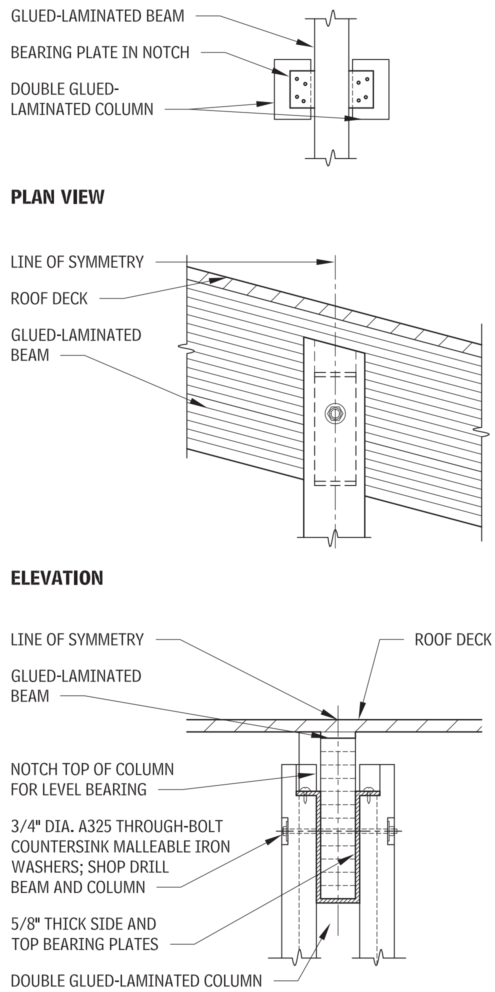
When examining the shapes of structural glued-laminated members, note the following:

- Beam names describe top and bottom surfaces of the beam. Sloped or pitched surfaces should be used on the tension side of the beam.
- The three-hinged arches and frames shown in Figure 11.171 produce horizontal reactions requiring horizontal ties or modified foundations.
- The triangulated and the radial arch are the two basic types of structural glued-laminated wood dome systems available. Both require a tension ring at the dome spring line to convert axial thrusts to vertical loads. Consideration must be given to the perimeter bond beam design, as wind forces will produce loads in this member. The lengths of the main members of the radial arch system, which must span a distance greater than half the dome diameter, limit the maximum practical dome diameter. The much smaller members of the triangulated dome result in the greater diameters. The triangulated system can be designed for five or more segments, with an equal number of peripheral supports at each segment.
- More complicated shapes may be fabricated. Contact the American Institute of Timber Construction (AITC) and the American Plywood Association (APA).

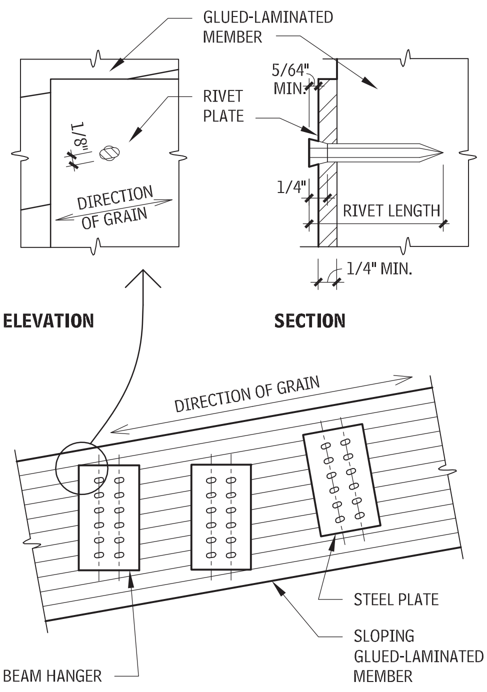
GLUED-LAMINATED COLUMN WITH ROOF BEAM
11.172



GLUED-LAMINATED BEAM/CONCEALED DOUBLE COLUMN
11.173

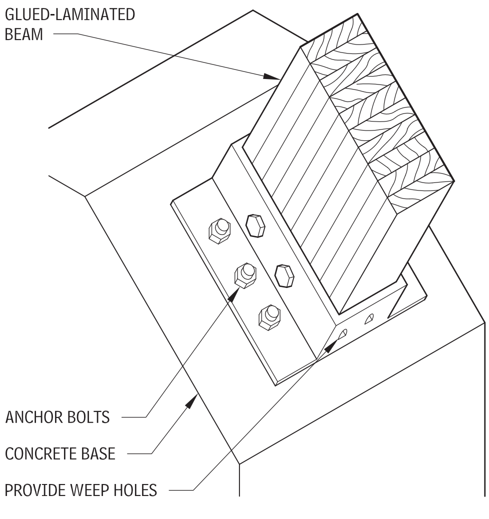


GLUED-LAMINATED RIVET CONNECTION AND INSTALLATION DETAILS
11.174

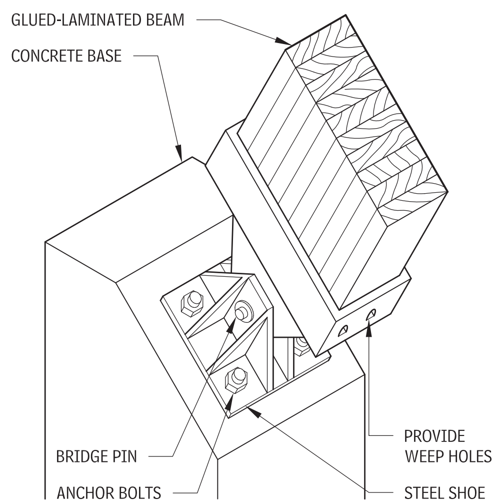


GLUED-LAMINATED CONSTRUCTION: CONNECTIONS

FIXED-ARCH ANCHORAGE
11.175



TRUE HINGE ANCHORAGE FOR ARCHES
11.176

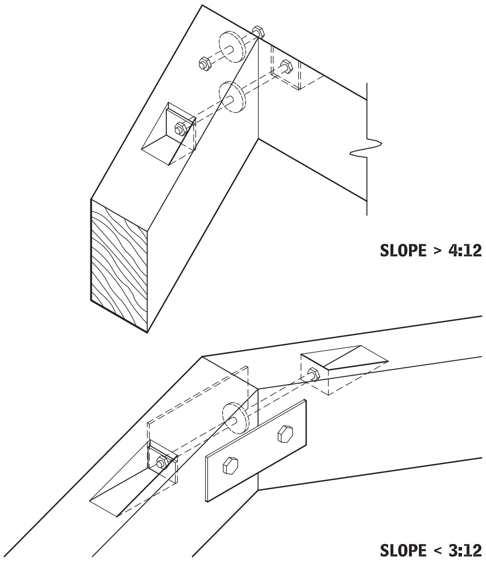


NOTES

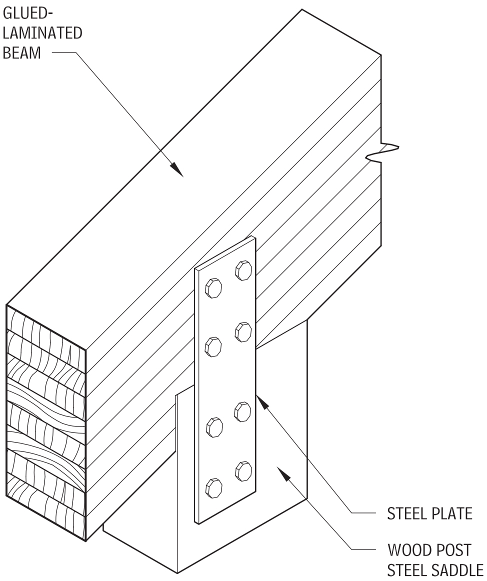
11.174 a. Rivets must be installed with their long axis parallel to the grain of the wood.
b. Rivets must be driven so that the conical head is firmly seated in the hole, but not flush.
c. Side plates must be at least 1/4-in. thick and must be hot-dipped-galvanized for use in wet service conditions.
d. Steel plates must be drilled (not punched) with 17/64- to 9/32-in. holes to accommodate the rivets.

Contributor:
David Nairne-Associates Ltds., North Vancouver, British Columbia.

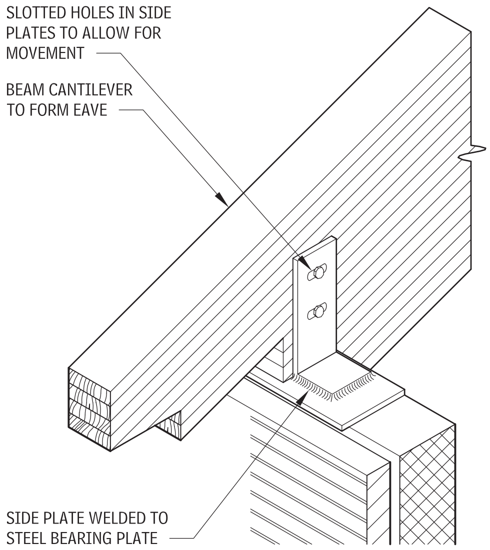
ARCH PEAK CONNECTION
11.177



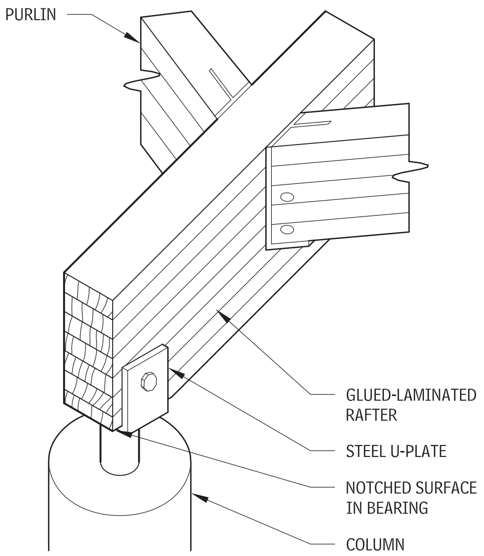
RAFTER TO COLUMN CONDITION
11.178



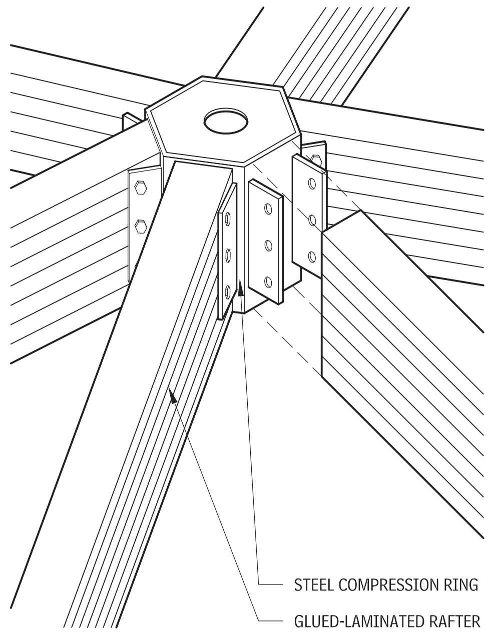
RAFTER TO BEARING WALL
11.179



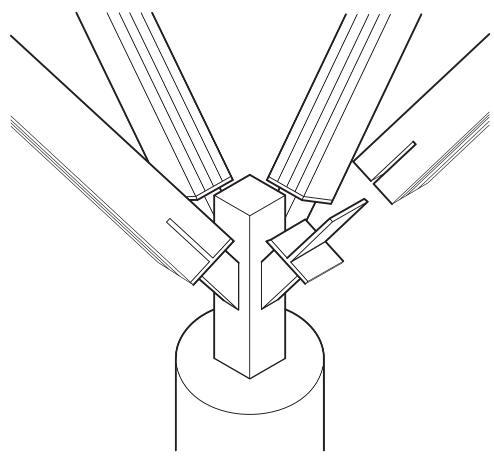
NOTCHED BEARING CONDITION
11.180



STEEL COMPRESSION BOX
11.181



SPECIAL CONNECTION
11.182

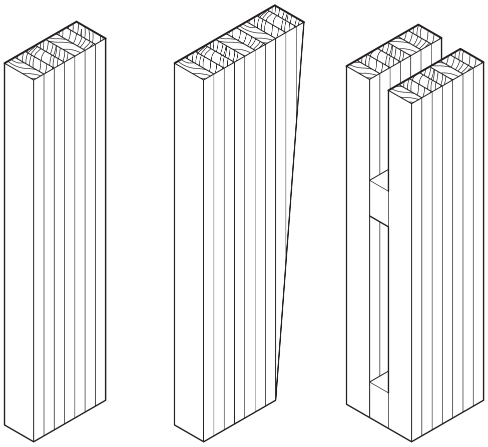


NOTES

11.180 a. An abrupt notch in the end of a wood member reduces the effective shear strength of the member and may permit a more rapid migration of moisture in the lower portion of the member, potentially causing splitting.
b. The shear strength of the end of the member is reduced, and the exposed end grain may also result in splitting because of drying. At inclined beams, the taper cut should be loaded in bearing.

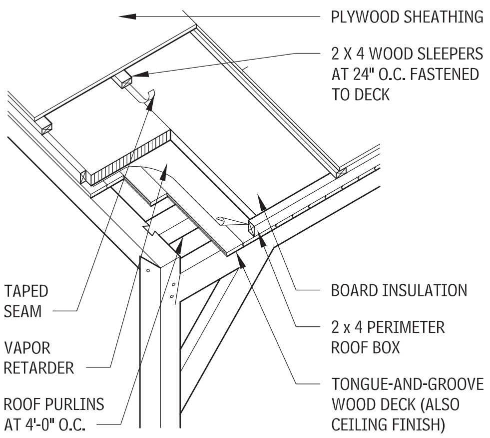
11.182 One of a large variety of special connections and connection assemblies that are possible using structural glued-laminated timber. It is critical that connections be designed carefully in accordance with good engineering practice.

GLUED-LAMINATED COLUMNS
11.183

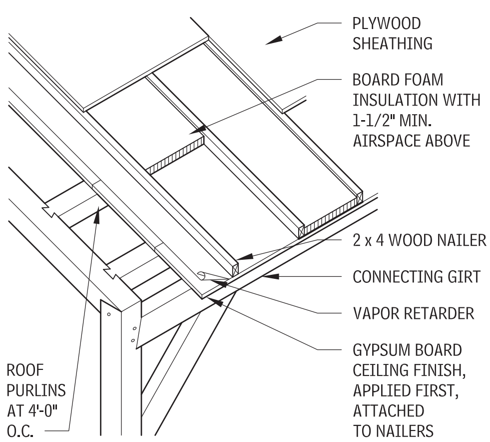


TIMBER FRAME ROOF DECKING

WOOD SLEEPERS AND TONGUE-AND-GROOVE CEILING ON ROOF PURLINS
11.184



WOOD NAILERS ON ROOF PURLINS
11.185



WOOD STAIRS

Wood stairs used in private, residential applications usually are not governed by the ADA; however, wood stairs in commercial facilities and places of public accommodation must conform to the accessibility guidelines adopted in the local jurisdiction.

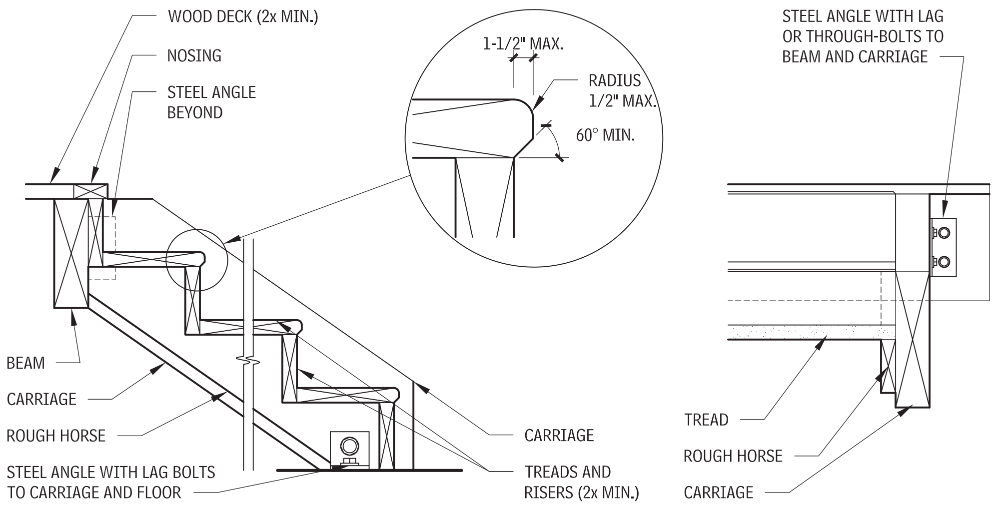
The following are general recommendations; verify specific requirements that may vary from

- A minimum interior stair width of 36 in. should be provided.
- Minimum headroom is 6 ft-8 in. as measured vertically from a diagonal line connecting tread nosings to the underside of the finished ceiling or stair landing directly above the stair run.
- Recommended headroom is 7 ft.

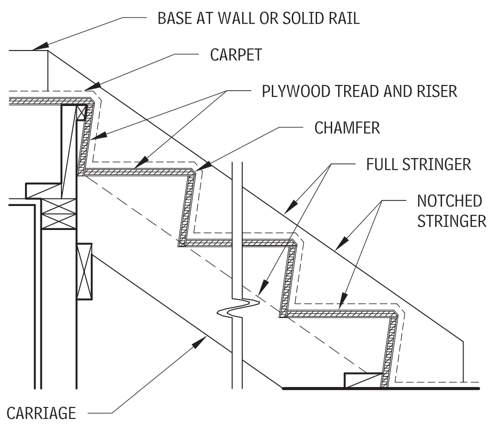
Only handrails and stair stringers may project into the required width of a stair. Use the following guidelines:

- The maximum handrail projection is 3–1/2 in.
- The maximum stringer projection is 1–1/2 in.
- The width of a landing or platform should be at least as wide as the stair.
- The maximum vertical rise of a stair between landings is 12.
- Riser height should be between 4 in. minimum and 7 in. maximum.
- Tread depth should be 11 in. minimum, measured from riser to riser or nosing to nosing.
- Variation in adjacent treads or risers should not exceed 3/16 in. The maximum variation allowed in the tread depth or riser height within a flight of stairs is 3/8 in.
- Nosings project 1–1/2 in. maximum.

DIMENSION LUMBER STAIR
11.186

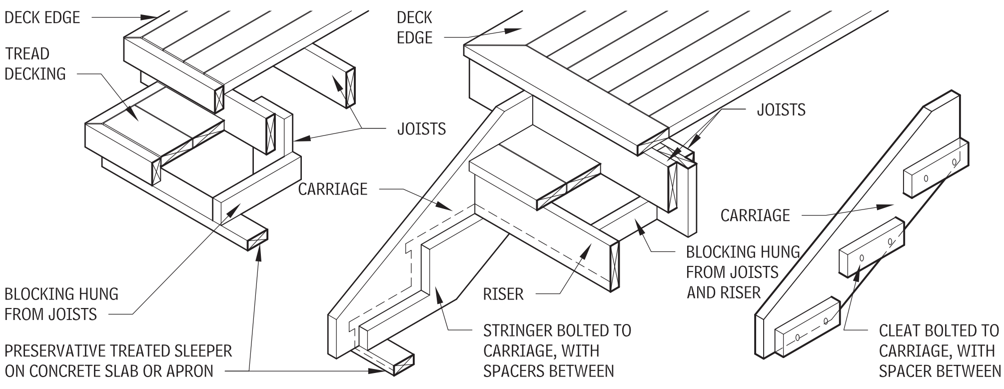


CLOSED RISER WOOD STAIR WITH CARPET FINISH
11.187



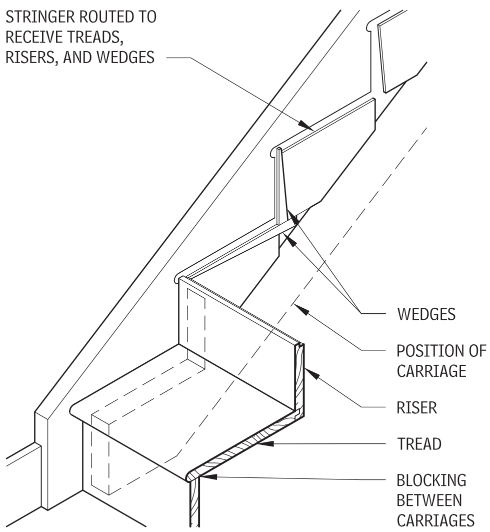
Contributors:
Roger W. Kipp, AIA, Thomas Hodne Architects, Inc., Minneapolis, Minnesota; American Plywood Association, Tacoma, Washington.

STEPS AND STAIRS
11.188

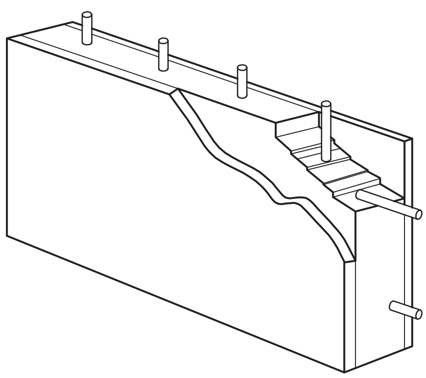


STEP PLATFORM **STAIR CARRIAGE WITH STRINGER** **CARRIAGE WITH CLEATS**

TREADS AND RISERS AT HOUSED STRINGER
11.189



INSULATING CONCRETE FORMING
11.190



FLAT WALL CORE WITH FORM IN PLACE

COMPOSITE SYSTEMS

INSULATING CONCRETE FORMING

Insulating concrete forms (ICFs) are basically forms for poured concrete walls that stay in place as a permanent part of the wall assembly.

The forms, made of foam insulation, are either formed interlocking blocks or separate panels connected with plastic ties. The left-in-place forms not only provide a continuous insulation and sound barrier, but also a backing for gypsum board on the inside and stucco cement plaster, lap siding, or brick on the outside.

Although all ICFs are identical in principle, the various brands differ widely in the details of their shapes, cavities, and component parts.

Block assemblies have the smallest individual units, ranging from 8 in. × 1 ft-4 in. (height × length) to 1 ft-4 in. × 41 in. A typical ICF block is 10 in. in overall width, with a 6-in. cavity for the concrete. The units are factory-molded with special interlocking edges that allow them to fit together much like plastic children's blocks.

Panel systems have the largest units, ranging from roughly 1ft × 8 ft. to 4 ft. × 12 ft. Their foam edges are flat, and interconnection requires attachment of a separate connector or "tie." Panels are assembled into units before setting in place—either on-site or prior to delivery.

Plank systems are similar to panel systems, but generally use smaller faces of foam, ranging in height from 8 in. to 12 in. and in width from 4 ft. to 8 ft. The major difference between planks and panels is assembly. The foam planks are outfitted with ties as part of the setting sequence, rather than being assembled into units.

Within these broad categories of ICF, individual brands vary in their cavity design. "Flat wall" systems yield a continuous thickness of concrete, like a conventional poured wall. "Grid wall" systems have a waffle pattern where the concrete is thicker at some points than others. Post-and-beam systems have widely spaced horizontal and vertical columns of concrete that are completely encapsulated in the foam form. Whatever the differences among ICF brands, all major ICF systems are engineer designed, code accepted, and field proven.

STRUCTURAL PANELS

Structural building panels are factory-assembled composite panels ready for installation as a complete structural and/or insulating wall section. The material of each component of the panel system is very important when selecting a panel manufacturer. Components include the skin, foam core, adhesive, and optional exterior or interior finish. The application for which the panel is intended determines the materials used. Consult manufacturers for specifications.

Sizes vary from 4-by-8-ft panels weighing about 100 lb., to 8-by-28-ft panels that must be installed using a crane.

PANEL TYPES

There are two main types of structural building panels:

- *Stressed skin panels:* These are manufactured by gluing and nailing plywood skins to both sides of a wood frame, resulting in a unit that performs like an I-beam. Stressed skin panels are not necessarily insulated.
- *Structural foam core panels:* These fall into two groups: sandwich panels and unfaced panels. Sandwich panels are rigid-foam panels faced with two structural-grade skins, usually made of oriented-strand board (OSB) or plywood. Depending on the application and the manufacturer, these foam core panels may or may not include framing members within the core. Unfaced structural foam core panels look like panels of stick-framing with thermal insulation between the members, instead of blanket insulation. Interior and exterior finishes are applied to these panels in the field.

The skins of structural building panels (such as I-beam flanges) resist tension and compression, while the wood frame or core (such as an I-beam web) resists shear and prevents buckling of the skins.

All structural foam core panels are insulated with a core of expanded polystyrene (EPS), extruded polystyrene, or urethane foam, from 3–1/2 to 11–1/4 in. thick. Urethane panels are either glued-laminated like polystyrene or foamed in place, either in the factory or in the field. Urethane has an R-value of 6 or 7 per inch, versus R-5 for extruded polystyrene and R-4 for EPS foam. Urethane is about twice as strong in compression as polystyrene, and has a perm rating of less than 1, which technically qualifies it as a vapor retarder. EPS has a perm rating of from 1 to 3 and may require an additional vapor retarder. EPS, however, is inert, nontoxic (if ingested), and resilient; it doesn't feed microorganisms and is generally cheaper than urethane.

Consult manufacturers on CFC and formaldehyde content in the foam core and skin material because it varies among manufacturers. Regarding flammability of both foam core types, consult with the manufacturer about the individual product.

CHARACTERISTICS

Using structural panels generally speeds construction because the panels replace three standard steps: framing, sheathing, and insulation. Panel assemblies offer superior energy performance compared to a conventional framing. This is largely because the thermal insulation has higher R-values, there are fewer seams to seal, and conductive heat is not lost through air infiltration around the framing. Structural building panels also offer good resistance to lateral loads.

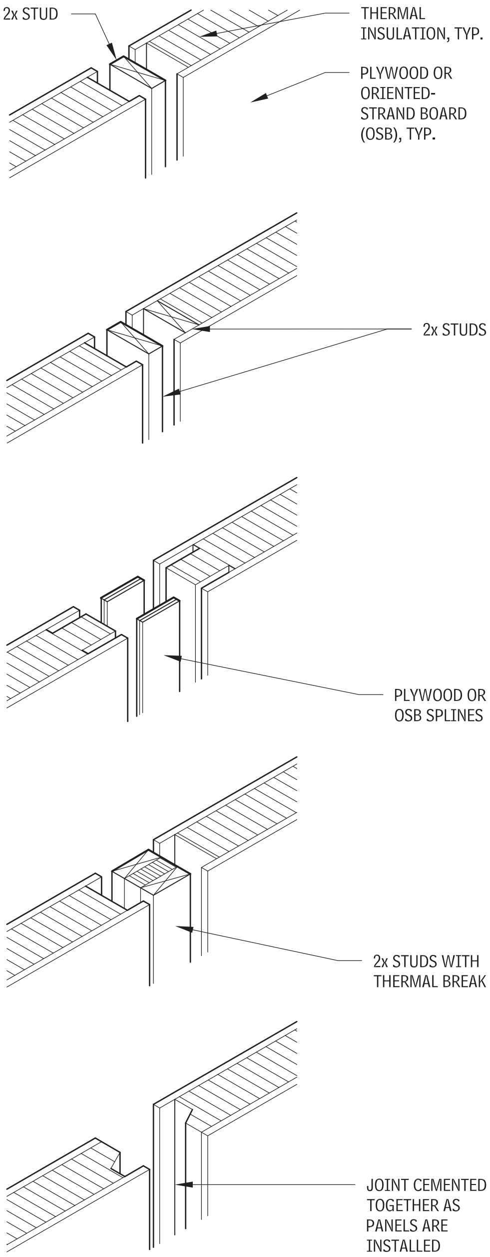
These panels can, however, be susceptible to infestation by insects such as carpenter ants and termites, which eat through wood and tunnel through the insulation material, reducing insulation value and even compromising structural integrity. Use of termite shields, foam cores treated with insect repellant, and other strategies should be considered.

Structural building panels are components of a relatively new building system, therefore it is important to consult code officials early to prevent any misunderstandings or delays in the code approval process. Also, check with manufacturers to determine whether their products have received compliance approval from authorities having jurisdiction.

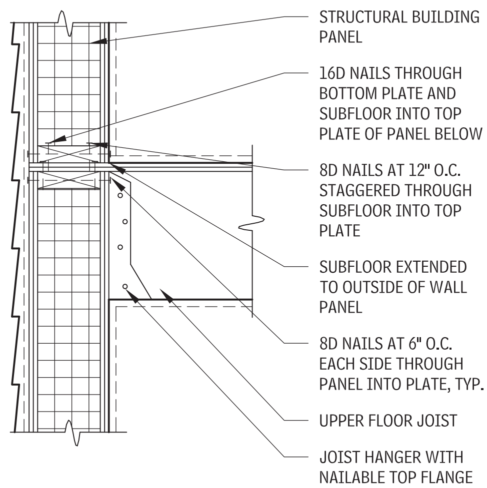
The seams between the panels are the part of the assembly most prone to infiltration and weakness, hence most likely to show the results of expansion and contraction. Tight spline connections with sealant at all edges (top, bottom, and sides) can greatly increase thermal efficiency.

In very cold climates, the seams of the panels should be taped and sealed against air infiltration and to prevent condensation and rotting inside joints.

TYPICAL INTERMEDIATE PANEL SPLINE DETAILS
11.191



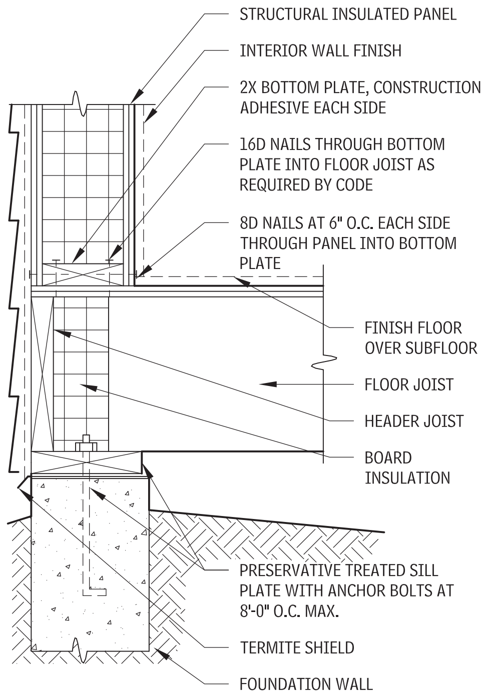
CONNECTION WITH FLOOR JOIST ADJACENT TO PANEL
11.192



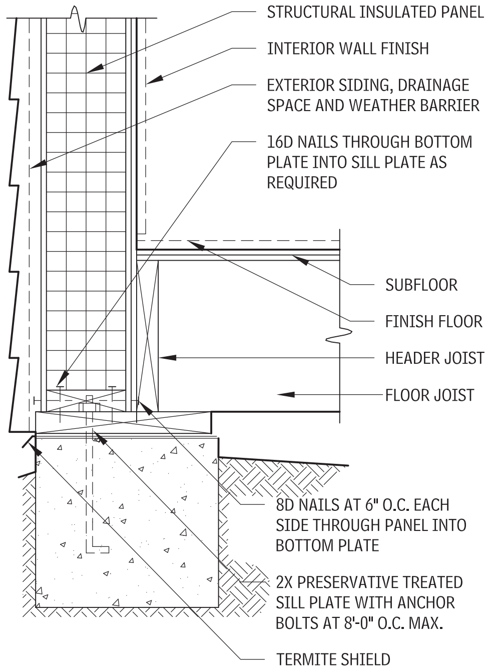
NOTE

11.191 Studs and splines are screwed, and usually glued, to panels from both sides. Consult manufacturer's literature. Joints are typically sealed with expanding foam.

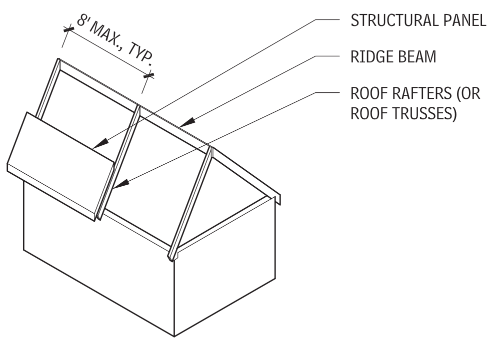
PANEL AT SILL, WITH FLOOR JOIST BELOW CONNECTION
11.193



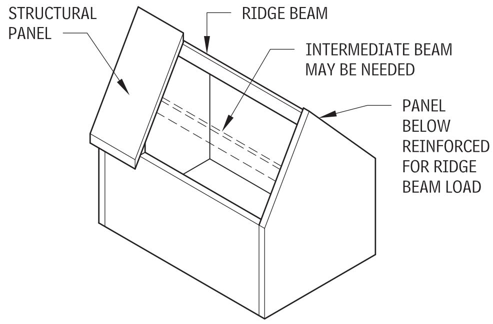
PANEL AT SILL CONNECTION, WITH FLOOR JOIST ADJACENT
11.194



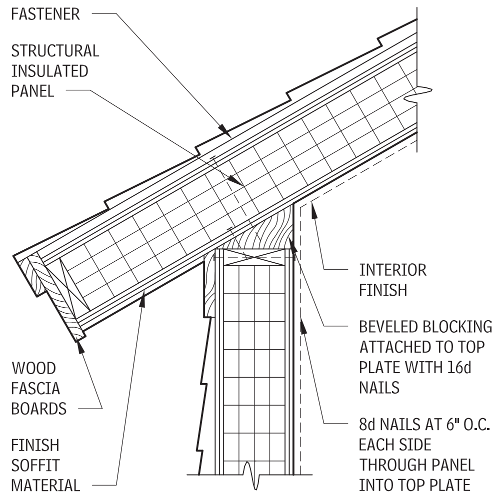
ROOF FRAMING WITH RAFTERS AND TRUSSES
11.195



ROOF FRAMING WITH RIDGE BEAM
11.196



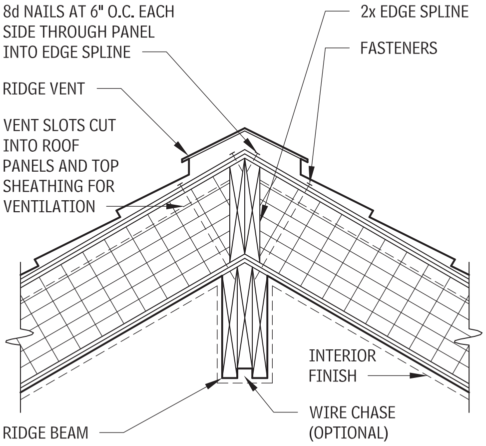
ROOF EAVE DETAIL WITH SLOPED CEILING
11.197



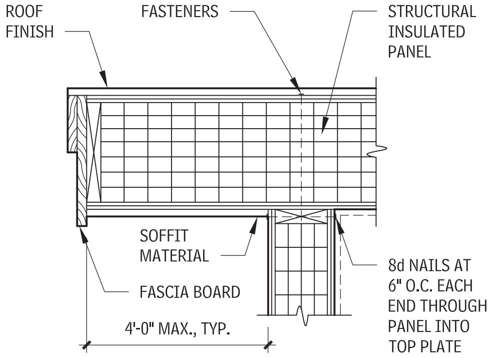
NOTE

11.194 Assembly where the panel adjacent to joist is more energy-efficient.

PANEL AT RIDGE CONNECTION
11.198



GABLE END OVERHANG AT ROOF PANEL DETAIL
11.199



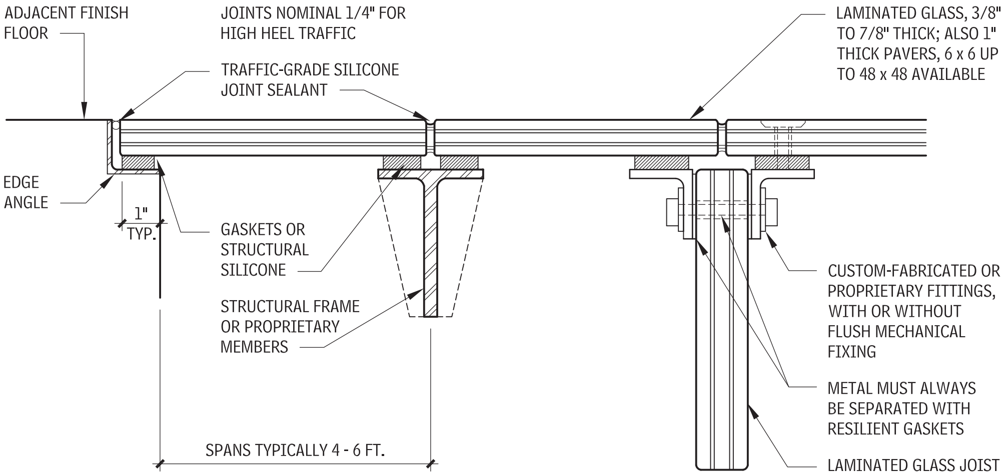
GLASS FLOORING

Glass floor panels are made from laminated glass, usually heat-treated for additional strength. Laminating glass ensures that the panel will retain its structural integrity if the glass breaks. Heat-strengthened glass is preferable to fully tempered glass, because when fully tempered units crack, they lose a higher percentage of the structural capacity.

Other features of glass flooring include:

- Five-layer laminations are common.
- Glass is generally translucent, rather than fully transparent for modesty, and because of the slip-resistant surface treatment.
- The glass panels are typically laid on gaskets over steel or aluminum frames, with traffic-grade silicone joint sealant. Panels can be supported on point support systems similar to those used for curtain walls.
- Laminated glass can also be used as a beam or joist to support glass floor panels. Joists are supported with gasketed shoes or clip angles.
- The walking surface is made slip-resistant by sandblasting, cast texture, fired-on frit, or applied coatings.

GLASS FLOORING
11.200



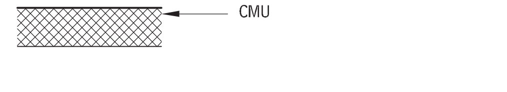
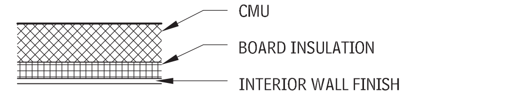
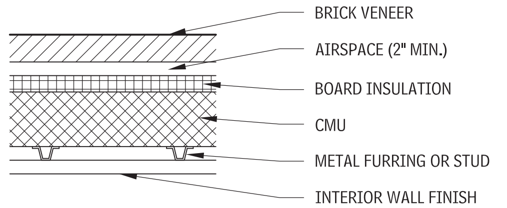
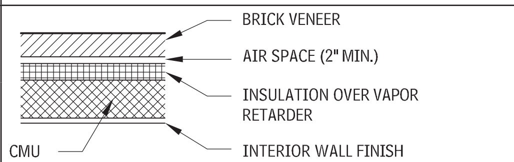
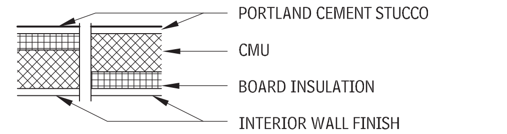
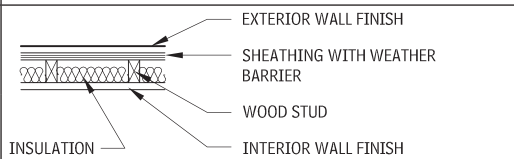
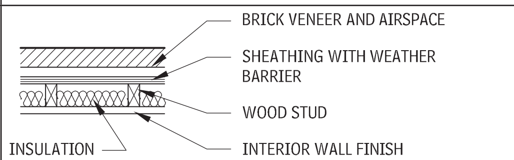
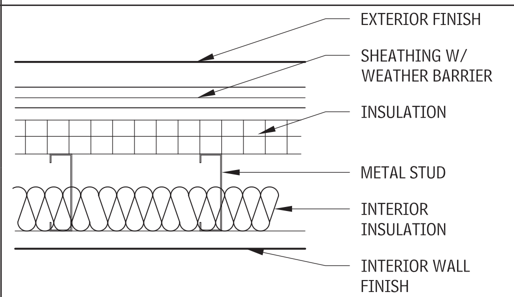
EXTERIOR VERTICAL ENCLOSURES

EXTERIOR WALLS

This section discusses exteriors wall and their construction. For additional information about the material presented in the tables and graphics in this section, consult literature from individual manufacturers and trade associations.

DESIGN CONSIDERATIONS

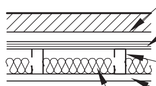
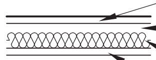
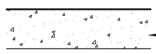
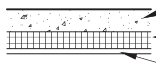
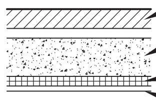
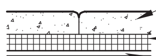
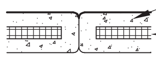
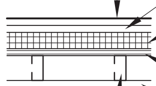
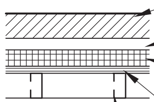
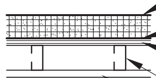
EXTERIOR WALL ASSEMBLIES
11.201

EXTERIOR WALL ASSEMBLY		WALL THICKNESS, NOMINAL (IN.)	WEIGHT (PSF)	VERTICAL SPAN RANGE (UNSUPPORTED HEIGHT) (FT)	RACKING RESISTANCE	SERVICE PLENUM SPACE	HEAT TRANSMISSION COEFFICIENT (U-FACTOR) (BTU/HR-SQ FT °F)
CMU		8	55	Up to 13	Good	None	0.56
		12	85	Up to 20			0.49
CMU (insulated)		8 +	60	Up to 13	Good	Through insulation	0.21
		12 +	90	Up to 20			0.20
CMU and brick veneer (interior insulation)		4 + 2 + 4 +	75	Up to 13 (with filled cavity)	Good	Through insulation	0.19
		4 + 2 + 8 +	100	Up to 20 (with filled cavity)			0.18
CMU and brick veneer (cavity insulation)		4 + 4 + 4	75	Up to 9	Fair	None	0.07
		4 + 4 + 8	100	Up to 13			0.11
CMU and portland cement stucco (insulated)		8 +	67	Up to 13	Good	Through interior insulation	0.16
Wood stud		4	12	Up to 14	Poor to fair	Between studs	0.06
		6	16	Up to 20 (L/d < 50)			0.04
Brick veneer on wood stud		4 + 4	52	Up to 14	Poor to fair	Between studs	0.07
Metal stud		5	14	Up to 13	Poor	Between studs	0.10
		7	18	Up to 17			0.08

EXTERIOR WALL ASSEMBLIES (continued)
11.201

WALL ASSEMBLY TYPE	WEATHER BARRIER LOCATION AND TYPE			RECOMMENDED CLIMATE AND PRECIPITATION ZONES (SEE FIGURES 11.1 AND 11.2)	PERFORMANCE COMMENTS (HAM = HEAT, AIR, AND MOISTURE)	RESISTANCE TO EXTERIOR AIRBORNE SOUND TRANSMISSION	EXTERIOR MAINTENANCE REQUIREMENTS	REMARKS
	EXTERIOR SIDE	NONE	INTERIOR SIDE					
Mass barrier wall	Coating			Hot; low-precipitation climate only	Very poor control of HAM.	Good	Washing, repointing joints, painting, sandblasting	Properties of nonengineered masonry are drastically reduced
		None		Mild; low-precipitation climate only				
			Coating	Cold; low-precipitation climate only				
Mass barrier wall	Coating or insulation facing			Mixed or hot; low precipitation	Very poor control of air and moisture. Average control of heat	Good	Washing, repointing joints, painting, sandblasting	Interior insulation is discontinuous
		None		Mixed; low precipitation				
			Sheet or insulation facing	Cold; low precipitation				
Drainage cavity	Coating or insulation or insulation facing			Mixed or hot; low to moderate precipitation	Poor control of air, water and transmission; adding weather barrier on cavity face of CMU improves performance to high precipitation.	Excellent	Washing, repointing joints, sand blasting	Interior insulation is discontinuous
		None		Mixed or hot; low to moderate precipitation				
			Coating or insulation facing	Cold; low to moderate precipitation				
Drainage cavity	As noted			All climates; extreme precipitation	Excellent control of heat, air, and moisture.	Excellent	Washing, repointing joints, sand blasting	Cavity allows installation of continuous insulation and weather barrier.
Mass barrier	Vapor retarder insulation			Mixed or hot; low precipitation	Average control of HAM. Adding weather barrier under stucco increases control of driving rain.	Good	Washing, painting, and re-stuccoing	Assembly with insulation on exterior and added WRB provides better control of HAM
		None		Mixed or hot; low precipitation				
			Sheet or insulation facing	Cold; low precipitation				
Internal drainage plane	MRB or vapor retarder insulation for sheathing			Hot; low to moderate precipitation	Average control of HAM. Upgrading water-resistant barrier to weather barrier increases control of driving rain.	Poor to fair	Washing, painting, and replacing exterior finish	Exterior wall finishes: wood, plywood, aluminum siding, stucco
		None		Mixed; low to moderate precipitation				
			Sheet or insulation facing	Cold; low to moderate precipitation				
Drainage cavity	MRB or vapor retarder insulation for sheathing			Hot; moderate precipitation	Average control of HAM. Upgrading water-resistant barrier to weather barrier to increase control of driving rain.	Good	Washing, repointing joints,	Note that brick veneer holds moisture that can be forced into insulation, allow for drying.
				Mixed; moderate precipitation				
			Sheet or insulation facing	Cold; moderate precipitation				
Internal drainage plane	MRB or vapor retarder insulation for sheathing			Hot; low to moderate precipitation	Average control of air and moisture. Add insulation over sheathing to increase thermal performance. Upgrading water-resistant barrier to weather barrier to increase control of rain.	Poor to fair	Washing, painting, and replacing exterior finish	Exterior wall finishes: wood, plywood, aluminum siding, stucco
		None		Mixed; low to moderate precipitation				
			Sheet or insulation facing	Cold; low to moderate precipitation				

EXTERIOR WALL ASSEMBLIES (continued)
11.201

EXTERIOR WALL ASSEMBLY		WALL THICKNESS, NOMINAL (IN.)	WEIGHT (PSF)	VERTICAL SPAN RANGE (UNSUPPORTED HEIGHT) (FT)	RACKING RESISTANCE	SERVICE PLENUM SPACE	HEAT TRANSMISSION COEFFICIENT (U-FACTOR) (BTU/HR-SQ FT °F)
Brick veneer on metal stud		4 + 2 + 6	54	Up to 15	Good	Between studs	0.10
Insulated sandwich panel		5	6	(See manufacturers' literature.)	Fair to good	None	0.05 (See manufacturers' literature.)
Concrete		8	92	Up to 13 (with reinforcement, 17)	Excellent	None	0.68
		12	138	Up to 20 (with reinforcement, 25)			0.55
Concrete (insulated)		8 +	97	Up to 13 (with reinforcement, 17)	Excellent	Through insulation	0.13
Concrete and brick veneer (insulated)		4 + 2 + 8 +	112	Up to 13 (with reinforcement, 17)	Excellent	Through insulation	0.13
Precast concrete		2 +	23	Up to 6	Fair to good	Through insulation	0.99
		4 +	46	Up to 12			0.85
Precast concrete sandwich		5	45	Up to 14	Fair to good	None	0.14
Rainscreen on metal studs		12 +	15-20	Up to 20	Poor to fair	Between studs	0.05
Brick veneer on metal stud		4 + 4 + 6	54	Up to 15	Good	Between studs	0.05
EIFS on metal stud		8	15	Up to 20	Poor to fair	Between studs	0.05

EXTERIOR WALL ASSEMBLIES (continued)
11.201

	WEATHER BARRIER LOCATION AND TYPE							
WALL ASSEMBLY TYPE	EXTERIOR SIDE	NONE	INTERIOR SIDE	RECOMMENDED CLIMATE AND PRECIPITATION ZONES (SEE FIGURES 11.1 AND 11.2)	PERFORMANCE COMMENTS (HAM = HEAT, AIR, AND MOISTURE)	RESISTANCE TO EXTERIOR AIRBORNE SOUND TRANSMISSION	EXTERIOR MAINTENANCE REQUIREMENTS	REMARKS
Drainage cavity	MRB or vapor retarder insulation for sheathing			Hot; moderate precipitation	Average control of air and moisture. Add insulation over sheathing to increase thermal performance. Upgrading water-resistant barrier to weather barrier to increase control of rain.	Good	Washing, repointing joints,	Note that brick veneer holds moisture that can be forced into insulation. Advisable to move all insulation into air cavity and add continuous rigid insulation and weather barrier.
		None		Mixed; moderate precipitation				
			Sheet or insulation facing	Cold; moderate precipitation				
Internal drainage plane. Some factory-insulated panels provide pressure-equalized rainscreen joint design.		None		All except extremely cold; low precipitation	Field assembled systems generally lower performance; factory insulated systems offer average performance.	Poor to good (See manufacturers' literature.)	Washing, steam cleaning, painting, replacing joint sealers	Temperature change critical; minimize metal through connections
Mass barrier wall		None		Mild; low precipitation only	Very poor control of heat, poor control of moisture, average control of air.	Good	Washing, sandblasting	Concrete walls have very high heat storage capacity
Mass barrier wall	Coating or insulation facing			Mixed or hot; low to moderate precipitation	Poor control of moisture, average control of heat and air.	Good	Washing, sandblasting	Insulation on interior minimizes advantage of heat storage capacity.
		None		Mixed or hot; low to moderate precipitation				
			Coating or insulation facing	Cold; low to moderate precipitation				
Drainage cavity	Coating or insulation facing			Mixed or hot; moderate precipitation	Average control of moisture. Average control of heat and air. Adding weather barrier on cavity face of concrete improves performance for high precipitation.	Excellent	Washing, repointing joints, sand blasting	Moving insulation into cavity maximizes heat storage of concrete
		None		Mixed; moderate precipitation				
			Coating or insulation facing	Cold; moderate precipitation				
Mass barrier wall	Coating or insulation facing			Mixed or hot; low to moderate precipitation	Poor control of moisture. Average control of heat and air.	Good	Washing, sandblasting, replacing joint sealers	Large-size economical (fewer joints) units available with various finishes. Joints are weak point for control of air and moisture.
		None		Mixed or hot; low to moderate precipitation				
			Coating or insulation facing	Cold; low to moderate precipitation				
Mass barrier wall		None		All climates; low to moderate precipitation	Poor control of HAM.	Fair	Washing, sandblasting, replacing joint sealers	Panels warp from differential temperatures unless one side is dramatically thickened. Control of vapor is difficult. Joints are weak point for control of air and moisture.
Drainage cavity	As noted			All climates; extreme precipitation	Excellent control of HAM. Upgrade to P.E. rainscreen system for even higher performance.	Good	Minimal washing	Rainscreens can be metal panels, wood siding, cement panel siding, resin panels, or terra cotta
Drainage cavity	As noted			All climates; extreme precipitation	Excellent control of HAM. Upgrade to P.E. rainscreen system for even higher performance.	Good to excellent	Washing, repointing joints	
Internal drainage plane		None		All climates; low to moderate precipitation	Poor control of moisture. Average control of air. Good control of heat.	Fair to good	Check sealants frequently. Repair of sealants is extremely difficult and will likely alter appearance of building so select highest quality sealant.	System is highly dependent on quality installation. Barrier type EIFS system not advised except at CMU or concrete back-up.

BASIC EXTERIOR WALL ASSEMBLY TYPES

Exterior wall assemblies can be defined in three basic categories:

- Barrier assemblies
- Drainage walls
- Pressure-equalized walls

BARRIER ASSEMBLIES

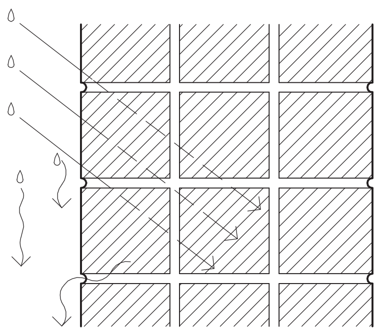
Mass barrier walls rely on thickness of water-resistant materials to absorb moisture and then dry when precipitation stops. Typical assemblies include:

- Cast-in-place concrete
- Precast concrete
- Concrete masonry units

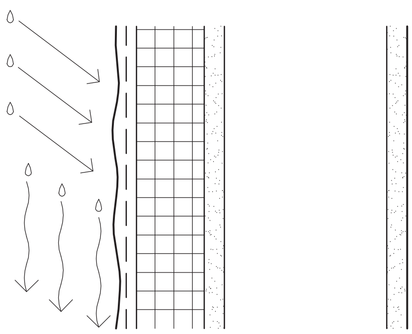
Face-sealed barrier walls rely on a perfect continuous seal at the exterior face. Common assemblies include:

- Exterior insulation and finish systems (EIFS)
- Windows with a single sealant bead

BARRIER ASSEMBLIES 11.202



MASS WALL



FACE SEALED

DRAINAGE CAVITY WALLS

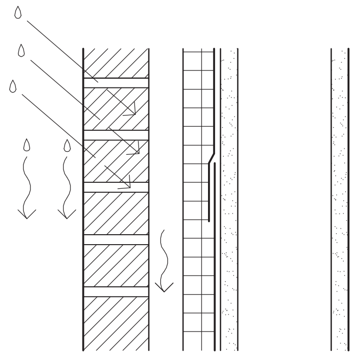
Drainage cavity walls resist air and moisture penetration with an outer layer, to block the bulk of precipitation, and an inner water barrier. At drainage cavity walls, a cavity of 3/4 in. or more is present in front of the drainage plane. If the water barrier is not also an air barrier, then another layer of the wall assembly must serve as an air barrier.

Common drainage cavity walls include:

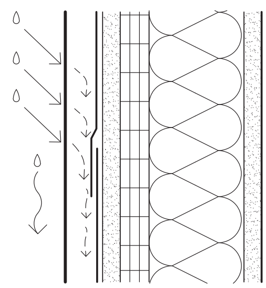
- Brick veneer
- Some metal panels

Mineral-fiber cement siding can be detailed to function as a drainage cavity wall, usually by adding 1 by 3 vertical furring strips.

DRAINAGE WALLS 11.203



DRAINAGE CAVITY



DRAINAGE PLANE

Typical internal drainage plane walls include:

- Portland cement stucco over lath and a weather barrier
- Wood or vinyl siding
- Water-drainage EIFS

PRESSURE-EQUALIZED WALL

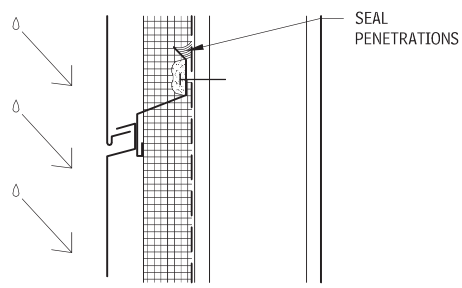
Pressure-equalized (PE) rainscreen walls use a drainage cavity, with the air pressure in the cavity, similar to the exterior air pressure. Proper detailing of joints and the PE chamber eliminates the migration of water across the cavity. PE rainscreen walls must include a weather barrier at the inner face of the cavity, venting, and compartmentalization of the cavity.

Typical pressure-equalized rainscreen walls include:

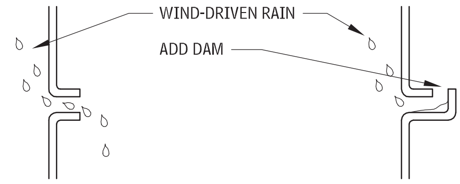
- Some unitized stone or metal panels
- Many curtain-wall systems

Through careful detailing, brick veneer and many siding products can be made into PE rainscreen assemblies.

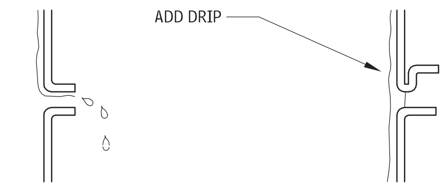
PRESSURE-EQUALIZED WALL 11.204



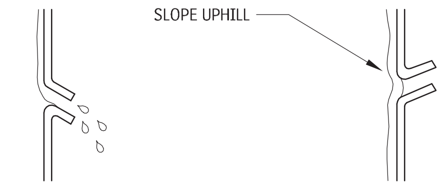
FORCES MOVING WATER ACROSS JOINTS 11.205



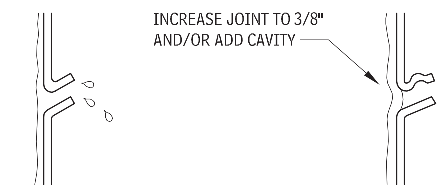
KINETIC ENERGY



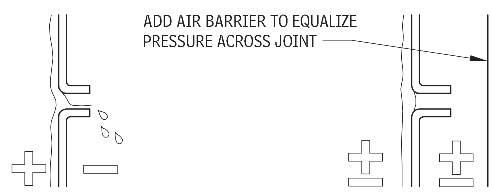
SURFACE TENSION



GRAVITY



CAPILLARY



PRESSURE DIFFERENTIAL

TILT-UP CONCRETE

Tilt-up concrete construction is a fast, economical method of enclosing a building with durable, load-bearing walls. The wall panel units are formed and cast horizontally at the job site, on either the building slab floor or a temporary casting slab. The panels do not have to be transported, so there are fewer restrictions on panel size. Wood formwork is typically used to define the edges, reveals, details, and openings in the panel. Once the concrete has reached sufficient strength, the panels are lifted (or tilted up) by crane and placed on isolated or continuous foundations (usually grade beams). The panels are braced against the floor slab or a brace foundation until they are tied to the roof and floor system, and then become an integral part of the completed structure. Although initially restricted primarily to single-story construction, tilt-up technology can now be used for buildings nearly 100-ft in height. Tilt-up load-bearing walls can be erected up to seven stories.

DESIGN

Panel thickness varies from 6 to 14 in., depending on height, loads, span, depth of reveals, surface finish, local codes, and construction practices. Full-height panel widths of 20 ft. and weights of 30,000 to 50,000 lb. are typical. Spans of 30 ft. are common for spandrel panels, as are cantilevers of 10 to 15 ft. Panels are designed structurally to resist lifting stresses, which frequently exceed in-place loads. A structural engineer designs the structural load-bearing envelope and slab with load transfer to typical foundation of either continuous footings or piers.

FINISH

Panels can be cast either face-down or face-up, depending on desired finish and formwork methods. The face-down method, however, is usually easier to erect. Casting method, desired finish, and available aggregates affect concrete mix design. Control of the concrete mix design and placement of the concrete in the forms are more difficult than with factory-cast units. Discoloration occurs if cracks and joints in the castings are not sealed. Tilt-up can replicate or incorporate a great variety of finishes using a variety of form liners, embedded materials, applied or cast-in colors, and various measures of abrasion, for the desired aesthetics.

HEAT, AIR, AND MOISTURE (HAM)

Tilt-up offers the broadest variety of thermal enveloped design and performance. Configured with high-strength, reinforced concrete, the panels are rated air barriers and when combined, the vertical joint treatments as well as caulking at openings, the wall system is easily maintained to current code requirements. Insulation systems are available for designer options for interior and exterior as well as the assembly known as sandwich panel, which is continuous insulation held between two layers of concrete panel.

WALL PANEL TO ROOF CONNECTIONS

The proceeding illustrations show four details of common roof terminations to tilt-up panels. Attachment of steel trusses and other common roof members to the panel is accomplished through four primary options:

Vertically supported along the panel top

Vertically supported at void-form pockets or ledges

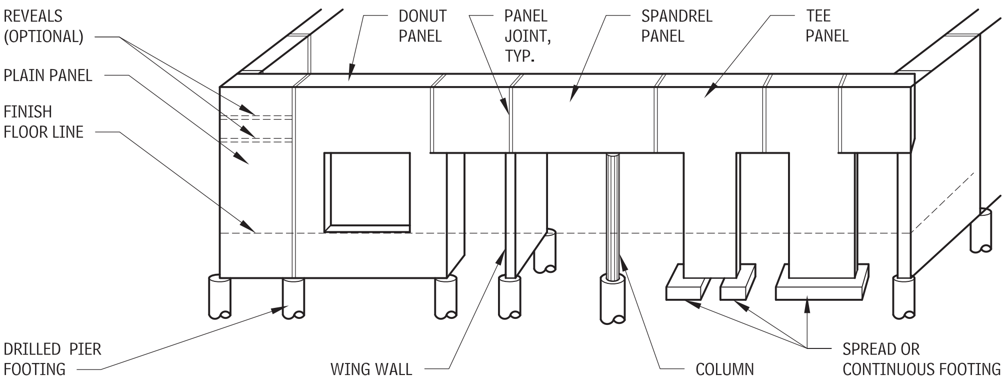
Vertically supported at seat angles or shoes

Vertically supported at integrally cast ledges or pilasters

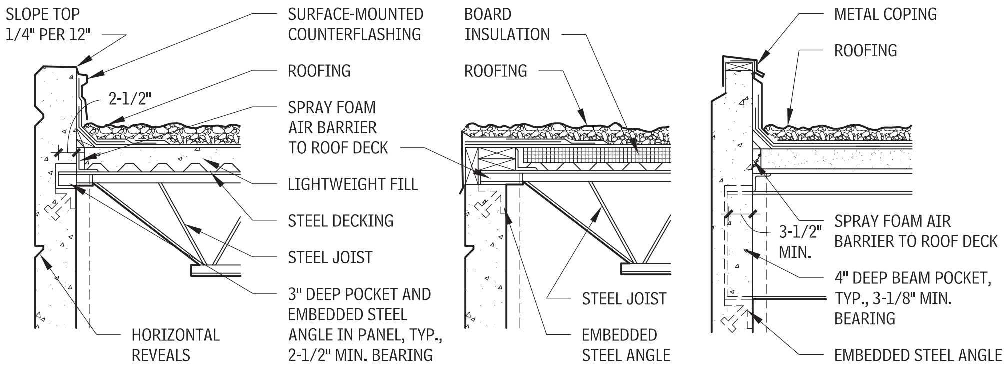
These bearing mechanisms allow the tilt-up panels to carry virtually any roof type, from wood joist/deck to heavy timber, from precast plank to cast-in-place deck, and from steel brace to standard steel joist/deck. Regardless of the type of roof structure, the connections to the tilt-up panel can be designed to accommodate the loads and required connection points. Aligning embedded plates or pocket-forming materials can be completed easily and checked for accuracy before any concrete is placed.

The primary design value for these connections that is consistent throughout these roof types and connection designs is the ease and simplicity of the erection procedure.

TILT-UP CONCRETE PANEL TYPES
11.206

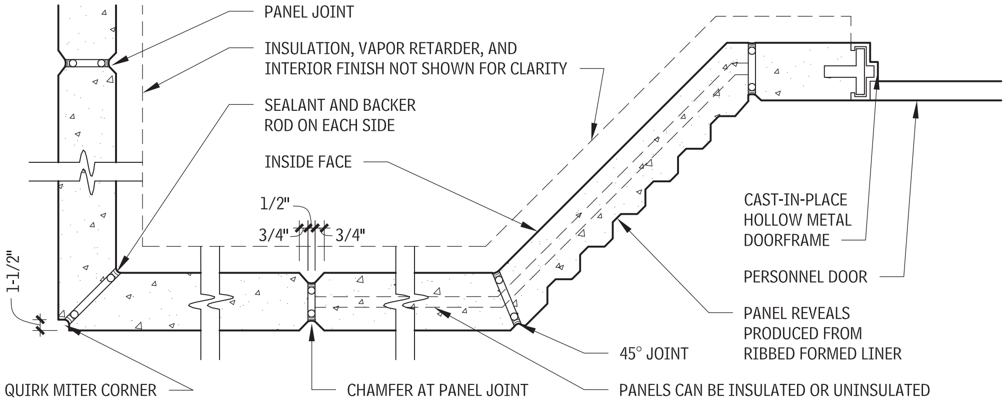


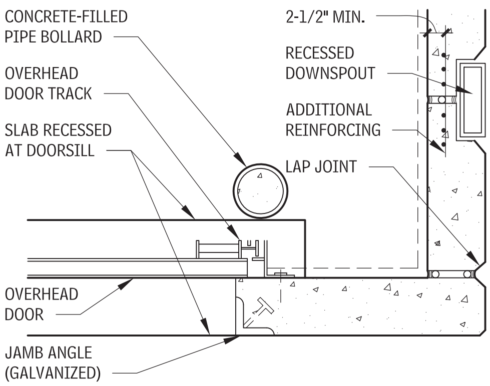
TILT-UP CONCRETE PANEL CONNECTIONS AT ROOF
11.207



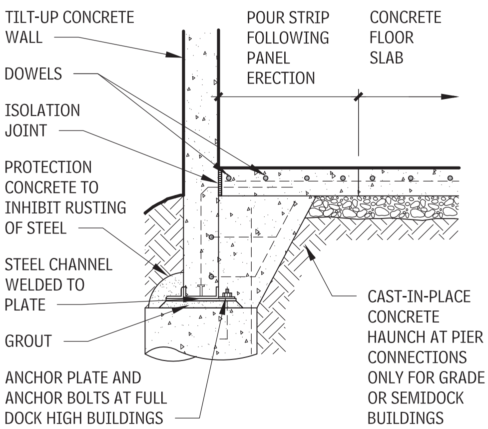
PARAPET AT JOIST MULTIBAY **FLAT** **PARAPET AT BEAM MULTIBAY**

TILT-UP CONCRETE PANEL DETAILS
11.208





PIER CONNECTION (SECTION)
11.209



PANEL TO FOOTING AND SLAB CONNECTIONS

There is a wide variety of methods used to connect tilt-up panels to foundations to ensure the transfer of building loads, including shear. Panels can extend below the finished floor elevation (sometimes substantially) to rest on the footing, or the footing height and or a foundation wall may be extended upward to meet the panel at a higher bearing elevation.

Whether connecting to the footing or the slab, a combination of inserts, reinforcing bars, and angles is often used with welded or bolted final constructions. The two proceeding details show different levels of floor slab intersection with the panels, including a dock-high elevation.

In general, the design of this intersection accommodates a balance between the ease of erection and the installation costs of the foundation system. At all locations, however, the panels initially bear on shim stacks and are supported long-term by a fully grouted base detail.

PRECAST CONCRETE

It is important to carefully distinguish between the more specialized architectural wall panel and the structural wall panel that is a derivative of floor systems. Work with fabricators early in the design process, giving careful attention to manufacturing and joint tolerance. Thoroughly examine joint sealants for adhesion and expected joint movement between the panels.

FINISHES

Form liner molds provide a wide variety of smooth and textured finishes. Finishes after casting (but prior to hardening) include exposed aggregate, broom, trowel, screed, float, or stippled. After hardening, finishes include acid-etched, sandblasted, honed, polished, and hammered rib.

COLORS

Select a color range, as complete uniformity cannot be guaranteed. White cement offers the best color uniformity, as gray cement is subject to color variations even when supplied from one source. Pigments require high-quality manufacturing and curing standards. Fine aggregate color requires control of the mixture graduation; coarse aggregate color provides the best durability and appearance.

HEAT, AIR, AND MOISTURE

Control of heat flow through the panel is typically accomplished by adding insulation to the interior side (except insulated sandwich panels). The insulation is best installed immediately adjacent to the inside face of the panel using board insulation installed with adhesive, stickpins, or Z-shaped furring channels. Because the insulation may be exposed to moisture penetrating the concrete, insulation should be selected that will withstand occasional moisture.

Blanket insulation may be used between stud walls erected inside of the precast panel, but thermal loss through the studs must be accounted for. Effectiveness of the insulation is dependent on close contact with the weather barrier, so the interior gypsum board should be sealed.

The precast concrete panels function as a weather barrier. To complete the weather barrier assembly, joints and penetrations should be double-sealed and allowance made for weepholes.

Precast concrete wall panels typically perform as mass barrier walls. The density and thickness of the concrete controls the penetration of water. In cold climates, a vapor retarder is typically applied over the interior face of the insulation. (Blanket insulation installed in a stud wall will probably need the vapor retarder to be sealed around electrical and other types of junction boxes.) However, even with the vapor retarder applied directly to the inside face of the insulation that is adhered to the inside panel, sealing joints is unlikely at the spandrel beams and columns, making the system less desirable in very cold climates. In hot climates, a vapor barrier can be applied to the interior face of the panel before adhering the insulation.

Access to the joints for sealing of the vapor retarder is difficult. In mixed climates, it is best to select an insulation that can tolerate wetting, provide no vapor retarder, and allow the assembly to dry to both the interior and exterior. Precast concrete may not perform well in areas of high precipitation or situations with an extreme vapor drive.

Joints between precast concrete panels are very susceptible to HAM problems. Therefore, joints should be designed as two-stage sealant joints as indicated in Figure 11.212.

GLASS FIBER-REINFORCED CONCRETE

Glass fiber-reinforced concrete (GFRC) is a composite material manufactured under controlled conditions and consisting of portland cement, fine aggregate, water, alkali-resistant glass fibers, and additives. It can be used for cladding applications, especially where weight is a significant factor. GFRC is categorized into two primary applications:

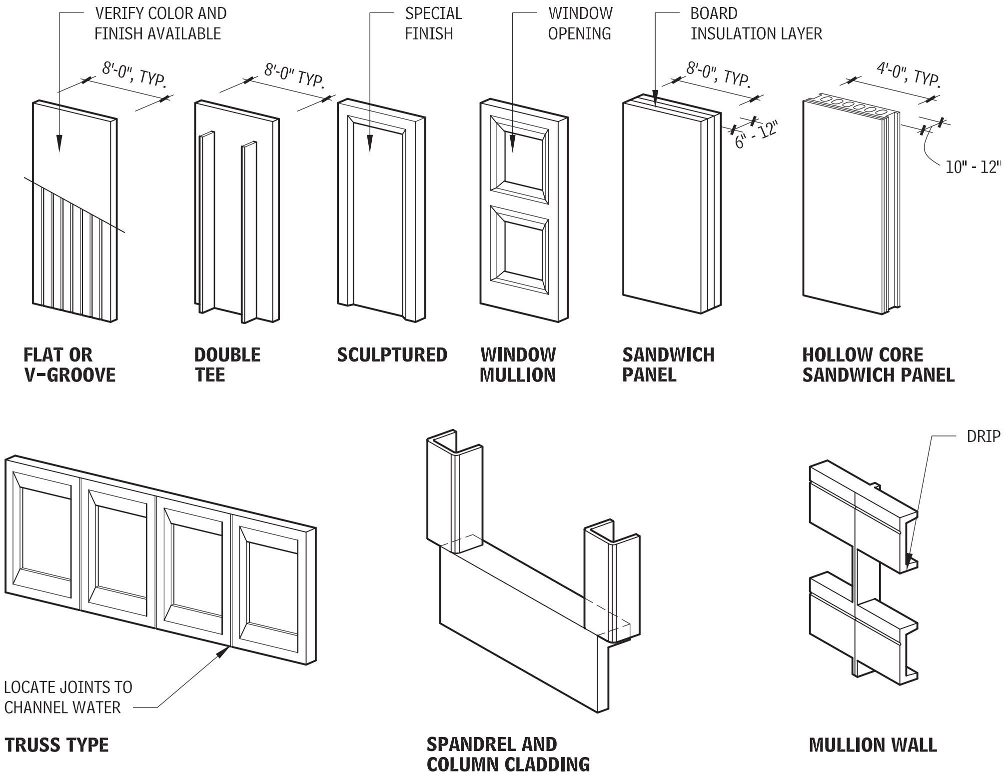
- *Architectural cladding panels* are very similar in application, strength, and performance to architectural precast concrete panels, except for providing a significant reduction in weight.
- *Decorative shapes* are generally smaller elements not part of the building enclosure.

GFRC ARCHITECTURAL PANELS

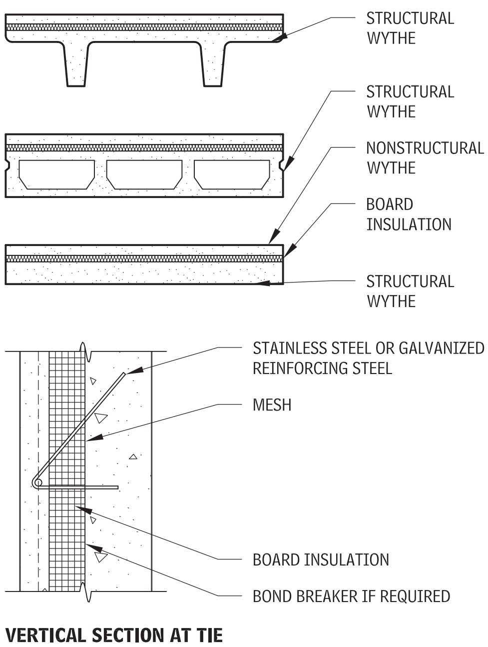
GFRC panels consist of a GFRC skin supported by a structural frame, usually constructed of cold-formed steel members or a small structural channel, angles, and tubes. The GFRC skin is typically sprayed into a mold approximately 1/2 to 3/4 in. thick. After spraying, the structural frame backup is suspended over the skin,

Contributors:
Stefan Pienkny, AIA and Cline McGee, AIA Hall Architects, Charlotte, North Carolina; Haynes Whaley Associates, Structural Engineers, Houston, Texas; Robert P. Foley, P.E., Con/Steel Tilt-up Systems, Dayton, Ohio.

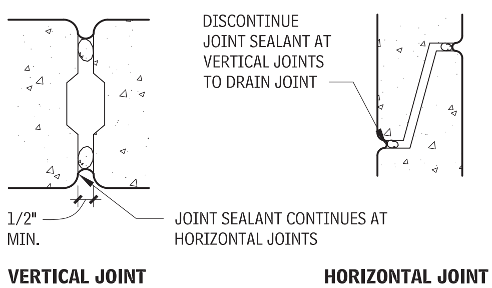
PANEL VARIATIONS
11.210



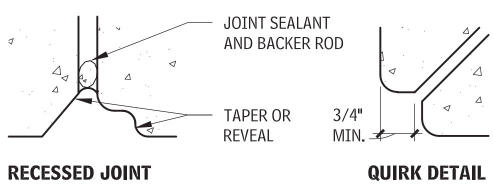
SANDWICH WALL CONSTRUCTION
11.211



TWO-STAGE SEALANT JOINTS
11.212



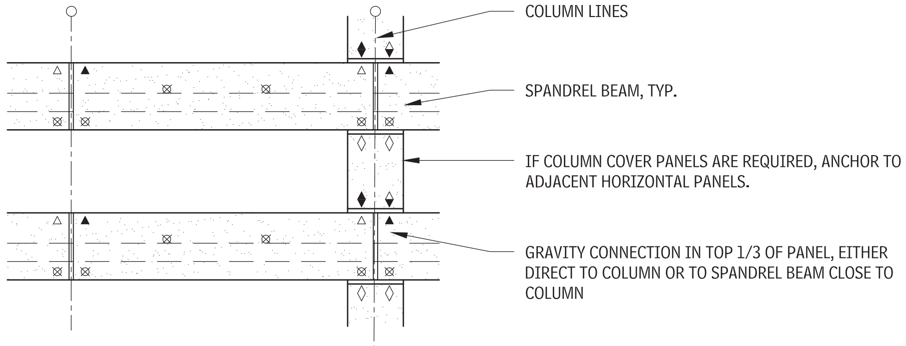
JOINT DETAILS
11.213



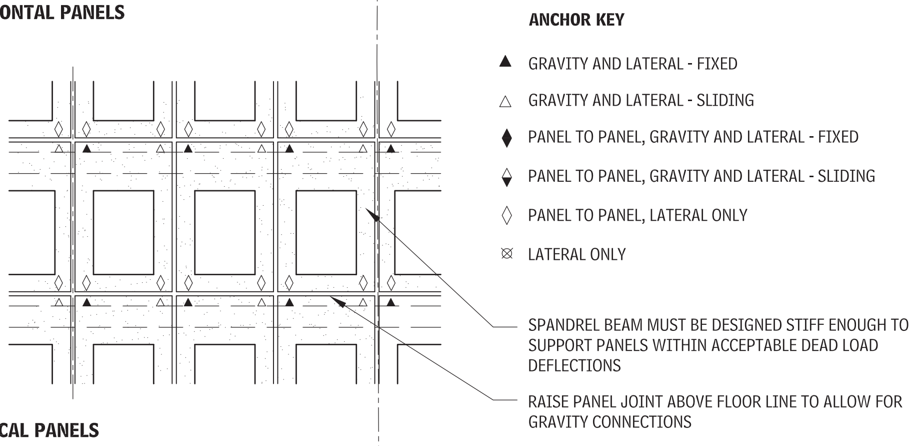
NOTE

11.211 Evaluate the capability of the structural wall to resist bowing caused by differential thermal expansion of inner and outer layers.

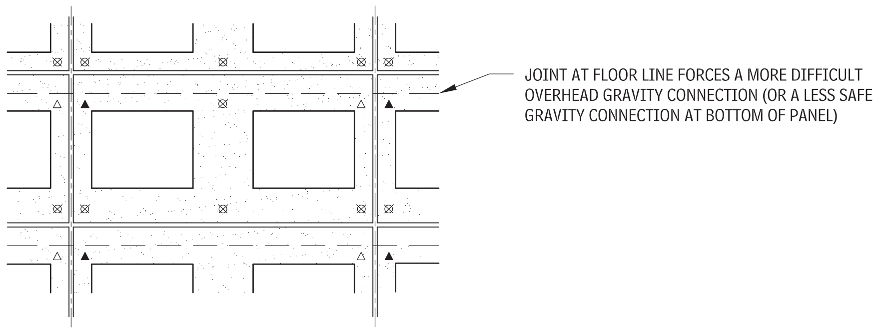
SUSPENDED PRECAST PANEL ANCHORAGE
11.214



HORIZONTAL PANELS

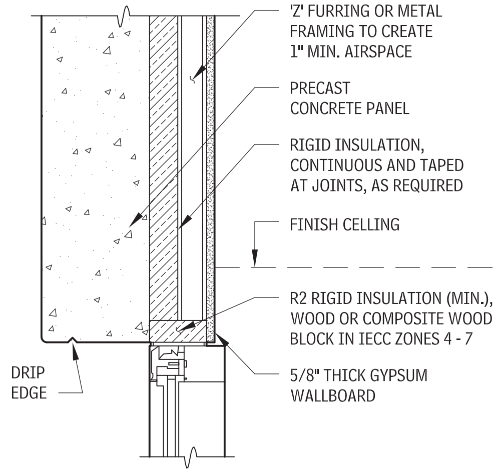


VERTICAL PANELS

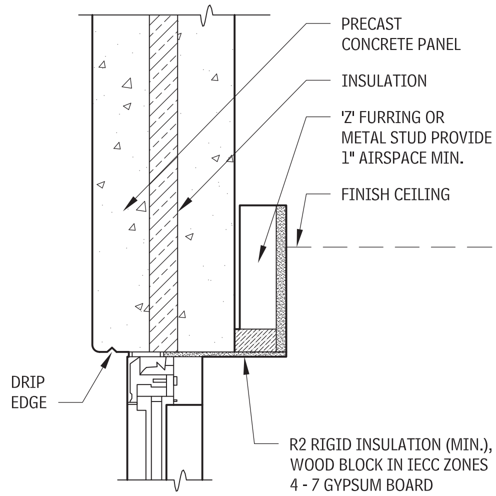


FULL STRUCTURAL PANELS

WINDOW IN PRECAST PANEL
11.215

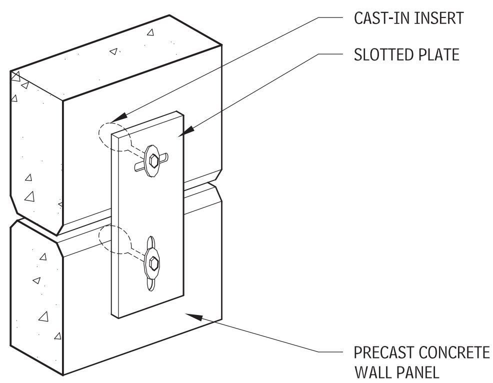


PRECAST PANEL



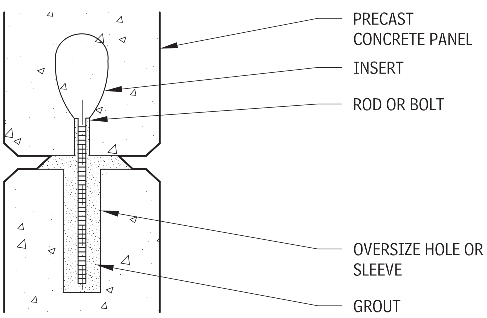
PRECAST SANDWICH PANEL

BOLTED ALIGNMENT
11.218

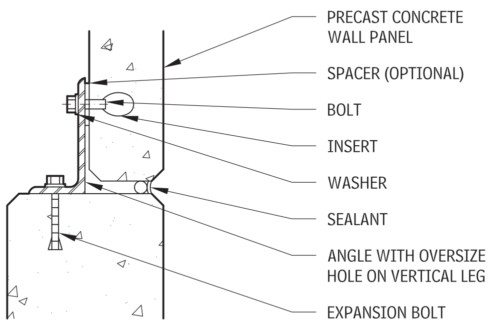


PRECAST CONCRETE CONNECTIONS

DIRECT BEARING CONNECTION
11.216



BOLTED TIEBACK
11.217

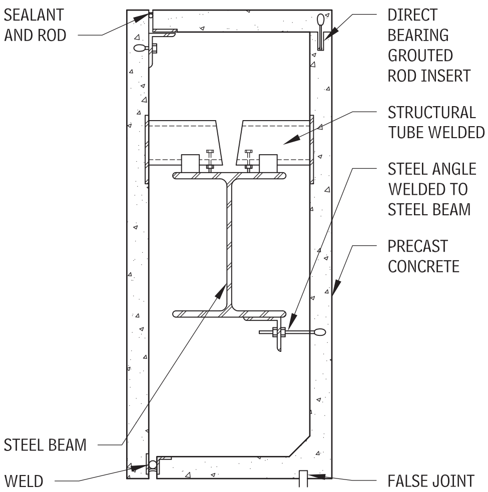


NOTES

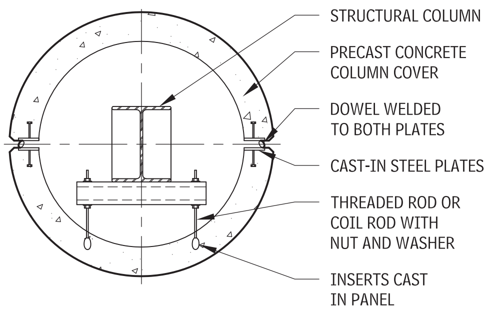
11.214 Each panel has only one three-way fixed gravity and lateral anchor. All other anchors must allow differential structural and thermal movement.
11.216 Shim stacks occur at two points per panel adjacent to connection.
11.217 This tieback accommodates a large tolerance with expansion bolts.

Contributors:
Precast/Prestressed Concrete Institute, Chicago, Illinois; Architectural Precast Association, Ft. Myers, Florida.

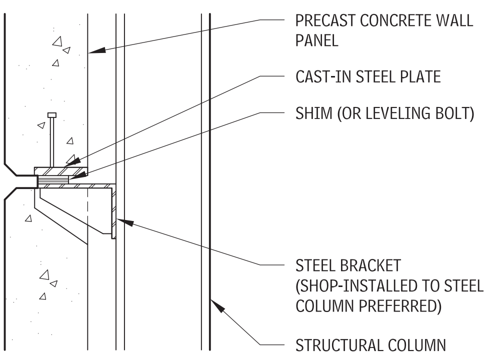
SPANDREL CONDITION
11.219



COLUMN COVER CONNECTION
11.220



DIRECT BEARING CONNECTION
11.221

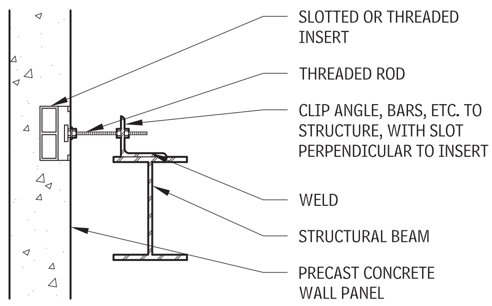


and anchors are embedded in the wet mix, which must be applied while the skin is still green. The anchors are designed to allow for a relatively large amount of differential movement between the backup and the skin.

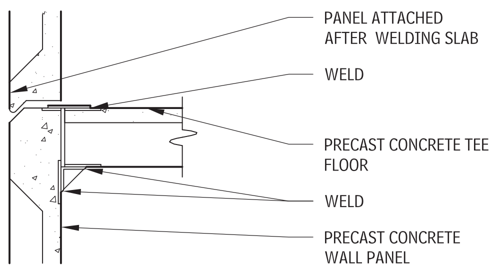
GFRC MIX

The GFRC mix is typically designed by the manufacturer's engineers in a process called delegated design. The mix is designed to comply with the performance requirements indicated by the design

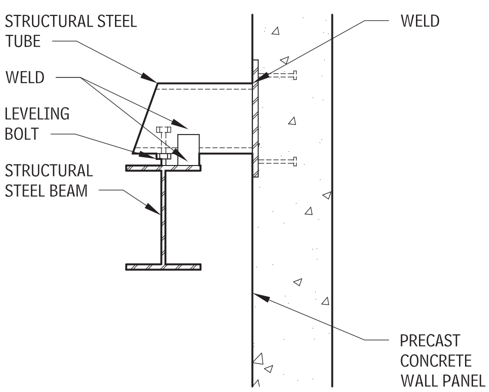
BOLTED TIEBACK CONNECTION
11.222



SLAB-TO-WALL CONNECTION
11.223



ECCENTRIC BEARING CONNECTION
11.224



team of record. The characteristics of GFRC differ from architectural concrete mixes often influencing the final design.

- The strength of GFRC is typically very high: 10,000 psi is not unusual, which is cost effective because a relatively small amount of material is required. The high strength results in a more dense material that is necessary to resist water penetration.
- Aggregates are generally small, 3/8 in. or less. Such small aggregate limits some of the surface textures available in architectural concrete.
- Because small amounts of aggregate are required, it is possible to carefully control the quality and moisture content. Oven-dried aggregate is available, which allows for very precise control of the moisture content of the finished mix and, therefore, better control over the finished color.

DESIGN AND FINISH

GFRC can be very similar to architectural precast panels, but the manufacturing process, assembly, and inherent qualities of GFRC allow for a slightly different design expression.

The fine aggregate, high cement ratio, and spray application allow for a fine level of finish, which is very effective at imitating the appearance of limestone and other tight-grained uniform stone. The finish and detailing can also produce a very precise and machine-like appearance. Other characteristics include the following:

- The low weight of the panels makes large overhangs, cornices, and other horizontal projections possible.
- Shipping of the panels is relatively inexpensive if the design allows for four to six panels to be shipped on each truckload.
- Relatively flat panels, articulated with joints, are the most cost-effective; but large three-dimensional configurations with reveals, returns, and setbacks can be economically produced because the lightweight material requires less structural support and limited backforming.
- The skin has relatively large amounts of thermal movement, so it is generally broken into multiple segments when more than 30 ft. long, even when mounted on a longer steel backup frame.

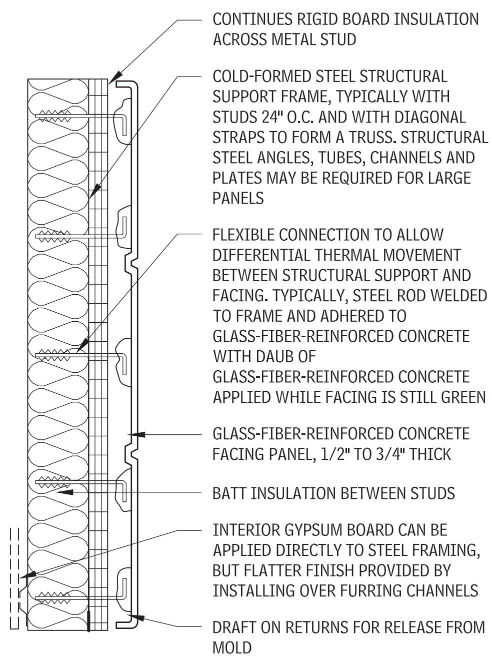
HEAT, AIR, AND MOISTURE

GFRC panels typically perform as thin barrier walls. The density of the thin concrete layer controls the penetration of water. GFRC panels may not perform well in areas of high precipitation or situations with an extreme vapor drive.

Joints between GFRC panels are very susceptible to HAM problems. As with precast, a double line of joint sealant is preferred, as indicated in Figure 11.227. Control of heat flow through the panel is typically accomplished by adding insulation between the studs of the backup frame. Reduction of effectiveness of the insulation because of conductive loss through the studs must be accounted for. In cold climates, a vapor retarder is typically applied over the interior face of the insulation. Fasteners joining the GFRC members may be in an environment that may get moist because of condensation. Therefore, stainless steel fasteners and careful touch-up of welds is very important.

The GFRC skin typically functions as a weather barrier. To complete the weather barrier assembly, joints and penetrations must also be sealed. For additional information, consult the *GFRC Handbook*, published by the Architectural Precast Association (www.archprecast.org/GFRC_handbook.htm).

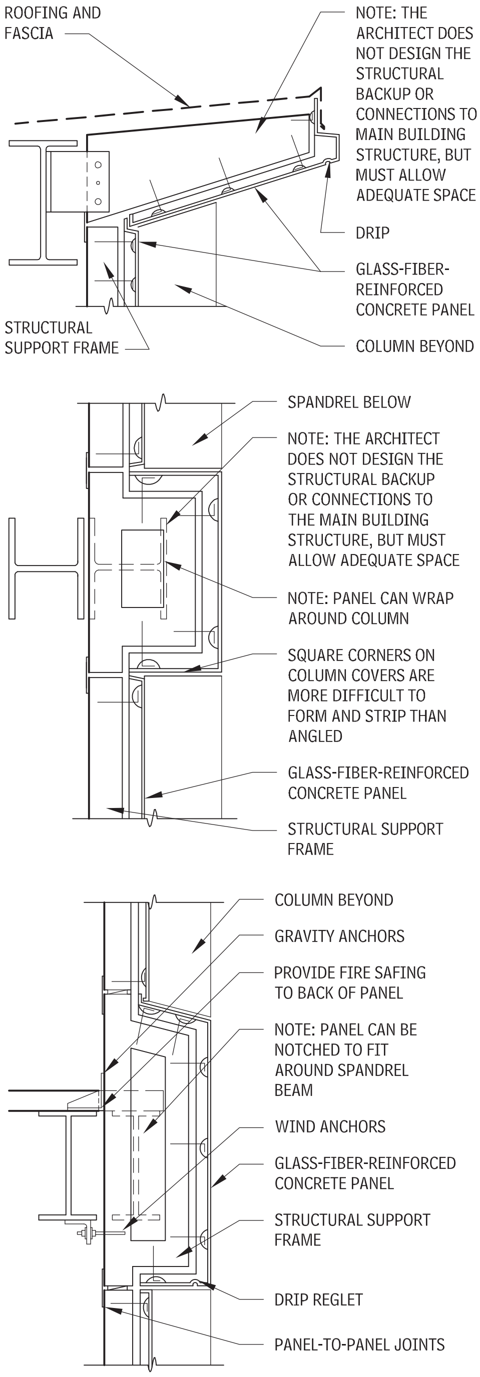
TYPICAL GFRC ARCHITECTURAL PANEL
11.225



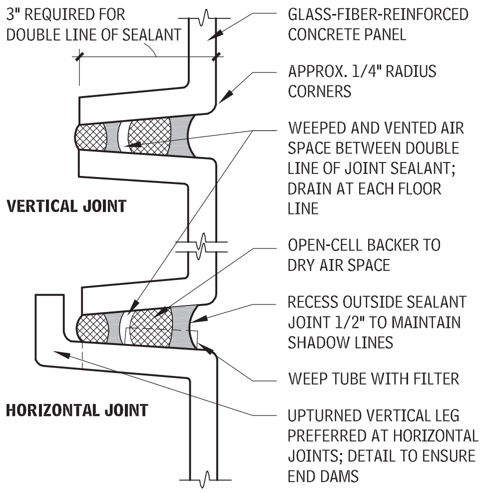
NOTES

11.223 a. Avoid use of this detail at both ends of slab to prevent excessive restraint.
b. Consider rotation of wall elements and effects on bracing wall connections and volume changes.
11.225 Panel size is limited by shipping availability—usually an over-the-road truck, 10 ft. by 40 ft. is common.

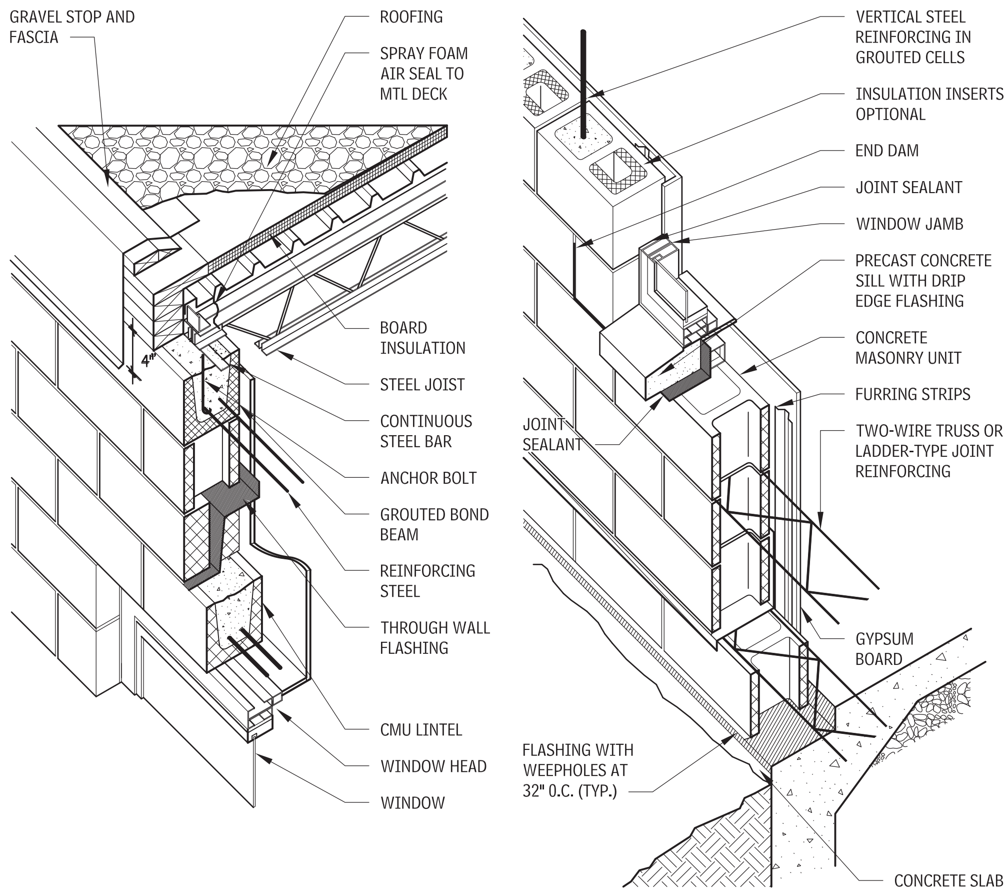
GFRC PROFILED PANEL
11.226



GFRC JOINT DETAILS
11.227



SINGLE WYTHE MASONRY WALL DETAILS
11.228



CONCRETE MASONRY UNITS

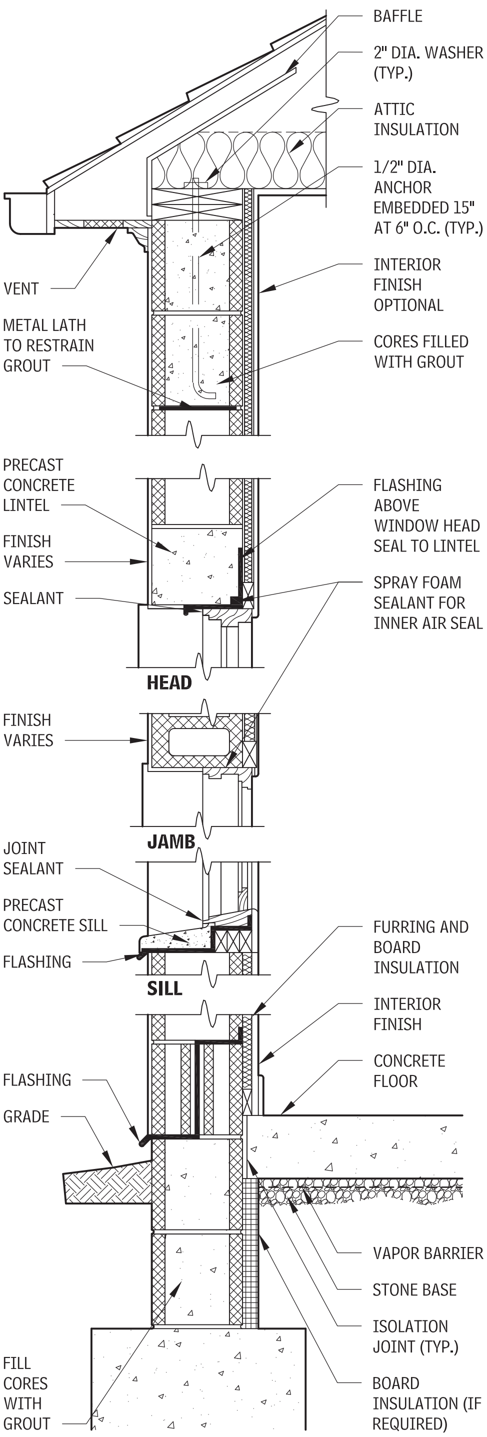
Single wythe CMU walls may be either load-bearing or non-load-bearing supported by the building frame. CMU walls are subject to significant movement from shrinkage caused by initial drying and then ongoing movement caused by temperature and moisture content variations. Therefore, control joints within the masonry must be provided at approximately 30-ft centers, near corners, and at changes in the strength of the wall (e.g., chases, changes of thickness, door openings, and window openings).

Masonry units for the wall may be structural, though architectural units may provide more design options. Architectural units include split-faced, scored, integrally colored, ground-faced, and specially shaped/sized. Glazed CMU and structural clay tile also may be used and are advantageous because they are less absorptive.

NOTE

11.226 For the sake of clarity, insulation, vapor retarder, and interior finishes are not shown.

SINGLE WYTHE MASONRY WALL SECTION
11.229



HEAT, AIR, AND MOISTURE

Single wythe masonry walls function as mass barrier walls. They absorb moisture during precipitation and then dry out. Control of heat flow is typically accomplished by adding insulation to the interior side or by inserting insulation into the cores of the CMU. Board insulation is best installed immediately adjacent to the inside face of the panel using stickpins, or Z-shaped furring channels. Because the insulation may be exposed to moisture, which penetrates the concrete, the insulation should be capable of withstanding occasional moisture. Blanket insulation may be used between stud walls erected inside of the CMU, but thermal loss through the studs must be accounted for, along with the use of a weather barrier. Insulation inside of the CMU cores can be factory-installed foam inserts, foamed-in-place insulation, or poured fill. Note, however, that insulation in the cores is less effective because it cannot cover the entire area. For both insulation applied to the interior face or in the cores, the advantage of the thermal mass of the masonry is largely lost because it is outside the thermal envelope.

CMU is generally too porous to function as a weather barrier; therefore, a different layer of the assembly must provide that function. A membrane may be applied to the interior surface or plaster may be applied to the exterior, or an interior gypsum board layer may be detailed as components of the weather barrier.

Single wythe CMU assemblies are very susceptible to water penetration. The porous nature of the CMU itself, the large number of joints that are only as deep as the thickness of the outer face, cracks caused by thermal movement, control joints, and lack of a dependable drainage path once moisture penetrates make single wythe walls a poor choice in relationship to heat, air, and moisture.

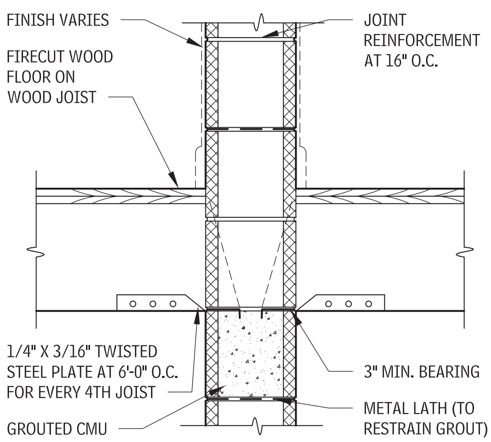
IMPROVED PERFORMANCE

A variety of proprietary water-repellant additives for both the concrete used to manufacture the CMU and in the mortar can help reduce water absorption. Flashing systems to provide internal drainage of the cores of the CMU at the base are also available, and may improve performance. The application of water-repellant coatings may help, but will need maintenance coatings over the life of the structure.

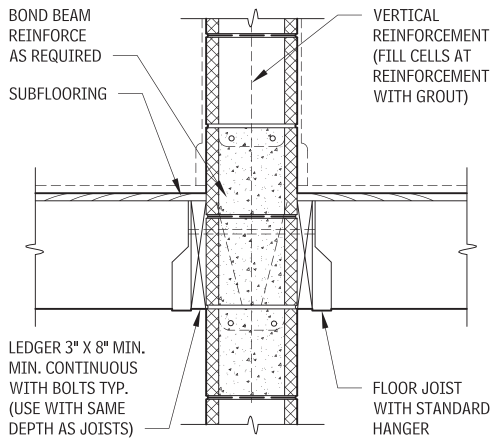
Applying a three-coat stucco system over the CMU may help minimize absorption. Exterior insulation and finish systems (EIFS) applied over the CMU will help with both minimizing absorption and continuity of the insulation layer. Providing a drainage mat and weather barrier to the inside face of the CMU can substantially improve performance.

For additional information consult the Boston Building Enclosure Council, a committee of the Boston Society of Architects for the Massachusetts Bureau of Building Regulations and Standards.

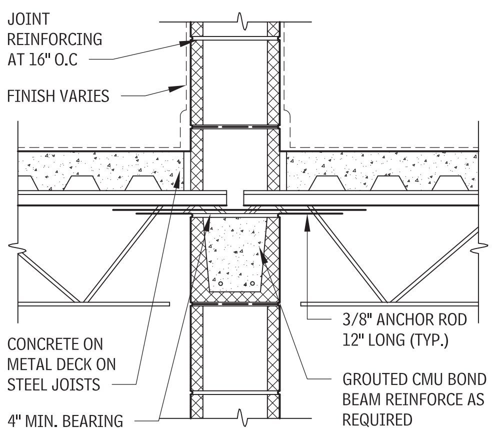
WALL ANCHORAGE DETAILS
11.230



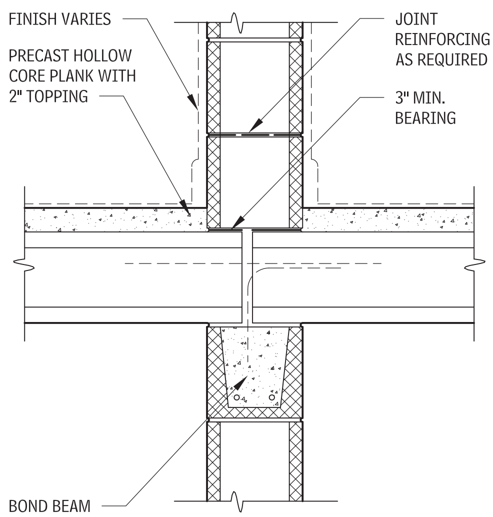
CMU WALL TO WOOD JOIST ANCHORAGE



INTERIOR WALL TO JOIST ANCHORAGE

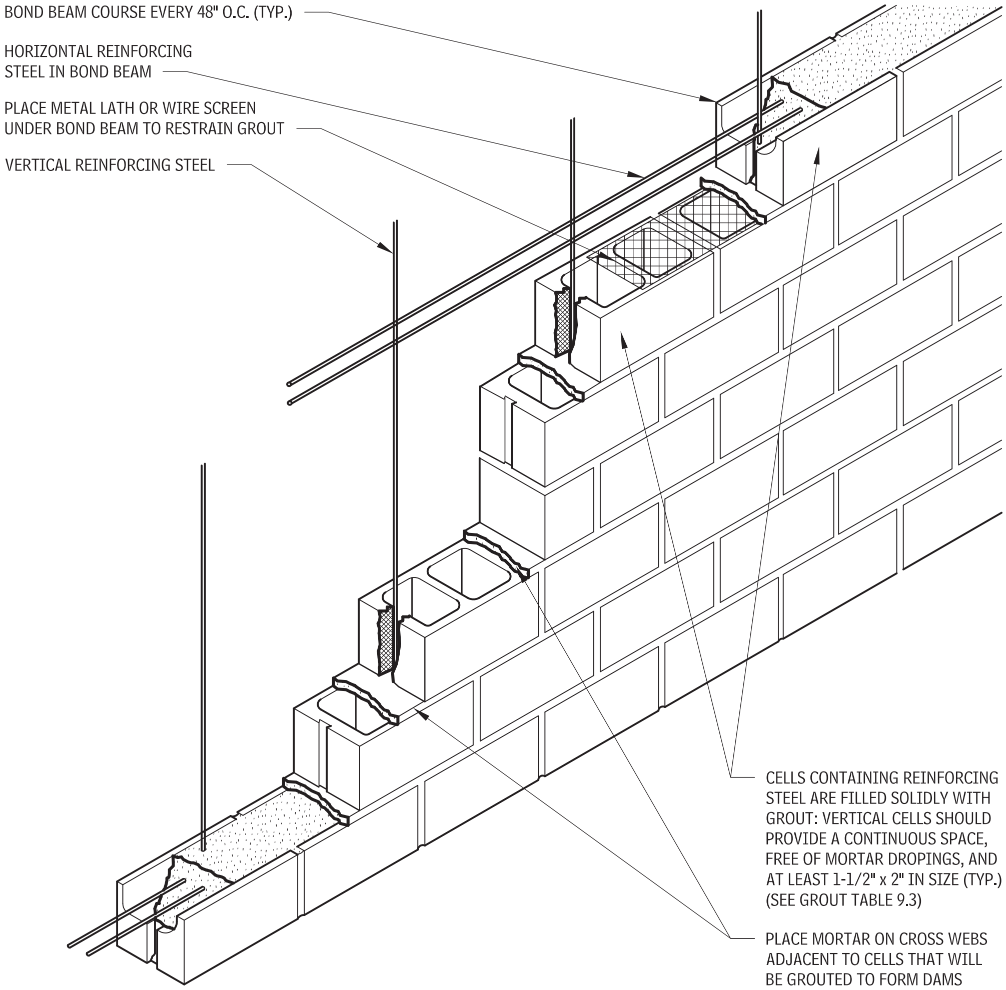


CMU WALL TO STEEL JOIST ANCHORAGE



CMU WALL TO CONCRETE JOIST ANCHORAGE

METHODS OF REINFORCING
11.231



CLAY AND BRICK MASONRY

Clay masonry, including brick used in veneer walls, can provide some of the most cost-effective, high-performance exterior wall assemblies available. The wall may function as a drained cavity wall or, possibly, as a pressure-equalized wall, when properly detailed and constructed. The brick veneer must be supported by a structural backup, most typically CMU, wood studs, or cold-formed steel framing, but may also be placed over structural concrete or precast concrete.

Architectural concrete masonry units (e.g., split-faced, scored, integrally colored, ground-faced, and specially shaped/sized) stone, cast stone, or most other masonry units may be substituted for the brick, with little or no effect on total performance.

STRUCTURAL BACKUP

- *CMU:* CMU provides a nearly ideal backup to brick veneer. It matches structural stiffness, is resistant to minor wetting, and has similar movement characteristics. The veneer is typically anchored with loose pintles attached to eyes on crosspieces of the horizontal reinforcing.
- *Cold-formed steel framing:* CFS framing should be designed stiff enough to limit cracks caused by deflection: L/600 is minimum, but L/720 or L/900 might be appropriate for longer performance. Veneer ties not only must provide structural anchorage but must also be able to seal penetrations through the sheathing.
- *Wood framing:* Wood framing is typically limited to residential and very light commercial construction without the benefit of structural engineering. Stud framing should be limited to normal limits dictated by codes. Sheathing varies widely from plywood, OSB, board insulation, wood fiberboard, and gypsum sheathing. Ties are normally light-gauge, corrugated galvanized steel tabs nailed to the studs.

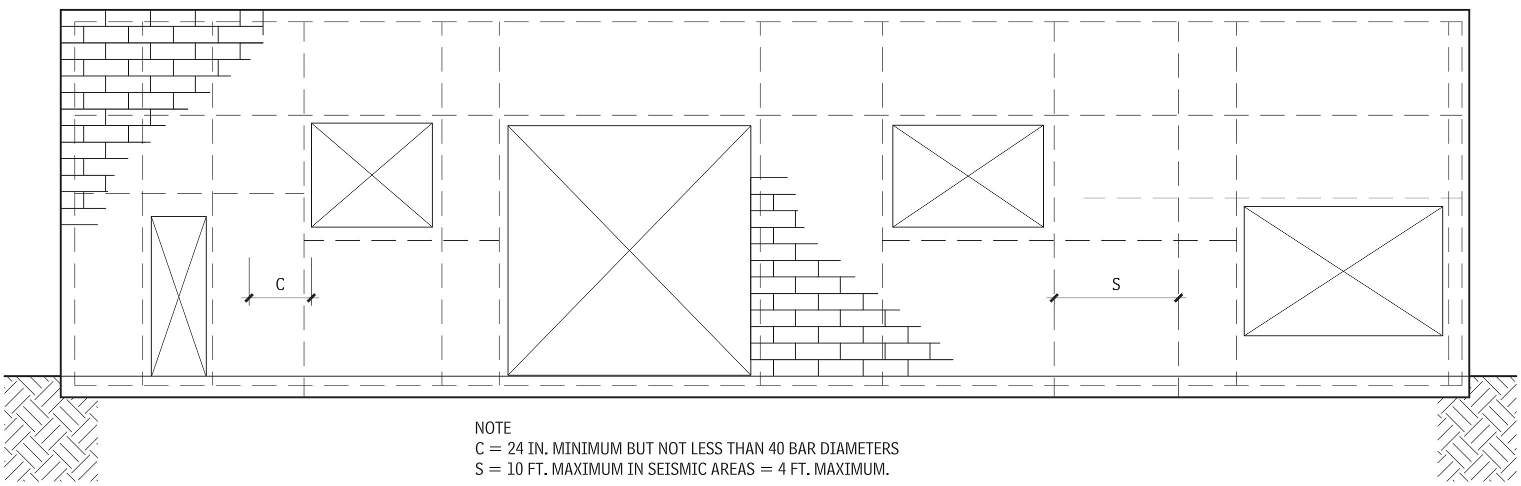
HEAT, AIR, AND MOISTURE

Brick veneer walls in commercial construction should always be detailed as drained cavity walls; and in high-rise situations or where very high performance is required, they may be upgraded to pressure-equalized walls. This wall assembly performs very well in all climates. The application of the weather barrier and insulation outside the backup allows for a continuous application with a minimum of breaks or gaps. If CMU backup is used, the mass stays within the insulation, providing a thermal reservoir.

Incorporate the following recommendations:

- 2–in. airspace. If airspace is reduced to 1 in., take extra care to keep airspace clear of mortar droppings, or add proprietary products.

REINFORCED LOAD-BEARING MASONRY WALLS
11.232



NOTE
C = 24 IN. MINIMUM BUT NOT LESS THAN 40 BAR DIAMETERS
S = 10 FT. MAXIMUM IN SEISMIC AREAS = 4 FT. MAXIMUM.

NOTE

11.232 C = 24 in. minimum, but not less than 40 bar diameters. In seismic performance category C, S = 10 ft., maximum; in seismic performance categories D and E, S = 4 ft., maximum.

- Functional weeps above every line of through-wall flashing.
- Through-wall flashing to direct any moisture within the airspace to the exterior.
- A continuous weather barrier applied to the airspace face of the backup. Coordinate the membrane into through-wall flashing, window frames, and other penetrations.
- Board insulation installed in the airspace.
- Movement capability of the veneer and of the structure, while maintaining continuity of the weather barrier.

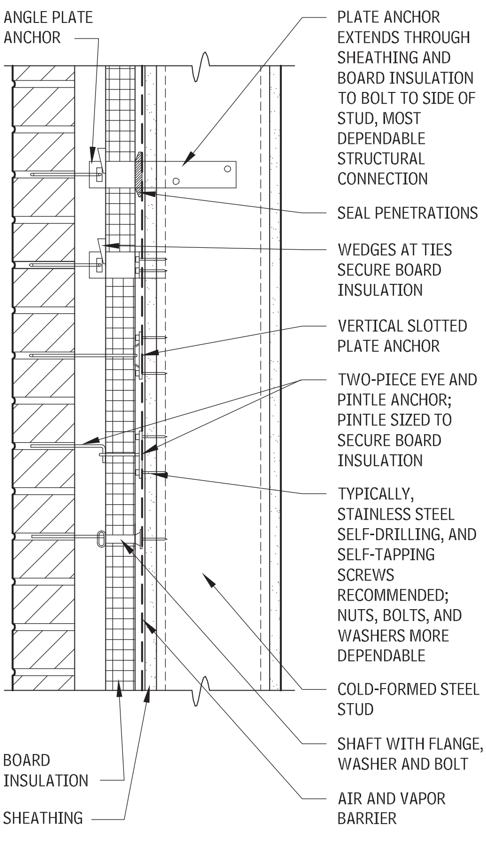
In cold-formed steel studs, avoid insulation in the stud space, unless dictated by economics. If required, evaluate the assembly for the proper location of the vapor barrier, the loss of effectiveness of the insulation because of thermal bridges through the studs, and the location of the air barrier. A water-resistant membrane must be installed over the sheathing; and if it also performs as a weather barrier, it may have to be vapor-permeable.

In residential wood-framed brick veneer walls, blanket insulation is typically installed in the stud space. The sheathing, board insulation, weather barrier, and detailing must all be carefully considered and balanced in relationship to the local climate.

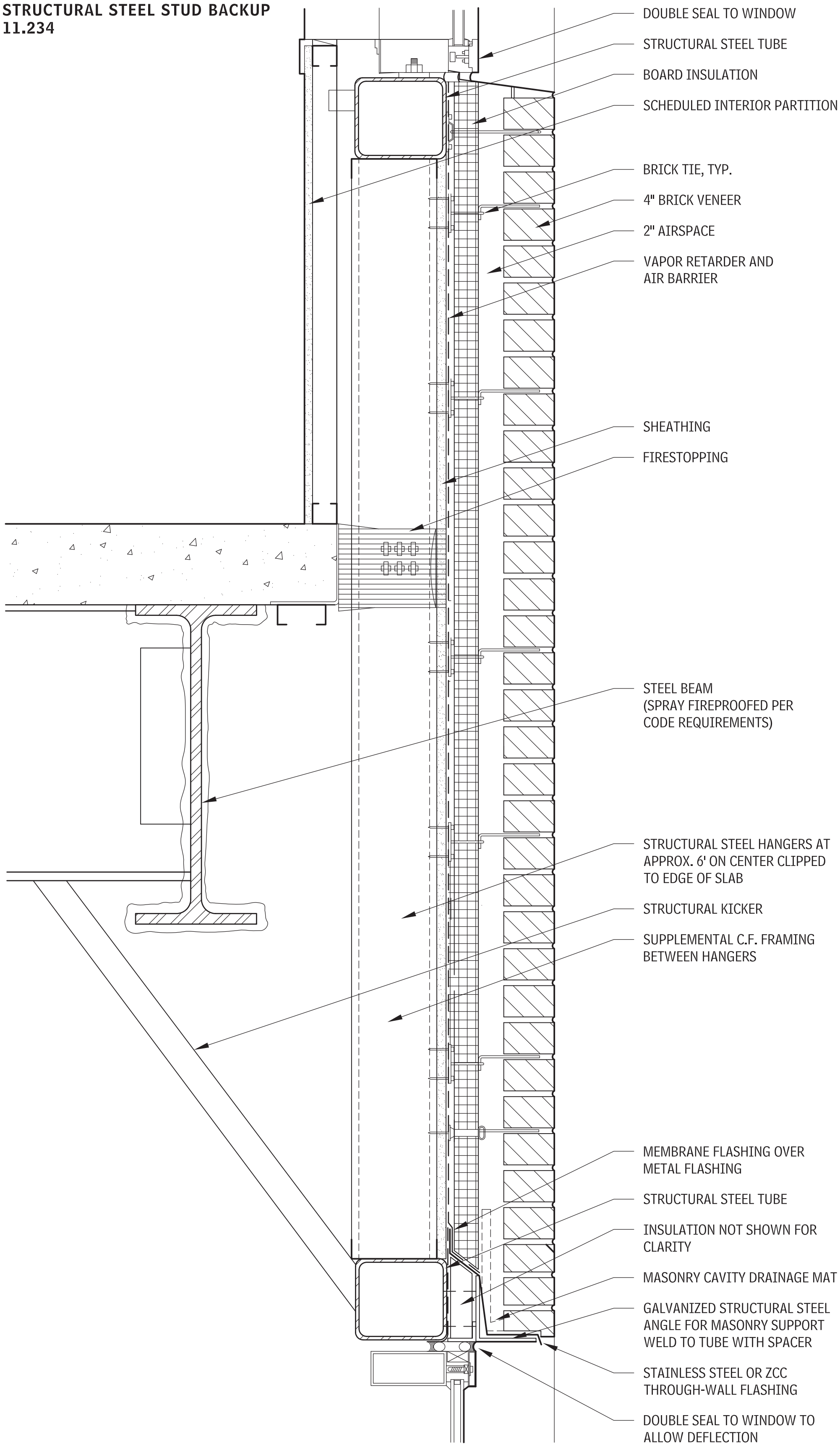
For pressure-equalized walls, divide the airspace behind the brick veneer into zones approximately one story high by 15 or 20 ft. wide. Divide the cavity at inside and outside corners approximately 5 ft. wide, because these are areas of large pressure changes. Extra venting at the top of the cavity is required. Ensure cavity is divided from roof at parapets.

BRICK VENEER

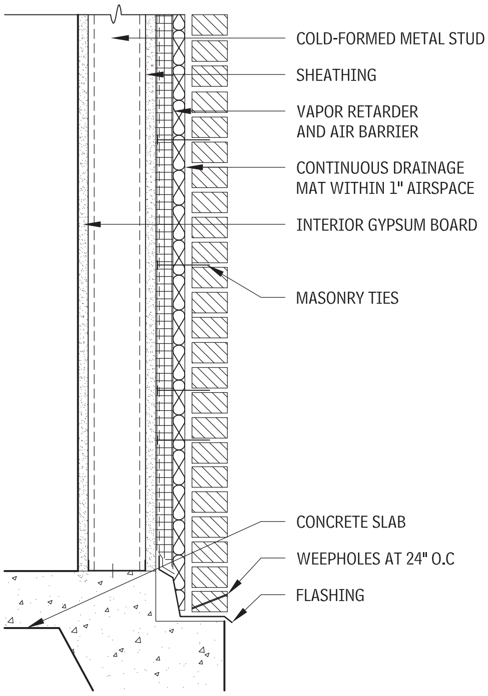
STEEL STUD VENEER ANCHORS
11.233



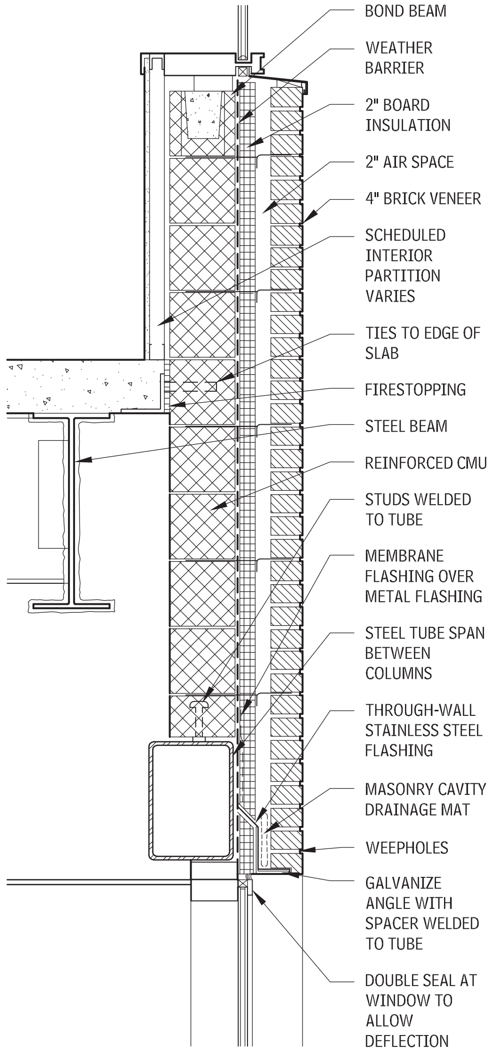
STRUCTURAL STEEL STUD BACKUP
11.234

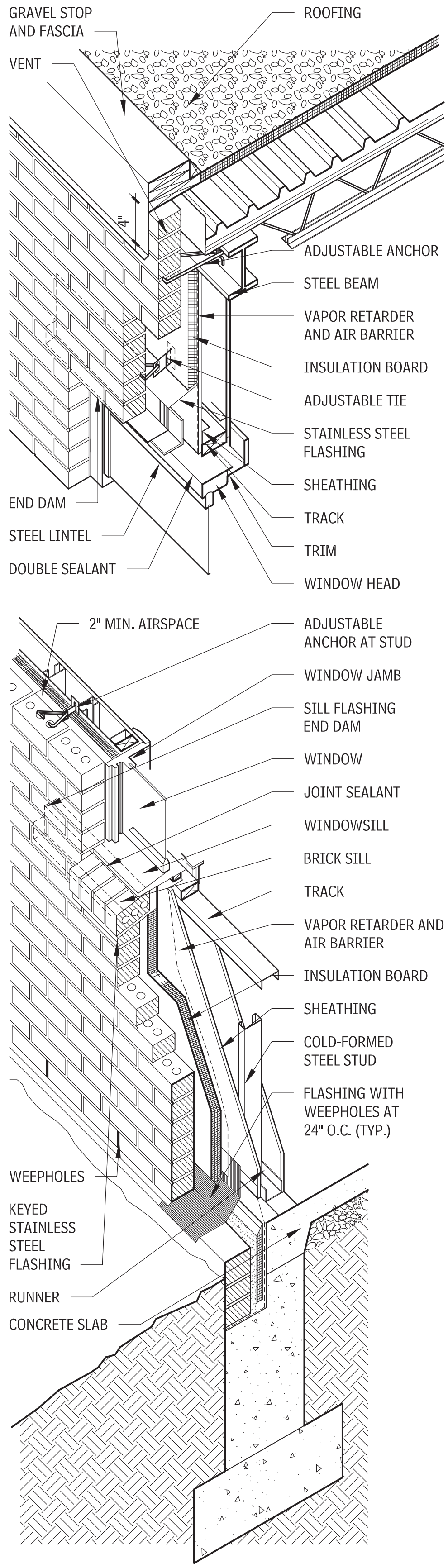


RAINSCREEN MASONRY VENEER WALL
11.235



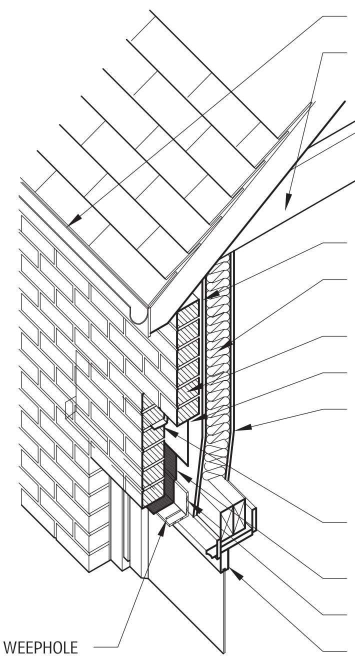
MASONRY CMU BACKUP
11.236

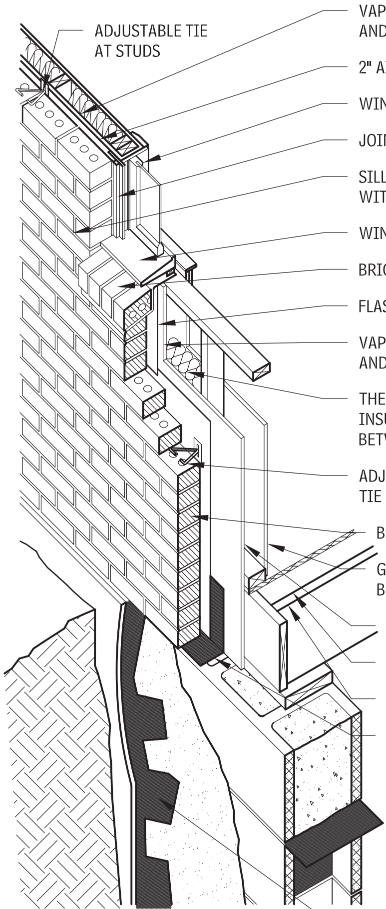




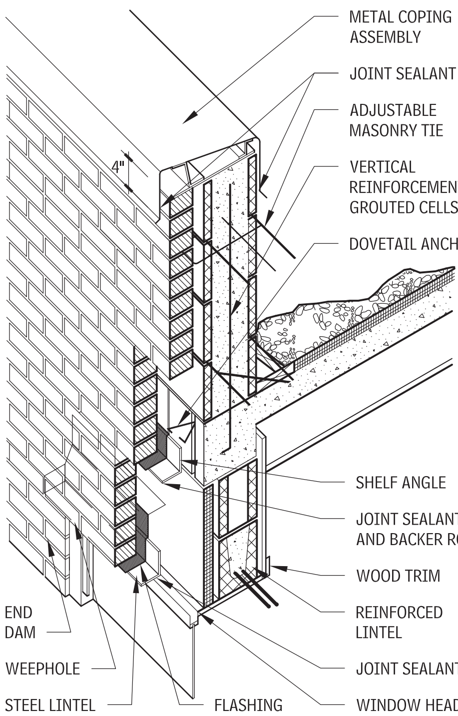
BRICK VENEER ON COLD-FORMED METAL FRAMING
11.237

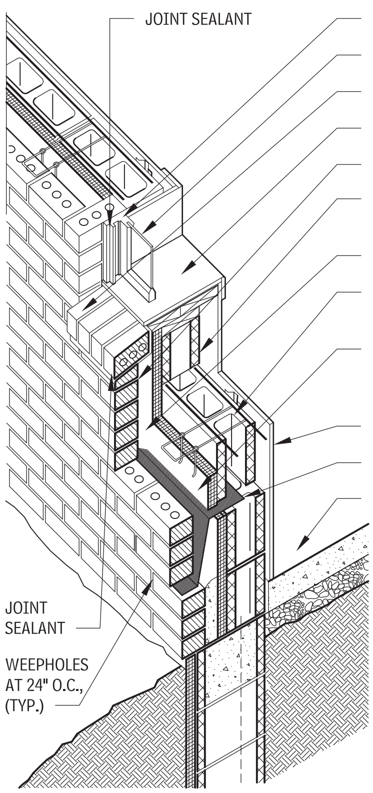
BRICK VENEER ON WOOD FRAMING
11.238



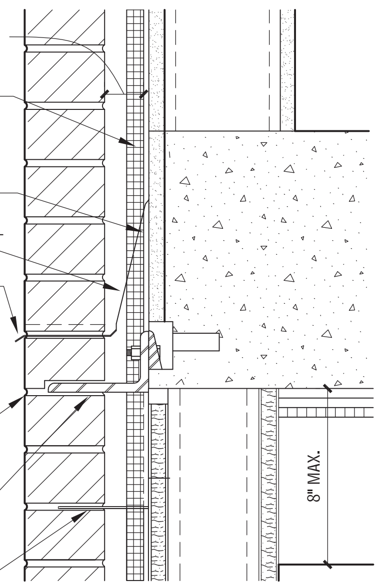


BRICK VENEER ON CMU
11.239

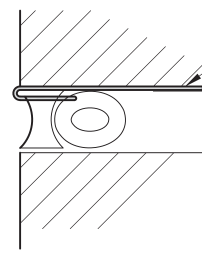


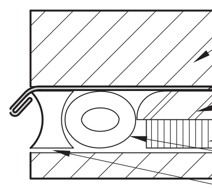


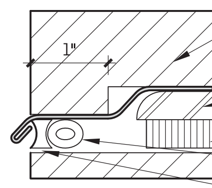
SHELF ANGLE DETAIL
11.240



HORIZONTAL SOFT JOINT
11.241





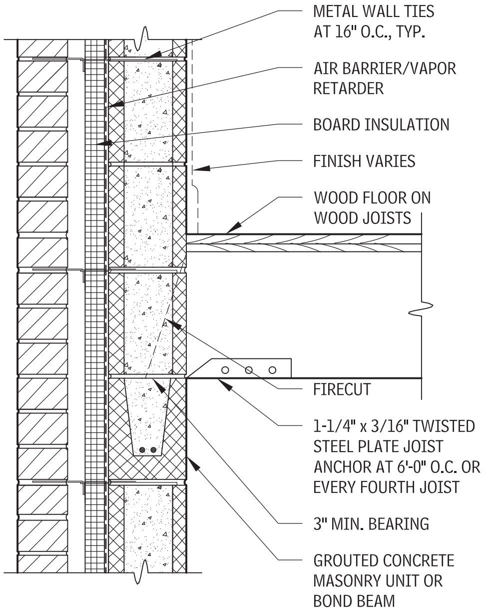


NOTE

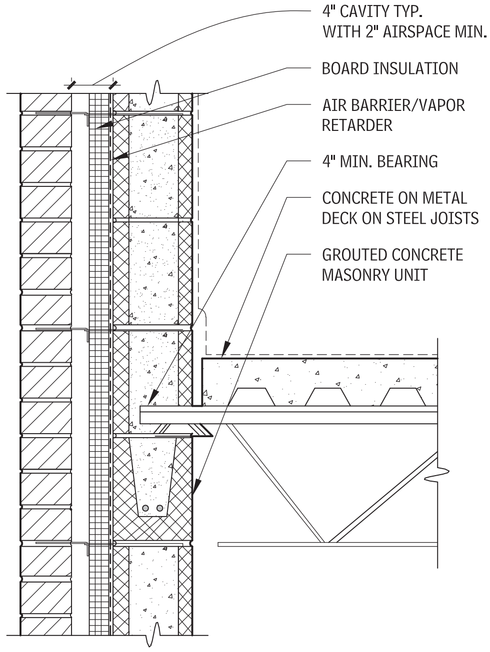
11.240 A common mistake is to seal the flashing to the brick above, which blocks the drainage.

Contributor:
Tom Van Dean, AIA.

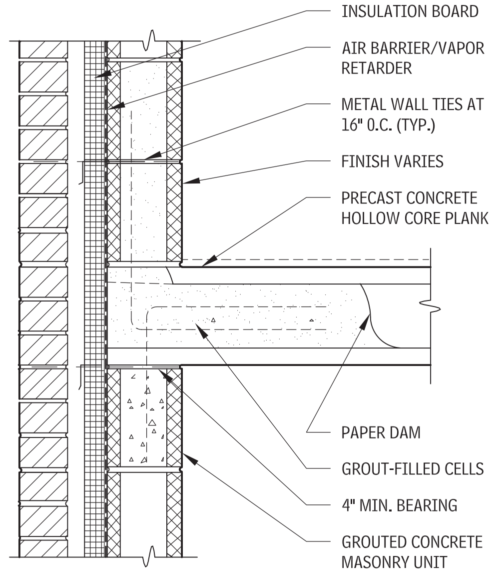
WALL TO FLOOR ANCHORAGE AT CAVITY WALLS
11.242



WOOD FLOOR

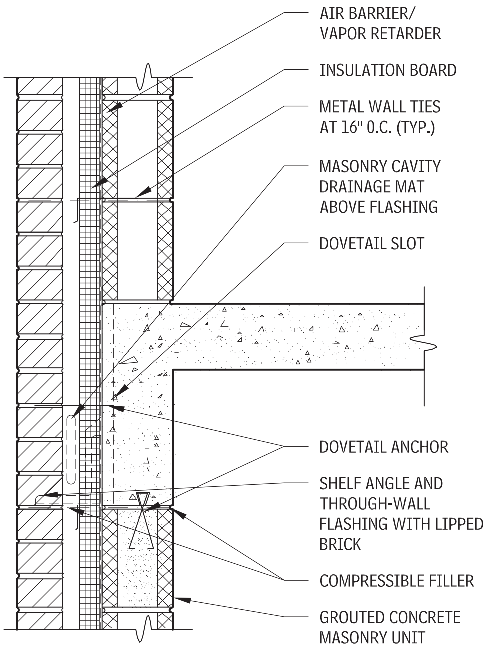


STEEL JOIST FLOOR

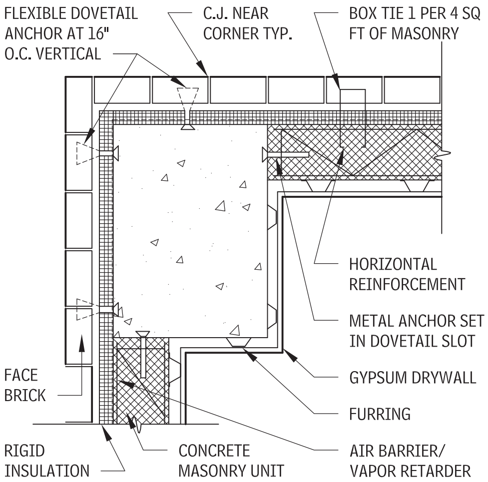


PRECAST HOLLOW CORE FLOOR

SPANDREL DETAIL
11.243



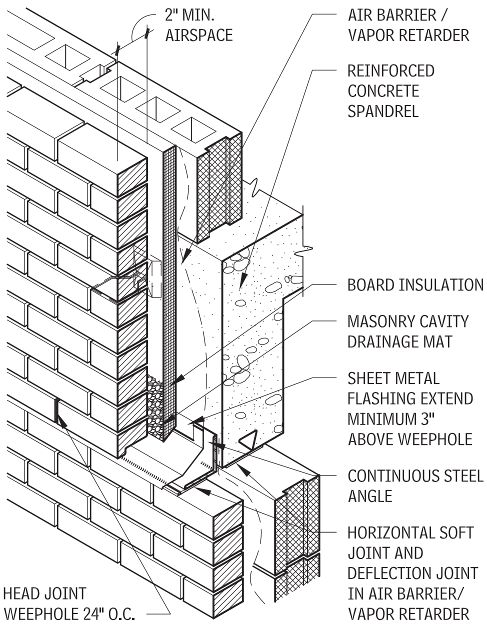
DOVETAIL ANCHORS AT CORNER
11.244

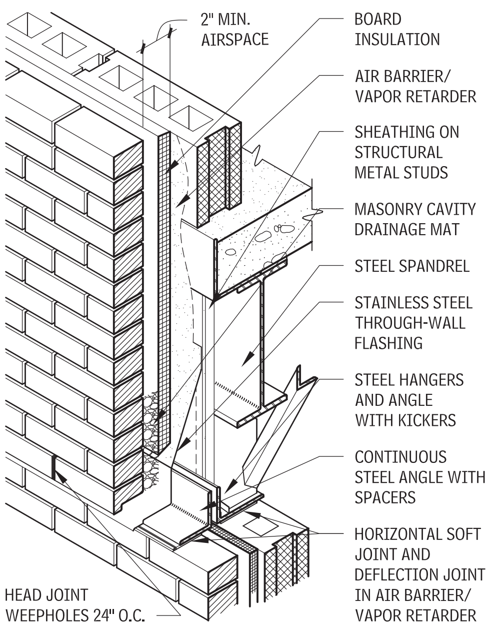


GLASS MASONRY UNITS

When specifying supports and shelf angles, the installed weight and deflection limitation of the glass block should be taken into account, and local building codes checked for any limits on panel sizes or installation details.

CAVITY WALL FLASHING
11.245



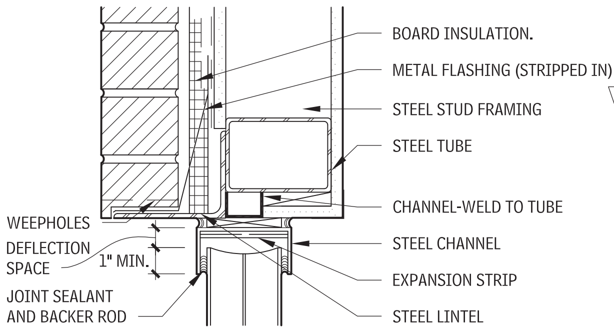


DEFLECTION LIMITATIONS

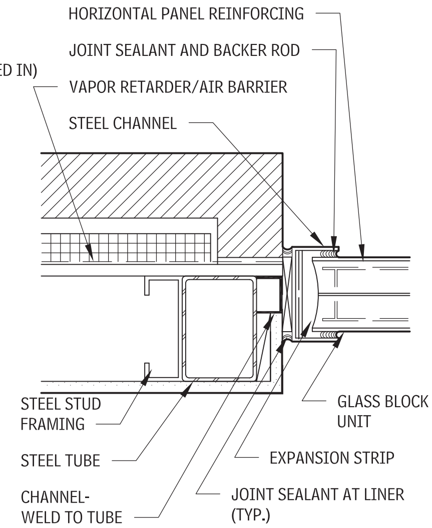
Maximum deflection of structural members supporting glass block panels must not exceed:

L/600
where L = distance between vertical supports.

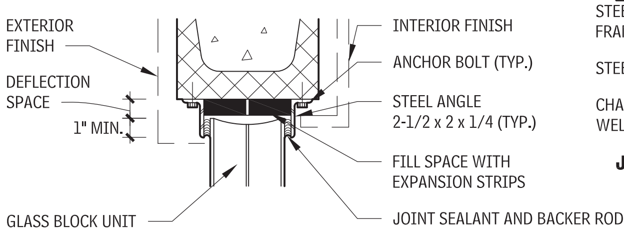
EXTERIOR CONNECTION DETAILS
11.246



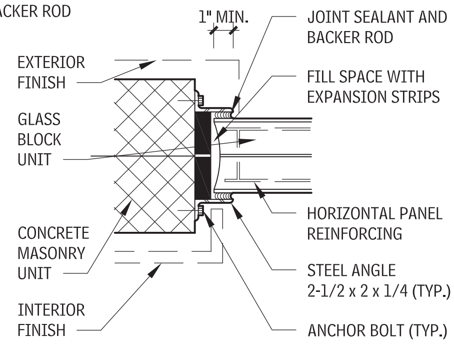
HEAD AT STUB WALL WITH BRICK



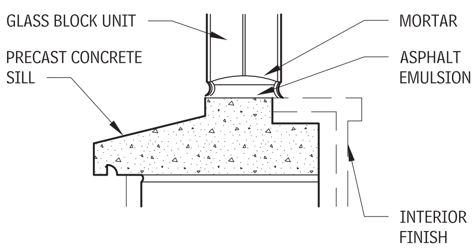
JAMB AT STUD WALL WITH BRICK



HEAD AT CONCRETE MASONRY UNIT WALL



JAMB AT CONCRETE MASONRY UNIT WALL



SILL AT CONCRETE MASONRY UNIT WALL

RAINSCREEN PANELS

Panels are used in a drained cavity exterior wall system by mounting over a suspension system with airspace, a weather barrier, and a structural backup (usually sheathing over studs). The panels come in a wide variety of base materials, sizes, and colors. Most manufacturers sell the tiles together with the suspension system as a proprietary system.

PANELS

Panels are available in a large variety of types. Some are homogeneous through the thickness, while others have the decorative finish applied to one or both faces. Common panel types include:

- *Solid phenolic resin panels with wood fiber binder:* These have a decorative face on one or both sides, with a black core.
- *Engineered wood panels, with veneers and/or cores in clear resin*: In these, the exposed face is available in a variety of high-quality wood veneers.
- *Resin panels with mineral filler:* These panels are generally integrally colored through the entire thickness.

SIZES

Panels range from 4 by 8 ft. to 5 by 12 ft. Thickness ranges from 5/16 to 1/2 in.

FINISHES

Not all panel types are available in all finishes.

- *Solid colors with smooth surfaces and satin gloss:* Standard color ranges are wide, and custom colors are available for larger runs.
- *Wood grain:* Real wood or printed wood veneer.
- *Speckled:* Stone-look or decorative speckled patterns.

WALL ASSEMBLY COMPONENTS

- *Panel:* Panel should be mounted to allow for relatively large amounts of thermal movement. Exposed fastener systems must provide oversized holes. Concealed clip systems should allow sliding of connections.
- *Structural backup:* CMU or gypsum sheathing over cold-formed metal framing.
- *Weather barrier:* Continuous barrier applied over sheathing or CMU.
- *Insulation:* Board or blanket insulation installed in the airspace between suspension system members.
- *Suspension system:* Commonly extruded aluminum or cold-formed galvanized steel furring with mounting clips, that may be propriety to the panel manufacturer. Wood battens can be used in residential or light commercial construction.
- *Through-wall flashing:* Stainless steel or aluminum sheet incorporated with weather barrier. Flashing must incorporate openings to allow ventilation and weeping of cavity.

HEAT, AIR, AND MOISTURE

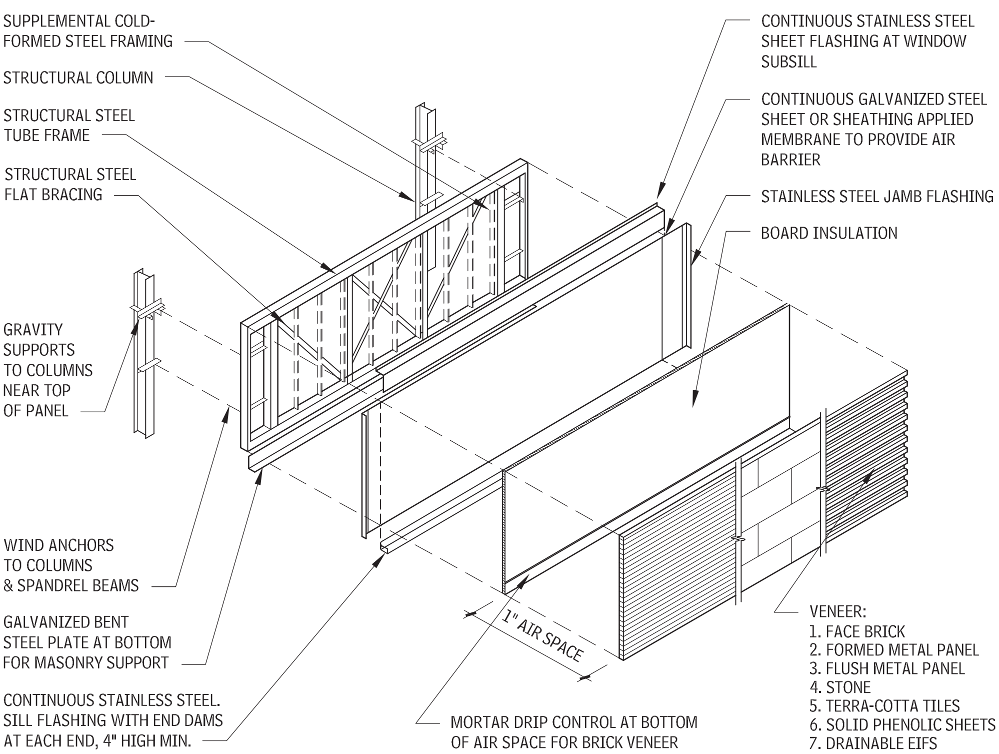
In commercial construction, high-rise situations, or where very high performance is required, rainscreen panel walls should be detailed as drained cavity walls; though they can also be pressure-equalized walls. This wall system performs very well in all climates. The application of the weather barrier and insulation outside the backup wall allows for a continuous application with a minimum of breaks or gaps. If CMU backup is used, the mass stays within the insulation, providing thermal dampening.

Avoid insulation in the stud space, unless dictated by economics. If required, evaluate the assembly for the proper location of the weather barrier and the loss of effectiveness of the insulation because of thermal bridges through the studs. A weather barrier should be installed over the sheathing; dependent on climatic conditions the weather barrier may need to be vapor-permeable.

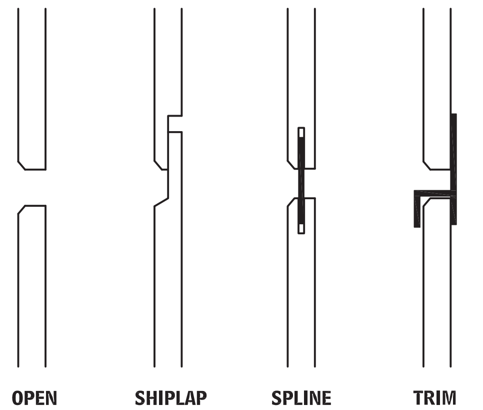
EIFS RAINSCREEN WALL SYSTEM

Water can penetrate the exterior face of a building when wind is driven through the cracks and unsealed surfaces. The rainscreen wall is based on a principle of providing a small air gap between the wall face and a water-proofed inner wall. This allows the moisture to be directed out. Companies produce a variety of proprietary synthetic stucco rainscreen systems based on this principle. The systems vary from exterior insulation boards that have extruded channels, drainage panels, and troweled adhesive, to facilitate water drainage. Particular attention is to be given to system flashing and sealing at expansion and control joints, wall openings such as windows and doors, or any water barrier penetrations within the wall structure.

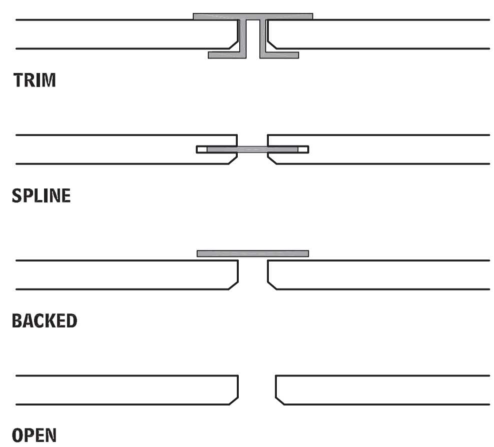
RAINSCREEN PANELS
11.247



PHENOLIC PANEL HORIZONTAL JOINTS
11.248



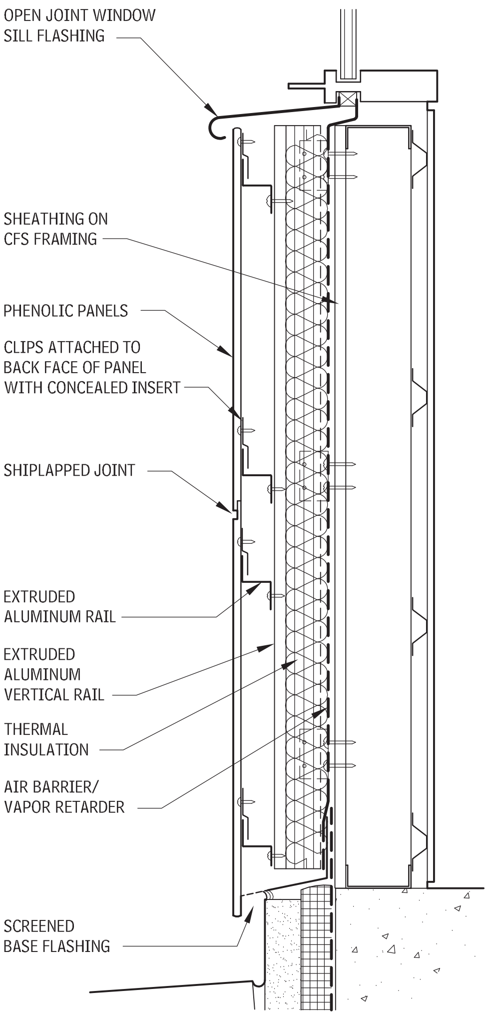
PHENOLIC PANEL VERTICAL JOINTS
11.249



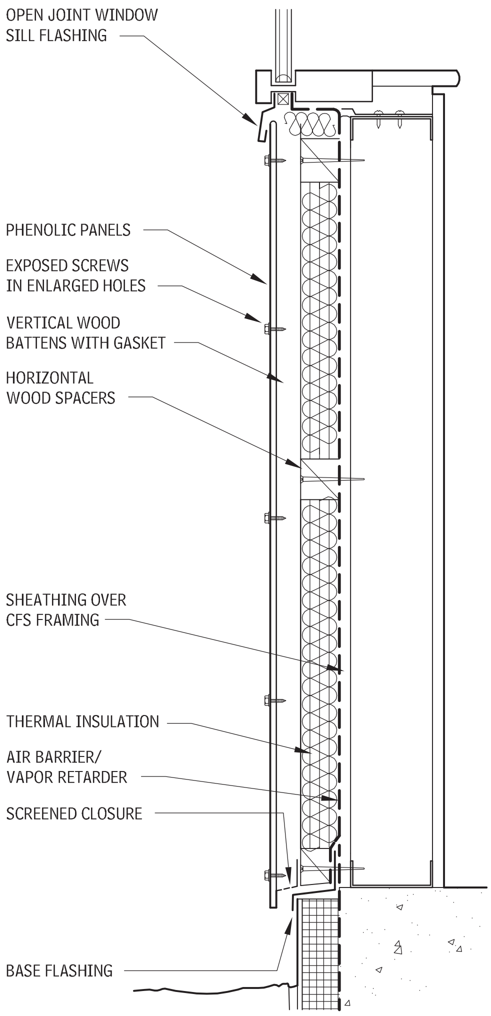
NOTE

11.249 It is preferable to use open joints in a rainscreen assembly that has been engineered by the manufacturer.

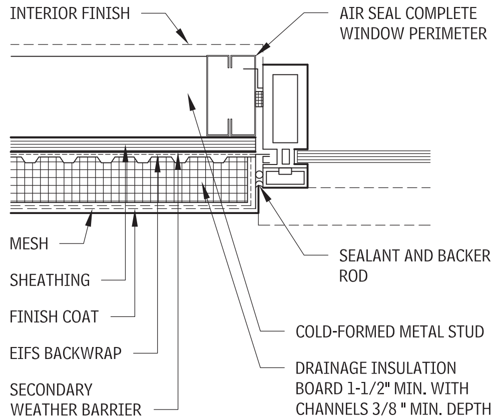
CONCEALED CLIPS ON ALUMINUM GRID
11.250



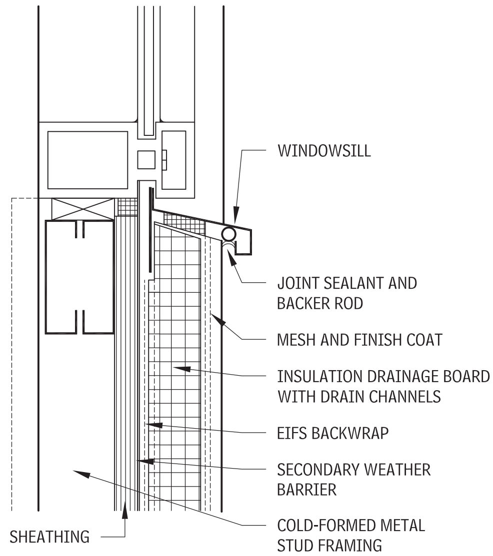
EXPOSED SCREWS INTO WOOD
11.251



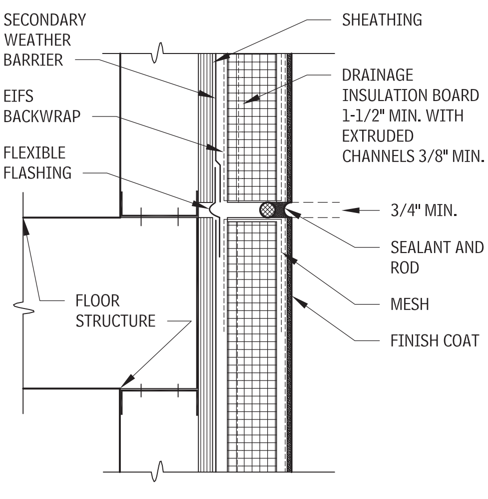
EIFS RAINSCREEN WALL AT WINDOW JAMB
11.254



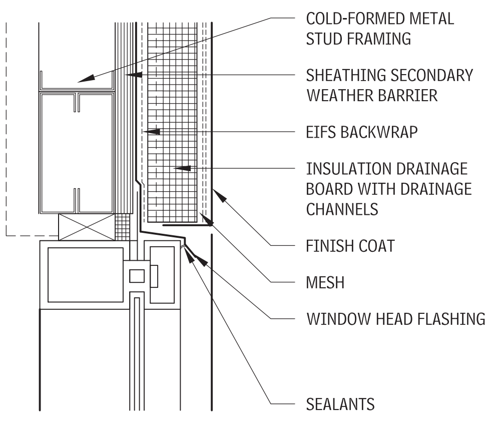
EIFS RAINSCREEN WALL WINDOWSILL
11.255



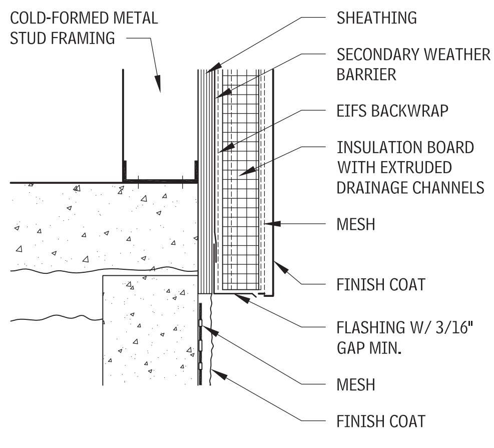
EIFS RAINSCREEN WALL EXPANSION JOINT AT FLOOR
11.252



EIFS RAINSCREEN WALL WINDOW HEAD
11.253



EIFS RAINSCREEN WALL AT FOUNDATION WALL
11.256



Contributor:
Stephan Pienkny, Cline McGee, AIA Hall Architects, Charlotte, North Carolina.

STUCCO

Stucco is a traditional exterior finish material, typically three coats of portland cement plaster, applied over weather barrier to create a drainage plane wall system. It is impact- and fire-resistant; and because it is applied in a plastic state, it can be made to conform to virtually any shape. Durable stucco is, however, highly dependent on knowledgeable and skilled application, as many of the problems attributed to stucco (e.g., cracking, delamination, water leakage) are not inherent to the product but are the result of improper installation.

Stucco is applied in three coats: scratch, brown, and finish.

- The scratch and brown coats are portland cement plaster, typically each approximately 3/8-in. thick; together they are called the base coat. The base coat must be moist-cured for two days, then further curing of five days before application of the finish coat. In very hot or windy conditions, it may be necessary to protect the base coat with tarps or sheeting.
- The scratch coat is so-called because, after application, the surface is roughened with a rake or other device to promote a mechanical bond of the brown coat.
- The brown coat is applied after the scratch coat has set up. IBC requires a minimum or 24 hours between coats if damp-curing is used, or 48 hours without. In the recent past, one week was common for curing. It is important that the scratch coat be properly cured before the application of the brown coat, to minimize the cracking. The brown coat may be reinforced with a variety of fibers, and it must be trowel-floated while still moist but after taking an initial set, to densify the surface and further reduce cracking. Application of the brown coat before the scratch coat has properly cured, and failure to make the additional trowel-float pass, are common causes of cracking in the finished stucco.
- The finish coat may be either portland cement plaster or acrylic, typically 1/8-in. thick. Portland cement-based finish coats are likely to be more durable, but acrylic finish coats generally have better color consistency. Factory-mixed finish coat mixes improve color consistency of cement-based finish coats.

LATH/ACCESSORIES

Lath is typically expanded metal or welded wire mesh of galvanized steel. Self-furring lath has crimps or dimples to space it off the substrate, allowing proper embedment of the stucco. Lath is available with a paper backing, but this should be avoided, because it is extremely difficult to create laps in the paper to properly control the flow of water.

Accessories should be formed from rust-resistant materials. Zinc is preferred, but depending on application and conditions, galvanized steel may be acceptable. Plastic accessories are also available. All accessories that are used at the base of the system (such as edge screeds, control joints, and expansion joints) must be perforated to allow drainage of water from within the stucco.

WEATHER BARRIER

Stucco requires weather barrier behind the lath to control the penetration of water. The paper must be continuous and properly shingled over each sheet and accessories to direct the flow of water. The weather barrier gets wet during application of the stucco and, after drying, pulls away from stucco, creating the drainage plane.

HEAT, AIR, AND MOISTURE

Stucco should be applied over weather barrier to create a drainage plane wall assembly. Stucco applied directly to CMU or concrete, which both function as a barrier system, should be limited to very dry climates. The performance of stucco assemblies can be upgraded by detailing the wall as a drainage cavity with insulation.

WALL ASSEMBLIES

Wall assemblies fall into five categories:

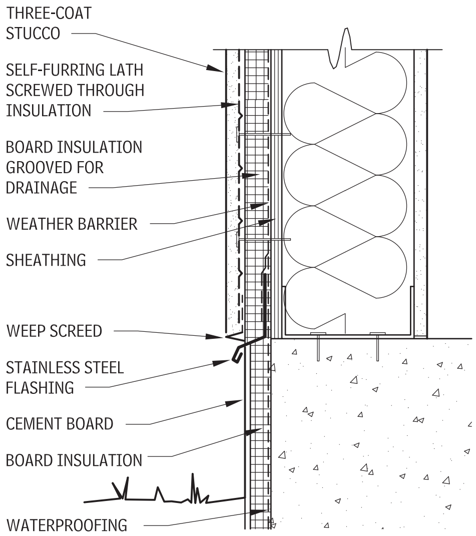
- *Stucco on CMU:* Limit the use of this assembly to very dry climates. Insulation needs to be added within the CMU cores or applied to the inside surface. (Refer to the analysis for single wythe masonry.)
- *Stucco on studs:* Application of stucco over open studs is possible, but not recommended, as proper installation of the weather barrier is very difficult. Without a backup, it is difficult to maintain a consistent thickness of the stucco, resulting in increased cracking. A reasonable amount of moisture will be introduced into insulation in the stud space, so drying of the entire assembly must be analyzed. The location or need of a vapor retarder must be analyzed to allow for drying. The interior gypsum board will need to be detailed as a continuous weather barrier.
- *Stucco on sheathing:* In this assembly, the sheathing provides for a better substrate for both the weather barrier and the stucco, resulting in improved performance of the drainage plane; moreover, the sheathing can be appropriately detailed as the weather barrier. Insulation in the stud space is susceptible to wetting and must be analyzed for moisture accumulation. The location or need of a vapor retarder must be analyzed to also allow for drying. In hot climates, the weather barrier can be upgraded to a weather barrier for improved performance.
- *Stucco on board insulation:* Moving the insulation to the outside of the sheathing allows for the installation of a continuous weather barrier, and improves performance of the drainage plane. Wetting of insulation within the stud space is eliminated, so this type of assembly is more appropriate for colder and wetter climates.
- *Stucco on furring:* Spacing the stucco away from the insulation creates a drainage cavity and improves the performance of the system. However, because a solid layer does not continuously back the lath, it is difficult to maintain consistent thickness of the stucco. Paper-faced lath is helpful.

PORTLAND CEMENT STUCCO VERSUS SYNTHETIC STUCCO

Portland cement stucco is a cement-based mixture of sand, lime, water, and portland cement. It is typically troweled directly onto the masonry or over metal lath, either in two or three coat layers.

Synthetic stucco, or Exterior Insulation Finish System, is formed of foam boards and coated with acrylic resin (which is similar to paint). A fine or coarse sand aggregate is added to the finish coat to give it a textured appearance, similar to cement-based stucco. It can be applied directly to a sheathing substrate, masonry, or concrete.

STUCCO ON BOARD INSULATION
11.257



CONTROL, CONSTRUCTION, AND EXPANSION JOINTS

Cement-based stucco dries hard, and is therefore susceptible to cracking. Placement of joints prevents cracking and spalling of stucco and results in long-lasting exterior finish.

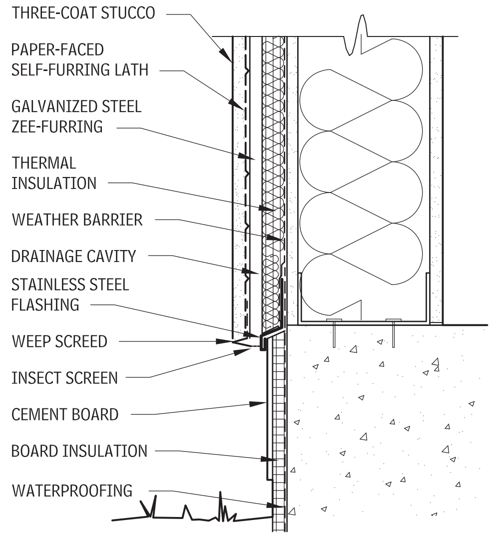
Control joint is a technique used to isolate or limit cracking due to internally or externally induced stresses. Stresses in exterior building envelopes can be caused by shrinkage, movement, or dissimilarity of materials. Joints should extend the full width and height of wall panels and should coincide with square corners such as windows, doors, or changes in heights.

A joint can be handled by insertion of a metal device which allows for construction and expansion caused by dissimilarity of materials, settlement, or building movements.

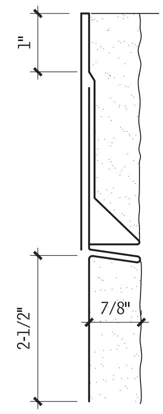
Joints in the stucco substrate such as masonry, concrete, or cold-formed metal stud walls, should be carried through to avoid cracking. The following are good principles for joint location and spacing:

- Length of wall no greater than 18 ft. in either direction
- Panel area not to exceed 144 sq. ft. for vertical applications
- Panel area should not exceed 100 sq. ft. for horizontal application, whether curved or angular

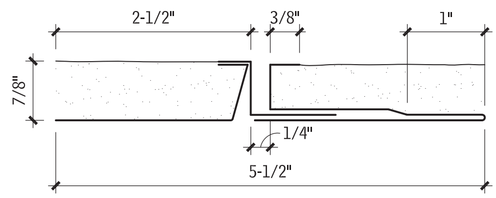
STUCCO ON FURRING
11.258



STUCCO EXPANSION JOINTS
11.259

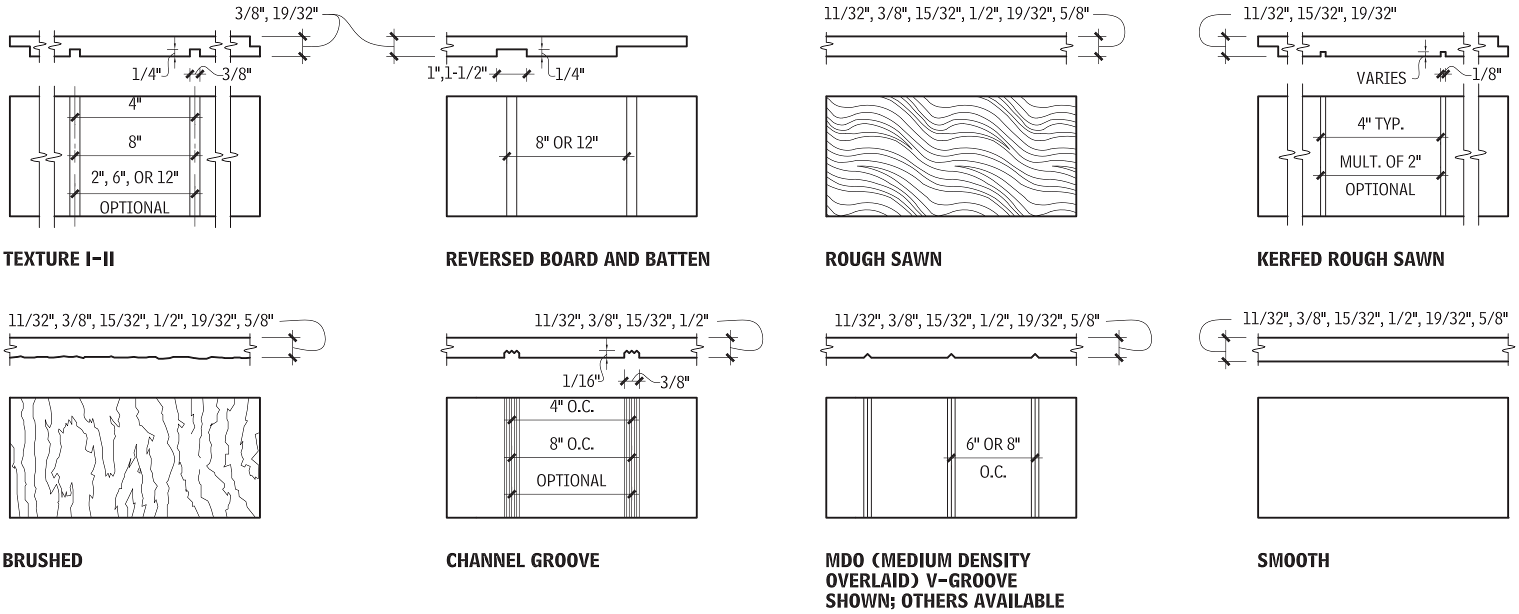


LATH TYPE EXPANSION JOINT – HORIZONTAL



LATH TYPE EXPANSION JOINT–VERTICAL

PLYWOOD SIDING—TYPES AND PROFILES
11.260



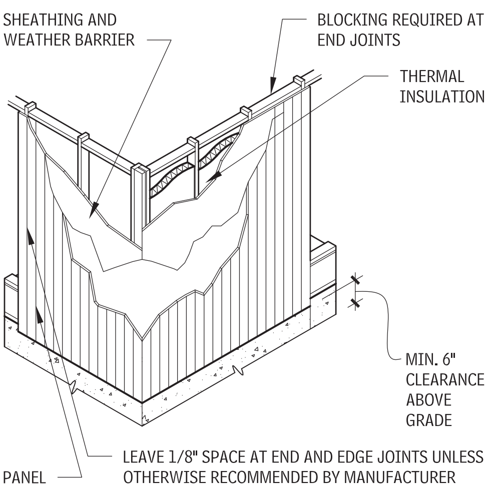
- Length-to-width ratio should not exceed 2 1/2 to 1 in any given panel.
- Joints are required at transition of materials or where joints are present in the substrate concrete, masonry, or masonry veneer walls.

SIDING

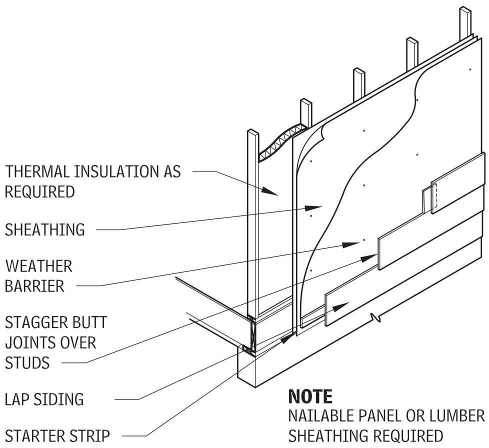
PLYWOOD SIDING PRODUCTS

The types of plywood recommended for exterior siding are APA grade trademarked, medium-density overlay (MDO), Type 303 siding; or Texture 1-11 (T1-11 special 303 siding). T1-11 plywood siding is manufactured with 3/8-in.-wide parallel grooves and shiplapped edges. MDO, which is recommended for paint finishes, is available in a variety of surfaces. The 303 plywood panels are also available in a wide variety of surfaces. The most common APA plywood siding panel dimensions are 4 in. by 8 ft., but the panels are also available in 9-ft and 10-ft lengths, with lap siding to 16 ft.

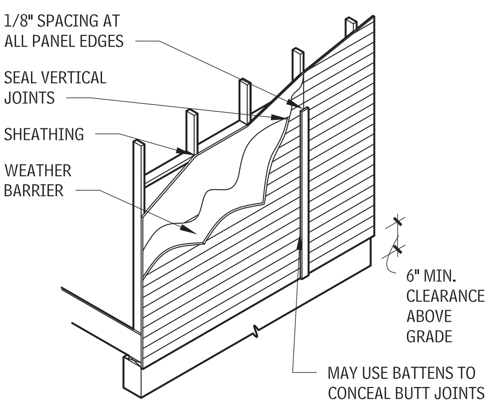
PANEL SIDING—VERTICAL APPLICATION
11.261



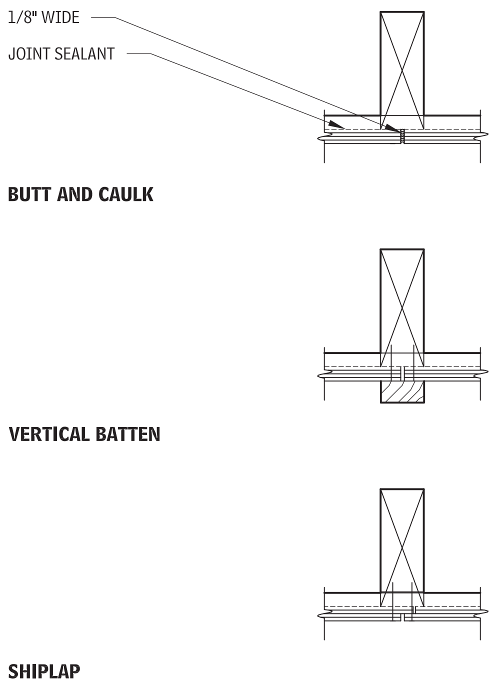
LAP SIDING APPLICATION
11.262



PANEL SIDING—HORIZONTAL
11.263



VERTICAL JOINTS
11.264



MINERAL-FIBER-REINFORCED CEMENTITIOUS PANELS

These panels, typically 5/16-in. thick, are available smooth or with a texture and factory finished or primed. Cement panels are extremely resistant to damage from moisture and come with warranties up to 50 years.

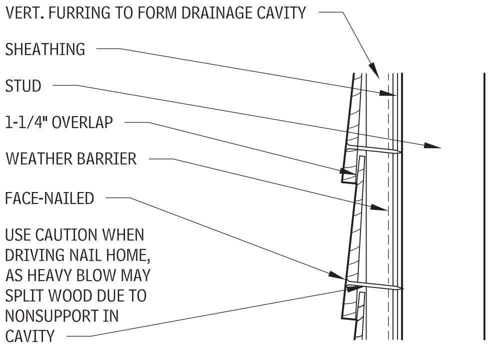
WOOD FIBER PANELS

Hardboard, fiberboard, and other engineered cellulose-based products are available.

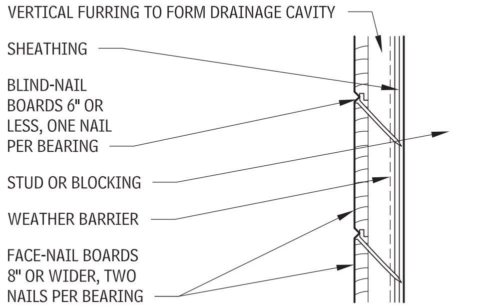
NOTE

11.262 Nailable panel or lumber sheathing is required.

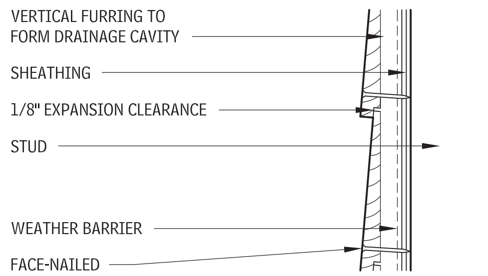
PLAIN BEVEL
11.265



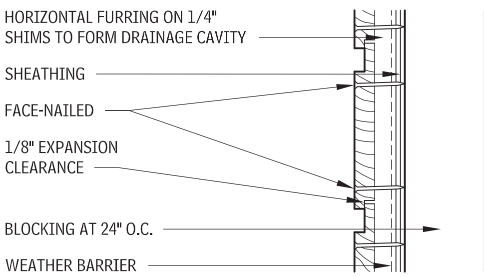
TONGUE-AND-GROOVE (VERTICAL OR HORIZONTAL)
11.266



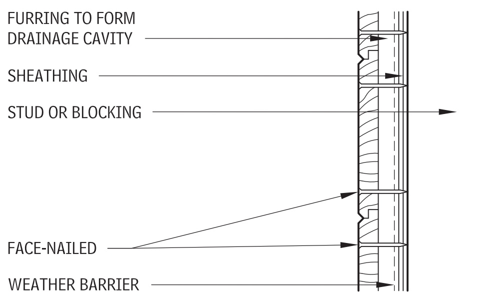
RABBETED BEVEL
11.267



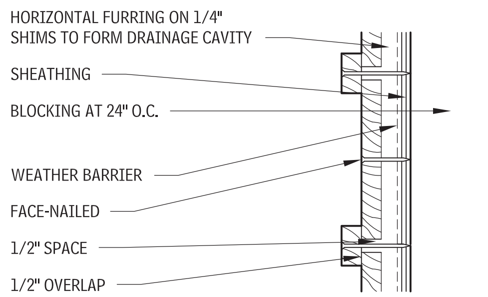
CHANNEL (VERTICAL)
11.268



SHIPLAP (VERTICAL OR HORIZONTAL)
11.269



BOARD AND BATTEN (VERTICAL)
11.270



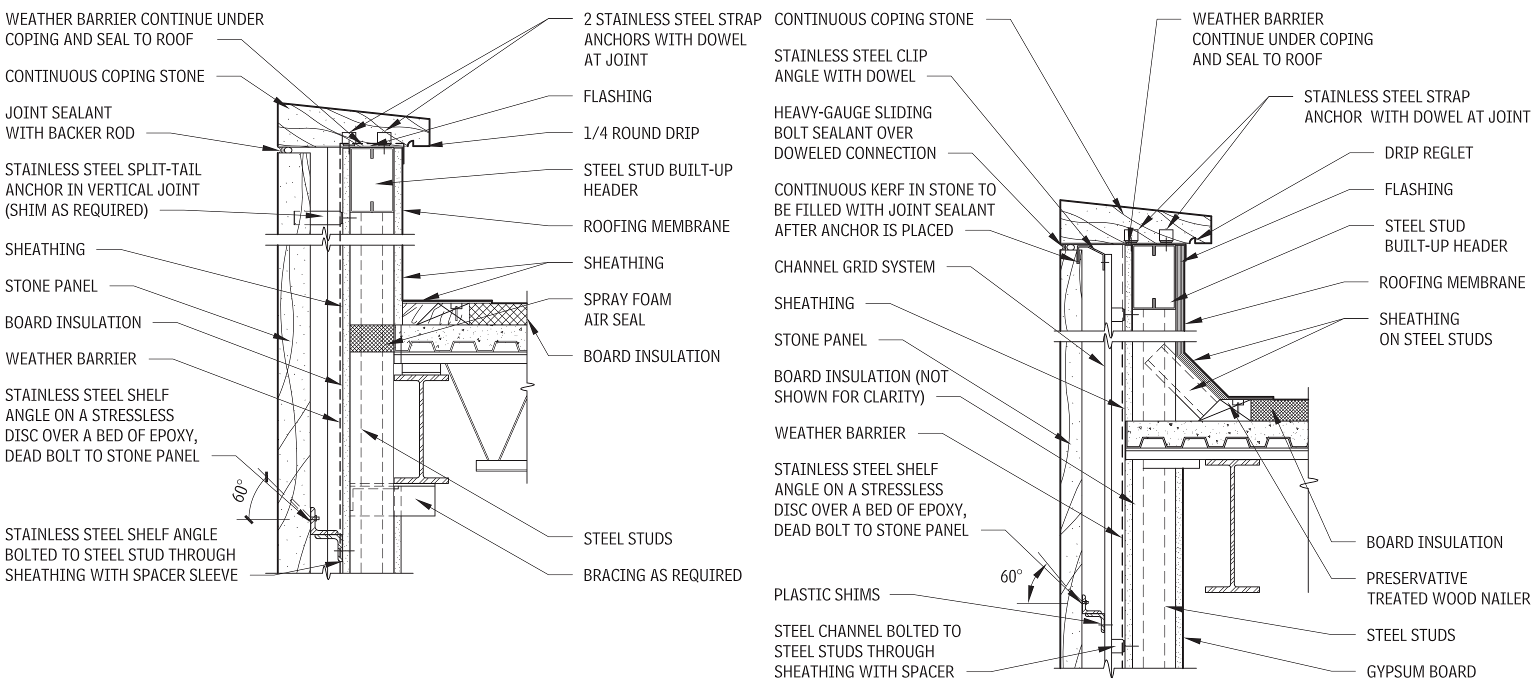
STONE PANELS

STONE PANELS ON STEEL FRAMING

Detailing stone panel wall assemblies is important; consider the following recommendations:

- Because of the cost and weight of stone, a highly reliable backup and support system is recommended.
- Provide a continuous weather barrier over the face of the sheathing.
- Insulation is located in the cavity; not in the stud space.
- CMU may be used for backup, instead of studs and sheathing.
- Bolt anchors to steel studs.
- Design considerations for bearing and retaining anchors include: width of cavity, adjustability of slotted connections, shim systems, avoidance of down-turned slots, and minimum thickness between anchor slot and face of stone.

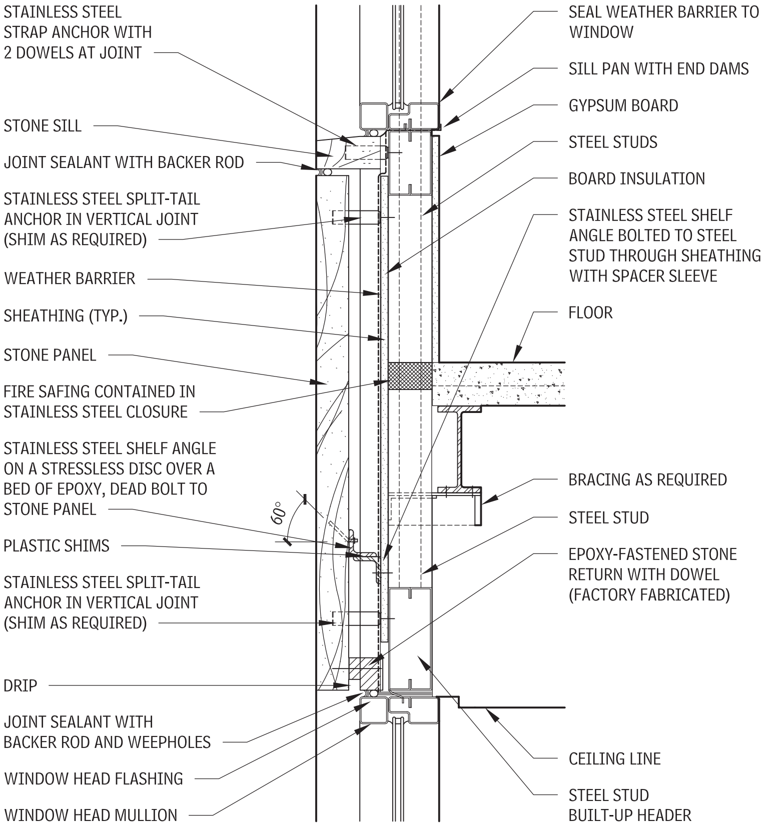
SECTIONS AT ROOF PARAPET
11.271

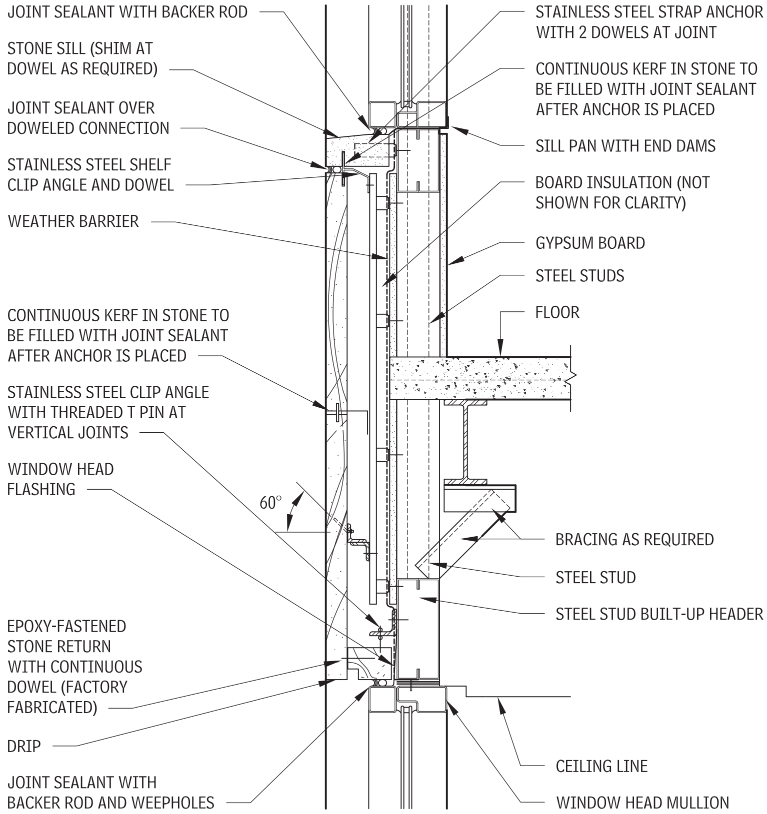


NOTE

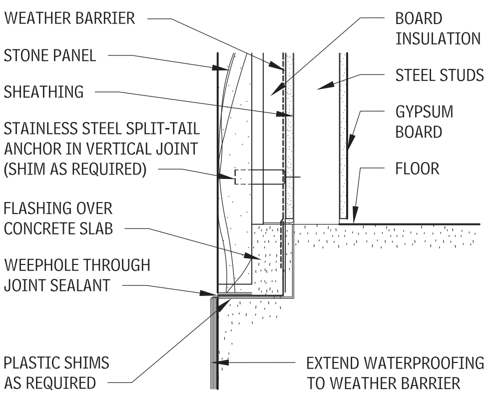
11.271 Fireproofing of steel has been omitted for clarity.

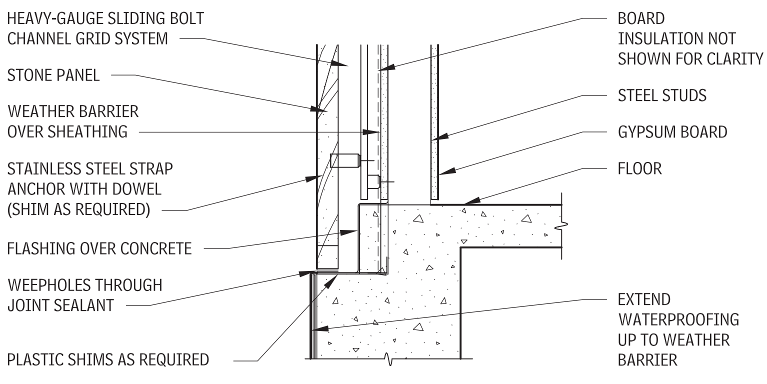
STONE SPANDREL AT WINDOW HEAD AND SILL
11.272



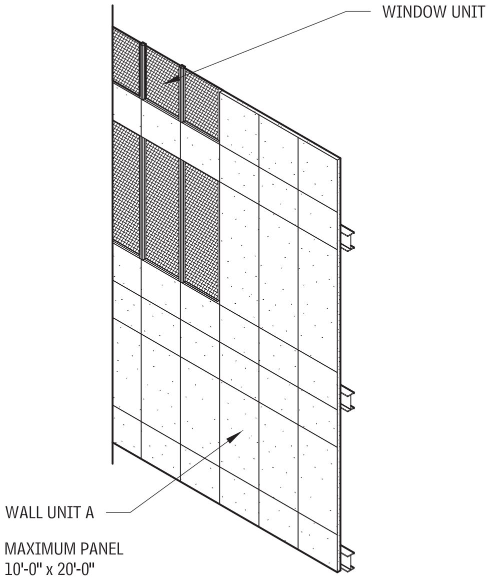


STONE SPANDREL AT FOUNDATION
11.273

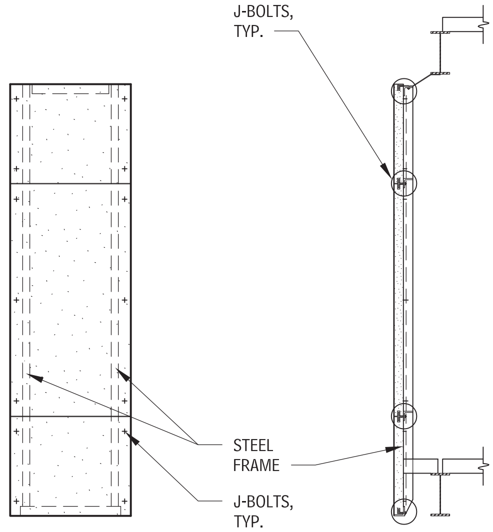




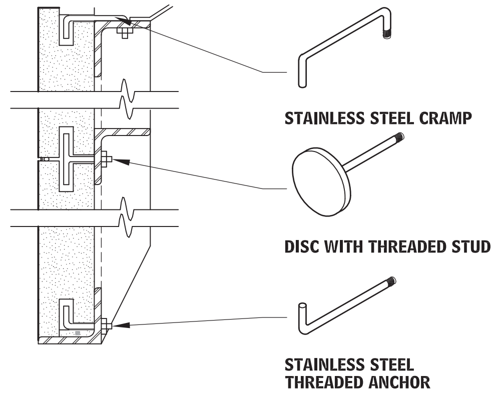
FABRICATED STONE PANELS
11.274



VIEW OF BUILDING FACADE

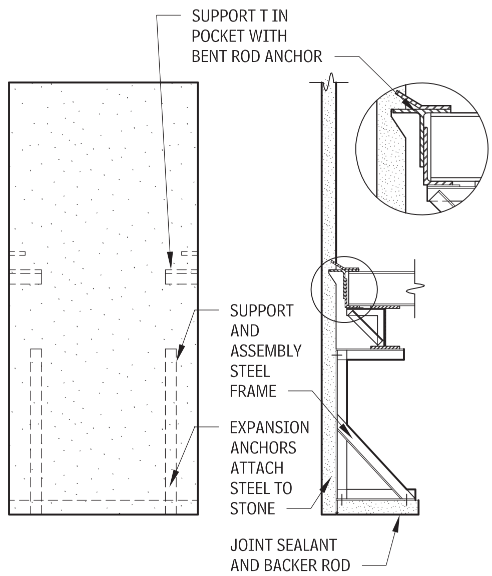


ELEVATION – UNIT A **SECTION – UNIT A**

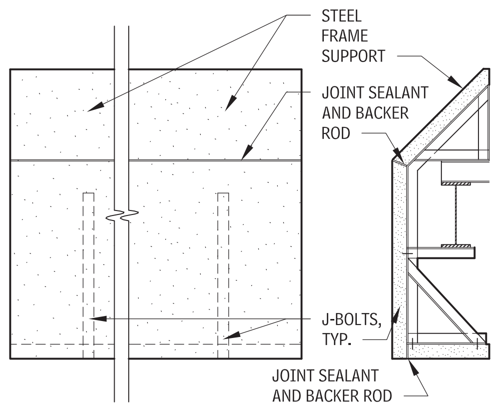


CONNECTION DETAILS

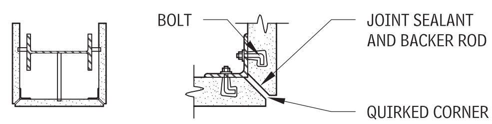
FABRICATED STONE PANELS ON STEEL FRAME
11.275



ELEVATION AND SECTION – PARAPET UNIT



ELEVATION AND SECTION – SILL, SPANDREL, AND SOFFIT UNIT



PLAN – COLUMN TRIM UNIT

FABRICATED STONE PANELS

Fabricated stone panel technology offers savings in on-site labor and accuracy in the joining of component stone units.

Shipping and erection stresses on the stone panels and stone anchorage system of the fabricated units should be evaluated.

Design of sealant joints between fabricated units should include at least the following:

- Thermal movement
- Fabrication and erection tolerances
- Irreversible material growth or shrinkage
- Sealant movement potential

STONE ON STEEL FRAME WITH EPOXY JOINTS

Stone panels are mounted in a steel frame, with expansion anchors and dowel pins (as recommended by the fabricator). Joints between the panels are sealed with epoxy, maintaining a gap of approximately 1/8-in. Stone panels in the assembly are anchored as a unit to the building structure. Fabricated stone panel installation reduces individual leveling, plumbing, and aligning; and on-site joint sealing is not as extensive as with individual stone panels.

COMPOSITE ASSEMBLIES OF STONE AND PRECAST CONCRETE

Stone units are bonded to reinforced precast concrete panels with bent stainless steel anchors. A weather barrier and a bonding agent are installed between the stone and concrete in conditions where concrete alkali slats may stain stone units.

STONE AND STEEL ASSEMBLIES WITH SEALANT JOINTS

Stone units are shimmed and anchored to a steel frame using standard stone connecting hardware. Joints may be sealed on-site, along with joints between assemblies.

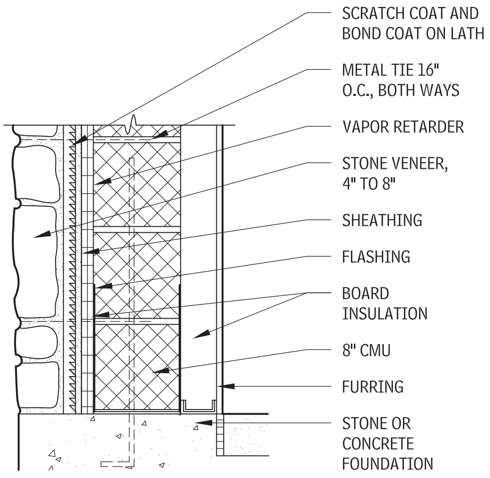
HEAT, AIR, AND MOISTURE

Fabricated stone panels function as mass barrier systems, similar to precast concrete. Use a double line of sealant with weeps.

STONE DETAILS

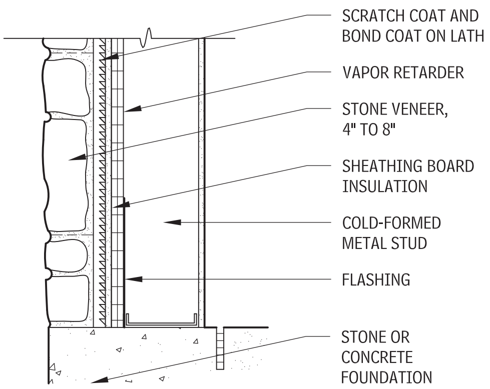
A traditional structural stone wall typically consists of two independent faces (interior and exterior) of closely fitted stones, with a code-prescribed percentage of bonding unit stones that extend the full thickness of the wall. Together, these two stone faces create a massively thick wall, rarely less than 24 in. thick. A stud or furred wall and insulation typically finish the interior wall assembly. The

STONE VENEER WITH CMU BACKING
11.276



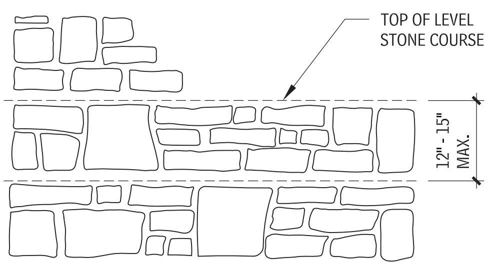
STONE VENEER WITH CMU BACKING

STONE VENEER WITH COLD-FORMED METAL STUD BACKING
11.277



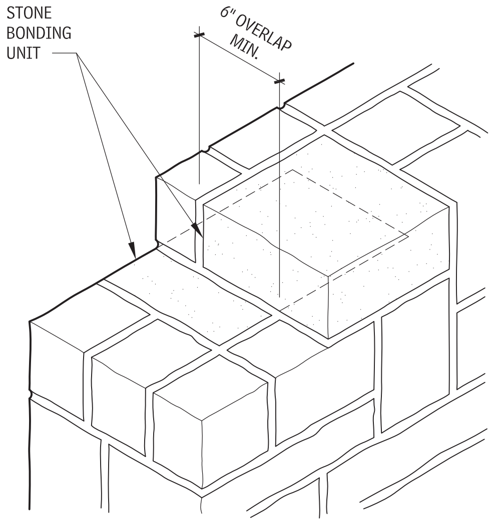
STONE VENEER WITH COLD FORMED METAL STUD BACKING

STONE WALL COURSES
11.278

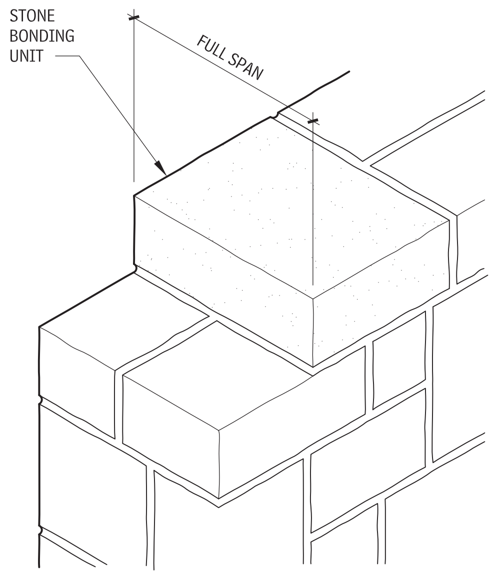


ELEVATION

STONE WALL BONDING UNITS
11.279

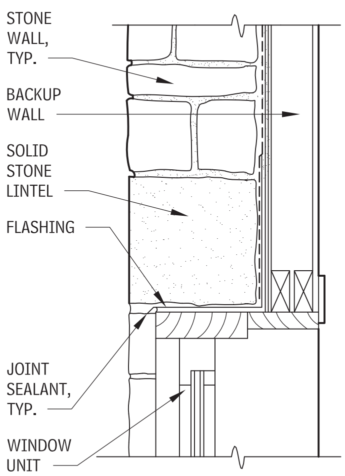


BONDING UNIT TYPE 2

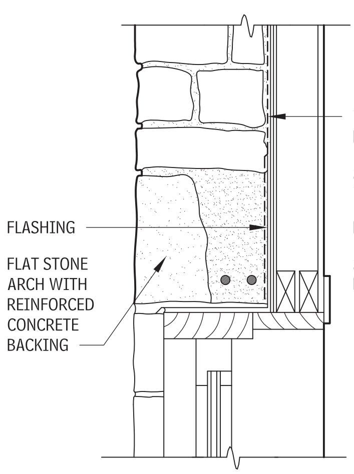


BONDING UNIT TYPE 1

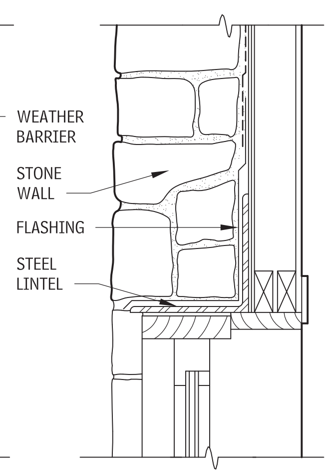
STONE WALL LINTELS
11.280



SOLID STONE LINTEL



STONE ARCH WITH REINFORCED CONCRETE BACKING



STEEL LINTEL

need for a vapor retarder, and the placement of the vapor retarder within the wall assembly, is determined by climate zone.

For structural stone walls, it is best to lay the stone in regular courses, 12 to 15 in. high per course. Limiting the height from the top of one level course to the top of the next level course ensures that the wall joints will be consistently bridged, thereby avoiding long continuous vertical joints both perpendicular and parallel to the plane of the wall face. This will help prevent long cracks from developing, which can cause large sections of the wall to split and fall off.

Control joints should be built into masonry construction in wall sections up to 30 ft. long to account for expansion and contraction of the stone.

A simple rule of thumb for masonry construction is to rely on gravity, not the bond of mortar, as the predominant "bonding agent" for stone. Consult codes to determine the minimum percentage of bonding units per structural stone wall. Some codes require that 15 percent of the face area be composed of bonding units.

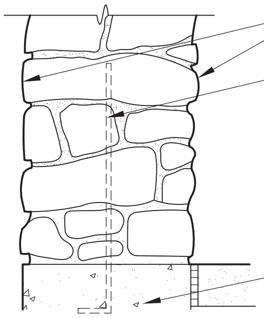
The thickness of veneer depends on the type of stone, to be verified with the supplier or quarry.

NOTE

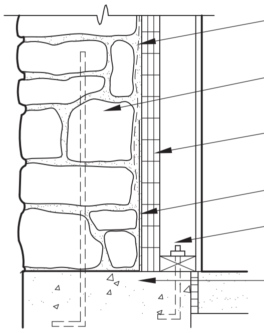
11.279 Some building codes require full-span bonding units while others permit a minimum 6-in. overlap between adjacent stones.

Contributors:
Marble Institute of America, Cleveland, Ohio; Indiana Limestone Institute of America, Bedford, Indiana.

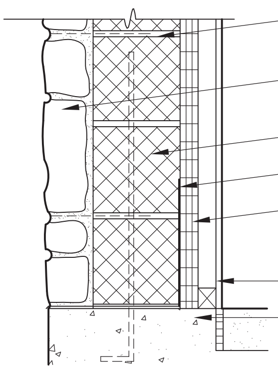
TYPICAL STONE WALL SECTIONS
11.281



TRADITIONAL/SOLID

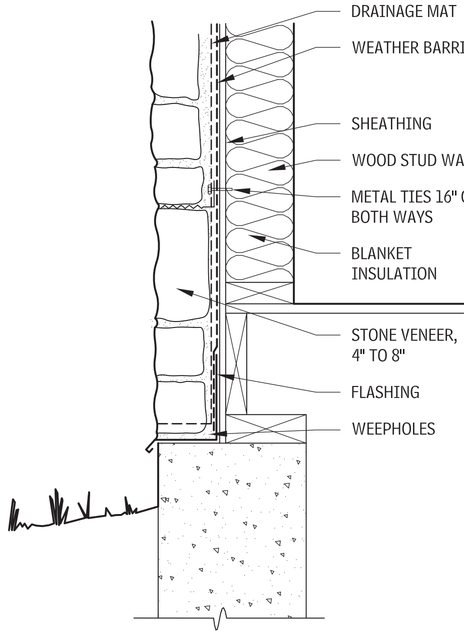


BOARD INSULATION BACKING

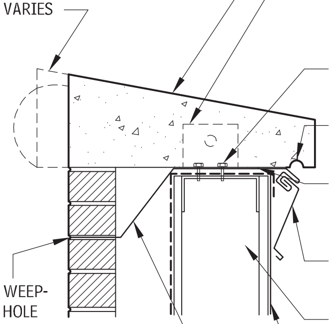


STONE VENEER WITH CMU BACKING

STONE VENEER WITH FRAME BACKING
11.282



CAST STONE COPING
11.283



CAST STONE VENEER

Cast stone is an architectural concrete unit manufactured to simulate natural cut stone. Cast stone can be used as a rainscreen veneer in an exterior enclosure wall assembly, essentially using the same methods as brick veneer. Individual pieces of cast stone may also be supported and anchored in much the same manner as dimensional stone.

Cast stone can be used for trim items (e.g., belt courses, windowsills, lintels, quoins, cornices, or copings) or for complete building facing. Cast stone is manufactured using cement and aggregates, with pigment only for color; or white cement with white sand and integrally colored aggregate (from crushed marble or granite) can be used for color and texture.

Cast stone is typically cast facedown in a mold with five formed sides and unformed back. For economy, L- or U-shaped pieces should be avoided, because the complicated forms are more costly than simply making a larger piece.

NOTES

11.282 Complete appropriate detailing for weather barrier and vapor retarder.
11.283 Weep at flashing through brick.

PANELIZED WALL CLADDING

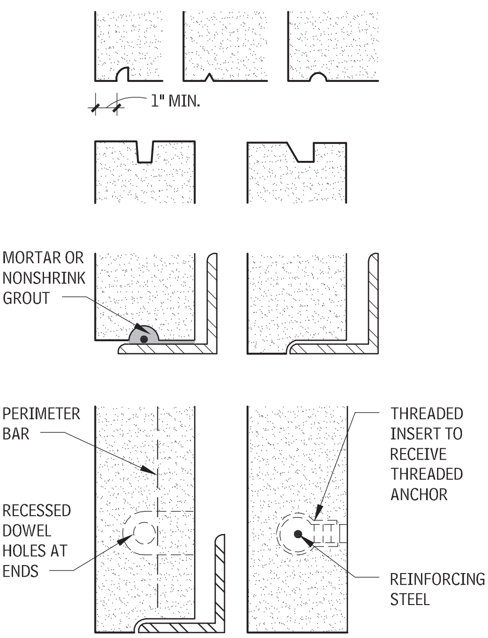
It is possible to panelize major pieces of complete wall assemblies. Panels are typically one structural bay wide and either one story high (if the design includes punched windows) or one spandrel high (if a horizontal strip window design is used). Anchoring of the panels includes one fixed-gravity anchor, one sliding-gravity anchor, and the remainder of the anchors for lateral loading only. Gravity anchors are preferred to be located near the top of a panel for erection safety.

Panelization provides a variety of benefits. Erection of the enclosure can be done faster and safer and during inclement weather, and factory fabrication provides a higher level of quality control and tighter tolerances. Although panelization does not usually result in a large cost savings, in comparison to conventional construction other savings can be realized: in schedule, temporary heat/enclosures, freeing up of the site to other trades, and similar considerations.

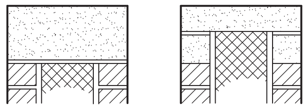
PANEL ASSEMBLY COMPONENTS

- *Structural supporting frame:* This is usually designed as a truss, to span from column to column, and is fabricated from structural steel shapes and/or cold-formed metal framing.
- *Sheathing:* Galvanized steel sheets are used to help provide structural rigidity, and gypsum sheathing is also common.
- *Weather barrier:* When gypsum sheathing is used, a weather barrier is required. The galvanized steel sheet may be detailed, with all joints shingled and sealed to form a weather barrier.
- *Insulation:* Insulation is installed in the airspace. Blanket insulation installed between the studs may be acceptable in some climates, but is not recommended.
- *Rainscreen panel:* Nearly all claddings that are used in drainage cavity or pressure-equalized wall assemblies are good candidates for panelization. These include brick, cast stone, and dimensional stone; aluminum composite material and plate architectural metal panels; formed metal panels; terra-cotta; resin-based panels; and EIFS.
- *Interior finish:* Normally, gypsum board is installed at the project site on furring or studs.

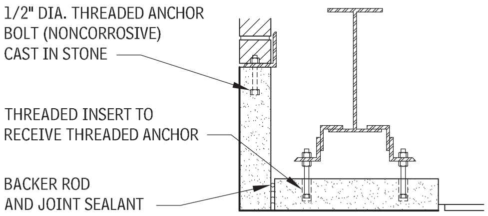
DRIPS, REGLETS, AND SUPPORT SYSTEMS
11.284



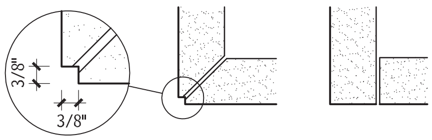
COPING, HEADER, AND RETURN SHAPES
11.285



COPING

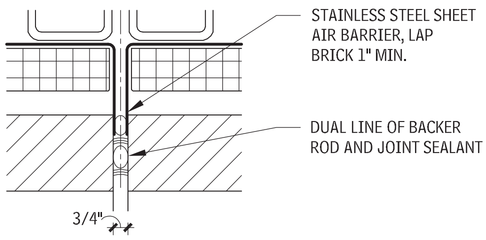


HEADER



RETURNS

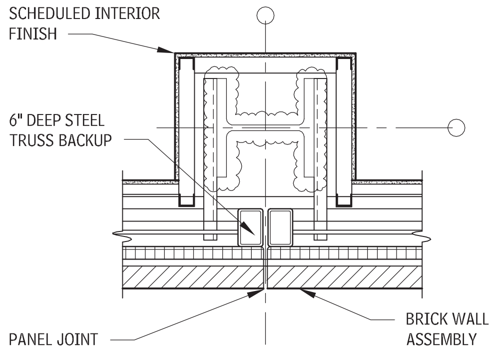
PLAN DETAIL AT MASONRY PANEL JOINT
11.286



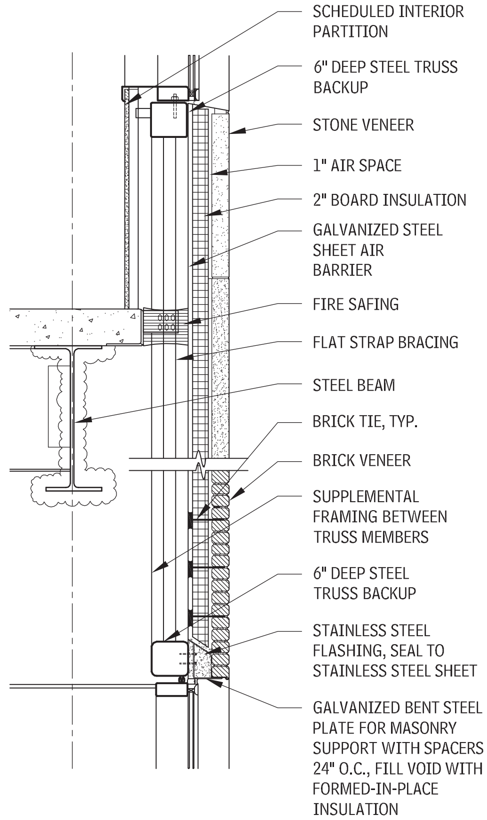
HEAT, AIR, AND MOISTURE

The perimeter flashing required for the shipping and field-joining of the panels results in a pressure-equalized rainscreen system that performs well in all climates and extreme precipitation. A potential weakness for panelized systems is at the panel joints; therefore, a double line of sealant with weepholes is required at panel-to-panel joints.

MASONRY PANEL WALL ASSEMBLY
11.287



PLAN



SECTION

Contributor:
Cast Stone Institute, Lebanon, Pennsylvania.

INSULATED METAL PANEL WALL ASSEMBLIES

Metal wall panels fall into two primary categories: field assembled and factory formed. Metal wall panels span between 4 and 15 ft., depending on gauge of metal, panel thickness, and wind load. Finish on metal panels can be raw galvanized sheet or any number of various factory-applied finishes ranging from baked-on enamel to high-performance polyvinyldene flouride (PVDF) coatings.

FIELD-ASSEMBLED PANELS

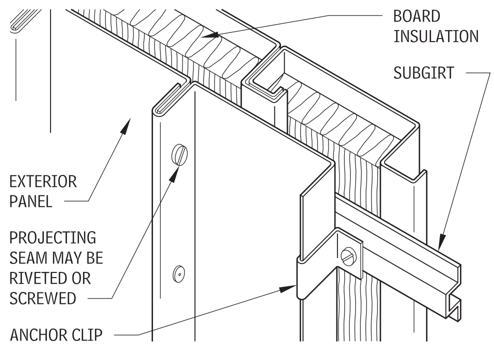
The order of assembly for these panels is as follows:

1. Metal liner panels are secured to structural girts with self-drilling, self-tapping screws. Liner panels are typically 24 in. wide. The depth of the liner panel is determined based on required insulation (2 to 4 in.).
2. Semirigid mineral wool insulation located on the inside liner panel.
3. Subgirts are screwed to liner panel flanges.
4. Outer metal panels are screwed to subgirts. Outer panels can be corrugated, standing seam, batten, or formed into box shapes. Fasteners that are typically exposed (but concealed fasteners are available).

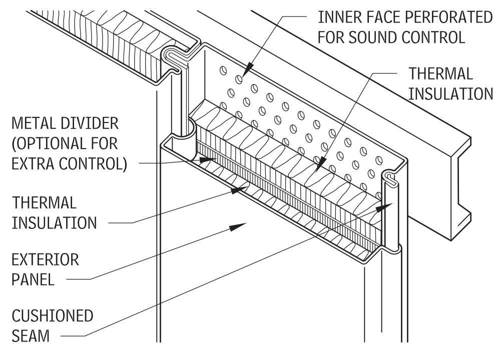
FACTORY-FORMED METAL PANELS

Panels are typically between 24 and 36 in. wide, up to 40 ft. long, and between 2 and 4 in. thick. Panels are fabricated either by laminating inner and outer sheet metal skins to rigid insulation or by injecting expanding foam between the two skins. Panels can be oriented horizontally or vertically and are available in a large number of profiles. Horizontally oriented panels provide rainscreen design joints.

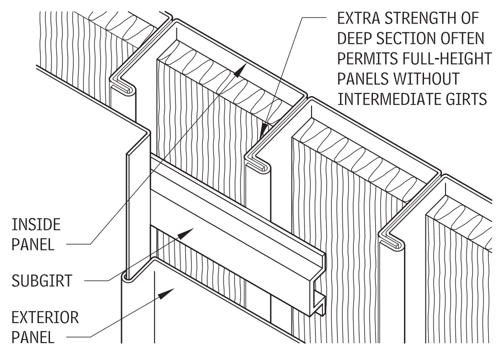
FIELD-ASSEMBLED WALL PANELS
11.289



TYPICAL INSULATED

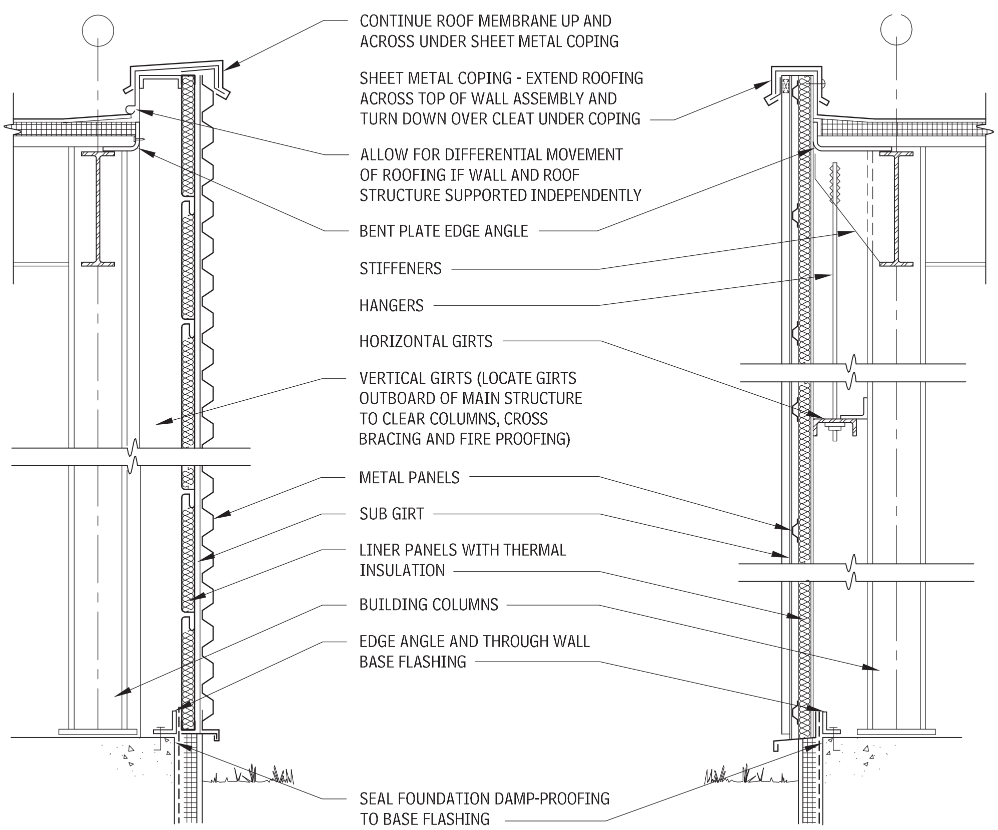


ACOUSTICAL



EXTRARIGID

METAL PANEL WALL SECTIONS
11.288



VERTICAL PANELS **HORIZONTAL PANELS**

HEAT, AIR, AND MOISTURE

Field-assembled insulated metal panels are drainage cavity-type walls. Water that may penetrate the outer skin is weeped to the outside by through-wall flashing. Factory-formed panels are available with pressure-equalized rainscreen-type joints or shingled overlap joints. For both types of systems, the inner sheet metal skin functions as the air barrier and must be sealed to make the system perform. Most panels accomplish this with a factory-installed gasket or bead of noncuring sealant inside of the receiving groove that is then compressed by the tongue during installation. Relatively slight misalignment of panels will not provide the proper compression of this inside seal, resulting in a large air leak and loss of function of the rainscreen joint. Joints across the short direction of the panel cannot be fabricated with the tongue and groove. Typically, the joints are backed up with girts or flashing, and the panels are bedded in sealant and an outer wet seal or dry gasket is added.

METAL CLADDING PANELS

Metal cladding panels are made in a wide variety of shapes and sizes. However, if properly designed as part of a drained cavity wall or drainage plane wall, all of them can perform well. Most of the panels, except interlocking tiles, can span several feet over a spaced support system.

Following is a list of cladding panel types:

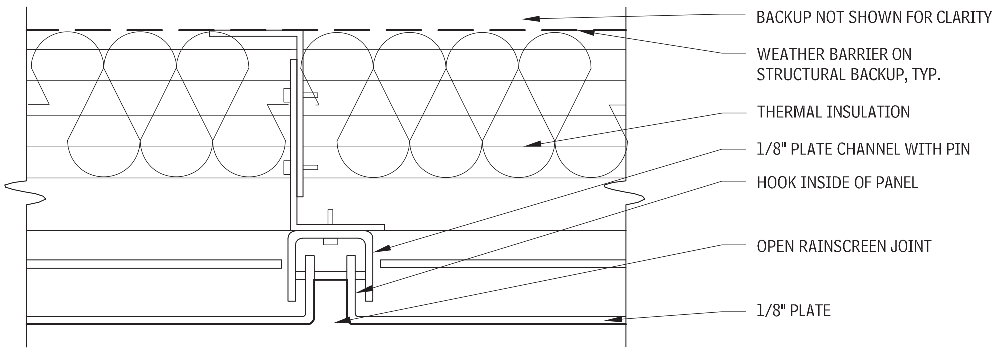
- *Formed sheet metal:* Made up of aluminum, galvanized steel, and, less common, stainless steel, zinc, or copper, these panels are formed into corrugated, standing seam, batten, or box shapes with exposed or concealed fasteners.
- *Aluminum composite material:* These types of panels consist of two gauge metal layers of aluminum bonded to a rigid plastic core. These panels are very flat and easily fabricated into a variety of configurations and mounting methods.
- *Plate:* Typically made up of 1/8-in.-thick solid aluminum or stainless steel, this panel is stretcher-leveled and fabricated with folded-back perimeter frames.
- *Interlocking flat lock seam tiles:* These panels are made from light-gauge copper, zinc, lead-coated copper, titanium, and stainless steel; they are shop-formed into small interlocking tiles for installation over a continuous substrate.
- *ACM and plate systems:* A wide variety of proprietary mounting methods for large-scale architectural panels are available, with associated pros and cons.
- *Staggered clip mounting:* Clips around the perimeter of the panels are spaced so that clips of adjacent panels do not overlap. ACM and plate systems can be formed for this mounting system, with wet sealant joints or dry gaskets. The primary advantage of this system is that it allows for nonsequential erection and repair of isolated panels without disturbing the remainder of the field.
- *Tongue-and-groove clip mounting:* Perimeter panel extrusions are supported by spaced tongue-and-groove type clips. Each clip supports the gravity load of only one panel while restraining the other panel against wind and allowing movement. Joints can be wet-sealed or dry-gasketed but are more commonly dry-splined with the same material as the panel fitting into the perimeter extrusion, though the spline can be the same or a contrasting finish. While requiring sequential erection, this system provides for less oil-canning of the panel and better joint alignment.
- *Hook-and pin mounting:* This is the most common plate system; each panel has hooks in the vertical edge that engage pins in vertical channels mounted to the support grid. The horizontal joints include a shingled overlapping joint that direct water to the vertical channel. Fabrication costs tend to make this system more expensive, but the free movement for flatness and nonsequential erection are positives.
- *Route and return:* Route and return is a method to fold ACM, and sometimes plates, to a very tight corner. A V-groove is routed out of the back of the panel, leaving only the thin outer skin intact, and then the edges are folded (or returned). Perimeter frames may or may not be added.
- *Continuous edge grip:* ACM panels have an extremely small groove routed in the plastic interlayer around the full perimeter of the panels. Aluminum extrusions with a small tongue are glued into this groove to hold the panel. A very small edge of the perimeter extrusion is visible.
- *Dry-gasketed joints:* Soft silicone, EPDM, or neoprene extruded gaskets provide a neater joint, easier future access to fasteners under the joint, and good weather performance.
- *Dry-splined joints:* Joints splined with ACM or plates may provide the sharpest corners and cleanest edges.
- *Open joint systems:* These panel systems consist of baffles and shingled flashing for pressure-equalized rainscreen systems.
- *Finishes:* Some metals have inherent finishes such as zinc, copper, and galvanized steel. Most metals require applied finishes that include anodized, color anodized, polyvinylidene fluoride (PVDF), baked-on enamels, powder coatings, and many others. PVDF coatings have become very common because of their wide range of colors and metallic finishes, extreme durability, and color consistency.

HEAT, AIR, AND MOISTURE

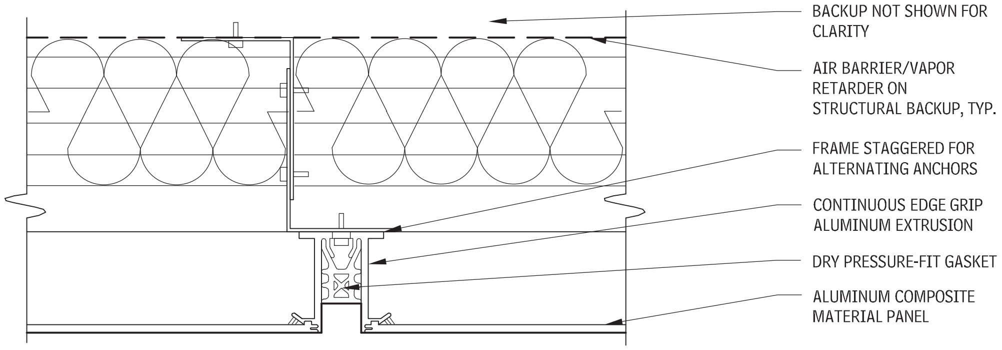
None of the metal cladding panels may provide a waterproof system by themselves. In fact, many of the ACM and plate systems require an air barrier to fully function. Note that a common standard for testing performance of the panels does not yet exist. The panels should always be installed over a water-resistant substrate that allows drainage and weeping of any water that may penetrate the joints. The most dependable method is to install the panels as a drained cavity system by mounting the panels on a support grid spaced away from the sheathing line with an applied A/V barrier membrane and insulation between the supports. Alternative systems may place some or all of the insulation inside stud cavities if proper evaluation of heat loss, vapor flow, and wetting and drying are considered. Interlocking flat lock seam tiles require a continuous nailable substrate, and, therefore, the provision of a proper drainage cavity can require multiple layers.

For high-rise or high-wind applications, the systems can be stepped up to a true pressure-equalized system by partitioning the drainage cavity behind the metal panels. Either the joint system should admit air (such as dry splines or hook and pin) or vents will be required in addition to the weeps. Joints must be designed to resist kinetic energy with sloped or vertical dams, break surface tension with drips, and eliminate capillary draw with joints at least 3/8 in. wide.

HOOK-AND-PIN PANEL
11.290

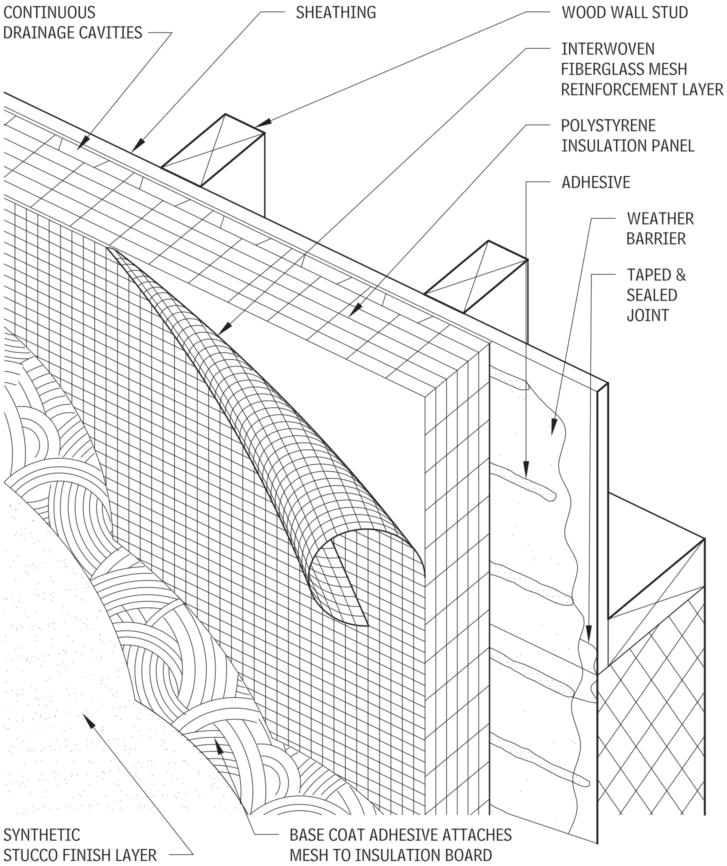


DRY GASKET
11.291

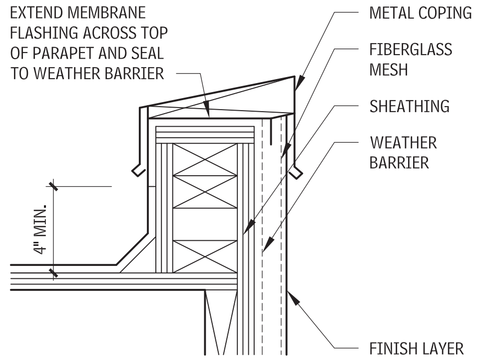


EXTERIOR INSULATION AND FINISH SYSTEMS

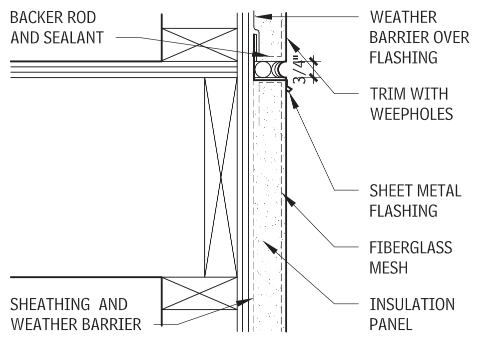
EXTERIOR INSULATION AND FINISH SYSTEM (POLYMER-BASED DRAINAGE PLANE SYSTEM)
11.292



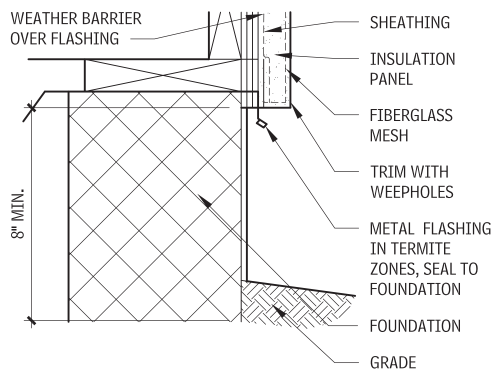
WOOD FRAME DETAILS
11.293



PARAPET DETAIL

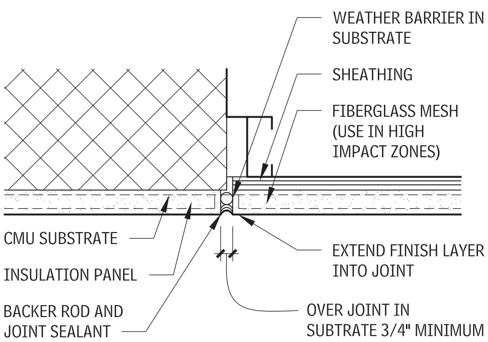


EXPANSION JOINT DETAIL AT FLOOR LEVEL

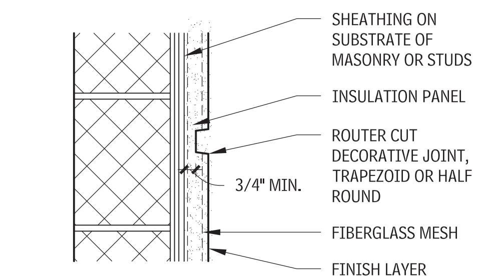


DETAIL AT GRADE

MASONRY DETAILS
11.294



EXPANSION JOINT AT DISSIMILAR SUBSTRATES



DECORATIVE JOINT

Exterior Insulation and Finish Systems (EIFS) provide an uninterrupted layer of board insulation, mechanically fastened but more typically adhered over a water-resistive membrane to the exterior walls of the building and then covered with a very thin layer of reinforced polymer-modified cement membrane (lamina).

LAMINA

The lamina consists of a base coat, reinforcing, and a finish coat. An EIFS is categorized by the lamina, either polymer-modified (PM) or polymer-based (PB). PM systems are thicker (3/16 in. or more) and have a higher cement content resulting in a harder finish. PB systems have a much higher proportion of polymer to cement and have a total thickness less than 1/8 in.

- *Reinforcing:* Reinforcing is typically fiberglass mesh and is available in several weights. Heavier weights are used where impact resistance is required but puncture is still likely at sidewalks or other high-traffic zones. It may be better to use a more durable material for the first floor or provide a wainscot.
- *Finishes:* Many colors are available in textures ranging from very smooth to medium rough. The smoothest finishes tend to telegraph more imperfections of the base coats. Some base coats now have silicone or other additives to help keep the surface clean.

INSULATION

Typically expanded polystyrene is used but extruded polystyrene or other noncombustible types may be incorporated dependent on construction classification. Insulation thickness ranges from 1 to 6 in. The insulation should be grooved or spaced away from the substrate to create a drainage plane. Mechanical fasteners are generally limited to polymer-modified (PM) systems. Polymer-based (PB) systems, especially with a weather barrier, are typically applied with adhesive. Note that while mechanical fasteners may seem to be a good safeguard, they can limit the flexibility of the PB lamina or cause ghosting.

WATER-RESISTIVE BARRIER

The substrate should be prepared with sealants, tapes, and primer to receive a water-resistive barrier membrane. The substrate and membrane together will provide an air barrier.

JOINTS

Joints in EIFS must be carefully located and detailed for their intended purpose. Aesthetic reveal joints provide for movement of the lamina and should be trapezoid or half-round shapes. V-shaped or square joints may flex and crack the lamina. Control joints should be detailed to extend completely through the system and be wide enough to allow for anticipated movement. Note that the bond of the sealant may be stronger than the bond of the finish to the base coats, so carefully select low-modulus sealant paired with proper joint width and detail joints for adhesion to base coat, not finish coat. Also, note that it is nearly impossible to properly reseal EIFS because it is very difficult to remove joint sealant from the lamina. Therefore, it is imperative to select the joint sealant and detail the joint.

HEAT, AIR, AND MOISTURE

EIFS are based on a face-sealed, thin-barrier system to resist moisture. Except for EIFS applied over CMU or concrete in structures where interior moisture control is not necessary, systems that use an internal drainage plane to add moisture protection are highly recommended. The location of the insulation layer fully outside the structure and supporting walls provides continuous and dependable barrier to heat loss/gain. EIFS does not breathe well; consequently, it is very important not to trap vapor within a wall assembly. Most EIFS manufacturers provide analysis of the complete wall assembly to decide whether a separate vapor barrier is necessary and if so, its proper location. The sheathing of the typical backup wall system needs to provide the air barrier so must be designed continuous and detailed to meet windows, doors, penetrations, and transitions to other systems. The water barrier membrane supplied with drainage plane EIFS will typically require that the joints in the sheathing be taped or sealed.

RECOMMENDATIONS FOR SUCCESSFUL EIFS

Properly installed EIFS does not allow water to penetrate the system. However, many buildings clad with EIFS have suffered from problems. From the design professional's (and, more importantly, the owner's) point of view, it is meaningless whether the problems are caused by the EIFS itself or are the result of poor construction at penetrations and transitions. Therefore, the following recommendations should be followed to increase the likelihood of a successful installation:

- Use a reputable manufacturer.
- Enlist the assistance of the manufacturer during the design and detailing process.
- Do not allow the installation of "accidental" vapor retarders such as vinyl wall covering.
- Ensure that all products within the system are from one manufacturer and that the manufacturer confirms compatibility and recommends use of the products in the exact configuration intended for the project.
- Ensure that the manufacturer has adequately trained and certified the installer.
- Arrange to have a manufacturer's technical representative visit the site periodically during installation.
- Use an internal drainage plane system, and avoid face-sealed barrier walls. Detail the drainage indicating flashing and weepholes.
- Use a moisture-resistant substrate. Do not use paper-faced gypsum sheathing or OSB.
- Provide a continuous weather barrier behind the EIFS.
- Do not expose any portions of the EIFS at horizontal areas. Flash windowsills, copings, and projections with sheet metal.
- For joints:
  - Understand the limitations and best profiles of aesthetic joints within the system.
  - Honor movement joints in the substrate through the EIFS.
  - Joints between EIFS should use a double line of low-modulus silicone sealant with closed-cell backer rods.
- Performance of EIFS depends strictly on adherence to the manufacturer's instructions. Quality measures beyond the requirements of other systems are reasonable.
- Require a large-scale mock-up, including typical joints, plus a window and other typical penetrations.
- Require inspection of the water-resistant layer prior to covering with insulation.
- Require periodic or continuous third-party inspections appropriate to the complexity of the project.

WATER REPELLANTS

A variety of thin membranes are available, which, under laboratory conditions, may be waterproof, but actually only slow water absorption because of their inability to bridge large cracks, accelerated weathering, and thin application. Because of this inevitable leakage, water repellants cannot replace proper detailing and construction of truly waterproof wall assemblies. Water repellants may provide passable performance on existing structures where retrofit of flashings, drainage plane, and weather barriers are not feasible.

CLEAR REPELLANTS

Clear repellants are typically used for concrete, CMU, brick, stone, and sometimes wood. Clear repellants come in two basic types: penetrating and film-forming sealers.

- *Penetrating sealers* typically include siloxanes, silanes, or combinations of the two. Advantages include resistance to UV degradation, vapor permeability, low color change, and usability on walkable surfaces.
- *Film-forming surfaces* include acrylics and urethanes. There is a relatively high risk of unsightly failure if vapor pressure is present under the film. However, they can fill larger cracks and work over rougher concrete and wood.

Clear repellants are typically applied by sprayed-on flood coating in one or two coats.

Comparisons of manufacturers marketing claims of the many varieties and concentrations of clear water repellants can be difficult. Review generic evaluations relative to the specific product type and check for proven performance on similar substrates in similar situations. Test an inconspicuous sample panel for performance and appearance before finalizing materials selection.

CEMENTITIOUS COATINGS

Cementitious coatings are typically portland cement-based with fine aggregate and additives to enhance bond, water and freeze-thaw resistance, and color. Cementitious coatings are generally brittle and will not bridge cracks. They are breathable, have excellent bonding strengths, and weathering capabilities, but may cause a substantial change to the appearance of the building. Crystalline waterproofing is also available, which fills the microscopic pores of concrete and CMU.

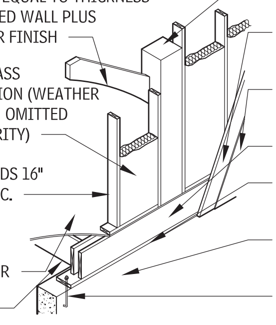
Cementitious coatings are usually applied by spray, but may also be brushed or troweled. For mortar between brick, the brick must be either masked individually or wiped clean after spraying (so-called bagged because of the burlap bags used).

ELASTOMERIC COATINGS

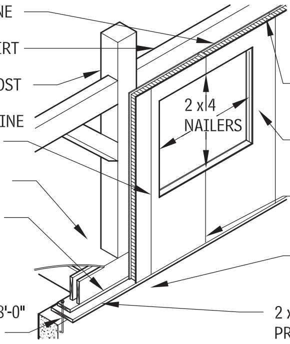
Elastomeric coatings are essentially high-build elastomeric paint, either water- or solvent-based. Some products are breathable. Elastomeric coatings have the highest crack-bridging capabilities, and can be applied over most substrates; but they have a drastic effect on the appearance of the building, may fade, and may require relatively frequent reapplication.

HEAVY TIMBER WALL CONSTRUCTION

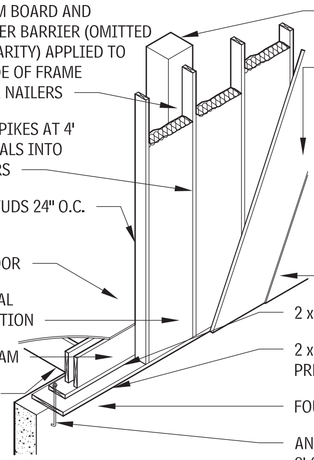
INFILL WOOD STUD ASSEMBLY
11.295



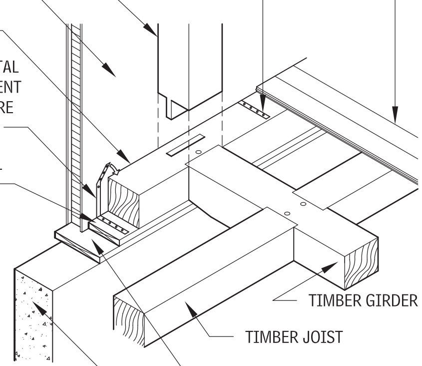
FOAM CORE PANEL WALL SYSTEM
11.296



EXTERIOR WOOD STUD SYSTEM
11.297



HEAVY TIMBER SILL AND JOIST ASSEMBLY
11.298

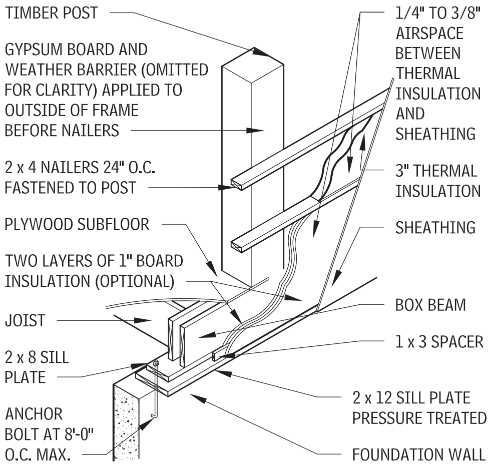


NOTES

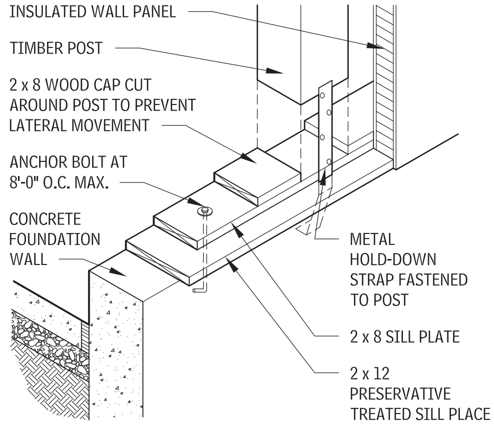
11.295 This assembly reduces the exposure of the heavy timber frame by partially concealing the frame in the wall system. It allows air infiltration due to shrinkage and movement, and requires an exterior board insulation layer to minimize the potential for air movement and condensation.
11.296 Structural foam core panels (with wood sheathing on both sides of the foam core) may be needed at areas that may have excess stress or loading, with interior finish attached to the frame before the panels are attached.

Contributor:
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland.

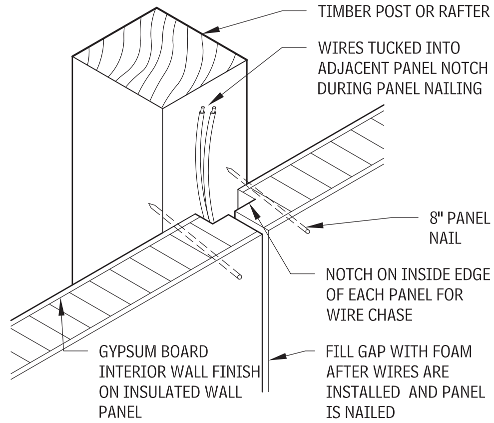
HORIZONTAL NAILER WALL ASSEMBLY
11.299



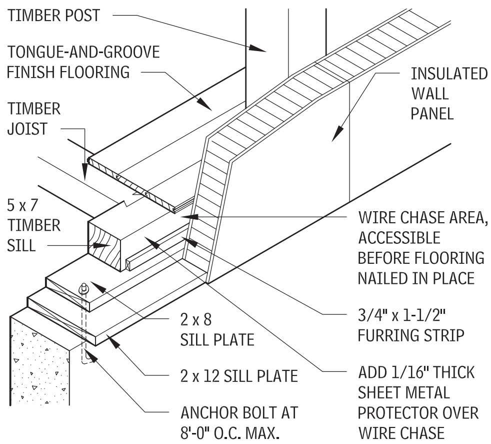
STANDARD 2X LUMBER SILL
11.300



HEAVY TIMBER POST OR RAFTER AT FOAM CORE PANEL—WIRE CHASE DETAIL
11.301

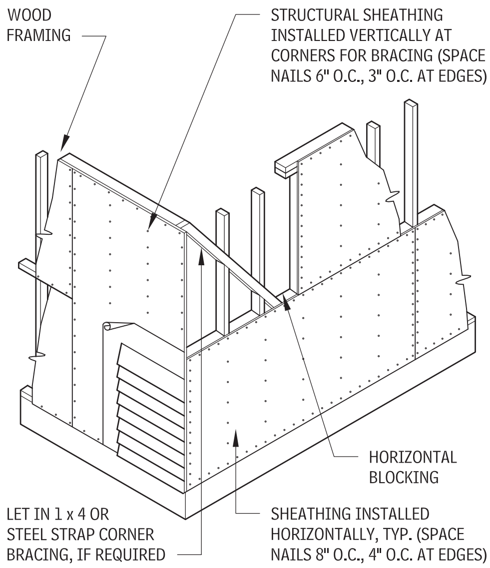


HEAVY TIMBER SILL—WIRE CHASE DETAIL
11.302

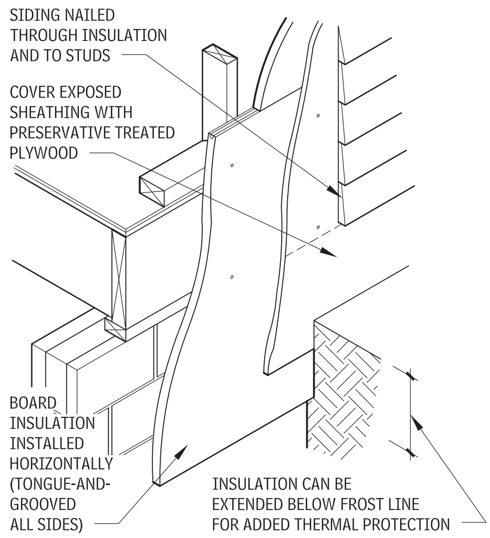


WALL SHEATHING

SHEATHING
11.303



BOARD INSULATION SHEATHING
11.304



Contributors:
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland; Tedd Benson and Ben Brungraber, PhD, PE, Benson Woodworking Co., Inc., Alstead, New Hampshire.

SHEATHING MATERIALS
11.305

CHARACTERISTICS	STRUCTURAL SHEATHING	GYPSUM	FIBERBOARD	FOAM PLASTIC
Nailable base	Yes	No	Only high-density	No
Vapor retarder	No	No	If asphalt-treated	Yes
Insulation R-value (1/2″ thickness)	1.2	0.7	2.6	Varies with manufacturer
Corner bracing provided	Yes	Yes (See manufacturers' recommendations)	Only high-density	No
Panel sizes (feet; except plastic, in inches)	4 × 8, 4 ×, 4 × 10	2 × 8, 4 × 8, 4 × 10, 4 × 12, 4 × 14	4 × 8, 4 × 9, 4 × 10, 4 × 12	16 × 96, 24 × 48, 224 × 96, 48 × 96, 48 × 108
Panel thickness (in.)	5/16, 3/8, 7/16, 15/32, 1/2, 19/32, 5/8, 23/32, 3/4, 7/8, 1, 1-1/8	1/4, 3/8, 1/2, 5/8	1/2, 25/32	1/2 to 6 (for roof)
Other remarks	Plywood grades commonly used for roof and wall sheathing have span ratings of 12/0, 16/0, 20/0, 24/0, 24/16, 32/16, 40/20, and 48/24; exposure durability classifications are Exposure 1 and Exterior. For unsupported edges, refer to manufacturers' recommendations. Oriented strandboard may be used instead of plywood, with appropriate span ratings.	Fire-rated panels are available in 1/2" and 5/8" thicknesses. Panels are noncombustible and not damaged by occasional exposure to weather. Avoid traditional paper-faced gypsum sheathing.	Also called insulation board. Can be treated or impregnated with asphalt. Available in regular and high-density panels.	Considered an effective vapor barrier, so walls must be well vented. Some products emit toxic fumes when burned; refer to manufacturers' specifications.

SHEATHING NOTES

- Sheathing may be strip-type, solid 1 by 6 in., and diagonal-type, in plywood, fiberboard, or gypsum board. Horizontal wood nailing strips (1 by 2 in.) should be used over fiberboard and gypsum sheathing. Space strips equal to shingle exposure.
- Many finishes can be used on red cedar shakes and shingles: solid color or semitransparent ("weathering") stains, exterior latex paint with primer, wood preservative, and bleaches.
- Breather mats, to allow shingles to be spaced off weather barrier, provide a drainage cavity and vent behind shingles. Mat provides better resistance to weather and longer life for shingles.
- Preferred method: detail sheathing or weather barrier to function as air barrier; 1/8" gaps required for wood sheathing.

EXTERIOR WALL VAPOR RETADERS, AIR BARRIERS, AND INSULATION

BUILDING SECTION ANALYSIS FOR POTENTIAL CONDENSATION

Hand in hand with such things as heat loss and insulation, comes the problems of moisture condensation and how to avoid it.

There is moisture in all the air around us. The amount is determined partially by the temperature of the air. Warm air can hold more moisture than cold air. When the air at a given temperature has all of the moisture that it can hold, it is said to be at 100 percent relative humidity for that temperature. If it contains 50 percent of the total moisture it can hold, then it is at 50 percent relative humidity. Air this saturated with moisture vapor will form water droplets if it is cooled, because it can't contain as much vapor at lower temperatures. When humid air contacts a cold surface, it is cooled to saturation and moisture droplets or condensation occurs. It has been cooled below its dew point temperature.

Any building section may be analyzed using simple calculations to determine where condensation might occur and what might be done in selecting materials or their method of assembly to eliminate that possibility. The section may or may not contain a vapor retarder, or it may contain an inadequate one; the building section may include cold-side materials of comparatively high resistance to the passage of vapor (which is highly undesirable). With few exceptions, the vapor resistance at or near the warm surface should be five times that of any components. Figure 11.306 supplies permeance and permeability of common building and vapor barrier materials. These values can be used in analyzing building sections by the following simple method:

1. List the materials, without surface films or airspaces, in the order of their appearance in the building section, beginning with the inside surface material and working to the outside.
2. Against each material, list the permeance (or permeability) value from the figure, or a more accurate value if available from tests or manufacturers' data. Where a range is given, select an average value or use judgment in assigning a value based on the character and potential installation method of the material proposed for use.
3. Start at the top of the list and note any material that has less permeance than the materials above it on the list. At that point, the possibility exists that vapor leaking through the first material may condense on the second, provided the dew point (condensation point) is reached and the movement is considerable. In that case, provide ventilation through the cold-side material or modify the design to eliminate or change the material to one of greater permeance.

In this example, the vapor barrier transmits one grain of moisture per square foot per hour for each unit of vapor pressure difference, or one perm; and nothing else transmits less. However, since the cold brick veneer is nearly as low in permeance, it is advisable to make certain that the vapor barrier is expertly installed, with all openings at pipes and with outlet boxes or joints carefully fitted or sealed. Alternatively, the brick veneer may have open mortar joints near the top and bottom to serve both as weepholes and as vapor release openings. They will also ventilate the wall and help reduce heat gain in summer.

Vapor (under pressure) would easily pass through the interior gypsum board finish, be slowed by the concrete masonry unit, and

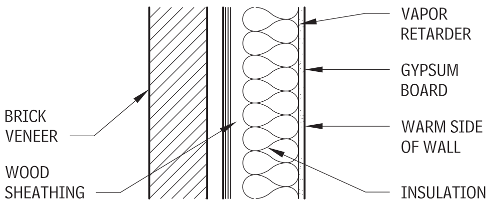
PERMEANCE AND PERMEABILITY OF MATERIALS TO WATER VAPOR
11.306

MATERIAL	PERM (IN.)[e]
MATERIALS USED IN CONSTRUCTION	
Concrete (1:2:4 mix)	3.2[e]
Brick-masonry (4″ thick)	0.8 to 1.1
Concrete masonry (8″ cored, limestone aggregate)	2.4
Plaster on metal lath (3/4″)	15
Plaster on plain gypsum lath (with studs)	20
Gypsum board (3/8″ plain)	50
Structural insulating board (sheathing quality)	20 to 50[e]
Structural insulating board (interior, uncoated, 1/2″)	50 to 90
Hardboard (1/8″ standard)	11
Hardboard (1/8″ tempered)	5
Built-up roofing (hot-mopped)	0.0
Wood, fir sheathing, 3/4″	2.9
Plywood (Douglas fir, exterior glue, 1/4″)	0.7
Plywood (Douglas fir, interior glue, 1/4″)	1.9
Acrylic, glass-fiber-reinforced sheet, 56 mil	0.12
Polyester, glass-fiber-reinforced sheet, 48 mil	0.05
THERMAL INSULATIONS	
Cellular glass	0.0[e]
Mineral wool, unprotected	29.0
Expanded polyurethane (R-11 blown)	0.4 to 1.65
Expanded polystyrene—extruded	1.2[e]
Expanded polystyrene—bead	2.0 to 5.8[e]
PLASTIC AND METAL FOILS AND FILMS[b]	
Aluminum foil (1 mil)	0.0
Polyethylene (4 mil)	0.08
Polyethylene (6 mil)	0.06
Polyethylene (8 mil)	0.04
Polyester (1 mil)	0.7
Polyvinylchloride, unplasticized (2 mil)	0.68
Polyvinylchloride, plasticized (4 mil)	0.8 to 1.4
BUILDING PAPERS, FELTS, ROOFING PAPERS[c]	
Duplex sheet, asphalt-laminated, aluminum foil one side (43)[d]	0.176
Saturated and coated roll roofing (326)[d]	0.24
Kraft paper and asphalt-laminated, reinforced 30-120-30 (34)[d]	1.8
Asphalt-saturated, coated vapor barrier paper (43)[d]	0.6
Asphalt-saturated, noncoated sheathing paper (22)[d]	20.2
15-lb asphalt felt (70)[d]	5.6
15-lb tar felt (70)[d]	18.2
Single kraft, double-infused (16)[d]	42
LIQUID-APPLIED COATING MATERIALS	
Paint—two coats	
Aluminum varnish on wood	0.3 to 0.5
Enamels on smooth plaster	0.5 to 1.5
Primers and sealers on interior insulation board	0.9 to 2.1
Miscellaneous primers, plus one coat flat oil paint on plastic	1.6 to 3.0
Flat paint on interior insulation board	4
Water emulsion on interior insulation board	
Paint—three coats	30 to 85
Styrene-butadiene latex coating, 2 oz/sq. ft.	11
Polyvinyl acetate latex coating, 4 oz/sq. ft.	5.5
Asphalt cutback mastic	
1/16" dry	0.14
3/16" dry	0.0
Hot-melt asphalt	
2 oz/sq. ft.	0.5
3.5 oz/sq. ft.	0.1

NOTES

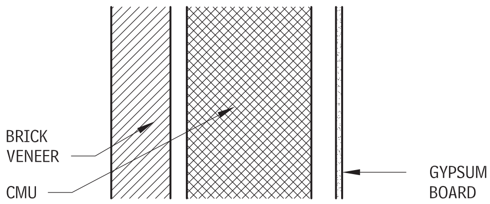
11.306 a. The vapor transmission rates listed will permit comparisons of materials, but selection of vapor retarder materials should be based on rates obtained from the manufacturer or from laboratory tests. The range of values shown indicates variations among mean values for materials that are similar but of different density. Values are intended for design guidance only.
b. Usually installed as vapor retarders. If used as exterior finish and elsewhere near cold side, special considerations are required.
c. Low-permeance sheets used as vapor retarders. High-permeance used elsewhere in construction.
d. Bases (weight in lb./500 sq. ft.).
e. Permeability (perm, in.)
f. Based on data from *ASHRAE Handbook of Fundamentals*.

ESTIMATED PERMEANCE—WOOD
11.307



Gypsum board (3/8 in.)	50.0
Vapor retarder	0.06 (lowest permeance)
Insulation	29.0
Wood sheathing	2.9
4-in. brick veneer	1.1 (next lowest permeance)

ESTIMATED PERMEANCE—CMU
11.308



Gypsum board (3/8 in.) Furred space	50.0
8-in. CMU	2.4
4-in. brick veneer	1.1 (lowest permeance)

be nearly stopped by the cold brick veneer. Unless this design is radically improved, the masonry will become saturated and, in cold weather, may cause serious water stains or apparent "leaks." In addition, alternating freezing and thawing of condensation within the masonry wall can physically damage the construction.

These types of analyses are not appropriate for buildings in mixed-climate areas. For additional instructions see Chapter 11, "Design Tools," by Anton TenWolde, in *Moisture Control in Buildings*, (ASTM Manual, No. 18) Heinz R. Trechsel (ed.), published by ASTM, 1984.

COMPUTERIZED ANALYSIS

The Figures 11.307 and 11.308 are simple graphical section analyses and are limited in reliability. They are two-dimensional, and do not include issues such as thermal bridging at insulation in stud cavities.

Computerized modeling is recommended for large projects, assemblies that require seasonal drying, and for projects located in mixed climates. WUFI, by Oak Ridge National Laboratory (www.ornl.gov), is one strong and widely recognized modeling tool.

AIR (WEATHER) BARRIERS

A weather barrier is a combination of interconnected materials, flexible sealed joints, and components of the building envelope that provide the airtightness of the building envelope. The main function of weather barriers is to prevent unintentional air and moisture flow through the building enclosure. Leakage can affect the occupants' comfort, as well as thermal performance and durability of the building.

BUILDING ENCLOSURE SEALING

The complete building envelope must be designed and constructed with a continuous weather barrier to control air and moisture leakage into or out of the conditioned space. This includes the lowest-level slab-on-grade or crawl space surface, foundation walls, exterior walls, and roof.

Performance of the weather barrier for the opaque envelope can be demonstrated by:

- Using individual materials that have an air permeance not to exceed 0.004 cfm/sq. ft. under a pressure differential of 0.3 in. water gage (w.g.) (1.57 psf) when tested in accordance with ASTM E 2178.
- Using assemblies of materials and components that have an average air leakage not to exceed 0.04 cfm/sq. ft. under a pressure differential of 0.3 in. w.g. (1.57 psf) when tested in accordance with ASTM E 1677.
- Testing the completed building and demonstrating that the air leakage rate of the building envelope does not exceed 0.40 cfm/sf at a pressure differential of 0.3 in. w.g. (1.57 psf) in accordance with ASTM E 779 or an equivalent approved method.

CHARACTERISTICS

The weather barrier is required to have the following characteristics:

- Be continuous throughout the envelope (at the lowest floor, exterior walls, and ceiling or roof), with sealed connections between all transitions in planes and changes in materials, at all joints and seams, and at all penetrations.
- Be joined and sealed in a flexible manner to the weather barrier component of adjacent assemblies, allowing for the relative movement of these assemblies and components.
- Be capable of withstanding positive and negative combined design wind, fan, and stack pressures on the weather barrier without damage or displacement; and transfer the load to the structure. It must not displace adjacent materials under full load.
- Where lighting fixtures or other similar devices are to be installed in such a way as to penetrate the weather barrier, provisions must be made to maintain the integrity of the barrier.

AIR BARRIER SYSTEMS

Many common building materials (concrete, plywood, roofing membranes, rigid insulation, and gypsum board) are capable of functioning as a weather barrier. For small-scale and residential construction, it is common to use either the sheathing or interior drywall as the weather barrier. Special sealing of these materials is required, but otherwise construction does not differ substantially from traditional frame construction. In commercial construction, the use of weather barriers applied over sheathing that fulfill the structural requirement is common. Common building materials that are not weather barriers include CMU, board and blanket insulation (even if compressed), and polyethylene sheets (that are taped as well).

AIR BARRIER MEMBRANES

Air barrier membranes are airtight materials specifically designed to control airflow through the building enclosure. The main types of air barrier membranes are summarized here. In addition to the primary membranes, air barrier systems must include installation and continuity accessories such as primers, mechanical fasteners, tapes, caulks and sealants, flashing, and transition membranes.

Based on the application method, air barrier membranes are classified into five categories:

- *Self-adhered (or peel-and-stick) membranes* are prefabricated sheets consisting of rubber-modified asphalt bonded to a carrier film, and protected by release paper on the membrane side. These membranes are applied by self-adhesion to a dry, clean, and primed substrate. Self-adhered membranes are vapor-nonpermeable.
- *Fluid-applied membranes* are one- or two-component formulations in organic solvents or water dispersions, which are spray or trowel applied to a dry, clean, and primed substrate. Most fluid-applied membranes are vapor-nonpermeable. There are fluid-applied membranes that are vapor-permeable, even though their permeability is quite low (<6 to 7 perms) and depend on the dry film thickness.
- *Mechanically fastened membranes* are lightweight sheets typically installed with mechanical fasteners. Their installation does not require special surface preparation such as drying, priming, or taping of sheathing joints. Building wraps are vapor-permeable membranes, even though their vapor permeability varies widely depending on the membrane type and the manufacturer. The main types of building wraps are: (1) spun-bonded polyolefins, (2) microporous films, (3) perforated films, and (4) asphalt-impregnated papers and felt. The seams and fasteners typically need to be taped or otherwise sealed.
- *Torch-applied membranes* are rubber-modified bitumen, laminated on a nonwoven substrate. The membrane is designed to be fused to a dry, clean, and primed substrate by heating the bitumen side with a propane torch. Torch-applied membranes are vapor-nonpermeable.
- *Sprayed polyurethane foams (SPF)* are two-component foam membranes that combine thermal insulation and weather barrier properties. Only a few closed-cell SPF insulation foams have the required air infiltration resistance to qualify as air barriers.

Based on vapor permeability, air barrier membranes are classified into vapor-permeable and vapor-nonpermeable membranes (air and vapor barriers)—Class I, II, III, or IV. Building wraps and a few fluid-applied membranes are vapor-permeable though permeability varies widely among the different types. All other air barrier membranes described previously are vapor-nonpermeable.

Vapor permeability of the weather barrier must be carefully considered when selecting a weather barrier for the building enclosure.

- *Vapor-permeable* weather barrier membranes can be placed anywhere in the wall assembly, based on ease of detailing. The membrane is often installed on the outer side of the exterior sheathing. In addition, there are no climate limitations for vapor-permeable air barriers. Air barriers can and should be used in all climates.
- *Vapor-nonpermeable* weather barrier membranes generally must be located on the warm side of the wall assembly to avoid moisture accumulation. "The warm side of the wall assembly" is climate-specific. In the United States, with widely varying climates, it could be on different sides of the wall during different seasons. Consequently, the weather barrier could end up on the cold side of the enclosure for part of the year, leading to moisture accumulation.

In summary, take into account the considerations listed in Figure 11.458 when selecting a weather barrier membrane.

AIR BARRIER CONSIDERATIONS
11.309

TYPE OF WEATHER BARRIER	LOCATION WITHIN BUILDING ENCLOSURE	CLIMATE CONSIDERATIONS AND LIMITATIONS
Vapor-permeable	Anywhere	No climate limitations; use in all climates
Vapor-nonpermeable (air and vapor barrier)	Warm side	Consider climate to avoid condensation and moisture accumulation

Vapor Retarder requirements for Climate Zones per the International Building Code 2009 are as follows:

- Class I (Vapor Barrier): < 0.1 perms
- Class II (Vapor Retarder): 0.1 to 1.0 perms
- Class III (Vapor Retarder): 1.0 to 10 perms
- Class IV (Vapor Open): >10 perms
- Zone1—Not Required
- Zone 2—Not Required
- Zone 3—Not Required
- Zone 4—Class III
- Zone 4 (Marine)—Class II or III
- Zone 5—Class II or III
- Zone 6—Class II
- Zone 7—Class II

IBC does not require Air Barriers in Climate Zones 1, 2, or 3; however, ASHRAE 90.1 performance models do require air barriers within all climate zones. See 11.1 for map of U.S. climate zones.

When they are part of a drainage or pressure-equalized wall assembly, weather barriers must also be resistant to the passage of water. Air barriers are crucial to the functioning of a pressure-equalized wall assembly. See Figure 11.310 for integration of flashings into these wall types.

The application of the flashing falls into two categories: through-wall flashing and flexible membrane flashing.

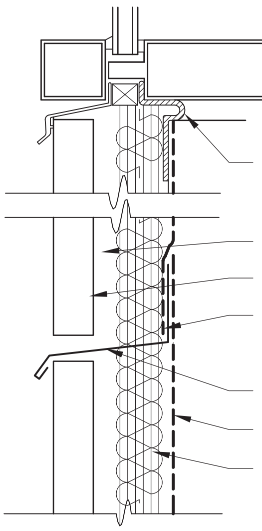
- *Through-wall flashing* must typically bridge across the open airspace and, therefore, is typically sheet metal. Stainless steel, aluminum, galvanized steel, and copper are most common.
- *Flexible membrane flashing* is used to bridge gaps, while allowing movement, and as a transition to other materials, assemblies, and systems. Flexible flashing can be self-adhered peel-and-stick membranes, but their use is limited to applications that do not require bridging a gap larger than 1/2 in. For larger gaps, and where more substantial movement is anticipated, neoprene sheets or extruded cured silicone sheets are common. Note that the membrane flashing sheets must be compatible with all of the adjacent materials they contact.

VAPOR RETARDERS

WATER VAPOR MIGRATION

Water is present as vapor in indoor and outdoor air and as absorbed moisture in many building materials. Within the range of temperatures encountered in buildings, water may exist in the liquid, vapor, or solid states. Moisture-related problems may arise from changes in moisture content, from the presence of excessive moisture, or from the effects of changes of state (such as freezing within walls, or deterioration of materials because of rotting or corrosion).

RAINSCREEN FLASHING 11.310



In the design and construction of the thermal envelope of buildings (the enclosure of desired temperatures and humidity), the behavior of moisture must be considered, particularly the change of state from vapor to liquid (condensation). Problems arise when moisture comes into contact with a relatively cold surface (temperature below the dew point), such as a window, or within outdoor walls or under-roof/ceilings. Excessive condensation within indoor walls that enclose cold spaces must be considered.

Although vapor moves by vapor pressure differences, it is important to recognize that moisture moved in air will move much larger quantities of water. Consequently, the causes of air motion must be considered, especially the infiltration/exfiltration at undesirable leakage rates at windows, doors, and other penetrations through the thermal envelope of the building.

Moisture problems generally occur in seasons when the outdoor temperature and vapor pressure are low and there are many indoor vapor sources. These sources may be occupant-induced, such as cooking, laundering, bathing, breathing, and perspiration, or machine-induced, including automatic washers and dryers, dishwashers, and humidifiers. All of these sources combine to cause vapor pressure indoors to be much higher than outdoors, so that the vapor tends to migrate outward through the building envelope. Vapor cannot permeate glazed windows or metal doors, but many other building materials are permeable to some extent. Walls are particularly susceptible to this phenomenon and such migration must be prevented, or at least minimized, by the use of low-permeance membranes, called *vapor retarders*. A vapor barrier is a material that has a flow rating of one perm or less (1 perm = 1 grain/hr ft.-in. Hg vapor pressure difference).

Vapor barriers, when installed along with properly treated joints and penetrations, form a vapor barrier assembly, though it does not stop all vapor transmission. Vapor barrier assemblies should be installed as close as possible to the side of the wall through which moisture enters. Therefore, it is important to establish the side of moisture entrance in walls of controlled rooms within buildings. Also note that the beneficial effects of good vapor retarders will be lost without adequate weather barriers.

Moisture in building materials usually increases their thermal conductance significantly and unpredictably. Porous materials that become saturated with moisture lose most of their insulating capability and may not regain it when they dry out. Dust, which usually settles in airspaces, may become permanently affixed to originally reflective surfaces. Moisture migration by evaporation, vapor flow, and condensation can transport significant quantities of latent heat, particularly through fibrous insulating materials.

Positive steps should be taken to prevent migration of moisture in the form of vapor, and accumulation in the form of water or ice within building components. Vapor retarders, correctly located near the source of the moisture, are an effective means of preventing such migration. Venting of moisture-laden air from bathrooms, laundry rooms, and kitchens will reduce indoor vapor pressure, as will the introduction of outdoor air with low moisture content.

METAL LOUVERS

Metal architectural louvers allow airflow through a wall for ventilation, especially of machine exhaust. They protect the interior space from vandalism, weather, insects, or birds, and can be used to obscure unsightly views. Louvers can be fabricated in standard rectangles or custom shapes such as circles, triangles, and ellipses. Radiused corners and other details are available from some manufacturers. Penthouses frequently incorporate louvered walls to screen equipment and provide airflow.

CHARACTERISTICS

Standard louver materials are 16-, 18-, or 20-gauge galvanized or cold-rolled steel, and 8-, 12-, or 14-gauge extruded aluminum alloy. Other metals can be used for special applications. Translucent fiberglass is a standard blade material when daylighting is desirable. Fasteners are either aluminum or stainless steel. The dimensions shown in the accompanying illustrations are the most common; other sizes are available.

Factory finishing is recommended for maximum control of color and durability. The finish for steel louvers is baked enamel, which comes in a variety of colors. Aluminum finishes include mill, clear lacquer, baked enamel, and anodic. Fluorocarbon polymeric finish coatings (Kynar), steel or aluminum, resist chalking, ultraviolet deterioration, salts, chemicals, and pollutants.

Mechanically assembled extruded aluminum louvers are the most common type of louver assembly on the market. Mechanical fasteners are better than welding in extruded aluminum alloy construction because annealing occurs near the weld, weakening the material along both sides. Also, repairs are easier when mechanical fasteners are used.

With sheet metal, welding an assembly of louvers is easier and less expensive than using clip angles and screws to fasten the blades to the framework.

Free area is the net area of free airflow through a louver, generally measured in square feet or as a percentage of the area in the louver type selected. Manufacturers' free area ratings should include the effects of bird or insect screens, which reduce free area.

For all louvers servicing mechanical equipment, consult a mechanical engineer for their design and specification. Louvers are rated for air performance and water penetration and certified through the Air Movement and Control Association. The Building Services Resources and Information Association also rates the performance of metal louvers.

Storm-resistant, high-performance louvers can control most rain penetration. However, louvers almost always entrain snow or rain, especially intake louvers. See the accompanying schematics for water management. Consider less-expensive louvers and use a waterproof intake plenum for maximum reliability.

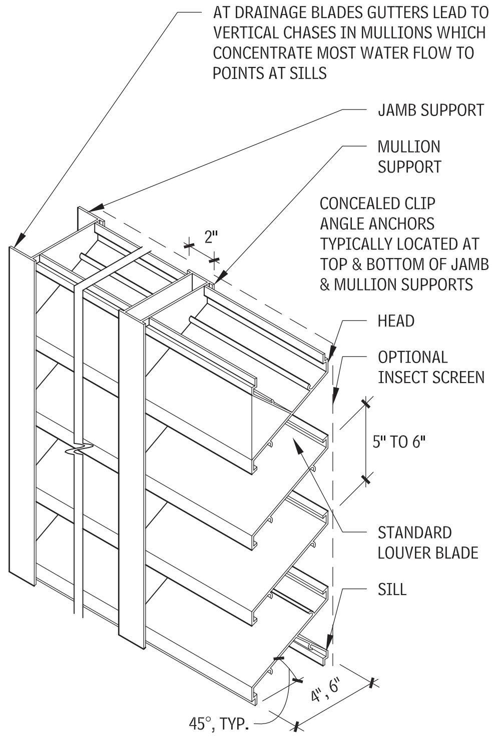
LOUVER BLADES

Louver blades come in many shapes, sizes, and performance types that vary with the manufacturer; the blades illustrated here represent the basic types. Some blades are fixed only; others can be opened and shut. The center-to-center dimensions given are approximate; generally, standard blades (not specialty blades such as acoustic, air-foil, and so on) are designed with minimal overlap, so they can obstruct views but maximize the free area.

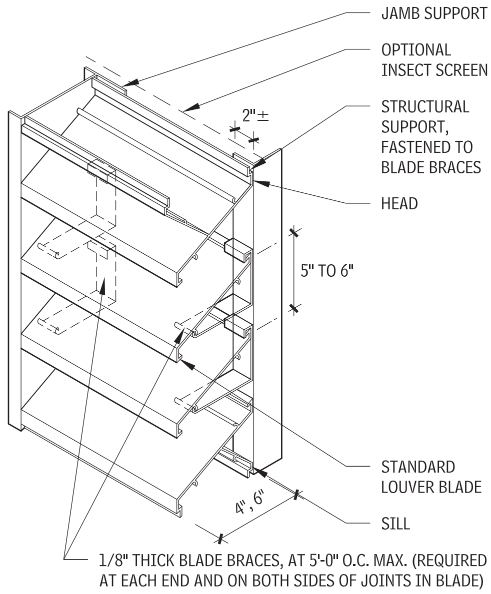
Standard blades, step blades, high-performance blades, and some double-drainable blades can be used with concealed vertical mullions for a continuous louver design. Verify with the manufacturer.

Contributor:
Maria Spinu, PhD, DuPont, Wilmington, Delaware.

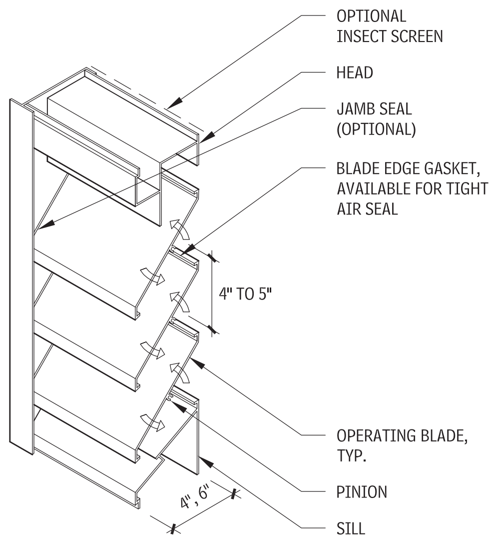
EXPOSED MULLION LOUVER
11.311



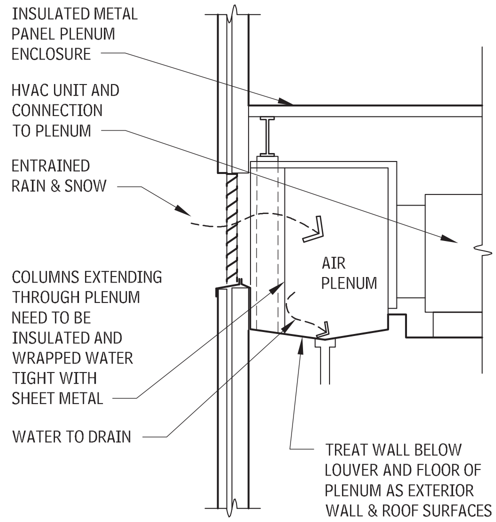
CONTINUOUS HORIZONTAL LOUVER
11.312



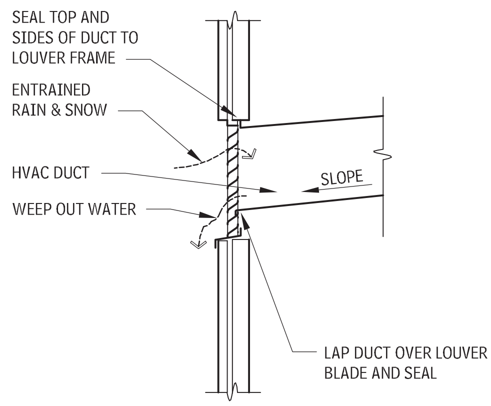
ADJUSTABLE OPERATING LOUVER
11.313



WATER MANAGEMENT THROUGH LOUVERS
11.314



LARGE PLENUM



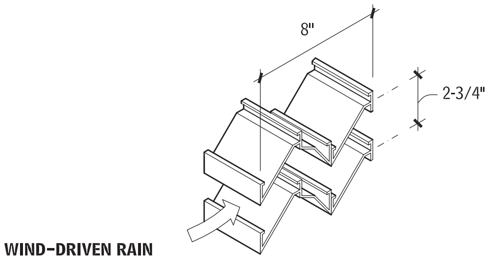
ISOLATED DUCT

NOTES

11.311 Generally, this is the most economical louver type.
11.312 This louver type offers a visual line uninterrupted by exposed vertical supports. It is not appropriate for blades with gutters.
11.313 Adjustable operating louvers are available with manual, electric, or pneumatic actuators. Free area is 38 to 58 percent.

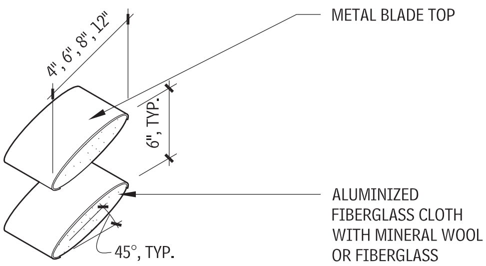
HORIZONTAL STORM-RESISTANT BLADE
11.315

Louvers using this blade design completely obscure views and are tamperproof and storm-resistant. This blade prevents nearly 100 percent of wind-driven rain from entering (generally tested with winds up to 30 mph for one hour).

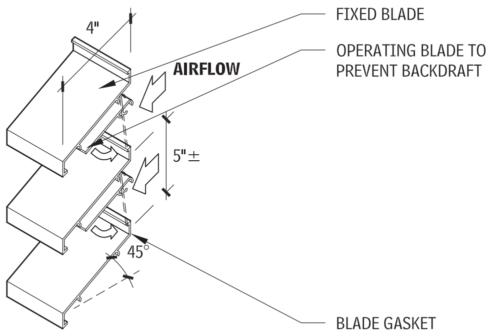


FIXED AIR-FOIL ACOUSTIC BLADE
11.316

Acoustically insulated air-foil blades block sound from inside or out and accommodate high air velocities. Free area is 29 percent, and blades may be fixed or operable.

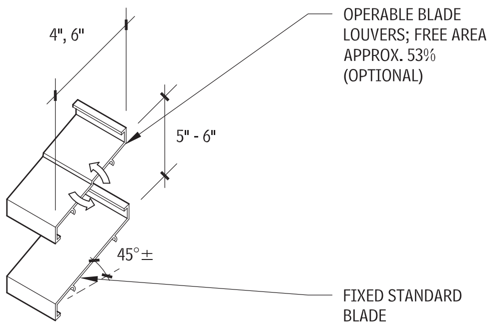


AUTOMATIC EXHAUST DAMPER/LOUVER
11.317



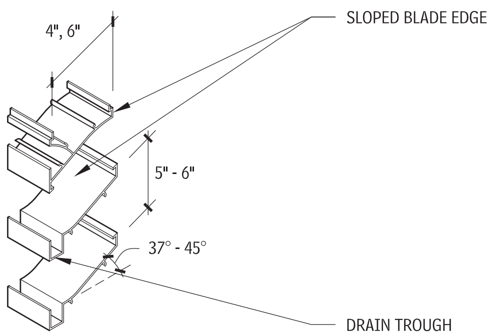
STANDARD BLADE
11.318

Standard blades are suitable for most applications where water infiltration is not a concern. Free area is approximately 48 percent. Single operating panels should not exceed 48 in. wide by 96 in. high. This blade can be either fixed or operable.



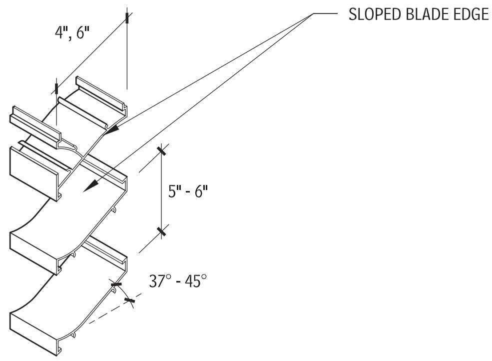
HIGH-PERFORMANCE DRAINABLE BLADE
11.319

Designed to provide high free area (55 percent) and low water penetration, this blade is not recommended for use with hidden mullions; louvers that employ these blades contain integral drains in their mullions that direct water away from the inside of the louver. All drain troughs must be kept free of debris. They are not designed to hinder wind-driven rain.

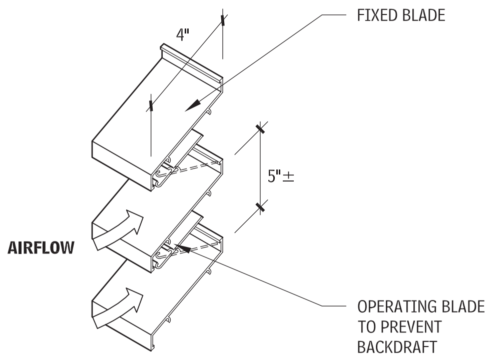


HIGH-PERFORMANCE STANDARD BLADE
11.320

Designed to provide a high free area (55 percent), this blade accommodates high air velocities and protects against wind-blown precipitation.



AUTOMATIC INTAKE DAMPER/LOUVER
11.321



EXTERIOR WINDOWS

Although architects choose fenestration products based on many unique priorities and circumstances, a number of common considerations apply to most situations. Here are the factors that affect window choice:

- *Appearance:* Size and shape, operating type and style, frame materials, glass color and clarity
- *Function:* Visible light transmittance (provision of daylight), glare control, reduction in fading from ultraviolet radiation, thermal comfort, resistance to condensation, ventilation, sound control, maintenance, and durability
- *Energy performance:* U-value, solar heat gain coefficient (SHGC) (which is replacing the shading coefficient), air leakage, annual heating and cooling season performance, and peak load impacts
- *Cost:* Initial cost of window units and installation, maintenance and replacement costs, effect on heating and cooling plant costs, and cost of annual heating and cooling energy

EXTERIOR WINDOWS

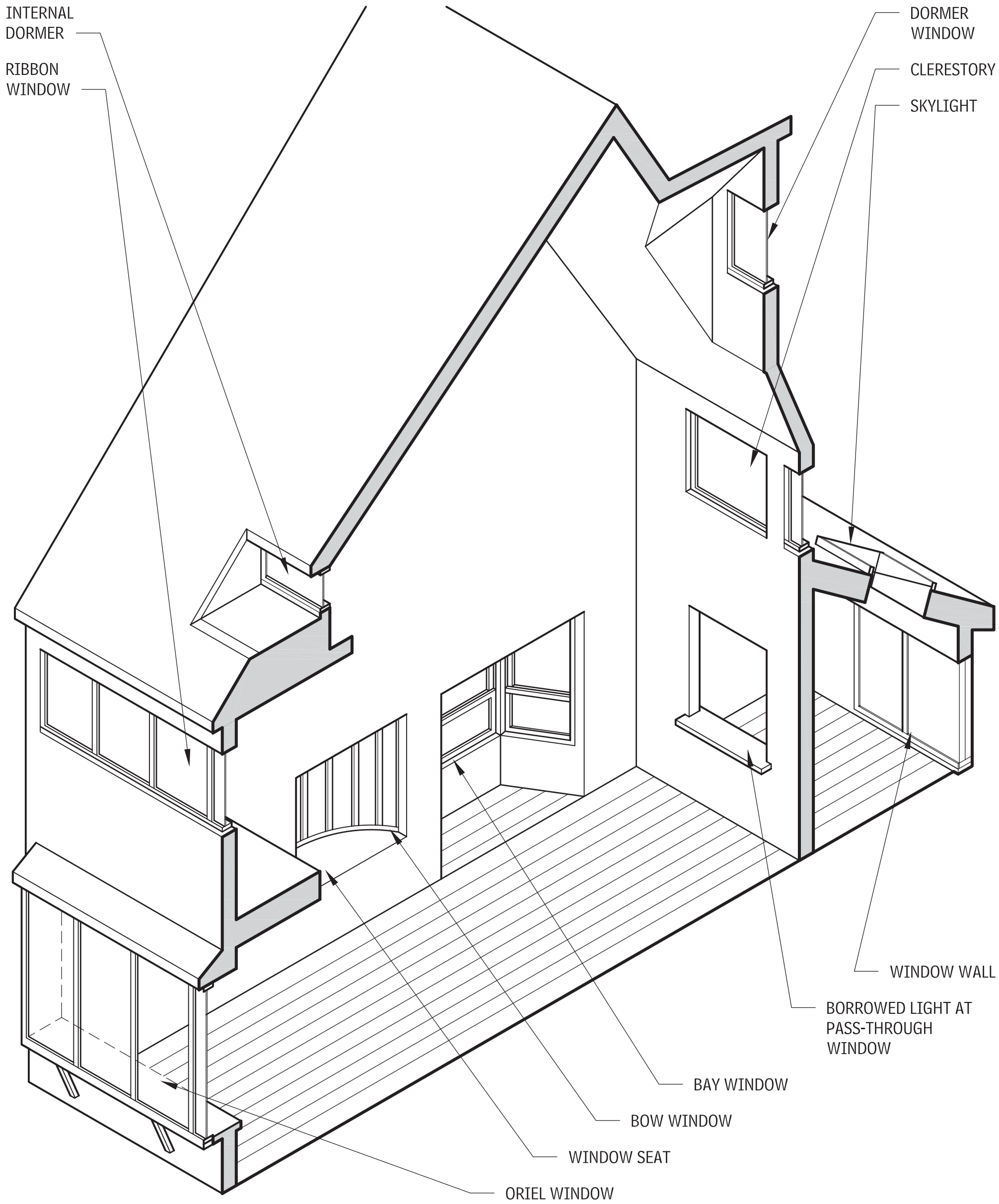
Many designers and homeowners find it difficult to assess the value of choosing a more energy-efficient window. Although some basic thermal and optical properties (e.g., U-factor, solar heat gain coefficient, and air leakage rate) can be identified if a window is properly labeled, this information does not tell how these properties influence annual energy use for heating and cooling. This must be determined by using an annual energy rating system or by computer simulation.

WINDOW BASICS

Any discussion on exterior windows must begin by defining these key terms:

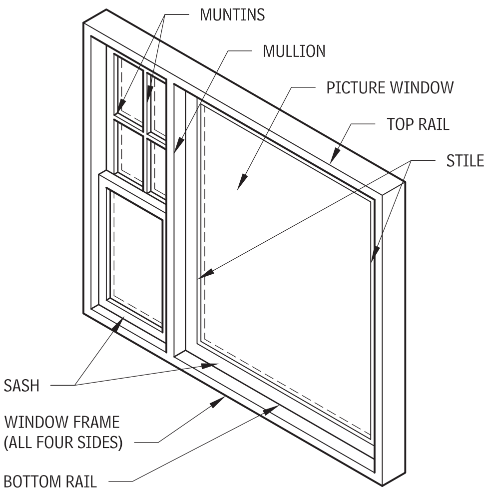
- *Borrowed light:* An interior wall opening or window that allows light to be transferred into another space
- *Clerestory:* The portion of a wall above an adjacent roof level; also, a fixed or operable window located in this part of a wall
- *Dormer:* A vertical window set above the line of a sloped roof in a small projecting space with triangular sidewalls
- *Internal dormer:* A vertical window set below the line of a sloped roof.
- *Oriel window:* A bay window supported by brackets, corbeling, or cantilevers.
- *Window wall:* A continuous series of fixed or operable sashes, separated by mullions that form an entire non-load-bearing wall surface.
- *Ribbon window:* A horizontal band of fixed or operable windows extending across a significant portion of the facade.
- *Mullion:* A slender vertical member separating lights, sashes, windows, or doors.
- *Muntin:* Nonstructural members separating panes within a sash; also called a *glazing bar* or *sash bar*.
- *Sash:* The basic unit of a window, consisting of frame, glazing, and gasketing; may be stationary or operable.

WINDOW CONFIGURATIONS
11.322



Contributor:
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland.

PARTS OF A WINDOW
11.323



PERFORMANCE

Performance standards can be divided in three categories:

- Structural, air filtration, and water leakage
- Thermal and condensation
- Specialized

STRUCTURAL, AIR INFILTRATION, AND WATER LEAKAGE PERFORMANCE

These elements are standardized through ANSI/AAMA/WDMA 101/I.S. 2-97, "Voluntary Performance Specifications for Windows, Skylights, and Glass Doors." The 101 specification establishes five classes for windows and doors: R, LC, C, HC, and AW (i.e., residential, light commercial, commercial, heavy commercial, and architectural, respectively). This specification was updated in 2002 and 2005. In brief, the specification says:

- Select the class based on the project. The class titles are somewhat self-explanatory, but not limiting. AW class windows are typically used for institutional type projects, but they can also be used on a very high-quality house, for example.
- Performance is designated by a number that follows the type and class. For example, "H-AW 40" designates a double-hung architectural window with a design pressure of 40 psf.
- The number is based on the anticipated structural wind load acting on the window, as determined from ASCE 7 and as required by the building code. Each type and class has minimum performance grades; optional grades increase in 5 psf increments.
- The designation is based on testing of samples for structural performance, air infiltration, and water leakage according to standardized methods. The higher the class, the more difficult the test.
- Windows can be selected of various grades to suit the field pressure and higher wind pressures at corners and higher elevations, or the windows for the entire building can be based on the highest wind pressure.

The 101 specification also provides standards for durability, operating forces, safety, materials, hardware, and overall quality.

Note that the ratings are based on specific test sizes, so it is necessary to verify that the tested size is at least as large as the windows required for the project. Also note that the tested window rarely includes perimeter pan flashing, receivers, mulled assemblies, or other nonstandard configurations, so it's important to ask the manufacturer how these conditions affect performance.

THERMAL AND CONDENSATION PERFORMANCE

Specific exterior climate and desired interior conditions affect the thermal performance of windows the most. Carefully evaluate these conditions to determine acceptable performance criteria, and then select windows that meet the criteria.

- Thermal performance of windows is rated according to NFRC 100, through standardized tests of windows. Note that glazing can dramatically affect the thermal performance, so verify the glazing used in the test versus project requirements.
- Condensation resistance is determined by AAMA test 1503.1; the higher the number, the better the performance. CRF (condensation resistance factor) testing is performed on standard-sized samples and includes glazing, which can influence the results. Note that the CRF test averages out a large number of temperature readings, meaning that a high reported value may still have areas that perform relatively poorly. If absolutely no condensation is acceptable, then greater scrutiny to the actual test data versus the final CRF value is recommended.
- Assuming frames have thermally resistive materials or have thermal breaks, the glazing may be the major determinant of CRF and overall thermal performance. See Figure 9.4 "Conditions That Lead To Condensation On Windows."
- Thermal and CRF performance affect not only energy use but also occupant comfort. Analyze the area of glazing, the location and activity of the occupant, and the use of supplemental heating for adequate protection.

SPECIALIZED PERFORMANCE

Standardized test procedures are available to evaluate a great many specialized performance criteria, including acoustic isolation, blast resistance, forced-entry resistance, and safety impact. Refer to AAMA.

DETAILING

Manufacturers of windows provide only generic details for installation. Adjacent construction is frequently shown as a hatched single line. Therefore, it is necessary to detail the window frame in project-specific assemblies.

WALL ASSEMBLIES

Window installation must be detailed as appropriate for the generic wall assembly type, as described below.

- *Barrier walls:* Seal the window to the barrier. Use a subsill flashing to avoid introducing water into the wall. For massive barrier walls such as precast concrete, head flashing may be required to ensure that water seepage does not get behind the window.
- *Drainage plane walls:* Provide the primary seal of the window to the water-resistant drainage plane, and an outer seal in line with the wallcovering. The subsill flashing should extend past the outer wallcovering.
- *Drained cavity walls:* Provide the primary seal of the window to the waterproof inner line of protection and an outer seal to the outer wallcovering. The subsill flashing may be detailed to weep into the drainage cavity because only incidental water should leak around the window.
- *Pressure-equalized (PE) rainscreen walls:* Use windows that incorporate PE rainscreen technology. Seal the air barrier of the window to the wall air barrier; likewise for the rainscreen. The subsill flashing may be detailed to seal to the air barrier.

AIR AND VAPOR BARRIERS

Detail the window installation so that the line of the air barrier and/or vapor barrier (if required) extends uninterrupted across the gap at the perimeter of the window. In windows with glass installed using wiggle glazing, or if interior removable stops are used, a heel bead may be required to maintain continuity of the air barrier between the frame and glass.

MOVEMENT

Window installation details must accommodate movement of the surrounding structure. Window heads (particularly at strip windows) often are located at shelf angles, and must accommodate movement typically in the range of 1/2 in. from above.

THERMAL CONTINUITY

Detail the windows to maintain a line of thermal insulation in the same plane as in the tested configuration and as intended by the window manufacturer. Windows installed over an airspace in a drainage cavity wall may be exposed to cold on sides for which proper thermal breaks are not provided.

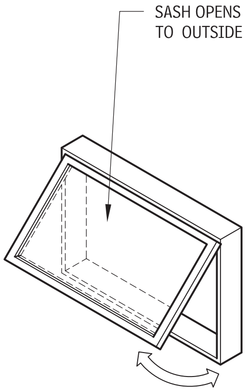
ADDITIONAL INFORMATION

For more information, see the *AAMA Window Selection Guide*.

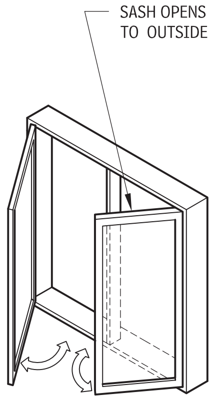
WINDOW OPERATION TYPES

Accessibility issues for windows are important for present and future occupants. See *Beautiful Universal Design: A Visual Guide* (John Wiley & Sons, New York, NY), by Cynthia Leibrock and James Evan Terry for a complete discussion.

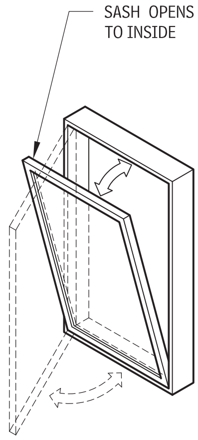
WINDOW OPERATION TYPES
11.324



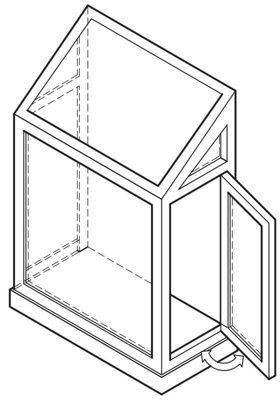
AWNING/PROJECTED



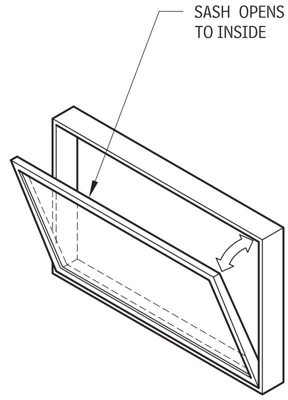
DOUBLE CASEMENT/ PROJECTED



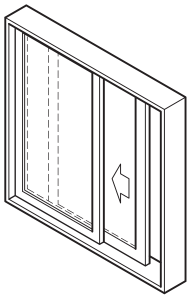
DUAL ACTION



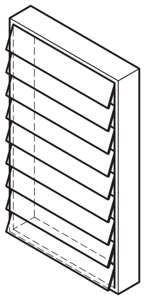
GREENHOUSE



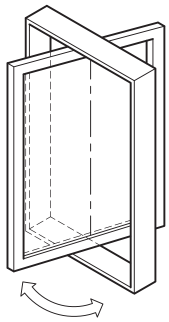
HOPPER



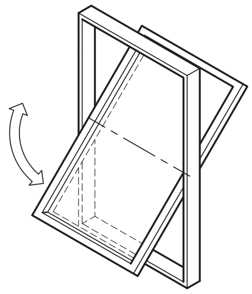
HORIZONTAL SLIDER



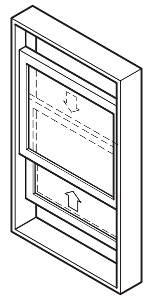
JALOUSIE



VERTICALLY PIVOTED



HORIZONTALLY PIVOTED



VERTICAL SLIDING (SINGLE- AND DOUBLE-HUNG)

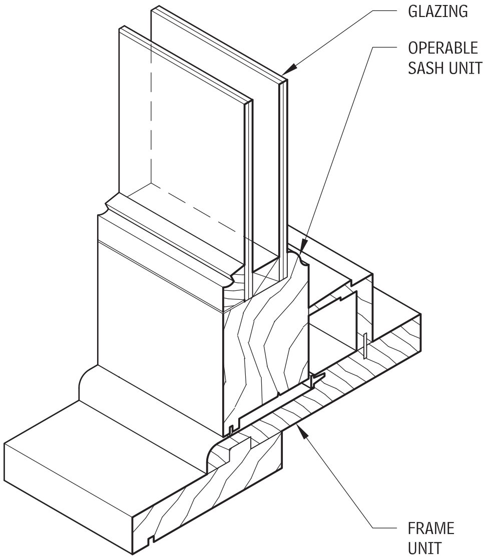
CHARACTERISTICS OF WINDOW OPERATION TYPES
11.325

OPERATION TYPE	DIRECTION	SCREEN LOCATION	MAXIMUM OPENING (%)	WEATHER PROTECTION (WHEN OPEN)	EGRESS (CLEAR OPENING SIZE GOVERNS)	CLEANABILITY (EXTERIOR FROM INTERIOR)	UNIVERSAL OPERATION	NOTES
Awning/projected	Swings outward from hinge or pivot at top	Interior	100	Limited	Not possible without special hardware	Difficult	Acceptable	Not for use adjacent to walkways
Casement/projected	Swings outward or inward from a hinge or pivot on the side	Interior or exterior	100	Poor (wind-buffeting)	Good	Single units are difficult; paired windows easier	Acceptable	When outswinging, not suitable for use adjacent to walkways
Dual action	Swings inward from hinge or pivot on bottom (hopper for ventilation, casement for cleaning)	Exterior	10, usually; 100, when casement	Good	Good	Easy	Acceptable	
Greenhouse (may be combined with other operation types)	May swing outward but may not be operable	Depends on window operation type	Depends on window operation type	Good	Poor	Difficult	Difficult	Unit projects from building; primarily residential use
Hopper/projected	Swings inward with hinge or pivot at bottom	Exterior	100	Good, with side vents	Not without special hardware	Easy	Acceptable	
Horizontal sliding	Slides sideways with a guide at top and bottom	Exterior	50, for equal-sized sash	Poor	Good	Difficult (easy with tilt-in feature)	Acceptable	Horizontal or square units operate more easily than tall units
Jalousie	Swings outward from pivots on the side	Interior	100	Limited (interior storm windows available)	Poor	Tedious	Acceptable	Translucent/opaque panes provide additional sunscreening; high air leakage
Pivoted/reversible (horizontally and vertically pivoted)	Swings around vertical or horizontal axis	Rare, but special-shaped screens	100	Poor (wind-buffeting)	Poor (size of clear opening restrictions)	Easy	Difficult	
Vertical sliding (single- and double-hung)	Slides up and down along guide on the side	Exterior	50, for equal-sized sash	Poor (but good with hospital sills)	Good	Difficult (easy with tilt-in feature)	Difficult	

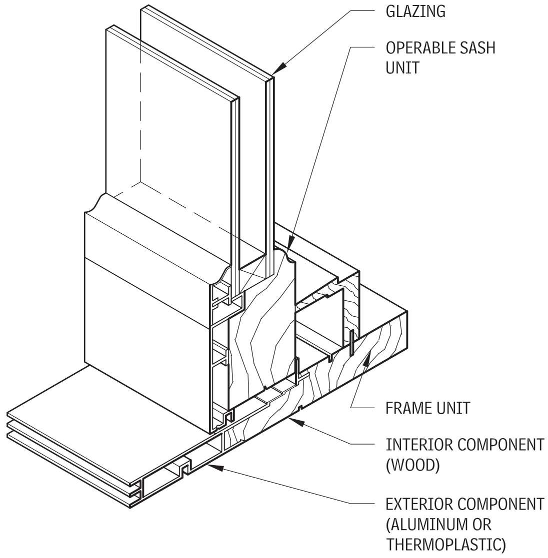
Contributors:
John Carmody, University of Minnesota, Minneapolis, Minnesota; Stephen Selkowitz, Lawrence Berkeley National Laboratory, Berkeley, California; Daniel F.C. Hayes, AIA, Washington, DC.

WINDOW FRAME TYPES

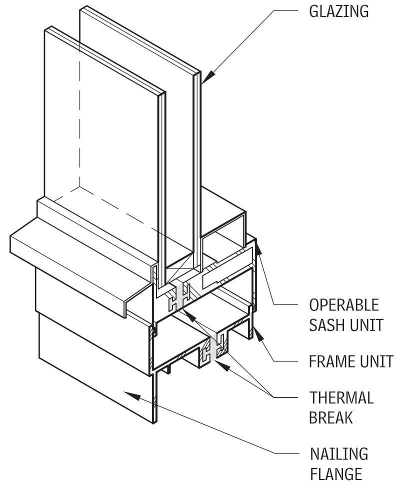
WINDOW FRAME DETAILS
11.326



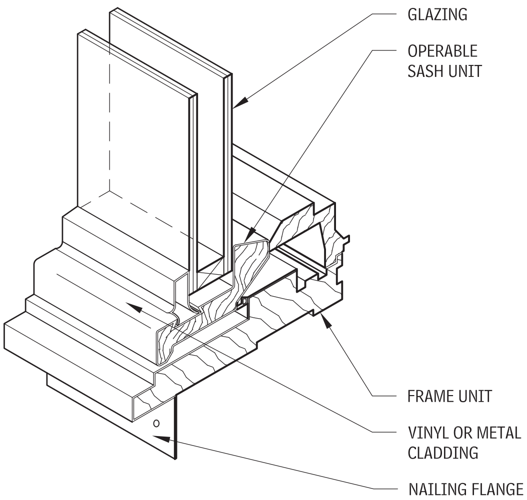
WOOD



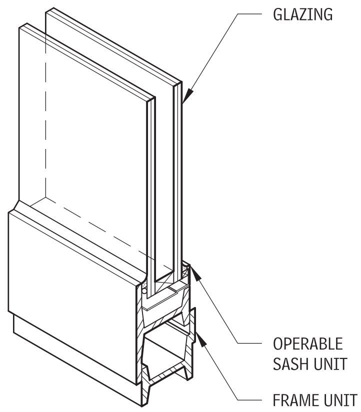
HYBRID



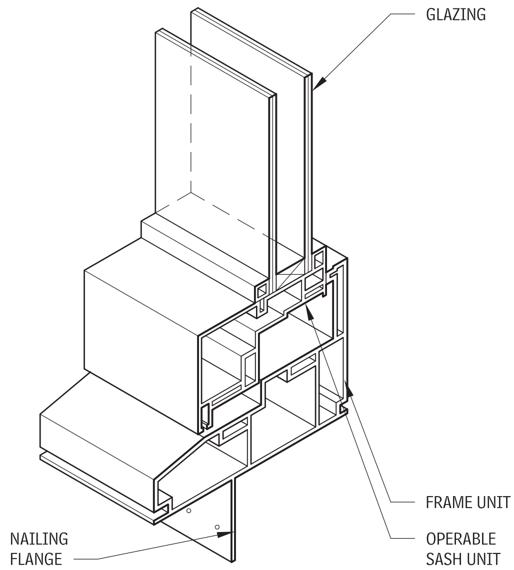
ALUMINUM



WOOD WITH CLADDING



STEEL



VINYL OR FIBERGLASS

WINDOW FRAME TYPES
11.327

FRAME TYPE	CHARACTERISTICS	MAINTENANCE	FINISHES	HEAT TRANSFERENCE	SUSTAINABILITY	NOTES
Wood	Solid members; ease of milling into complex shapes; attractive and traditional appearance U-factor: 0.3–0.5	Rot prevention: refinish in 5- to 10-year cycle, or use permanent finish	Oil or latex paint, stains, oils, or varnishes; preservatives; polyurethane resin coatings; prefinished or site-finished	Low	Renewable resource; requires high-quality solid stock	Traditional and typical material; variety of species available; easy repair
Wood with cladding	Metal- or plastic-clad wood U-factor for vinyl clad: 0.3–0.5; for metal clad, 0.4–0.6	Minimal	See metal and plastic frames	Low with vinyl cladding, slightly higher with metal	Use of less desirable wood materials; salvageable cladding	Wood for stability/strength, cladding for maintenance
Hybrids	Wood interior, metal or plastic exterior U-factor for vinyl/wood: 0.3–0.5; for metal/wood, 0.4–0.6	See wood, metal, and plastic categories.	See other categories	Low with vinyl/wood hybrid, slightly higher with metal/wood hybrid	Use of lower quantities of any one material	Good interior look with good exterior performance and low maintenance
Steel	Thin bar/angle steel profiles; cast, extruded, forged U-factor: similar to that of aluminum	Rust prevention: refinish in 5- to 10-year cycle or use permanent finish	Galvanizing, zinc-phosphate coatings; primed; painted; factory finishes: baked enamel, fluoropolymer, polyurethane coatings	Moderate, unless thermal break is installed	Nonrenewable, salvageable	High strength/smallest frame profiles of all types; stainless steel available but expensive
Aluminum	Box profiles; extrusions; lightweight U-factor: 1.0 with thermal break; 1.9–2.2 without thermal break	Minimal	Natural; factory-applied: baked enamel, epoxy, anodized, electrostatic (powder), fluoropolymer coatings	High, unless thermal break is installed	Nonrenewable, salvageable	High strength, no maintenance
Vinyl (PVC)	High impact resistance; box profiles; multichambered extrusions U-factor for hollow: 0.3–0.5; for insulated, 0.2–0.4	Minimal	Integral when fabricated (limited colors)	Low	Nonrenewable, petroleum-based	UV/sun protection from discoloration may be required; acid- and salt-air-resistant
Fiberglass	Box profiles, polymer-based thermoplastic; dimensionally stable U-factor for hollow: 0.3–0.5; for insulated, 0.2–0.4	Minimal	Integral when fabricated	Low	Spun glass in resin binders	More expensive but more structurally stable than vinyl

WINDOW INSTALLATION

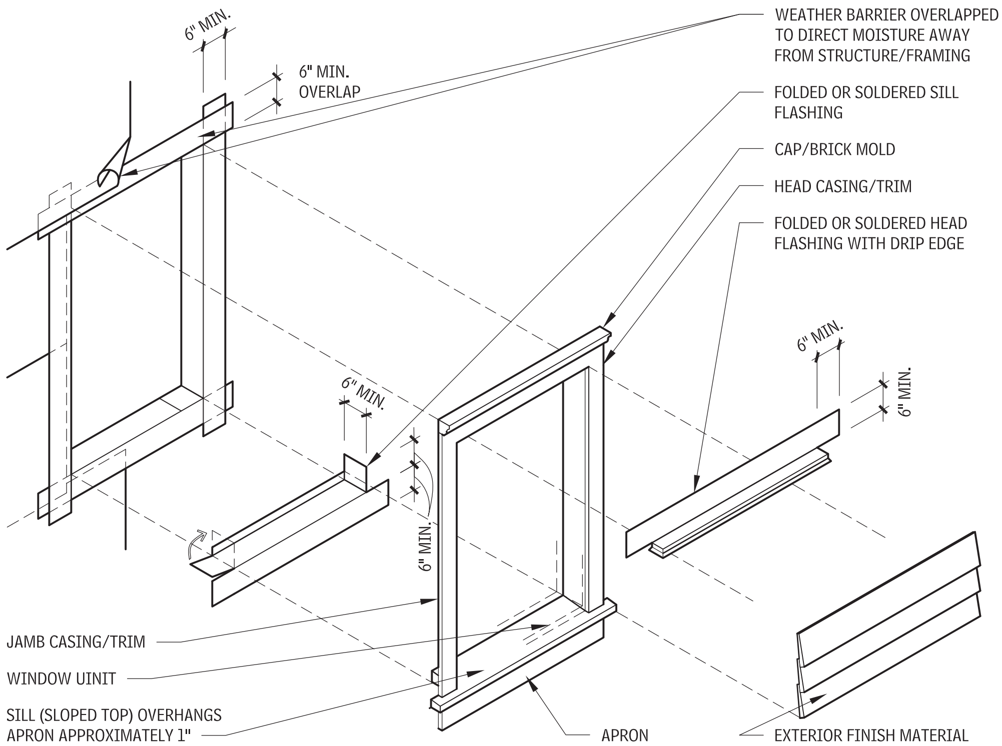
Regardless of the quality of the window unit, ultimate performance depends on proper installation. The intersection of the window frame with surrounding walls has always been a difficult detail, and light modern materials have exacerbated the problem. AAMA 2400-02, "Standard Practice for Installation of Windows with a Mounting Flange in Stud Frame Construction," and ASTM E2112-01, "Standard Practice for Installation of Exterior Windows, Doors and Skylights," both establish a variety of methods for quality installations.

The architect may desire to exceed the standard installation practices for more durable and dependable service. In particular, it is recommended to always provide a subsill of sheet metal or other impervious material, with watertight end dams and a slope to the exterior, and to avoid penetrations in the horizontal portion of the sill.

Qualified installers who understand the importance of many detailed tasks to the overall level of quality are essential. Consider AAMA Certified "Installation Masters" or similar independently trained and certified installers.

For more information, see the *AAMA Window Selection Guide*.

WINDOW WEATHERPROOFING DETAILS
11.328

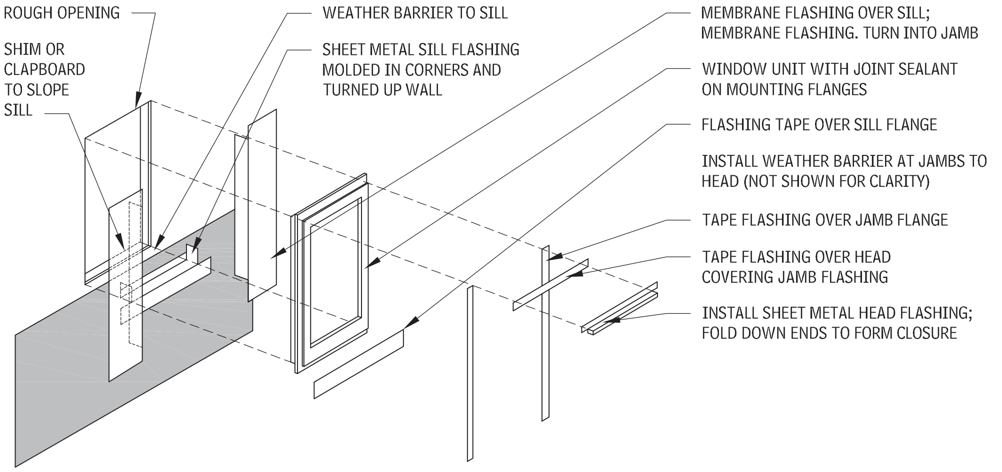


NOTES

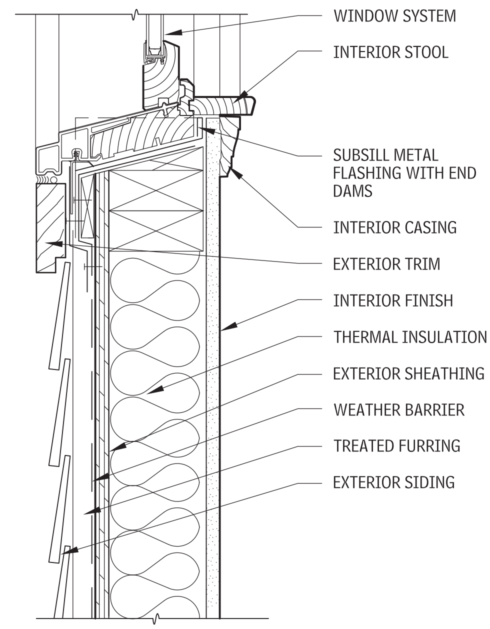
11.328 a. Caulking, sealant, adhesive, or gasket seals window framing and wall joints to form air barrier.
b. These principles are also applicable to door weatherproofing.

Contributors:
John Carmody, University of Minnesota, Minneapolis, Minnesota; Stephen Selkowitz, Lawrence Berkeley National Laboratory, Berkeley, California.

RESIDENTIAL-TYPE WINDOW FLASHING DETAIL WITH WEATHER BARRIER
11.329

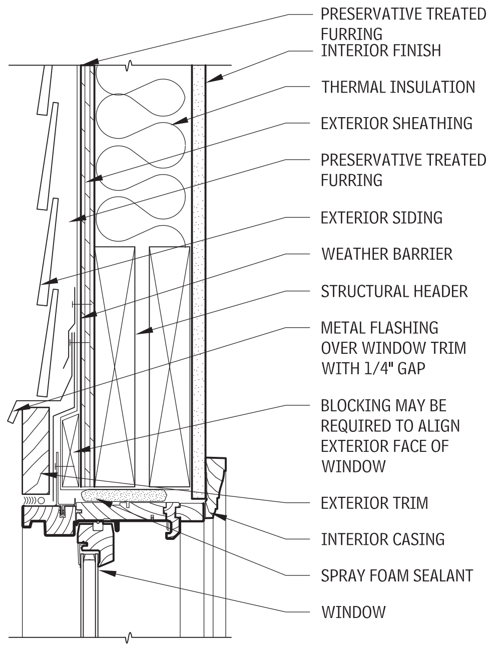


RESIDENTIAL WOOD WINDOW SILL DETAIL
11.332



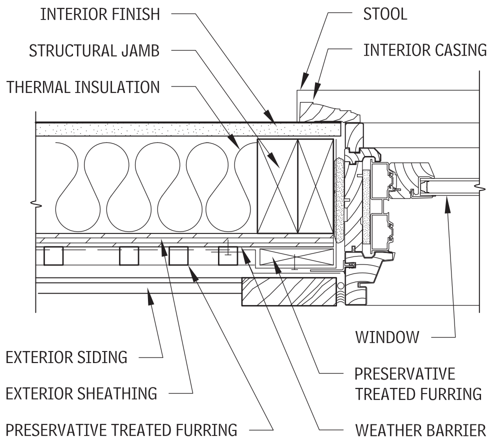
RESIDENTIAL WOOD SILL DETAIL

RESIDENTIAL WOOD WINDOW HEAD DETAIL
11.330



RESIDENTIAL WOOD HEAD DETAIL

RESIDENTIAL WOOD WINDOW JAMB DETAIL
11.331

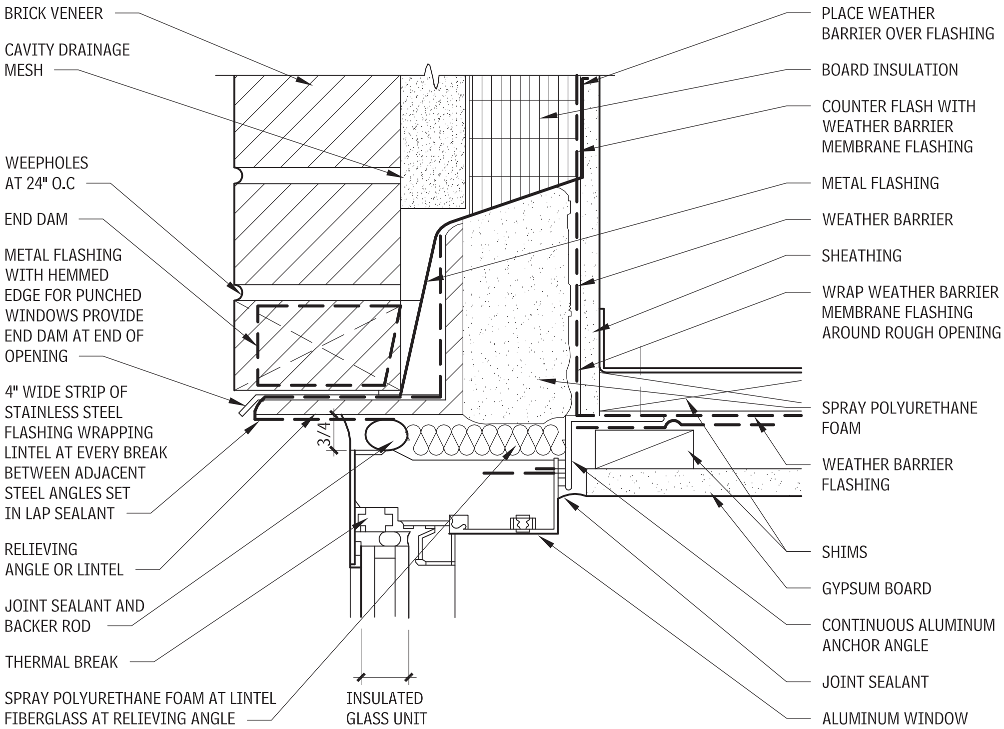


RESIDENTIAL WOOD JAMB DETAIL

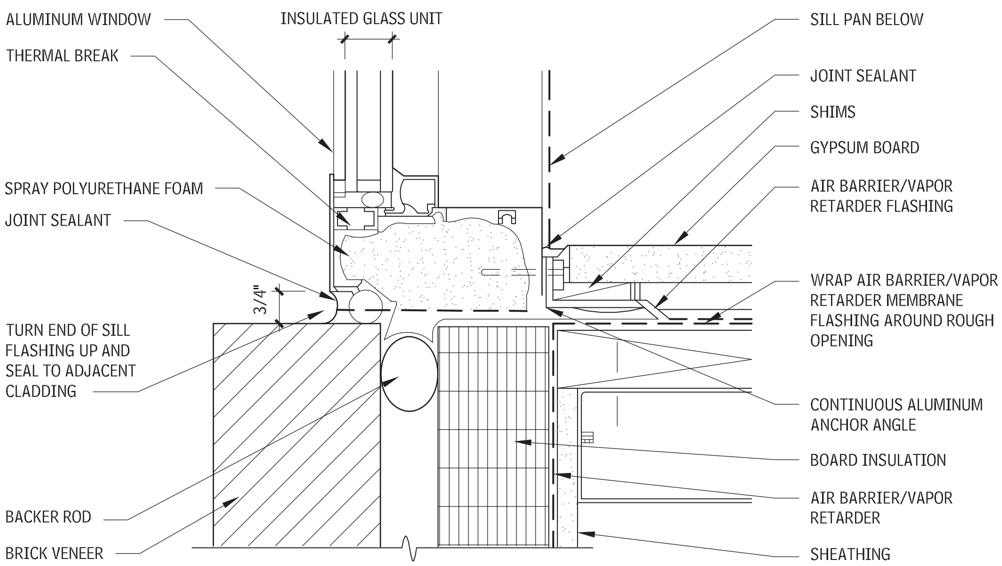
NOTES

11.332 a. Install weather barrier above head (not shown, for clarity).
b. Install expanding foam seal between rough opening and window frame on four sides (not shown).

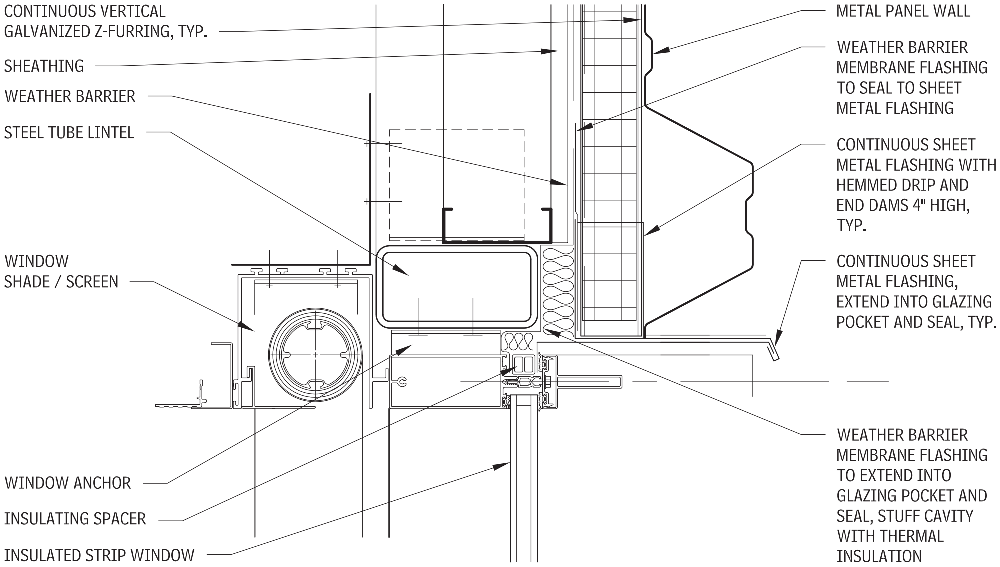
TYPICAL HEAD AT CAVITY WALL
11.333



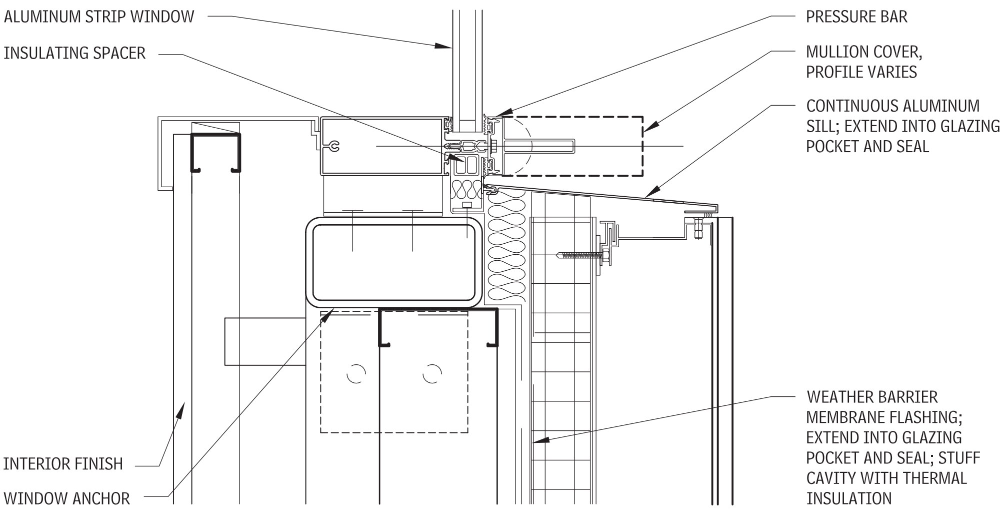
TYPICAL WINDOW JAMB AT CAVITY WALL
11.334



ALUMINUM HEAD DETAIL
11.335



ALUMINUM SILL DETAIL
11.336



ALUMINUM SILL DETAIL

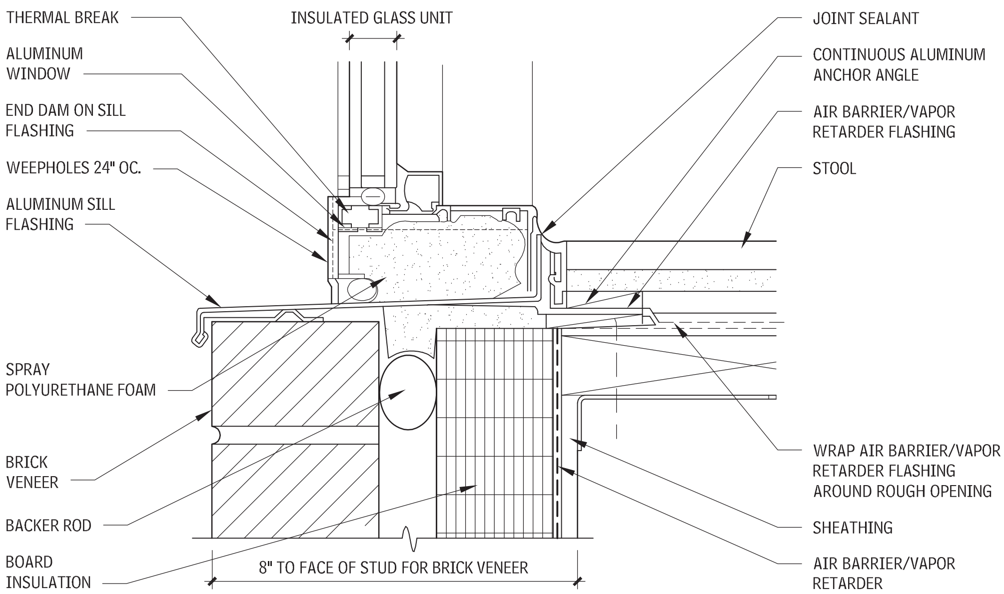
STOREFRONT DESIGN AND DETAILS

Glass and metal frame storefront systems typically are designed to allow good views into and out of ground-level commercial spaces. Metal members and glass sections are assembled on-site to form both wall and entrance systems, which typically are attached to the floor structure below and the bottom of structure above, or to a suspended structural frame above the ceiling. Storefront systems typically have lower resistance to air and water infiltration, and less structural performance. Most storefront systems are not pressure-equalized, but do manage water that penetrates into the glazing pocket. Watertight subsills with end dams are required.

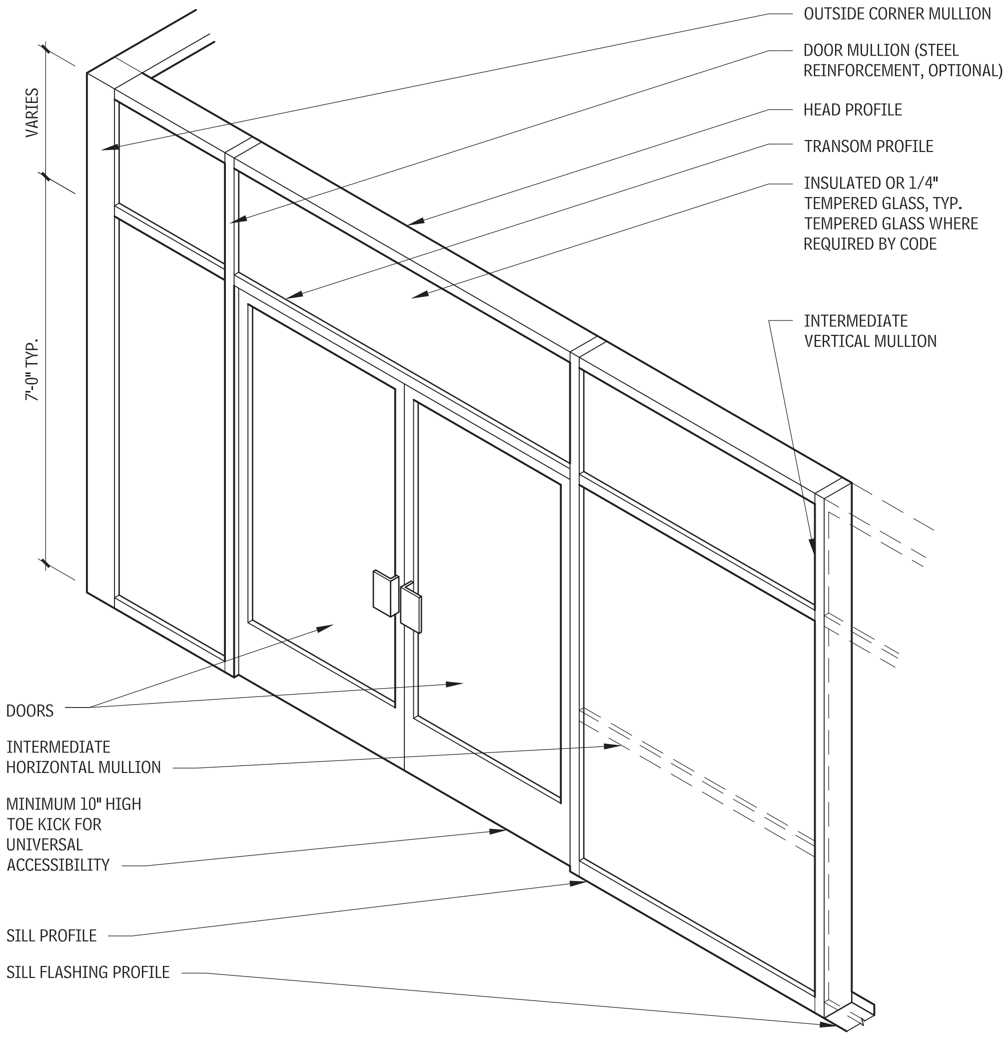
Storefront systems design involves these considerations:

- Storefront systems are available in a variety of attachment/assembly types, depending on the structural or aesthetic design and on the manufacturer. Glass and metal materials come in various shapes, colors, profiles, and structural capabilities.
- Applicable codes must be consulted for safety requirements, glass size, thickness, and tempering. Consult all applicable codes, standards, and regulations for accessibility requirements. These may include requirements for hardware, thresholds, opening forces, and closing speeds.

TYPICAL SILL AT CAVITY WALL
11.337

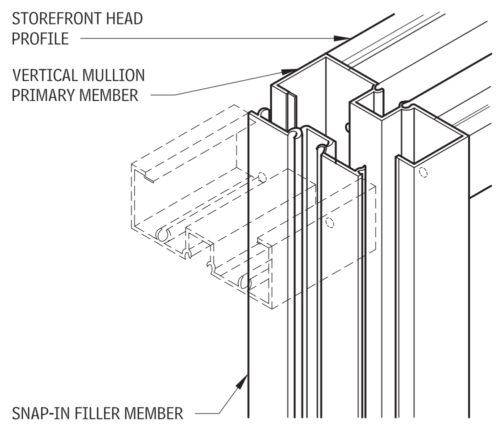


TYPICAL STOREFRONT
11.338



- Manufacturers' data on structural adequacy must be consulted for required loads, and for frame and transom bar reinforcement. Calculations for deflection and wind-load stresses must be considered in the design of storefront systems. Reinforcing for required loads can be provided by steel reinforcing inserts or by use of a heavier metal mullion profile. Consult a structural engineer for analysis and design.
- The height of entrance doors is typically 7 ft-0 in. Typical door widths are 3 ft-0 in., 3 ft-6 in., pair of 2 ft-6 in., and pair of 3 ft-0 in. For accessible doors, at least one leaf of a pair must be 32 in. minimum clear width.
- Perimeters of storefront systems are difficult to detail for both an outer seal and an inner air/vapor barrier seat. Therefore, limit use to low-rise construction, preferably under canopies or overhangs in areas of heavy rainfall.
- Select systems with thermal break and condensation resistance factor (CRF) to suit interior and exterior conditions.

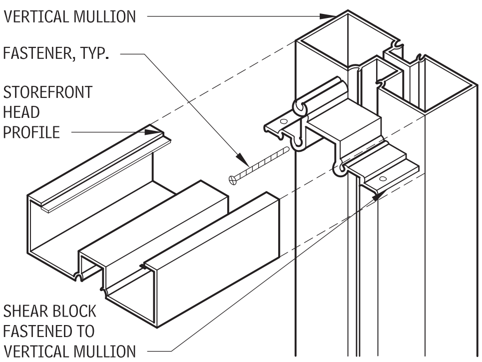
SNAP-TOGETHER/SCREW SPLINE STOREFRONT ASSEMBLY
11.339



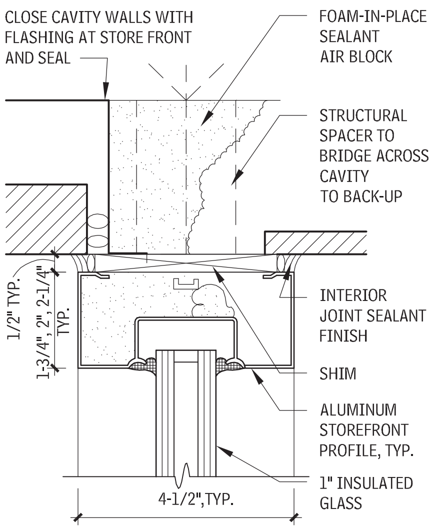
NOTE

11.339 The head, intermediate horizontal profile, and sill members are screwed to vertical members at predrilled locations.

SHEAR BLOCK STOREFRONT ASSEMBLY
11.340



WALL SECTION AT STOREFRONT
11.341



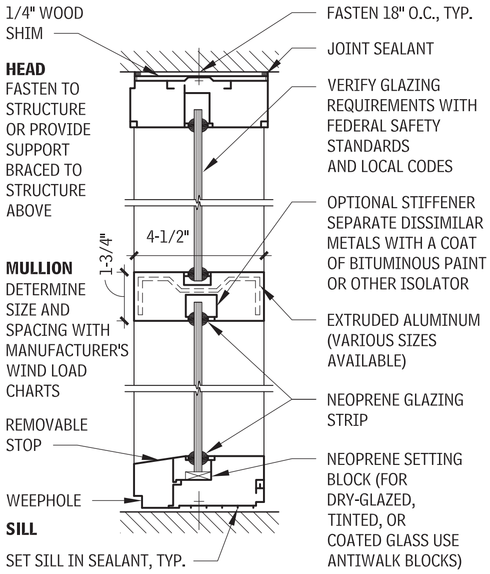
HEAD/JAMB

STOREFRONT SYSTEMS

Keep the following in mind when working with storefront systems:

- Storefront systems typically require a watertight sill or subsill to direct water within the system to the exterior, unless interior or protected by a large overhang. Verify the manufacturer's details and customize to suit the project.
- Review tinted and coated glass applications and details to eliminate the possibility of thermal breakage caused by shading devices and shadow patterns.
- Review setting-block spacing, size, and hardness to prevent glass slippage and breakage.
- Weepholes are required at sill for double glazing.
- Other materials such as hollow metal or wood can be used for custom work and in saltwater atmospheres where aluminum will corrode.
- Various aluminum anodized color finishes are available. Class I (0.7 mil) and Class II (0.4 mil) in black, bronze, or clear, are standard with most manufacturers. Class I is recommended for most exterior applications.
- To extend life of aluminum and to reduce the tendency of surface pitting, wash aluminum periodically with water and mild detergent.
- Glass edges mitered at corners are not recommended. Maximum vertical span for butt glazing is 10 ft. by 8 ft. wide.
- Mullions are clear glass. Tinted or coated glass lights may be considered for small areas. Maximum vertical span is 30 ft.

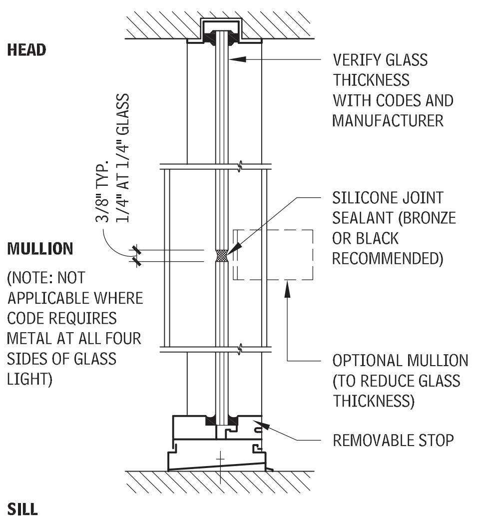
CENTER GLAZED
11.342



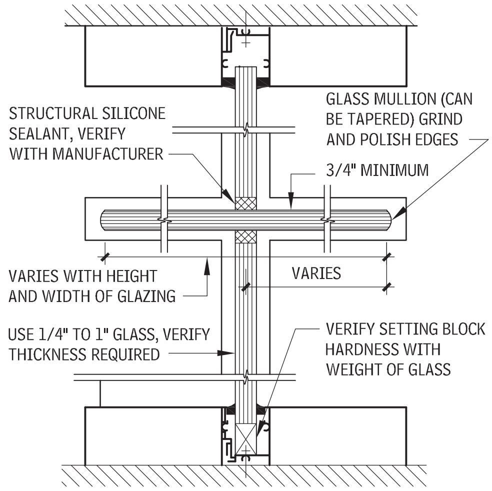
- Care should be taken to protect the public from the possibility of overhead glass breakage. Laminated glass provides the highest level of protection, but fully tempered glass may be acceptable.
- Higher bulkheads can be built up with aluminum tubing and applied stops. Locate expansion mullions 20 ft. o.c.
- Use receptor for deflection or dimensional tolerance.

Refer to manufacturers' current recommendations for specific applications.

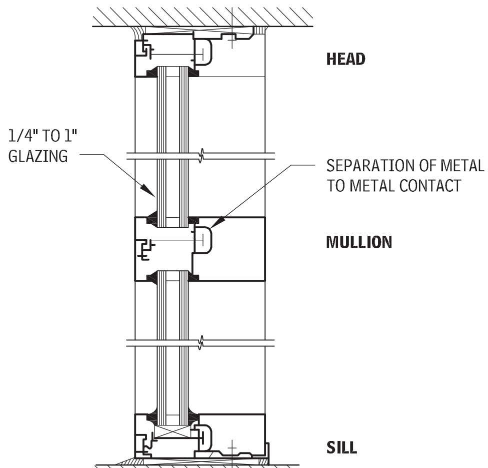
BUTT-GLAZED WITH FLUSH HEAD AND JAMB
11.343



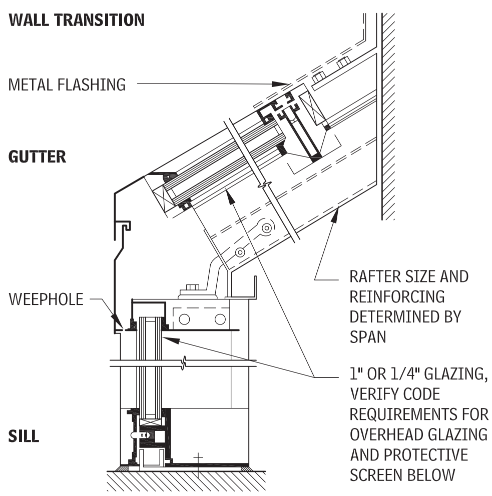
GLASS MULLION
11.344



THERMAL GLAZING
11.345



SLOPED GLAZING
11.346



Contributor:
Daniel F.C. Hayes, AIA, Washington, DC.

GLAZED CURTAIN WALL

The term *curtain wall* was used in the early days of modern architecture to describe virtually any enclosure system that was supported by the building frame, as opposed to masonry or other bearing walls. A modern curtain wall is most typically thought of as a metal frame, usually aluminum, with large areas of glass. Other materials of metal or stone can be used to infill the frame at opaque areas (such as spandrels at floor framing). The frames span past, and are supported by, the floor edges, as opposed to bearing on the floors or spandrel beams. Gravity loads are frequently supported at every other floor, with lateral supports for lateral load only at floors between.

CHARACTERISTICS

A curtain-wall system is typically manufactured using one of the following methods:

- *Standard commercial systems* use collections of typical mullion sections and accessories, which are selected, fabricated, reinforced, and assembled into custom-sized walls to suit the project.
- *Custom systems* are designed specifically for the project, using specially designed mullions, parts, and accessories. The cost of custom design and engineering is offset by the efficiency of scale inherent with large projects.

Curtain-wall water penetration management methods:

- The highest-performing systems are fully pressure-equalized rainscreen systems, with the glazing pocket around each individual light a pressure-equalization chamber that is separated from other lights, weeped, and vented.
- Nonpressurized systems tend to direct water that penetrates the outer seals to vertical mullions, and then weeps at the base of wall.

Curtain-wall installation methods:

- *Stick systems* assemble individual vertical and horizontal mullions on-site, and infill with glass, metal, stone, or other panels. Stick systems require careful attention to sealing the intersecting members.
- *Unitized systems* are substantially factory assembled off-site, complete with frames, glazing, and as much trim or accessories as reasonable. The panels are typically between 5 and 10 ft. wide, and one or two stories high. The unitized panels are hoisted onto the wall and anchored in place. Unitized panels are more often a custom system than stick systems, and are used more often on large or high-rise projects. Because the sealing of the intersecting members takes place in a shop or factory, they are more likely to be well made. However, the connections between units are blind and, therefore, must be carefully engineered and verified by mock-up testing.

Curtain-wall glazing types:

- *Pressure-plate glazing:* In this system, the glass and infill panels are installed from the exterior of the building. Pressure-plate glazing allows for sealing of all joints in the framing and easy integration with an air/vapor barrier. Toe beads, cap beads, or complete wet glazing are possible to improve performance. However, all of the glass must be handled from scaffolding or lifts.
- *Dry glazing:* In this system, the glass and infill panels are installed from the interior. The exterior frame is fixed and glazing gaskets are installed. Typically, only the top mullion has a removable interior stop. The glass unit is slid into a deep glazing pocket on one jamb far enough to allow clearing the opposite jamb, then slid back and dropped into the sill glazing pocket. The removable interior stop is applied and, finally, an interior wedge gasket is installed. Sometimes this method is called "jiggle" or "wiggle" glazing because of the manipulation necessary to get the glass into place. Installation of the glass units from inside the building is desirable from a constructability standpoint, but performance is slightly reduced because dry metal-to-metal joints result at the removable stop at a point that should be airtight and watertight. Heel beads will improve performance, and some systems incorporate an extra gasket to form an air seal between frame and glass. Installation of spandrel areas may have to be from the exterior because of limited access space on the interior side.
- *Structural silicone glazing (SSG):* This system depends on adhering the glass to the frame or other glazing with a bead of silicone. Outer silicone weather seals supplement the structural seal. Unitized systems are frequently structural silicone glazed because it allows work from one side only, and is highly reliable. Two-sided SSG can be completed in the field with either pressure plate or jiggle-glazed frames in the other direction. Four-sided SSG should only be done under controlled conditions in a factory. If the frames are stick-built, then an aluminum subframe is adhered to the glass at the factory, and the resulting assembly is mechanically fastened to the main frame in the field.

Water management for nearly all curtain walls uses pressure-equalized rainscreen technology.

PERFORMANCE

Standardized levels of performance for curtain-wall systems are not commonly available in the industry, but standardized test procedures and ranges of typical values are relatively well known.

- Structural capacity of a curtain wall is tested according to ASTM E 330, "Standard Test Method for Structural Performance of Exterior Windows, Curtain Walls, and Doors by Uniform Static Air Pressure Difference." The loads required for the project are determined by code, normally ASCE-7. For large projects, boundary-condition wind-tunnel testing may be performed to establish more accurate wind loads. Wind-tunnel testing may lower the average field loads and may also help identify hot spots of higher loads.
- Air infiltration is tested according to ASTM E 283, "Standard Test Method for Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors," with values of leakage tested at certain differential pressures. Common leakage values are 0.06 cfm per sq. ft. of wall area. Common test pressures are 1.56 psf (25 mph wind) for low-rise, 6.24 psf (50 mph) or 10 psf (63 mph) for mid-rise construction, and 12 psf (70 mph) and up for high-rise or monumental buildings. Pressures are also selected at approximately 20 percent of the structural loads.
- Water leakage is tested according to ASTM E 331, "Standard Test Method for Water Penetration of Exterior Windows, Curtain Walls, and Doors by Uniform Static Air Pressure Difference," and AAMA 501.1, "Standard Test Method for Metal Curtain Walls for Water Penetration Using Dynamic Pressure." Test pressures usually match those for air infiltration. The architect should establish leakage criteria—frequently acceptable are water amounts appearing on interior sills small enough to not run off the mullion. The static pressure test is more common, but might give an optimistic result because the test procedure may suck glass against gaskets, making a better than expected seal. Dynamic testing, which may help reveal leaks that would occur under the buffeting conditions of variable winds, is particularly effective at operable sash.
- Thermal performance is tested according to AAMA 501.5, "Test Method for Thermal Cycling of Exterior Walls." U-values should be specified by the design team. Condensation performance is extrapolated from the thermal performance.

DETAILING

Manufacturers of curtain walls typically provide generic details for installation. Adjacent construction is frequently shown as a hatched single line. Detail the curtain-wall frame in project-specific assemblies.

- *Mullions and covers:* Standard rectangular commercial mullions are available from manufacturers in widths from 2 to 3 in. (2-1/2 in. is most common), in depths from 1 to 12 in. from the inside face of glass. Snap-on mullion covers are available in many shapes, and can be easily customized because they have limited impact on the performance of the curtain wall. Large external mullion covers, however, may seriously affect the thermal performance of systems without complete thermal breaks.
- *Interface with adjacent assemblies:* Seal the air barrier of the curtain wall to the wall air barrier; likewise the rainscreen. Use subsill flashing at the base of the wall, detailed to seal to the air barrier. At the interface with barrier walls, provide a dual line of sealant.
- *Weather barriers:* Detail the curtain-wall installation so that the line of weather barrier (if required) extends uninterrupted across the gap at the perimeter of the curtain wall by connecting to the inner shoulder of the glazing pocket.
- *Anchoring:* Curtain walls are typically anchored to each floor slab or spandrel beam. Every other floor is a gravity and wind anchor, with a wind-only slip anchor in between. The anchorage scheme should be determined by the architect and structural engineer, and indicated on the drawings. Unitized panels commonly have a wind and gravity anchor at each floor, with slip joints providing wind load resistance at the stack joints. Anchors for stick systems are commonly mounted on the side of beams or slab edge. Anchors for unitized panels are commonly mounted in pockets on the top of slabs. Manufacturers have a variety of proprietary anchors that allow three-dimensional adjustment and fixed or slip connection.
- *Movement:* Because curtain walls span floor-to-floor from slab or spandrel beam, they must accommodate differential movement of the spandrel beams and lateral drift of the structure along with the large thermal movement inherent with aluminum. Curtain-wall heads (particularly at a strip curtain wall) often are located at shelf angles and must accommodate movement typically in the range of 1/2 in. from above.
- *Thermal continuity:* Detail the curtain wall to maintain a line of thermal insulation in the same plane as in the tested configuration, and as intended by the curtain-wall manufacturer.
- *Firestopping:* The intersection of a floor slab with a curtain wall requires firestopping.
- *Spandrel/shadowboxes:* Where the curtain wall is in front of a structure or areas that otherwise need to be opaque, spandrel glass or a shadowbox is used. Spandrel glass is composed of

single or insulated glass units, with the inside layer opacified by a film or fired-on ceramic frit. Reflective coating can be used. If an insulated glass unit is used, the second or third surface can be coated with patterned ceramic frit. Shadowboxes are more effective at blending spandrel areas with vision areas, especially if the back panel is reflective. As opposed to spandrel areas, the cavity inside the shadowbox is typically vented and weeped, but there are differences of opinion among experts and manufacturers regarding venting of the cavity. Vented airspaces shift the thermal enclosure to the back of the curtain wall and may result in thermal short circuits and uncontrolled condensation; and, in time, the inside surface may get dirty. Unvented shadowboxes may overheat, especially with clear glass. Note that heat buildup within shadowbox cavity can cause off-gassing of sealants and plastics of some materials and may deform composite materials and insulation. The manufacturer can assist with an analysis.

- *Parapets and copings:* When the curtain wall extends past the edge of the roof, the curtain wall becomes a parapet. Special care must be taken to stop air movement through hollow mullions and to control the thermal conduction to the exterior. Most curtain-wall systems are not designed for exposure to weather from the back side, but they can be modified to properly function. If a spandrel of shadowbox is used for an opaque parapet, the back of the curtain wall can be furred, sheathed, and waterproofed with roofing base flashing. Transparent or translucent parapets can be provided by terminating the roof base flashing at a mullion approximately 8 in. above the roof. Special precautions must be taken because the back surface of a curtain wall is typically not watertight. Curtain walls extending past the conditioned space into the parapet can create thermal short-circuits and uncontrolled condensation. Provide air seals to prevent moisture-laden air from contacting cold surfaces, both inside the mullions and between the mullions and the roof structure. Foam-in-place sealants work well. Because of the inherent thermal break with extending a curtain wall to form a parapet, it is best avoided in cold climates. Thermal analyses can check insulation and design of air/vapor barriers to verify that temperatures never reach dew points. Extend roof base flashing or membrane flashing across the top of the parapet and seal it into the glazing pocket. Cap with brake metal coping, which is also sealed into the glazing pocket.

INSTALLATION

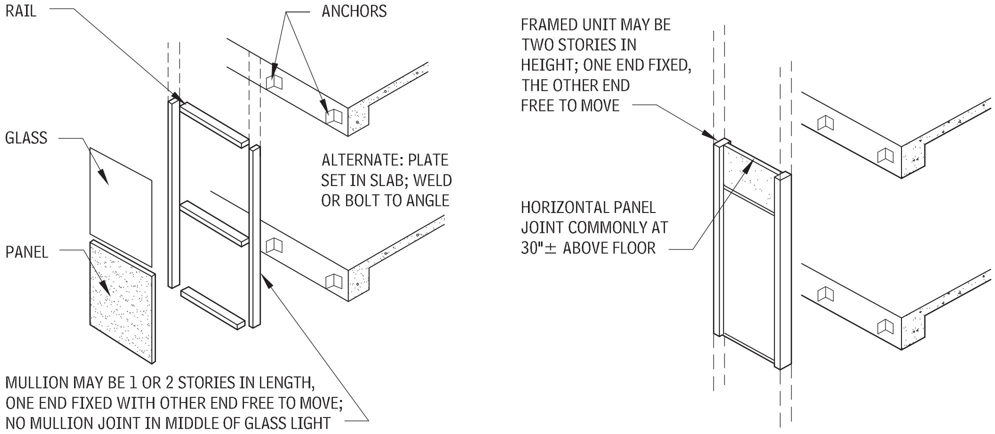
Whatever the quality of the curtain wall, ultimate performance depends on proper installation. The intersection of the curtain wall frame with surrounding walls has always been a difficult detail, and light modern materials have exacerbated the problem.

Stick systems require a high level of quality control in the field, as there are numerous extremely important and detailed steps in the assembly of the curtain wall.

- Anchors and mullions must be installed to allow movement.
- Joints at the mullion intersection must be made airtight and be properly compartmentalized for pressure-equalized systems.
- Glazing gaskets must be cut precisely and the corners sealed.
- Pressure plates must be torqued to specified values to compress the gaskets sufficiently for watertight performance.

Even unitized systems require attention to detail during field installation but because more assembly takes place in the factory there are fewer crucial requirements. The most important point is the flashing of the four-way intersection.

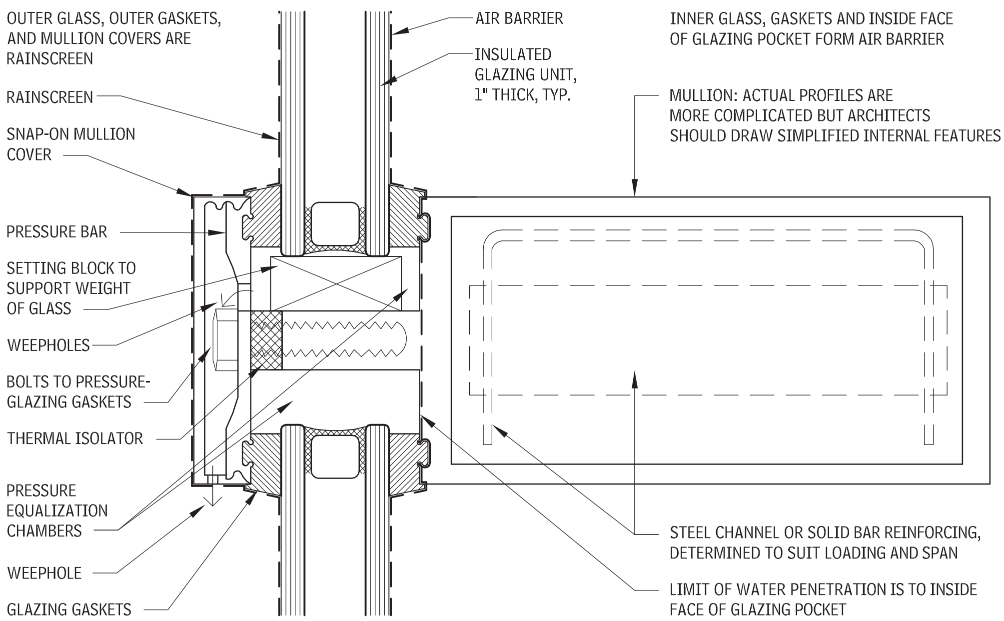
STICK AND UNITIZED CURTAIN-WALL CONSTRUCTION
11.347



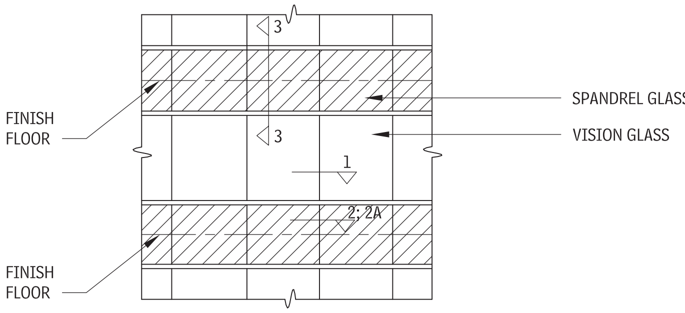
STICK SYSTEM
FRAMING MEMBERS VISUALLY PROMINENT. COMPONENTS INSTALLED PIECE BY PIECE.

UNITIZED SYSTEM
COMPLETELY PREASSEMBLED UNITS MAY OR MAY NOT INCLUDE INTERIOR FINISH

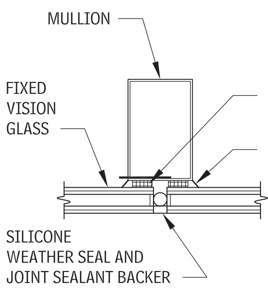
TYPICAL PRESSURE-PLATE MULLION
11.348



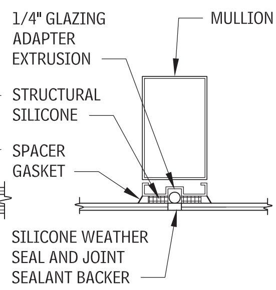
TWO-SIDED STRUCTURAL GLAZING SYSTEM WITH STRUCTURAL SILICONE JOINT SEALANT
11.349



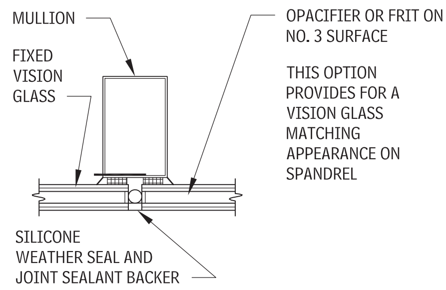
TYPICAL ELEVATION



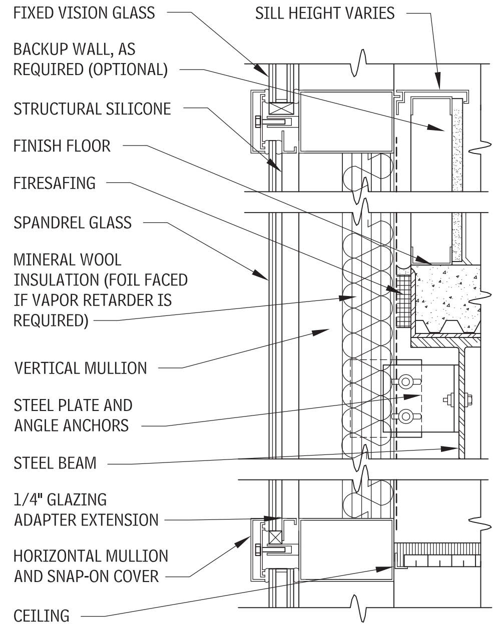
SECTION 1



SECTION 2

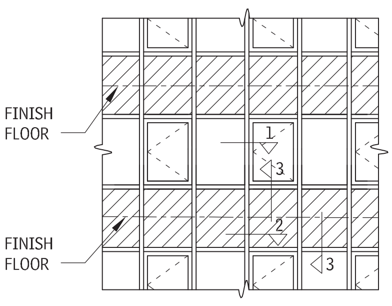


SECTION 2A

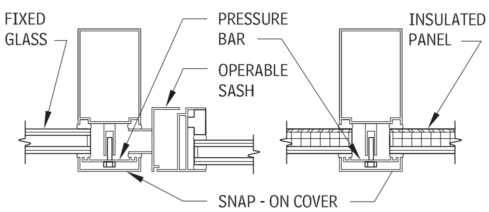


SECTION 3–3

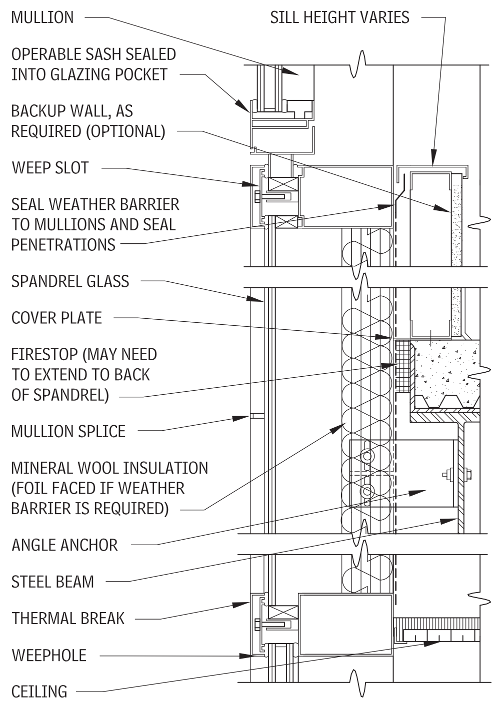
GRID SYSTEM (STICK OR STUD), ALUMINUM PRESSURE BAR
11.350



TYPICAL ELEVATION – WINDOW AND PANEL TYPES OPTIONAL



SECTION 1 **SECTION 2**

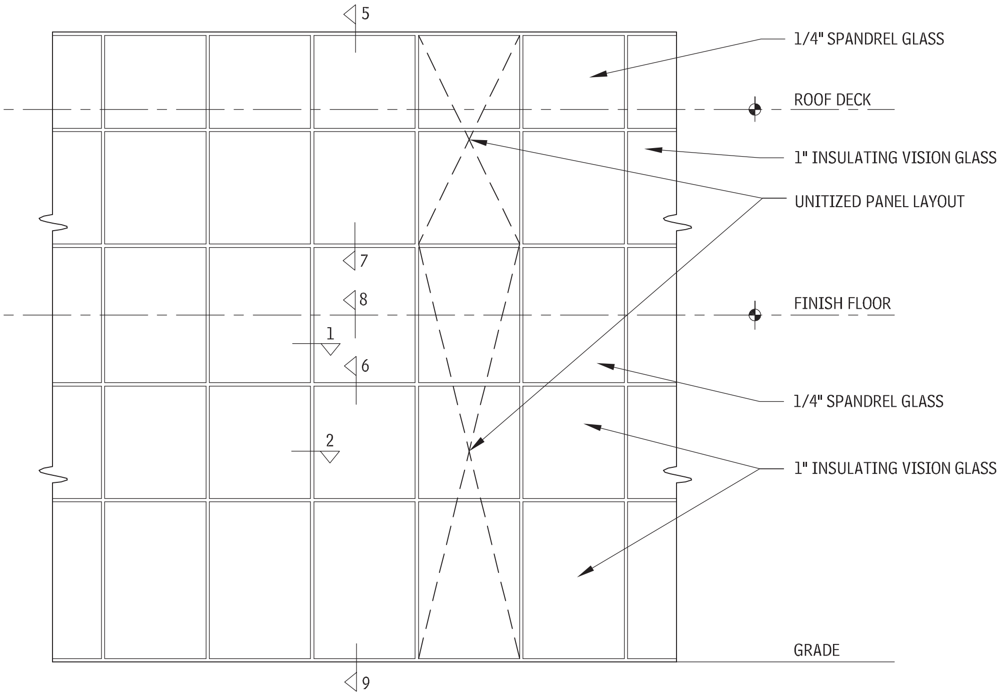


SECTION 3

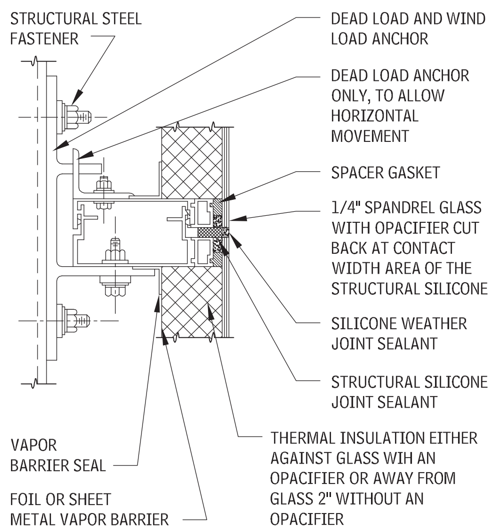
NOTE

11.350 Horizontals are weeped for positive performance against water infiltration, with slots at glazing pressure plate and holes at cover.

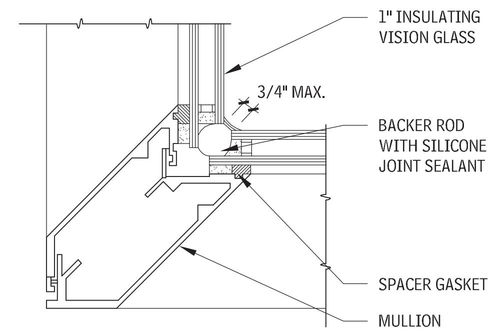
TYPICAL FOUR-SIDED STRUCTURAL SILICONE GLAZING, CUSTOM-UNITIZED SYSTEM
11.351



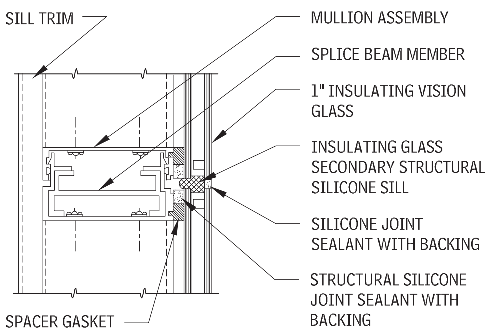
MULLION DETAIL 1 AT SPANDREL GLASS—VERTICAL PANEL JOINT
11.352



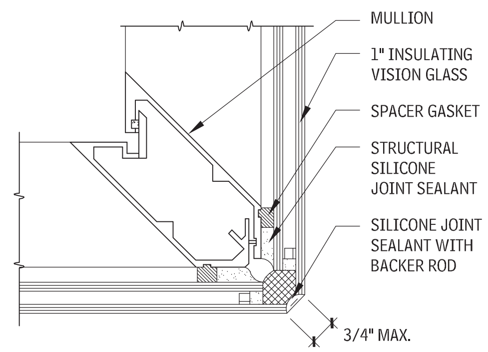
MULLION DETAIL 4 AT INSIDE CORNER—VERTICAL PANEL JOINT
11.355



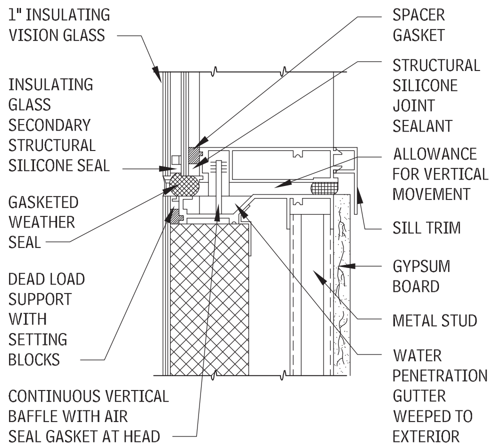
MULLION DETAIL 2 AT VISION GLASS—VERTICAL PANEL JOINT
11.353



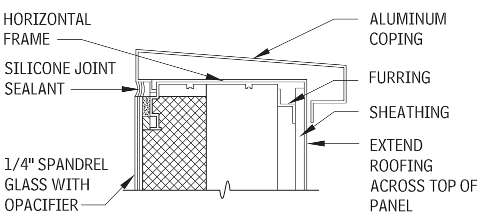
MULLION DETAIL 3 AT OUTSIDE CORNER—VERTICAL PANEL JOINT
11.354



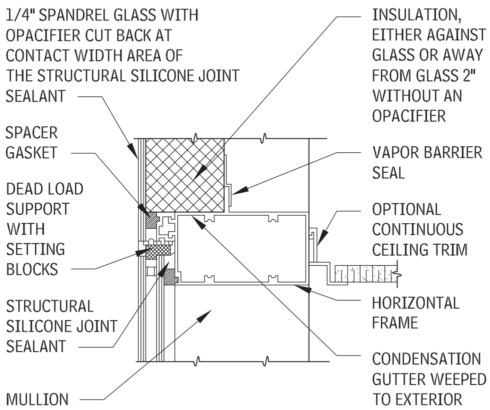
SILL DETAIL 7, AT HORIZONTAL
11.358

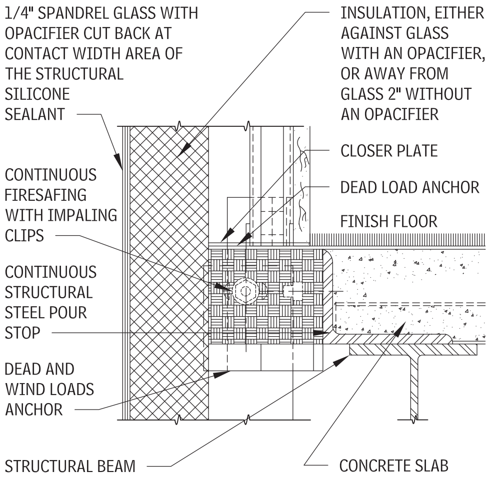


COPING DETAIL 5
11.356

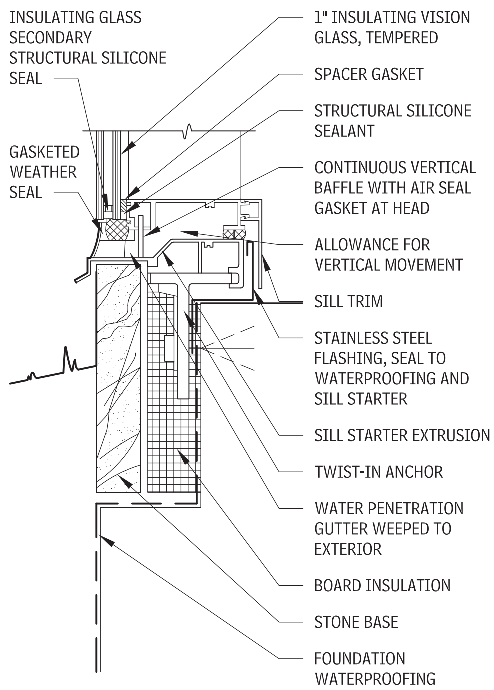


HEAD DETAIL 6
11.357

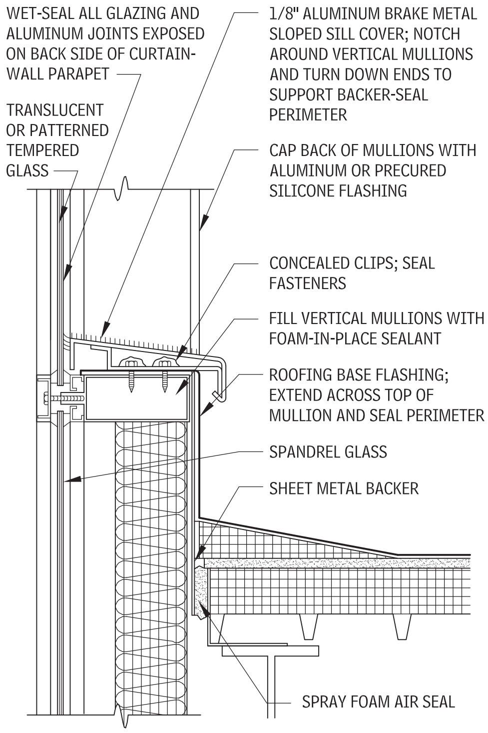




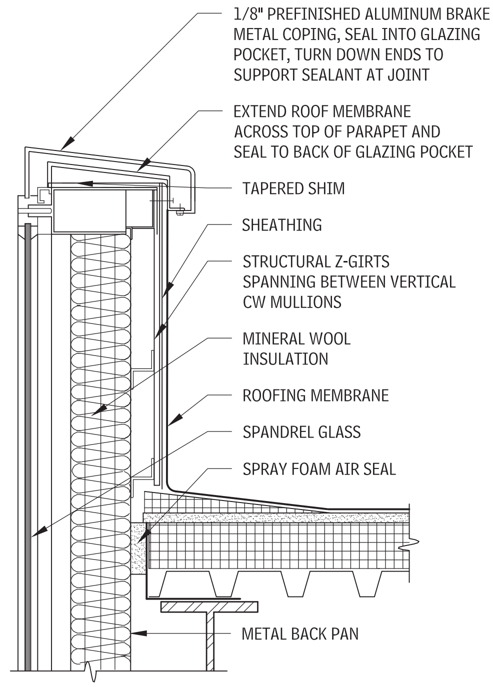
FLOOR SLAB DETAIL 8
11.359



GRADE DETAIL 9
11.360



SILL AT GLAZED PARAPETS
11.361



CURTAIN-WALL PARAPET
11.362

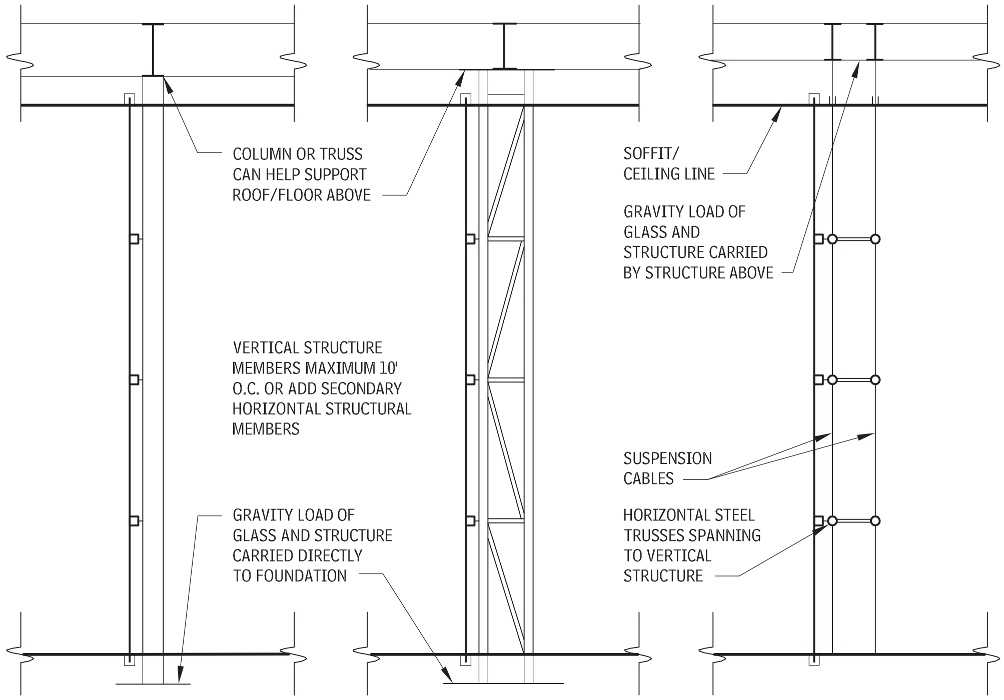
SPECIALIZED CURTAIN WALL

Design professionals have been challenging the traditional assumptions regarding the support and glazing of curtain walls. These walls have frequently been used at large lobbies, atria, and other monumental-scale spaces, but they have also been used to enclose entire buildings. More sophisticated, lightweight, and visually transparent wall support structures have been developed, including the use of architectural exposed structural steel trusses, trusses with cable and rod tension members, tension grid supports, glass mullions and support fins, the use of the glass itself as part of the load-resisting components, and other innovative solutions. The glazing of these systems frequently depends on point support devices or patch fittings at corners, and silicone butt glazing, resulting in a frameless, visually uninterrupted surface.

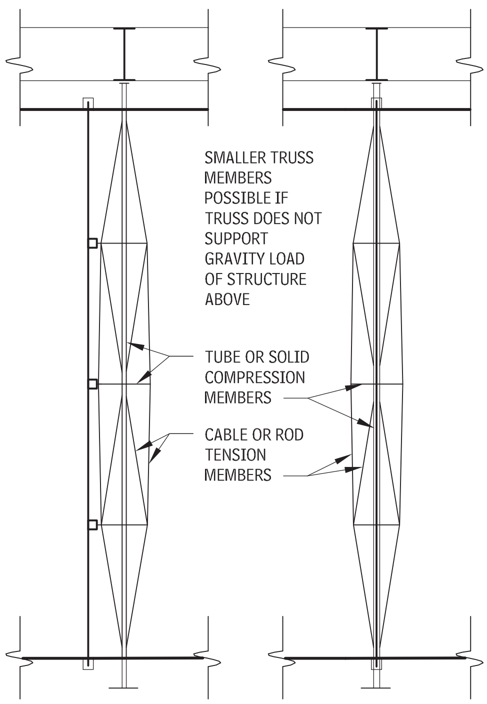
Specialized curtain walls require extremely close coordination between the architect, structural engineer, manufacturer, installer, and other contractors. In particular, if the glass is used structurally, there are relatively few engineers qualified to perform the analysis and few installers who understand the difficult sequencing required to temporarily hold the wall in place until all components can be tensioned to design values. The following are issues:

- Heat gain/loss and glare control can become sizable problems with large areas of glass. Shading and specialized glass are required.
- The adjacent building structure may need to accommodate large loads resulting from suspending walls that might otherwise be gravity-loaded to a foundation or to resist large tension loads.
- The interface with surrounding walls, copings, and roofs may need to accommodate significant movement within and between the systems.

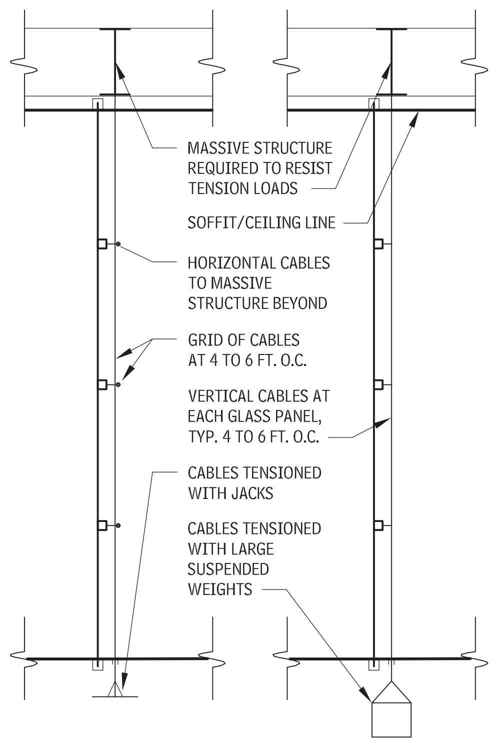
STRUCTURAL STEEL SUPPORT—LONG-SPAN CURTAIN WALL
11.363



TENSION CABLE TRUSSES—LONG-SPAN CURTAIN WALL
11.364



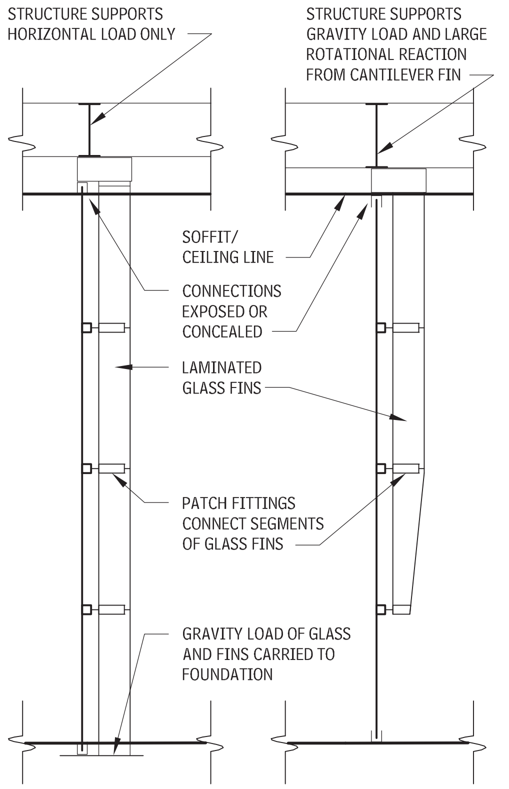
TENSIONED CABLES—LONG-SPAN CURTAIN WALL
11.365



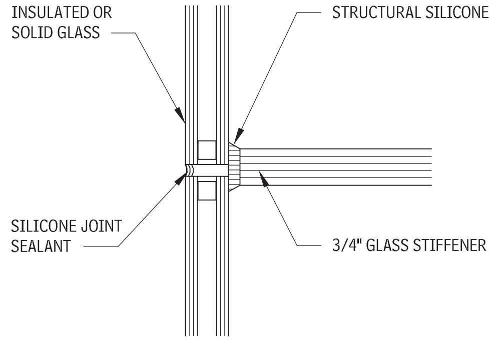
NOTES

11.363 a. Weather and thermal barriers must continue above curtain wall. They are not shown, for clarity.
b. Some or all of the steel components may be solid or laminated timber.
c. Structure above must accommodate large horizontal loads from vertical members.
11.364 Weather and thermal barriers must continue above curtain wall. They are not shown, for clarity.
11.365 Weather and thermal barriers must continue above curtain wall. They are not shown, for clarity.

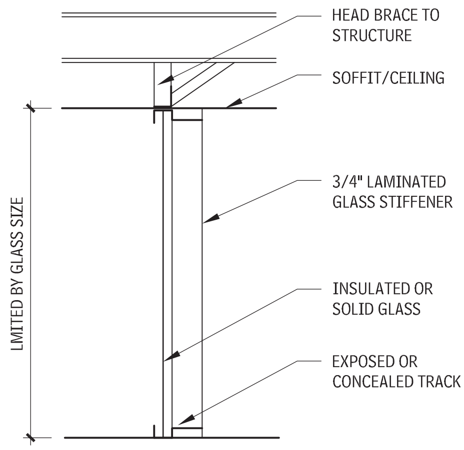
GLASS FINISH SUPPORTS—LONG-SPAN CURTAIN WALL 11.366



FULL HEIGHT **CANTILEVERED**



PLAN DETAIL



SINGLE SPAN

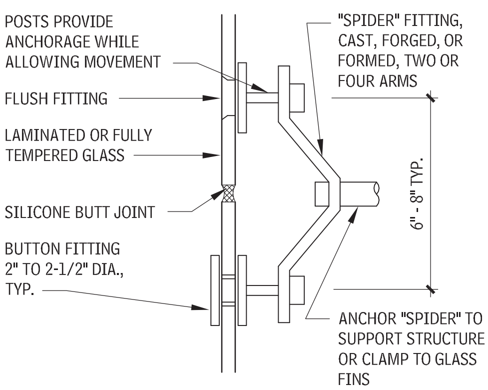
CHANNEL GLASS CURTAIN WALL

Channel glass walls are composed of single or double layers of extruded glass channels, silicone-sealed together and held at head and sill in an extruded track. The walls are translucent rather than transparent. The double-layer walls are thermally efficient if frames are also thermally broken.

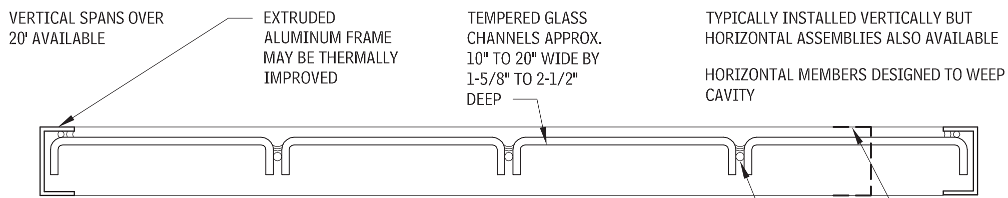
Consult the following references:

- *Double-Skin Façades* by Eberhard Oesterle, Rolf-dieter Lieb, Martin Lutz, and Winfried Heusler (Munich, Germany: Prestel Verlag, 2001)
- *Glass in Architecture* by Michael Wigginton (New York, NY: Phaidon Press Ltd, 1996)

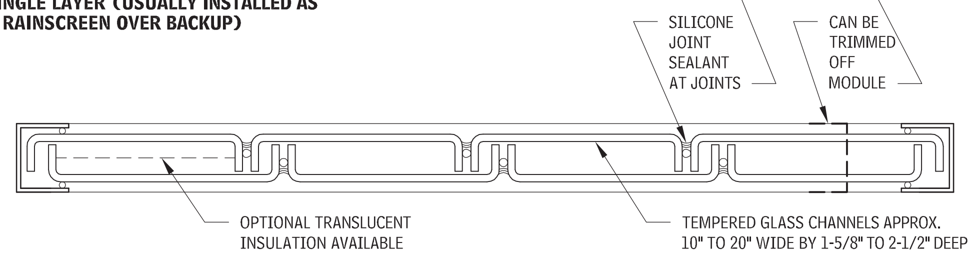
POINT SUPPORT 11.367



CHANNEL GLASS CURTAIN WALL 11.368



SINGLE LAYER (USUALLY INSTALLED AS A RAINSCREEN OVER BACKUP)



DOUBLE LAYER

NOTE

11.366 Weather and thermal barriers must continue above curtain wall. They are not shown, for clarity.

EXTERIOR DOORS

DESIGN CONSIDERATIONS

Exterior doors allow access and egress, while maintaining a separation between the interior and exterior environments. Doors must also provide security from intrusion, and may need to be fire-rated.

Doors and frame types include:

- *Hollow metal doors and frames:* These comply with performance standards in the *Hollow Metal Manual*, by Hollow Metal Manufacturers Association (HMMA) and NAAMM and the Steel Door Institute (SDI).
- *Residential prehung doors:* These include insulated, metal-skinned, fiberglass-skinned, and wood doors in wood or metal frames. Refer to AAMA/WDMA/CSA 101/I.S.2/A440-05, "Standard/Specification for Windows, Doors, and Unit Skylights." Drafts and heat loss from residential doors present a larger problem than for commercial buildings. It is likely that the comfort of the occupants will be affected to a greater degree, and that the energy loss will result in a greater impact on the overall energy usage.
- *Aluminum and glass entrance doors:* This type includes doorframes of extruded aluminum with glass or insulated aluminum infill panels. Standardized test procedures are available to evaluate many specialized performance criteria, including acoustic isolation, blast resistance, forced-entry resistance, and safety impact. Refer to AAMA.
- *Specialty entrance doors:* Tempered safety-glass doors, frameless with patch fittings, with top and bottom rails or with solid metal frames, are available on a custom basis for monumental entrances. Refer to GANA.

ACCESSIBILITY

Entrance doors are not limited by IBC or ADAAG for operating force for accessibility, primarily because the low force is not sufficient to keep the doors closed against wind pressures. However, this should be verified, as some local codes do have maximum operating forces.

It is good practice to provide automatic doors at entrances to public buildings to allow for universal access. Overhead concealed and exposed operators, as well as operators concealed in the floor, are available. Push-button, card key, or motion sensor activators can be used.

Thresholds must provide a continuous walkable surface, with minimal vertical offsets to allow for universal access that is free from tripping hazards and impediments to wheeled traffic. The lack of vertical offset can create an opportunity for water to be pushed under doors by wind pressure, so compensate with generous canopies or overhangs and ensure that the paving slopes away. Trench drains with closely spaced grilles immediately in front of doors will also stop water.

INSTALLATION

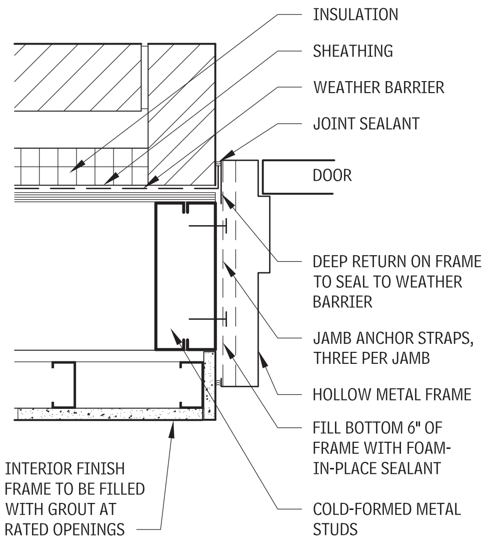
Regardless of the quality of the door and frame, ultimate performance depends on proper installation. The intersection of the doorframe with surrounding walls has always been a difficult detail, and light modern materials have exacerbated the problem.

ASTM E 2112-01, "Standard Practice for Installation of Exterior Windows, Doors, and Skylights," establishes a variety of methods for quality installations of prehung residential doors. The architect may exceed the standard installation practices for more durable and dependable service. In particular, it is recommended to coordinate waterproofing, dampproofing, and flashing below grade with the threshold.

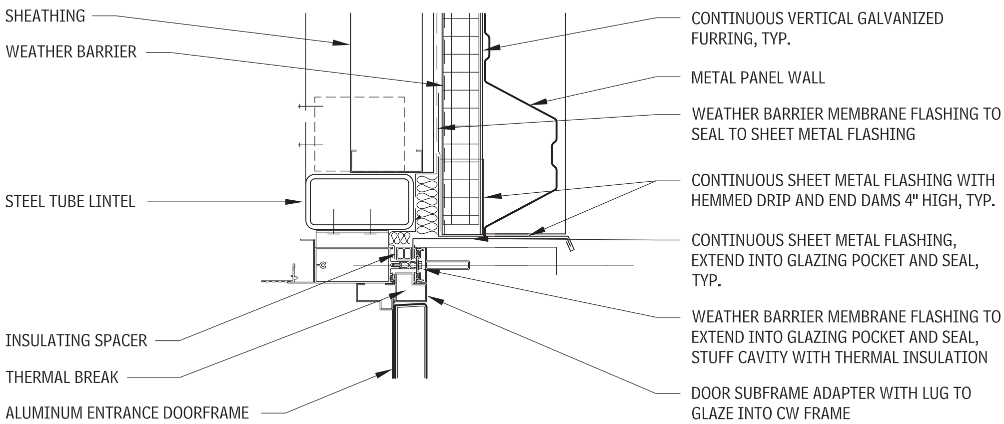
Door installation must be detailed as appropriate for the generic wall assembly types, which include:

- *Barrier walls:* Seal the doorframe to the barrier. Use a subsill flashing to avoid introducing water into the wall. For massive barrier walls such as precast concrete, head flashing may be required to ensure that water seepage does not get behind the window.

HOLLOW METAL JAMB DETAIL
11.369



ALUMINUM ENTRANCE JAMB DETAIL
11.370



- *Drainage plane walls:* Provide the primary seal of the doorframe to the water-resistant drainage plane, and an outer seal in line with the wallcovering. The flashing below the threshold should extend past the doorframes and be lapped by the water-resistant drainage plane in the wall. Ensure continuity of the air barrier, wherever it is located in the wall assembly.
- *Drained cavity walls:* Provide the primary seal of the doorframe to the waterproof inner line of protection, and an outer seal to the outer wallcovering. The flashing below the threshold should extend past the doorframes and be lapped by the water-resistant barrier in the wall. Ensure continuity of the air barrier if it is not located at the inner line of protection.
- *Pressure-equalized (PE) rainscreen walls:* Use doorframes that incorporate PE rainscreen technology. Seal the air barrier of the doorframe to the wall air barrier; likewise for the rainscreen. The flashing below the threshold should extend past the doorframes and be lapped by the air/vapor barrier in the wall.
- *Air and vapor barriers:* Detail the door installation so that the line of the air barrier and/or vapor barrier (if required) extends uninterrupted across the gap at the perimeter of the doorframes.

These organizations can be contacted for more information:

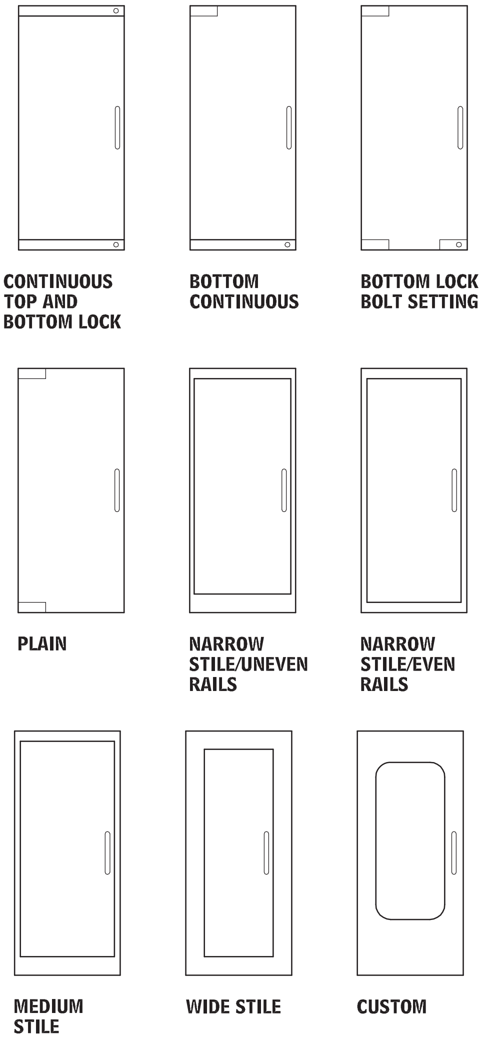
- Hollow Metal Manufacturers Association (HMMA)
- Steel Door Institute (SDI)
- American Architectural Manufacturers Association (AAMA)
- Window and Door Manufacturers Association (WDMA)

GLASS ENTRANCE DOORS

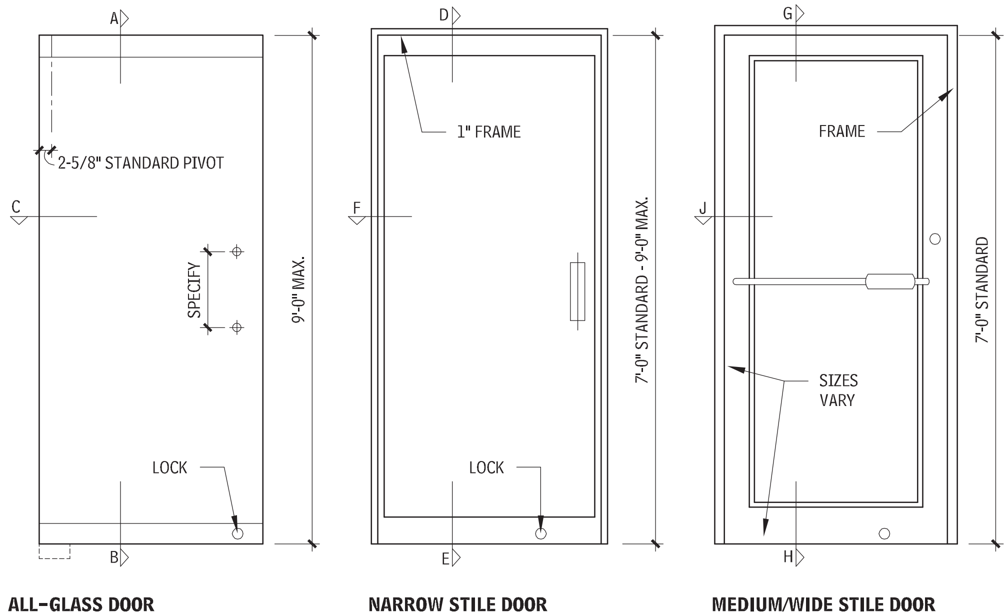
Keep the following in mind when working with glass entrance doors:

- Consult applicable codes for safety requirements, glass size, thickness, and tempering.
- Frameless 1/2-in. glass doors are available in clear, gray, or bronze tints, in sizes up to 60 by 108 in. Frameless 3/4-in. glass doors are available only in clear tint in sizes up to 48 by 108 in.
- Consult manufacturers' data on structural adequacy for required loads and for frames and transom bars reinforcement.
- Aluminum doors and frames are available in all standard aluminum finishes in sizes up to 6 by 7 ft.
- Frameless doors may not permit adequate weather stripping. The use of frameless doors in exterior walls in northern climates should be evaluated for energy efficiency and comfort.
- Refer to all applicable codes, standards, and regulations for specific requirements for doors that must be accessible.

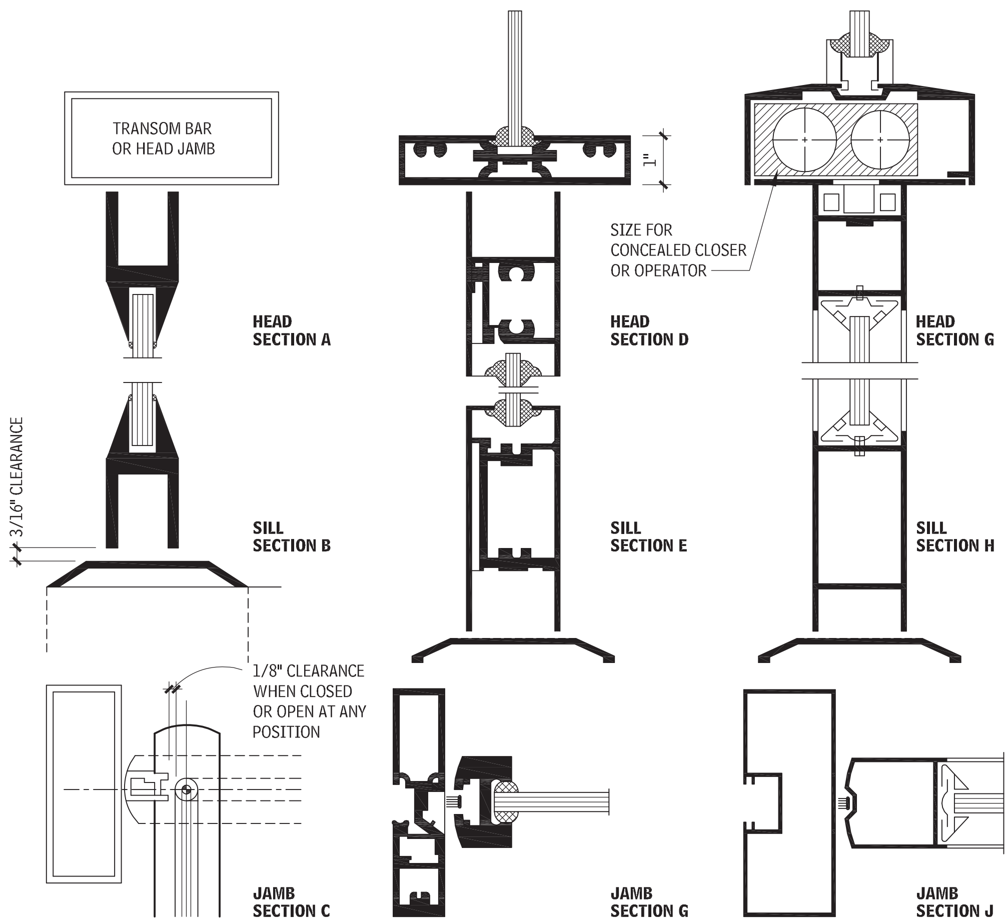
GLASS DOOR TYPES
11.371



ELEVATION—TYPICAL GLASS ENTRANCE DOORS
11.372



DETAILS—TYPICAL GLASS DOORS
11.373

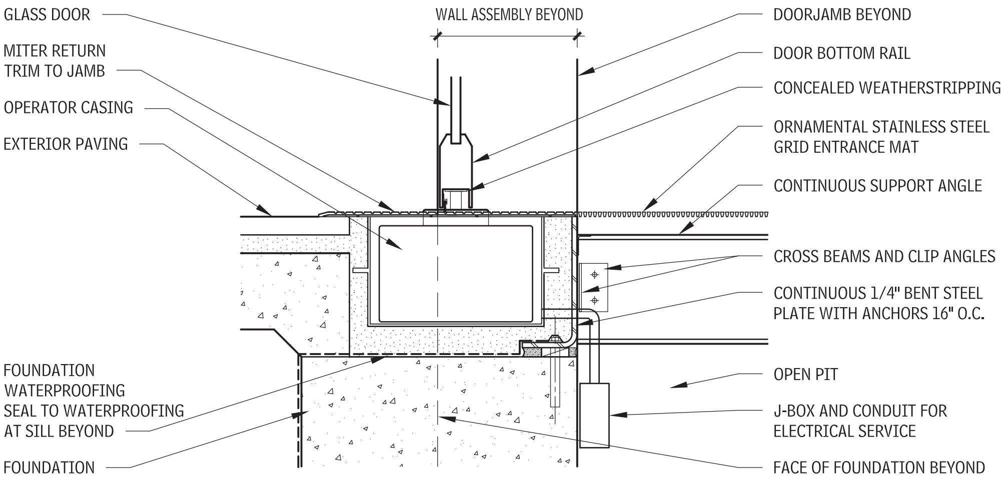


NOTE

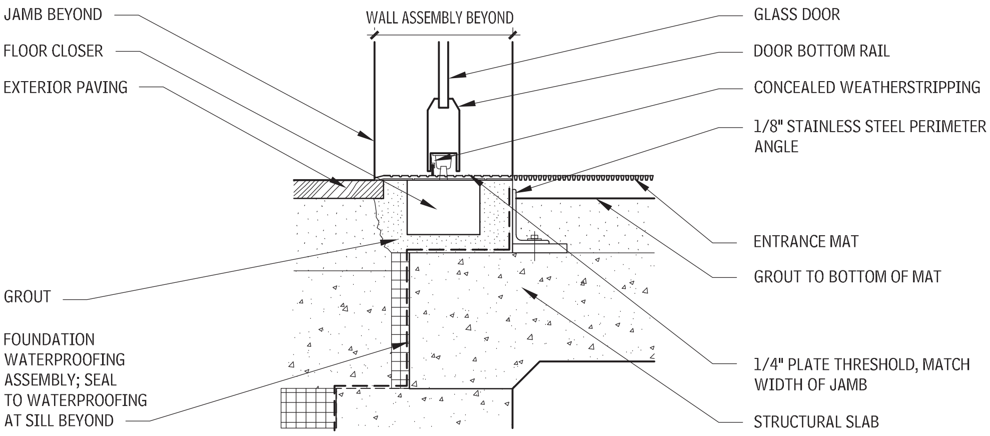
11.371 Doors with narrow stiles should not be used in heavily trafficked areas.

DOOR THRESHOLDS

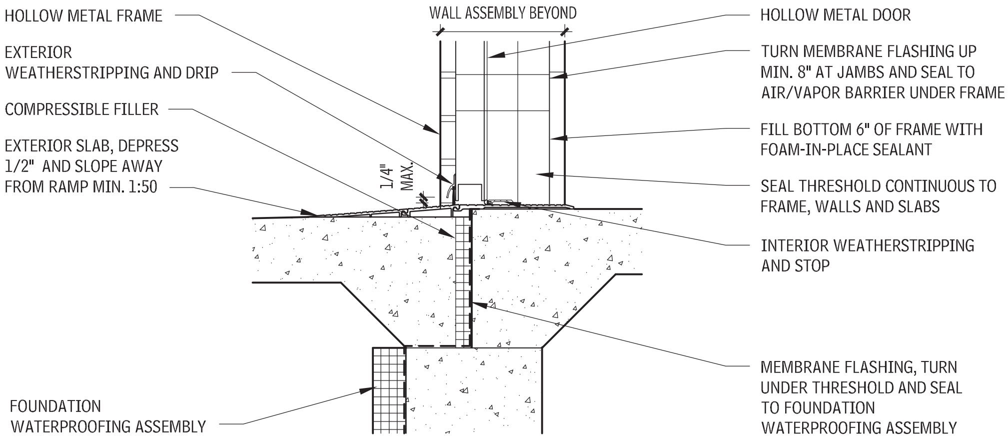
THRESHOLD WITH OPERATOR CASING
11.374



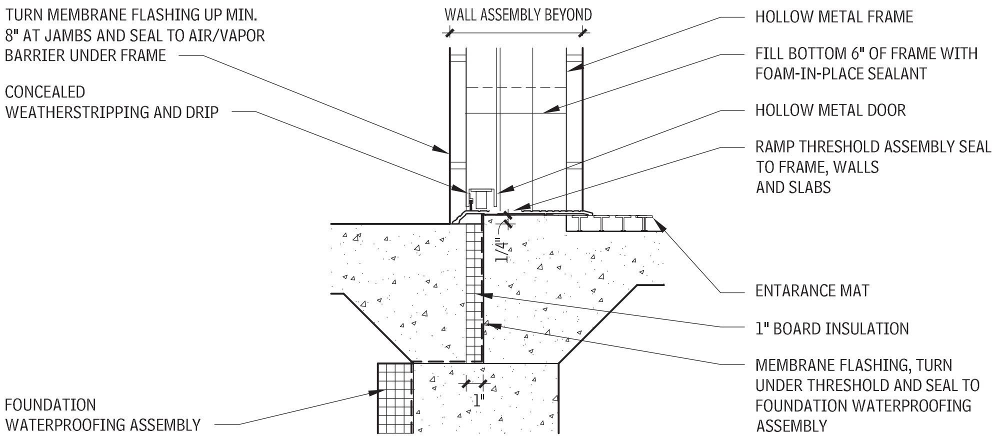
THRESHOLD WITH FLOOR CLOSER
11.375



THRESHOLD AT EXTERIOR SLAB
11.376

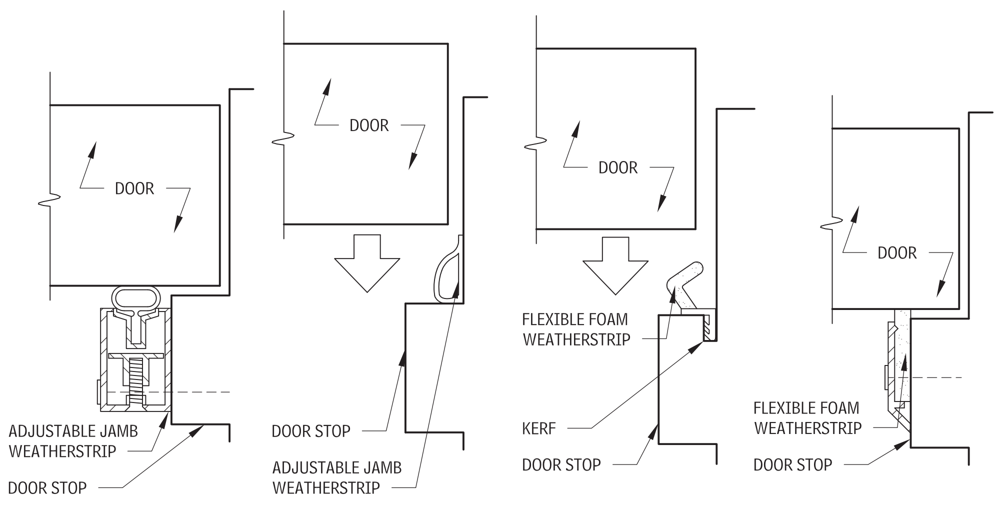


THRESHOLD AT ENTRANCE MAT
11.377

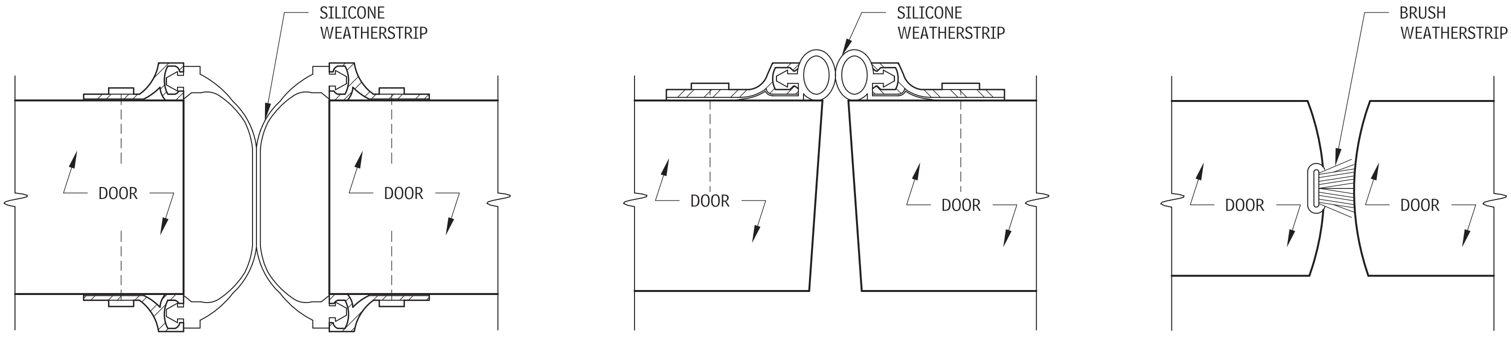


DOOR AND WINDOW WEATHERSTRIPPING

JAMB WEATHERSTRIPPING
11.378



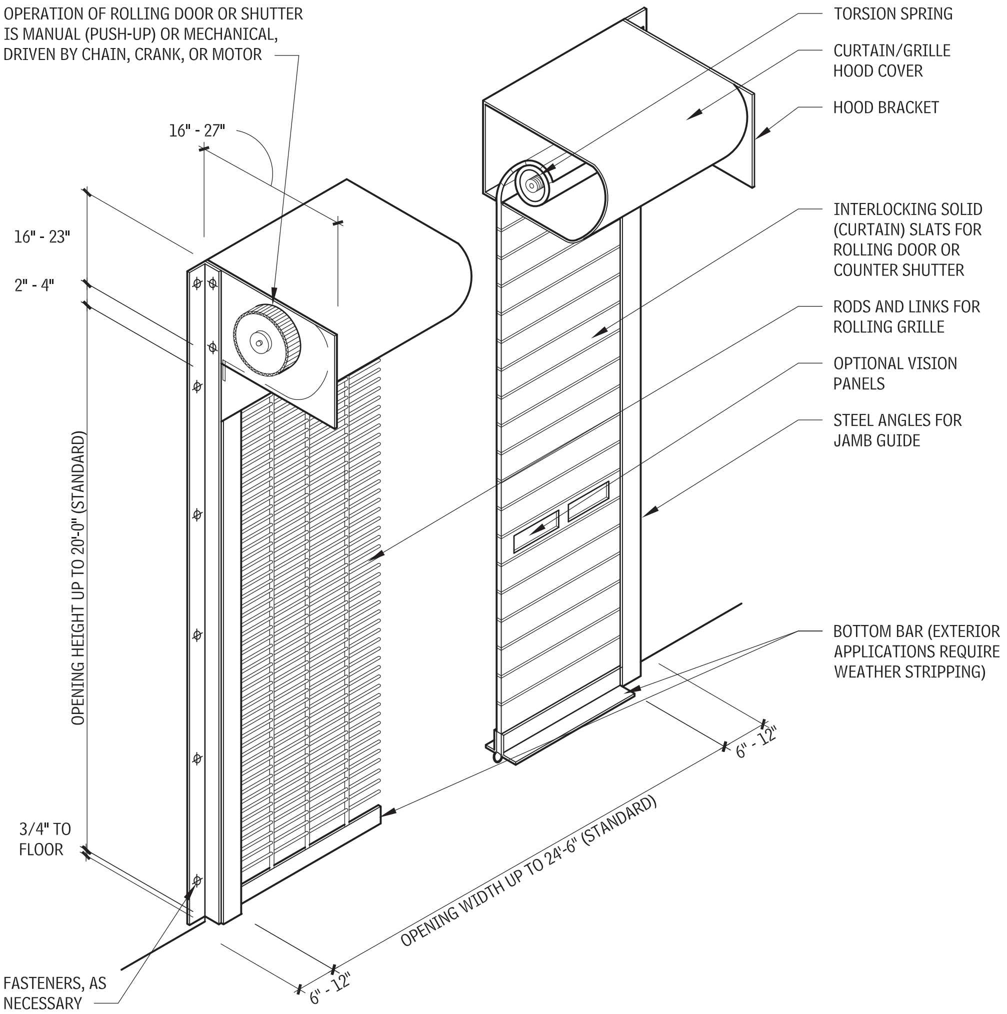
ASTRAGAL WEATHERSTRIPPING
11.379



SPECIAL DOORS

COILING DOORS AND GRILLES

TYPICAL COILING DOOR AND GRILLE
11.380



NOTES

11.380 a. Motor operators vary from 1/3 HP to 2 HP and may be wall-mounted alongside a curtain hood bracket or bracket-mounted alongside or behind a curtain hood, depending on building conditions. Consult manufacturers for all requirements and clearances.
b. Rolling fire doors are typically rated up to UL Class180. Automatic door closure and hood smoke and flame baffle activation are initiated when fusible link melts or when electromechanical devices are activated by heat detector, smoke detector, or building alarm system.
c. Rolling doorjamb guides for fire-rated doors are required to have 3/4-in. clearance below bottom of guide to allow for heat expansion, in case of fire.
d. Standard curtain doors are designed to withstand a wind load of 20 lb./sq. ft., but should be specified to suit the project.

Contributor:
Daniel F.C. Hayes, AIA, Washington, DC.

EXTERIOR HORIZONTAL ENCLOSURES

ROOFING DESIGN CONSIDERATIONS

Roofing generally falls into two broad categories, steep slope and low slope. Selecting the appropriate roof assembly is dependent on many factors, including:

- Initial and lifecycle cost
- Reliability
- Substrate material
- Structural capacity of the deck
- Fire resistance
- Environmental conditions including wind speed and seasonal weather (hail, snow, and rain)
- Building height
- Future access
- Roof-mounted equipment
- Complexity of the building geometry
- Number of penetrations
- Thermal performance
- Construction sequencing
- Building codes

STEEP SLOPE ROOFING

Steep slope roofing is generally designated as roofing with slopes greater than 3 in 12. Steep slope roofing is a water-shedding roof, typically comprised of many small overlapping units; as such, it is not a continuous waterproof membrane. The slope must be steep enough so that water runs off by gravity and cannot be pushed uphill by wind or capillary action. Some steep slope roof assemblies can be installed at slopes less than 3 in 12 in accordance with the manufacturer's recommendations.

CHARACTERISTICS AND CONSIDERATIONS

Steep slope roofing is typically a ventilated or "cold" roof design, with insulation below the roof deck and the surface temperature of the roofing system near outdoor conditions. The insulation and weather barrier are typically located at the ceiling below the attic cavity.

Steep slope roofing assemblies can be designed as a compact "warm" or "unvented" roof design with insulation between the shingles or covering and the structural deck. Evaluate the manufacturer's recommendations for compact roof design, because there may be concerns about the possibility of elevated surface temperatures causing premature failure of the assembly. Forensic investigation has shown that roof orientation (south versus north slopes) and material color have a major impact on surface temperature.

Steep slope roofing is most commonly used for residential and light commercial construction. Although it provides long-term performance at competitive costs, it is generally cost effective for use on large commercial buildings because it does not provide a platform for roof-mounted HVAC or window cleaning equipment, nor is it as easy to maintain or replace on tall buildings. For buildings with large footprints, steep slope roofing can result in excessive internal volume that is not usable.

Roof warranties are offered by most manufacturers of synthetic roof shingle materials, but not for natural products such as slate and wood. However, these warranties are primarily a means for manufacturers to limit their liability, rather than to protect an owner. Furthermore, some products are promoted as having extremely long warranty periods, but the fine print limits coverage to replacement of defective materials on a prorated cost basis to the original owner. Defective installation is not covered, nor is there any value available for the cost of labor to make repairs. Therefore, design professionals should read the warranty carefully, and not rely on it as a basis for product selection. In the end, keep in mind that no piece of paper will keep water out of a building, and a warranty only provides a road map to fixing a leak after it has occurred.

Selecting the steep slope roof system is dependent on many factors, including initial and lifecycle costs; appearance; reliability; historical accuracy; structural capacity of the deck; fire resistance; wind speed; resistance to weather conditions including hail, rain, and snow; and building codes.

Selection recommendations include:

- Consider light-colored, highly reflective roofs to reduce heat island effect in cities and, in warm climates, energy costs for the building.
- In areas susceptible to forest fires, select noncombustible roofing such as concrete or clay tiles, or slate.
- Consider recycled material content, life span, reuse options, embodied energy, distance to source, and other sustainable criteria.

Steep slope roofing consists of four major components: the roof covering; the weather barrier; the structural roof deck; and flashing at the edges, transitions, and penetrations.

WEATHER BARRIER

Steep slope roofing is almost always installed over a weather barrier that provides temporary protection until the roofing is installed and serves as a second layer of defense against water penetration.

The traditional material for weather barrier is building felt. Considering the relatively low material cost of felt, it is recommended to invest in heavier grades, double coverage, or both, to provide more robust performance, especially at shallower slopes.

Self-adhering (peel-and-stick) modified bituminous weather barrier provides an increased level of moisture protection. This type of weather barrier is frequently used to seal seams and is flexible enough to form to complicated configurations. Self-adhering membranes are typically recommended for use at edges, eaves, rakes, valleys, hips, ridges, crickets, and other difficult areas. It is important to consider that modified bituminous membranes are vapor barriers, and in cold or mixed climates their placement should be carefully designed to avoid trapping moisture in the roof assembly.

Slip sheets are necessary under metal roofs to keep them from sticking to the felt weather barrier. Some modified bituminous membranes may come with a surfacing that can be used under metal roofing. The barrier should also be a high-temperature barrier in these locations due to the increased temperatures under metal roofs.

Ice dams are a problem for many shingle roofs in cold climates. The first defense against ice dams is to detail the roof framing to allow full thickness of insulation to the edge of the roof, and proper venting to ensure that the roof deck stays cold. Additional protection can be provided by installing a modified bituminous membrane at eaves and up the roof surface past the location of the building wall.

ROOF DECK

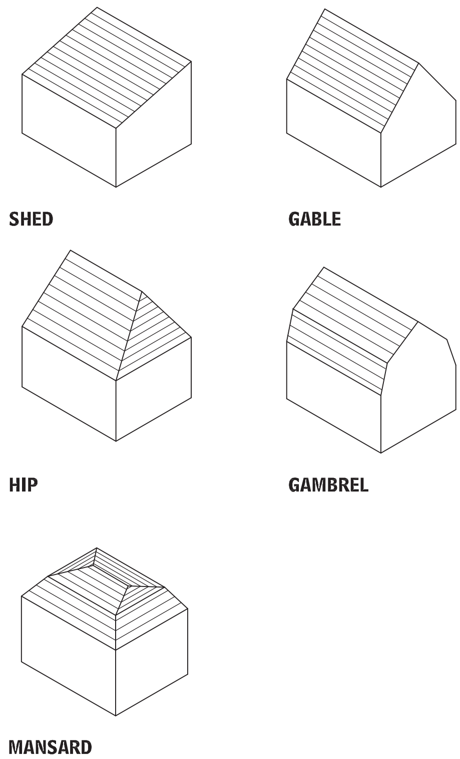
Roof decks under steep slope roofing are almost always plywood or oriented strand board (OSB) panels. Proper installation of the panels is important, especially the spacing between panels to allow expansion without telegraphing through the shingles.

In some commercial construction, steep slope roofing may be installed over metal decking or, occasionally, concrete planks. In these cases, board insulation is typically installed over the metal or concrete deck, and a nailable panel is added over the insulation. Up to slopes of 6 in 12, the panels may be simply screwed through the insulation layer. With steeper slopes, it may be necessary to install wood sleepers to avoid pulling the fasteners downslope, depending on the weight of the roof covering and the thickness of the insulation.

FLASHING

Flashing is an additional component of steep slope roofing assemblies used at edges, transitions, and penetrations, to provide a watertight assembly. Flashing has traditionally been sheet metal, but elastomeric sheets are replacing some sheet metals for the purpose of flashing, particularly at penetrations. Sheet metal, especially when installed in long lengths, must be allowed to expand and contract independent of the roof deck and the roof covering. Running lengths of sheet metal should be installed with clips and not be directly nailed. Where flashing is installed at points that interrupt the flow of water, it must be carefully detailed to control and redirect the water. Crimped dams at valleys and folded crickets are two examples.

COMMON STEEP SLOPE ROOF SHAPES
11.381



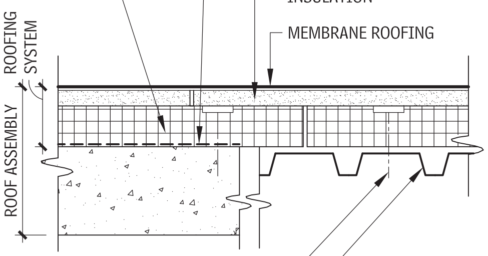
LOW SLOPE ROOFING

Low slope roofing is generally designated as roofing with slopes at or less than 3 in 12. Low slope roofing is typically comprised of a continuous waterproof membrane. Low slope roofs are not flat; most have a minimum slope of 1/4 in. in 12. Many low slope roof assemblies can be installed at slopes from 3 in 12 up to vertical in accordance with manufacturers' recommendations. Low slope roofing is typically designed as a compact "warm" roof design, with insulation between the roof covering and the structural deck and with no ventilation.

Consult the following reference:

- *NRCA Roofing and Waterproofing Manual*, 5th edition.

TYPICAL LOW SLOPE ROOF ASSEMBLY
11.382



CHARACTERISTICS AND CONSIDERATIONS

Low slope roofing provides long-term performance at competitive costs and a platform for roof-mounted HVAC and window cleaning equipment. Low slope roofing is relatively easy to maintain and replace on tall buildings. This is no panacea, however, as any roofing will suffer from poor design and installation. With proper detailing and installation low slope roofing assembly can deliver 20 or more years of service with minimal maintenance.

Low slope roofing consists of five major components: the roof covering; the insulation with a cover board; a vapor barrier (if present) and sheathing to support the vapor barrier over the metal deck; the structural roof deck; and flashing at the edges, transitions, and penetrations. Everything above the roof deck constitutes the roofing system.

INSULATION

Roof insulation not only reduces the energy required to condition the building, it also helps to control condensation; provides a smooth substrate for the roof membrane; and can be used to slope the surface for drainage.

The ideal low slope roof insulation would be compatible with the membrane, adhesives, and substrates; be dimensionally stable and strong enough for anchorage, uplift, traffic, and impact; be fire-resistant; have a high and stable thermal value; and not be affected by moisture. No single material embodies all of these attributes, however, so the use of two or more layers with complementary properties is recommended.

- *Polyisocyanurate foam:* This is one of the most common commercial roof insulation boards. It is fire- and moisture-resistant, compatible with nearly all membranes and adhesives, and has excellent thermal properties. A more rigid cover board is recommended. Use the more conservative, aged R-value to evaluate long-term thermal performance.
- *Polystyrene foam:* Both extruded and expanded types are available. Polystyrene has a very high R-value and is unaffected by wetting; however, it is combustible and may require a weather barrier of gypsum board to comply with building codes. Moreover, polystyrene is difficult to install with hot asphalt adhesives and may not have sufficient rigidity for mechanical fasteners. Nevertheless, it is very commonly used in ballasted systems and inverted roof membrane assemblies (extruded type). A cover board is recommended to isolate asphalt-based membranes. Polystyrene foam may be recycled.
- *Perlite:* Manufactured from expanded minerals and binders, perlite insulation is noncombustible and has moderate thermal resistance, good strength, and excellent compatibility with most roofing materials. The perlite will absorb moisture.
- *Wood fiberboard:* Manufactured from wood or cane fibers and binders, wood fiberboard shares many traits with perlite. Its disadvantage is that it can burn and degrades when wet.
- *Insulating concrete:* Portland cement or gypsum with lightweight aggregates (possibly with foaming agents), and usually supplemented with expanded polystyrene, provide strength, thermal resistance, and no gaps, and readily produces a sloped, finished surface. Density is typically between 20 and 40 psf. The system inherently introduces moisture into an assembly that should be dry, thereby creating an opportunity for trapped moisture and resulting failures. Venting of the completed assembly is recommended, which may affect the interior ceiling plenum and create leaks. Careful control of the drying time before installation must be maintained while also protecting the insulating concrete from precipitation.
- *Gypsum sheathing:* While not technically insulation, gypsum sheathing is a high-quality cover, providing a strong substrate for attaching the roof membrane, which is both fireproof and resistant to moisture. Preprimed boards are available for hot-asphalt applications.
- *Miscellaneous boards:* Other types of insulation include cellular glass, fibrous glass, mineral fiber, and others used for specialized applications.
- *Composite boards:* Composite boards that combine two insulation materials laminated into one board are available; commonly polyisocyanurate or polystyrene foam bonded to plywood, OSB, or gypsum sheathing.

Insulation should be installed in at least two layers, with joints offset between the two. The offset joints reduce air leaks that waste energy and could result in condensation on the cold underside of the membrane.

Insulation is mechanically fastened, set in adhesive or hot asphalt, or ballasted. It is preferable to not have mechanical fasteners extend through the entire assembly to the bottom of the roof membrane because the anchors may puncture or abrade the membrane. Therefore, limit mechanical fasteners to the bottom layer of insulation and install subsequent layers with adhesive.

Also, it is best to limit the size of insulation boards to 4 ft by 4 ft to reduce the size of cracks that may develop from shrinkage. Tapered insulation can be used to build up the roof slope and crickets.

Provide a cover board over the insulation if the top layer is not a composite board or lightweight concrete. Cover boards are typically gypsum sheathing, perlite, or wood fiberboard, to provide the physical rigidity and strength that most insulations do not possess. The cover board can count as the second layer of insulation.

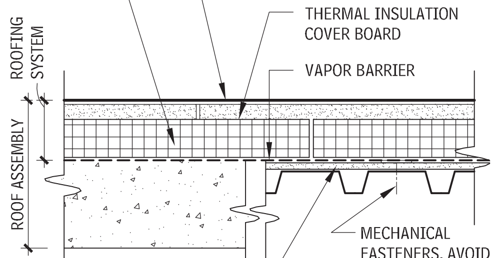
WATER VAPOR CONTROL

Water vapor moves through low slope roof assemblies under two methods: air leakage and water vapor diffusion. Just as in walls, air leakage can carry much more moisture than diffusion. Use offset joints in multiple layers of foam insulation and air seals at edges and penetrations to limit the flow of cold interior air to the underside of the membrane, where it will likely condense. For buildings in cold climates with high interior winter humidity, the vapor drive may be strong enough that a vapor barrier on the warm underside of the insulation may be required, in addition to air sealing.

Additional water vapor control recommendations include:

- Most roof membranes are also vapor barriers, so adding a separate vapor barrier on the inside face may trap moisture in the insulation. Therefore, avoid a separate vapor retarder, unless it is actually required.

LOW SLOPE ROOF ASSEMBLY WITH VAPOR RETARDER
11.383



- The NRCA recommends a vapor retarder over concrete decks to protect the roof system from the effects of latent moisture.
- An inverted roof membrane assembly places the roof membrane on the warm side of the insulation and, therefore, is an ideal system for control of water vapor in cold climates.
- Vapor barrier membranes can be two- or three-ply built-up roofing, modified bituminous membranes, self-adhering peel-and-stick membranes, polyethylene sheets, or aluminum foils. It is best to select a membrane that will seal around mechanical anchors; or even better, select a membrane over which all subsequent layers of the assembly can be set in hot asphalt or other adhesive.
- On a metal deck, a weather barrier board of gypsum sheathing or a thin layer of insulation may be required to provide a smooth substrate for the installation of the vapor barrier membrane, although some membranes can be installed directly on the metal deck.
- At the perimeter of roof vapor barriers, it may be best to connect to wall air and vapor barriers. Otherwise, ensure that the vapor barrier at the perimeter keeps moisture out of the roof assembly. Detail penetrations to be vapor-tight, similar to details for the roof membrane.

ROOF DECK

Roof decks for low slope roof assemblies must support the gravity loads from snow, rain, and rooftop equipment, and must resist wind uplift loads that may be greater than the gravity loads. The deck also is frequently sloped to provide drainage, and must be stiff enough to ensure that deflection does not result in localized water ponding.

Metal deck, concrete, and plywood are the three most common roof deck materials, but other materials are available. Concrete and poured gypsum decks must be cured before installing roof covering.

FLASHING

Similar in use to flashing for steep slope roofing, flashing includes additional components for low slope roofing systems and is used at edges, transitions, and penetrations to provide a watertight assembly. Particularly at penetrations, traditional sheet metal has been replaced with elastomeric sheets and preformed cones. Sheet metal moves more with temperature change than roofing. Therefore, it is better to avoid embedding long lengths of sheet metal directly into the roof membrane. At gravel stops and other similar conditions, constrain the movement of the metal by nailing in two rows, with nails 3 in. apart.

LOW SLOPE ROOF SYSTEM DESIGN

Roof membrane manufacturers produce standards and recommendations for their roof assemblies. These standards will typically include details for standard conditions, such as penetrations, edges, and terminations. Modifications to these details, such as increased roof slope and the use of tapered edge strips at the base flashing can extend the service life of the roof and should be considered by the design professional.

Many assemblies have specific detailing and installation procedures that are required to obtain a 20-year warranty. These details should be adhered to even if the warranty is not required. No single low slope roof assembly solution is appropriate for every roofing condition.

Design guidelines and recommendations include:

- Consider light-colored, highly reflective roofs, to reduce the heat island effect in cities and, in warm climates, energy costs for the building.
- Avoid gravel-coated or ballasted systems on buildings in high-wind areas where stone fragments may become projectiles, causing collateral damage by breaking out windows.
- Consider recycled material content, life span, reuse options, embodied energy, distance to source, and other sustainable criteria.
- Consider planted green roofs to slow water runoff, reduce the heat island effect, and increase thermal performance.

ROOF SLOPE AND DRAINAGE

Positive drainage increases roof life and is mandated at 1/4 in. in 12 in most codes and systems, although some large government and corporate owners require 1/2 in. in 12. All surfaces of the finished roof should be sloped sufficiently so that no ponding occurs 48 hours after a rain.

Design guidelines include:

- Consider deflection of deck, particularly at long spans. Deflection may be sufficient to negate the roof slope. If the deflection creates a low area, ponding may increase the deflection, progressively increasing until failure. Structural engineers should check for this failure mode.
- It is typically less expensive to slope the roof deck and use tapered insulation to create crickets in small areas. If the roof deck is planned as a future floor and is flat, then tapered insulation should be used to build up slope.
- In addition to primary drains, the roof must have provisions for secondary drainage. Overflow scuppers are the most reliable, but piped secondary drains are an option in most jurisdictions. Requirements for piped secondary drains may mandate that the size be twice as large as the primary drains to avoid clogging, or that the rainwater conductors discharge near an entrance so that building personnel will be alerted to the fact that the roof is not draining properly. The height of the scupper and the resulting impounded water should be checked against the structural capacity of the deck.

WEATHER BARRIER

The roof system frequently also functions as the weather barrier on the top of the building. Roofs over concrete roof decks may function as a weather barrier, but the roof membrane or a vapor barrier is more frequently chosen as the air barrier. Some manufacturers will not warrant their membrane when it is to be used as an air barrier, particularly mechanically fastened single-ply membranes.

COOL ROOFS

Light-colored, reflective, and high-emissivity roof systems reduce cooling loads and heat island effect in urban areas. Refer to the ENERGY STAR listing at *www.energystar.gov*.

THICKNESS AND ATTACHMENT CALCULATIONS

Designs of roof edge copings, gravel stops, and horizontal roof edges require calculations for material thickness that lead to satisfactory flatness and minimize corrosion. The standard, as developed by ANSI SPRI ES-1, takes into account the structural integrity of the substrate that anchors the edge, wind resistance of the edge detail, and materials specified.

FIRE-RATED ROOF ASSEMBLIES

For most fire-rated roof assemblies, a Class A roof covering and listed insulation is acceptable, but verify with the roofing manufacturer and authority having jurisdiction. Note that unlike floor assemblies, penetrations through roofs do not need to be firestopped, except in portions of roofs where openings are not permitted (such as near firewalls).

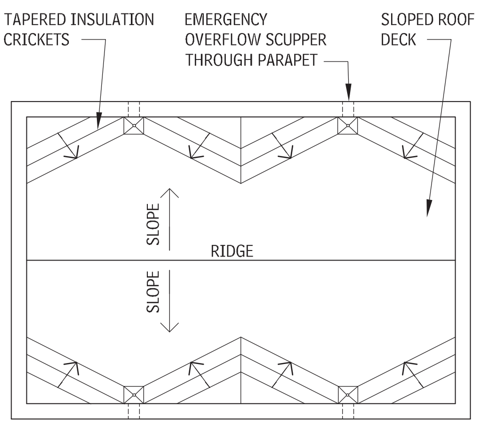
Some products are promoted as having extremely long warranty periods, but they lack in-place proven performance to back up these claims. Design professionals should read the warranty provisions carefully and not rely too heavily on the warranty as a basis for product selection.

Note that warrantable roof assemblies and details reflect a compromise chosen by the manufacturer between dependable service and a low initial cost, to remain competitive in the open market. Therefore, do not automatically assume that the offer of a warranty implies the highest quality.

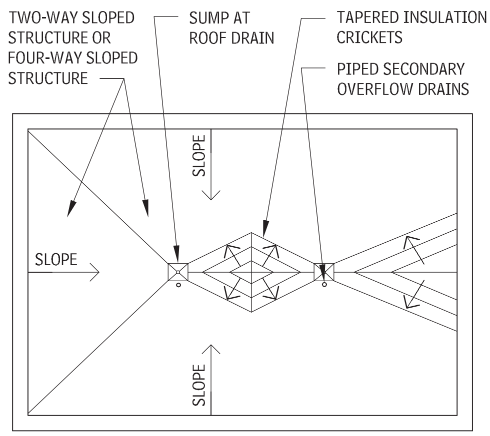
Consult the following references:

- *NRCA Roofing and Waterproofing Manual*; (National Roofing Contractors Association, 2006)
- *Roofing Design and Practice* (Pearson Education, 2000) by Stephen Patterson and Madan Mehta

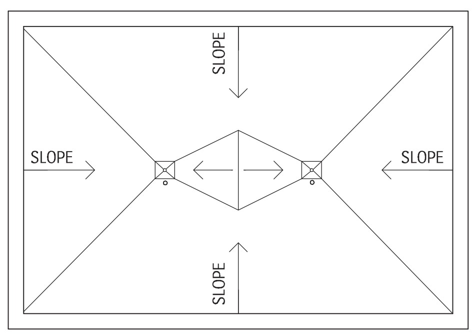
ROOF SLOPE SCHEMES
11.384



SLOPE TO PARAPET



SLOPE TO CENTER



NOTE

11.384 Slopes can be accomplished with tapered insulation on flat roof decks.

Contributor:
Jarrett B. Davis, LEED AP BD+C, Hall Architects, Charlotte, North Carolina.

ROOF COVERINGS

STEEP SLOPE ROOF COVERINGS

WOOD SHINGLES AND SHAKES

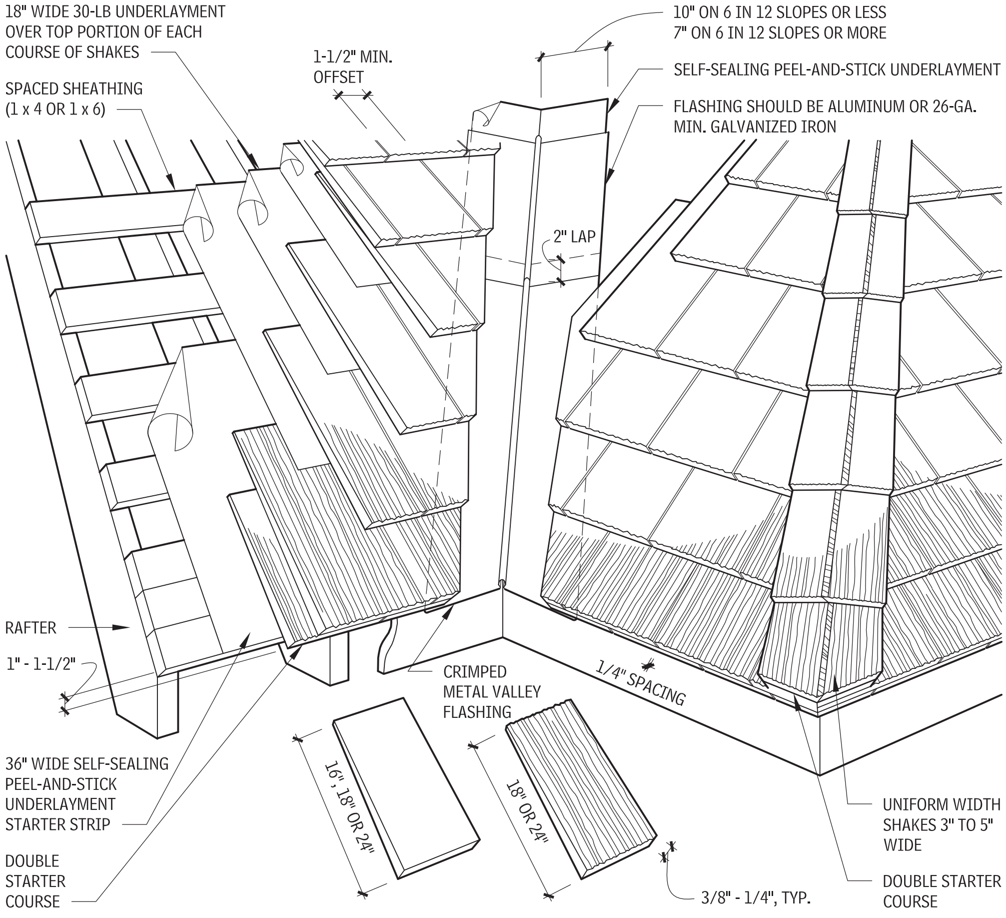
Wood shingles and shakes are cut from wood species that are naturally resistant to water, sunlight, rot, and hail (i.e., red cedar, redwood, and tidewater red cypress). They are typically installed in the natural state, although stains, primers, and paint may be applied.

Nails must be hot-dipped in zinc or aluminum. Nail heads should be driven flush with the surface of the shingle or shake but never into the wood.

The weather barrier and sheathing should be designed to augment the protection provided by the shingles or shakes, depending on roof pitch and climate. A low-pitched roof subject to wind-driven snow should have solid sheathing and an additional weather barrier.

Use self-sealing peel-and-stick modified bituminous membrane weather barrier at eaves, valley, rake, and other detail areas. Modified bituminous weather barrier is a vapor retarder, so is it not recommended for continuous application where the weather barrier needs to breathe.

RED CEDAR HANDSPLIT SHAKES
11.385



SHINGLE (SAWN) SHAKE (HANDSPLIT)

RED CEDAR HANDSPLIT SHAKES
11.386

GRADE	LENGTH AND THICKNESS	DESCRIPTION
No. 1 handsplit and resawn	15″ starter-finish	These shakes have split faces and sawn backs. Cedar logs are first cut into desired lengths. Blanks or boards of proper thickness are split and then run diagonally through a bandsaw to produce two tapered shakes from each blank.
	18″ × 1/2″ medium	
	18″ × 3/4″ heavy	
	24″ × 3/8″	
	24″ × 1/2″ medium	
	24″ × 3/4″ heavy	
No. 1 taper-split	24″ × 1/2″	Produced largely by hand, using a sharp-bladed steel froe and a wooden mallet. The natural shingle-like taper is achieved by reversing the block, end for end, with each split.
No. 1 straight	18″ × 3/8″ side wall	Produced in the same manner as taper-split shakes, except that by splitting from the same end of the block, the shakes acquire the same thickness throughout.
	18″ × 3/8″	
	24″ × 3/8″	

RED CEDAR SHINGLES
11.387

	NO. 1 BLUE LABEL			NO. 2 RED LABEL			NO. 3 BLACK LABEL		
	MAXIMUM EXPOSURE RECOMMENDED FOR ROOFS (IN.)								
ROOF PITCH	16	18	24	16	18	24	16	18	24
3 in 12 to 4 in 12	3-3/4	4-1/4	5-3/4	3-1/2	4	5-1/2	3	3-1/2	5
4 in 12 and steeper	5	5-1/2	7-1/2	4	4-1/2	6-1/2	3-1/2	4	5-1/2

NOTE

11.385 Copper flashing should not be used with red cedar.

WEATHER BARRIER AND SHEATHING
11.388

ROOFING TYPE	SHEATHING	WEATHER BARRIER	NORMAL SLOPE		LOW SLOPE	
Wood shakes and shingles	Solid or spaced	No. 30 asphalt saturated felt underlayment	4 in 12 and up	Weather barrier starter course; weather barrier over entire roof	3 in 12 to 4 in 12	Single layer weather barrier over entire roof; weather barrier over entire roof

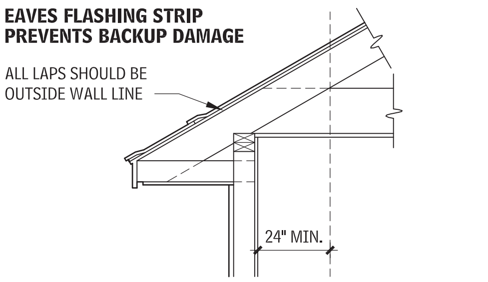
ASPHALT AND COMPOSITION SHINGLES

SCHEDULE OF WEATHER BARRIER
11.389

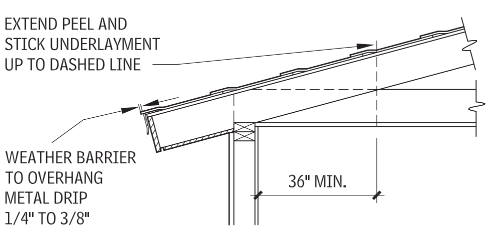
SLOPE	TYPE OF WEATHER BARRIER
Normal slope: 4 in 12 and up	Single layer of 15-lb asphalt saturated felt over entire roof
Low slope: 3 in 12 to 4 in 12	Two layers of 15-lb asphalt saturated felt over entire roof

EAVE FLASHING
11.391

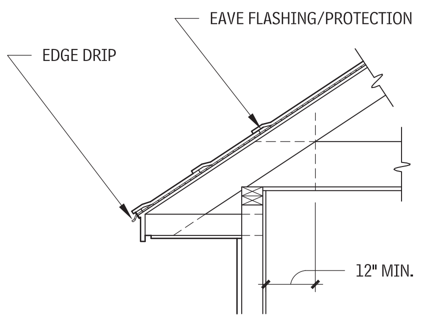
EAVES FLASHING STRIP PREVENTS BACKUP DAMAGE



NORMAL SLOPE

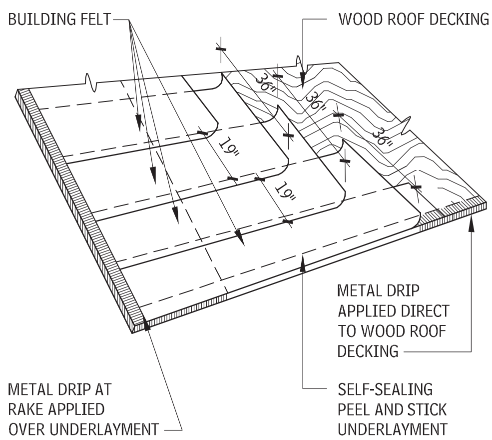


LOW SLOPE

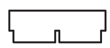


STEEP SLOPE

APPLICATION OF WEATHER BARRIER ON STEEP SLOPE ROOFS
11.390



SCHEDULE OF SHINGLE TYPES
11.392

DESCRIPTION	DESIGN[a]	MATERIAL	UL RATING	WEIGHT	SIZE
Three-tab square butt		Fiberglass	A[d]	205–225 lb/sq	36″ × 12″
		Organic felts	C[d]	235–300 lb/sq	36″ × 12″
Two-tab square butt		Fiberglass	A[d]	260–325 lb/sq	36″ × 12″
		Organic felts	C[d]	300 lb/sq	36″ × 12″
Laminated overlay[b]		Fiberglass	A[c]	300 lb/sq	36″ × 14″
		Organic felts	C[c]	330–380 lb/sq	36″ × 14″
Random edge cut		Fiberglass	A[c]	225–260 lb/sq	36″ × 12″
		Organic felts	C[c]	250 lb/sq	36″ × 12″

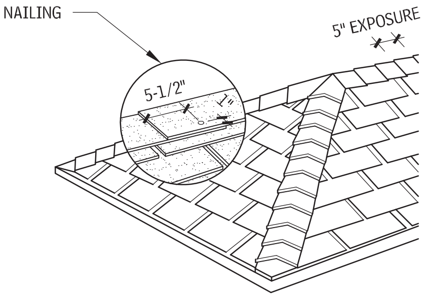
NOTES

11.391 Eave flashing is required whenever the January daily average temperature is 30°F or less or where there is a possibility of ice forming along the eaves.

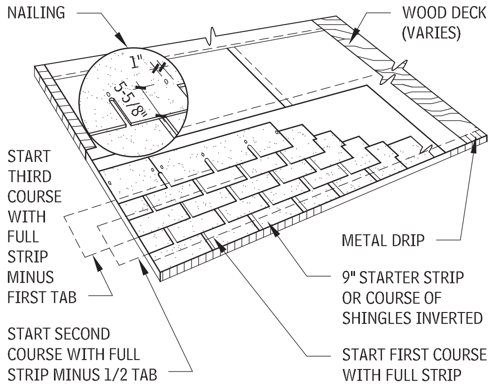
11.392 a. For all designs: exposure, 5 in.; edge lap, 2 in.
b. More than one thickness, for varying surface texture.
c. Many rated as wind-resistant.
d. All rated as wind-resistant.

Contributor:
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland.

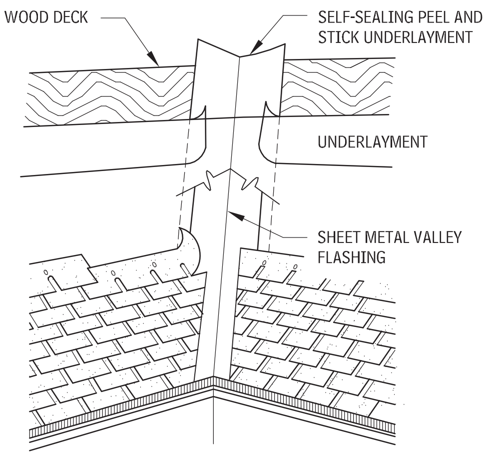
SHINGLE APPLICATION DIAGRAMS
11.393



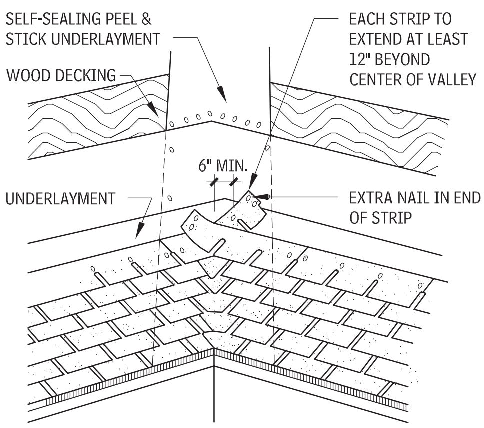
HIP AND RIDGE



THREE TAB SQUARE BUTT STRIP SHINGLES

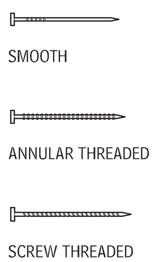


OPEN VALLEY



CLOSED VALLEY

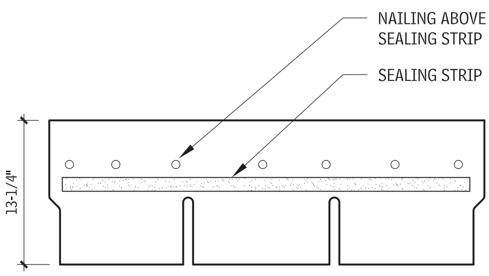
NAIL TYPES
11.394



NAILING OF SHINGLES RECOMMENDATION
11.395

DECK TYPE	NAIL LENGTH
1″ wood sheathing	1-1/4″
3/8″ plywood	7/8″
1/2″ plywood	1″
Reroofing over asphalt shingles	1-3/4″

STANDARD THREE-TAB SHINGLE
11.396



TILE ROOFING

Tile roofs can make a long-lasting, durable roof if well detailed and constructed. Roofing tiles are available in either clay or concrete and in a large number of profiles, sizes, colors, and textures. All tiles absorb moisture and, generally, the more porous, the less strong and durable the tile. Concrete tile is generally more porous than clay, and may require a sealer. The sealer may require reapplication that is inconsistent with tile's otherwise durable quality. Typical 1/2-in.-thick tiles weigh approximately 10 psf, with proportional increases for thicker tiles.

Tile is made from two basic materials, clay and concrete:

- *Clay:* Clay tiles are formed from natural material, so color uniformity is dependent on the uniformity of the raw clay—unless glazed. Unglazed tile weathers only slightly over time. Glazed tiles are available in a larger number of colors, including bright blues, greens, reds, and oranges.
- *Concrete:* Concrete tiles are pressed in molds under high pressure. The synthetic oxide compounds color the surface. Tiles are sometimes painted, which may fade with time.

PROFILES

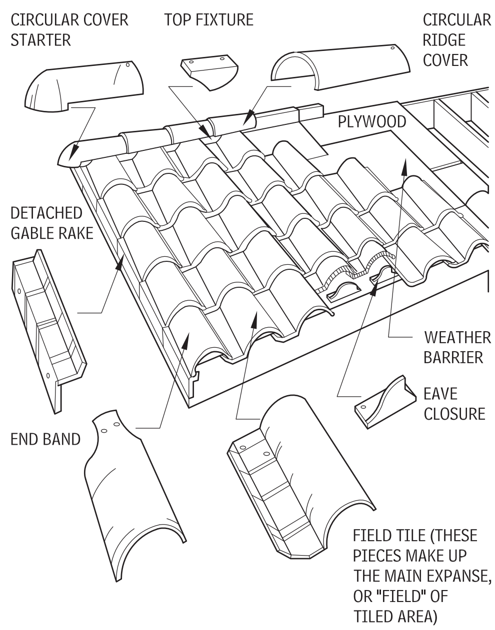
Tiles are typically available in three profiles, flat, barrel, and S-shaped. Barrel and S-shaped are also called *mission tiles*.

- *Flat:* These are sized approximately 10 by 13 up to 13 by 20 in. Flat tiles may be very simple, requiring a doubled shingled overlap, or may be interlocking, with approximately a 3-in. head overlap. Tiles may be fluted on the back to reduce weight, or lugged to hang on battens.
- *Barrel:* Barrel tile sizes are typically 16 by 8, 19 by 10, or 18 by 12 in., punched for one hole.
- *S-shaped:* These tiles are approximately 10 by 13 up to 13 by 20 in. S-shaped tiles are essentially the pan and cover portions of barrel tiles in one piece.

INSTALLATION

- *Weather barrier:* Tile roofs in areas of high rain or wind-driven rain are likely to allow some water under the tiles and therefore the weather barrier provides the final defense against water intrusion. Therefore, the weather barrier must be more robust and detailed more thoroughly than in some other steep roofing systems. The minimum weather barrier is a double layer of No. 30 unperforated asphalt saturated felt except single coverage allowed at slopes over 20 in 12. In comparison to the cost of the tiles, the felts are inexpensive; consider using heavier No. 45 or 60 felts or hot-mopped bitumen sheets. For all edges and detail areas, such as eaves, valleys, rakes, and crickets, it is recommended to install a self-sealing, peel-and-stick modified bituminous weather barrier. The modified bituminous membrane provides an additional level of protection by sealing around the nails and stopping migration of water under loose felts. Self-sealing membrane is especially important for protection against ice dams in cold climates. Modified bituminous membranes are vapor retarders and should not be used across the entire roof substrate if a continuous vapor retarder is not desired.
- *Flashing:* Sheet metal flashing embedded in the tile should be minimum 24-oz. copper or lead-coated copper or 26-gauge stainless steel, fabricated to allow differential thermal movement.

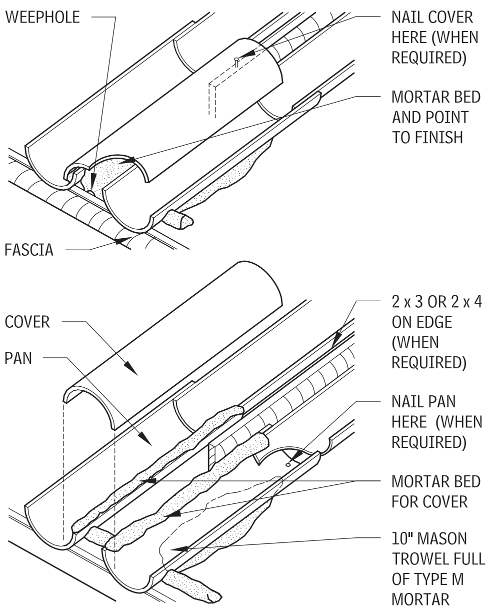
SPANISH TILE
11.397



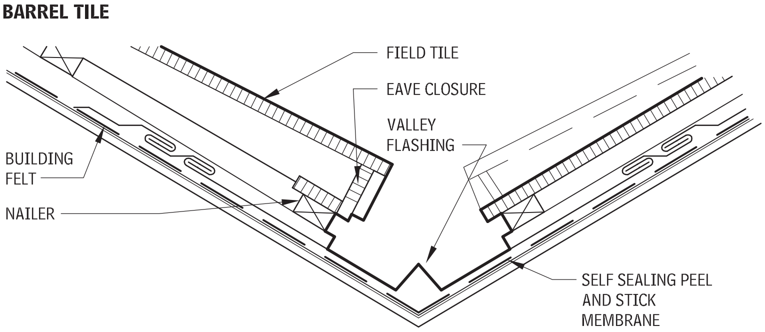
Contributors:
Robert E. Fehlberg, FAIA, CTA Architects Engineers, Billings, Montana;
Stephan Pienkny, Cline McGee, AIA Hall Architects, Charlotte, North Carolina.

- *Wood nailers:* Although the simplest and least expensive method to install tiles is to nail them directly to the wood deck, nailers can help secure the tiles and provide drainage. For tiles with lugs, horizontal battens with a 1/2 in. space every 48 in. is recommended. Mission tiles may require vertical nailers of 2 by 3's or 2 by 4's, spacing to suit tiles plus nailers at ridges and hips. For maximum reliability and long-term performance it is recommended to install vertical nailers at 24 in. on center with horizontal nailers to suit the tiles. This lattice arrangement allows maximum drainage and drying below tiles. Nailers should preservative treated.
- *Tiles:* Barrel tiles are typically secured with a single nail each. Flat and S-shaped tiles typically are installed with two nails. Nailing may be reduced in the field of the roof depending on slope and wind conditions; verify with local code. Some tiles, especially barrel tiles, are laid in cement.
- *High-wind areas:* For high-wind areas, refer to *The Concrete and Clay Tile Installation Manual*, published by the Florida Roofing, Sheet Metal, and Air Conditioning Contractors Association and the Roof Tile Institute.

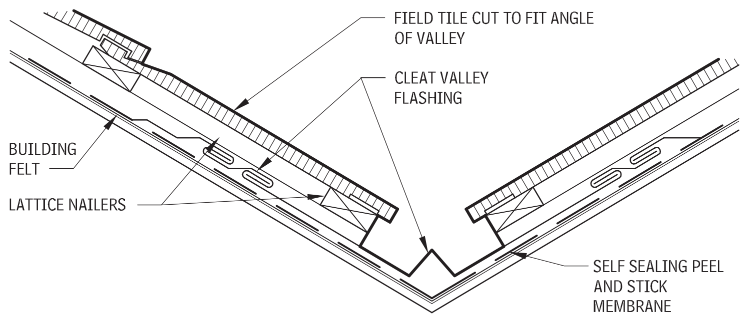
TILE ROOFING DETAILS 11.398



BARREL TILE



VALLEY SECTION



VALLEY SECTION

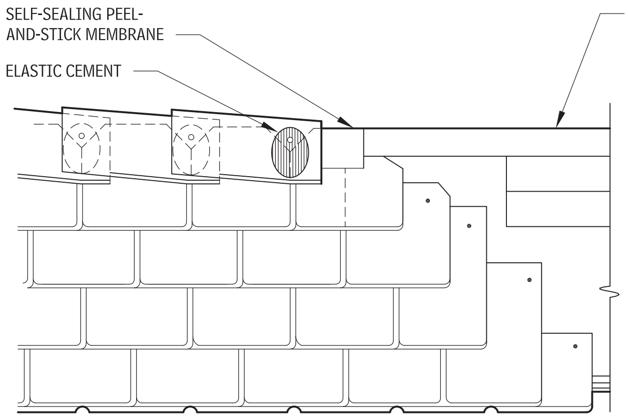
CLAY TILE DETAILS

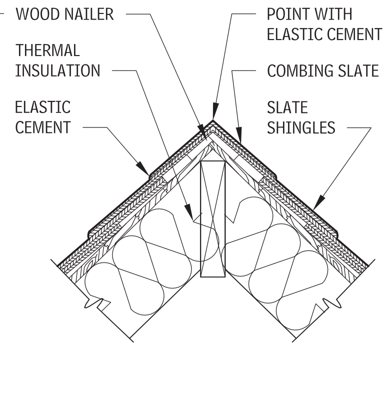
SLATE ROOFING

Slate roofs are extremely durable, sometimes lasting 75 or 100 years. Due to the expense and durability of the slates, it is important to select all supporting and accessory materials for a similar life span. Use the following as selection guidelines:

- *Commercial standard:* The quarry run of 3/16-in. thickness; includes tolerable variations above and below 3/16 in.
- *Textural:* A rough-textured slate roof with uneven butts. The slates vary in thickness and size, which is generally not true of slate more than 3/8-in. thick.
- *Graduated:* A textural roof of large slates. Greater variation in thickness, size, and color.
- *A square of roofing slate:* A number of slates of any size sufficient to cover 100 sq ft with a 3-in. lap. Weight per square: 3/16 in., 800 lb; 1/4 in., 900 lb; 3/8 in., 1100 lb; 1/2 in., 1700 lb; 3/4 in., 2500 lb.
- *Standard nomenclature for slate color:* Black, blue-black, mottled gray, purple, green, mottled purple and green, purple variegated, and red. These should be preceded by the word "unfading" or "weathering." Other colors and combinations are available.
- *Durability:* Durability of slates is rated for their expected service life according to ASTM C 406 as: S1 for over 75 years, S2 for 40 to 75 years, or S3 for 20 to 40 years.
- *Weather barrier:* The minimum weather barrier is a single layer of No. 30 unperforated asphalt saturated felt with double coverage up to 20 in 12 slopes. Use No. 45, 50, or 60 felts under textural or graduated slates. In comparison to the cost of the slates, the felts are inexpensive; consider using heavier No. 45 or 60 felts. For all edges and detail areas, such as eaves, valleys, rakes, and crickets, it is recommended to install self-sealing, peel-and-stick modified bituminous underlayment. The modified bituminous membrane provides an additional level of protection by sealing around the nails, stopping migration of water under loose felts, and is especially important for protection against ice dams in cold climates. Note that the modified bituminous membrane is a vapor retarder and it should not be used across the entire roof substrate if a continuous vapor retarder is not desired.
- *Nail fastener:* Use large-head, hard copper wire nails, cut copper, cut brass, or cut yellow metal slating nails. Each slate is punched with two nail holes. Use nails that are 1 in. longer than thickness of slate. Cover all exposed heads with elastic cement. In dry climates, hot-dipped galvanized nails may be used.
- *Flashing:* Sheet metal flashing embedded in the slates should be minimum 20 oz. copper or lead-coated copper, fabricated to allow differential thermal movement.
- *Imitation slates:* Slates manufactured from recycled tires, mineral fiber, portland cement, and a variety of other proprietary materials are available, generally at a lower cost than true slate. However, the appearance varies greatly and is rarely the same as true slate, and the expected service life may not be as long.

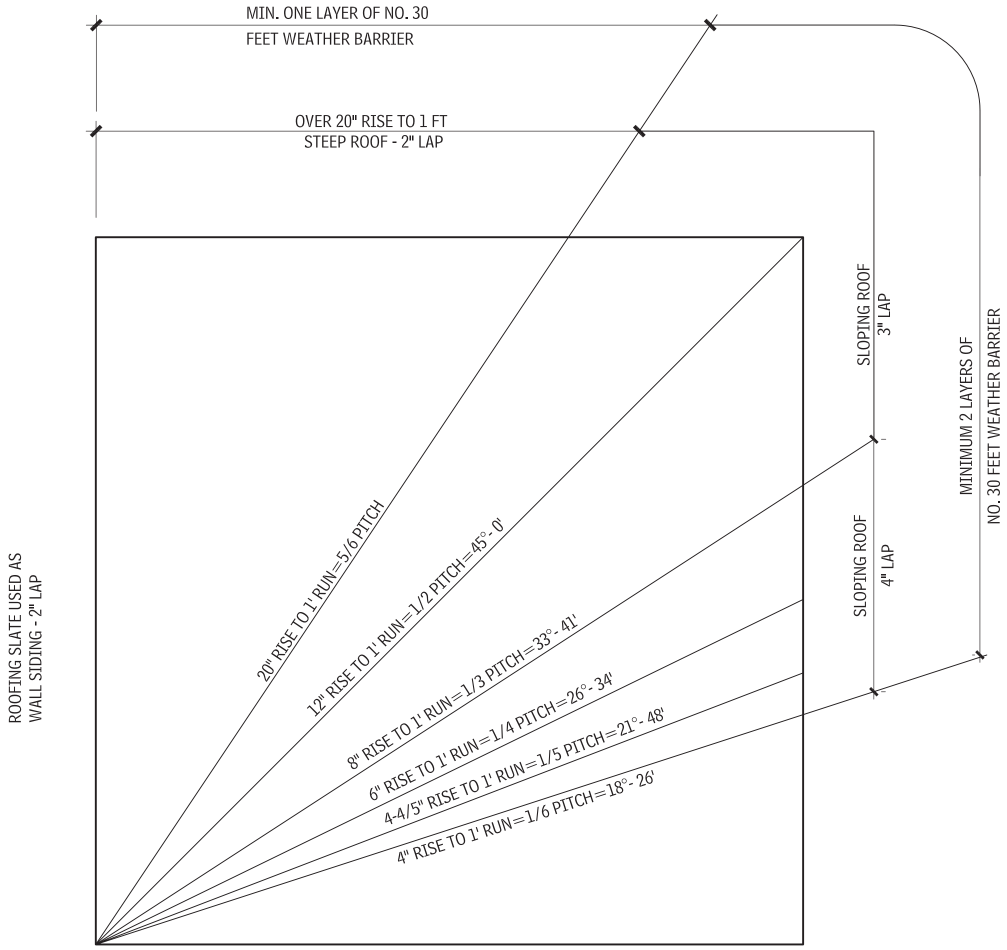
SADDLE RIDGE 11.399



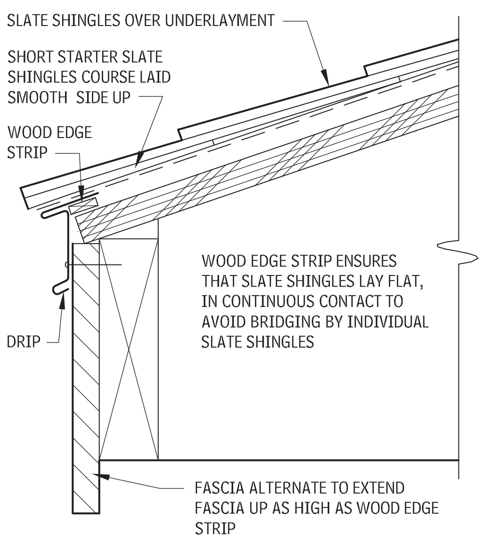


SECTION

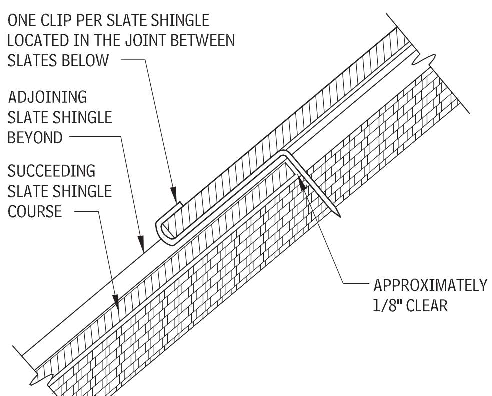
DIAGRAM OF PROPER LAP FOR RISE/RUN
11.400



EAVE
11.401



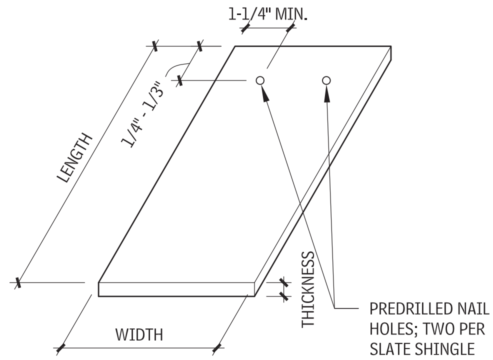
SLATING CLIPS
11.402



Mineral-fiber cement tiles should be applied to nailable decks only. For plywood decks with rafters spaced 20 in. or less, the plywood should be at least 1/2 in. thick. If rafters are spaced greater than 20 in., 5/8-in. plywood is recommended. To fasten, use standard 1-1/2 in. galvanized 11-gauge flat-head roofing nails with 3/8-in. heads. Flashing should be of a noncorrosive metal not lighter than 28 gauge.

When wood fibers are used the tiles are lightweight and can be used for reroofing as well as for new construction. They have excellent impact resistance and are easily sawn and nailed. As a richly textured, composite product, mineral-fiber tiles create an aesthetic similar to that of heavy cedar shakes, yet provide the fire protection associated with cementitious products. The portland cement is noncombustible and allows for Class A fire ratings, and the wood fibers provide excellent tensile strength and a light weight when compared to standard concrete tiles.

ROOFING SLATE
11.403



CERAMIC SLATE

Ceramic slate tiles combine the look of natural slate with the fired-in strength and durability of ceramic tile. These tiles have the thickness, texture, and appearance of older slate but at a fraction of the weight and cost. They are impervious to freeze-thaw cycles, fire, moisture, and efflorescence.

BUILT-UP BITUMINOUS ROOFING

A built-up bituminous roofing assembly is composed of a base sheet attached to the roof substrate, two or more reinforcing felt ply sheets, and a surfaced cap sheet. Asphalt and coal tar are the primary bituminous materials used for built-up roofing. Coal tar bitumen has a history of maintaining functional characteristics for a very long period, but there are some questions regarding safety from coal tar fumes, and this is generally more expensive. As the heated mopping bitumen fuses with the saturating bitumen in the roofing felts, the layers are welded together. Surfacing components include aggregate, minerals, protective or reflective coatings, and smooth surface. Built-up bituminous roofing can be a very durable and high-quality roof, but requires more skill to install than some other assemblies. If the owner is willing to invest in frequent independent inspection of the roof, then a BUR is an excellent choice.

Four types of asphalt and two types of coal tar are presently used as bitumen in built-up roofing assemblies. The grade of asphalt used for BUR systems should be appropriate for the slope of the roof. Backnailing of felts is recommended for built-up roofing whenever the roof slope exceeds 1/2 in 12. Aggregate-surfaced built-up roofing should not be used on slopes exceeding 3 in 12.

NOTE

11.402 Stainless steel clips properly space slates, allow movement, and eliminate nailing through slate and associated problems of broken slates caused by improper nailing.

COAL TAR TYPES
11.404

TYPE NO. PER ASTM D450	TYPE OF COAL TAR	SOFTENING POINT (°F)	
		MINIMUM	MAXIMUM
I	Coal-tar pitch	126	140
II	Waterproofing pitch	106	126
III	Coal-tar bitumen	133	147

ASPHALT TYPES
11.405

TYPE	KIND OF ASPHALT	SOFTENING POINT (°F)		MAXIMUM TEMPERATURE (°F)
		MINIMUM	MAXIMUM	
I	Dead-level asphalt	151	135	475
II	Flat asphalt	176	158	500
III	Steep asphalt	205	185	525
IV	Special steep asphalt	225	210	525

Reinforcing felts for BUR may be saturated, coated, or impregnated with bitumen and are manufactured from both organic and inorganic materials. Organic felts are manufactured from the fiber of paper, wood, or rags. Saturated felts are saturated with asphalt or coal tar bitumen. Impregnated roofing felts are generally lighter in weight and termed "impregnated" because their surface is not completely covered (coated) with asphalt. Saturated and coated roofing felts are generally factory-coated on both sides and surfaced on one or both sides with fine mineral sand or other release agents to prevent adhesion inside the roll prior to application.

Prepared roofing felts have been saturated and coated with talc, mica, sand, or ceramic granules incorporated into the weather surface of the felts, both to provide weather protection and for decorative purposes. Reinforced flashing membrane consists of a glass-fiber base felt that is laminated with cotton, or glass-fiber fabric coated with asphalt. Rosin-sized sheathing paper is a rosin-coated building paper generally used in built-up bituminous roofing to separate felts from wood roof decking.

BITUMEN TEMPERATURE

Proper application temperatures are vital to the creation of a quality built-up bituminous roofing assembly. Temperatures that are too high can lead to incomplete coverage, voids, and lack waterproofing qualities. Temperatures that are too low can lead to poor adhesion, high expansion properties, and low tensile strength.

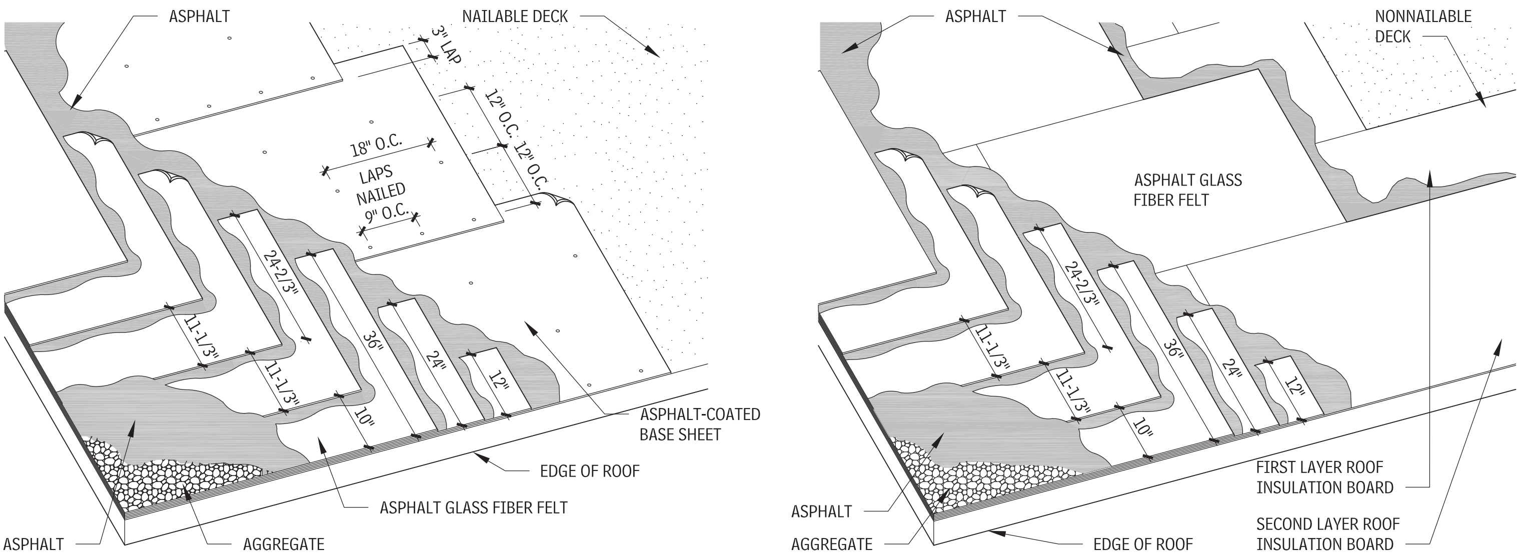
Bitumen can be heated at high temperatures for short periods of time without damage; in fact, they must be heated at high temperatures to achieve complete fusion and strong bonding of the plies. There is an optimum viscosity range and an optimum temperature range at the point of application that allow complete fusion, optimum wetting and mopping properties, and the desirable inter-ply bitumen weight called the *equiviscous temperature* (EVT). Excessive and prolonged heating of asphalt and coal tar products may have a deleterious effect on the quality of the product.

BUILT-UP ROOF SURFACING

Surfacing protects the bitumen and felts of a built-up bituminous roof from direct sunlight and weather exposure, and may provide other properties such as fire resistance or reflectivity. Surfacing types include aggregate, smooth surfacing, and mineral cap sheet.

- *Aggregate surfacing:* The aggregate in roofing serves as an opaque covering that improves the appearance and fire resistance of the roof and helps resist premature aging and damage from weather, temperature fluctuations, and ultraviolet rays. Aggregate also increases the wind uplift resistance of the roof membrane and permits much heavier application of bitumen than would otherwise be possible.
- *Smooth surfacing:* Built-up bituminous roofing may be left smooth, surfaced with a top coating of hot asphalt. Smooth surfacing should not be confused with a built-up membrane left unsurfaced (exposed felts). Smooth-surfaced built-up roofing should be specified only in those circumstances where aggregate-surfaced built-up bituminous roofing is impractical, such as when the slope of the roof surface exceeds 3 in 12, where the proximity of air-intake or exhaust equipment may cause loose aggregate, and where appropriate aggregate is not available.
- *Mineral-surfaced (cap sheet):* Some areas of the country (particularly the far western and southern states) use mineral-surfaced cap sheets as the final surfacing for built-up roofing membranes. These assemblies are similar to aggregate and smooth-surfaced except that a final layer of roofing material with a finished surface is installed on top of the multi-ply roof assembly. This assembly is not popular in colder climates, primarily because it requires phased construction of the final layer of roofing material.

BUILT-UP BITUMINOUS ROOFING—AGGREGATE SURFACE
11.406



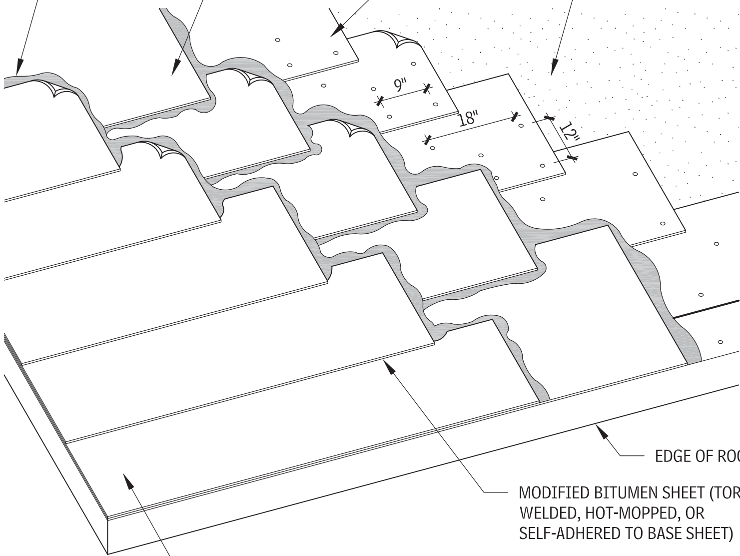
OVER NAILABLE DECK **OVER NONNAILABLE DECK**

NOTES

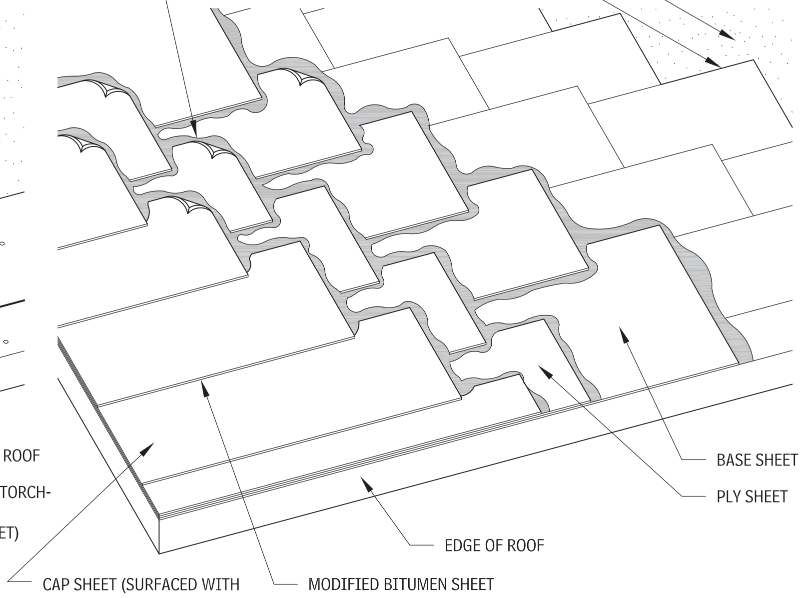
11.406 a. If applied over wood sheathing, add rosin-sized sheathing paper between the sheathing and base bitumen sheet.
b. In lieu of asphalt, coal tar is an acceptable product.
c. For a more conservative system, specify four plies rather than three.

Contributor:
National Roofing Contractors Association, Rosemont, Illinois.

THREE-PLY MODIFIED BITUMINOUS MEMBRANE
11.407



THREE-PLY OVER NAILABLE DECK



THREE-PLY OVER NON-NAILABLE DECK

MODIFIED BITUMINOUS MEMBRANE ROOFING

Polymer-modified bituminous membrane roofing couples bitumen and polymers with various modifiers to form a membrane system with improved properties. Modifiers include atactic polypropylene, styrene-butadiene-styrene, and styrene-butadiene-rubber. The modifying compounds impart improved flexibility, cohesive strength, toughness, and resistance to flow at high temperatures. The seams are sealed by torch-welding or with hot asphalt. Thickness ranges from 40 to 160 mils. Modified bituminous membranes of varying quality are manufactured by many companies. The design professional should carefully investigate and understand the characteristics and details of the assembly to obtain the desired quality.

For some systems, a base sheet is first fastened to the deck or insulation cover board. In the hot-mopped system, the membrane is constructed similar to a built-up roof with hot asphalt mopped between the plies. Self-adhered sheets have a factory-applied asphalt-adhesive coating on the underside. The protective sheet is peeled away to stick the membrane to the roof deck. Torch-applied membrane systems have a factory-applied coating of modified asphalt on the underside of the sheet, which is melted with a propane torch to make the sheet adhere.

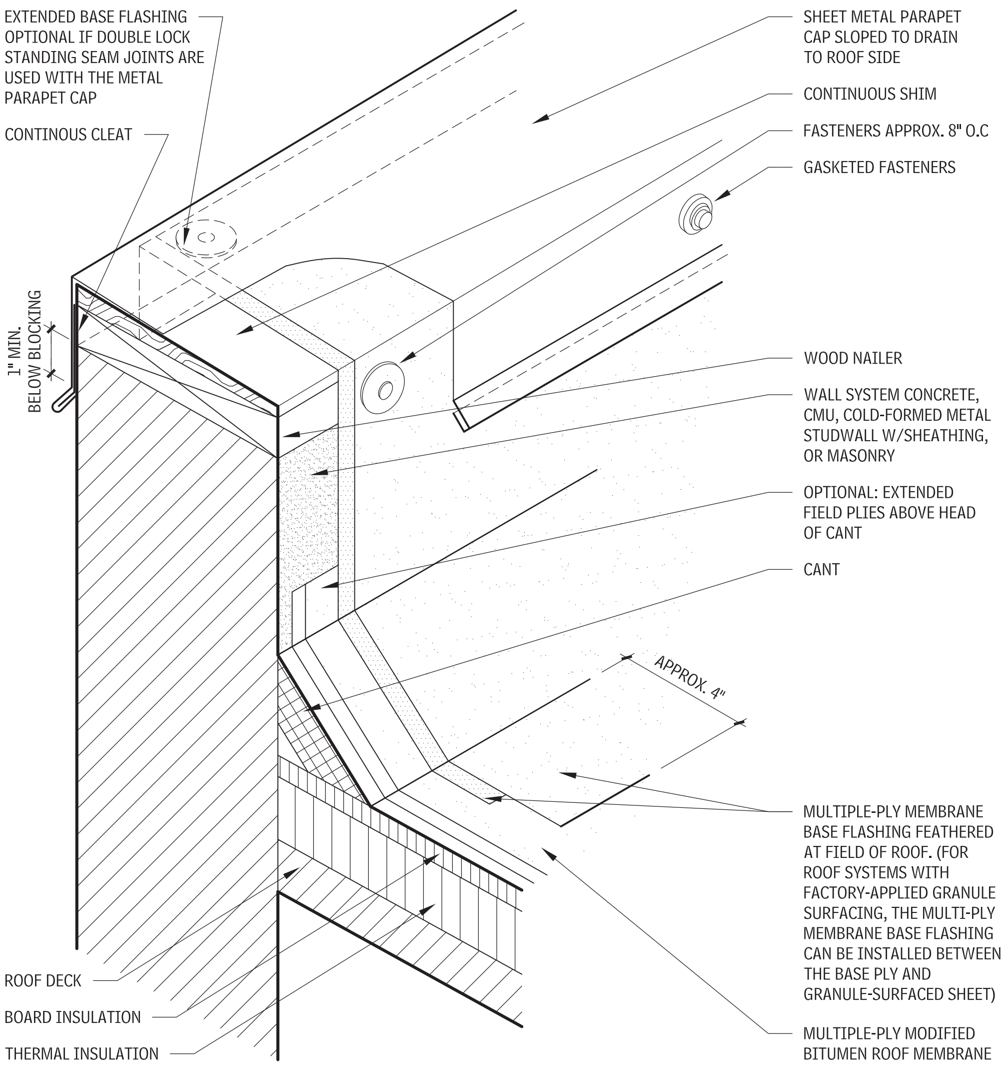
Because the base ply is airtight, application of the cap sheet may be delayed until construction is nearly complete, thereby avoiding damage caused by ongoing construction work.

Reinforcing materials for polymer-modified bitumen membranes include plastic film, polyester mat, glass fiber, felt or fabric, and metal foils, embedded within or laminated onto the modified bitumen sheet. Membranes may be surfaced with liquid coatings, metallic laminates, or ceramic or mineral granules to enhance resistance to weathering, ultraviolet rays, or fire or to improve appearance. Terminations at roof edges, parapets, and other flashings may be torch-applied, hot-mopped, or self-adhered. Laps are formed as the sheet is being applied.

NOTE

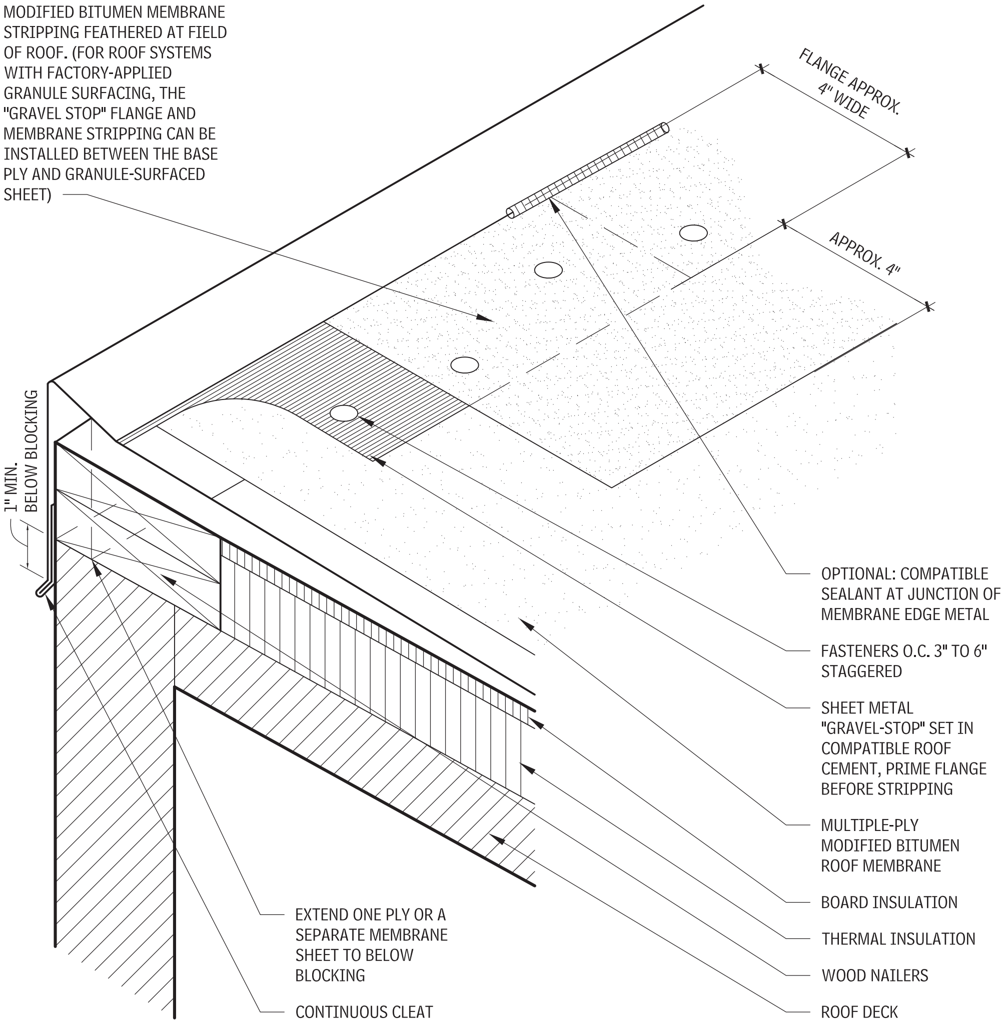
11.407 If applied over wood sheathing, add rosin-sized sheathing paper between the sheathing and base bitumen sheet.

PARAPET COPING AND BASE FLASHING FOR MODIFIED BITUMEN ROOFING
11.408

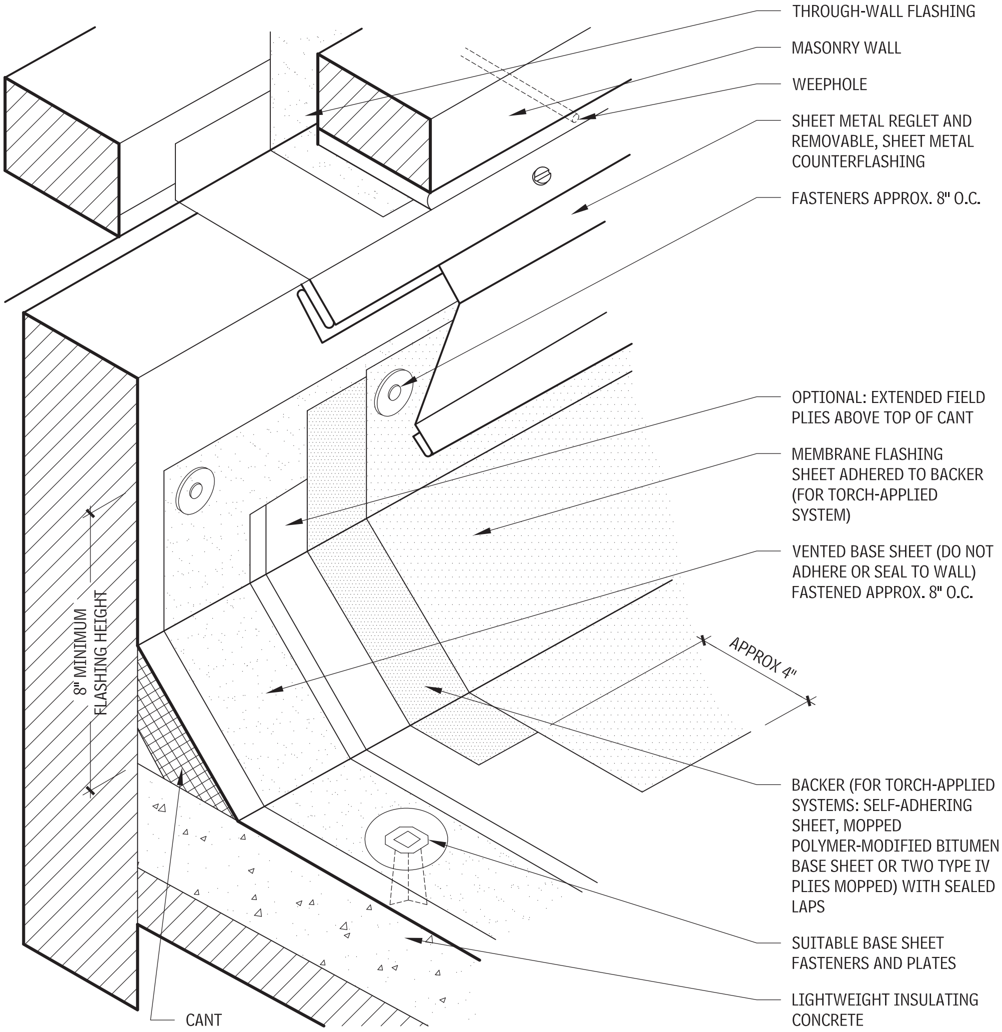


Contributor:
National Roofing Contractors Association, Rosemont, Illinois.

ROOF EDGE METAL FLASHING FOR MODIFIED BITUMEN ROOFING
11.409



BASE FLASHING FOR WALL-SUPPORTED DECK WITH MODIFIED BITUMEN ROOFING
11.410



ELASTOMERIC AND THERMOPLASTIC MEMBRANE ROOFING

Elastomeric membrane roofing and thermoplastic membrane roofing assemblies are both types of single-ply membrane roofing. Single-ply membrane roofing uses large sheets that are joined into a continuous roof membrane. In these assemblies the seams and flashing may be vulnerable to defects in workmanship, thus comprise a primary weakness of the system. Single-ply membranes are also generally less resistant to physical abuse and cannot as easily be resurfaced as other types.

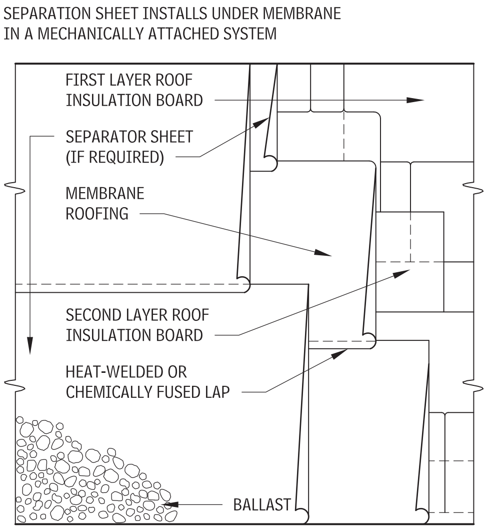
Single-ply membranes are available in two types: thermoset and thermoplastic. Thermoset materials cure during manufacture and can only be bonded at seams with adhesive. Ethylene propylene diene monomer (EPDM) is the most common thermoset membrane; chlorosulfonated polyethylene (CSPE) and polyisobutylene (PIB) are also available, but not as common. Thermoplastic membrane roofing materials are uncured and, therefore, are capable of being hot-air-welded or solvent-welded. Polyvinyl-chloride (PVC) and thermoplastic-polyolefin (TPO) are two common thermoplastic membranes.

Single-ply membranes may be installed using three methods:

- *Loose-laid ballasted assemblies:* Loose-laid assemblies are the least expensive and require the least skills of the installer. There are, however, a number of disadvantages. First, membrane is susceptible to puncture from ballast when maintenance staff walks across the roof. Second, leaks are very hard to find because the water is free to travel horizontally within the insulation before appearing on the interior, and the membrane is covered with stones. Third, the loose ballast is problematic because it can be moved around on the roof by the wind, leaving some areas of the membrane unsecured and ballast may also fly off the roof as dangerous projectiles. Size and weight of ballast should be designed for the specific project site, with increased weights at perimeter and corner zones. Specially designed lightweight concrete roof pavers that are cast for use as roof ballast may be used in place of regular aggregate ballast for some or the entire roof—refer to Figures 11.426 and 11.471. Avoid ballasted roofs in hurricane areas and on high-rise structures. The ballast can be a light color, but is generally not as reflective as white single-ply membrane roofing.
- *Fully adhered assemblies:* Fully adhered assemblies are generally the most expensive of the three applications and offer the highest-level of performance. Fully adhered assemblies may use non-reinforced or reinforced sheets, which generally take longer to wear through. Leaks are relatively easy to find because an area of wet insulation usually forms immediately below the gap in the membrane.
- *Mechanically attached assemblies:* Membranes for mechanically attached assemblies should be reinforced to resist the tearing forces generated by uplift. Because a relatively large amount of seaming is required, thermoplastic sheets are becoming more popular. The level of difficulty of finding leaks within mechanically attached systems is between the loose-laid and fully adhered systems.

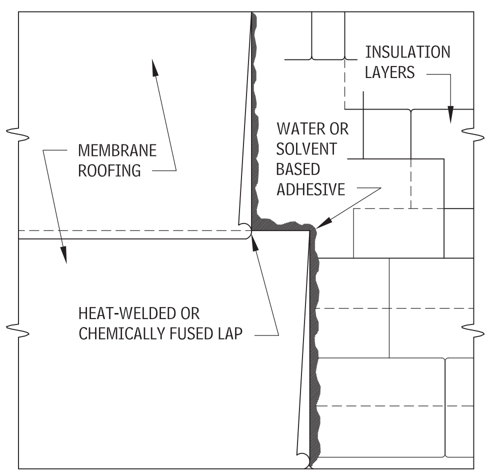
LOOSE-LAID BALLASTED SHEETS
11.411

Membrane sheets and insulation are laid loose with the membrane secured at the perimeter and around penetrations only. The membrane is then covered with a ballast of river-washed stones (typically 10 lb/sq ft) or appropriate pavers. This system works efficiently with insulation approved by the membrane manufacturer and on roofs with a slope not exceeding 2 in 12.



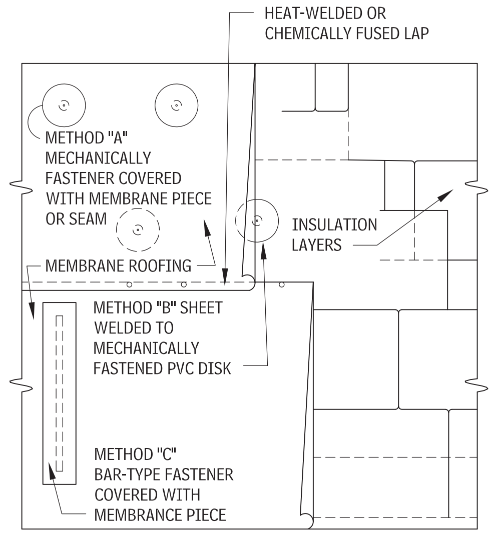
FULLY ADHERED SHEETS
11.412

Fully adhered membrane assemblies are not limited by slope, because the membrane is secured to the substrate with bonding adhesive and by mechanically fastening the membrane to the perimeter and penetrations. This assembly is appropriate for contoured roofs and roofs that cannot withstand the weight of a ballasted assembly. The membrane can be directly applied to numerous types of roof deck surfaces including concrete and wood and may be compatible with insulation or protection board.



MECHANICALLY ATTACHED SHEETS
11.413

A mechanically attached roof assembly is appropriate for roofs that cannot carry the loads imposed by ballasted roof assemblies. Assemblies are available with fasteners that penetrate the membrane, or that require no membrane penetration. The membrane is anchored to the roof using metal bars or individual clips, and it may be installed over concrete, wood, metal, or compatible insulation.



EPDM ROOFING

Ethylene-propylene-diene-monomer (EPDM) membranes are typically 30 to 60 mils in thickness, single-sheet roofing materials. The membranes are available either non-reinforced or reinforced with fabric. Seams in the membrane are spliced and cemented. EPDM membranes are highly resistant to degradation from certain chemicals, ozone, and ultraviolet radiation, and have excellent resilience, tensile strength, abrasion resistance, hardness, and weathering properties.

EPDM membranes may be loose-laid, mechanically fastened, or fully adhered to either nailable or nonnailable decks. For loose-laid systems, ballast provides resistance against wind uplift forces. Field application of surfacing or coatings may enhance the weather-resistance properties, or may be simply aesthetic. Terminations at roof edges, parapets, and other flashings use material identical to the roof membrane material shaped to conform to the substrate and area being flashed.

PVC ROOFING

Polyvinyl-chloride (PVC) membranes may be non-reinforced or reinforced with glass fibers or polyester fabric. The membranes are typically 45 to 60 mils in thickness. Seams are sealed by heat or chemical welding, and may require additional caulking. PVC membranes are resistant to bacterial growth, industrial chemical atmospheres, root penetration, and extreme weather conditions. PVC membranes also have excellent fire resistance and seaming capabilities.

ASTM Standard D-4434 categorizes PVC materials into several types and classes, depending on the construction of the sheet material:

- *Type I:* Non-reinforced sheet
- *Type II, Class I:* Non-reinforced sheet containing fibers
- *Type II, Class II:* Non-reinforced sheet containing fabrics
- *Type III:* Reinforced sheet containing fibers or fabrics

PVC membranes may be loose-laid, mechanically fastened, or fully adhered to either nailable or nonnailable decks. For loose-laid systems, ballast provides resistance against wind uplift forces. Some PVC membranes have a factory-applied coating to enhance weather resistance or aesthetics. Field application of the coatings may be an option, and is dependent on the membrane manufacturer.

KEE ROOFING

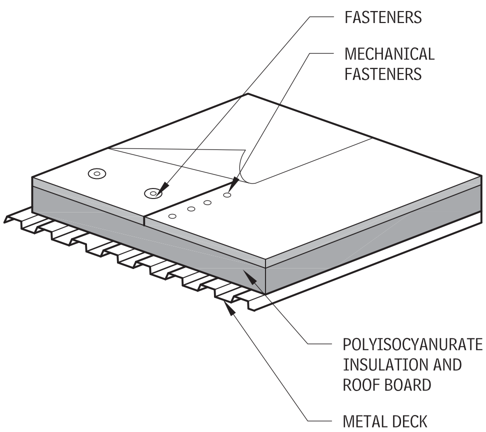
KEE membranes are a relatively new roofing type on the market similar to PVC. Basically it is an improved PVC roof with plasticizers for better reflecting high-heat, such as the reflective heat from solar panels.

TPO ROOFING

Thermoplastic-polyolefin (TPO) membranes are blended from polypropylene and ethylene-propylene rubber polymers, and may include flame retardants, pigments, UV absorbers, and other modifiers. Membrane sheets are available reinforced and non-reinforced in thicknesses from 40 to 100 mils. TPO membranes range from stiff and "boardy" to soft and flexible. Seams are heat-welded and may require additional caulking to protect wicking of the reinforcing. TPO is resistant to animal fats, some hydrocarbons, and vegetable oils.

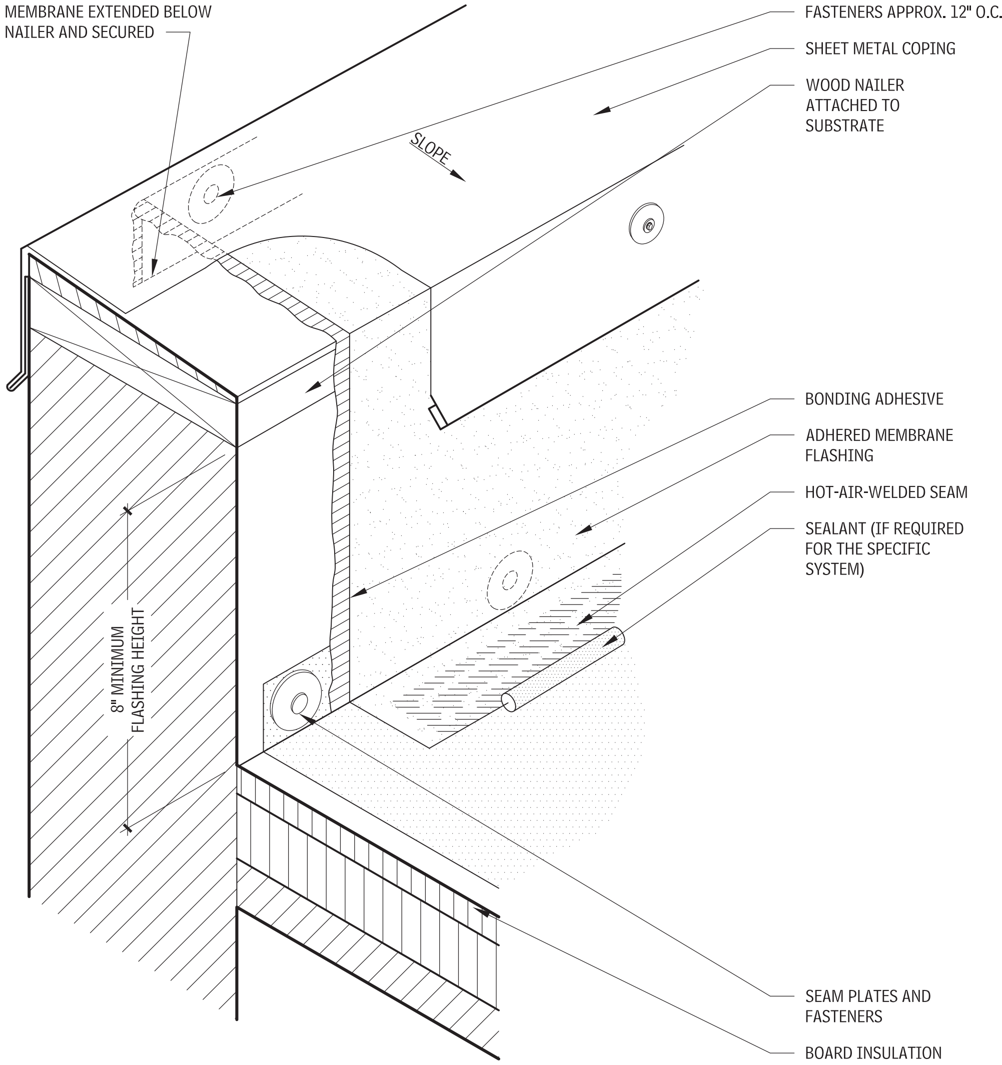
TPO membranes may be loose-laid, mechanically fastened, or fully adhered. Some membranes are white or light in color, or field coatings may be applied.

PVC, TPO, OR KEE ROOFING
11.414

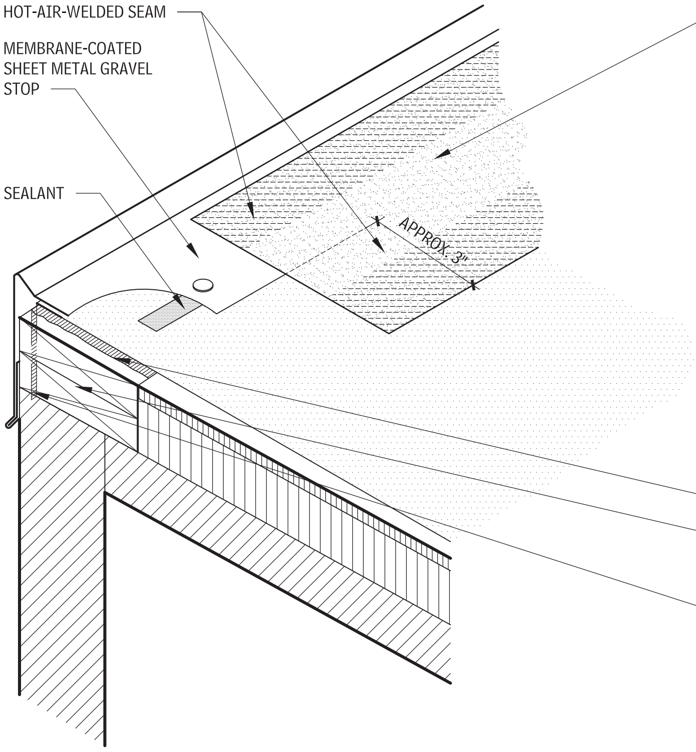


PVC, TPO, OR KEE ROOFING MEMBRANE

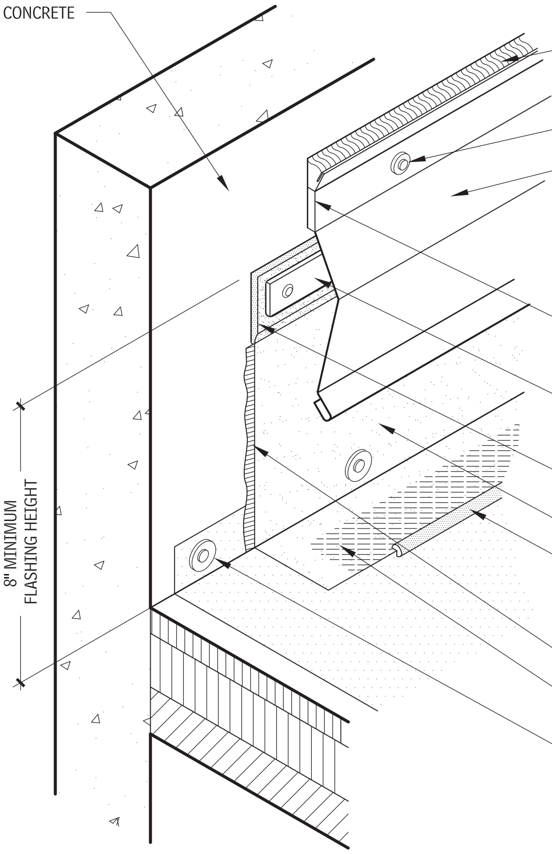
PARAPET COPING AND BASE FLASHING FOR THERMOPLASTIC ROOF MEMBRANE
11.415



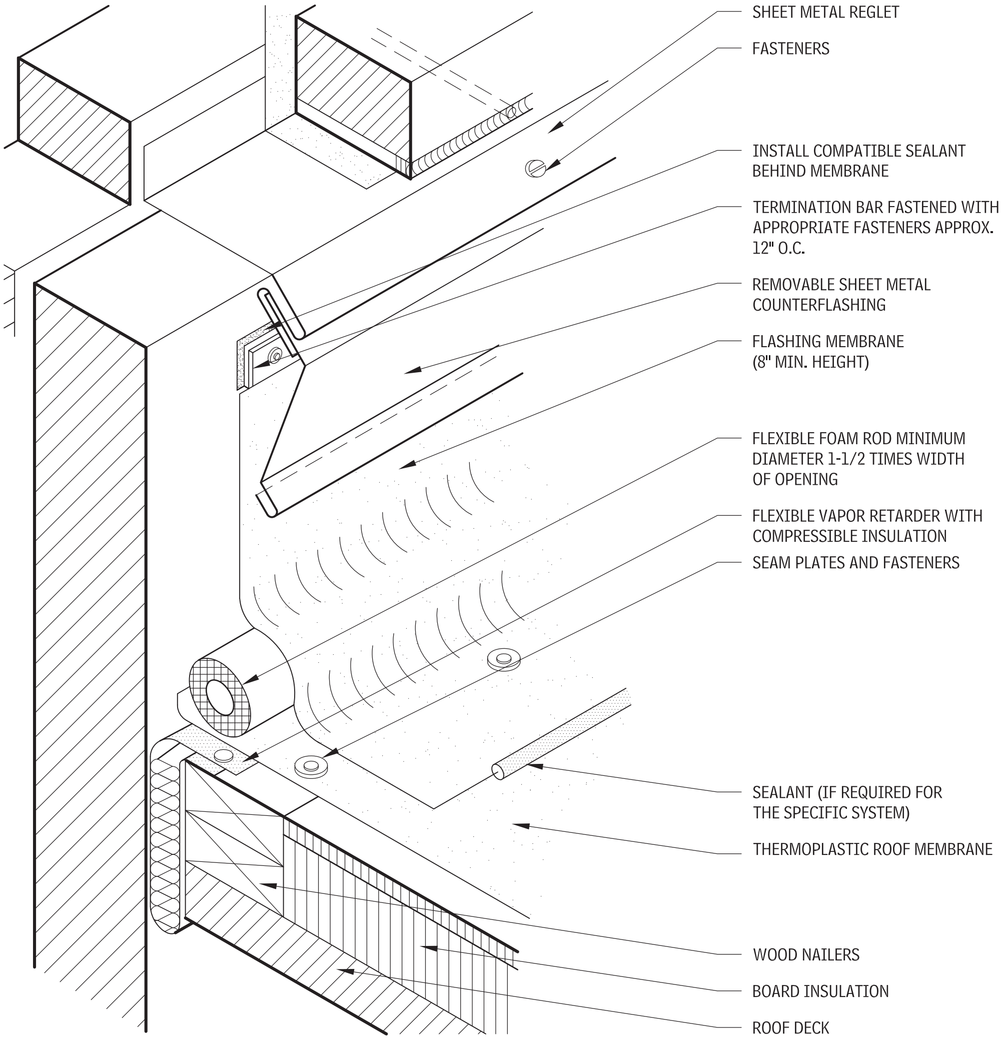
ROOF EDGE FLASHING FOR THERMOPLASTIC ROOF MEMBRANE (EMBEDDED)
11.416



COUNTERFLASHING DETAIL AT CONCRETE WALL FOR THERMOPLASTIC ROOF MEMBRANE
11.417



BASE FLASHING FOR NON-WALL-SUPPORTED DECK FOR THERMOPLASTIC ROOFING MEMBRANE
11.418



FLUID-APPLIED ROOFING

Fluid-applied roofing assemblies may be applied at ambient temperatures or heated in kettles. Most of them have some sort of reinforcing fabric that is applied along with the liquid component. Fluid-applied roofing used over existing roofs is not generally accepted as a "membrane," but rather as a coating.

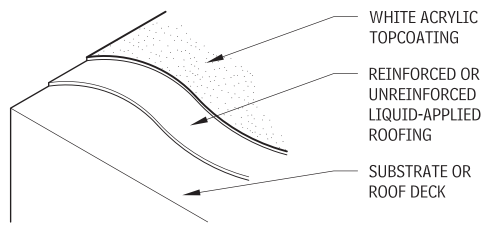
Acrylic latex and urethane are the two main types of cold liquid-applied roofing. Acrylic latex refers to a family of products that use water-based polymers and cure by water evaporation. Liquid-applied urethane roof coatings are chemically cured to form an elastomeric membrane. Because these coatings are applied as liquids, installation is relatively simple, even for roofs with irregular geometries or multiple penetrations. For assemblies using a reinforcing fabric, a coating is applied to an acceptable surface. While the coating is still wet, a layer of polyester or fiberglass is laid into it, followed by an additional layer of coating. Subsequent layers may be added as desired or necessary.

Fluid-applied roofing is appropriate for new construction but is most commonly used as enhancements or for repairs to existing roofs, including modified bituminous roofs and built-up roofs.

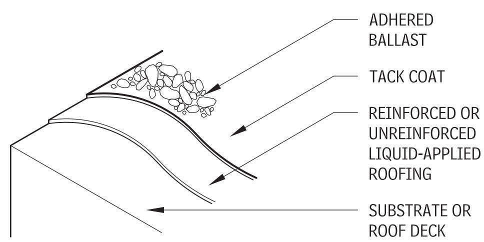
The advantages of fluid-applied roofing are that it conforms very well to irregular surfaces, is easily applied, and comes in various colors. However, it is sensitive to the skills of the installer, and is best used in sloped roof situations.

FLUID-APPLIED ROOFING
11.419

Fluid-applied roofing may also be used under rigid insulation and ballast for further protection.



REFLECTIVE

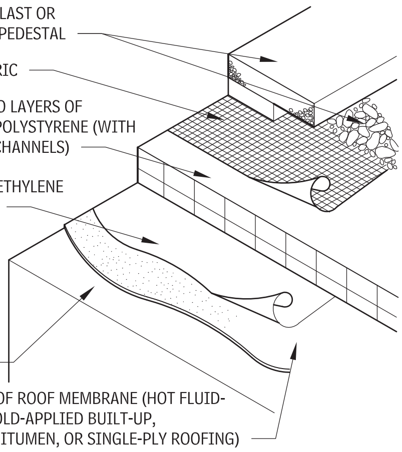


ADHERED BALLAST

HOT FLUID-APPLIED ROOFING

Most commonly, hot fluid-applied membranes are composed of rubberized asphalt applied at 150 to 210 mils in two coats with a reinforcing sheet between the layers. Although the membrane has limited puncture resistance, because it is most often applied directly to a concrete substrate and protected by insulation, puncture resistance is less critical. The membrane is self-healing to minor punctures, has crack-bridging ability, is relatively forgiving of rough substrates, and can be protected shortly after installation. Moreover, fluid-applied membranes allow for easier penetration flashing, so they are particularly suited to complicated roof shapes with many penetrations.

PROTECTED MEMBRANE ROOF SYSTEM
11.420



PROTECTED MEMBRANE ROOFING

In a typical roofing assembly, the waterproof membrane (built-up, modified bitumen, or single-ply) is applied over the insulation, which is on top of the substrate and/or structural deck. The membrane in this situation is exposed to temperature extremes, as well as wear and tear from people walking or working on the roof. In a protected membrane roof (sometimes called the *inverted* or *insulated roof membrane assembly*, or *IRMA*), a layer of extruded polystyrene insulation board protects the membrane. Extruded polystyrene is the only material generally approved for this application because it does not absorb moisture. This roofing system is best used in extreme climates, where it is important to protect the membrane from the elements, or where the rooftop will receive heavy use (e.g., plaza or parking deck applications).

VEGETATED ROOFING

Varying approaches have been taken to vegetated roofing design, so-called green roofing. The type of assembly selected will depend in part on the job conditions, including climate, plant community desired, and load-bearing capacity of the roof deck. Green roof assemblies are compatible with both conventional and protected roof membrane (PRM) waterproofing systems. All assemblies will include the following characteristics:

- Protection of the waterproofing membrane from root and biological attack
- Protection of the waterproofing membrane from physical abuse and accident
- Base drainage layer
- Separation layer, to prevent fine-grained engineered soils from fouling or clogging the drainage layer system
- Engineered soil, to support the vegetation

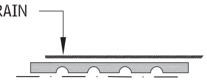
Some waterproofing membranes do not require supplemental root protection. Assemblies 6 in. and thinner are referred to as *extensive;* assemblies 12 in. and thicker are referred to as *intensive*.

Optional components can be incorporated, among them:

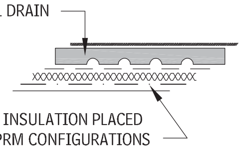
- Irrigation
- Slope-stabilizing elements
- Root-reinforcement elements
- Enhancements to retain rainfall moisture
- Air layers to dehumidify the insulation layer (some PRM systems)
- Self-contained modules
- Ballasts to resist wind uplift

Most engineered soils intended for green roof use are manufactured from lightweight mineral aggregates. These materials typically have wet densities between 60 and 90 lb./cu ft., measured according to ASTM E2399.

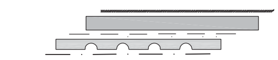
VEGETATED COVER SYSTEMS FOR ROOFS
11.421



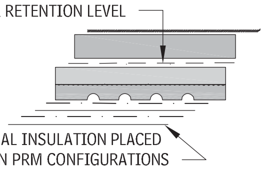
I
FOLIAGE: SUCCULANTS TYPICAL THICKNESS 2–4 INCHES



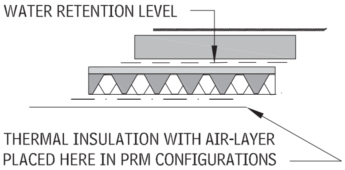
II
FOLIAGE: SUCCULANTS–HERBS TYPICAL THICKNESS 3–6 INCHES



III
FOLIAGE: SUCCULANTS–MEADOW GRASS–HERBS TYPICAL THICKNESS 4–8 INCHES

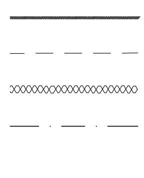


IV
FOLIAGE: MEADOW GRASS–HERBS– WILDFLOWERS –TURF TYPICAL THICKNESS 6–24 INCHES



IV
FOLIAGE: MEADOW GRASS–HERBS– WILDFLOWERS –TURF TYPICAL THICKNESS 6–24 INCHES

LEGEND



* AIR-LAYER IS A GEOCOMPOSITE DRAINAGE SHEET

NOTES

11.420 a. Ballast weight is a minimum of 10 lb./sq. ft.
b. Refer to ANSI/SPRI/RMA RP-4 for wind design guidance.
c. In lieu of aggregate or concrete ballast, proprietary insulation boards with concrete topping are available. These boards weigh between 4.5 lb./sq. ft. and 10 lb./sq. ft., depending on the product selected.
11.421 The air layer is a generally composed of a geocomposite drainage sheet.

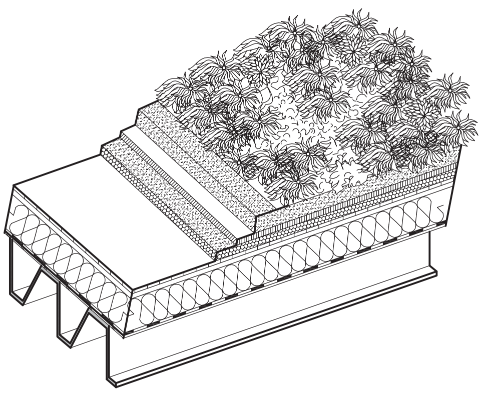
Contributors:
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland; Rich Boon, Roofing Industry Educational Institute, Englewood, Colorado.

Green roof assemblies can be classified into five categories:

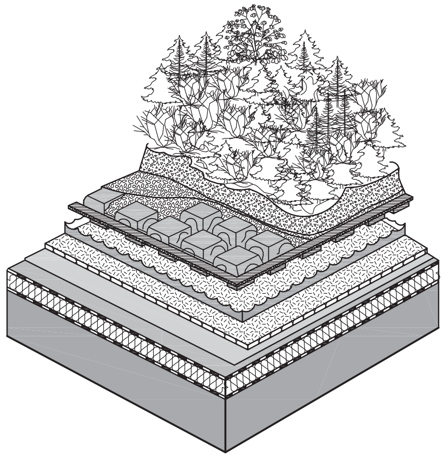
- *Category I:* Single-layer assemblies usually installed with a fabric or foam mat to provide physical protection and improve drainage. The overall thicknesses of these assemblies are rarely greater than 4 in. These assemblies are associated with pitched roof installations. They also offer the least expensive option for roof greening.
- *Category II:* Two-layer assemblies in which the engineered soil is placed over an efficient geocomposite drainage layer. A common variation utilizes a drainage layer that can also retain some water. To reduce plant stress during drought conditions, the drainage layer should not be thicker than 1 in. Typical overall assembly thicknesses range from 3 to 6 in. These are probably the most commonly encountered extensive assemblies in the United States.
- *Category III:* Two-layer assemblies in which a highly permeable coarse granular material is used to create the drainage zone. Typical overall assembly thicknesses range from 4 to 8 in. Compared to a Category II assembly of comparable thickness, a Category III assembly would be markedly more drought-tolerant and accommodate a broader plant selection.
- *Category IV:* Similar to Category III assemblies but with a deeper drainage layer to accommodate base (bottom-up) irrigation methods. The minimum thickness for this assembly is 6 in.
- *Category V:* These assemblies involve the use of a water retention panel that is filled with coarse granular material. As in the Category III and Category IV assemblies, a surface layer of engineered soil is placed over the granular layer and separated from it by a filter fabric. This assembly introduces an air layer at the bottom of the profile. The minimum thickness for this system is 6 in.

Category IV and V systems are irrigated and are most frequently associated with intensive applications. Irrigation enhances landscape design opportunities, and in warm climates can also enhance cooling effects. These assemblies are well represented in deep plaza landscapes that can support large perennial plants and trees.

CATEGORY III
11.422



CATEGORY V
11.423



ENVIRONMENTAL BENEFITS

Vegetated roofing provides three important environmental benefits including:

- Prolong the life expectancy of the underlying waterproofing materials, which will reduce waste generation and the amount of embedded energy associated with the roof.
- Restore a natural hydrologic balance to developed sites, including reducing flooding and promoting more effective water utilization by plants.
- Improve the energy performance of buildings.

The scale of the energy benefit will, of course, depend greatly on the climate; northern-temperate and semitropical climates will benefit most. When selecting green roof systems, ask the following questions:

- What contained materials are manufactured from recycled materials or, alternatively, are recyclable?
- How durable is the combined waterproofing and green cover system likely to be? How can its longevity be enhanced?
- To what extent can irrigation be eliminated through appropriate selection of the engineered soil, system configuration, and plant selection?

SPECIAL CONSIDERATIONS

With appropriate precautions, vegetated roofs have been successfully installed in combination with all major waterproofing system types. These membranes do not require supplemental root-protection layers. Also, ASTM E2397 provides a standardized procedure to establish maximum combined assembly weights for use when determining dead loads.

A critical part of all vegetated roof design is protection for the drains and flashings that is comparable to that offered by the vegetated cover elsewhere. The flashing, in particular, is typically the weak link in the overall roofing assembly. As a result, it is considered good practice to armor flashings with metal counterflashing or to protect the it with "sacrificial" layers of membrane.

Green roof techniques have been employed with great success in Europe for more than 40 years. In most German cities, for example, vegetated roofing is an indispensable part of the country's urban runoff management and water treatment strategies. Very effective methods for protecting underlying waterproofing membranes have been developed. Also, electrical techniques are available that make it possible to locate even small leaks with pinpoint accuracy.

Methods of installing plants include:

- Plugs
- Reinforced vegetated mats
- Seed and cuttings
- Modules planted in the nursery

Consult the following references:

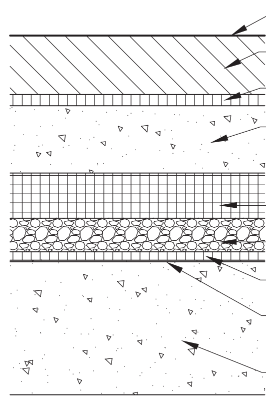
- *www.wbdg.org/designgreenroofs.php*
- *www.greenroofs.com*
- *www.greenroofs.org*.
- *Planting Green Roofs and Living Walls*, by Nigel Dunnett and Noel Kingsbury (Timber Press, 2004)
- *Merging Landscape and Architecture: A Guide to Living Green Roofs and Landscape over Structure*, by Katrin Scholtz-Barth and Susan Weiler (John Wiley & Sons, Inc., 2006)
- *Green Roof Plants: A Resource Guide*, by Edmund C. Snodgrass and Lucie L. Snodgrass (Timber Press, 2006)

HORIZONTAL WATERPROOFING

SHEET WATERPROOFING

The basic components, subsystems, and features for a building deck waterproofing system are the structural building deck or substrate to be waterproofed, the waterproofing membrane, protection of the membrane, drainage, insulation, and wearing course.

BASIC COMPONENTS OF WATERPROOFING SYSTEMS
11.424



SUBSTRATE

The preferred substrate is reinforced cast-in-place structural concrete. Precast concrete slabs pose more technical problems than cast-in-place concrete, and the probability of lasting watertightness is greatly diminished and difficult to achieve because of the multitude of joints that have movement capability and must be treated accordingly.

The concrete used for the substrate should have a minimum density of 110 lb./cu ft. and have a maximum moisture content of 8 percent when cured.

The underside of the concrete deck should not have an impermeable barrier. A metal liner or coating that forms a vapor barrier on the underside traps moisture in the concrete and destroys or prevents the adhesive bond of the membrane to the upper surface of the concrete.

Contributor:
Charlie Miller, P.E., Roofscapes, Inc., Philadelphia, Pennsylvania.

The surface should be of sufficiently rough texture to provide a mechanical bond for the membrane, but not so rough as to preclude achieving continuity of the membrane of the specified thickness across the surface.

The concrete should be cured a minimum of seven days and aged a minimum of 28 days, including curing time, before application of the liquid-applied membrane. Curing is accomplished chemically with moisture and should not be construed as drying. Liquid or chemical curing compounds should not be used unless approved by the manufacturer of the liquid-applied membrane as the material may interfere with the bond of the membrane to the structural slab.

SLOPE FOR DRAINAGE

A minimum cast-in-place concrete substrate slope of 1/8 in 12 should be maintained. Slope is best achieved with a concrete structural slab. If topping slabs are used, create a 3/4-in. depression at edges to avoid tapering fill to a feather edge. Drains should be designed with a wide flange or base as an integral part. The drain base should be set flush with the structural slab.

MEMBRANE

Membranes for horizontal plaza waterproofing include hot fluid-applied membranes, cold fluid-applied membranes, single-ply sheet membranes, modified bituminous membranes, built-up membranes, bentonite clay membranes, cementitious coatings, and others. Many are similar to the roofing membranes of the same composition.

Some membranes can tolerate a dead-flat substrate but many require a slope of approximately 1/4 in. per foot. If possible, the substrate should always be pitched no matter what the membrane. Fluid-applied membranes are preferable for complicated plazas with many penetrations and details. Hot fluid-applied roofing is a popular system for plazas.

Leakage detection can be a significant problem when the membrane is not bonded to the structural slab, or when additional layers of materials separate it from the structural slab. Therefore, only membranes that can be bonded to the substrate should be used.

The membrane should be applied under dry, frost-free conditions on the surface, as well as throughout the depth of the concrete slab.

When the membrane is turned up on a wall, it is preferable to terminate it above the wearing surface to eliminate the possibility of ponded surface water penetrating the wall above the membrane and running down behind it into the building.

Penetrations should be avoided wherever possible. For protection at critical locations, pipe sleeves should be cast into the structural slab against which the membrane can be terminated by flashing onto the pipe sleeve.

Treatment at reinforced and non-reinforced joints depends on the membrane used.

Two concepts can be considered in the detailing of expansion joints at the membrane level: the positive seal concept, directly at the membrane level, and the watershed concept, with the seal at a higher level than the membrane. Where additional safeguards are desired, a drainage gutter under the joint could be considered. Flexible upward support of the membrane is required in each case to provide watershed-type drainage. Expansion joint details should be considered and used in accordance with their movement capability.

- The positive seal concept entails a greater risk than the watershed concept, as it relies fully on positive seal joinery of materials at the membrane level, where the membrane is most vulnerable to water penetration. However, the precision required to achieve this is not always possible, so this concept is best avoided.
- The watershed concept, even though it requires a greater height and more costly concrete forming, is superior in safeguarding against leakage, as it has the advantage of providing a monolithic concrete water dam at the membrane level. However, if a head of water rises to the height of the materials joinery, this concept becomes almost as vulnerable as the positive seal concept. Therefore, drainage is recommended at the membrane level.

PROTECTION BOARD

The membrane should be protected from damage throughout construction. Protection board should be applied after the membrane is installed. The proper timing of application after placement of the membrane is important and varies with the type of membrane used. Follow the manufacturer's printed instructions.

DRAINAGE SYSTEM

Drainage should be considered a component of the total system, from the wearing surface down to the membrane, including use of multilevel drains.

Drainage at the wearing surface is generally accomplished in one of two ways:

- Using an open-joint and pedestal system, which permits the rainwater to penetrate rapidly down to the membrane level and subsurface drainage system.
- Using a closed-joint assembly designed to remove most of the rainwater rapidly by slope surface to drains and to allow a small portion to infiltrate to the membrane.

A drainage course of washed, round gravel or prefabricated drainage composite should be provided above the protection board, over the membrane. This permits water to filter to the drain and provides a place where it can collect and freeze without damaging the wearing course.

INSULATION

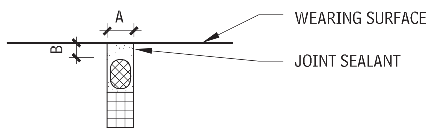
Insulation should be located above the membrane but not in direct contact with it. Insulation is typically extruded polystyrene for water resistance and from 40 to 100 psi, as required to support loads on a plaza.

PROTECTION OR WORKING SLAB

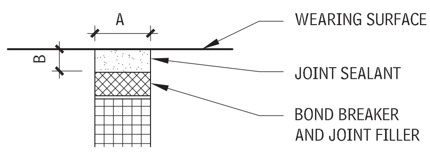
A concrete slab could be placed soon after the membrane, protection board, drainage course, and insulation, if required, have been installed. It would serve as protection for the permanent waterproofing materials and insulation below, provide a working platform for construction traffic and storage of materials (within weight limits), and serve as a substantial substrate for the placement of the finish wearing course materials.

WEARING COURSE

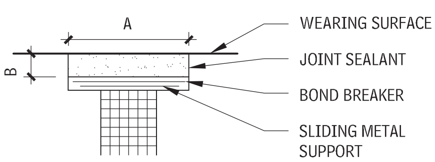
WET SEALANT DETAILS AT WEARING SURFACE 11.425



FOR JOINTS UP TO 1/2" WIDE



FOR JOINTS UP TO 1-1/2" WIDE



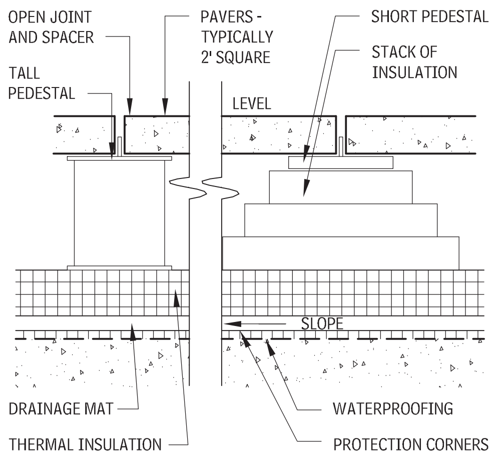
FOR JOINTS WIDER THAN 1-1/2"

The major requirements for the wearing course are a stable support of sufficient strength, resistance against lateral thrust, adequate drainage to avoid ponding of water, and proper treatment of joints. Stone or precast concrete pavers with open joints on pedestals comprise a common wearing course. A prefabricated drainage composite under a thickset mortar bed supporting masonry units helps resist freeze-thaw damage to the wearing course by expediting water flow down to the subsurface drainage system.

Joints in which movement is anticipated should be treated as expansion joints. Various compression seals are available that can be inserted into a formed joint under compression. Most of these, however, are not flush at the top surface and could, therefore, fill up with sand or dirt.

Wet sealants are the materials most commonly used in moving joints at the wearing surface level. Dimension A is the design width dimension, or the dimension at which the joint will be formed. The criterion normally used for determining this dimension with sealants capable of plus 25 percent movement is to multiply the maximum expected movement in one direction by 4. Generally, this is expected to be about 3/4 of the total anticipated joint movement; but if there is any doubt, multiply the total anticipated joint movement by 4. It is better to have the joint too wide than too narrow. Dimension B (sealant depth) is related to dimension A and is best established by the sealant manufacturer. Generally, B is equal to A for widths up to 1/2 in., 9/16 in. for a 5/8-in. width, and 5/8 in. for 3/4-in. and greater widths. This allows some tolerance for leveling sealants. Joints over a soft backer rod should be limited to 1/4 in. to support high loads. High-shore hardness sealant should be used for plaza surfaces.

PAVERS ON PEDESTALS 11.426



TERMINATION AT DRAINS

Drains should be designed with a wide flange or base as an integral part. The drain base should be set flush with the structural slab. Vehicular supporting drains generally require additional weepholes drilled into them.

TREATMENT AT REINFORCED JOINTS

One recommended treatment of reinforced concrete joints in the structural slab is to apply a double layer of membrane over the crack. This type of detail is, however, quite limited and implicitly relies on the membrane's crack-bridging capability. An alternative approach is to prevent the membrane from adhering to the substrate for a finite width centered on the joint or crack by means of a properly designed compatible bond-breaker tape.

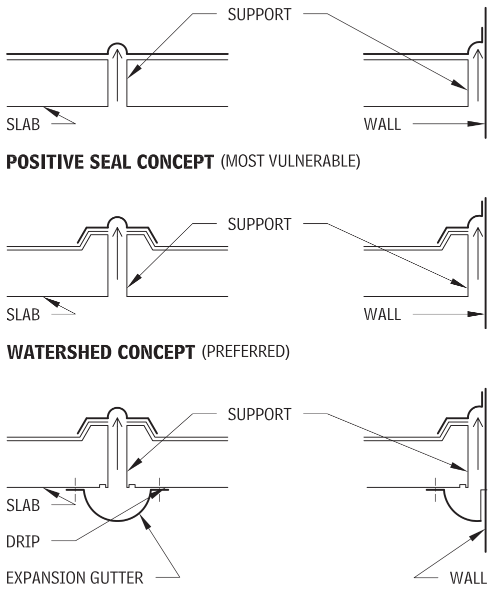
TREATMENT AT NON-REINFORCED JOINTS

Because the joints are not held together with reinforcing steel, some movement, however slight, should be anticipated and provided for, as the liquid-applied membrane has limited capability to take movement.

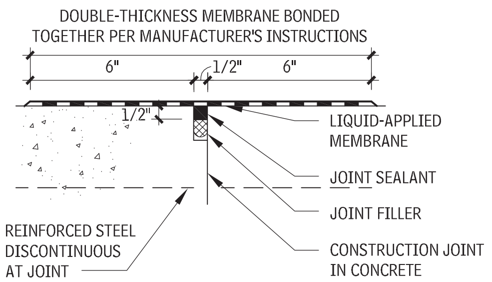
TREATMENT AT EXPANSION JOINTS

Gaskets and flexible preformed sheets lend themselves better to absorbing large amounts of movement. Such materials, when used at an expansion joint, must be joined to the liquid-applied membrane, therefore the watershed concept should be used.

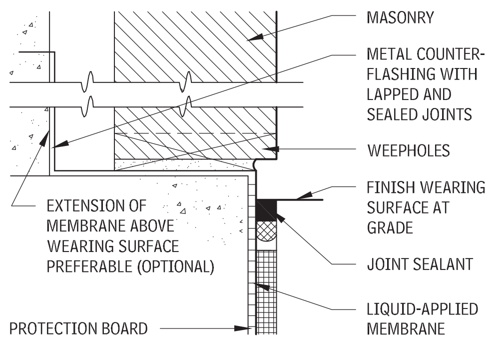
EXPANSION JOINT CONCEPTS AT MEMBRANE LEVEL
11.427



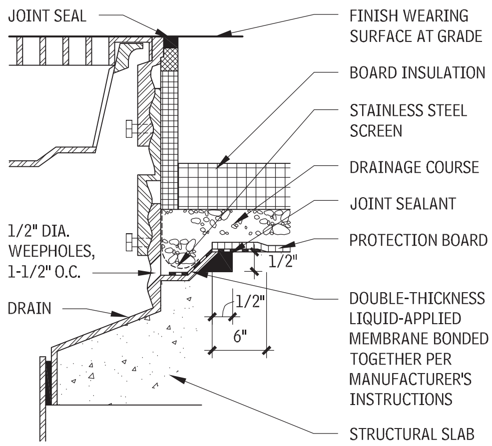
TREATMENT OF NON-REINFORCED BUTTED JOINT IN CONCRETE SLAB
11.428



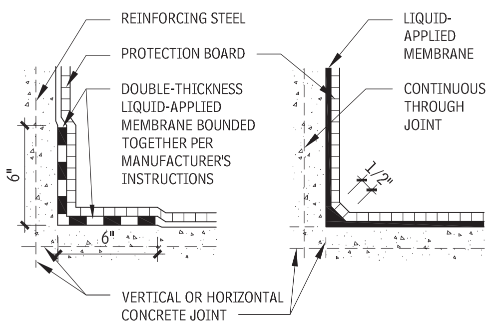
TERMINAL CONDITION WITH MASONRY ABOVE FINISH WEARING SURFACE AT GRADE
11.429



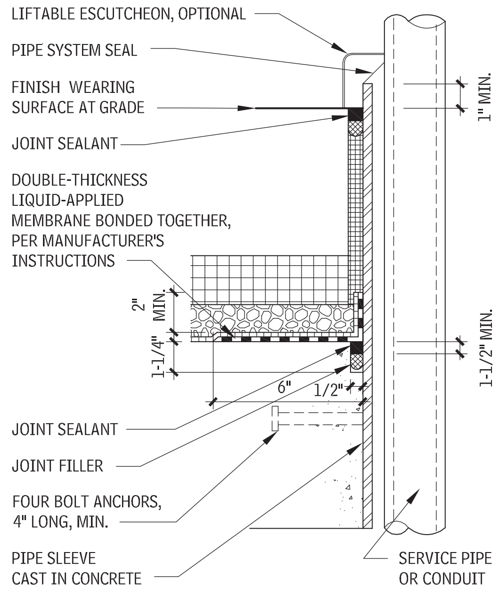
TERMINATION AT DRAIN
11.430



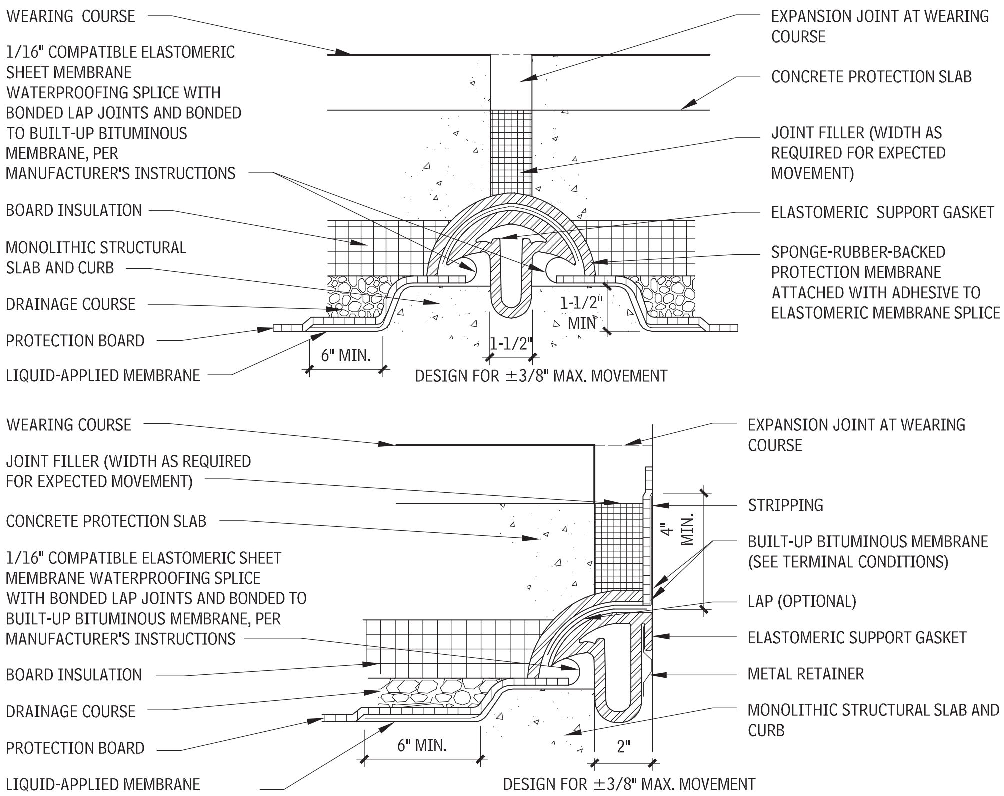
TURN-UP DETAILS AT REINFORCED JOINT
11.431



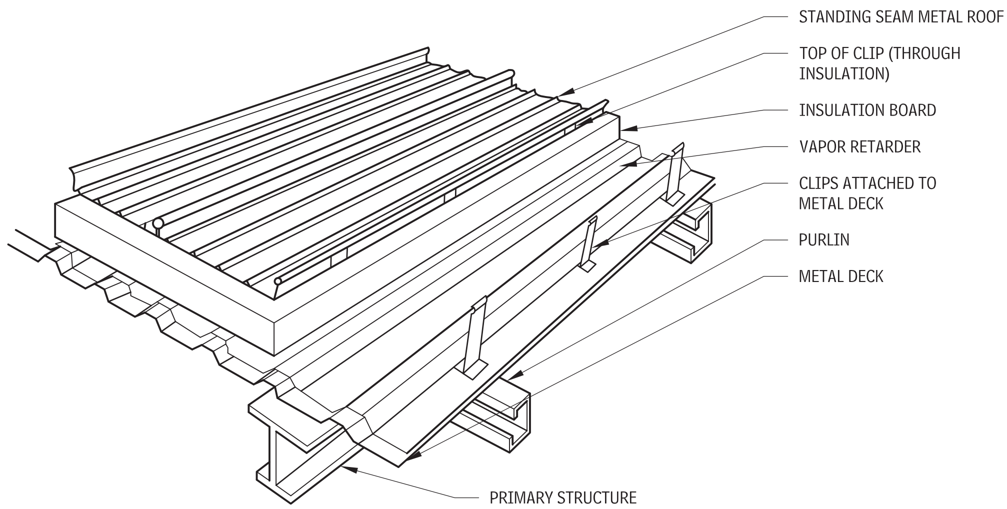
TERMINATION AT PIPE PENETRATIONS
11.432



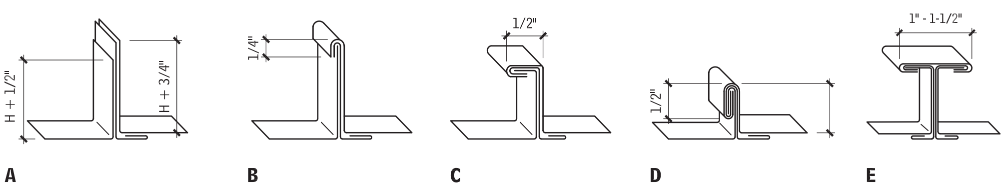
WATERSHED CONCEPT EXPANSION JOINT
11.433



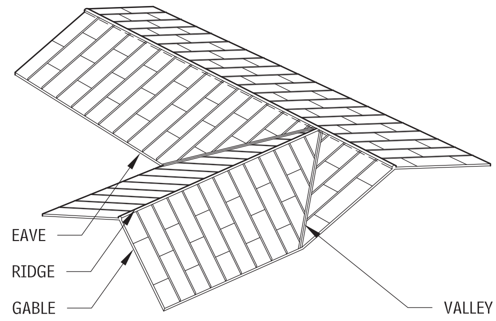
STRUCTURAL STANDING SEAM METAL ROOFING ON PURLINS
11.435



FIELD METHOD OF FORMING STANDING SEAM
11.436



STANDING SEAM METAL ROOF
11.434



METAL ROOFING

There are four types of metal roofing, in two major categories. The first category is the traditional metal roofing, which needs continuous structural deck support and is sometimes called architectural metal roofing. The second category is structural metal roofing, which is capable of spanning over open purlins. Structural metal roofing includes

- Standing seam
- Bermuda
- Batten seam
- Corrugated or formed sheet metal

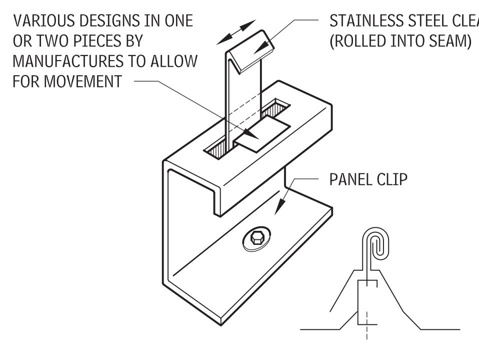
STANDING SEAM ROOFING

Standing seam roofing may be installed on slopes as gentle as 1/4 in 12. Because of the architectural appearance of the roof system, it is more commonly used on steeper roof slopes, allowing the panels to be seen as part of the overall design.

The spacing of seams may vary to suit the architectural style of the facility. Formed sheets (used with metal building systems) have seam spacing set by locations of punched holes in the structural framing members.

Two methods of forming a standing seam are used: the pan method and the roll method. In the pan method, the top, bottom, and sides of the individual sheets are preformed to allow locking together at each edge. Seams at the top and bottom of each sheet are called *transverse seams*. In the roll method, a series of long sheets are joined together at their ends with double flat-lock seams. These field-formed seams can be executed either manually or with a seaming machine (a wheeled electronic device that runs along the sheet joint forming the seam). In either method, cleats (spaced as recommended by the manufacturer) are formed into the standing seam. Seam terminations are usually soldered.

MOVABLE CLEAT
11.437



To allow for expansion and contraction movement in roof panels, some manufacturers set movable cleats into a stationary panel clip system, particularly for structural standing seam metal roofing. Note that the cleat must be anchored to a rigid substrate to limit rotation of the clip that constrains movement. If mounted over

Contributor:
Charles J. Parise, FAIA, FASTM, Smith, Hinchman & Grylls Associates, Inc., Detroit, Michigan.

insulation, provide a layer of plywood or OSB board or provide the manufacturer's large anchoring plate to distribute the load over a large area.

BERMUDA ROOF

The Bermuda roof may be used for roofs having a slope greater than 2-1/2 in 12. Wood framing must be provided as shown in Figure 11.439. Dimension ("D") and gauge of metal will depend on the size of sheet used.

Bermuda roof is applied beginning at the eave. The first pan is hooked over a continuous cleat. The upper portion of the first and each succeeding pan is attached, as shown in detail 2 of Figure 11.439. Cleats spaced on 8-in. centers are nailed to batten, as in portion A of detail 2. All cross seams are single-locked and soldered except at expansion joints. Cross seams should be staggered. Expansion joints should be used at least every 25 ft and formed as shown in detail 3 of Figure 11.439.

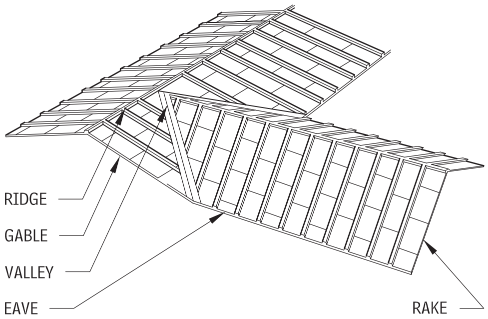
BATTEN SEAM ROOFING

Batten seam roofing may be applied on slopes of 3 in 12 or greater. If the surface to receive the roofing is other than wood, the battens should be bolted into place. All batten fasteners must be countersunk into battens.

The spacing of the wood battens may vary within reasonable limits to suit the architectural style and scale of the building, but the recommended maximum distance is 20 in. between battens. Care should be taken to space the battens in such a manner that waste of metal is held to a minimum.

Sheets are formed into pans with each side turned up 2-1/8 in. A 1/2-in. flange is turned toward the center of the pan. Pans are installed starting at the eave and are held in place with cleats spaced not over 12 in. o.c. Each pan is hooked to the one below it and cleated into place. After pans are in place, a cap is installed over the batten.

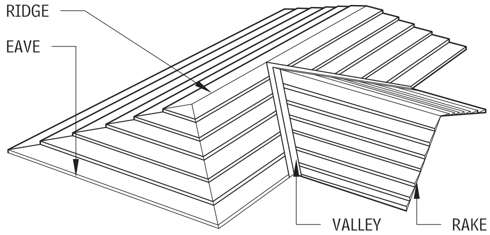
BATTEN SEAM METAL ROOF
11.438



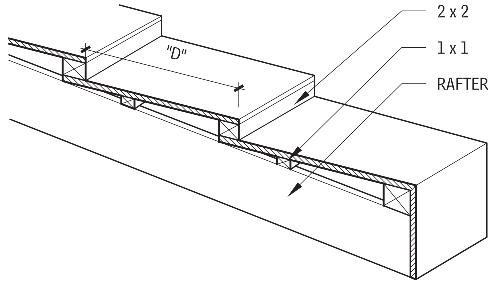
ROOF DETAILING

- Elevate base flashing and penetration flashing above any standing water by using tapered edge strips. This detail is not required by most manufacturers but is a small amount of additional dependability.
- Provide crickets behind any interruption to the downhill flow of water such as at curbs, rails, and rooftop-mounted equipment.
- Depress roof drains in large sumps approximately 3 to 4 ft. square and minimum 1-1/2 in. deep using tapered insulation to ensure that there is no standing water at drains. In cold climates the underside of the drain body should be insulated with spray foam or else cold rainwater could cause condensation. The rainwater conductor should also be insulated, at least for a length sufficient to allow warming of drain water.

BERMUDA-TYPE METAL ROOF
11.439



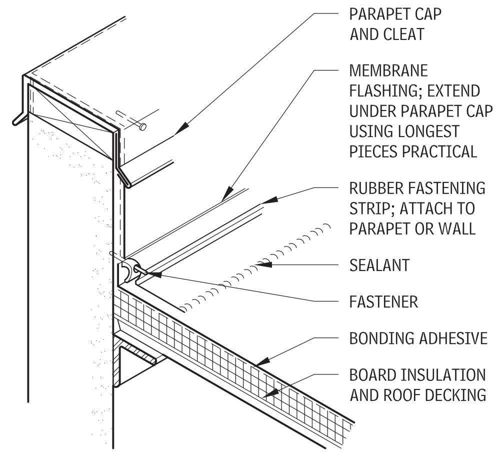
BERMUDA-TYPE METAL ROOF



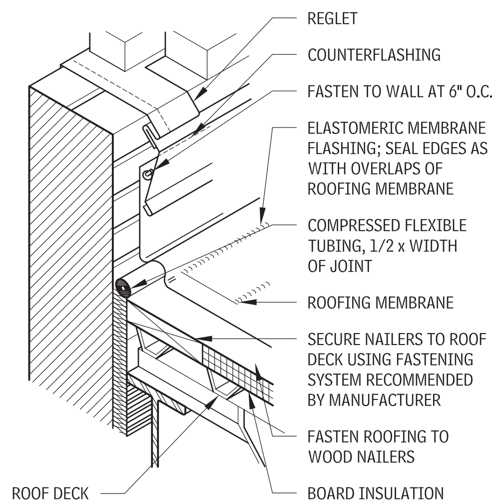
WOOD FRAMING

- Verify that roof decks and the adjacent parapet wall or penetrating element are supported together. If they are not, then the base flashing must be detailed to accommodate the anticipated movement.
- Heavy pieces of roof-mounted equipment may need to have curbs mounted directly on the structural frame of the opening or the flutes of the metal deck may need to be blocked full to prevent crushing.
- Base flashing should be carried up and across the top of parapets and curbs if possible to ensure that water does not get behind the base flashing and under the roofing. If the wall includes an air barrier or water-resistant drainage plane, then connect base flashing to membrane.
- Pitch pockets should be avoided. Detail penetrations through the roof using square or round shapes that are nearly perpendicular to the plane of the roof.
- Detail lightning protection systems to provide adequate anchorage of air terminals and support of cables without penetrating roof membrane. Air terminals and cable at perimeter should be mounted to the inside face of the parapet or on coping. Air terminals in the field should be adhered to precast concrete pavers. Cable running across the field of the roof should be supported on traffic walkways or pavers. Cable laying on bituminous roof membrane will eventually become embedded in the softened membrane.
- Detail for replacement of the roof membrane. The membrane will need to be topped or replaced several times over the life of the building. It should be possible to install a new membrane under counterflashing and copings by removing and replacing the sheet metal without damage.
- Joints and fasteners in sheet metal flashing are notoriously susceptible to leakage after expansion and contraction. Back-up sheet metal flashing with flexible membrane flashing.
- Expansion joints and area dividers should be detailed above the plane of the roof.
- Expansion joints should be specifically designed for the purpose and should have factory-fabricated intersections, tees, transitions, and intersections. Joints made in the field should be simple, straight butt joints.
- Expansion joints fabricated from roof membrane do not maintain continuity of the expansion joint as well as factory-fabricated systems.
- Roof expansion joints must transition without leaks into vertical expansion joints in parapets and walls.
- Expansion joints should be provided with a second line of defense, usually of a watertight vapor barrier membrane. Systems are available with secondary drains.
- Area dividers are similar to expansion joints but do extend through the building structure. Area dividers are recommended at 200 to 300 ft. centers, located at ells, tees, changes of deck span, and other similar conditions where movement will damage the roof membrane. Note that many roof membranes are flexible enough to not require area dividers but the underlying cover board and insulation are not flexible and allowing space for their thermal movement will prevent telegraphing of the substrate.
- Two primary sources for information regarding roof details is the *NRCA Roofing and Waterproofing Manual*, which covers most detail conditions for nearly every type of roofing system. NRCA details are nearly universally accepted. The second source for roofing details is the roof membrane manufacturer.
- Note, however, that the manufacturer will publish details that are selected to be less expensive, sometimes resulting in lesser performance. Pitch pockets are an excellent example. For more dependable details, review manufacturers' data for details required for an extended 20-year warranty and compare against NRCA.
- Note that details from NRCA or the manufacturer need to be customized to suit the specific project conditions.

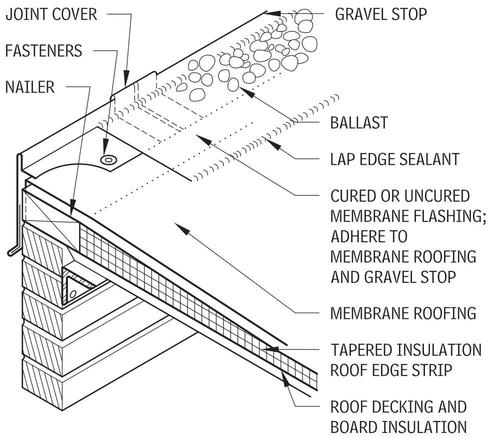
FULLY ADHERED ROOF AT PARAPET OR WALL
11.440



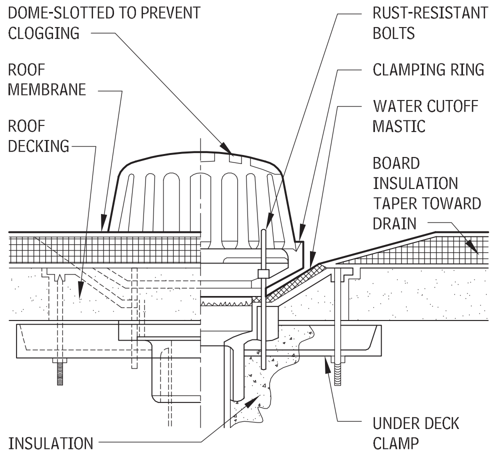
ROOF EDGE AT NONSUPPORTING WALL
11.441



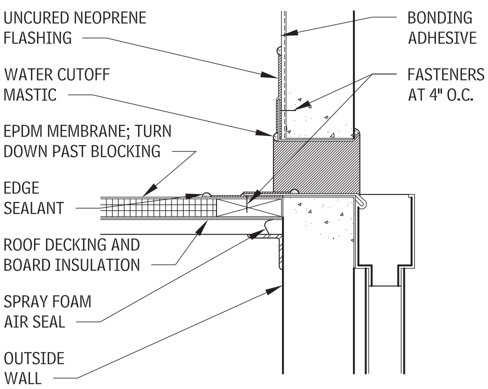
METAL ROOF EDGE
11.442



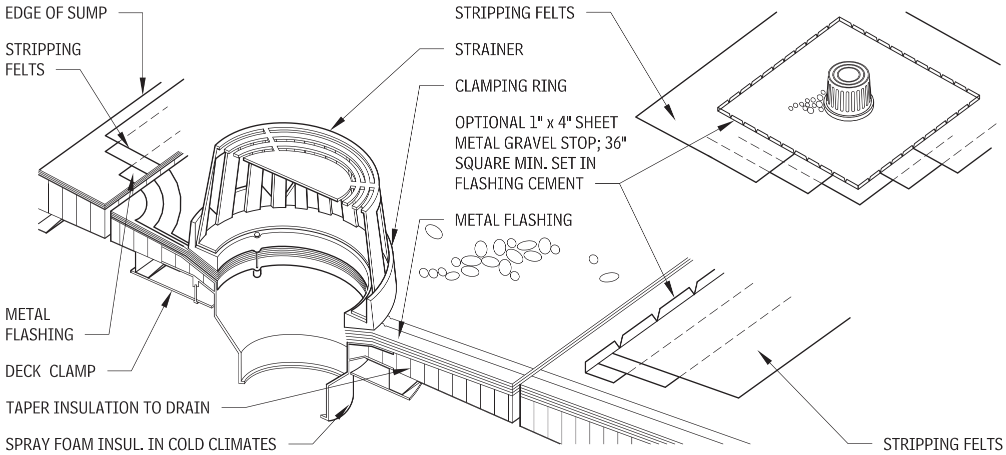
ROOF DRAIN
11.445



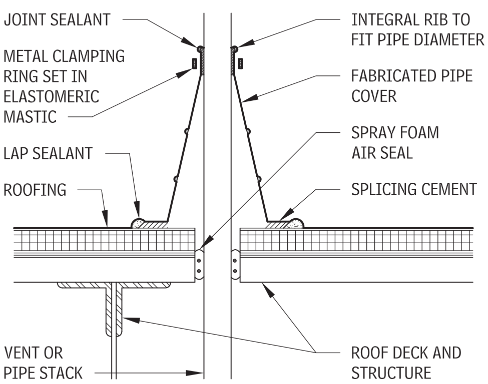
FULLY ADHERED ROOF SCUPPER
11.443



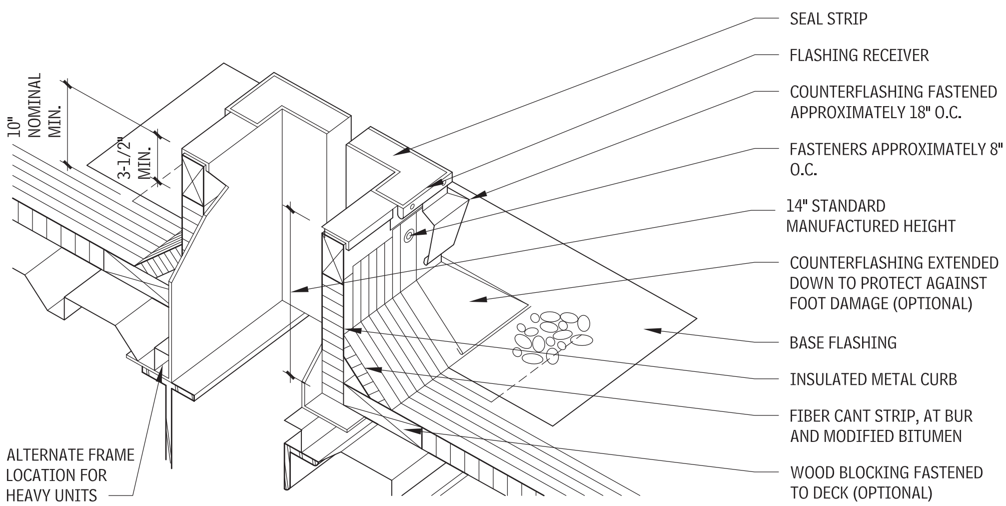
ROOF DRAIN
11.446



FABRICATED VENT PIPE FLASHING
11.444



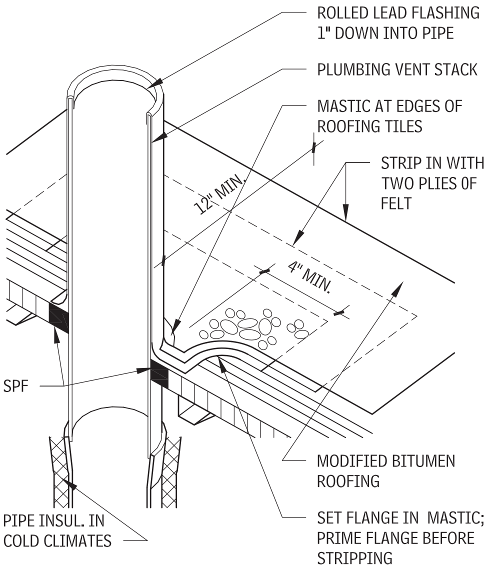
EQUIPMENT CURB
11.447



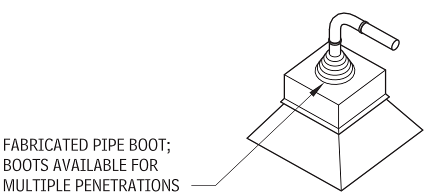
NOTES

11.446 a. Minimum 30 in. square, 2-1/2 to 4-lb lead or 16-oz. soft copper flashing set on finished roof felts set in mastic. Prime top surface before stripping.
b. Membrane plies, metal flashing, and flash-in plies extend under the clamping ring.
c. Stripping felts extend 4 in. and 6 in. beyond edge of flashing sheet, but not beyond edge of sump.
d. The use of metal deck sump pans is not recommended.

SINGLE PIPE PENETRATION
11.448

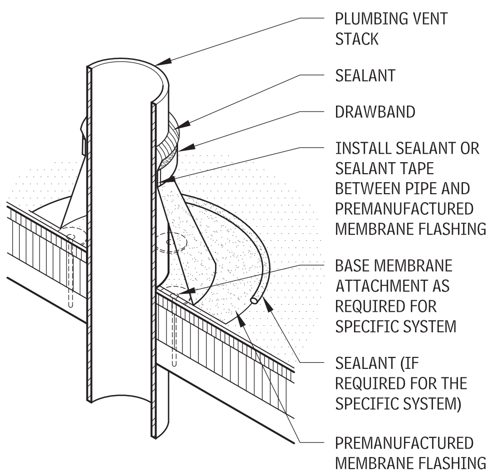


SITE-FABRICATED DETAIL



PREFABRICATED DETAIL

PIPE PENETRATION (THERMOPLASTIC MEMBRANE) BOOT
11.449

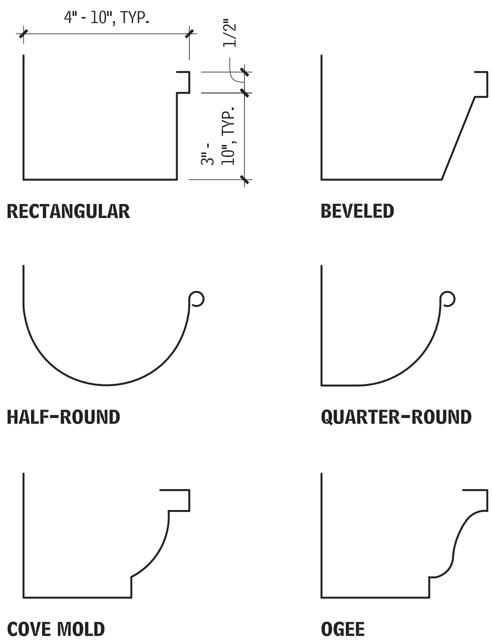


PREMANUFACTURED BOOT (PREFERRED)

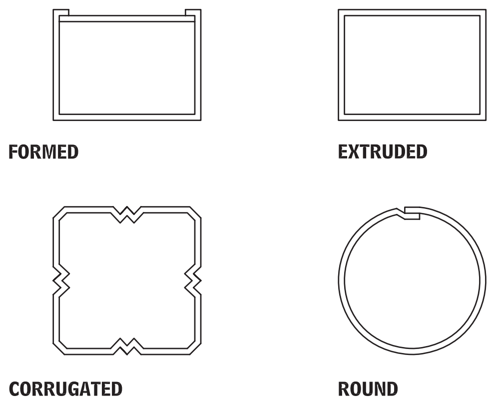
- Always keep the front of the gutter lower than the back.
- Use a minimum width of 4 in., except for canopies and small porches. The minimum ratio of depth to width should be 3 to 4.
- Many custom shapes for gutters and downspouts are available; consult manufacturers' design manuals.

For more information on gutter sizing and details, refer to the Sheet Metal and Air Conditioning Contractors National Association (SMACNA) Architectural Sheet Metal Manual. For more on rainfall intensity, sizing of gutter, and sizing and spacing of downspouts, contact the Sheet Metal and Air Conditioning Contractors National Association (SMACNA).

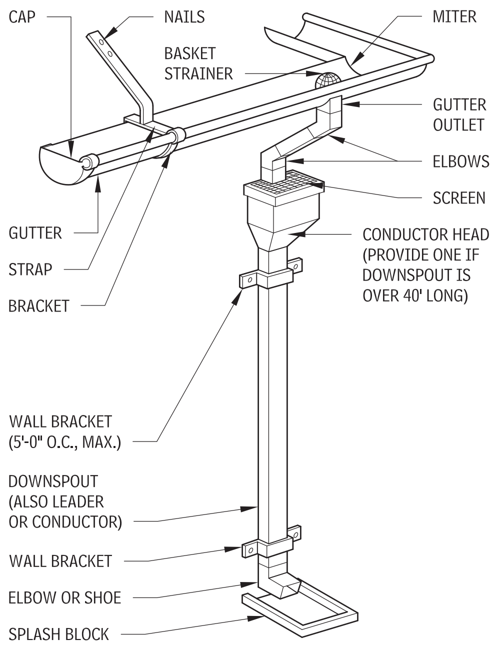
TYPICAL GUTTER SHAPES AND SIZES
11.450



TYPICAL DOWNSPOUT SHAPES AND SIZES
11.451



PARTS OF A GUTTER/DOWNSPOUT SYSTEM
11.452



FLASHING AND SHEET METAL

Flashing is a thin material inserted in an assembly to direct the flow of water to the exterior. Flashing has traditionally been sheet metal, but modern elastomeric sheets are gaining in usage. Sheet metal flashing has traditionally been prone to leakage at joints. The joints can be soldered or welded, but this is not recommended for long lengths. In long lengths, joints have traditionally been waterproofed with sealant, but the joint design is not ideal and is also prone to fail. Therefore, it is recommended to back up the sheet metal flashing with a layer of an elastomeric membrane.

GUTTERS AND DOWNSPOUTS

Important notes regarding the design of gutters and downspouts are as follows:

- Continuous gutters may be formed at the installation site with cold-forming equipment, thus eliminating joints in long runs of gutter.
- Gutters and downspouts are available in aluminum, galvanized steel, copper, and stainless steel. Consult manufacturers for custom materials.
- *Girth* is the width of the sheet metal from which a gutter is fabricated.
- Although all joining methods are applicable to most gutter shapes, lap joints are more commonly used. Seal all joints with mastic or by soldering. Lock, slip, or lap joints do not provide for expansion.
- Expansion joints should be used on all straight runs over 40 ft. In a 10-ft section of gutter that will undergo a 100° temperature change, linear expansion will follow these coefficients of expansion (CE) and movements: aluminum: CE, .00128, movement, .15 in.; copper: CE, .00093, movement, .11 in.; galvanized steel: CE, .0065, movement, .08 in.

FLAT ROOF DRAINAGE

The size and number of scuppers should be carefully determined to control ponding on roofs. Rectangular shapes convey more water (per inch of water depth on the roof) than round shapes. The performance of rectangular shapes approximates that of a broad-crested weir. Standard equations for channel flow are based on test models larger than typical roof scuppers. Downspout sizes normally are based on draining a given area of roof, but that flow rate may not pass through a scupper that has been sized to have a cross-sectional area equal to the downspout area.

The scupper sizing procedures are:

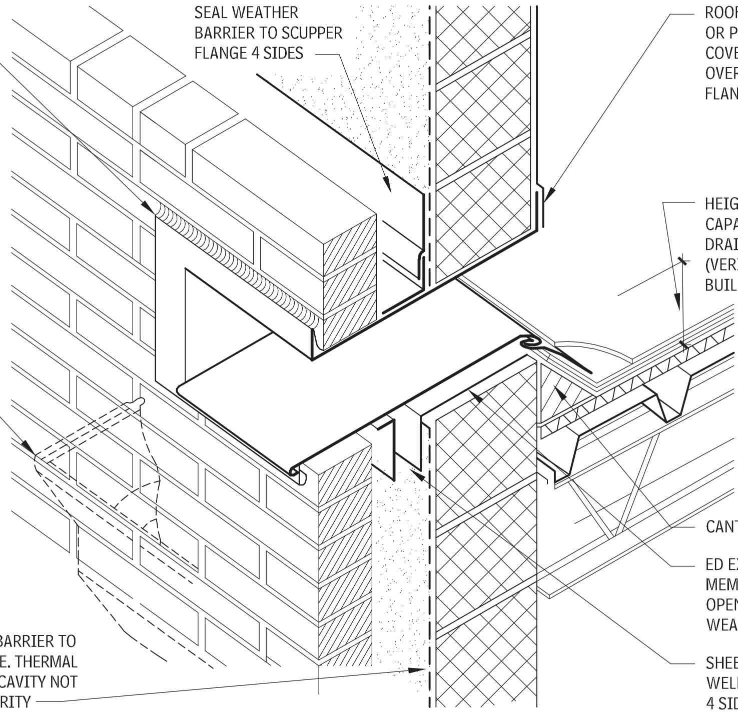
- Determine the head (H) in inches of water (typically 1 in. minimum by code) at a point 6 ft back from the scupper opening.
- Determine the roof drainage area in square feet (SF).
- Using rainfall intensity in inches per hour (IPH) from a rainfall data table, determine discharge capacity in gallons per minute (GPM). GPM = SF of roof area × IPH × 0.0104. The constant is 7.48 gallons per cubic foot divided by 12 in. per foot divided by 60 minutes per hour: GPM = (0.0104) IPH × SF.
- Using H and the GPM, find the aggregate scupper length (L) in the Scupper Capacity in GPM (Table 11.454).
- Select enough individual scuppers to satisfy the total GPM requirement and locate them proportionately.

NOTES

11.448 a. Sheet lead minimum of 2-1/2 lb./sq. ft.
b. Minimum clearance of 12 in. from cant strips and other curbs or pipes.
11.451 a. Formed and extruded downspout sizes are 3 by 4 to 6 by 6; round sizes are 3, 4, or 5 in. diameter. (Extruded downspouts are for heavy traffic.)
b. Generally, space downspouts a minimum of 20 ft and a maximum of 50 ft apart.
c. A downspout of 7 sq in. minimum should be used, except for canopies or small porches.
d. Corrugated shapes resist breakage due to freezing better than straight profiles.
e. Elbows are available in 45°, 60°, 75°, and 90° angles.

Contributor:
National Roofing Contractors Association, Rosemont, Illinois.

OVERFLOW SCUPPER DETAIL AT PARAPET WALL
11.453

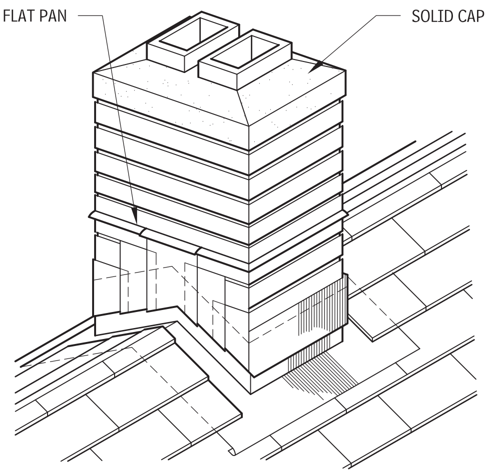


SCUPPER CAPACITY IN GPM*
11.454

HEAD (H) (IN.)	LENGTH (L) OF WEIR (IN.)									
	4	6	8	10	12	18	24	30	36	48
1	11.0	17.4	23.40	29.3	35.4	53.4	71.5	89.5	107.5	143.2
2	30.5	47.5	64.4	81.4	98.3	149.1	200.0	251.1	302.0	403.4
3	52.9	84.1	115.2	146.3	177.5	270.9	364.3	457.7	551.1	737.9
4	76.7	124.6	172.6	220.5	269.0	412.3	556.1	700.0	843.7	1133.3
6	123.3	211.4	299.4	387.5	475.5	739.7	1003.9	1268.1	1532.3	2060.7

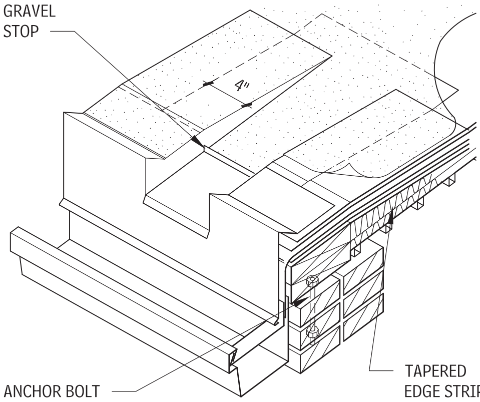
*Based on the Francis formula: Q = 3.33 (L - 0.2H) H1.5, in which
Q = Flow rate, cu ft. per second
L = Length of scupper opening, ft (should be 4 to 8 times H)
H = Head on scupper, ft (measured 6 ft back from opening)
GPM = 448.8 CFS

FLASHING AT RIDGE
11.457



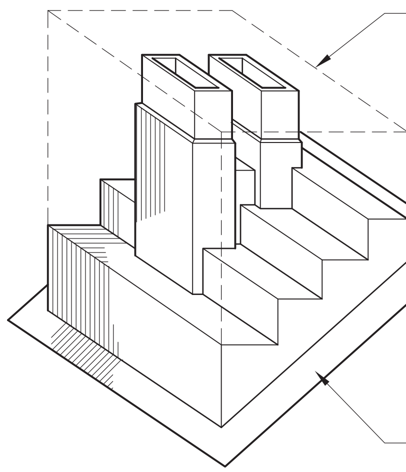
COMBINATION SCUPPER AND GUTTER
11.455

Scuppers that empty into a gutter may be integrated with a roof edge. The scuppers are soldered into a formed gravel-stop fascia system. The suggested maximum scupper interval is 10 ft. The front rim of the gutter must be 1 in. below the back edge, and it should be below the nailers used to elevate the roof edge. The drip edge on the fascia should lap the back edge of the gutter a minimum of 1 in. The gutter must be free to move behind the fascia.



CHIMNEY FLASHING

STEPPED-PAN THROUGH-WALL FLASHING
11.456



NOTES

11.453 a. Use overflow scuppers when roof is completely surrounded by parapets and drainage depends on scuppers or internal damage.
b. Precast concrete panels with scuppers do not need closure flanges on face; all penetrations should be seated.
11.456 Recommended for chimneys built of stone, rubble, ashlar, and any porous material.

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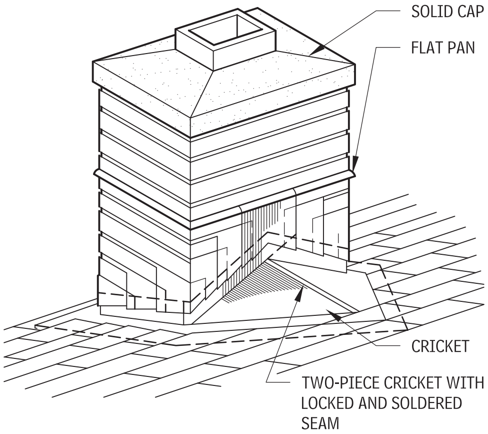
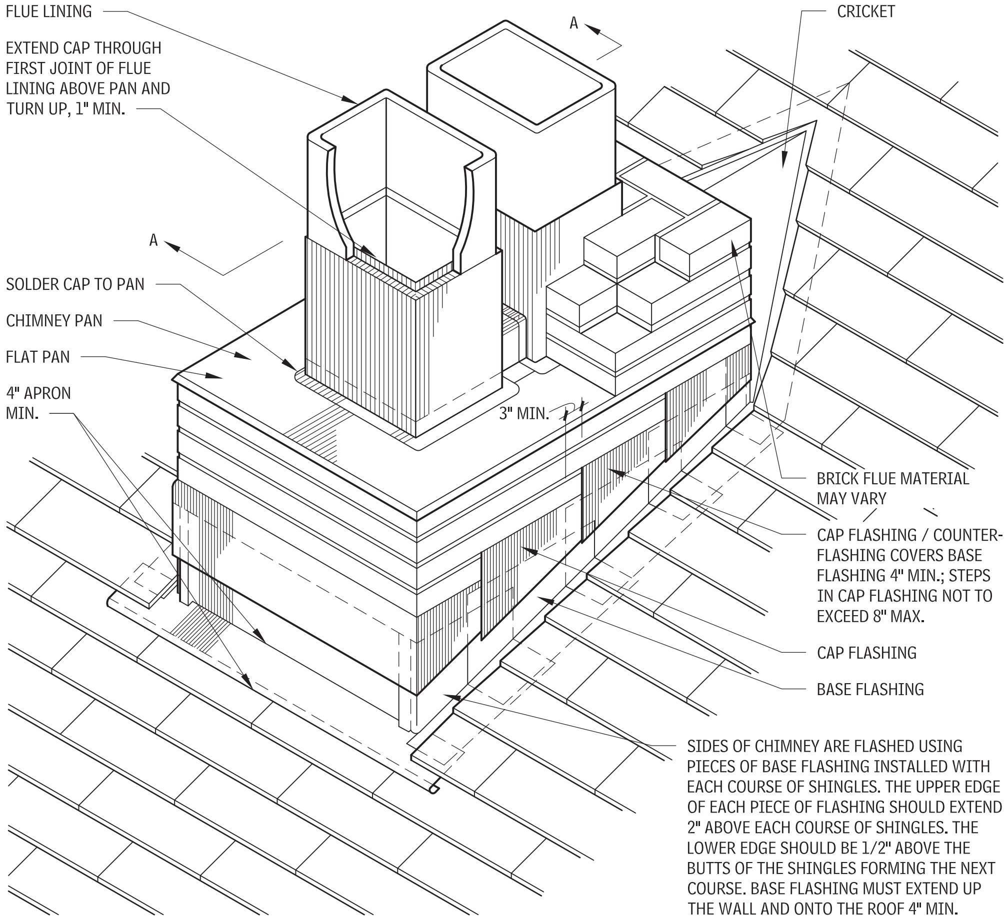
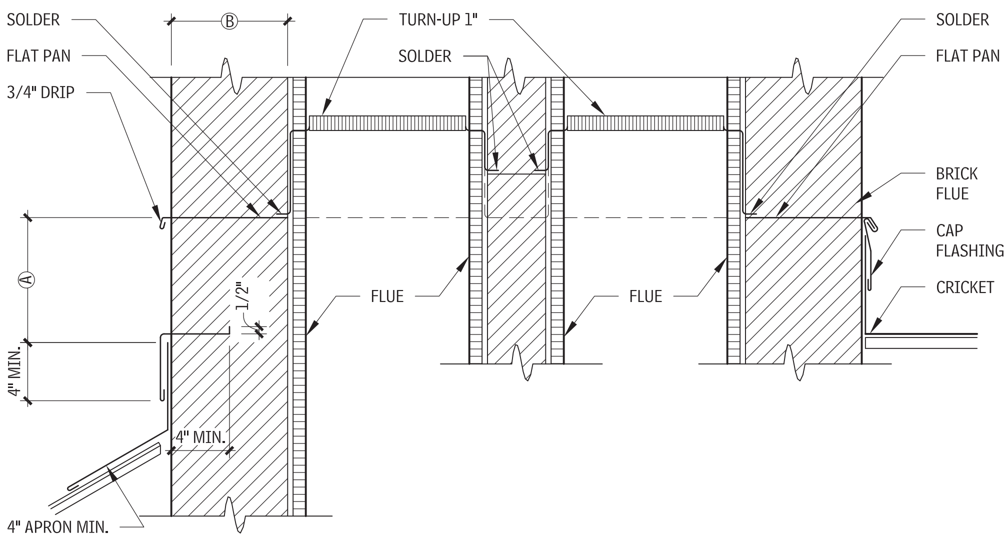
FLASHING WITH CRICKET
11.458



FLAT PAN THROUGH-WALL FLASHING
11.459





SECTION A–A

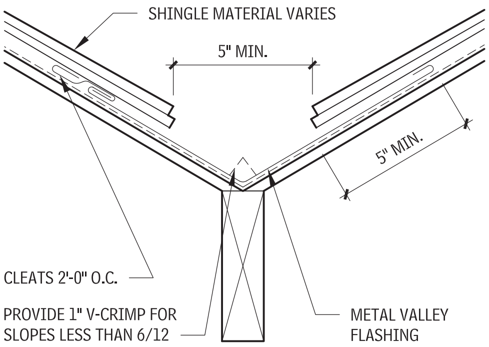
CHIMNEY CRICKETS

Chimneys shall be provided with crickets when the dimension parallel to the ridgeline is greater than 30 inches and does not intersect the ridgeline. Cricket heights vary from 1/2 of width (for 12:12 roof slope) to 1/6 of width (for 4:12 roof slope).

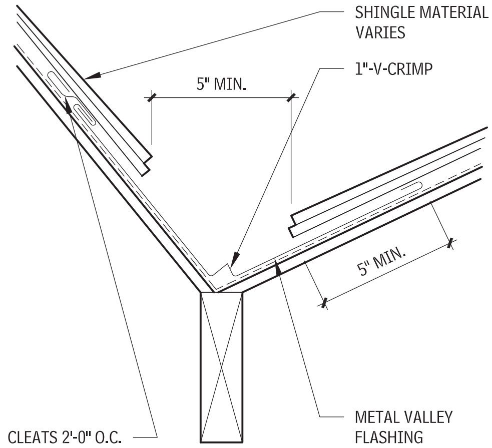
NOTE

11.459 A weather barrier of self-sealing peel-and-stick modified bituminous membrane should be provided for approximately 36 in. around chimney and turned up approximately 6 in. on the chimney and under sheet metal flashing.

OPEN VALLEY FLASHING
11.460

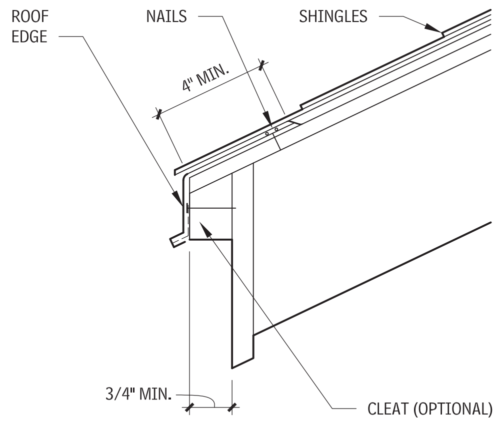


EQUAL SLOPES

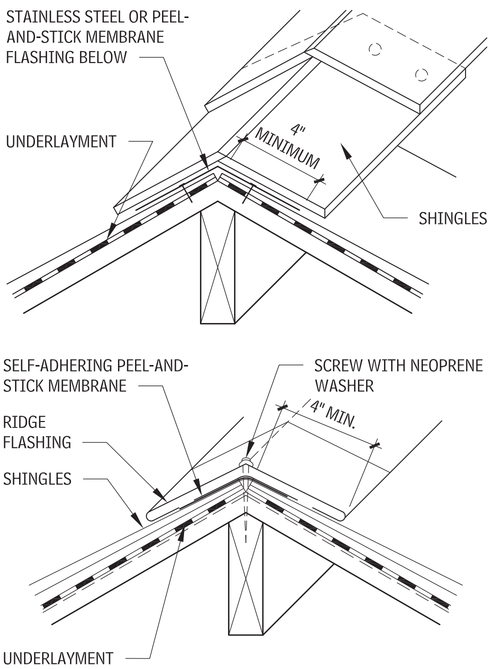


UNEQUAL SLOPES

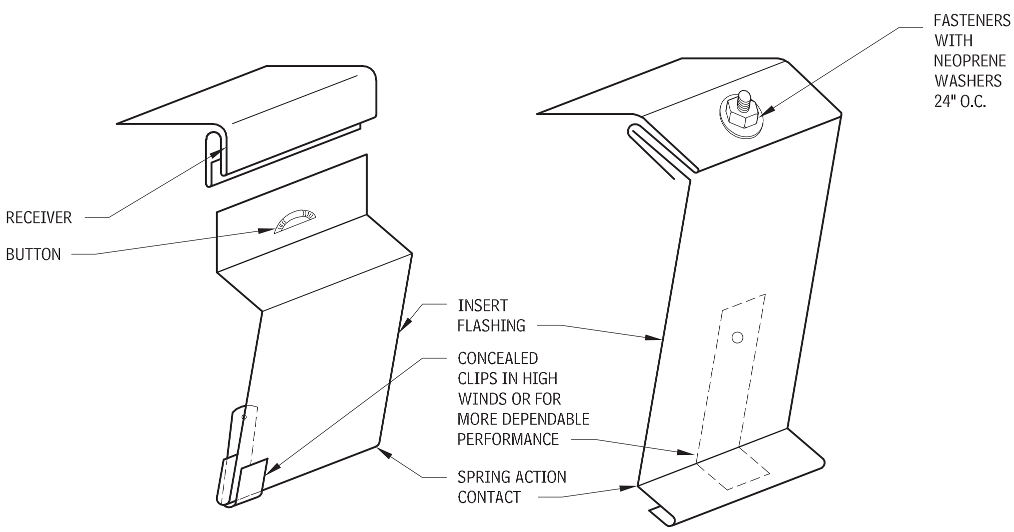
ROOF EDGE FLASHING
11.462



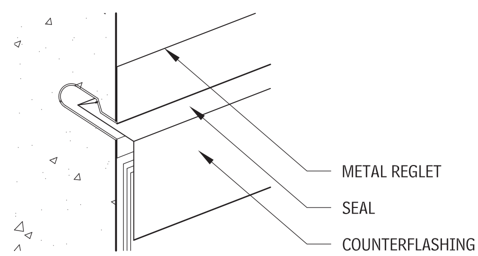
CONCEALED AND EXPOSED RIDGE FLASHING
11.461



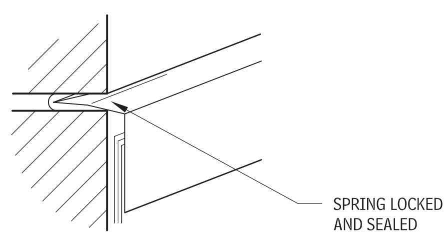
TWO-PIECE COUNTERFLASHING
11.463



INSERT FLASHING DETAIL
11.464



SNAP-IN



SPRING LOCKED

BASE AND COUNTERFLASHING ASSEMBLIES

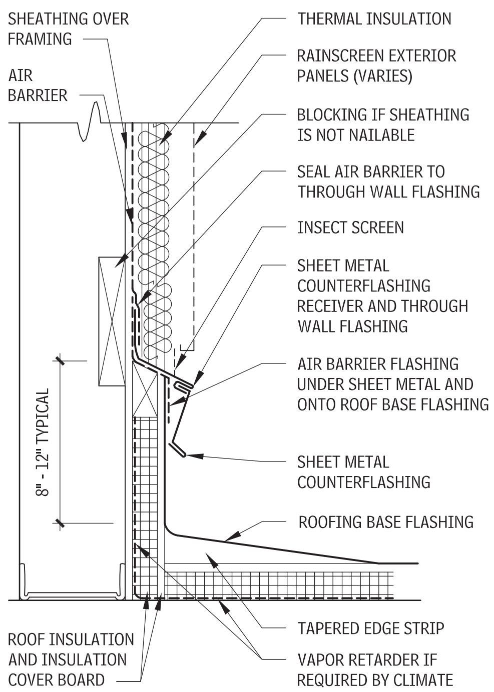
The intersection of the roof and a wall or other vertical surface creates an area of special concern. The changes of plane and multiple materials at an area of drifting snow and large amounts of water make this detail particularly problematic. To address these issues, follow these guidelines:

- Detail the transition from roof membrane to base flashing in accordance with SMACNA and manufacturer's instructions.
- Elevate the base flashing detail out of most standing water by providing a continuous tapered edge strip.
- Even though counterflashing is designed to protect against water intrusion by shedding running water, it is still recommended, to seal the top of base flashing to protect against water that gets under counterflashing and to serve as protection from drifted snow.
- Use two-piece counterflashing, to allow for easier sequencing of construction and future repair or replacement of roof membrane. This is particularly important, as the roof membrane has a life span much lower than that of the wall assembly.
- Back up all sheet metal flashing with a layer of flexible membrane or self-adhering peel-and-stick membrane.
- When the roof deck is supported separately from the adjacent wall assembly, create a joint between the two, to allow for the anticipated differential movement.
- If possible, avoid steps in elevation of counterflashing. Locate counterflashing at a high spot on the roof, and hold elevation. At doors to the roof, detail a step up and over curb with the door threshold at the elevation of the counterflashing receiver.

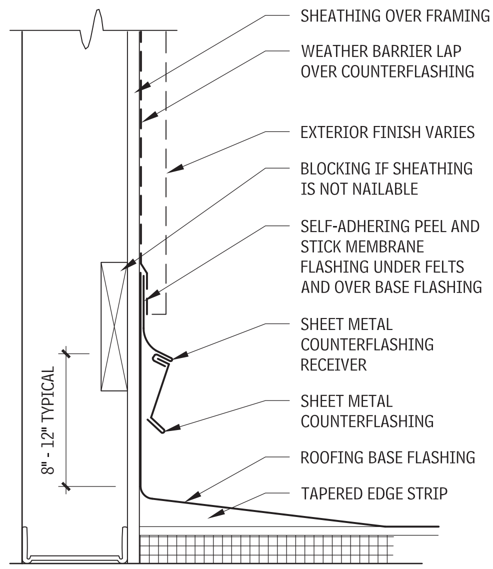
NOTE

11.462 It is typical to provide an approximately 36-in.-wide strip of self-adhering peel-and-stick membrane flashing at all detail areas, shingled with felt weather barrier.

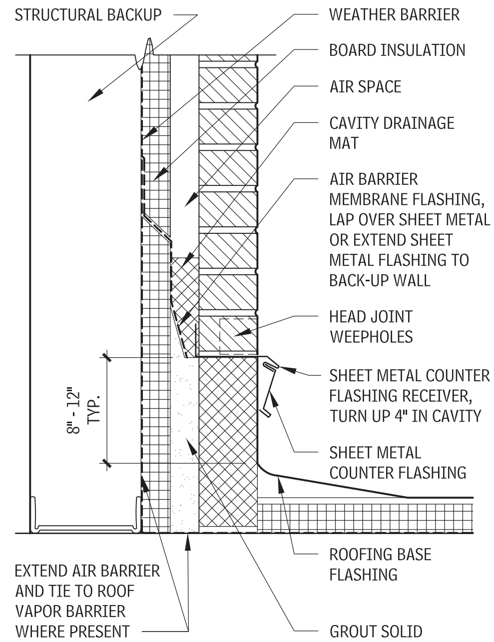
BASE AND COUNTERFLASHING AT RAINSCREEN WALL
11.465



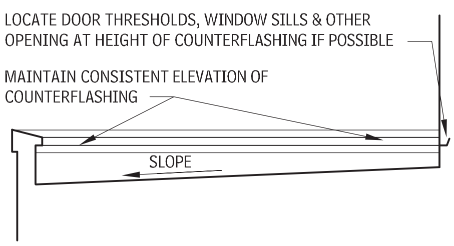
BASE AND COUNTERFLASHING AT FRAME WALL
11.466



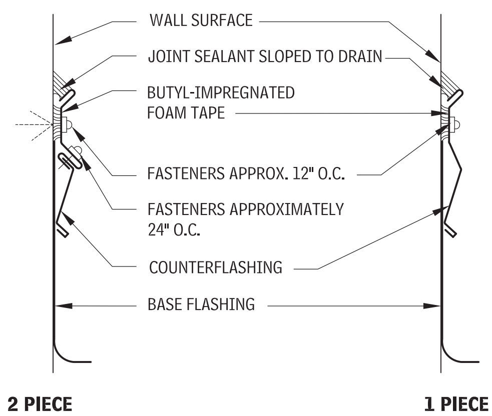
BASE AND COUNTERFLASHING AT BRICK VENEER
11.467



COUNTERFLASHING DIAGRAM
11.468

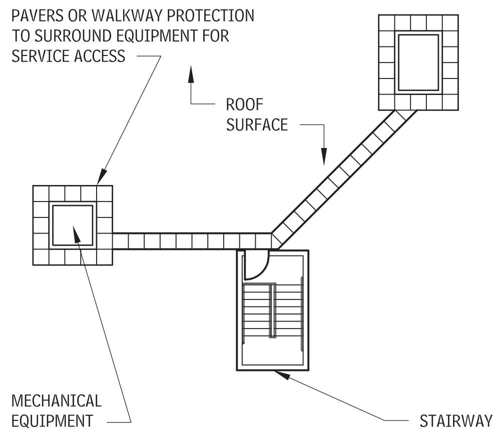


SURFACE-MOUNTED COUNTERFLASHING
11.469

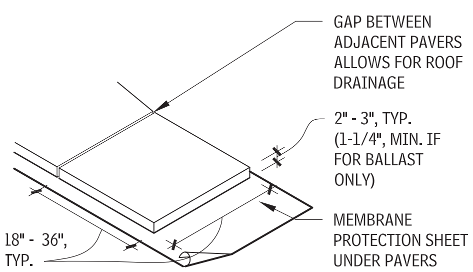


OTHER ROOFING DETAILS

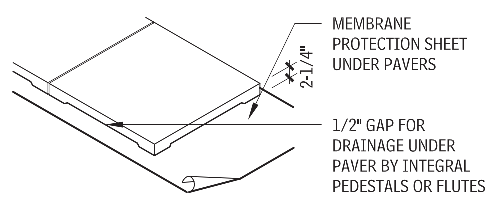
SERVICE WALKWAYS ON ROOFS
11.470



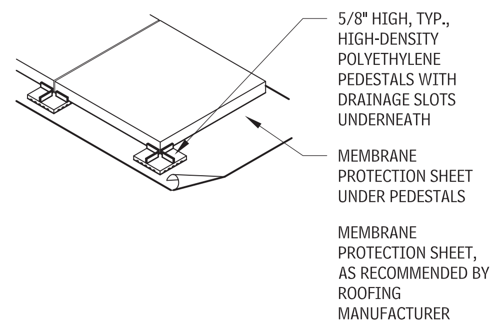
BALLAST PAVERS
11.471



TYPICAL PAVER



PAVER WITH INTEGRAL PEDESTAL



PAVER ON SUPPORT PEDESTALS

NOTES

11.469 Not for walls with internal drainage plain.

11.470 Roof pavers provide a stable walking service on any flat roof surface and protect the roof membrane from wear and tear. Most membrane manufacturers also provide walkway protection mats or rolls as part of their roofing assemblies. Service walkways should follow the most direct route to equipment to avoid shortcuts by maintenance personnel. Walkways may be required to maintain the roof warranty. Coordinate required access with equipment.

11.471 Ballast pavers are typically made from precast concrete with a nonskid texture on the surface. Use membrane protection sheet as recommended by roofing manufacturer.

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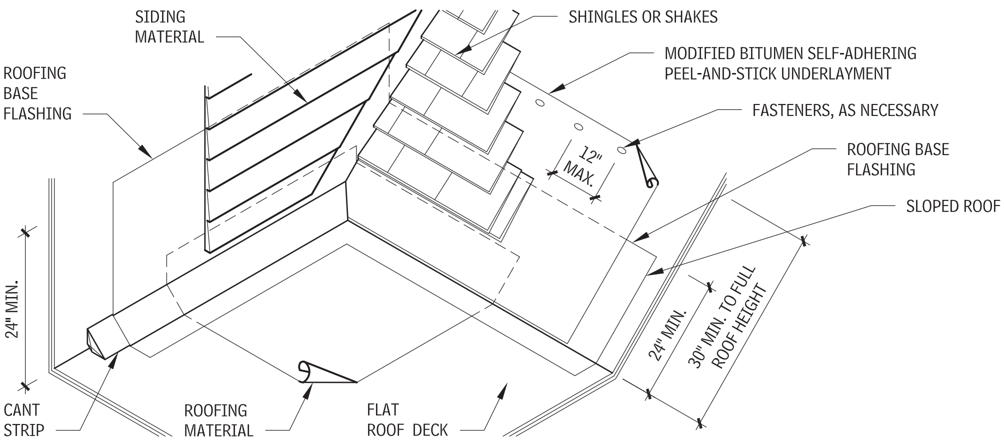
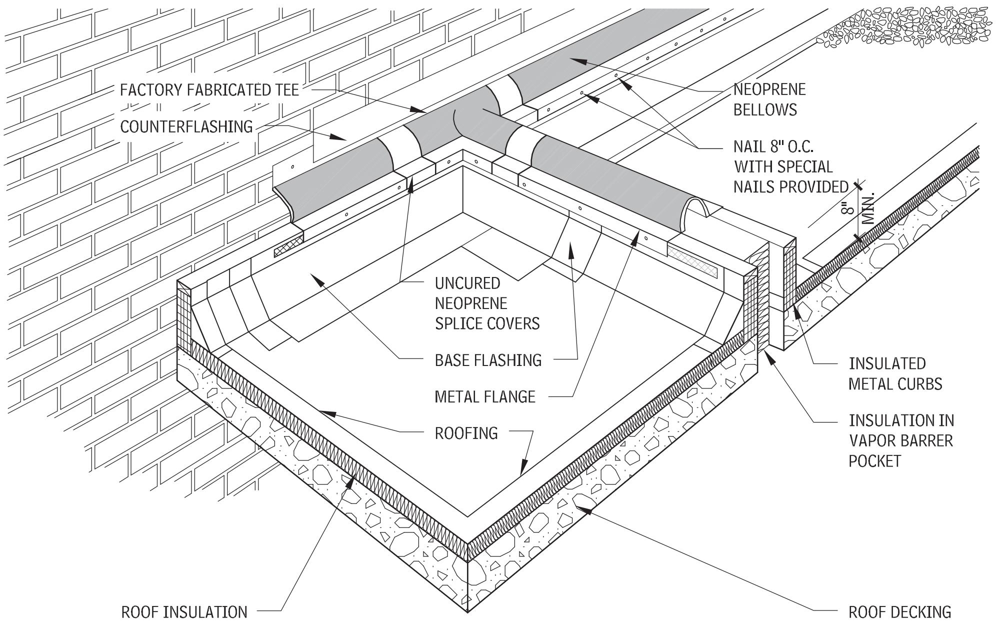
WATERPROOFING AT ROOF TRANSITIONS
11.472



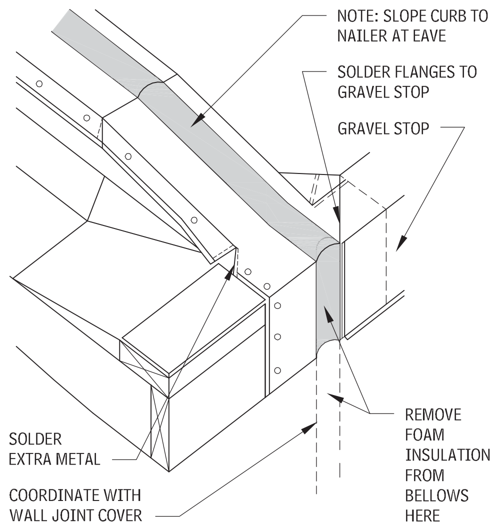
ROOF AND PARAPET EXPANSION JOINTS

- Where building expansion joints occur, they must extend through the roof assembly. Maintaining weathertightness, while allowing movement, especially in low slope roofing is difficult. It is recommended that the expansion joint include a redundant inner waterproof membrane. Some manufacturers provide the inner layer with outlets to be piped to drains.
- It is best to elevate the expansion joint assembly with insulated metal curbs above the line of the roof membrane.
- Expansion joint assemblies with shop drawings and factory-fabricated intersections, transitions, and other unusual details provide higher quality than those fabricated on-site.
- Elastomeric bellows systems are functional and relatively inexpensive. Shop- or factory-fabricated metal cover assemblies are more resistant to physical abuse.

CURB FLANGE EXPANSION JOINT COVER AT WALL (PREFERRED)
11.473



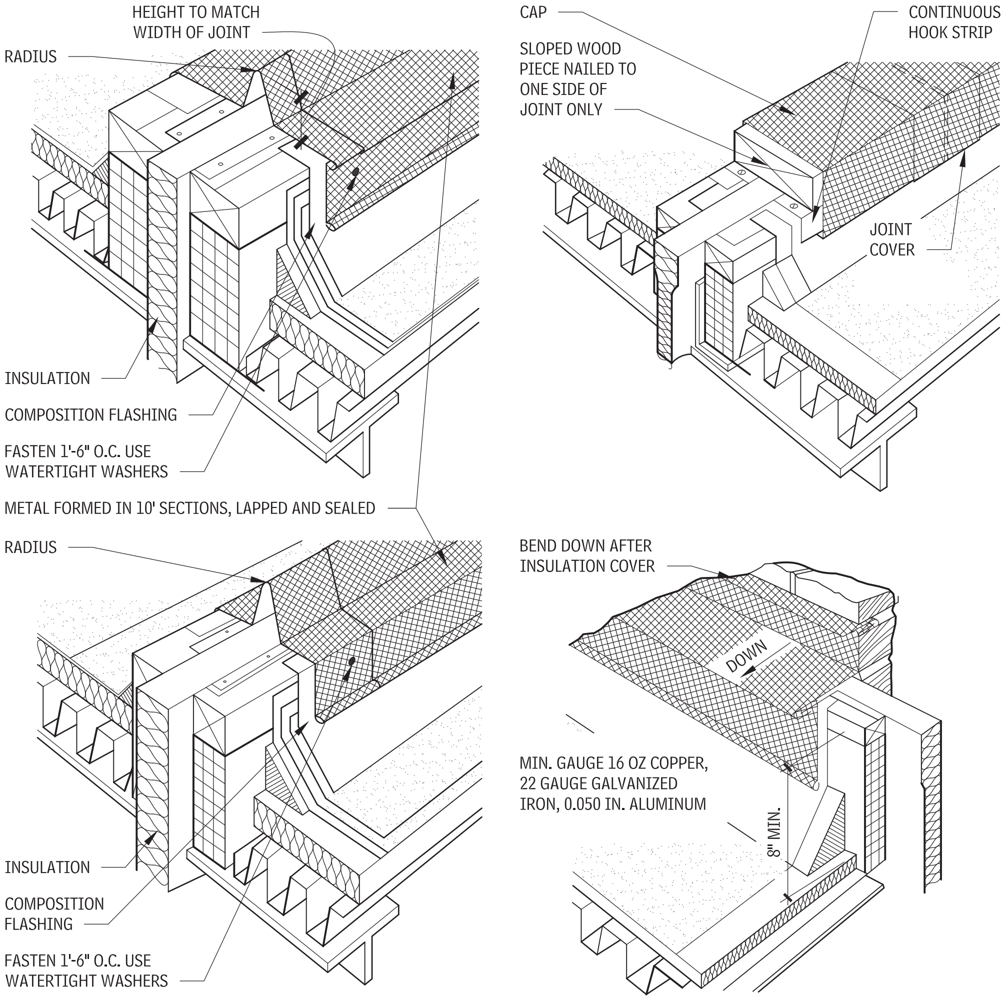
CURB FLANGE AT GRAVEL STOP
11.474



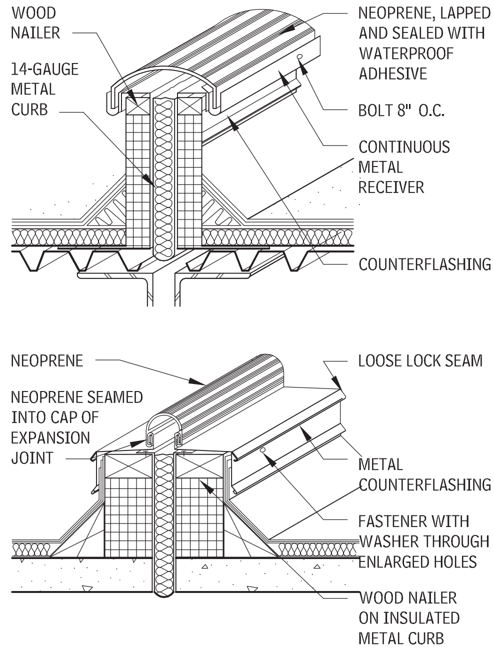
NOTES

11.472 a. Peel-and-stick modified bituminous sheets used to provide self-sealing around fastener.
b. Height of flashing and waterproof sheet depends on local snow probabilities and codes and on the roof slope.

METAL ROOF EXPANSION JOINT ASSEMBLIES
11.475

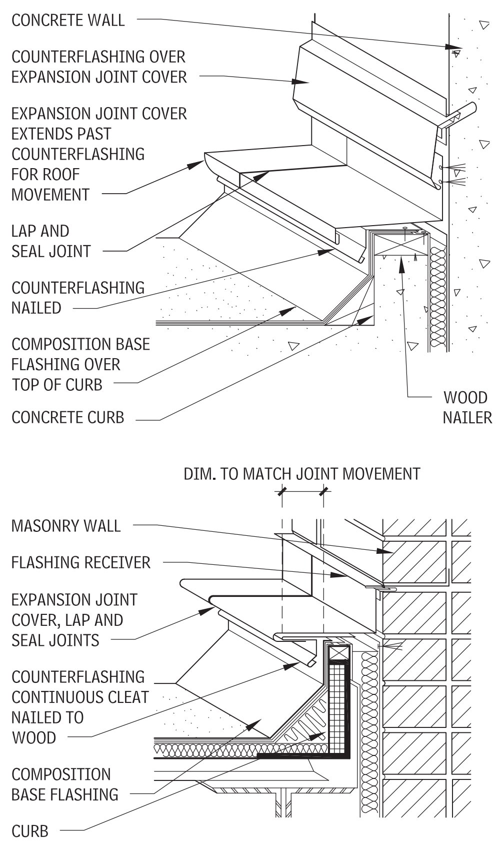


NEOPRENE EXPANSION JOINT ASSEMBLIES
11.476



NEOPRENE COVERS

METAL ROOF TO WALL EXPANSION JOINT ASSEMBLIES
11.477



NOTES

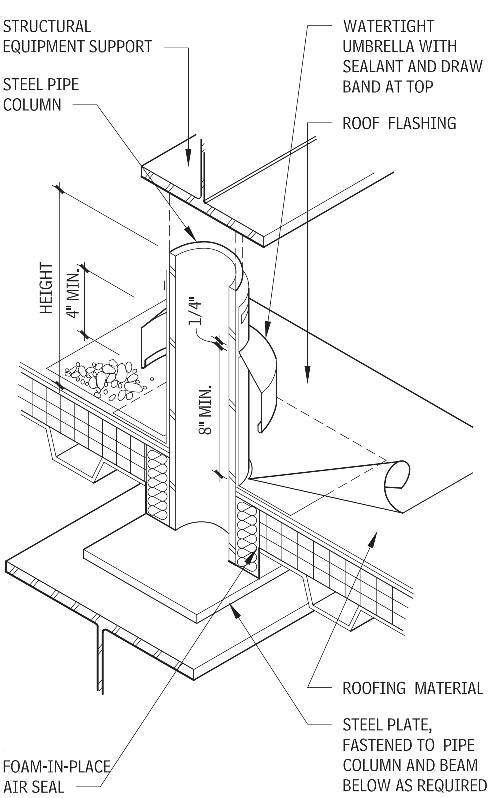
11.475 The minimum recommended gauge for the expansion joint shown is 24-gauge stainless steel, 16-oz. copper, 22-gauge galvanized steel, or 0.050-in. aluminum.
11.477 Minimum recommended gauge for the expansion joint shown is 24-gauge stainless steel, 16-oz. copper, 22-gauge galvanized steel, or 0.050-in. aluminum.

EQUIPMENT SUPPORTS

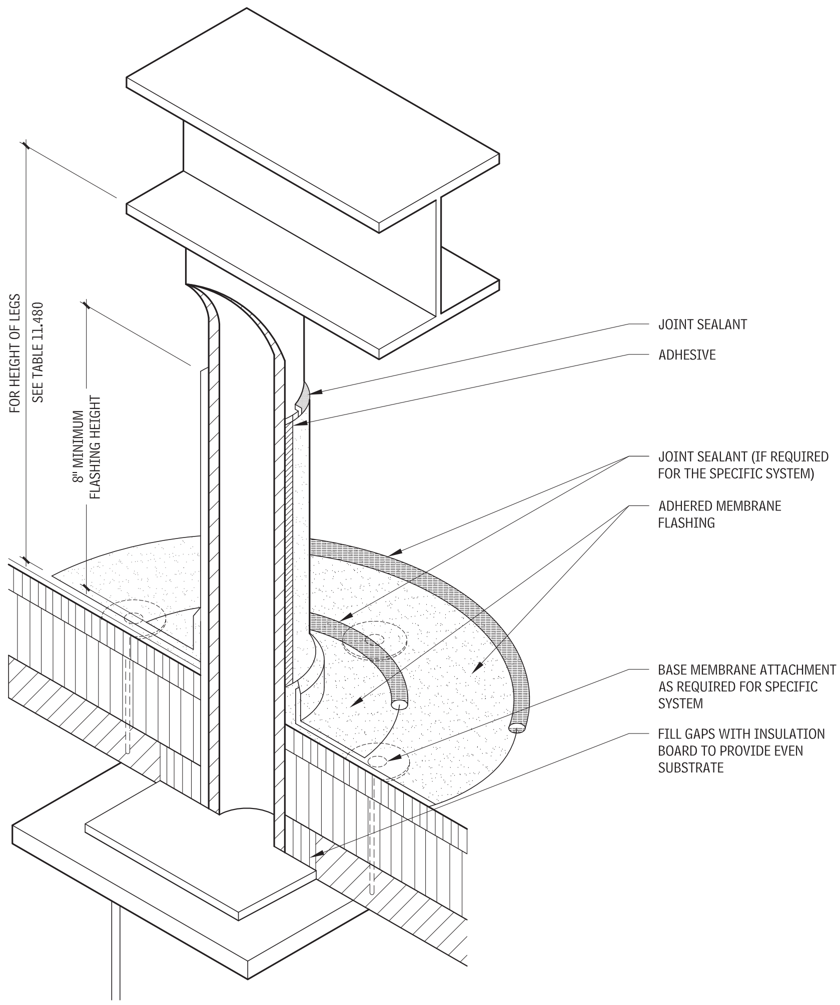
Low slope roofs provide inexpensive space to locate building mechanical equipment and other systems. The equipment must be supported in a manner that maintains a watertight roof and allows maintenance of both the equipment itself and the roof membrane. Once equipment is located on the roof, it frequently requires screening, which then results in more supports. Equipment supports include:

- *Curbs support equipment:* These are inexpensive and keep the equipment low. The space within the curb often has opening for ducts or forms a plenum. It may be difficult to isolate the sound of the equipment when a curb is used.
- *Rails:* These are essentially linear curbs that allow water to continue to drains under large equipment or long runs of ducts or pipes.
- *Dunnage:* This is a grid of structural steel elevated above the roof on columns that provides a platform for the equipment. Dunnage is a good choice for large amounts of equipment and when acoustic isolation is desired.

COLUMN EQUIPMENT SUPPORT
11.478



EQUIPMENT SUPPORT LEG DETAIL
11.479



PIPE COLUMN HEIGHT
11.480

EQUIPMENT WIDTH (IN.)	COLUMN HEIGHT (IN.)
Up to 24	14
25 to 36	18
37 to 48	24
49 to 60	30
61 and wider	48

NOTES

11.478 a. This detail can be adapted for other uses, such as sign supports.
b. Many roofing manufacturers offer fabricated flashing pieces or permit the use of materials other than those shown here for flashing, though the proprietary designs vary; consult the manufacturers.
c. For access to areas under equipment, vary pipe column height as shown in Figure 11.480.

ROOF OPENINGS

Roof openings such as skylights, scuttles, and vents must be detailed with care, because they will be exposed to the same external factors as the roof assembly itself. These factors include wind pressure, both positive and negative, which acts on the framing and/or glazing; rainwater penetration; live loads from snow and ice; dynamic loads from impact; daily cycles of thermal expansion and contraction; drainage of water and melting snow; and abuse from maintenance personnel. In addition, measures must be specified to keep people from falling through these openings.

SKYLIGHTS

Skylights provide daylight to interior spaces and can reduce dependence on electrical lighting. In passive solar designs, skylights are used to admit direct solar radiation, enhancing space heating, and when vented properly, to induce convective airflow, reducing cooling loads through natural ventilation.

Skylights are available as units (which are shipped to the site ready to be installed) or as framed assemblies of stock components (which arrive fabricated for site assembly). Both fixed and hinged skylights are manufactured. The hinged variety can be opened manually or by remote control devices for venting. Frames are typically mounted on a built-up fabricated or site-built curb, with integral counterflashing; they can be assembled with or without insulation.

Self-flashing skylight units are available with or without curbs. Those without curbs are intended only for pitched roof assemblies and are not recommended for roof assemblies with finished spaces below.

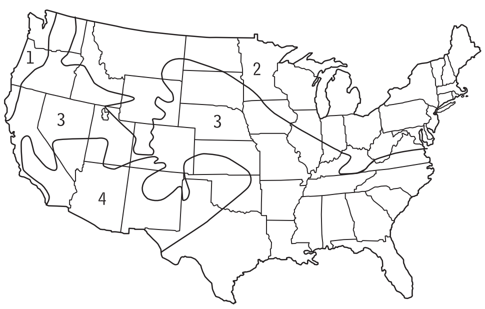
Framed skylight assemblies are custom-designed by manufacturers to meet the necessary wind, roof, and dead loads of the assembly itself. When a skylight is pitched beyond a certain angle, it must be designed to resist environmental factors, as does a curtain-wall assembly. Roof drainage for rainwater and stormwater can limit skylight dimensions. Many skylights are face-sealed as a barrier system, but some are available as a pressure-equalized rainscreen system. Condensate gutters are needed in the body of the skylight assembly and around its perimeter. Gutters should be designed to evaporate collected water or be drained to the building plumbing system. Condensate drains through the skylight curb, common to many systems, violates the air barrier, resulting in energy losses and possible condensation.

Finishes for aluminum frame components are available as mill finish, clear anodized, duranodic bronze or black, acrylic enamel, and fluorocarbon.

In determining the desired form and size of the skylight unit/assembly, consideration should be given to:

- Environmental conditions, including orientation and winter and summer solar penetration angles at the site
- Prevailing wind direction and patterns
- Precipitation quantity and patterns
- Adjacent topography and landscaping (shade trees, etc.)
- Coordination with the HVAC system
- Use of shading, screening, or light reflecting/bouncing devices
- Views desired relative to view obstructions (streetlights)

PERCENTAGE OF ROOF AREA RECOMMENDED FOR SKYLIGHTING
11.481



LIGHT ZONE	LIGHT DESIGN LEVELS (FC)		
	30	60	120
1	3.3	5.2	13.3
2	2.8	4.3	10.8
3	1.8	3.2	6.9
4	1.5	2.8	4.0

FRAMING, GLAZING, AND GASKETS

The heart of a well-designed skylight lies in the detailing of frames, glazing, and sealant systems. The thickness, size, and geometric profile of all glass and acrylic glazing materials should be carefully selected for compliance with building codes and manufacturers' recommendations. The following glazing materials are considered resistant to impact and breakage and are generally approved by codes (listed in descending order of cost):

- Formed acrylic with mar-resistant finish
- Formed acrylic
- Polycarbonates
- Flat acrylic
- Laminated glass
- Insulated glass units

Insulated glass units have a laminated glass inner light and tempered or heat-strengthened outer light.

Framed skylights require somewhat greater mullion widths when glazed with acrylics in order to accommodate the expansion and contraction characteristics of plastics. For economy, tinted acrylics should be limited to 1/4-in. thickness. A combination fiberglass sheet and aluminum frame system with high insulating value and good light diffusion can be a cost-effective alternative. Domed acrylic glazing is almost self-cleaning, as the sloped shapes facilitate rain-washing of the surface.

Gaskets are especially subject to degradation from solar ultraviolet rays. Excessive expansion and contraction of acrylic glazing can cause "rolling" of the gasket between metal framing. Small valleys created at the bottom of the sloped glazing and the horizontal glazing cap will hold water, which increases the chance of gasket breakdown and subsequent water infiltration.

SHADING AND GLARE CONTROL

Skylights can introduce too much uncontrolled light, especially in areas where video screens and computers will be used. Skylights also can allow excessive heat build-up. To mitigate these issues:

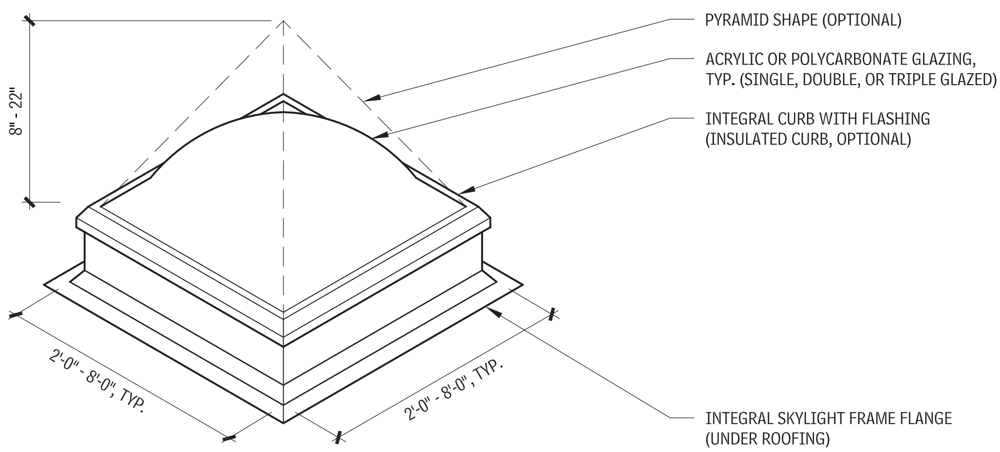
- Select extent of skylight, glazing, and shading devices to balance the gains of daylighting against heat gain.
- Select glass with low-E coatings, tint, reflective coatings, frits, or combinations to lower the solar heat gain coefficient.
- Approximately 40 to 50 percent visible light transmission in a skylight will appear as bright as vertical glazing with 60 to 70 percent visible light transmission.
- Shading devices such as louvers, grilles, and shades should be added to control direct sun. Movable systems, particularly if fully automated to track the sun, are more effective than fixed systems, for controlling glare while maximizing daylighting.

SECURITY AND SAFETY

Frames or screens to protect glazing from impact, fire, or forced entry may be designed into the skylight assembly. To avoid forced entry, a framed skylight should include deterrents to disassembling the framing, removing the snap-on cover, and melting the glazing (acrylics can easily be burned with a torch). Metal security screens may be required.

UNIT SKYLIGHTS

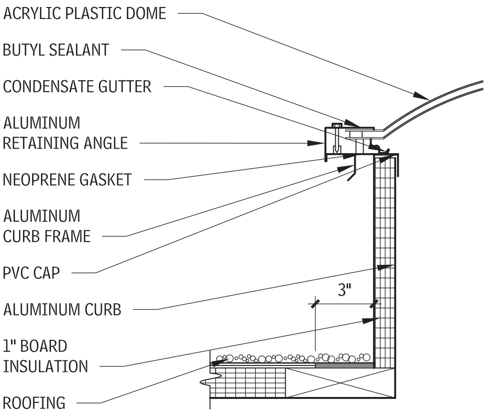
DOME UNIT SKYLIGHT—FLAT ROOF
11.482



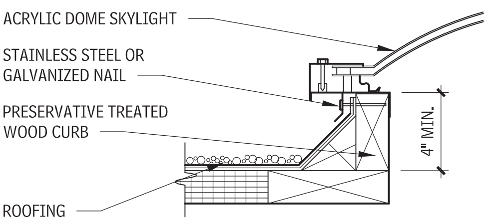
NOTE

11.482 Glazing is typically clear, tinted transparent, or white translucent.

UNIT SKYLIGHT SECTION
11.483

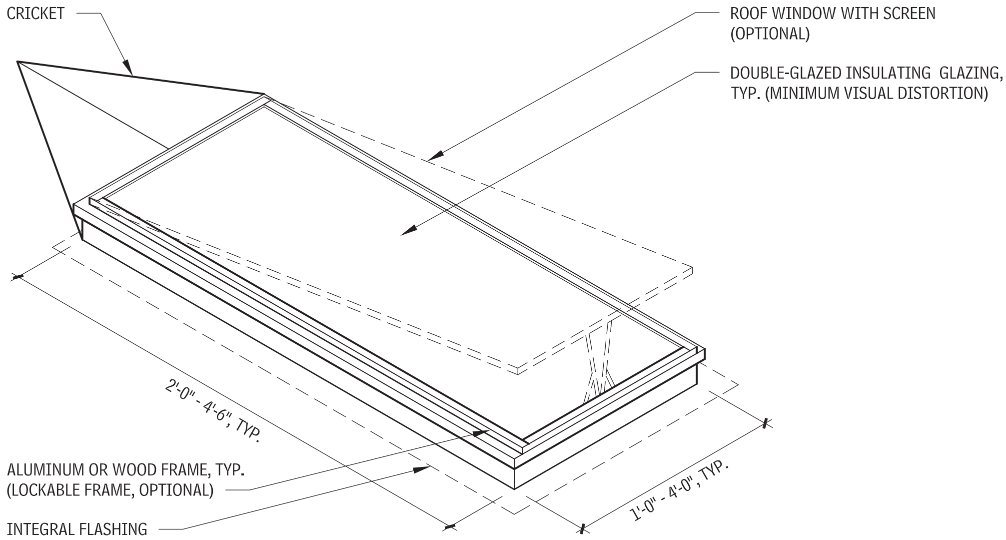


INSULATED CURB

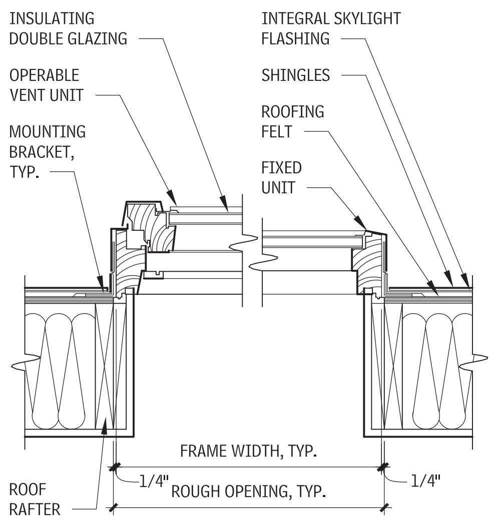


WOOD CURB

FLAT PANEL UNIT SKYLIGHT—SLOPED ROOF
11.484



FLAT PANEL UNIT—SKYLIGHT SECTION
11.485



FRAMED SKYLIGHT TYPES

Framed skylights are available in two different structural types, three glazing types, and two water-management systems. Most manufacturers only provide systems in a limited number of the possible combinations.

STRUCTURAL TYPES, STRUCTURAL OR SKIN

- Structural skylights span across the skylight opening and support all loads.
- Skin systems have a frame that performs glazing and waterproofing functions. They are applied to a separate structural system, typically of wood or steel. Skin systems frequently resemble structural systems, except that the members are much more shallow.

GLAZING TYPES

- Four-sided retained systems have pressure plates or other glazing stops on the full perimeter of each pane of glass. Glazing should be a wet/dry type or, preferably, a fully wet glazing for maximum reliability. Avoid systems (especially face-sealed systems) that use dry gaskets.
- Two-sided structural silicone-glazed (SSG) assemblies have pressure plates or glazing stops on the mullions that run parallel to the slope, and structural silicone glazing on mullions running across the slope. Because the SSG has no mullion cover above the plane of the glass, no water is trapped to cause potential leaks or stains from the evaporated water. Two-sided SSG systems are recommended for most framed skylights.
- Four-sided structural silicone glazed assemblies provide the advantages of two-sided SSG systems, plus a more streamlined appearance.

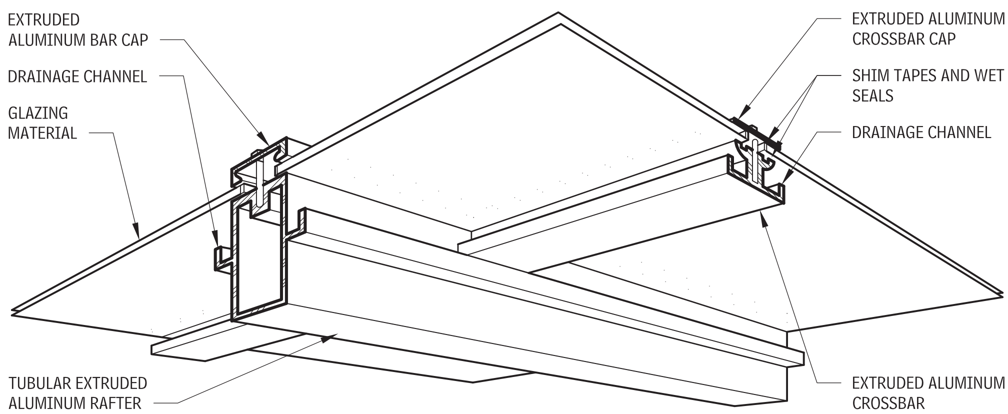
WATER MANAGEMENT SYSTEMS

- Face-sealed systems rely on a perfect watertight seal at the exterior face of glazing. Gutters and weeps on the interior side of the glazing are provided to control condensation only.
- Rainscreen systems employ redundant pressure-equalized rainscreen technology to control both air and water penetration. Gutters and weeps on the interior face drain not only condensation but also any minor leaks that get past the exterior seals. Although less common, PE rainscreen systems are more reliable.

POINT-SUPPORTED FRAMELESS SKYLIGHT SYSTEMS

- Frameless skylights supported on point glazing mounts are the most transparent and expensive skylights. They provide a nearly invisible separation between the interior and exterior. The systems rely on perfect silicone butt joint glazing. The structural support can be one-way or two-way trusses of steel, aluminum, wood, laminated glass, tension cables, or combinations of these.

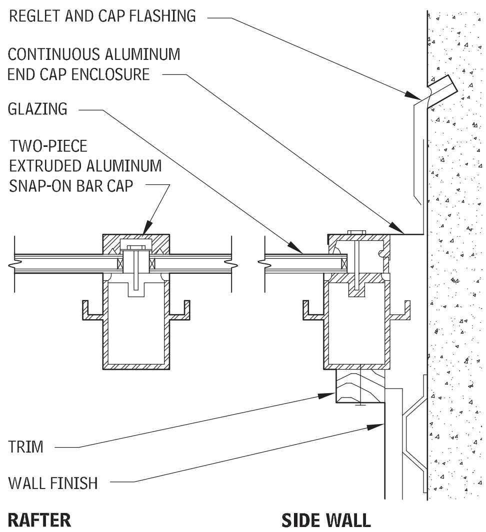
TYPICAL TUBULAR ALUMINUM FRAMING
11.486



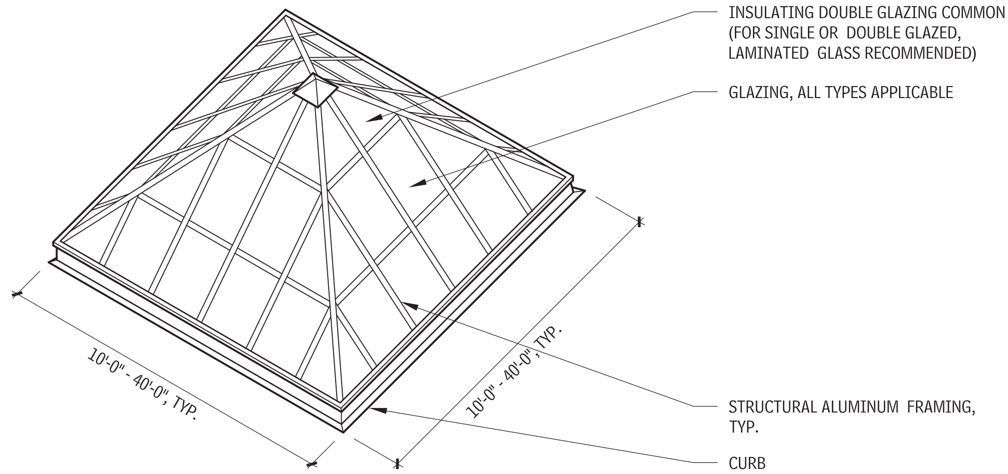
NOTES

11.484. Clear and tinted transparent glass is typical, but tempered, laminated, and wire glass also are available.
b. Manual and powered vent operation, venetian blinds, shades, and exterior awnings are available. Consult manufacturers for available options.

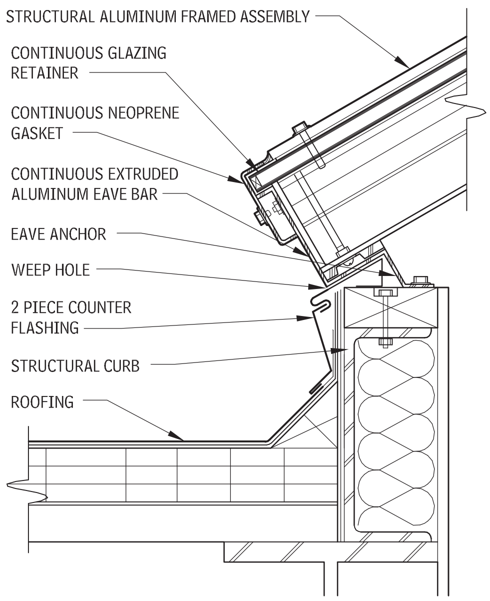
RAFTER AND SIDE WALL DETAIL
11.487



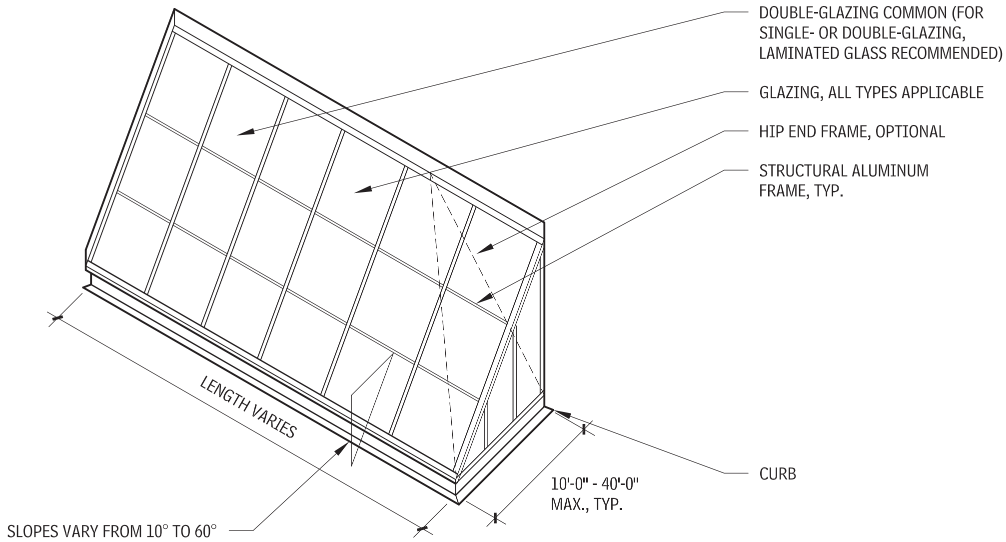
PYRAMID FRAMED SKYLIGHT ASSEMBLY
11.488



CURB DETAIL AT SLOPED FRAMED ASSEMBLY
11.489



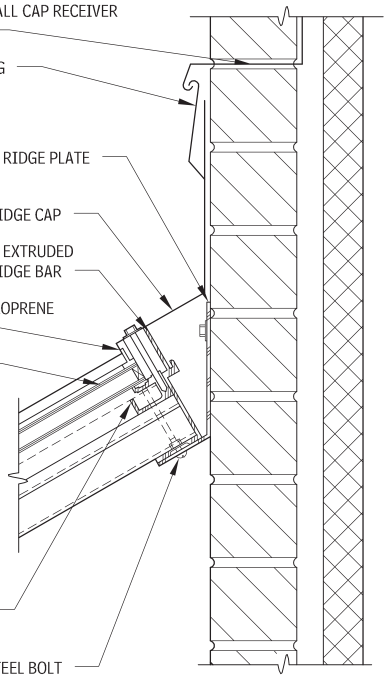
SINGLE-PITCH FRAMED SKYLIGHT ASSEMBLY
11.490



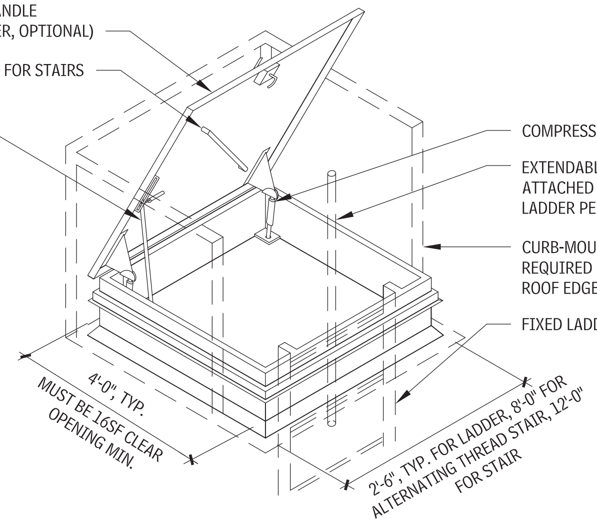
NOTE

11.490 Sloped aluminum frame may be segmented or curved.

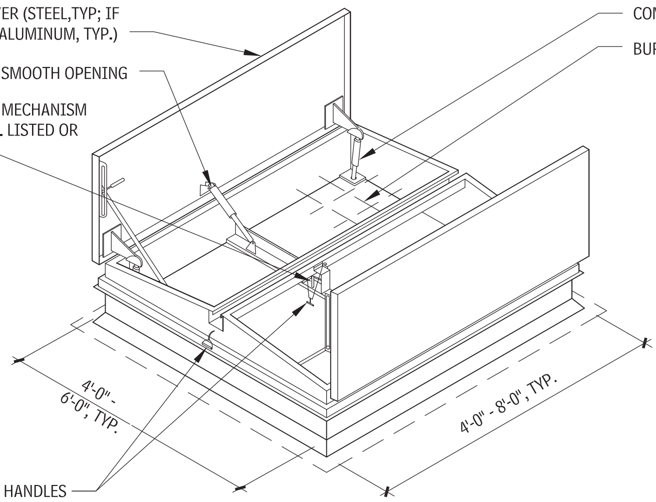
BACK WALL DETAIL AT SKYLIGHT HEAD
11.491



ROOF SCUTTLE
11.492



FIRE AND SMOKE VENT
11.493



NOTE:
FIRE/SMOKE HATCH AREA AND QUANTITY IS BASED ON CALCULATION OF AREA OF SMOKE EVACUATION REQUIRED FROM AREA BELOW, AS INDICATED BY CODE.

HATCHES AND VENTS

Hatches allow access to roofs for maintenance. Vents allow the release of smoke and heat from within the building.

AWNINGS AND CANOPIES

Awnings and canopies may be factory-fabricated or custom-fabricated and are designed to provide sun and rain protection for windows, entrances, and walkways. They can be illuminated with backlighting or graphically embellished and used as signage as well.

Code requirements and design needs may determine the shape, size, graphics, materials, and lighting chosen. After lighting is installed, the underside of the awning or canopy is finished with a "ceiling" (normally, a prismatic glass, egg crating, or an open-weave vinyl-coated polyester or other translucent fabric) to hide the hardware and maximize light reflection.

Climatic conditions, wind and snow load requirements, and local design customs will affect the construction details of the awning or canopy framework systems.

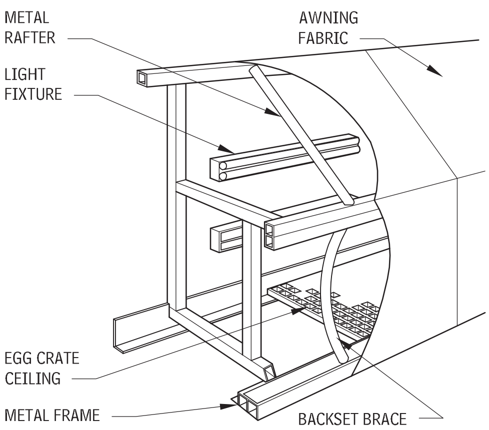
A variety of methods are used to apply graphics to the awning, including: silk screening, handpainting, airbrushing, cut-out lettering, heat color transferring, pressure-sensitive graphics, and eradicating.

Slip fittings with setscrews or direct tube-to-tube welding are the most common frame construction practices. Welded joints are more rigid; but shipping, assembly, and disassembly are easier and quicker with slip-fitting joints.

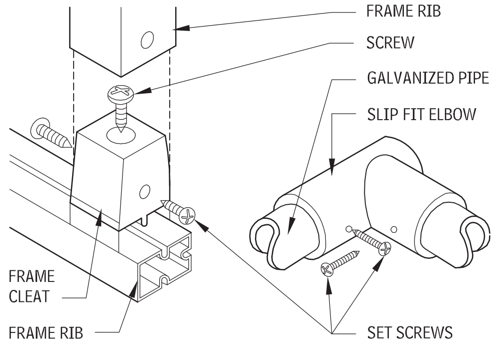
NOTES

11.492 Double-leaf scuttles are available for larger openings.
11.493 The fire and smoke vent section is similar in construction, hardware, and integration to the roof scuttle.

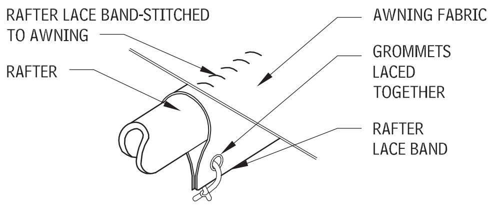
FRAMEWORK DETAILS
11.494



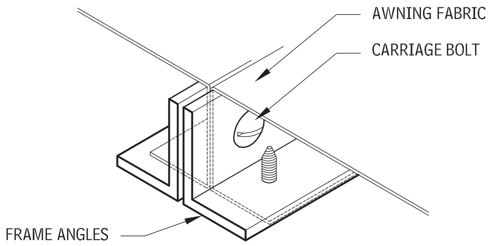
TYPICAL AWNING FRAMEWORK



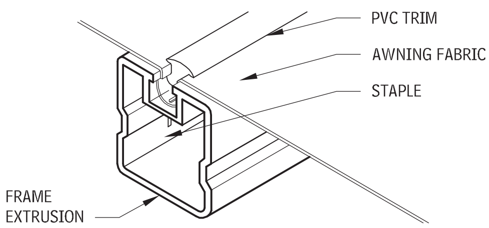
SLIP JOINT DETAILS



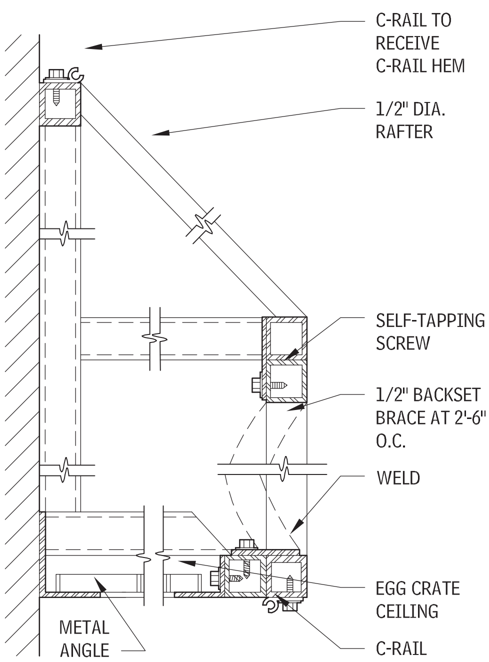
RAFTER LACE DETAIL



FRAME DETAIL WITH MINIMUM SHADOW LINE

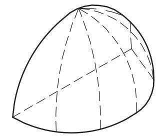


EUROPEAN STAPLE – IN METHOD

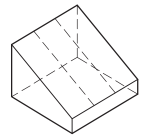


SECTION THROUGH AWNING FRAME

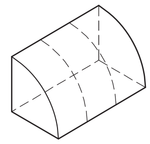
CANOPY AND AWNING SHAPES
11.495



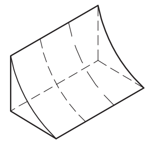
DOME



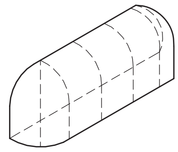
STANDARD STATIONARY



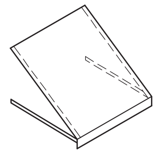
CONVEX



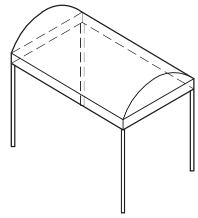
CONCAVE



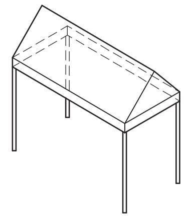
ELONGATED BULLNOSE



RETRACTABLE



ARCHED MARQUEE



GABLED MARQUEE

AWNING FABRIC CHARACTERISTICS
11.496

GENERAL CLASSIFICATION	PAINTED ARMY DUCK	VINYL-COATED COTTON	VINYL-LAMINATED POLYESTER	SOLUTION-DYED ACRYLIC	VINYL-COATED POLYESTER	ACRYLIC-COATED POLYESTER	VINYL-COATED POLY-COTTON BLEND	SOLUTION-DYED MODACRYLIC
Description	Acrylic-painted cotton duck fabric	Vinyl-coated on cotton duck fabric	Trilayer fabric; top and bottom layers are vinyl, middle layer is a woven polyester	Woven fabric, made of 100% acrylic solution-dyed fibers with a fluorocarbon finish	Vinyl-coated on each side of polyester base fabric	Acrylic-coated on each side of a polyester base fabric	Vinyl-coated on each side of a 50% polyester base	Woven fabric made of 100% solution-dyed modacrylic fiber with fluorocarbon finish
Typical weight	11 oz. per sq yd	15 oz. per sq yd	10-16 oz. per sq yd	9.25 oz. per sq yd	11-17 oz. per sq yd	9.5-12.5 oz. per sq yd	13 oz. per sq yd	9.25 oz. per sq yd
Properties	Resistant to ultraviolet light, mildew, and water	Resistant to ultraviolet light, mildew, and water	Resistant to ultraviolet light, mildew, and water	Resistant to ultraviolet light, color degradation, water, and mildew	Resistant to ultraviolet light, mildew, and water; cleanable	Resistant to ultraviolet light and mildew; water-repellent	Resistant to ultraviolet light and mildew; water-repellent	Resistant to ultraviolet light and color degradation; water-repellent and -resistant
Colors	Stripes or solids; primary colors, pastels, and some earth tones	Stripes or solids; all colors are available	Stripes or solids; primary colors and pastels	Wide variety: stripes and solids; primary colors and earth tones	Solids; same color on both sides or solid on front and back	Predominantly solids with some stripes; same color both sides	Solid colors; same color both sides	Solid colors and tweeds; same color, both sides
Underside	Pearl gray, green, or pearl gray with floral print	Solid pearl gray	Linenlike pattern; solid coordinating color to match topside, or same color as top	Same as top surface	Same as top surface	Same as top surface	Same as top surface	Same as top surface
Surface	Matte finish, with linenlike visible texture.	Smooth, nonglare surface with little or no texture	Smooth or matte, with slight woven or linenlike texture	Woven texture	Smooth, somewhat glossy top surface	Surface textured with cloth appearance	Surface textured	Woven texture surface
Transparency level	Opaque	Opaque	Translucent, depending on color; certain styles, formulated for backlighting, are highly translucent	Translucent, depending on color	Translucent, depending on color	Translucent, depending on color	Opaque	Translucent, depending on color
Abrasion resistance	Very good	Very good	Good—base fabric is very strong	Good	Good	Very good	Very good	Good
Dimensional stability (stretch)	Very good	Very good	Very good	Good; some shrinkage in cold weather, some stretch in hot weather	Stable	Very good	Very good	Good
Mildew resistance	Good, but not recommended for areas of high humidity	Good, but recommended for areas of high humidity	Very good; recommended for sustained high humidity	Very good	Very good	Very good	Very good	Very good
Durability	5-8 years	5-8 years	5-8 years	5-10 years	5-8 years	5-8 years	5-8 years	5-10 years
Flame resistance (FR)	Some colors available with flame-retardant treatment	Some colors available with flame-retardant treatment	All colors flame-resistant	Non-flame-resistant	All colors flame-resistant	All colors flame-resistant	All colors flame-resistant	All patterns flame-resistant
Width (in.)	31	31	31 and 62	46 and 60	37 and 62	31 and 62	60 and 61	46

NOTE

11.496 Durability depends on climate and proper care of fabric.

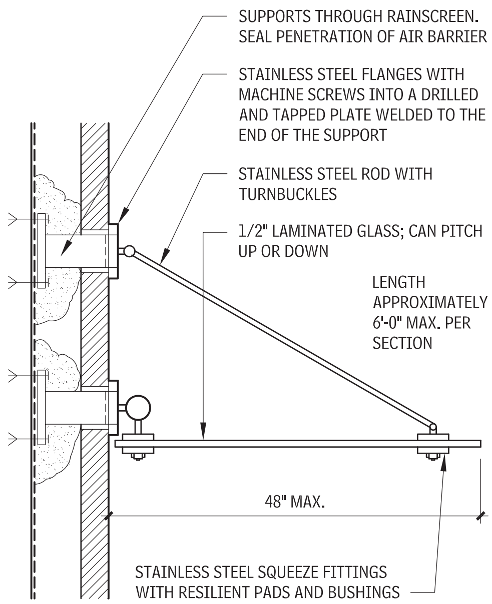
Contributors:
Industrial Fabrics Association International, St. Paul, Minnesota;
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland.

FRAME CHARACTERISTICS
11.497

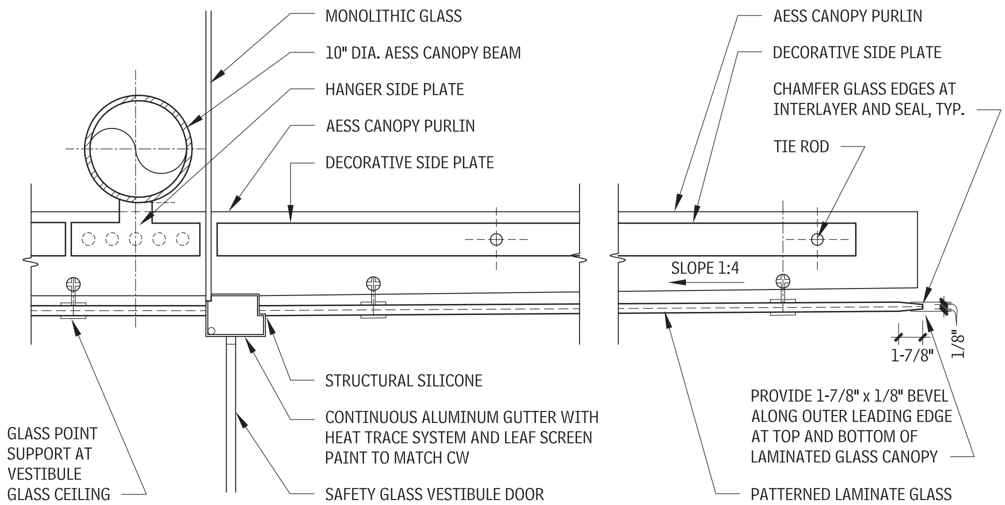
GENERIC CLASSIFICATION	COMMON STANDARDS	YIELD STRENGTH (PSI)	MODULUS OF ELASTICITY (PSI)	REMARKS
Steel tube	ASTM A 53E	35,000	29×10^6	Obtainable in black iron or galvanized. Nominal sizes are larger than equivalent nominal sizes for most tubing. Relatively thick walls. Available only in round shape.
	ASTM A 53S			
Steel tubing	AISI 1018	32,000	29×10^6	Generally hot-rolled materials, which preserve ductility. Easily worked and welded. Must be painted or otherwise coated to provide corrosion protection. Can be obtained galvanized in certain sizes.
	AISI 1020	35, 000–44,000		
	ASTM A 513, Type 1	32,000		
	ASTM A135	30,000–35,000		
Aluminum tubing	6061-T6	37,000	10×10^6	Note lower value for modulus of elasticity: this will produce larger deflections. Welded joints will cause materials to lose their heat treatment and result in locally reduced strength; designer must take this into account. Good corrosion resistance; lightweight; available round, square, and rectangular.
	6063-T6	31,000		
	6063-T5	21,000		
Electrical metallic tubing	UL 797		29×10^6	Difficult to specifically determine the steel properties, as UL 797 only requires that it be mild, ductile steel. Available only in round shape.
High-strength coated tubing (cold-formed)	ASTM A500	46,000–52,000	29×10^6	Strong, relatively lightweight, thin-wall tubing with corrosion protection. Designer should take adequate account of the thin-wall characteristics, less ductile properties, and higher strength of the product, as compared to mild steel tubing. Available in round or square shapes.
Stainless steel tubing	AISI Type 304	30,000–50,000	28×10^6	Excellent strength, corrosion resistance, and weldability.

GLASS CANOPIES

FABRICATED GLASS CANOPY
11.498



CUSTOM GLASS CANOPY
11.499



NOTES

11.498 Laminated glass requires edge protection, or edge may discolor. Protect with clear silicone or adhere a structural silicone on a metal edge.
11.499 Carefully consider monolithic glass and structural steel supports for condensation.

Contributor:
Anthony Golebiewski, AIA, Kling, Philadelphia, Pennsylvania.

ELEMENT C: INTERIORS

12

INTERIOR CONSTRUCTION

INTERIOR PARTITIONS

This section discusses common types of partitions, in particular, gypsum board assemblies, concrete masonry units, glass unit masonry, glazed, and operable partitions, as well as the design of fire-resistant partitions.

GYPSUM BOARD ASSEMBLIES

GENERAL REQUIREMENTS

Gypsum board is applied over wood or steel framing or furring. The quality of the application is largely dependent on the accurate alignment of the framing or furring to which the gypsum board is attached.

FIRE-RESISTANCE AND SOUND-TRANSMISSION RATINGS

Refer to Chapter 3—Building Resiliency for fire-resistance and sound-transmission ratings for wood stud, metal stud, and shaft wall gypsum board assemblies.

LOADS

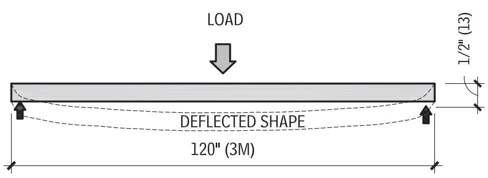
Framing members and their installation must be selected according to their ability to withstand the loads to which they will be subjected. These include live loads (contributed by the occupancy and elements such as wind, snow, and earthquake) and dead loads (weight of the structure itself). The minimum lateral load for interior partitions is 5 psf for exterior walls, the minimum lateral load is 15 to 45 psf or greater, depending on the building height and geographic location.

DEFLECTION

Even though an assembly is structurally capable of withstanding a given load, its use may be restricted if the amount of deflection that would occur when the lateral load is applied exceeds that which the surfacing material can withstand without damage.

For drywall assemblies, it is desirable to limit deflection to L/240 (L = length of the span in inches) and to never exceed L/120 (L/180 in some codes). The preferred limit for veneer assemblies is L/360 and should not exceed L/240.

GYPSUM BOARD DEFLECTION—L/240
12.1



D = DEFLECTION LIMIT = L/240 (36M)

L = 10' OR 120" (3M)

D = 120/240

D = 1/2" (13)

WOOD STUD FRAMING

Wood stud partitions are suitable for residential and light-commercial construction where combustible framing is permitted by code. These designs include single- and double-layer gypsum board facings, single- and double-row studs, those with insulating blankets, and those with resilient attachments. Performance values up to two-hour fire resistance and an STC of 58 can be obtained.

The choice and installation of framing depends on a number of factors. In the case of wood framing, these include the species, size, and grade of lumber used. Equally important are the height of the wall, the frame spacing, and the maximum span of the surfacing material.

Wood framing that meets the following minimum requirements is necessary for proper performance of all assemblies.

1. The framework should meet the minimum requirements of applicable building codes.
2. Framing members should be straight, true, and of uniform dimension. Studs and joists must be in true alignment; bridging, firestops, soil pipes, and so on, must not protrude beyond the framing.
3. All framing lumber should be the correct grade for the intended use, and 2 × 4s nominal size or larger should bear the grade mark of a recognized inspection agency.
4. All framing lumber should have a moisture content not in excess of 19 percent at the time of gypsum board application.

For wood framing installed in the conventional manner, with lumber meeting the requirements outlined above, the maximum frame spacing is as shown in following figures:

MAXIMUM FRAME SPACING—GYPSUM BOARD CONSTRUCTION
12.2

APPLICATION	PANEL THICKNESS	LOCATION	APPLICATION METHOD	MAXIMUM FRAME SPACING O.C.
Single layer	3/8″	Ceilings	Perpendicular	16″
			Parallel	16″
	1/2″	Ceilings	Perpendicular	24″
			Parallel	16″
		Side walls	Parallel or perpendicular	24″
			Parallel	16″
	5/8″	Ceilings	Perpendicular	24″
		Side walls	Parallel or perpendicular	24″
Double layer	3/8″	Ceilings	Perpendicular	16″
		Side walls	Parallel or perpendicular	24″
	1/2″ and 5/8″	Ceilings	Parallel or perpendicular	24″
		Side walls	Perpendicular	See Note g.

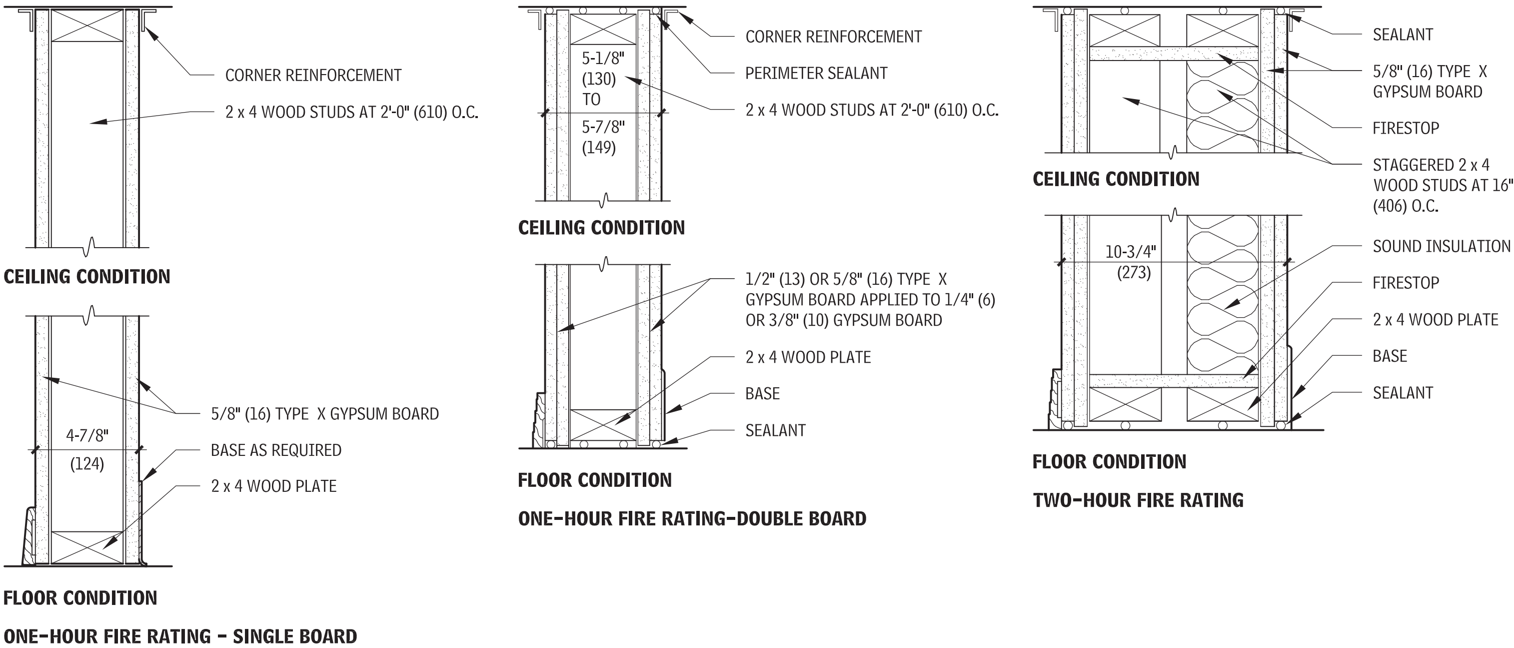
MAXIMUM FRAME SPACING—VENEER PLASTER CONSTRUCTION
12.3

GYPSUM BASE THICKNESS	CONSTRUCTION	LOCATION	APPLICATION METHOD	MAXIMUM FRAME SPACING O.C.
1/2″	1 layer, 1-coat finish	Ceilings	Perpendicular	16″
		Side walls	Parallel or perpendicular	16″
	1 layer, 2-coat finish	Ceilings	Perpendicular	16″ or 24″
		Side walls	Parallel or perpendicular	16″ or 24″
	2 layers, 1- and 2-coat finish	Ceilings	Perpendicular	24″
		Side walls	Parallel or perpendicular	24″
5/8″	1 layer, 1-coat finish	Ceilings	Perpendicular	16″ or 24″
		Side walls	Parallel or perpendicular	16″ or 24″
	1 layer, 2-coat finish	Ceilings	Perpendicular	24″
		Side walls	Parallel or perpendicular	24″
	2 layers, 1- and 2-coat finish	Ceilings	Perpendicular	24″
		Side walls	Parallel or perpendicular	24″

NOTES

12.2 a. Panel thickness:
5/8-in. thickness is recommended for the finest single-layer construction, providing increased resistance to fire and transmission of sound.
1/2-in. thickness is recommended for single-layer application in new residential construction and remodeling.
3/8-in. thickness is recommended for repair and remodeling over existing surfaces.
b. Application methods indicate long-edge position relative to framing.
c. 3/8-in. gypsum board ceilings are not recommended below unheated spaces.
d. Water-based texturing material:
3/8-in. gypsum board ceilings are not recommended if water-based texturing material is to be applied.
Parallel-applied 1/2-in. gypsum board ceilings or side walls are recommended if water-based texturing material is to be applied.
Maximum frame spacing is 16 in. for 1/2-in. perpendicular-applied gypsum board ceilings if water-based texturing material is to be applied.
e. If specifically manufactured interior ceiling board is used in place of gypsum panels, maximum spacing is:
24 in. O.C. for perpendicular application with weight of unsupported insulation not exceeding 1.3 psf.
16 in. O.C. with weight of unsupported insulation not exceeding 2.2 psf.
f. Adhesive must be used to laminate 3/8-in. board for double-layer ceilings.
g. If fire rating is required, maximum frame spacing is 16 in. O.C. for double-layer:
3/8-in. perpendicular or parallel side walls.
1/2-in. and 5/8-in. perpendicular side walls.
1/2-in. and 5/8-in. perpendicular or parallel ceilings.
12.3 a. Perpendicular application is preferred on all applications for maximum strength. Where fire rating is involved, application must be identical to that in assembly tested. Parallel application is not recommended for ceilings.

WOOD FRAME—FIRE-RATED WALL SECTIONS
12.4



METAL STUD FRAMING

Metal stud partitions are suitable for all types of construction. Designs include single- and multilayer gypsum board facings, single- and double-row studs, those with sound attenuation or fire blankets, and those with resilient attachments. Performance values up to four-hour fire resistance and an STC of 65 can be obtained.

Selection of a stud thickness (gauge) and size must take into account a number of factors. The key design consideration is whether the assembly is for a load-bearing or non-load-bearing or curtain-wall application. Other design variables include anticipated wall height, weight and dimensions of mounted fixtures, fire rating desired, sound attenuation needed, anticipated wind loads, insulation requirements, deflection allowance, and desired impact resistance.

Metal studs were previously specified using gauge to identify the thickness of the material. The new standard for specifying steel studs, however, is thickness. The most commonly used stud gauges for interior partitions are 25 and 20; however, design professionals should take care in specifying thickness as not all manufacturers provide the same thickness for a given gauge, which could affect the design considerations mentioned above.

It is not unreasonable for the design professional to select the stud depth. There are two methods for obtaining the correct thickness. The design professional can, based on a particular manufacturer's criteria, evaluate the partition(s) in question and specify an exact stud depth, thickness, and spacing. Alternatively, the design professional can specify the stud depth and use the maximum deflection as the criterion for the partition subcontractor to establish the required thickness and spacing of the studs.

In general, stronger or heavier studs are needed to accommodate taller walls. Stronger studs also reduce deflection and vibration. Fire-rated systems are usually designed, tested, and classified based on using the lightest thickness (gauge), shallowest stud depth, and maximum stud spacing, as indicated in the assembly description. Stud thickness and depth may be increased without affecting the fire-resistance rating of the assembly.

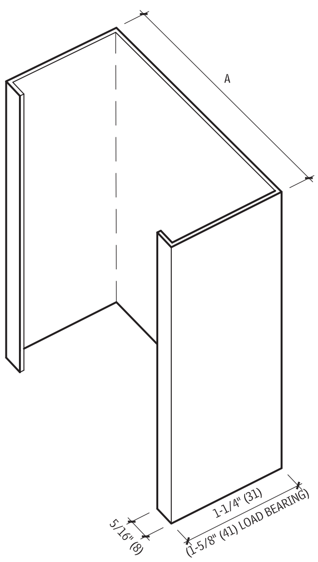
Strength and performance characteristics can be achieved in a variety of ways. Wall strength can be increased by using heavier thickness material, stronger stud designs, narrower stud spacing, or larger web dimensions.

Metal studs are typically manufactured in two different styles:

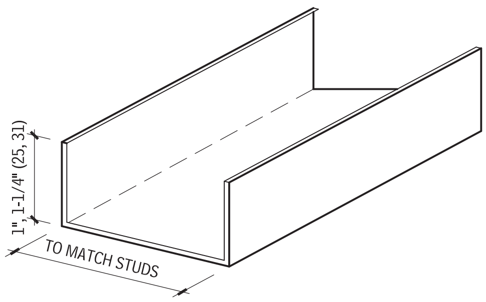
- Studs designed for non-load-bearing interior drywall partition applications have a minimum 1-1/4 in. flange width on both sides. The web design incorporates a cutout for bracing and for electrical, communications, and plumbing lines.
- Studs designed for load-bearing drywall partition applications have a 1-5/8 in. flange width on both sides. Cutouts in the web accommodate bracing, utility service, and mechanical attachments.

Consult manufacturer's literature for proper use and installation.

METAL STUD
12.5



METAL STUD RUNNER
12.6



TYPICAL METAL THICKNESS—METAL STUDS
12.7

REFERENCE-ONLY GAUGE NUMBER	DESIGN	MINIMUM THICKNESS (MILS)
25	0.0188″	18
22	0.0283″	27
20 drywall	0.0312″	30
20 structural	0.0346″	33
18	0.0451″	43
16	0.0566″	54
14	0.0713″	68
12	0.1017″	97

Source: Data is from Steel Stud Manufacturers Association (SSMA) catalog, printed in *USG Gypsum Construction Handbook*, 6th ed., p. 27, R.S. Means Company, Inc., Kingston, Massachusetts, 2009.

NOTES

12.3 b. For the following veneer applications, 24-in. O.C. frame spacing requires joint tape reinforcement and setting-type joint compound:
1/2-in. gypsum base, one layer, two-coat finish ceilings and side walls.
5/8-in. gypsum base, one layer, one-coat finish ceilings and side walls.
12.4 a. STC range 35–39.
b. STC range 45–49.
c. STC range 55–59.

12.5–12.6 Copyrighted work of USG Corporation, *USG Gypsum Construction Handbook*, 6th ed., p. 27, R.S. Means Company, Inc., Kingston, Massachusetts, 2009.
12.7 Minimum thickness shown represents 95 percent of the design thickness and is the minimum acceptable thickness delivered to the job site based on Section A3.4 of the 1996 AISI specification.

LIMITING HEIGHTS—INTERIOR PARTITIONS, 25-GAUGE
12.8

STUD WIDTH	STUD SPACING	ALLOWABLE DEFLECTION	PARTITION, ONE LAYER	PARTITION, TWO LAYERS	FURRING, ONE LAYER
25-GAUGE STUD (0.0179″ MIN.)				X.Xb	X.Xc
1-5/8″	16″	L/120	10′-9″f	10′-9″ d	10′-3″d
		L/240	9′-6″d	10′-6″d	8′-3″ d
		L/360	8′-3″ d	9′-0″ d	7′-3″d
	24″	L/120	8′-9″ f	8′-9″ f	8′-9″ f
		L/240	8′-3″ d	8′-9″ f	7′-3″ d
		L/360	7′-3″ d	8′-0″ d	6′-3″ d
2-1/2″	16″	L/120	13′-9″ f	13′-9″ f	13′-9″ d*
		L/240	12′-6″ d	13′-6″ d	11′-0″ d
		L/360	10′-9″ d	11′-9″ d	9′-9″ d
	24″	L/120	11′-3″ f	11′-3″ f	11′-3″ f
		L/240	10′-9″ d	11′-3″ f	9′-9″d
		L/360	9′-6″ d	10′-3″ d	8′-6″ d
3-5/8″	16″	L/120	16′-9″ f	16′-9″ f	16′-9″ f*
		L/240	16′-0″ d	16′-9″ f	14′-6″ d*
		L/360	14′-0″ d	14′-9″ d	12′-9″ d*
	24″	L/120	13′-6″ f	13′-6″ f	13′-6″f*
		L/240	13′-6″ f	13′-6″ f	12′-9″ d*
		L/360	12′-3″ d	13′-0″ d	11′-0″ d
4″	16″	L/120	17′-3″ f	17′-3″ f	17′-3″ f*
		L/240	17′-3″ d	17′-3″ f	15′-9″ d*
		L/360	15′-0″ d	15′-9″ d	13′-9″ d*
	24″	L/120	14′-3″ f	14′-3″ f	14′-3″f*
		L/240	14′-3″ f	14′-3″ f	13′-9″d
		L/360	13′-0″ d	13′-9″ d	12′-0″ d
6″	16″	L/120	20′-0″ f	20′-0″ f	20′-0″ f*
		L/240	20′-0″ f	20′-0″ f	20′-0″ f*
		L/360	20′-0″ f	20′-0″ f	18′-9″ f*
	24″	L/120	15′-0″ v	15′-0″ v	15′-0″ v*
		L/240	15′-0″ v	15′-0″ v	15′-0″ v*
		L/360	15′-0″ v	15′-0″ v	15′-0″ v*

Source: United States Gypsum Company SA923, *Gypsum Board/Steel Framed Systems*.

MAX PARTITION HEIGHT—BASED ON STUD DEPTH
12.9

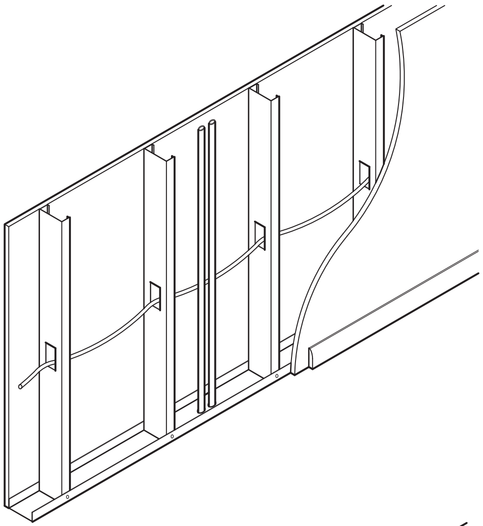
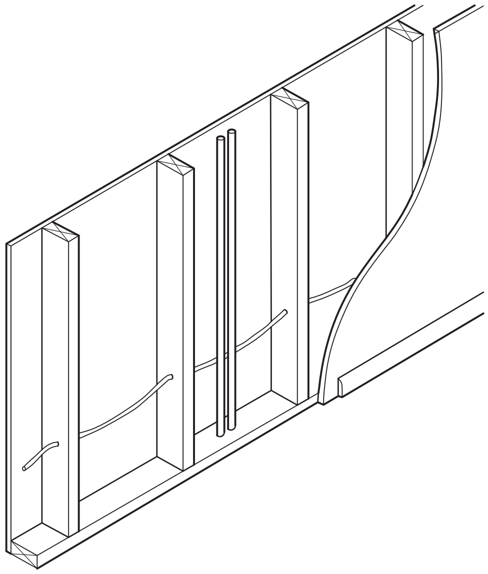
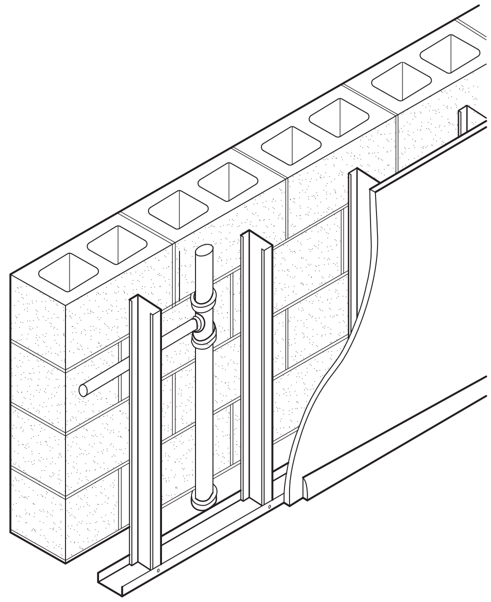
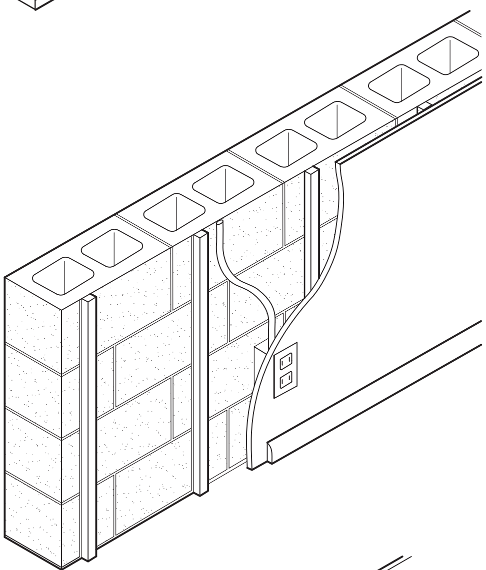
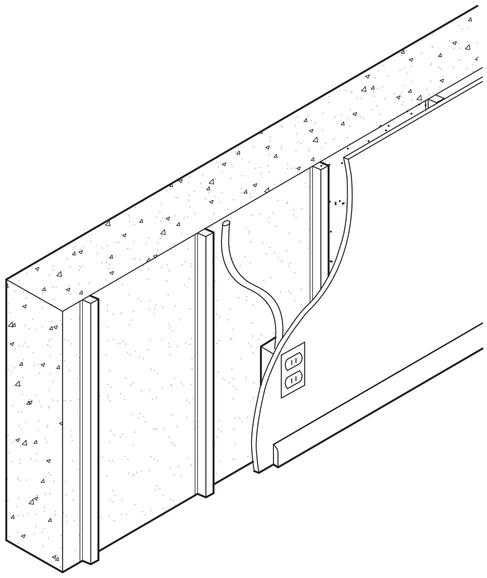
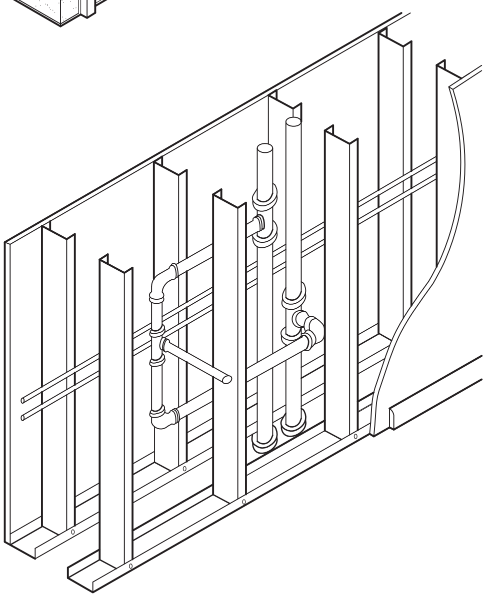
STUD DEPTH	GYPSUM BOARD LAYERS	STRUCTURAL CRITERIA			
		L/120 AT 5 LB./FT.[a] SPACING		L/240 AT 5 LB./FT.[a] SPACING	
		16′-2″	24″[b, c]	16″[b]	24″[b]
1-5/8″	One	11′-0″	10′-0″	8′-9″	7′-11″
	Two		12′-4″		9′-9″
2-1/2″	One	14′-8″	13′-5″	11′-8″	10′-8″
	Two		15′-10″		12′-7″
3-5/8″	One	19′-5″	17′-3″	15′-5″	13′-8″
	Two		19′-5″		15′-5″
4″	One	20′-8″	18′-5″	16′-5″	14′-7″
	Two		20′-8″		16′-5″

Source: ASTM C 754, Specification for Installation of Steel Framing Members to Receive Screw-Attached Gypsum Panel Products.

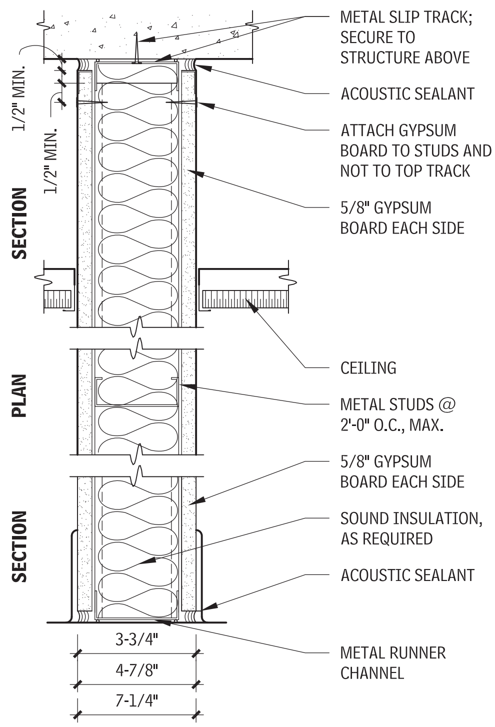
NOTES

12.8 a. *Studs exceeding 12 ft. in height require a mid-height anchor to the exterior wall.
b. The typical limiting-heights tables are based primarily on the suggested minimum physical and structural properties (I^x and S^x).
c. Physical and structural properties may vary by region and manufacturer. Request actual physical and structural property data from your local steel framing manufacturer.
d. Limiting criteria: d—deflection, f—bending stress, v—end-reaction shear. Consult local code authority for limiting criteria.
e. Consult manufacturer's literature for proper use and installation.
12.9 a. L/120 refers to the maximum allowable deflection based on the length, L, of the stud. Partition heights are the height from the bottom runner to the top runner, not the finished ceiling height.
b. On center. Consult the manufacturer's literature for proper use and installation.

GYPSUM BOARD ASSEMBLIES
12.10

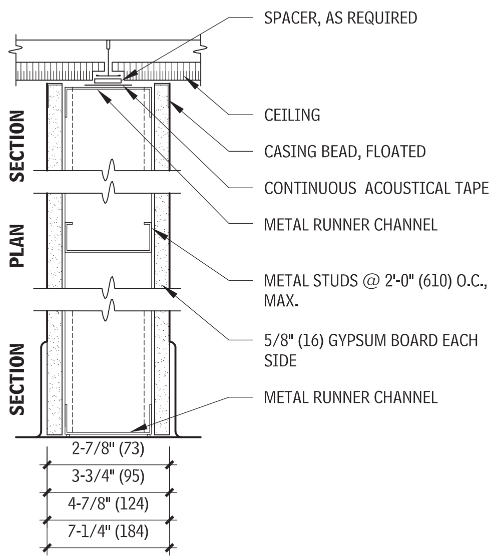
SLIP JOINT AT STRUCTURE ABOVE
12.11



NOTE

12.11 Nonrated partition. Used where flexibility in the partition is desired to minimize cracking of the gypsum board.

CEILING HEIGHT PARTITION
12.12



SHAFT WALL ASSEMBLIES

SHAFT WALLS

Shaft walls are typically fire-rated partitions that enclose elevator shafts, stairwells, and mechanical/electrical/plumbing and other vertical building penetrations, making the shafts the lifelines of the building. They are critically important for protecting the occupants and services from fire.

The fire-resistance and hourly ratings for shaft wall assemblies are established by building codes based on the construction type and building use group. Consult authorities having jurisdiction for specific code requirements.

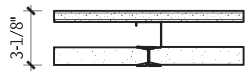
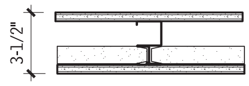
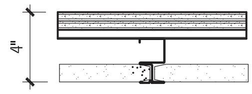
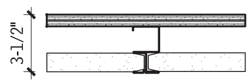
Shaft walls are non-load-bearing gypsum board assemblies constructed from the room/floor side of the shaft (leaving the shaft free of scaffolding). They are constructed of special gypsum liner profile studs, which are set in top and bottom tracks. Metal stud profiles are specific to a particular proprietary assembly and therefore cannot be used in an untested system. Shaft wall assemblies can be used in both vertical and horizontal applications and can provide up to four-hour fire resistance and sound ratings up to 51 STC.

Considerations for shaft wall assemblies include limiting-height and span support capabilities; allowable deflection limits; and, in elevator shafts, intermittent air pressure loads, which may cause the walls to flex. The design criteria for determining limiting partition height for elevator shaft walls uses deflection, bending stress, and end-reaction shear. Designs are available for intermittent lateral loads up to 15 psf. For sustained pressure in air returns, design uniform pressure loads should not exceed 10 psf.

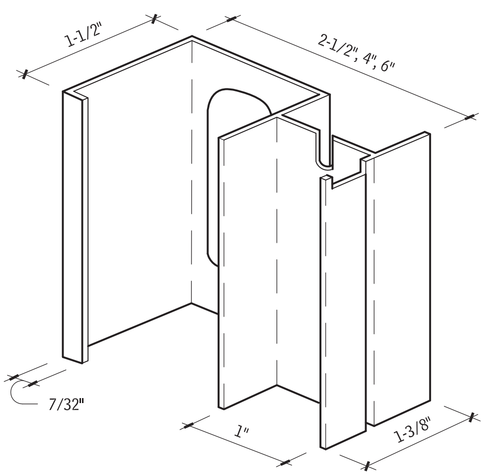
All openings and devices must not compromise the fire-resistance rating. In elevator shafts, this includes hoistway doors, elevator call buttons, indicator lights, and other items installed within the assembly.

Consult manufacturer's literature for proper use and installation.

ONE- AND TWO-HOUR-RATED SHAFT WALL ASSEMBLIES
12.13

FIGURE	FIRE TEST NO.	RATING (HOURS)	SYSTEM THICKNESS	STC	DESCRIPTION
	UL Des U415 System A or U469	1	3-1/8″	NA	5/8″ Type X gypsum panels, joints finished
					2-1/2″ 25-gauge C-H studs 24″ O.C.
					1″ gypsum liner panels
			4-5/8″	39	Based on 4″ 25-gauge C-H studs
	UL Des U415 System E or U467	2	3-1/2″	NA	1/2″ Type C gypsum panels
					2-1/2″ 25-gauge CH studs 24″ O.C.
					1″ gypsum liner panels
					1/2″ Type C gypsum panels
					Joints finished both sides
			5″	44	Based on 4″ 25-gauge C-H studs
	UL Des U415 System F	2	4″	51	Double-layer 1/2″ Type C gypsum panels, face layer joints finished
					RC-1 resilient channel or equivalent 24″ O.C.
					2-1/2″ 25-gauge C-H studs 24″ O.C.
					1″ gypsum liner panels
			5-1/2″	53	Based on 4″ 25-gauge C-H studs, 3″ mineral fiber insulation
			6″	58	Based on 4″ 25-gauge C-H studs, additional layer on liner side, 3″ mineral fiber insulation
	UL Des U415 System B or U438	2	3-1/2″	38	Double-layer 1/2″ Type C gypsum panels, face layer joints finished
					2-1/2″ 25-gauge C-H studs 24″ O.C.
					1″ gypsum liner panels
			5″	43	Based on 4″ 25-gauge C-H studs
			3-1/2″	48	Based on 1″ sound batts
			5″	50	Based on 4″ 25-gauge C-H studs, 3″ mineral fiber insulation

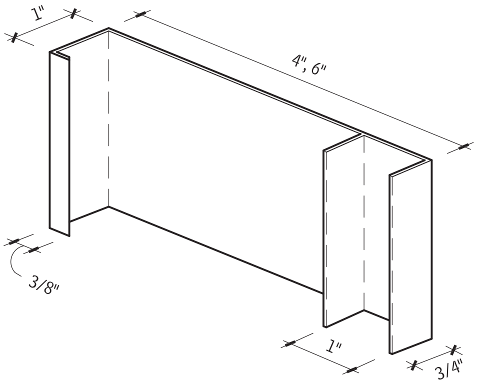
METAL C-H STUDS
12.14



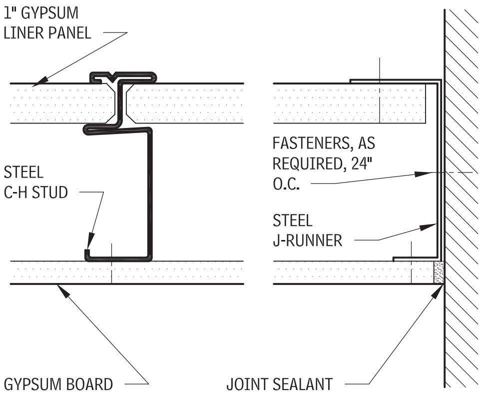
NOTES

12.12 Nonrated partition.
Ceiling is installed prior to installation of partition.
2-1/2-in. metal stud is adequate for most commercial ceiling height partitions.
3-3/4-in. partition type may not accommodate back-to-back devices, such as junction boxes.
Sounds such as normal conversation, telephones, and some equipment may be audible.
STC range 35 to 39.

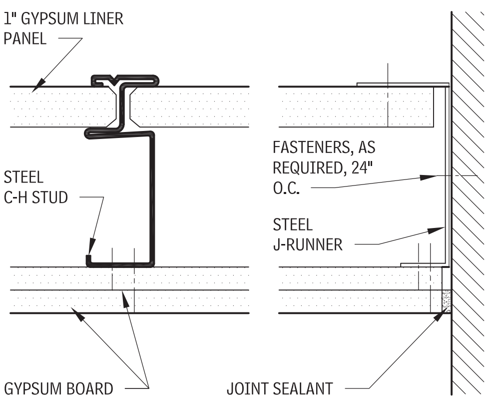
METAL E-STUDS
12.15



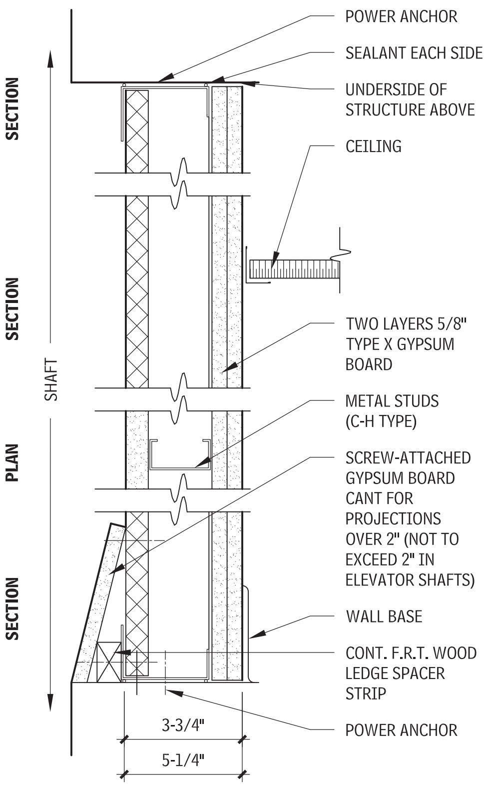
ONE-HOUR-RATED ASSEMBLY—CORRIDOR CEILING AND STAIR SOFFIT
12.16



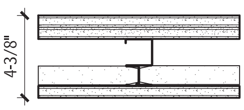
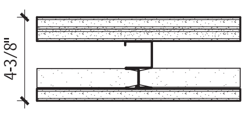
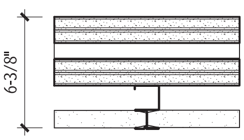
TWO-HOUR-RATED ASSEMBLY—CORRIDOR CEILING AND STAIR SOFFIT
12.17



TYPICAL SHAFT WALL
12.18



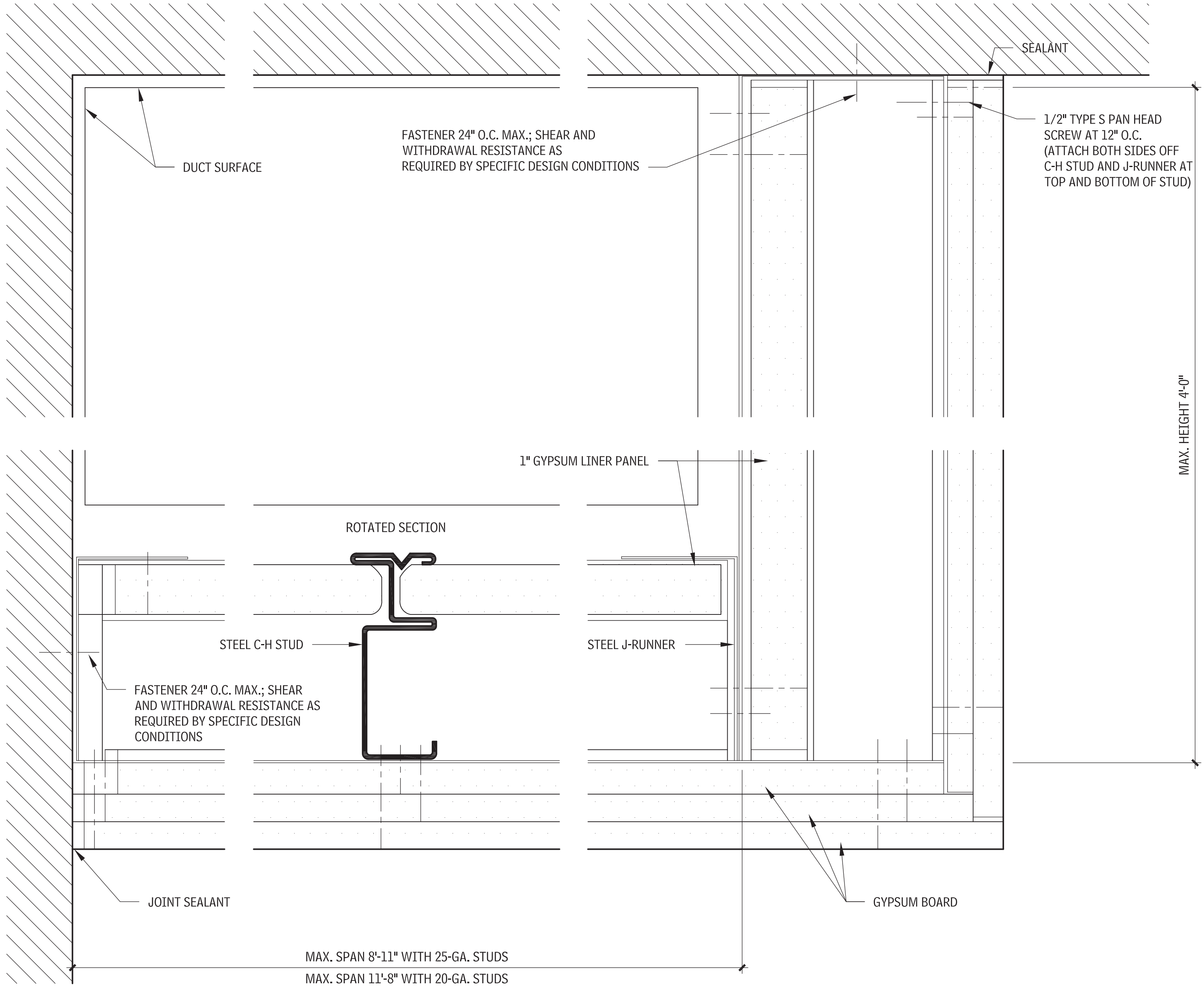
THREE- AND FOUR-HOUR-RATED SHAFT WALL ASSEMBLIES
12.19

FIGURE	FIRE TEST NO.	RATING (HOURS)	SYSTEM THICKNESS	STC	DESCRIPTION
	UL Des U415 System H	3	4-3/8″	NA	5/8″ Type C gypsum board, face layer joints finished
					2-1/2″ 25-gauge C-H studs 24″ O.C.
					1″ gypsum liner panels
					5/8″ Type C gypsum board, face layer joints finished
			5-7/8″	49	Based on 4″ 25-gauge C-H studs
	UL Des U415 System G	3	4-3/8″	NA	5/8″ Type C gypsum board, face layer joints finished
					2-1/2″ 25-gauge C-H studs 24″ O.C.
					1″ gypsum liner panels
			5-7/8″	45	Based on 4″ 25-gauge C-H studs
			5-7/8″	51	Based on 4″ 25-gauge C-H studs, 3″ mineral fiber insulation
	UL Des U415 System I	4	6-3/8″	NA	3/4″ Type X gypsum board, on furring channel 24″ O.C., over two layers 3/4″ Type X gypsum board, face layer joints finished
					2-1/2″ 25-gauge C-H studs 24″ O.C.
					1″ gypsum liner panels
					Base layer over furring channel applied vertically

NOTES

12.15 The 2–1/2" size does not have the 3/8" return.
12.16–12.17 Copyrighted work of USG Corporation, *USG Shaft Wall Systems*, p. 23, www.usg.com.

TWO-HOUR-RATED ASSEMBLY—METAL DUCT ENCLOSURE
12.20



NOTE

12.20 Copyrighted work of USG Corporation, *USG Shaft Wall Systems*, p. 23, www.usg.com.

CONCRETE MASONRY UNITS

SINGLE-WYTHE MASONRY

Single-wythe masonry wall construction is common for many applications, both load-bearing and non-load-bearing and interior and exterior walls. These single-wythe masonry systems are frequently used as interior partitions for fire protection.

Single-wythe walls may be insulated on the interior or exterior. The insulation may be adhered or mechanically fastened directly to the masonry, or it may be installed in conjunction with conventional furring or studding systems.

DIMENSIONING CMU WALLS

Concrete masonry unit construction should be dimensioned and detailed to minimize cutting and fitting on the site. The module established for concrete masonry design is 4 in. vertically and horizontally. Maintaining this module reduces waste and provides ready coordination with other masonry products, as well as window and door openings.

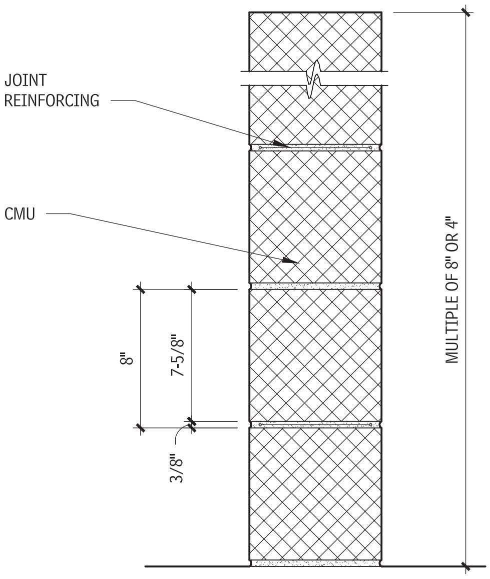
Standard dimensions for concrete masonry units are equal to the nominal dimension less the thickness of one mortar joint of 3/8 in. The nominal 8-in.-high, 16-in.-long concrete masonry unit has an actual height of 7-5/8 in. and an actual length of 15-5/8 in. When laid into a wall with a 3/8-in. mortar joint, the unit always occupies an area 8 by 16 in.

From the outside corner to the outside corner, a CMU wall has one fewer mortar joint than it has blocks. To calculate the actual length of the wall, the 3/8-in. width of a mortar joint must be deducted from the nominal length of the wall.

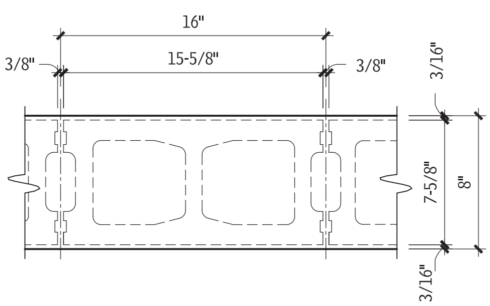
Between an outside corner and an inside corner, a CMU wall has the same number of mortar joints and blocks. The length of the wall will be an exact multiple of 8 in., and the actual length will be the same as the nominal length of the wall.

From inside corner to inside corner, a CMU wall has one more mortar joint than it has blocks, with an actual dimension of 3/8 in.

SINGLE-WYTHE CONCRETE MASONRY UNIT WALL
12.21

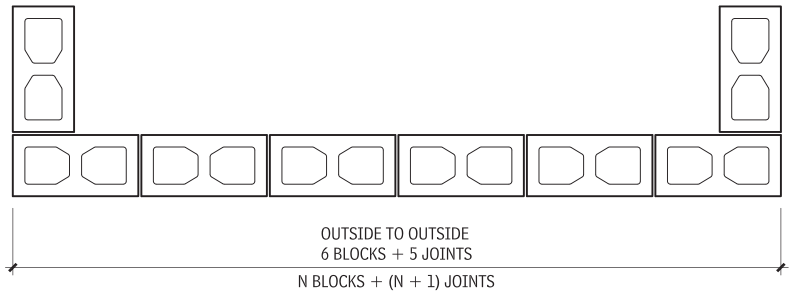


CMU WALL SECTION

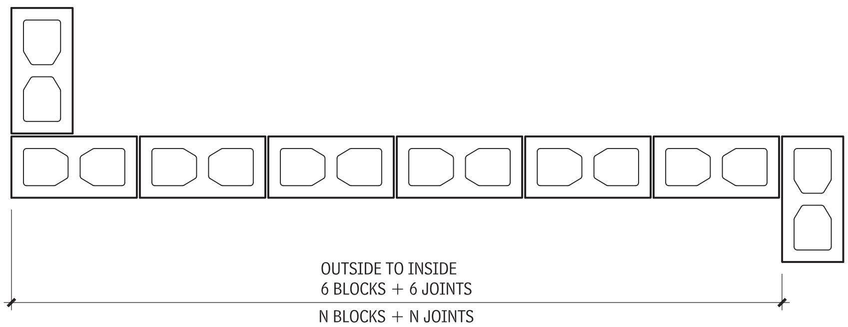


CMU WALL PLAN

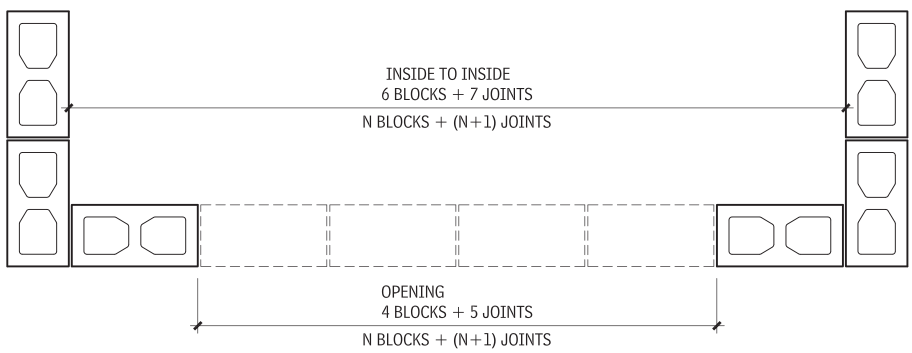
CALCULATING CMU WALL LENGTHS
12.22



OUTSIDE CORNER TO OUTSIDE CORNER MEASUREMENT

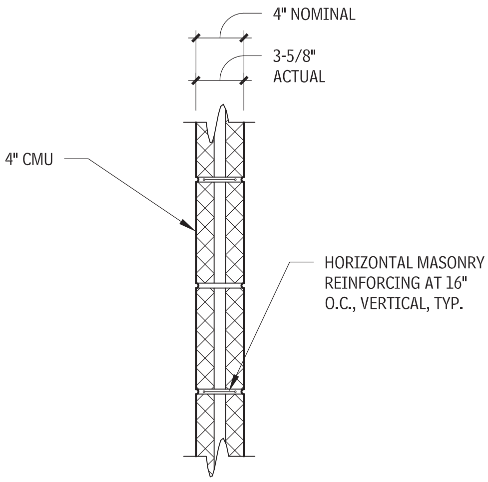


OUTSIDE CORNER TO INSIDE CORNER MEASUREMENT

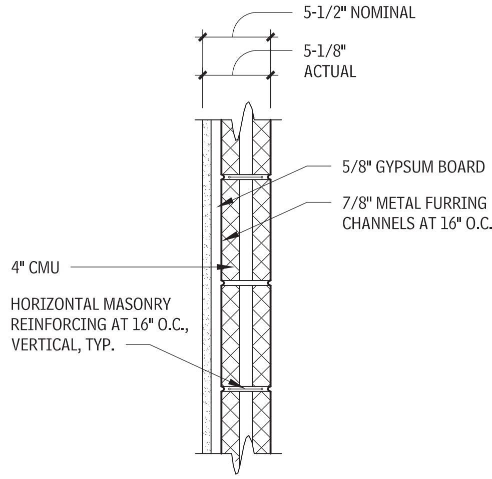


INSIDE CORNER TO INSIDE CORNER MEASUREMENT

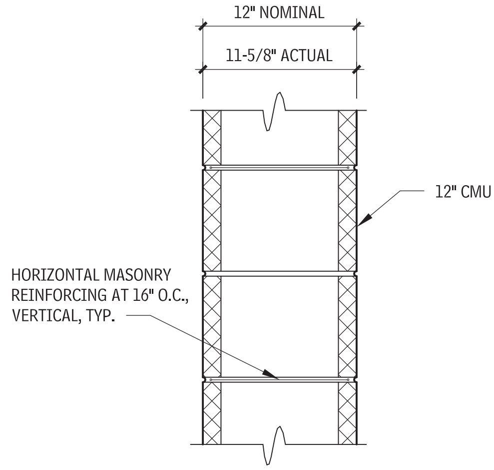
STANDARD CMU WALL SECTIONS
12.23



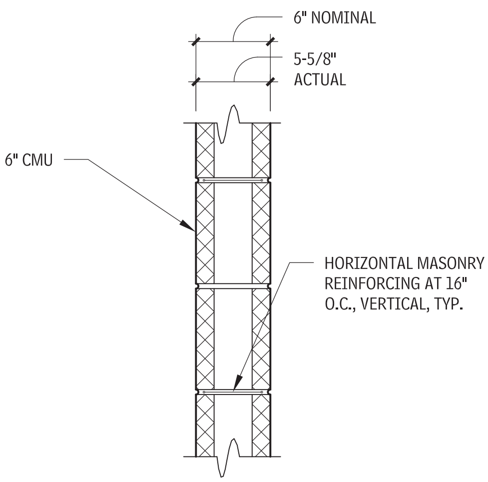
4-IN. WALL



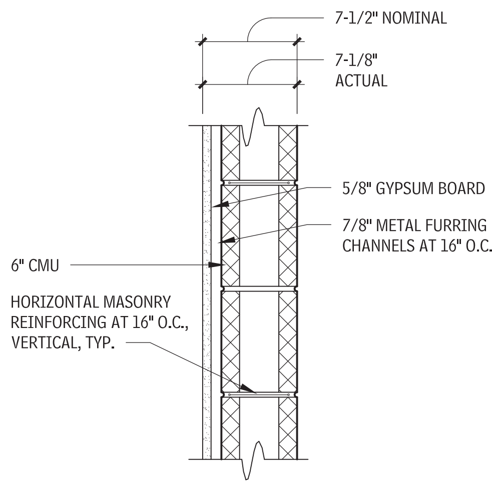
5-1/2-IN. WALL



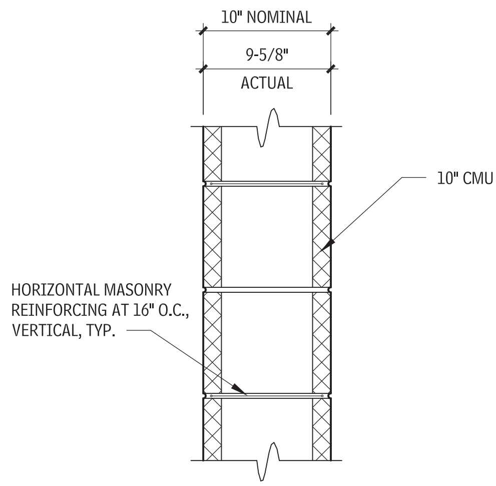
12-IN. WALL



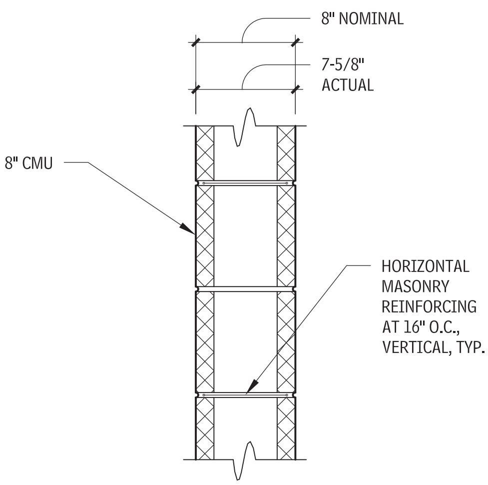
6-IN. WALL



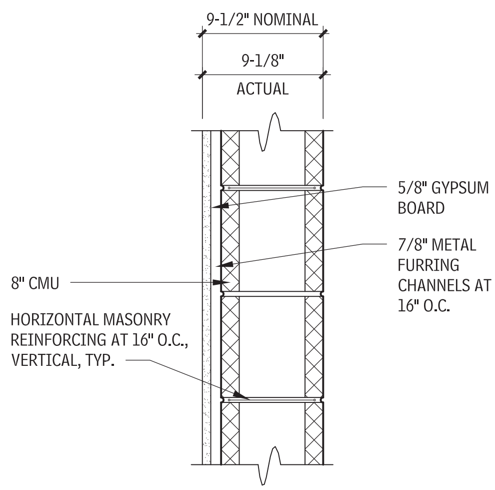
7-1/2-IN. WALL



10-IN. WALL

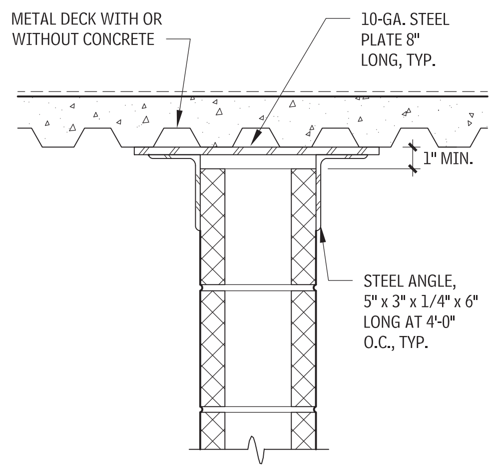


8-IN. WALL



9-1/2-IN. WALL

HORIZONTAL SUPPORT FOR NON-LOAD-BEARING WALLS—METAL DECK
12.24



REINFORCEMENT

In many applications, single-wythe walls are reinforced. The term "partially reinforced" is erroneous; reinforcement schedules are designed for a particular application, and all the required reinforcement is necessary. Non-reinforced single-wythe walls are used in interior construction where no loads, including lateral loads, or other forces are anticipated. Consult with the National Concrete Masonry Association and engineers to determine wall construction requirements.

Concrete masonry unit walls are often partially grouted; that is, only the cells or cavities of the wall containing reinforcement are grouted. When walls are partially grouted, special units or construction fabric are used for vertical containment of the grout. Horizontal containment is usually provided by mortaring the webs of the masonry units. When steel placement is frequent, it may become economical or necessary to fully grout the walls.

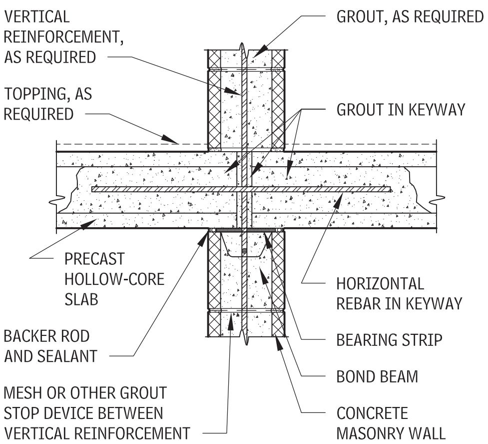
Structural components of a building using reinforced masonry combine the tensile strength of reinforcement with the compressive strength of the masonry to resist design loads. The benefits of incorporating reinforcement are improved ductility, structural integrity, and resistance to flexural and shear stresses. Reinforced masonry provides economical construction, especially when a high degree of resistance to lateral loads is necessary.

Seismic performance categories A and B require no special provisions. In many instances, the wind loads will govern the minimum reinforcing levels in seismic performance category C and above.

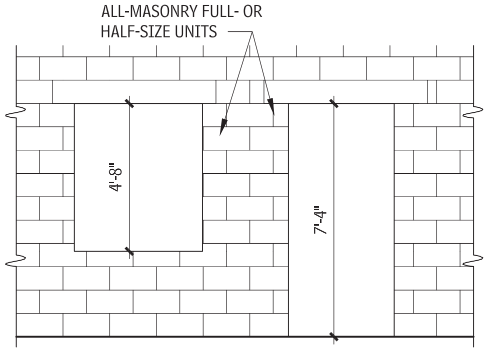
For designs in seismic performance category C, vertical reinforcement of at least 0.20 in. in cross-sectional areas must be provided continuously from support to support at each corner, at each side of each opening, and at the ends of walls. Horizontal reinforcement of not less than 0.20 in. must be provided at the bottom and top of all openings and extend not less than 24 in. nor less than 40 bar diameters past the opening. Horizontal reinforcement should be installed continuously at structurally connected roof and floor levels, at the tops of walls, and at the bottom of the wall or at the top of the foundation; maximum spacing is 10 ft., unless uniformly distributed joint reinforcement is provided.

For designs in seismic performance categories D and E, walls must be reinforced both vertically and horizontally. Requirements in addition to those for seismic performance category C include that spacing cannot exceed 4 ft., except for designs using moment-resisting space frames, where the spacing of principal reinforcement must not exceed 2 ft. Also, the diameter of the reinforcement cannot be less than 3/8 in., except for joint reinforcement. Consult with an engineer and the National Concrete Masonry Association for information on specific project requirements for reinforcing.

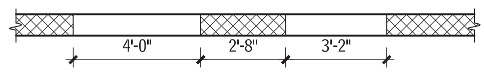
CMU WALL/CEILING INTERSECTION
12.25



CMU WALL DESIGN AND CONSTRUCTION
12.26



ELEVATION



PLAN

GLASS UNIT MASONRY ASSEMBLIES

Glass unit masonry, commonly referred to as glass block, is a diverse building material whose many applications exhibit its multifaceted characteristics. The varying forms of glass block—type, thickness, size, shape, and patterns—along with the methods of installation can be combined to create unique design solutions. Applications range from entire facades, windows, interior dividers, and partitions to skylights, floors, walkways, and stairways. In all applications, glass block units permit the control of light, both natural and artificial, for function or drama. Glass block also allows for control of thermal transmission, noise, dust, and drafts. With the use of thick-faced glass block or solid 3-in. bullet-resistant block, security can also be achieved.

An optimum mortar mix for installing glass block units is 1 part portland cement, 1/2 part lime, and 4 parts sand. Use Type S or Type N mortar to suit the application.

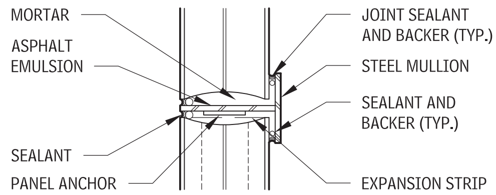
GUIDELINES FOR GLASS BLOCK

1. Glass block panels should not be designed to support structural-loads.
2. Maximum deflection of structural members supporting glass-block panels should not exceed L/600.
3. Sills of all panels must be painted with a heavy coat of asphalt emulsion and must cure for two hours before the first mortar bed is placed.
4. Provision for expansion and movement must be made at the jambs and heads of all panels. Mortar must not bridge expansion spaces.
5. Mortar should be mixed and applied in accordance with the recommendations of the glass block manufacturer.
6. Design and installation of glass block projects should be done by whole units; cutting glass block is not recommended.

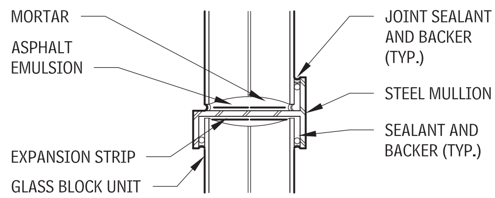
GLASS BLOCK SUPPORT

When specifying supports and shelf angles, the installed weight and deflection limitation of the glass block should be considered. Local building codes should be consulted for limits on panel sizes or installation details. The 2009 International Building Code (IBC) references TMS 402/ACI 530/ASCE 5 as the standard. Panels with an expansion joint stiffener incorporating a concealed vertical plate should be limited to a maximum height of 10 ft.

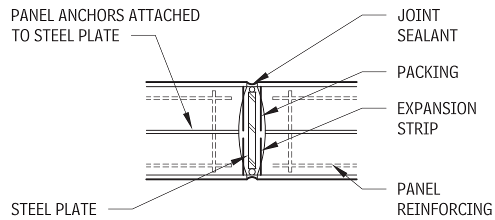
SECTIONS AT SUPPORT
12.27



SUPPORT WITH PANEL ANCHOR



SHELF ANGLES IN MULTIPLE VERTICAL PANELS



SUPPORT IN MULTIPLE HORIZONTAL PANELS

GLASS MASONRY UNIT TYPES

The basic glass block unit is made of two halves fused together with a partial vacuum inside. Faces may be clear, figured, or with integral relief forms.

Glass block is available in thicknesses ranging from a minimum of 3 in. nominal for solid units to a maximum of 4 in. nominal for hollow units. Metric thicknesses range from 76 to 98 mm. Metric sizes are available from foreign manufacturers through distributors in the United States.

SQUARE GLASS BLOCK SIZES
12.28

U.S. SIZES	METRIC SIZES AVAILABLE THROUGH U.S. DISTRIBUTORS
6″ × 6″ (5-3/4″ × 5-3/4″ actual)	115 × 115 mm
1/2″ × 7-1/2″	190 × 190 mm
8″ × 8″ (7-3/4″ × 7-3/4 actual)	240 × 240 mm
12″ × 12″ (1′-1-3/4″ × 1′-1-3/4″ actual)	300 × 300 mm

Some manufacturers provide thick-faced blocks for critical applications where a heavier glass block is needed. These blocks have superior sound transmission rating and fire-rated properties. Their faces are three times as thick as regular glass block units.

Solid glass block units (glass bricks) are impact resistant and allow through vision. Surface decoration may be achieved with fused-on

NOTE

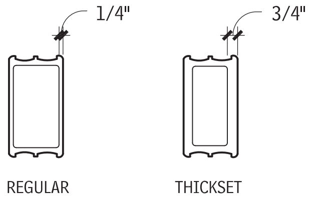
12.26 Example is correct, as no cut CMU units are required.

Contributors:
Grace S. Lee, Rippeteau Architects PC, Washington, DC; Stephen S. Szoke, PE, National Concrete Masonry Association, Herndon, Virginia; Brian E. Trimble, Brick Institute of America, Reston, Virginia; MASTERSPEC®, published by ARCOM, Salt Lake City, Utah; Brian Cooper, AIA, and Jana Gunsul, AIA, DES Architects & Engineers, Redwood City, California, with Nick Loomis, Senior Systems Engineer, Pittsburgh Corning Corporation, Pittsburgh, Pennsylvania; Jana Gunsul, AIA, DES Architects & Engineers, Redwood City, California.

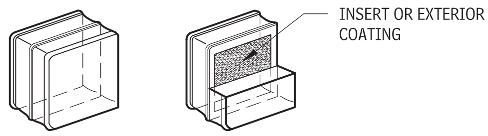
ceramic, etching, or sandblasting. A stipple pattern embossed on the exterior face is also available.

High-performance laminated solid blocks have been developed for high ballistic rating and high impact; nominal size is 8 by 8 by 3 in. Hurricane-rated products are also available.

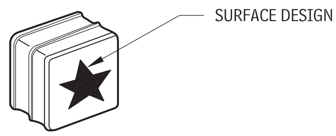
GLASS MASONRY UNIT TYPES
12.29



THICK BLOCK

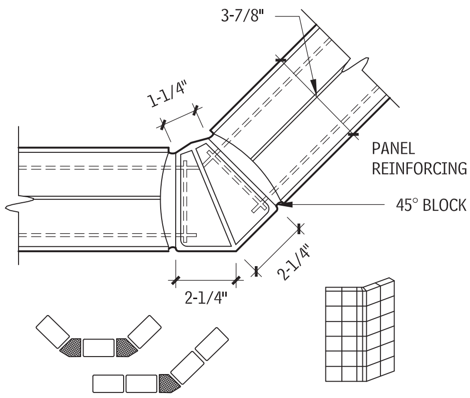


SOLID UNITS

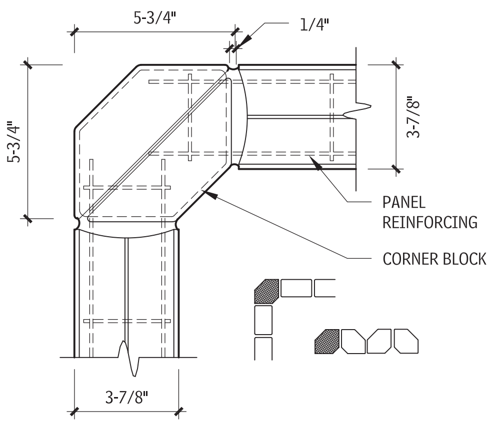


SURFACE DESIGN

SPECIAL CORNER SHAPES
12.30



45° BLOCK



CORNER BLOCK

GLASS UNIT MASONRY STC RATINGS
12.31

STC	SIZE	PATTERN	ASSEMBLY CONSTRUCTION
31	8″ × 8″ × 3″	All patterns	Silicone system
31	8″ × 8″ × 3″	All patterns	Silicone system
37	8″ × 8″ × 4″	All patterns	Mortar
40	8″ × 8″ × 4″ with LX fibrous filter	All patterns	Mortar
48	8″ × 8″ × 4″ thick-faced block	Thick block	Mortar
53	8″ × 8″ × 3″ solid units	Solid block	Mortar

CURVED PANEL CONSTRUCTION

Curved areas should be separated from flat areas by intermediate expansion joints and supports. Expansion joints should be installed at every change of direction of a multicurved wall, at points of curved wall intersection with straight walls, and at the center of curvature in excess of 90°.

When straight, ladder-type reinforcing is used on curved walls, the innermost parallel wire may be cut periodically and bent to accommodate the curvature of the wall.

GLAZED PARTITIONS

GLAZING IN CORRIDORS

IBC 714.3.6 covers glazing in corridors. When corridor walls are required to have a one-hour fire-resistive rating, any glazing in the corridor wall must meet the requirements for interior fire window assemblies. The allowable amount of glass depends on which type of glass is used—fire-protection-rated glazing or fire-resistance-rated glazing:

- Fire-protection-rated glazing includes 1/4 in. wire glass set in steel frames and approved glass block. When this type of glazing is used, the total area of glass cannot exceed 25 percent of the area of the common wall separating two spaces or rooms.
- Fire-resistance-rated glazing includes products such as clear ceramics, tempered glass, and insulated glass. These products carry various fire ratings of up to two hours and are tested as part of a wall assembly. The 25 percent limitation does not apply to these types of products, although each manufacturer's product may have size limitations based on the fire rating of the product.

Both types of glazing must have a label or other identification permanently affixed showing the manufacturer's name, test standard, and fire protection rating.

GLAZING IN DOORS

Requirements for glazing in doors are as follows:

- If wire glass is used, size limitations apply, based on the fire door rating. Fire-resistance-rated glazing may be used, including ceramic, special-tempered, and insulated glass. These products do not have size limitations, except for those developed during manufacturer's testing.
- For most interior work, a 20-minute-rated door is required when used in a one-hour fire-resistance-rated partition used as an exit access corridor wall, and a 3/4-hour-rated door is required when used in a one-hour partition other than a corridor wall.

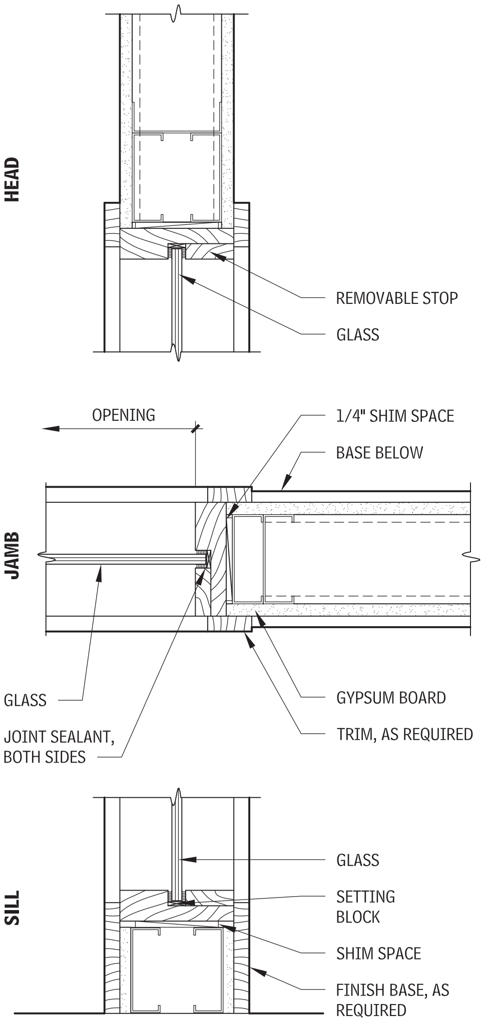
Both doors require gasketing for draft and smoke control.

SECURITY GLAZING APPLICATIONS

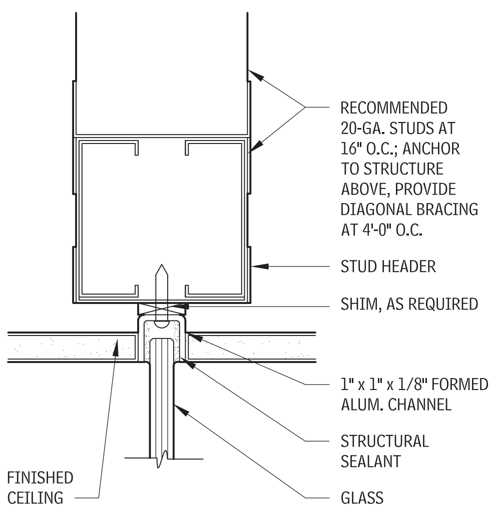
Security glazing is composed of multiple layers of glass and/or polycarbonate plastic laminated together. Depending on the degree of security protection required, thickness can range from 3/8 in. to approximately 2-1/2 in. Security glazing is subject to size limitations.

Contributors:
Brian Cooper, AIA, and Jana Gunsul, AIA, DES Architects & Engineers, Redwood City, California, with Nick Loomis, Senior Systems Engineer, Pittsburgh Corning Corporation, Pittsburgh, Pennsylvania.

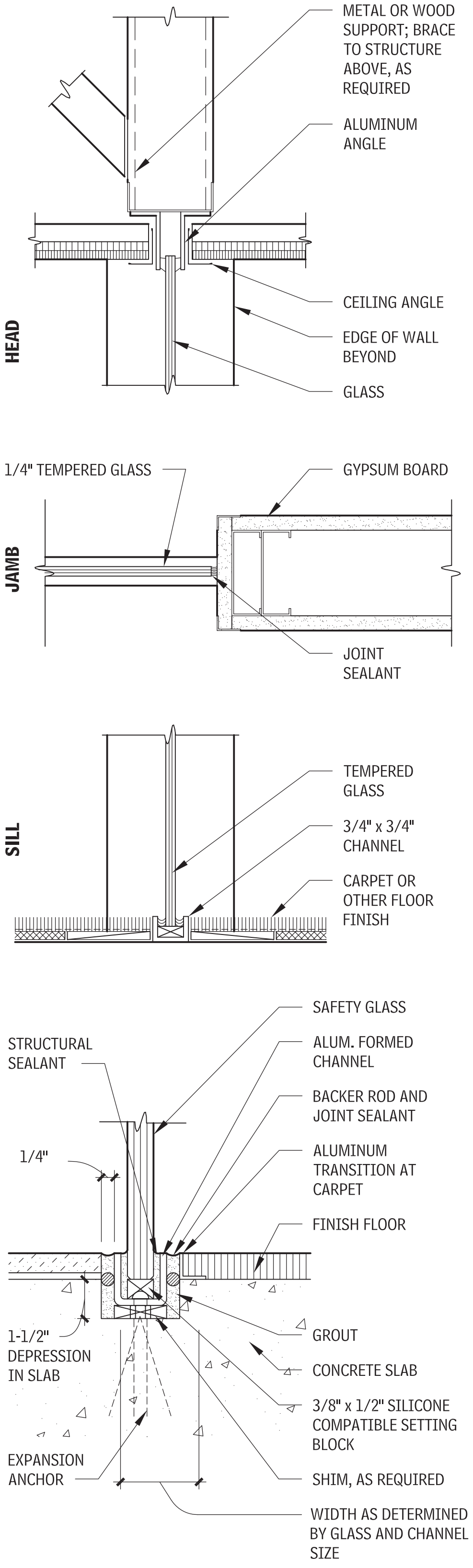
FRAMED GLAZING DETAIL
12.32



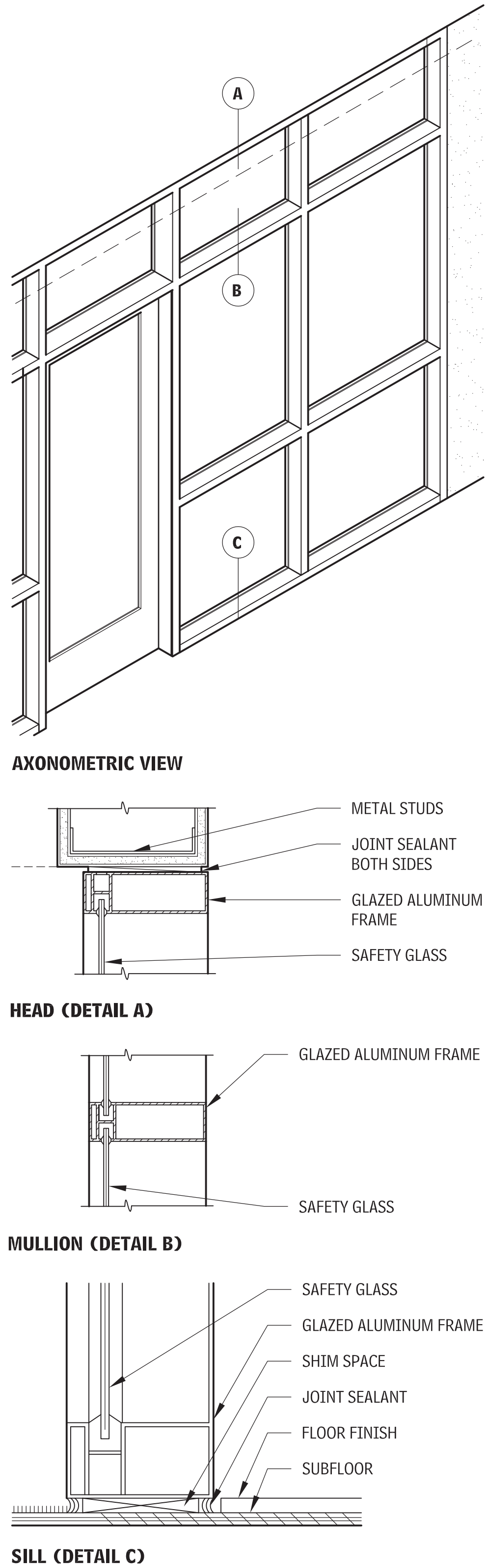
CONCEALED FRAME GLASS PARTITION
12.33



FRAMELESS GLAZING DETAILS
12.34



INTERIOR STOREFRONT
12.35



WALL FINISHES

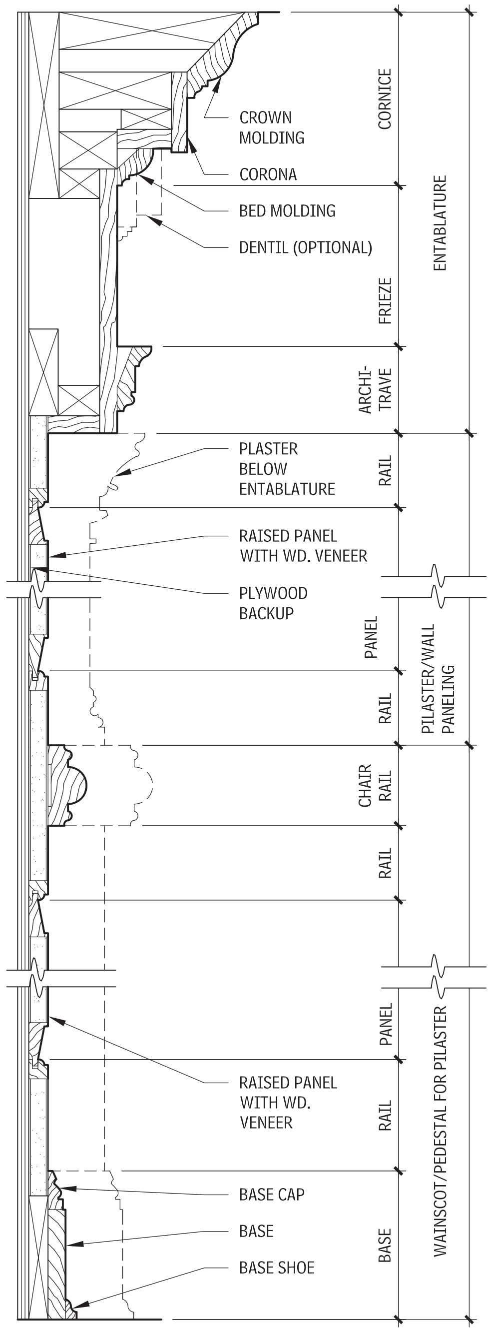
WOOD PANELING

Wood paneling consists of a series of thin sheets of wood panels framed together by strips of wood, vertical stiles, and horizontal rails. Wood paneling includes shop-fabricated wall paneling that may be fabricated as solid lumber paneling, wood veneer paneling, and plastic laminate–faced wood paneling. Board paneling fabricated from standard profile boards is considered finished carpentry, and should not be confused with wood paneling, classified as architectural woodwork.

Wood panels 1 in. thick or less may be solid lumber panels or made from veneer over plywood or composition boards. The stiles and rails are typically made from solid wood or veneered boards. Rim and lip moldings and other trims are made almost exclusively from solid wood.

Mortise and tenon or doweled joints are used to join stile to rail. Stile-to-stile joints at outside corners are spline joints or lock miters; inside corners are butt jointed. Because of its stability, plywood is preferable to solid lumber or other materials as backup.

FULL-HEIGHT WALL PANEL
12.36

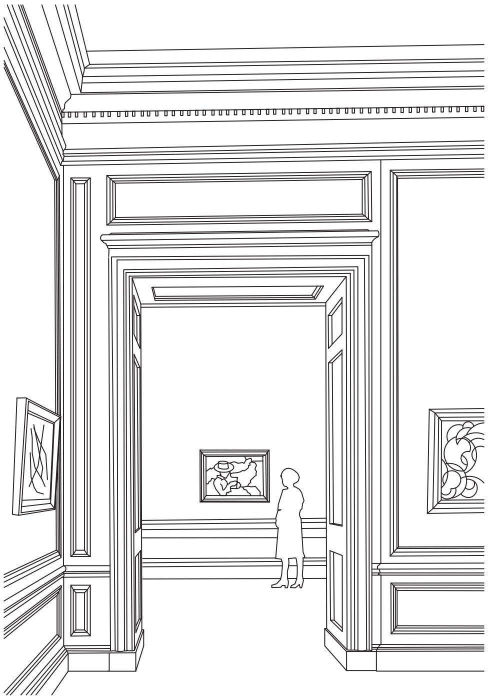


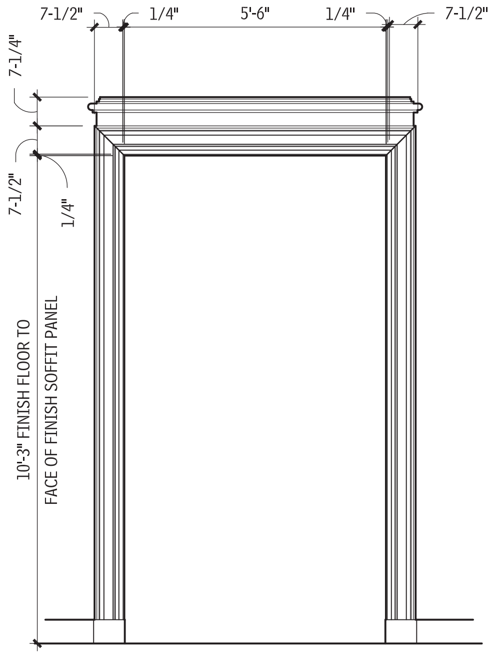
CUSTOM ARCHITECTURAL WOODWORK

Wood veneer wall surfacing that is made-to-order is subject to variables within the room, including doors, windows, and cabinets, as well as overall room dimensions. The use of balanced-matched panels rather than center-balanced-matched panels decreases the variation in leaf width from panel to panel, maximizing grain continuity.

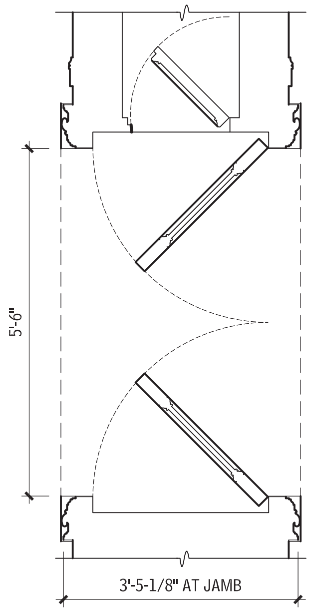
Edge-banding options include veneer banding, inset solid wood bands, or applied solid wood with corner joints. The bottom edge of veneered wall surfacing is edge banded and finished above floor level for durability. Reveals and reveal joints can be designed in a variety of ways.

PANELED PORTAL WITH ACCESS DOORS
12.37

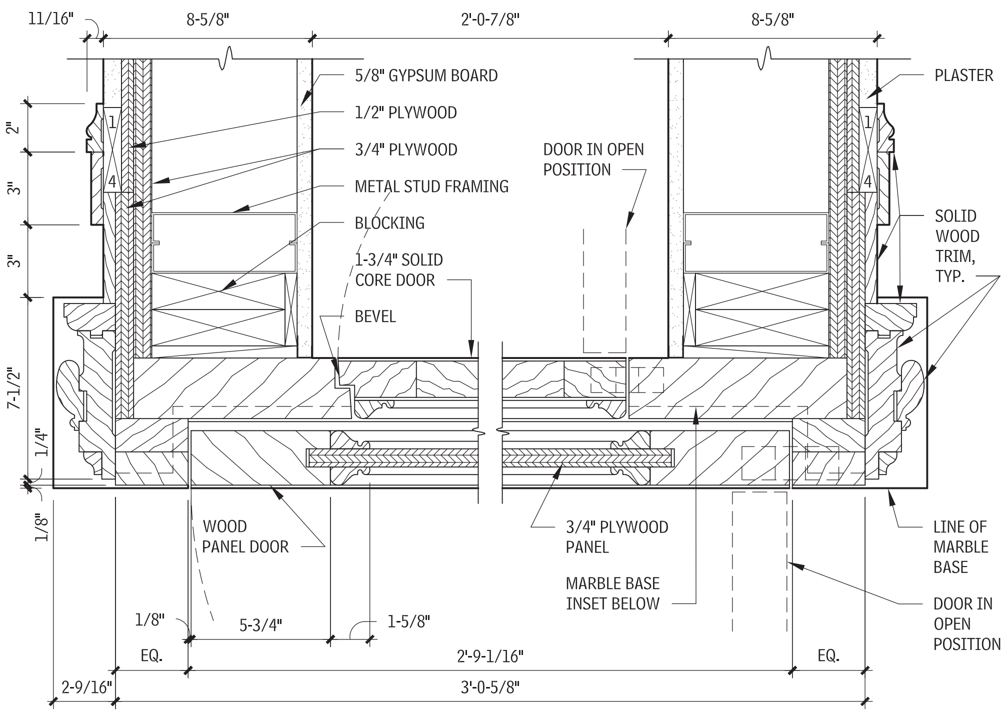




DOOR ELEVATION



PLAN AT DOOR



DOOR JAMB

NOTE

12.37 National Gallery of Art in Washington, DC, designed by the Vitetta Group/Studio Four in Philadelphia, Pennsylvania. The woodworker was Washington Woodworking Company, Inc. of Landover, Maryland. This project was originally published in *Design Solutions*, Summer 1990.

Contributors:
Greg Heuer, Architectural Woodwork Institute, Potomac Falls, Virginia;
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland.

INTERIOR WOOD TRIM

Wood trim is, generally, a decorative treatment applied after wall, floor, and ceiling finishes have been installed. It can be made of flat or molded wood, and can consist of single pieces of wood or be built up of several pieces that give a more complex and decorative appearance. Trims made of MDF with durable plastic finishes are also available.

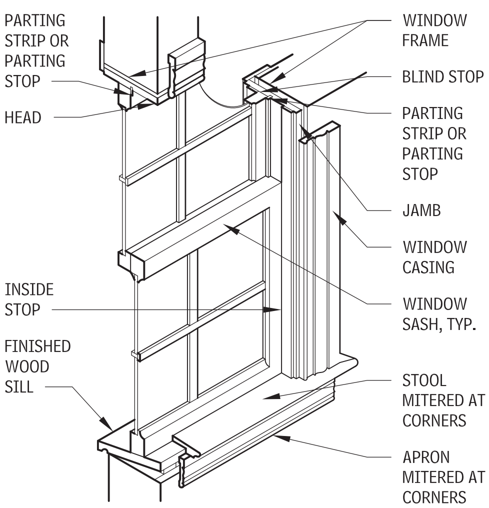
Interior trim conceals joints between different materials and blocks air infiltration through walls, which typically is greatest at material joints. Interior trim also frames wall and ceiling openings (door and window/skylight trim), defines planar edges (crown and base molding), and acts as a visual divider between dissimilar materials (chair rail).

The Architectural Woodwork Institute differentiates wood trim according to its length: Standing trim refers to the trims of fixed length delivered to the job site (i.e., door jambs and casings, window stools, etc.); running trim refers to the trims of random, longer length delivered to the job site (i.e., base, chair rail, crown molding, etc.).

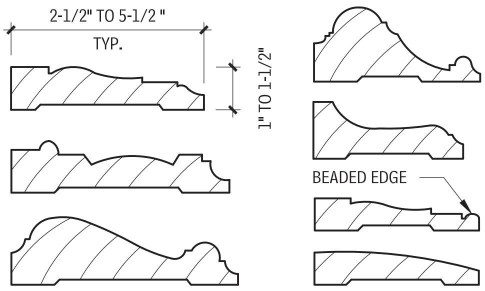
Guidelines for working with interior wood trim include the following:

- Blocking that receives moldings should be set plumb, level, true, and straight, with no distortion, and should be provided for full surface contact. Attach blocking to substrates with nails, screws, or bolts.
- Woodwork should be stored in a dry, ventilated space. If this is not possible, seal the ends of all pieces as soon as possible. Moldings should be at optimum moisture content at the time of installation and should be allowed to acclimate to project conditions before installation.
- Joints in adjacent and related members should be staggered. Cope at inside corners, and miter at outside corners, to produce tight-fitting joints with full surface contact throughout the length of the joint; use scarf joints (face mitered) for end-to-end joints in trim.
- Blind-nail where possible and use finishing nails in exposed areas. Predrill as required to eliminate splitting; set exposed nail heads for filling.
- Most flat trim like bases and casing have a ploughed or relieved back, which gives wide trim a degree of flexibility, allowing it to fit snugly against a wall surface.

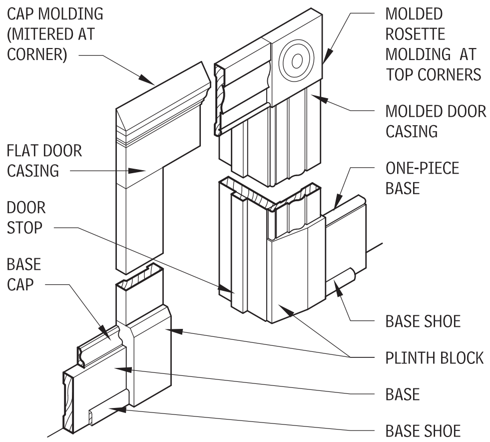
TYPICAL WINDOW TRIM
12.38



TYPICAL CASING PROFILES
12.39



TYPICAL DOOR CASING AND BASE TRIM
12.40



CERAMIC TILE

Ceramic tile is fabricated from clay or a mixture of clay and ceramic materials. Natural clay is most commonly used, but porcelain is also available. Porcelain tile is fine grained and smooth. It can be formed into sharply detailed designs.

Tile dimensions are typically nominal. Ceramic tile thickness is usually 3/8 or 1/2 in. Refer to the manufacturer's data for specific tile and trim piece dimensions.

ANSI A137.1, "Specifications for Ceramic Tile," quantifies the four levels of water absorption for tile. The density and porosity of the tile determine its capability to absorb moisture. In general, the lower the water absorption level, the better the stain resistance of the tile.

TILE COMPOSITION AND GLAZE

Ceramic tile is made from either natural clay or porcelain, and is glazed or unglazed.

- Porcelain tile is a ceramic mosaic or paver tile generally made by the dust-pressed method. It is dense, impervious, fine grained, and smooth with a sharply formed face.
- Natural clay tile is a ceramic mosaic or paver tile with a distinctive, slightly textured appearance. It is made by the dust-pressed or plastic method from clays that have a dense body.
- Glazed tile has an impervious facial finish of ceramic materials that is fused to the body of the tile. The body may be nonvitreous, semivitreous, vitreous, or impervious.
- Unglazed tile is a hard, dense tile of uniform composition that derives color and texture from the materials used in its fabrication.

WALL TILE TYPES

Ceramic wall tiles are modular surfacing units of fired clay and other ceramic materials. They provide a permanent, durable, waterproof surface for interior walls, and are available in bright or matte glazes in a wide range of colors and surface designs. Wall tiles are usually 5/16 in. They are available in square, hexagon, and octagon shapes, as well as some custom shapes.

Glazed ceramic wall tiles have a nonvitreous body and bright, matte, or crystalline glazes that are impervious to water. Decorative thin wall tile is glazed tile with a thin, usually nonvitreous body intended for decorative interior residential use. Because it is not resistant to breakage, it is not recommended for commercial applications or use on floors.

Cementitious backer boards made of portland cement or treated gypsum and lightweight aggregate can be used under thinset tile and as a water-resistant base for tile regularly exposed to water (such as a shower surround).

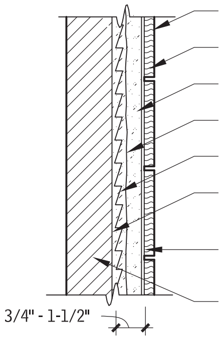
Standard sizes for ceramic wall tiles include:

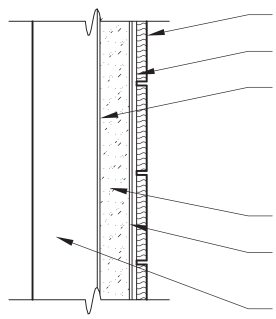
- 4-1/4 by 4-1/4 in.
- 4-1/4 by 6 in.
- 6 by 6 in.

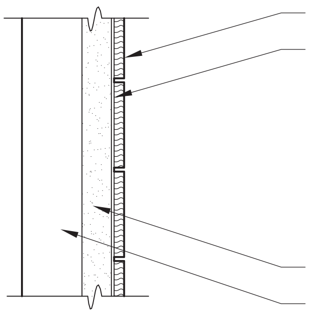
WATER ABSORBTION OF CERAMIC TILE
12.41

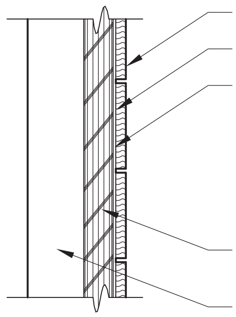
TYPE	WATER ABSORPTION	CERAMIC MATERIAL	USE
Nonvitreous	More than 7%	Natural clay	Not for use in continually wet locations
Semivitreous	More than 3%, but not more than 7%	Natural clay	Not for use in continually wet locations
Vitreous	0.5–3%	Natural clay	For use in continually wet locations
Impervious	0.5% or less	Porcelain	For use in continually wet locations; superior wear resistance

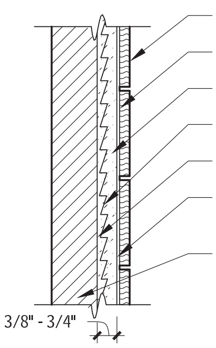
CERAMIC TILE INSTALLATIONS
12.42











WALL TILE TRIM SHAPES

Ceramic wall tiles come in a variety of trim shapes for finished angles and edges. A sanitary base is a coved tile set at the intersection of the floor and wall. Its curved angle helps to prevent dirt from accumulating and makes cleaning easier.

Ceramic wall tile trim pieces include:

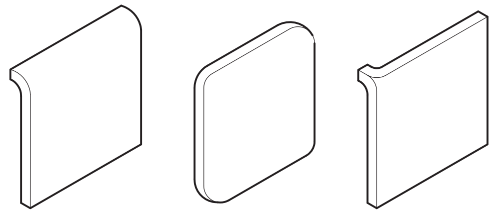
Bead: Rounded horizontal bead for top edges
Bullnose:

- Surface bullnose with a flat bottom and eased top edge
- Surface cap with a flat bottom and rounded top edge, used horizontally or vertically
- Corner bullnose with two rounded finished edges to complete a corner where horizontal and vertical bullnoses meet

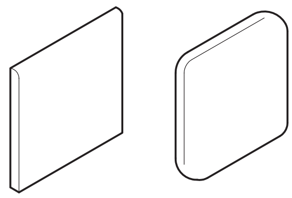
Curb: Tile curb for horizontal use
Base:

- Cove base to connect to floor tile
- Stack-on cove base with coving on the bottom and a flat edge on the top to accommodate wall tile
- Rounded top cove base, used where wall tile is not installed above the base
- Surface base with a coved lower edge and an eased top edge

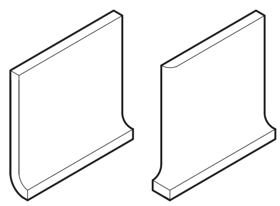
WALL TRIM SHAPES
12.43



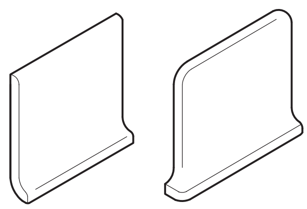
BULLNOSES FOR THICKSET INSTALLATIONS



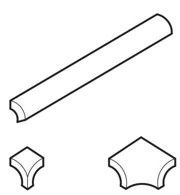
BULLNOSES FOR THINSET INSTALLATIONS



COVE BASES



SANITARY COVE BASES (ROUND TOP)



BEADS

NOTE

12.42 Tile Council of North America, Inc., Anderson, South Carolina;

Contributor:
Corky Binggeli, *Materials for Interior Environments*, John Wiley & Sons, New York, 2008.

STONE WALL PANELS

TYPES OF STONE

GRANITE
Granite can be used on interior walls in many finishes, ranging from highly polished to a rough thermal finish. A water jet finish is a texture between honed and thermal that brings out the color of the stone. It will appear slightly darker than a thermal finish. Granite is much harder than marble, and is therefore more costly to fabricate and finish.

MARBLE
Marble varieties that are not recommended for exterior use can be successfully used in interior wall panel applications, if properly prepared for vertical installations. Heavily veined marbles, prized for their aesthetic qualities, are examples. Dry seams can be glued together (sticking), voids can be filled (waxing), and weak areas can be reinforced with metal rods glued into the back of the stone panel (rodding). During fabrication, fragile marbles are frequently reinforced with a layer of fiberglass-reinforced plastic prior to final fabrication and polishing of the marble.

SERPENTINE MARBLE
Green varieties of marble, called serpentine marble, are sensitive to water and are prone to warping when wet. When installing serpentine stone, use setting materials that do not contain water, such as water-cleanable epoxy adhesives.

GREENSTONE
Greenstone, a general term for metamorphosed igneous basaltic type rock, is typically available in honed or cleft finishes, and is not suitable for a highly polished finish, due to the stone structure. Greenstone contains minerals that give it a green appearance: actinolite, chlorite, or epidote. Sources are usually European, as it is no longer quarried in the United States.

DOLOMITIC LIMESTONE
Dolomitic limestone is more widely used for interior stone facing, as it is typically not as porous as oolitic limestone (which contains small spheres of calcium carbonate formed around sand grains or shell fragments), and is often polished similar to marble. It is also available with a smooth honed finish, a textured sandblasted finish, or a split-face finish.

SLATE
Slate is commonly used as a contemporary interior floor or wall finish. It is available in a palette of dark, rich colors, including green, black, purple, and red. Slate splits easily into thin sheets. The finish resulting from the natural face is referred to as a cleft finish. Slate can also be sand-rubbed to a smooth or honed finish.

TRAVERTINE
Travertine is distinguished by its natural cavities, formed by plants embedded during the rock's formation, which must be filled to achieve a smooth surface. Filling materials are typically portland cement, epoxy resins, or polyester resins. Travertine is actually a kind of limestone, but some types that take a polish are classified as marble. It is popular for use as flooring because its visual texture conceals dirt much better than most other stones.

STONE FACING

Numerous types of stones can be used for stone facing; however, consideration should be given to the selection of a stone that is appropriate for the intended use. Stone facing typically does not need to meet the rigorous performance criteria of stone flooring, but care should be taken to select a stone that can be cut and dressed to meet the project's design. A review with the stone fabricator or supplier is recommended to minimize the risk of incompatibility of the stone with the intended use.

Stone facing is available in two basic types: dimension stone panels and dimension stone tiles. Marbles and other stones that might be considered too soft for flooring can usually be used for stone facing, with the proper reinforcement and installation.

DIMENSION STONE PANELS

Dimension stone is defined as quarried stone with usually one or more mechanically dressed surfaces. These are thick slabs of stone that are marked as they are cut for matched-pattern installations, such as book-matched or end-matched configurations. Dimension stone facing panel dimensions typically range from larger-dimension units with face areas up to 48 sq. in. and 3/4 in. or more thick. Sizes and shapes are limited to the specific stone's characteristics. A panel that is 2 ft-6 in. by 5 ft-0 in. is a size that stone fabricators can easily handle, and it conforms to the 5-ft module of many buildings.

DIMENSION STONE TILES
Stone tiles are fabricated under different conditions from dimension stone panels and are not typically matched to create patterns, such as book matching or end matching. The greater variation in stone color, pattern, and texture is common in stone tile, and should be factored into the project review prior to installation.

Stone tile modules are dimension stone units that do not exceed 4 sq. ft. and are less than 3/4 in. thick. Stone tiles are typically 12 by 12 in. up to 24 by 24 in., and 1/4, 3/8, or 1/2 in. thick. They are usually furnished with a protective backing such as fiberglass to improve their strength. Larger stone tile sizes are offered by selected manufacturers.

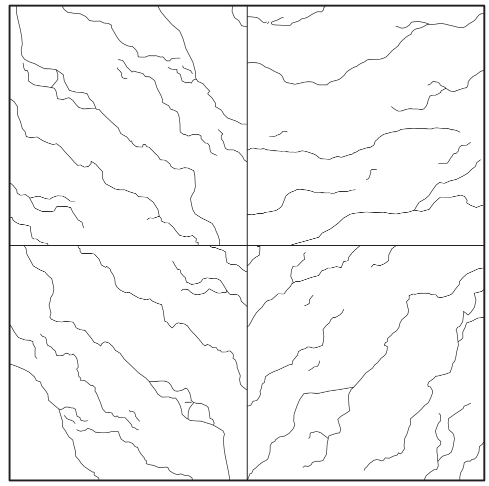
Granite and marble stone tiles 1/4 to 1/2 in. thick are available, usually with a face dimension of 12 by 12 in. Tiles can be directly applied to a wall with adhesive or thinset mortar, similar to flooring applications. Tiles are not recommended for walls over 8 ft. high.

MARBLE WALL FACING

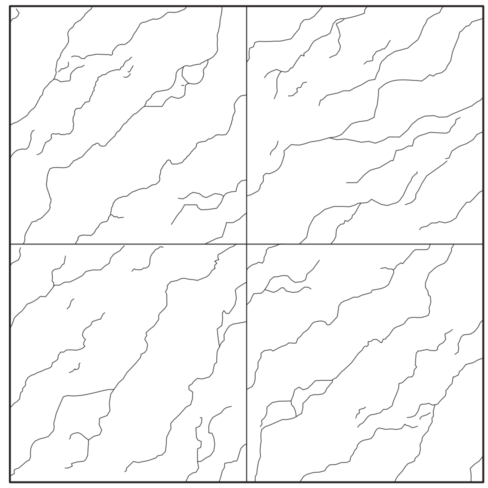
PATTERNS
Stone with distinctive texture and markings, such as certain marbles, lends itself to specific pattern arrangements. The markings vary depending on whether the marble veneer is cut with or across its setting bed. Dimension stone panels are available in the following patterns:

- *Blend pattern:* Panels of the same variety of stone but not necessarily from the same block are arranged at random.
- *Side-slip pattern:* Panels from the same block are placed side by side or end to end in sequence, to ensure a repetitive pattern and blended color.
- *End-matched pattern:* Adjacent panel faces are finished, and one panel is inverted and placed above the other.
- *Book-matched pattern:* Adjacent panel faces are finished, and one panel is placed next to the other.

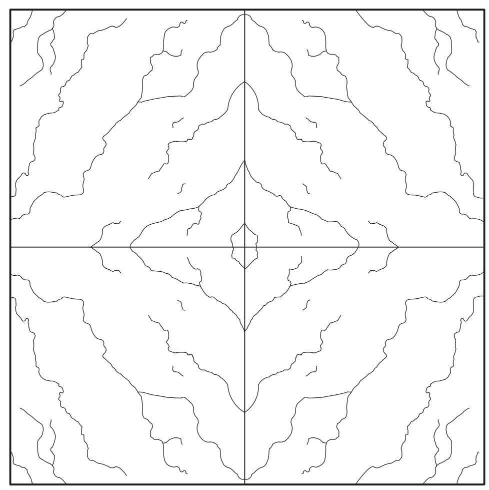
MARBLE WALL FACING PATTERNS
12.44



BLEND PATTERN



SIDE-SLIP OR END PATTERN



END-MATCHED, BOOK-MATCHED, OR QUARTER-MATCHED PATTERNS

VENEER CUTTING

Marble quarry blocks are reduced to slabs by a gang saw consisting of a series of parallel steel blades that move forward and backward in a frame. The most productive and precise gang saws use diamond-tipped blades with individual hydraulic blade tensioners; others are fed a cutting abrasive in a stream of water.

Marble blocks can be sawn either parallel or perpendicular to the bedding plane. The perpendicular cut is referred to as an across-the-bed, or vein, cut. The parallel cut is a with-the-bed, or Fleuri, cut. Other marbles produce a pleasing surface only when sawn in one direction, and are generally available only in that variety.

VENEER PATTERNS

Only certain marbles lend themselves to specific pattern arrangements, such as side slip or end slip, which require a constant natural marking trend throughout the marble block. Formal patterns require selectivity, which usually increases the installed cost of the marble veneer. Usually, material sawn for a vein cut can be matched. Fleuri cuts can only be blended.

Perfection in veneer matching is impossible because a portion of the marble block is lost during the sawing process, and because the vein shifts. Ideally, jointing should be planned for groupings of four panels of equal size.

ENGINEERED COMPOSITE STONE

New technology has enabled the development of engineered composite stone products. Formulated from stone aggregate and synthetic resin matrix materials, these products are available in sizes ranging from tile units to large panel sheets for horizontal and vertical applications. Composite stone characteristics are strength, nonporosity, durability, and flexibility. Finishes are typically limited to polished finishes; colors range from natural stone tones to vibrant colors. Thicknesses vary, and due to the strength of the composite units, can sometimes be thinner than natural dimension stone. Typical sheet sizes are 3/4 or 1-1/8 in.; 3/8-in.-thick sheet panels may also be available. Tile units are installed with the same thinset methods as for ceramic tile.

ABRASION RESISTANCE

Abrasion resistance is the capability of the stone to resist wear and absorption, which affects staining and soiling of the stone. For interior stone facing, abrasion resistance is typically not a factor, unless the stone will be subjected to frequent bumping and scraping. Consult with the stone fabricator or supplier for the selection of appropriate stone types for a particular installation and intended use.

INSTALLATION OF STONE PANELS

ANCHORING SYSTEMS

Wire-tie anchoring systems with plaster or mortar spots are the traditional methods for installing interior stone facing. Mechanical anchoring systems fasten stone directly to the backup wall, eliminating the need for additional studding and gypsum board and providing verifiable seismic restraint.

WIRE TIES

Wire ties are anchored to the gypsum board, masonry, or concrete wall. In gypsum board construction, wire ties are embedded in plaster-filled metal boxes or are inserted through the gypsum board and are fastened to the partition framing. In masonry walls, the wire ties are embedded in voids filled with mortar or plaster.

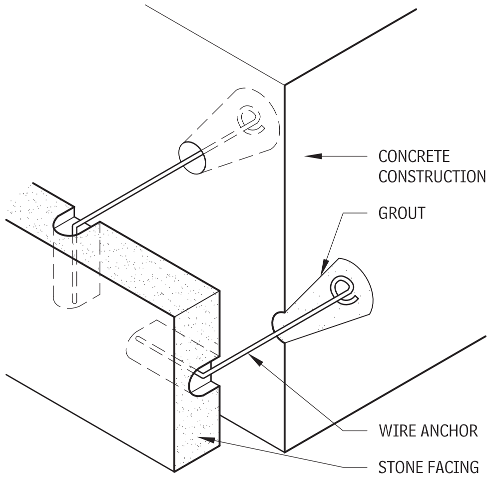
The disadvantages of wire-tie anchoring systems are twofold: First, fire-rated gypsum board walls require another row of metal studs and another layer of gypsum board if the wire ties are not allowed to penetrate the fire-rated wall; second, seismic restraint for the stone panels is difficult to engineer.

A minimum of four anchors should be provided for stone panels up to 12 sq. ft., with two additional anchors for each additional 8 sq. ft. of surface area. For stone facing panels over 96 in. high, the wire-tie method must be supplemented with intermediate horizontal supports for the vertical stone loads.

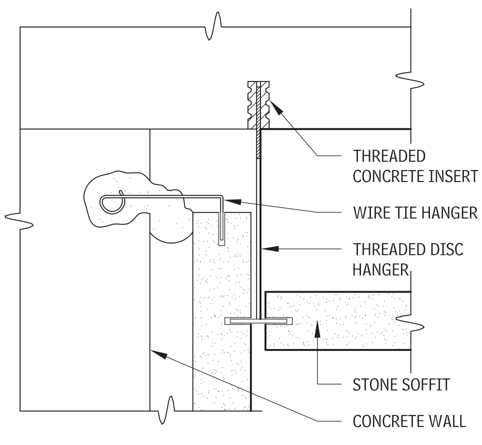
TYPICAL FINISHES AND COMMON SIZES OF INTERIOR STONE WALL PANELS
12.45

STONE	GRADE	FINISH	MINIMUM THICKNESS	MAXIMUM FACE DIMENSION	NOTES
Granite	Building (exterior)	Polished	3/4″ to 1-1/4″	5′-0″ × 5′-0″	This very hard and durable surface is not likely to stain. Many colors and grains are available.
	Veneer	Honed			
	Masonry				
Marble	Group A (exterior)	Polished	1/2″ to 7/8″	4′-0″ × 7′-0″	The most colorful and interesting marbles are in Groups B, C, and D; however, some filling of natural voids may be required. Many colors and patterns are available.
	Group B	Honed			
	Group C				
	Group D				
Limestone	Select	Smooth	7/8″ to 3″	4′-0″ × 9′-0″	Soft and easy to shape, but shows wear and may discolor over time. Colors range in the buffs and grays.
	Standard	Tooled			
	Rustic	Polished			
	Variegated				
Slate	Ribbon	Natural	1″ to 1-1/2″	2′-6″ × 5′-0″	Ribbon stock is distinguished by its ornamental integral bands, which are usually darker than the rest of the stone. Colors range in the pastel hues.
	Clear	Cleft			
		Sand			
		Rubbed			
		Honed			

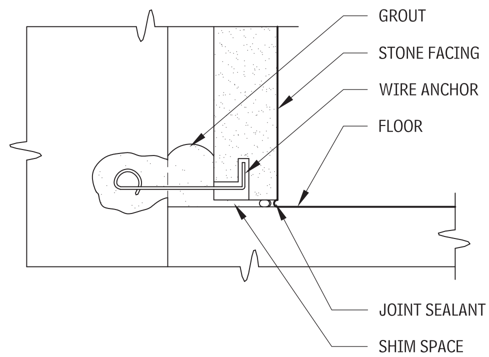
STONE FACING WIRE ANCHOR CONNECTION
12.46



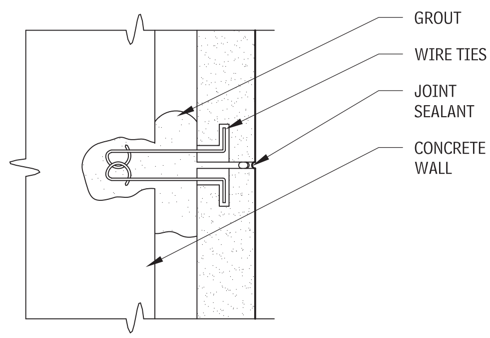
SOFFIT DETAIL AT WALL
12.47



BASE DETAIL
12.48



VERTICAL JOINT DETAIL
12.49



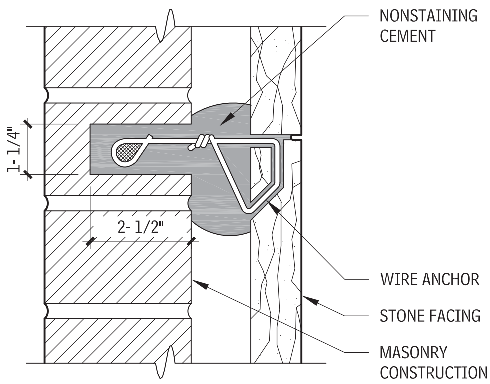
MECHANICAL ANCHORING SYSTEMS

In mechanical anchoring systems, the stone is kerfed (grooved or notched) on the back side and is restrained by the use of straps or clips. Anchor systems similar to those used for exterior work over masonry or metal framing may be fastened to metal studs through gypsum board. Exterior anchors may also be used with metal channel struts, eliminating the need to coordinate stud locations with anchor locations. This type of anchor may still require plaster-setting spots.

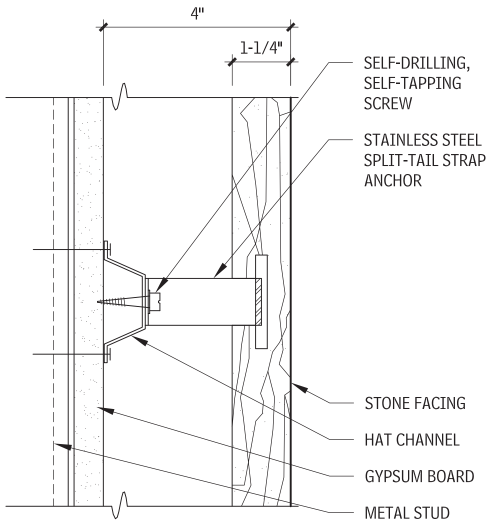
NOTE

12.46 Wire ties are not recommended for Indiana limestone.

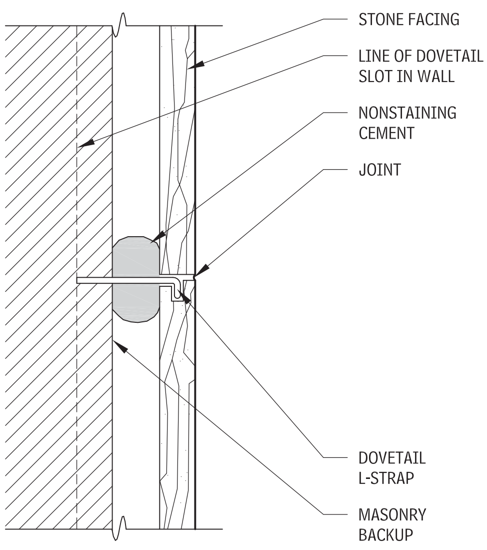
WIRE LACE ANCHOR
12.50



STRAP ANCHOR
12.51



DOVETAIL ANCHOR
12.52



GROUT
Grout for interior stone facing is commonly mixed with latex additives, which produces a more flexible and durable joint installation. The stone industry references ANSI standards for ceramic tile—grouting materials. Dryset grouts are mixtures of portland cement and water-retentive additives. Unsanded grouts are typically used in joints up to 1/8 in. wide. Wider grout joints are typically sanded, as the sand reduces grout shrinkage and minimizes cracking. When installing sanded grout on polished stone surfaces, protect the stone face to avoid scratching the surface finish.

JOINT SIZES
Joint sizes vary depending on the type of stone and finish selected and whether joints are to be coordinated with exterior or floor joints. For polished stone installations, joints from 1/16 to 1/8 in. wide are used. Currently, the wider joint size is prevalent to allow for more latitude in fabrication dimensions and in backup construction dimensions. For highly textured stone finishes, such as a thermal or cleft finish, a joint width of 1/4 to 3/8 in. is common. The larger joint dimension minimizes the visibility of lipping of stone panels. When combining different stone textures, one size joint for the entire installation is recommended, usually the largest required for the different textures.

LIPPAGE
Lippage is the condition where one panel is higher than adjacent panels; it is more common in thinset installations. The recommended maximum variation of the finished stone surface should be no greater than 1/8 in. cumulative over a 10 ft. lineal measurement, with no greater than a 1/32-in. variation between individual tiles or panels. Each interior stone facing project should be reviewed to determine the best method of installation for the installation conditions. Setting space dimensions and project conditions may indicate the use of a particular installation method.

INSTALLATION OF STONE TILE
Stone tile may be installed in a full mortar bed, in a thinset mortar bed, or with an adhesive. Thin stone tiles are typically not restrained by ties or anchors; therefore, their installation has limitations.

Tiles that are installed above 8 ft. high must be additionally restrained with anchors. Interior stone anchoring systems must be compatible with the stone and substrate. Stone facing may be installed on gypsum board construction, masonry, or concrete walls. Butt joints are not recommended due to potential spalling (surface chipping or scaling) if movement occurs in the structure.

MORTAR BEDS
Mortar beds can be used when installing thin stone tiles and thin panels in a thick portland cement mortar system consisting of metal lath, a scratch coat, and a float coat. The stone tile is set into the float coat.

THINSET BEDS
Thinset installations are appropriate for vertical application of stone tiles and thin panels up to 1/2 in. thick. The stone is set in the same manner as ceramic tiles, directly on the substrate of gypsum board or cementitious backer units, using specific thin-bed setting systems. Adhesives used with thinset installations should be nonstaining, especially when installing light-colored stone.

GYPSUM BOARD

GYPSUM BOARD
Gypsum board (also called sheet rock or gyp board) is the generic name for a family of sheet products consisting of a noncombustible gypsum core faced with a paper surface. Certain gypsum board assemblies provide fire resistance and sound transmission reduction of varying degrees. Gypsum board may be finished with paint or other applied finish materials, such as a wallcovering, wood, or tile.

Design professionals should make sure that their specifications use the correct designation, ASTM C 1396, "Standard Specification for Gypsum Board," so that they are in compliance with both industry standards and code language. This standard consolidates and replaces ASTM standards C 36, C 79, C 442, C 630, C 931, and C 960.

Mold and moisture dynamics have grown as increasingly important design and specification concerns with materials that have absorptive characteristics and are prone to mold and mildew problems. Gypsum board must be properly installed, finished, and provided with adequately designed and operated climate control systems to avoid these problems.

The North American gypsum industry has developed a responsible and environmentally conscious attitude toward issues of reclamation, preservation of natural resources, recycling and waste management, and otherwise protecting the environment. Over 90 percent of the gypsum board paper used comes from recycled materials. The industry increasingly uses synthetic gypsum to manufacture gypsum board. This raw material is a by-product, or waste, from other manufacturing processes as well as the desulfurization of flue gases in fossil fuel power plants.

GYPSUM BOARD TYPES
A number of specialized gypsum panel products and gypsum boards have been developed for specific uses, including:

- Gypsum wallboard for interior walls and ceilings
- Gypsum ceiling board for interior ceilings, 1/2 in. thick, with a sag resistance equal to 5/8-in. wallboard
- Type X gypsum board for fire-resistance-rated building systems
- Fiber-reinforced gypsum panels for interior and exterior walls, ceilings, and tile base
- Gypsum sheathing for exterior walls and roof systems
- Glass mat gypsum substrate for use as sheathing on exterior walls and ceilings
- Gypsum soffit board for use on exterior soffits and ceilings
- Water-resistant gypsum backing board (green board) for use as a tile base and in wet areas (contingent on building code restrictions) where wetting is intermittent
- Glass mat water-resistant gypsum backing board for use as a tile base and in wet areas (contingent on building code restrictions) and where moisture and direct water flow are present
- Gypsum backing board for use as a base for multi-ply systems
- Gypsum lath for use as a base for gypsum plaster; available in 16-in. widths
- Gypsum plaster base (blue board) for use as a base for veneer plaster
- Gypsum shaft liner board for shaft, stairway, and duct enclosures
- Predecorated gypsum board for accent walls, offices, and movable partitions
- Foil-backed gypsum board for use as a vapor retarder
- Gypsum fiber underlayment for use in residential floor construction
- Fiber-reinforced panel, 1/4 to 3/8 in. thick

Not all types of gypsum panel products are available in all lengths, widths, and thicknesses. Metric (SI) thicknesses are the industry-accepted metric designations for gypsum panel product thicknesses.

Contact the manufacturer for the availability of gypsum panel products in hard metric (SI) widths and lengths.

TYPICAL BOARD USES AND SIZES
12.53

	TYPICAL USES		
THICKNESS	LENGTHS	WIDTH	
1/4″	Remodeling, double-layer walls, curved surfaces, sound attenuation	48″	8′-0″, 9′-0″, 10′-0″
5/16″	Manufactured housing walls and ceilings	48″	8′-0″, 9′-0″, 10′-0″, 12′-0″
3/8″	Remodeling, base for rigid panels, double-layer walls and ceilings, curved surfaces	48″	8′-0″, 9′-0″, 10′-0″
1/2″	Any interior and some protected exterior uses	48″	8′-0″, 9′-0″, 10′-0″, 12′-0″, 14′-0″, 16′-0″
		12′-0″ also available 54″	
5/8″	Any interior and some protected exterior uses	48″	8′-0″, 9′-0″, 10′-0″, 12′-0″, 14′-0″, 16′-0″
		12′-0″ also available 54″	
3/4″	Interior walls, shaft walls, area separation walls, party walls, fire walls, stairways, duct enclosures	24″, 48″	8′-0″, 9′-0″, 10′-0″, 12′-0″
1″	Interior walls, shaft walls, area separation walls, party walls, fire walls, stairways, duct enclosures	24″	8′-0″, 9′-0″, 10′-0″, 12′-0″

TYPES OF EDGES
Gypsum board sheets come in a variety of edge types. These include:

- Square
- Tapered
- Rounded tapered
- Beveled
- Double beveled
- "V" tongue and groove

GYPSUM BOARD BEAD AND TRIM

ACCESSORIES

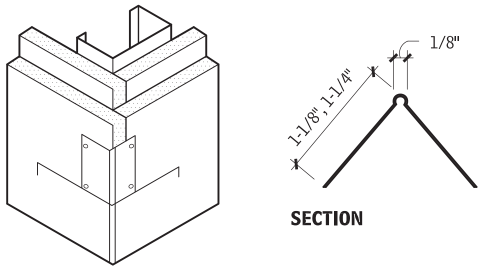
PAPER-FACED METAL BEAD AND TRIM
Paper-faced metal bead and trim is applied using setting-type, taping, or all-purpose joint compound instead of nails to bond the bead to gypsum panel surfaces.

METAL BEAD
Metal bead is screwed, nailed, stapled, or attached with a clinch-on tool to framing through the panels and concealed with joint compound. The exposed nose of the bead helps prevent outside corner damage from impact and provides a screed for finishing. Consult manufacturer's literature for proper use and installation.

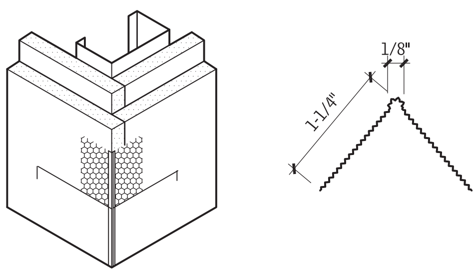
PAPER-FACED METAL GYPSUM BOARD ACCESSORIES
12.54

TYPE	USE	DESCRIPTION
Outside corner tape-on bead	90° outside corners	Any wallboard thickness
Inside corner tape-on trim	True 90° inside corner	Any wallboard thickness
Offset outside corner tape-on bead	135° outside corners	Any wallboard thickness; smaller bead height for less joint compound fill
Offset inside corner tape-on bead	Inside corners greater than 90°	Any wallboard thickness
3/4″ bullnose outside corner tape-on bead	Rounded 3/4″ radius, 90° corner angle	Gypsum panels 1/2″ or 5/8″ thick
Inner cove tape-on trim	Rounded 3/4″ radius, 90° inside corner	Gypsum panels 1/2″ or 5/8″ thick
Bullnose offset outside corner tape-on bead	Rounded 135° offset outside corner	Used for bay windows and similar applications
Offset inner cove tape-on trim	135° inside corners	Forms smooth cove
1-1/2″ bullnose outside corner (Danish) tape-on bead	Broader, gentler corner than 3/4″ radius bullnose	Gypsum panels 1/2″ or 5/8″ thick
Corner reinforcing tape	Flexible tape for straight, sharp corners at any angle	Cathedral and drop ceilings, arches, around bay windows; also used to join drywall partition to plastered wall in remodeling, and for repairing chipped and cracked corners
L-shaped tape-on trim	Used where wallboard abuts other surfaces	Joints at suspended ceilings, beams, plaster, masonry and concrete walls; also untrimmed door and window jambs
J-shaped tape-on trim	Used to finish rough gypsum board panel ends	Used at window and door openings and casements
Outside corner microbead	Reduced height results in less joint compound consumption	Extra-wide flanges for maximum corner coverage
Reveal tape-on trim	Solves problems with reveals on soffits, wall offsets, ceilings, light boxes, other architectural features	Paper flange on both trim legs eliminates need to caulk edge of reveal details; provides cleaner, straighter line

GALVINIZED STEEL REINFORCEMENT EXTERNAL CORNER PROTECTION
12.55

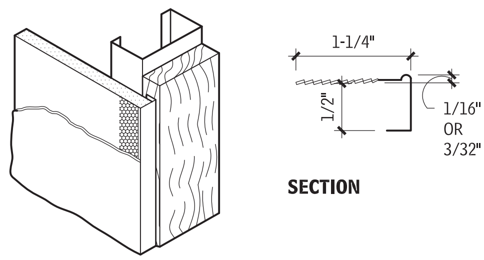


EXPANDED FLANGE CORNER BEAD
12.56



METAL TRIM
Metal trim is applied similarly to metal bead and provides protection and neat finished edges to gypsum panels. Consult manufacturer's literature for proper use and installation.

METAL TRIM FOR VENEERED PLASTER AT CASED OPENINGS
12.57



NOTES

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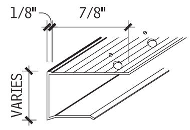
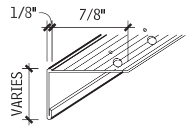
12.57 Copyrighted work of USG Corporation, *USG Gypsum Construction Handbook*, 6th ed., p. 214, R.S. Means Company, Inc., Kingston, Massachusetts, 2009.

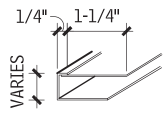
GYPSUM BOARD ACCESSORIES
12.58



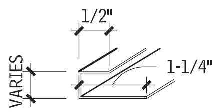
METAL EDGE TRIM SCREWED



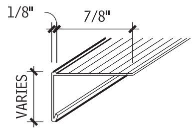
METAL EDGE TRIM L-SHAPED SCREWED



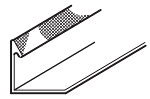
METAL EDGE TRIM 1-1/4" FLANGE



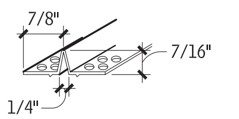
METAL EDGE TRIM J-SHAPED



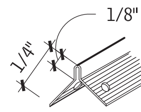
METAL EDGE TRIM L-SHAPED



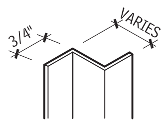
PREFINISHED CORNER



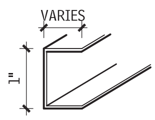
CONTROL JOINT



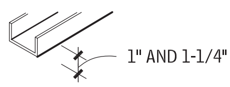
METAL THIN-COAT BEAD



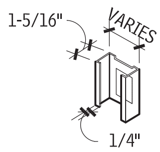
Z-FURRING CHANNEL



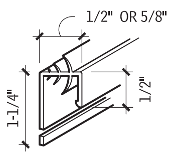
COLD-ROLLED CHANNEL



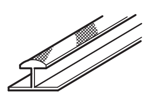
METAL RUNNER



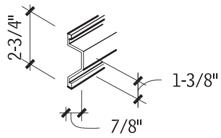
METAL STUD



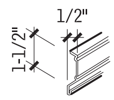
VINYL TRIM



PREFINISHED DIVIDER



METAL FURRING CHANNEL



METAL-RESILIENT CHANNEL

REINFORCING TAPES

Joint tape is for use with joint compounds in the reinforcement and concealment of flat joints and inside corners. It is approximately 2 to 2-1/2 in. wide and comes in various roll lengths ranging from 75 to 500 ft. Consult manufacturer's literature for proper use and installation.

There are generally two types of products:

- Paper tape for treatment with joint compounds is designed for both embedding by hand and application with a mechanical taping tool; joint is covered with a thin layer of compound before taping.
- Glass fiber tape for veneer plaster finishes comes with a pressure-sensitive adhesive backing or plain back for fastening with staples. Typically used when one-day joint finishing is required.

FINISHES

Gypsum board panels are finished using reinforcing tapes and gypsum board taping, topping, or all-purpose compounds. Products are available in site-mixed or ready-mixed formulations.

Taping compounds are designed for embedding tape. They have excellent bond and crack resistance but are harder to sand and finish than topping or all-purpose compounds.

All-purpose joint compounds are good for taping, topping, and repairing cracks. They perform with versatility for use as tape, finish, texture, laminate, or skim coat applications.

Topping compounds, which have low shrinkage and are easy to apply and sand, are most suitable for second- and third-coat applications.

- *Level 0:* Temporary construction or where final finish has not been determined.
- *Level 1:* Frequently specified in plenum areas above ceilings, in attics, where assembly is concealed, or in building service corridors and other areas not normally open to public view. Some degree of sound and smoke control is provided; sometimes referred to as fire taping. Where a fire-resistance rating is required for gypsum board assembly, details of construction should be in accordance with reports of fire tests of assemblies that have met the fire-rating requirement.
- *Level 2:* Specified where water-resistant gypsum backing board (ASTM C 1396) is used as a substrate for tile. May also be specified in garages, warehouse storage, or other similar areas where surface appearance is not of primary concern.
- *Level 3:* Typically specified in appearance areas that are to receive heavy- or medium-texture sprayed or hand-applied finishes before final painting or where heavy-grade wallcoverings are to be applied. Not recommended where smooth painted surfaces or light- to medium-weight wallcoverings are specified.
- *Level 4:* Specified where flat paints, light textures, or wallcoverings are to be applied. In critical lighting areas, flat paints applied over light textures tend to reduce joint photographing. Gloss, semi-gloss, and enamel paints are not recommended over this level of finish. Carefully evaluate weight, texture, and sheen level of wallcoverings. Joints and fasteners must be adequately covered with wallcovering material that is lightweight, and which has limited pattern or a gloss finish. Unbacked vinyl wallcoverings are not recommended.
- *Level 5:* Highly recommended where gloss, semigloss, enamel, or nontextured flat paints are specified or where severe lighting conditions occur. This highest-quality finish is the most effective method to provide a uniform surface and minimize the possibility of joint photographing and of fasteners showing through the final decoration.

GYPSUM BOARD FINISH LEVELS
12.59

LEVEL	JOINTS AND INTERIOR ANGLES	ACCESSORIES	FASTENERS	SURFACE
0	No taping, finishing, or accessories required			
1	Tape set in joint compound	Optional in corridors, other areas with pedestrian traffic	Tape and fastener heads need not be covered with joint compound	Tool marks and ridges acceptable; surface free of excess joint compound
2	Tape embedded in joint compound and wiped with a joint knife, leaving a thin coat of compound over all joints and interior angles	Covered by one separate coat of joint compound	Covered by one separate coat of joint compound	Tool marks and ridges acceptable; surface free of excess joint compound. Joint compound applied over body of tape at time of embedment shall be considered a separate coat of joint compound and shall satisfy conditions of this level.
3	Taped as in Level 2, then covered with one separate coat of joint compound	Covered by two separate coats of joint compound	Covered by two separate coats of joint compound	Joint compound smooth and free of tool marks and ridges. Recommended that prepared surface be coated with a drywall primer prior to application of final finishes. Refer to painting/ wallcovering specification.
4	Taped as in Level 2, then covered with two separate coats of joint compound over all flat joints and one separate coat applied over interior angles	Covered by three separate coats of joint compound	Covered by three separate coats of joint compound	Joint compound smooth and free of tool marks and ridges. Recommended that prepared surface be coated with a drywall primer prior to application of final finishes. Refer to painting/ wallcovering specification.
5	Taped as in Level 2, then covered with two separate coats of joint compound over all flat joints and one separate coat applied over interior angles	Covered by three separate coats of joint compound	Covered by three separate coats of joint compound	Thin skim coat of joint compound trowel-applied or material manufactured especially for this purpose applied to entire surface. Surface smooth and free of tool marks and ridges. Recommended that prepared surface be coated with a drywall primer prior to application of final finishes. Refer to painting specification.

NOTE

12.59 Adapted from Gypsum Association, www.gypsum.org.

Contributor:
Del Shuford, AIA, Gensler, Dallas, Texas.

PLASTER

PLASTER WALL FINISHES

For centuries, prior to the advent of gypsum board, plaster was the primary interior wall and ceiling finish. Conventional plaster provides superior wear resistance to gypsum board assemblies, and is preferred to attain a uniform, monolithic surface; however, plaster finishes are more labor-intensive, require greater skill, and can take as long as two days to cure, compared to gypsum board assemblies. For these reasons, plaster finishes are most commonly used in restoration to match existing conditions and in high-end installations.

Three-coat plaster applications are required on all metal lath and on edge-supported gypsum lath used in ceilings. In addition, three-coat applications are preferred, although two-coat applications are acceptable where gypsum lath is properly supported, and on masonry plaster bases such as porous brick, clay tiles, and rough concrete masonry units.

Keene's cement plaster is a specialty finish coat of gypsum plaster primarily used where a smooth, dense, vandal-resistant, white finish is desired.

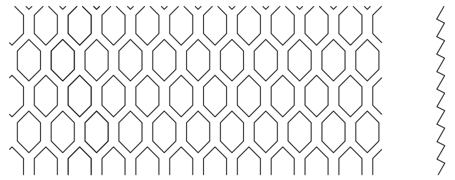
Thickness, proportion of mixes of various plastering materials, and finishes vary. Methods of application also vary widely, depending on local traditions and innovations promoted by the industry.

PLASTER TERMINOLOGY

When working with plaster, it is important to know these terms:

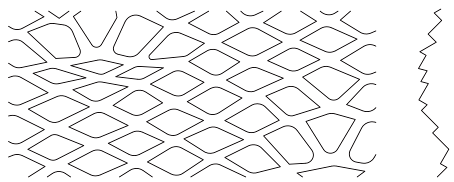
- *Basecoat:* A plaster coat applied before finish coat, scratch coat, and blow coats in three-coat plaster.
- *Brown coat:* In three-coat plaster, the second coat; in two-coat plaster, the first coat.
- *Fibered plaster:* Gypsum plaster containing fibers of hair, glass, nylon, or sisal.
- *Finish coat:* The final coat of plaster, which provides the decorative surface.
- *Furring:* Generally, channels or Z-shapes attached to the underlying wall (or structure for ceilings) for attaching gypsum or metal lath while allowing an airspace. Often used on cementitious substrate, resilient furring is used to reduce sound transmission.
- *Gypsum:* Hydrous calcium sulfate, a natural mineral in crystalline form.
- *Gypsum lath:* A base for plaster; a sheet having a gypsum core, faced with paper. Also perforated for interior use.
- *Hydrated lime:* Quicklime mixed with water, at the site, to form a lime putty.
- *Lime:* Obtained by burning various types of limestone, consisting of oxides or hydroxides of calcium and magnesium.
- *Lime plaster:* Basecoat plaster of hydrated lime and an aggregate.
- *Neat plaster:* Basecoat plaster, fibered or unfibered, used for site-mixing with aggregates.
- *Perlite:* Siliceous volcanic glass containing silica and alumina, expanded by heat for use as a lightweight plaster aggregate.
- *Plaster:* Cementitious material or combination of cementitious materials and aggregate, which when mixed with water forms a plastic mass that sets and hardens when applied to a surface.
- *Portland cement:* Manufactured combination of limestone and an argillaceous substance for exterior or wet-atmosphere applications.
- *Scratch coat:* In three-coat plastering, the first coat, which is then scratched to provide a bond for the second, or brown, coat.
- *Stucco portland cement:* Plaster used in exterior application. This plaster requires a waterset and must not be applied to a smooth dense surface or gypsum lath; it requires control joints, and cannot have a Keene's cement-lime putty finish.
- *Three-coat plaster:* Preferred application for all substrates; required over metal lath.
- *Two-coat plaster:* Acceptable on lath and on the interior face of rough concrete block, clay tile, or porous brick.
- *Vermiculite:* Micaceous mineral of silica, magnesium, and alumina oxides made up in a series of parallel plates, or laminae, and expanded by heat for use as a lightweight plaster aggregate.

METAL LATH TYPES 12.60



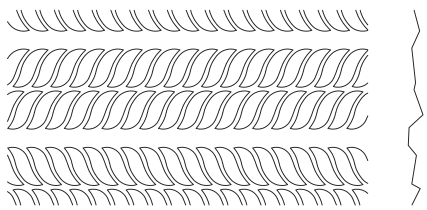
FRONT VIEW SIDE VIEW

DIAMOND MESH EXPANDED METAL



FRONT VIEW SIDE VIEW

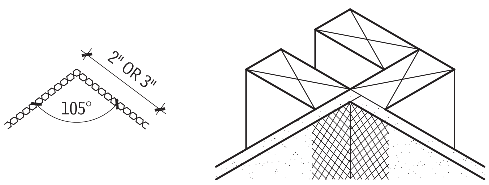
SELF-FURRING DIAMOND MESH



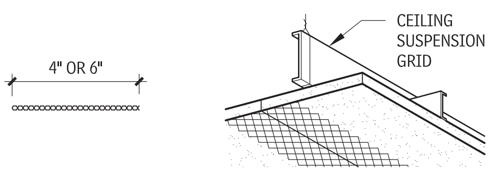
FRONT VIEW SIDE VIEW

RIB-EXPANDED METAL

JOINT REINFORCEMENT 12.61

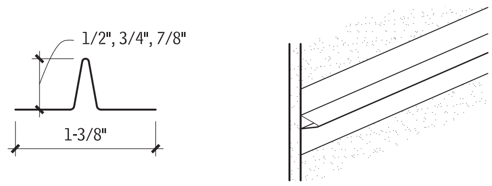


CORNER LATH

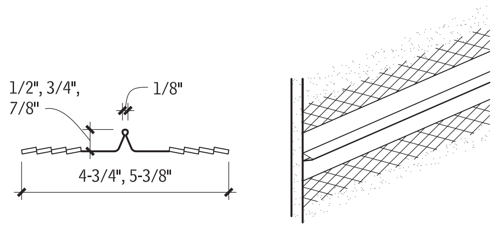


STRIP LATH

BASE SCREEDS 12.62

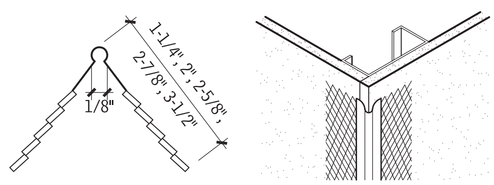


SOLID

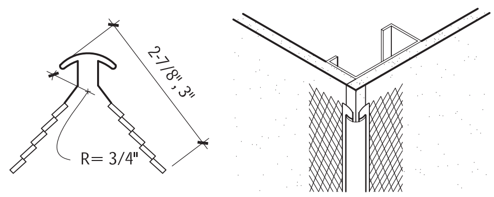


EXPANDED WING

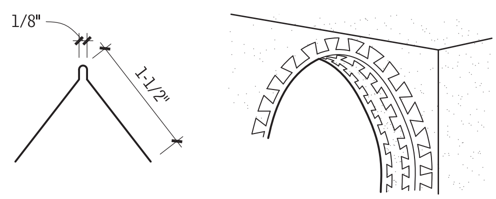
CORNER BEADS 12.63



EXPANDED WING



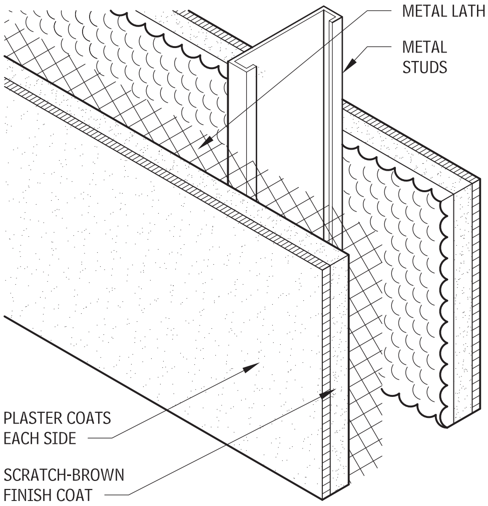
BULLNOSE



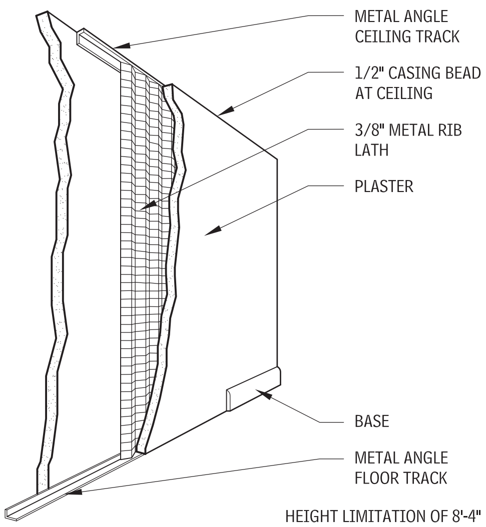
ARCH OR FLEXIBLE

Contributor:
The Marmom Mok Partnership, San Antonio, Texas.

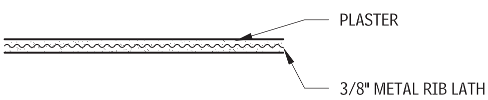
METAL STUD PARTITION WITH PLASTER AND LATH
12.64



PLASTER OVER METAL RIB LATH
12.65

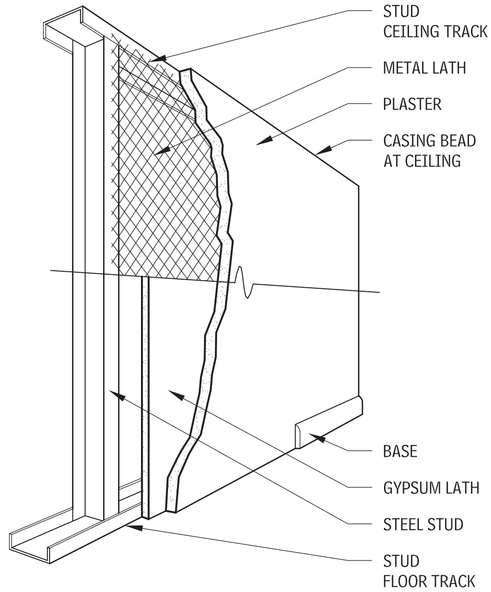


CUTAWAY WALL SECTION

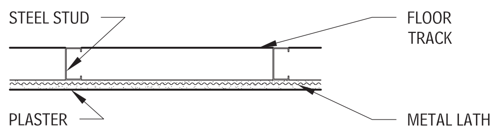


PLAN

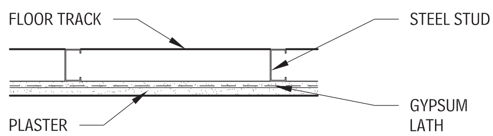
PLASTER OVER METAL OR GYPSUM LATH AND METAL STUDS
12.66



CUTAWAY WALL SECTION



PLAN



PLAN

WALL COVERING

WALL COVERING FINISHES

Wall coverings offer improved durability over paint finishes while providing texture and pattern to the wall surface. Wall covering types include vinyl, textile, wallpapers, fiberglass, and wood veneer. The most popular wall covering for commercial use is vinyl, favored for its affordability and durability.

VINYL WALL COVERINGS

The two vinyl wall covering manufacturing processes are calendering and plastisol methods:

- Calendering squeezes liquid vinyl over a series of hot metal rollers, flattening the compound into a sheet. The vinyl is then laminated under heat and pressure to a backing material.
- Calendered vinyl wall covering is harder, tougher, and usually much thicker than wall covering manufactured by the plastisol method.
- The plastisol method spreads liquid vinyl onto a backing material, which is then fused together under high temperatures. Plastisol technology is used primarily for residential wall coverings.

TEXTILE WALL COVERINGS

Not all textiles are suitable for use as wall coverings, nor are textile wall coverings appropriate in applications where wear resistance is a concern.

Textiles must be back-coated to be installed as wall covering. The backing provides a barrier to prevent adhesives from bleeding through and ruining the finish face of the fabric. Backings also provide the dimensional stability required for a textile to withstand the stretching and smoothing operations of wall covering installation. Two types of back-coating treatments are paper backing and acrylic latex backing:

- Paper backing involves laminating paper to the reverse side of the textile, which stiffens the textile for easier installation. The textile assumes properties similar to those of wallpaper.
- Acrylic latex coating involves stretching the textile in a frame and applying a latex compound. The textile retains some of its inherent flexibility but is much less dimensionally stable than paper-backed textiles and may increase installation costs. Latex backings do, however, improve ravel resistance and seam slippage. Often, due to its lack of rigidity, the adhesive used with this wall covering must be applied to the wall, rather than to the back of the wall covering. Consequently, this process is more labor-intensive and requires a higher degree of skill.

FIBERGLASS WALL COVERINGS

Fiberglass wall covering is composed of fiberglass yarns adhered together. Fiberglass wall covering is inherently flame-resistant and is suitable for use in reinforcing fragile or deteriorating wall surfaces. It is permeable, making it intrinsically mold- and mildew-resistant. Fiberglass wall coverings must be painted after installation; and, typically, a latex paint is selected to maintain the breathability of the wall. This wall covering type provides a textured pattern only, not a color.

WOOD VENEER WALL COVERINGS

Wood veneer wall covering is made by bonding veneer slices, about 1/64-in. thick, to a woven backing material. The resulting wall covering is thin enough to be pliable along the grain lines but too thick to be flexible in the horizontal direction (perpendicular to the wood grain). The inherent flexibility of wood veneer wall covering makes installation easy around columns and other curved surfaces.

The thinness of wood veneer wall covering does, however, raise three major concerns:

- Finishing operations after installation
- Proper substrate preparation
- Moisture

Moreover, wood veneer wall covering is too thin to be sanded. Therefore, care must be taken during installation to prevent the surface from being stained or damaged. Also, wall surface imperfections tend to telegraph through the thin veneer, so in areas where the substrate cannot be prepared to a smooth, level surface, veneered plywood panels are a better choice. Buckling and warpage caused by moisture can be additional significant problems for this kind of wall covering; therefore, it is not recommended for application to the interior surface of an exterior wall, unless the finish face of the wall is furred out and dampproofed.

Wood veneer wall coverings are available prefinished or unfinished. Unfinished veneers must be stained and finished after they are installed. Some finishes, for example, penetrating oils, can have an adverse effect on the wall covering adhesive. Coatings applied to the surface of installed wood veneer should be approved by the wall covering manufacturer.

The installation of wood veneer wall covering is similar to the installation of other types of wall covering; however, the sheets must be butted together and cannot be overlapped and trimmed.

WALL PREPARATION

There are four traditional ways to prepare a wall surface for a wall covering: prime, seal, size, or apply a wall liner.

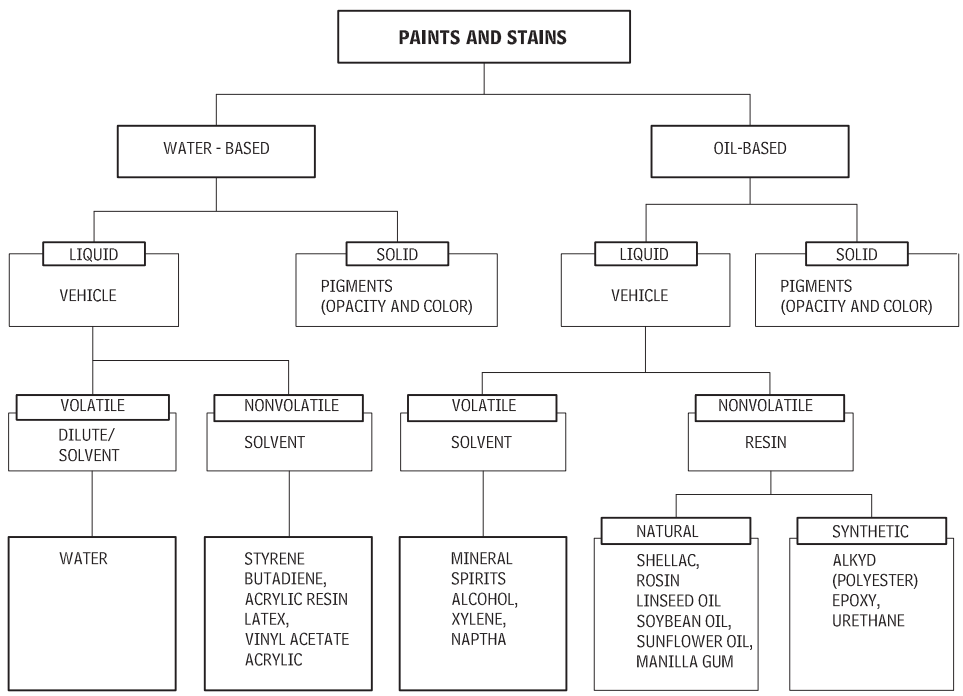
- Primers ensure proper adhesion and are the most commonly required wall preparation for commercial installations.
- Sealers are usually oil-based, made either of an alkyd or shellac. They provide stain-sealing properties; for example, walls that have suffered water damage must typically be sealed before they can be finished with either paint or wall covering. Sealers also promote strippability without damage to the wall surface.

- Sizing a wall surface lowers the absorbency of the wall by reducing the penetration of the paste. However, sizing does not necessarily improve the bond between the adhesive and the wall surface.
- Wall liners are nonwoven sheets; their installation is similar to that of wall covering. They are sometimes required where wall surfaces cannot be prepared by conventional means. Wall liners can be used to prevent cracks, holes, and gaps from telegraphing through the wall covering. They may also be used in lieu of primers/sealers to mask contrasting colors or areas of light and dark on the substrate.

DEFINITIONS OF SIX WALLCOVERINGS ORGANIZED BY PERFORMANCE 12.67

CATEGORY	DESCRIPTION	USE	COMMENTS
I	Decorative only	For decorative purposes	Wall coverings are not tested. Wallpaper and other primarily residential wall coverings fall into this category.
II	Decorative, with medium serviceability	Primarily decorative but more washable and colorfast than Category I wall coverings	In addition to the testing required for minimum washability and colorfastness, wall coverings are tested for maximum flame spread and smoke development. Primarily for residential use.
III	Decorative, with high serviceability	For medium use, where abrasion resistance, stain resistance, scrubbability, and increased colorfastness are necessary	In addition to the testing required for Category II wall coverings, in this category wall coverings are tested for minimum scrubbability, stain resistance, and cracking resistance. They meet more stringent requirements for colorfastness than Category II wall coverings. Primarily for residential use.
IV	Type I (Light Duty) commercial serviceability	For use where higher abrasion resistance, stain resistance, and scrubbability are necessary in heavy consumer and light commercial use	In addition to the testing required for Category III wall coverings, these wall coverings are tested for maximum shrinkage and minimum abrasion resistance, breaking strength, tear resistance, blocking resistance, coating adhesion, cold-cracking resistance, and heat-aging resistance. All test methods listed in the standard apply to Category III wall coverings, but these wall coverings meet more stringent requirements for colorfastness and scrubbability than those in Category III. Appropriate for private offices, hotel rooms, and areas not subject to unusual abrasion or heavy traffic.
V	Type II (Medium Duty) commercial serviceability	For use where better wearing qualities are required and exposure to wear is greater than normal	Tested according to more stringent requirements for scrubbability, abrasion resistance, stain resistance, tear resistance, and coating adhesion than Category IV wall coverings. Appropriate for public areas such as lounges, dining rooms, public corridors, and classrooms.
VI	Type III (Heavy Duty) commercial serviceability	For use in heavy-traffic areas	Category VI wall coverings are tested for the highest scrubbability, abrasion resistance, breaking strength, tear resistance, coating adhesion, and maximum shrinkage. Category VI, Type III wall coverings are commonly used in high-traffic service corridors where carts may bump into the walls.

PAINTS AND STAINS 12.69



COMMON PAINT ADDITIVES 12.68

ADDITIVE	PURPOSE
Antiskinning agent	Prevents skin from forming in can prior to use.
Biocide	Prevents spoilage resulting from bacterial growth.
Coalescent	Aids in formation of continuous film in latex paint.
Defoamer	Eliminates air from paint or reduces bubbling upon application.
Drier	Accelerates conversion of solvent paints from liquid to solid state.
Freeze-thaw stabilizer	Lowers latex paint freezing point.
Mildewcide	Resists growth of mildew.
Surfactant	Stabilizes mixtures of resins or pigments in solvents or water.
Thickener	Increases consistency of paint and prevents separation of pigment in oil- and water-based paints.

PAINTS AND STAINS

INTERIOR WALL PAINTING

A variety of primers, paints, coatings, and stains are available, some of which are described here. Note in Figure 12.146 that paints and stains can be categorized as either water- or oil-based.

PRIMERS

Primers make a surface more paintable by providing improved adhesion for coatings. They are selected in relation to the characteristics of the selected topcoat, and serve the following functions:

- Conceal the substrate surface so that the existing coating color does not "read" through.
- Provide a barrier to prevent moisture from destroying the paint bond.
- Bind the substrate surface with the topcoat.
- Limit the paint absorption of a porous substrate, such as a skim coat of plaster.
- Recondition old paint to receive future paint coatings.
- Act as a rust inhibitor.

ALKYD PAINTS

The solvent-thinned resin in alkyd paint is made from synthetic oils. Alkyd resins are oil-modified polyesters made primarily from alcohol and acid. They are the most common paint resin. Alkyd paints are faster drying, harder, and more durable, and have better color retention properties than oil-based paints. They are easy to apply, are washable, and have fewer odors than other paints using solvent thinners. However, alkyd paints have poor resistance to alkaline surfaces, such as masonry, and should not be used unless these substrates are properly primed.

LATEX PAINTS

Most water-based paints are referred to as latex paint. Latex paints have very little odor and a fast drying time. Their water-base thinner makes them easy to apply, clean up, and discard. Latex paints are porous, meaning that when applied a latex coating retains microscopic openings that allow it to breathe. Adhesion failure is prevented because moisture that might become trapped beneath the paint's surface can evaporate through these openings. The disadvantage of latex paints is that they have a greater blistering tendency when high levels of tinting color are present.

NOTE

12.67 *Per ASTM F 793, "Standard Classification of Wall Covering by Use Characteristics."
The backing material, sometimes called the *substrate*, is the major component in determining the strength and dimensional stability of a wall covering.

Contributors:
Mark Form, Leo A. Daly Company, Washington, DC; George M. Whiteside, III, AIA, and James D. Lloyd, Kennett Square, Pennsylvania; Alexander Keyes, Darrel Downing, Rippeteau, Architects, PC, Washington, DC; Elizabeth Aukamp, Rhode Island School of Design, Providence, Rhode Island.

OIL-BASED PAINTS

The solvent-thinned resin in oil-based paint is made from natural oils, such as linseed oil (from flax seed), soya oil (from soybeans), and tung oil (from china wood tree fruit).

CATALYZED EPOXY PAINTS

Catalyzed epoxy coatings resist chemicals, solvents, stains, physical abrasion, traffic, and cleaning materials. They have good adhesion and color retention. Catalyzed epoxies come in two parts: resin and catalyst. They have a limited "pot life," hence are required to be mixed just prior to use. When applied to a substrate, a chemical action occurs that causes a dense hard film to form, similar to baked enamel. Adequate ventilation must be provided during and after application.

Three types of catalyzed epoxies are commonly used in commercial interiors:

- Polyester epoxies, which produce a tough glossy surface
- Polyamide epoxies, which provide a flexible but durable film
- Urethane epoxies, which are the most versatile of the epoxy coatings

EPOXY ESTER PAINTS

Epoxy esters are similar to catalyzed epoxy, but have no pot-life restrictions and are packaged like conventional paint. The paint film occurs due to oxidation, rather than a chemical reaction triggered by a catalyst. Epoxy esters are less durable than catalyzed epoxies.

INTUMESCENT PAINTS

Intumescent paints slow the rate at which fire spreads by delaying the ignition of the surface that has been coated. They are used on combustible materials such as wood to achieve the required flamespread ratings. These paints delay but do not prevent a fire from spreading. Fire-retardant paints are intumescent and protect the substrate from burning by swelling to form a charred layer of blisters when exposed to extremely high heat.

Intumescent paint is a foam-like material made with either a water-based or solvent-based thinner. Requisite fire ratings are achieved with this material based on the number of coatings applied to the substrate at a prescribed thickness. Intumescent paint manufacturers certify painters to ensure that their products are correctly applied.

FIRE-RETARDANT PAINTS

Fire-retardant paints resist the spread of fire by not contributing to the flame. They are, however, less effective at controlling the spread of fire than intumescent coatings.

MULTICOLOR COATINGS

Multicolor coatings are durable and scratch-resistant. They add a three-dimensional quality to a surface, similar to hand-sponge techniques. Multicolor coatings can be water-thinned or solvent-thinned. Traditional solvent-thinned multicolor coatings are composed of tiny bubbles of different sizes and colors suspended in a nonpigmented solution. The separated beads of pigment remain separate until they are spray-applied. They burst upon impact with the surface.

STAINS

Stains made from dyes dissolved in either drying oil or water provide translucent or transparent coatings for wood. Oil-based stains use drying oil made from various plants. The oil dries by absorbing oxygen from the surface, and the air creates a tough elastic film that protects wood. Wood surfaces can be filled before staining in order to affect surface porousness and smoothness, but fillers may cause stains to be absorbed unevenly. Stain may be applied with a brush, spray, roller, or rag pad.

INTERIOR WINDOWS AND GLAZING

GLASS

Glass is a hard, brittle amorphous substance made by melting silica (sometimes combined with oxides of boron or phosphorus) with certain basic oxides (notably sodium, potassium, calcium, magnesium, and lead) to produce annealed flat glass by a controlled cooling process. Most glasses soften at 932° to 2012°F. Minute surface scratches in manufacturing greatly reduce glass strength.

Glass is considered a liquid, even though it is rigid and behaves like a solid. As is characteristic of a liquid, the atoms in a sheet of glass are randomly arranged. They are frozen in place by rapid cooling during manufacturing. In most other mineral solids, the atoms are arranged in a recognizable geometric pattern and have a crystalline structure.

FLOAT GLASS

Generally accepted as the successor to polished plate glass, float glass has become the quality standard of the glass industry. More than 95 percent of the glass manufactured in the United States is float glass. It is manufactured by floating molten glass on a surface of molten tin. Because the molten metal is denser than the glass, the two liquids do not mix together. This process produces a glass with very uniform thickness and flatness. After forming, the glass is cooled by a controlled process known as annealing.

Annealing relieves internal strains that may have developed during the manufacturing process. It ensures that the glass does not cool and contract at different rates across its surface. If glass is not annealed, it may fracture from differential stresses throughout the sheet when it reaches room temperature.

The requirements for float glass are defined in ASTM C 1036, "Standard Specification for Flat Glass." Float glass is available in thicknesses ranging from 1/8 to 7/8 in.

STRENGTHENED GLASS

There are several types of glass with increased strength: fully tempered, heat strengthened, laminated, and wire glass.

FULLY TEMPERED GLASS

Fully tempered glass is produced by heating float glass and then suddenly cooling it with special blowers. The outer surface cools quickly and contracts, constraining the hot inner core as it continues to cool. The surface and edges of fully tempered glass are in compression, while the inner core is in tension. Fully tempered glass is three to five times more resistant to impact, applied pressure, and bending stresses than annealed glass, because the surface tension must be overcome before the glass can be broken. The tempering process is defined by ASTM C 1048, "Standard Specification for Heat-Treated Flat Glass—Kind HS, Kind FT, Coated, and Uncoated Glass."

Cutting or drilling fully tempered glass will destroy the integrity of the skin's compressive strength and will likely cause breakage; therefore, fully tempered glass cannot be field cut. Fully tempered glass must be fabricated with the required holes or cutouts. It is available in thicknesses ranging from 1/8 to 1 in.

HEAT-STRENGTHENED GLASS

The heat-strengthened glass manufacturing process is similar to that of fully tempered glass, except that the glass is only partially tempered. Annealed glass is heated and cooled in a manner similar to that for fully tempered glass; however, lower surface stresses are produced. Heat-strengthened glass is about twice as resistant to breakage as float glass.

LAMINATED GLASS

Laminated glass consists of two or more layers of glass and an interlayer material sandwiched together to form a single sheet. There are two types of interlayers: polyvinyl butyral (PVB) sheets, which are bonded under heat and pressure; and urethane acrylate resin, a liquid that is cured under ultraviolet light. PVB interlayers can be colored or patterned and can be combined for a decorative effect. The interlayer blocks a portion of ultraviolet rays, and is a sound barrier that dampens vibrations between the two pieces of glass. Rice paper and other ornamental sheets can also be used in the lamination process. Cast resin interlayers are clear or custom colored and allow more heavily textured glass to be laminated. Annealed, fully tempered, heat-strengthened, and wire glass types can be laminated. Security glass (bullet or burglar resistant) and acoustic glass are types of laminated glass using thicker interlayers. If laminated glass is broken, the glass remains bonded to the interlayer, offering protection from injury; this makes it popular for use in skylights. Laminated glass with an interlayer of 0.030-in. minimum thickness meets the Federal Safety Glazing requirements of ANSI Z97.1, "Safety Glazing Materials Used in Buildings—Safety Performance Specifications and Methods of Test," and Consumer Product Safety Commission (CPSC) 16 CFR 1201, "Safety Standard for Architectural Glazing Materials, Category II," similar to tempered glass. Laminated glass with an interlayer thickness of 0.015 in. meets the requirements of Category I glass. The standard for laminated glass is ASTM C 1172, "Standard Specification for Laminated Architectural Flat Glass."

WIRE GLASS

Wire glass has wire mesh or parallel wires rolled into the center of the glass sheet. It is available in various patterns and pattern sizes such as square-welded mesh, diamond-welded mesh, and linear parallel wire. Pattern sizes range from 1/2 to 1 in., depending on pattern type. Some distortion, wire discoloration, and misalignment are inherent. If breakage occurs, the wire helps to hold the glass fragments in the opening, thus preventing personal injuries. This is the standard glass type used for fire-rated doors or partition assemblies.

SAFETY GLASS

Safety glass is glazing material that breaks in a way that reduces the likelihood of cutting and piercing injuries if shattered. Fully tempered glass and laminated glass qualify as safety glass. Fully tempered glass breaks into small cubical pieces. If laminated glass is shattered, the broken glass adheres to the interlayer.

The requirements for safety glass are defined by two very similar standards: CPSC 16 CFR 1201 and ANSI Z97.1. These standards use the same test procedures, with the exception that the CPSC standard uses a greater impact load. Although wired glass does not pass the tests for safety glass described in CPSC 16 CFR 1201, it is granted an exemption because it is the only glass type that performs successfully in fire tests.

BASIC GLASS TYPES
12.70

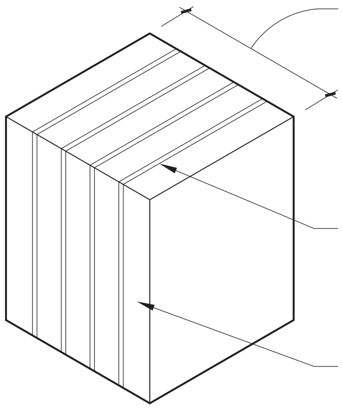
TYPE	ANNEALED (REGULAR FLOAT GLASS)	FULLY TEMPERED	HEAT STRENGTHENED	LAMINATED	WIRED
Safety glass	No	Yes	No	Yes	No
Can be field-cut or drilled	Yes	No	No	Depends on glass type laminated	Yes
Shatter pattern	Shards	Small cubes	Shards	Pieces adhere to interlayer	Pieces held in place by wire
For use in fire-rated assemblies	No	No	No	No	Yes

SECURITY GLASS

Security glass is composed of multiple layers of glass and/or polycarbonate plastic laminated together under heat and pressure with a polyvinyl butyral (for glass) or polyurethane plastic (for polycarbonate) film. It is available in multilayer laminated glass, insulating, laminated insulating, and double-laminated insulating or spaced configurations. Thicknesses range from 3/8 to 2-1/2 in. as a laminated product and up to about 4-3/4 in. for insulating and spaced construction products.

Bullet-resistant glass should meet the requirements of UL 752, "Standard for Bullet-Resisting Equipment," and burglar-resistant glass should meet the requirements of UL 972, "Standard for Burglary-Resisting Glazing Material." Consult manufacturers for blast-resistant glass. Security glass products, depending on type, are subject to size limitations; consult with the manufacturer for glazing requirements and restrictions on use.

SECURITY GLASS
12.71



TINTED AND REFLECTIVE GLASS

Tinted glass was developed to control solar heat gain and glare. Float glass is available tinted in green, bronze, gray, and blue, in thicknesses ranging from 1/8 to 1/2 in. The glass absorbs a portion of the sun's energy due to its admixture content and thickness; it then dissipates the heat to both the exterior and the interior. The thicker the glass is, the greater the solar energy absorption. Newer tinted glass types allow more visible light transmission, while blocking a higher percentage of infrared energy than standard tinted glass.

Heat-absorbing tinted glass has a higher temperature when exposed to the sun than clear glass; the central area expands more than the cooler shaded edges, causing tensile stress buildup.

Indoor shading devices such as blinds and draperies reflect energy back through the glass, thus increasing the temperature of the glass. Spaces between indoor shading devices and the glass, including ceiling pockets, should be vented adequately. Heating elements should be located on the interior side of shading devices, directing warm air away from the glass. Consider tilt-limit devices on horizontal blinds to allow for ventilation.

LEADED STAINED GLASS

Decorative stained glass is characterized by pieces of glass joined together with lead cames (H-shaped strips) of various widths. Varying the widths adds to the window's decorative effect. Joints are soldered on both sides of the panel. To prevent leakage, a mastic waterproofing material is inserted between the glass and the came flange.

Another method of joining the pieces of glass is to band the edges of the glass with a copper foil tape, burnished to the glass and then soldered with a continuous bead of solder on both sides.

Bracing bars are fastened to the sash at frequent intervals to strengthen and support the leaded glass. Round bars tied to the leaded glass with twisted copper wires are the most flexible and resilient, allowing for great amounts of thermal movement. Where this system is not suitable, galvanized steel flat bars can be soldered to the surface of the leaded glass.

When the glass requires detail painting, shading, or texturing, it must be done with special mineral pigments and fired at temperatures of 1000° to 1200°F or higher to ensure absolute permanency.

Decorative glass panels should not exceed 12 sq. ft., making it necessary to divide larger openings with metal division bars. Tee bars are used for single glazed windows, and special channel bars are used for windows with outside protection glass.

Machine-made and blown glass from the United States, England, France, and Germany is available in most solid colors, as well as mixed colors and textures. Uniformity of color will vary from glass of different batches. Special colors are derived by sumping, or kiln firing.

SPECIAL COLORED GLASS SHAPES

In the mid-twentieth century, a glass technique called *dalle de verve* was introduced. Glass dalles, slabs 8 by 12 by 1 in., are cast in hundreds of different colors. Dalles can be cut to any shape and used in combination with an opaque matrix of epoxy resin or reinforced concrete 5/8 to 1 in. in thickness, to create translucent windows and walls of great beauty. Sizes are limited, and an outer protection glass is required.

Glass rondels are handspun using techniques that date back to the Middle Ages. They are available as disks 3 to 14 in. in diameter or as square bull's-eye sheets for restoration work.

REFLECTIVE GLASS

Reflective glass reduces the amount of incident light transmitted, absorbed, and reflected by portions of the light and energy spectrum, thus improving the energy balance within a building. Typically, Type I (hard-coat or pyrolytic) coatings, which are more scratch-resistant than Type II (sputtered or soft-coat) coatings, are used on exposed glass surfaces. Reflective coatings are derived from metals, and are applied to glass based on the glazing system requirements. Pyrolytic reflective coatings on the outside surface are susceptible to exterior environmental factors. Reflective coatings on inner surfaces are protected from damage. Reflective glass can be used in interior applications such as shower doors and enclosures, countertops, wall cladding, and furniture.

ENERGY-EFFICIENT GLASS

LOW-EMISSIVITY GLASS

Low-emissivity (low-E) glass was developed to address energy efficiency concerns for glazing. Hard or soft metallic coatings are applied to the glass, based on application type. Low-E coatings provide more reflectivity for the shortwave solar energy that strikes the glass at a high angle of incidence during the summer, while permitting this warmth to enter during the winter when the angle of incidence is lower. Low-E coatings are applied to the inside (side 2) on the first pane of glass in a double-glazed unit. The overall light transmission rate is higher than in tinted and reflective glass types.

INSULATING GLASS

Insulating glass acts as a barrier to conductive heat loss. Insulated glass units are created by sealing an air pocket between two lights of glass, separated by a spacer. The energy efficiency of insulated glass can be increased by adding more layers of glass, or by the use of thin heat-reflecting films suspended between the spacers. New spacer types have been developed that provide a thermal break between the two layers of glass, for conditions in which there is a large temperature differential between the edges and the center of the glass. Stresses on the seal may cause the eventual deterioration of the sealant, and moisture may appear as condensation between the glass layers.

Insulated glass dampens vibrations and sound. Insulated glass units may be created to protect and seal specially treated glass, such as sandblasted glass surfaces.

SPECIALTY GLASS TYPES

LOW-IRON GLASS

Low-iron glass, or ultraclear glass, has high clarity and high visible light transmittance, without the marked greenish tint visible on the edge of standard glass. The clarity in the glass is achieved by reducing the iron content by approximately 10 percent. Thicknesses range from 1/8 to 3/4 in. Low-iron glass can be heat strengthened, tempered, sandblasted, etched, or assembled into laminated glass. Low-iron glass is used in areas where color rendition is critical, and for furniture, mirrors, museum display cases, signage, and where glass is to be back-coated with light-colored pigments.

TEXTURED GLASS

Textured patterned glass is also known as rolled or figured glass. It is made by passing molten glass through rollers that are etched to produce the design. Designs include flutes, ribs, grids, and other regular and random patterns, which provide translucency and a degree of obscurity. Usually only one side of the glass is imprinted with a pattern. Patterned glass can be silvered, sandblasted, or have applied colored coatings. One form of textured glass is impression glass, in which a clear resin, applied to the glass, is impressed with a pattern.

Tempering and sheet size limitations for patterned glass must be verified. Patterning a glass surface may make tempering impossible. Sheet sizes and thicknesses can vary greatly, depending on the type of pattern desired.

PHOTOVOLTAIC GLASS

There are two types of photovoltaic (PV) glass: crystalline silicon sandwiched between two layers of glass, and thin-film amorphous silicon applied to an interior-facing glass surface. When these arrangements are exposed to sunlight, they generate either direct current (DC) or alternating current (AC) power, which is transferred by concealed wiring to the building's power system. Pressure bar framing systems or structural silicone, flush-glazed curtain walls and skylights, awnings, sunshades, light shelves, and roof panels are some of the systems that can incorporate PV glass. Both types of PV glass are used for opaque curtain-wall spandrel panels and can be used for curtain wall or skylight vision glass if the quality of daylighting and visibility is acceptable. Consult PV glass and metal-framing system manufacturers to determine availability, suitability, and cost for a particular application.

PRIVACY GLASS

BLIND GLASS

Blind glass is float glass that is acid etched on both sides in a linear, offset pattern, obscuring visibility when viewed perpendicular to the glass. Visibility through the glass is possible when viewing at a 45° angle. Produced in 3/16- and 5/16-in. thicknesses, the thicker glass is more effective for a see-through effect, while the thinner glass is suited to areas requiring more privacy, such as in doors and in furniture applications.

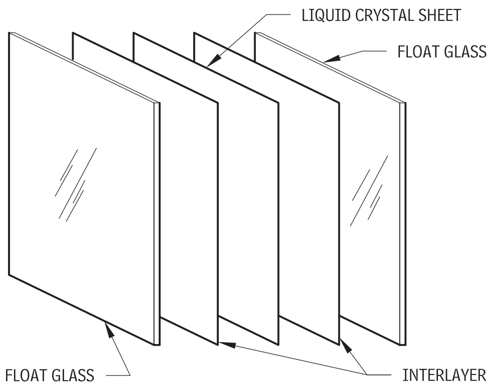
ELECTROCHROMIC GLASS

Electrochromic glass switchable privacy glazing, identified as polymer-dispersed liquid crystal (PDLC), consists of liquid crystals that are enclosed in transparent polymer capsules. The capsules are sandwiched between two sheets of transparent electroconductive film. When voltage is applied, the liquid crystals line up in rows, allowing light to pass freely through the transparent film and glass. Without voltage, the liquid crystals do not line up in rows. This diffuses the light, making the glass appear opaque or obscure.

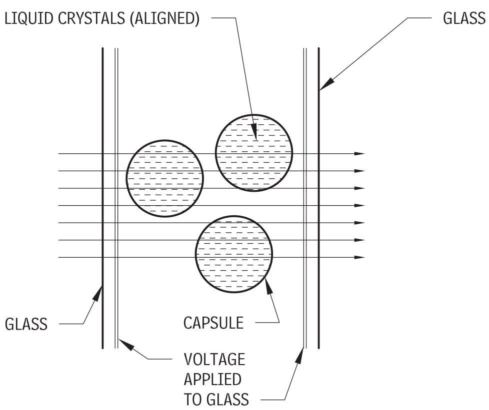
OTHER SPECIALTY GLASS TYPES

X-ray shielding lead glass, super-heat-resistant glass for industrial uses, and other special-use glass types are available for custom applications. Consult manufacturers for information.

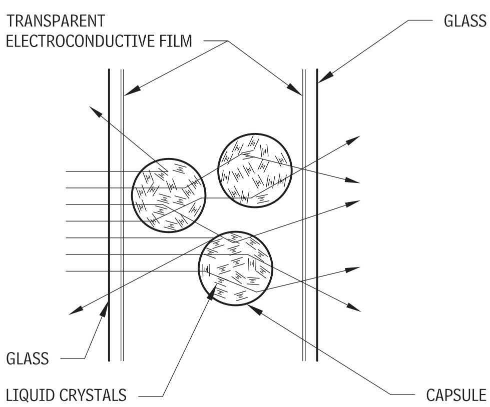
POLYMER-DISPERSED LIQUID CRYSTAL PRIVACY GLASS
12.72



POLYMER-DISPERSED LIQUID CRYSTAL DISPLAY
12.73



VOLTAGE APPLIED



WITHOUT VOLTAGE

FORMED GLASS

CAST GLASS

Cast glass, also known as molded glass, is formed in molds, using combinations of colors and textures to create the desired product. Cast glass may be molded to precise dimensions and tolerances, or it may be formed into art glass units. The casting process allows an unlimited number of glass forms, colors, and textures to be created. Thicknesses and overall sizes are dependent on the design and intended use for the cast glass. Cast glass products include glass tiles, stair treads, countertops, artwork, and glass panels.

TRANSLUCENT LINEAR GLAZING SYSTEM

A channel-shaped translucent cast glass that can be used as an interior wall system is manufactured as a proprietary product. Its most common face dimension is about 10 in. wide, and its structural capabilities allow it to be used in interior application heights of 20 ft. or more, providing a dramatic linear effect.

Translucent linear glazing is nearly always installed double glazed, creating an airspace that offers a smooth appearance on both surfaces, and STC reduction of up to 42 dB. It is installed in a system of aluminum channels that can be finished to complement the surrounding conditions, or recessed into the perimeters for a flush appearance. The system can be curved, and glass-to-glass angled corners also can be easily installed, eliminating the necessity of any vertical metal framing at the interior glass area.

FUSED GLASS

Multiple-layer glass units are formed by fusing compatible glass together under controlled heating. Various glass colors, textures, and compatible three-dimensional materials such as wire, stainless steel, and copper screen can be incorporated into the fused unit. A texture or tack fuse maintains a degree of separation between the individual pieces of glass. A full fuse melts the various elements and layers into a uniform homogeneous form with a smooth surface with rounded edges. Different colors used in a full-fused piece will blend more than in a tack-fused piece. Coated and reflective glass may be fused onto glass substrates. Fused glass is typically used for furniture and decorative accents, glass borders, tiles, panels, light fixtures, and other interior elements.

SLUMPED GLASS

Glass can be molded into various shapes when heated to provide the proper viscosity in a semimolten state. Slumped glass with thicknesses up to 3/8 in. will have the impression of the mold translated to the back side, while thicker glass units will be relatively smooth on the opposite side. Tinted or reflective glass types can be slumped, and processes such as gold leafing, silvering, and airbrushed coloring can be incorporated into the slumped glass texture. Panels up to 4 by 8 ft. are possible, and the slumped glass can be tempered if required. Molds are made of materials that can withstand the kiln-slumping temperature of approximately 1350°F. Tabletops, shower enclosures, wall panels, and signage can be created from slumped glass.

BENT GLASS

A precise, strict-tolerance form of slumped glass is known as bent glass. Bent glass is often laminated to meet safety glazing requirements, and may be tempered. Some visual distortion may occur when the radius of the bent glass is tight. Curved shower enclosures, wall partitions, and automobile windshields are applications for bent glass.

A variety of other forms of glass, including clear, tinted, laminated, and wire glass, can be bent in thicknesses to about 1 in. and to a minimum radius of about 4 in. Sharp angle bends to 90°, edgework, pattern cutting, tempering that meets safety glazing standards, and heat strengthening are also available. Bent glass can be fabricated into insulating glass units. Bent glass tolerances must be compatible with the glazing system. Size, configuration, and product availability vary by fabricator.

SURFACE TEXTURES

Surface textures on glass soften transmitted light, add decorative designs, increase obscurity for privacy, or lightly fracture the glass surface for a frosted effect. Surface-texturing processes can be applied to clear, tinted, or reflective glass, prior to tempering.

SANDBLASTING

Sandblasting is used to create a translucent frosted effect of a desired design on the glass surface. The glass is blasted with small abrasive particles of sand and high-pressure air projected through a nozzle. Different degrees of coarseness are used to achieve varying levels of smoothness. The resulting granular-textured surface is susceptible to the absorption of oils. Fingerprints and dirt are typically visible on sandblasted surfaces unless treated with an applied sealer. The sandblasted surface may be protected by enclosing it within an insulated double-glazing unit.

Sandblasting is the first treatment applied to glass, prior to additional treatments. A sandblasted surface provides improved adhesion for applied sprayed coatings. Laminated glass may be sandblasted, but care should be taken so that the interlayer is not compromised.

ACID ETCHING

In the process of acid etching, sandblasted glass is submerged in a bath of hydrofluoric and hydrochloric acids to create a hardened, sealed surface. The glass appears matte, with a soft, light-diffusing quality. Depending on the coarseness of the sandblasting grit, the etched texture may be relatively smooth or grainy. Acid-etched glass may be coated or silvered. It does not show dust, dirt, or fingerprints, and is used in retail, residential, and commercial applications for tabletops, counters, shelving, wall cladding, stair treads, and other interior architectural elements. Stencils and etching creams are available to etch smaller areas of glass for signage, mirrors, and windows.

GLUE CHIP GLASS

Hot glue is applied to sandblasted glass to create a fractured, ice crystal—like frosted effect known as glue chip glass. As it cools, the glue dries and shrinks, removing flakes of glass from the surface. Traditionally, horsehide glue was used for this process, but it has been replaced by synthetic glues. Greater pattern density can be created by a second application of the glue, resulting in a more obscure, frosted appearance. Clear or tinted glass may be glue chipped, and the glass may be tempered for added strength.

FRIT GLASS

To create decorative silk-screened (frit) glass, annealed clear or tinted glass is washed, and ceramic frit paint in standard or custom colors is silk screened on its surface in a standard or custom pattern or design such as dots, holes, lines, or a logo. The paint is then dried in an oven. The frit-coated glass is then subjected to very high temperatures in a tempering furnace to fire the ceramic frit permanently to the glass surface. As a result, silk-screened glass will be either heat strengthened or tempered after firing. Reflective and low-emissivity coatings can also be applied to the glass surface. Silk-screened glass can be used monolithically or for insulating or laminated glass products.

A newer coating process for silk-screened glass uses water-based polymers. This material can be custom colored, and is available in metallic, crackle, frosted, and other custom finishes. This process is much more environmentally friendly than solvent-based coatings. The finish is cured in a low-temperature oven, and the glass may be tempered. Using this process, the glass may be cut, drilled, polished, and post-fabricated to suit project needs.

MISCELLANEOUS COATINGS

Epoxy coatings are typically applied to the back of glass units. Special printing techniques provide numerous design options on the glass. Coatings may contain glass beads and mica chips, which add a more reflective or metallic appearance. Special metallic coatings can be applied to increase glass reflectivity to light and heat and to carry an electric current.

A dichroic coating is a metallic coating consisting of molecularly thin layers of titanium or zirconium that are highly reflective of one color wavelength of light, while transmitting an entirely different color. Dichroic coatings can be applied to clear or textured glass substrates. Size restrictions may apply due to the dichroic application process limitations. It is used in furniture, accent glass pieces, and art glass.

Silicone coatings have been used for decades as a color backing for spandrel glass.

APPLIED FILMS

Applied films can be used to modify the appearance or performance of glass. Mylar films can be permanently bonded to the glass with nonyellowing adhesives to create special designs. Tinted films are used as a low-cost alternative to tinted glass in retrofits of existing glass in commercial, residential, and automotive applications. Clear, tough films are available with a Category II safety glazing alternative for glass that is too thin, textured, or shaped so that it cannot be tempered. Applied films are used in jewelry store windows and display cases, where additional protection is needed without affecting the visual quality of the glass. Nylon-fiber-reinforced adhesive-backed films are used on the backs of mirrors for wardrobe doors and wall cladding where safety is a concern but where tempering would cause unacceptable visual distortion.

MIRRORS

Mirrors are created by coating a piece of glass with a reflective coating of silver, backed with copper, and protected by an epoxy paint topcoat. Tinted and clear glass may be silvered with the pyrolitic process to produce mirrors.

One-way mirrors are used for discreet observation, such as in lineup rooms in law enforcement facilities. These mirrors are created by the use of a special reflective coating, which allows approximately 12 percent transmission and is reflective to the side with the highest light intensity. Light on the observation side is reduced by a 10:1 ratio, which maintains the reflective differential. One-way mirrors should be installed according to the manufacturer's instructions, and the lighting should be coordinated to provide secure one-way visibility.

FIRE-RATED GLASS

Fire-rated glass is a transparent ceramic product. It can be used in fire-rated partitions, in larger areas than typically permitted for wire glass. Consult local codes and manufacturer's information for limitations.

All fire-rated glass is listed and labeled by Underwriters Laboratories (UL). Fire ratings vary by type of fire-rated glass and thickness, but range from 20 minutes to 2 hours. Three-hour ratings are available with some insulated glass units. Thicknesses range from 3/16 in. for nonimpact locations, such as transoms, to 5/16 in. for laminated, impact-safety-rated fire-rated glass used in doors. Fire-rated glass may be polished, unpolished, or patterned (obscure).

Fire-rated or fire/impact-safety-rated insulated glass units (IGUs) are composed of fire-rated glass and either tempered or annealed float glass. These units are available in tinted, low-E, reflective, one-way mirror, and art glass units. Consult manufacturers for specific unit types and applications.

Fire-rated and impact-safety-rated glazing is available that has an intumescent gel layer between two panes of glass. When exposed to heat and light, the gel layer turns opaque and blocks the transfer of radiant heat through the glass for a short period of time.

Special framing is required for fire-rated glazing installations, which must be compatible with the fire rating of the glass. Approved glazing compounds and fire-rated glazing tapes are required to maintain the rating of the installation.

CUTTING AND EDGE TREATMENTS

POLISHED EDGES

Polished edges are created either by machine or by hand, using progressively finer sanding grits with a final polishing with a cork belt impregnated with a polishing compound. If the glass is to be tempered, the sharp shoulders of the edge are sanded, or seamed, to remove small cutting nicks, chips, and sharpness. This treatment is necessary to minimize thermal stresses that may occur with small edge fractures. Edge finishing of laminated glass is typically done by hand to protect the soft interlayer, and is typically limited to flat or pencil polishing, in which the side edge is rounded. If a glass edge is flat polished, the shoulders are accentuated with a slight polished chamfer known as an arris on both sides of the glass.

BEVELED EDGES

Beveled edges on glass surfaces change the reflection angle of the light and give a framed appearance to the glass. Bevels are ground onto the face of the glass with a succession of diamond grinding and polishing wheels. Beveled glass is tempered with the bevel side down toward the horizontal rollers. Thick glass with bevels more than 1 in. wide may slump and warp at the edges, due to the heat required for the glass thickness during the tempering process. Some inconsistencies can be polished out after the tempering process is complete.

WATERJET CUTTING

Waterjet cutting is a precise computer-controlled glass-cutting method. High-velocity water is forced through a small ceramic nozzle, combined with a fine abrasive used as a cutting medium. It is capable of cutting through multiple layers of glass and is useful when dissimilar materials such as metals are nested together with the glass. Tolerances are 0.001 in. Shapes too intricate to be cut by hand or traditional glass-cutting techniques can be waterjet cut.

INTERIOR GLAZING

CODE REQUIREMENTS

IBC 2406 covers glazing. In addition to the requirements for the use of glazing in fire-resistance-rated assemblies, the use of safety glazing is required in hazardous locations. Hazardous locations are those subject to human impact, such as glass in doors, shower and bath enclosures, and glass sidelights in partitions.

Safety glazing is defined as glazing that meets the test requirements of Consumer Product Safety Commission (CPSC) 16 CFR 1201, Category II. Generally, tempered glass and laminated glass are considered safety glazing.

INTERIOR DOORS

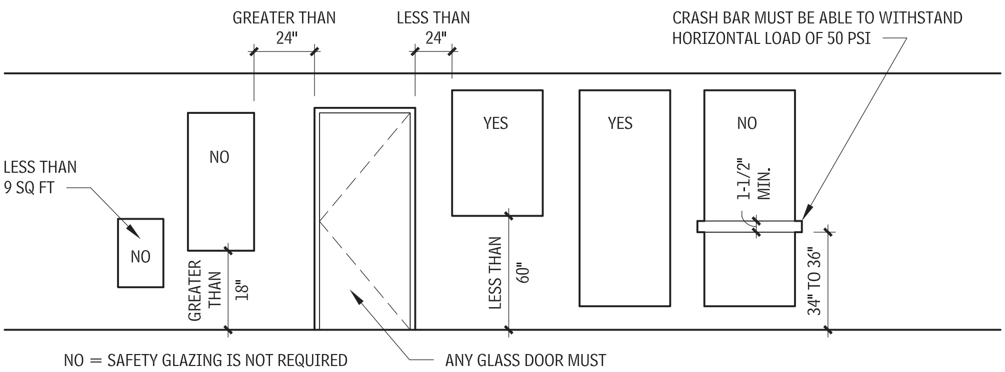
This section begins by introducing the basic concepts and terminology encountered when working with interior doors. It goes on to examine common types of doors and special considerations such as fire safety.

BASIC DOOR TERMINOLOGY

These are basic terms and concepts inherent to door design:

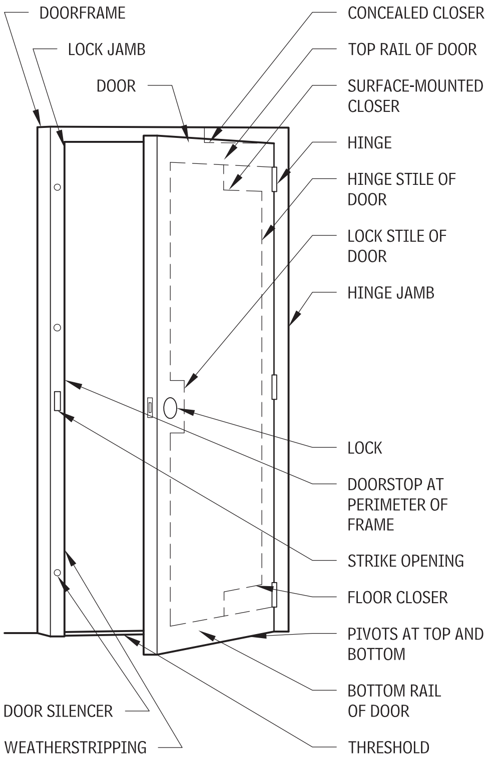
- *Active leaf:* The primary operating leaf of a door pair.
- *Air curtain:* A mechanically produced downward stream of air across a door opening intended to prevent transmission of heat and weather.
- *Automatic closing:* A door that is normally open, but that closes without the necessity for human intervention, and is activated as a result of a predetermined temperature rise, rate of temperature rise, or combustion products.
- *Automatic door bottom:* A device applied to the back side of a door at the bottom, or mortised into the bottom edge of a door, which seals the undercut of a door as it is closed.
- *Balanced door:* A door equipped with double-pivoted hardware designed to cause a semi-counterbalanced swing action when opening.
- *Buck:* A subframe of wood or metal set in a wall or partition to support the finish frame of a door.
- *Casing:* The finished, often decorative framework around a door opening, especially that which is parallel to the surrounding surface and at right angles to the jamb.
- *Coordinator:* A device used on a pair of doors to ensure that the inactive leaf is permitted to close before the active leaf.
- *Door bevel:* The slight angle given to the lock stile (vertical edge) of a door, which prevents the door from touching the lock jamb as it swings. Typical bevels are:
  - 1-3/8-in. door—none
  - 1-3/4-in. door—7/64 in.
  - 2-1/4-in.—9/64 in.
- *Double-egress door:* A pair of doors within a single special frame that swing in opposite directions to allow emergency egress from either side. Typically used where a fire or smoke partition crosses a corridor.
- *Flush bolt:* A door bolt set flush with the face or edge of the door.
- *Fire-door assembly:* Any combination of a fire door, frame, hardware, and other accessories that together provide a specific degree of fire protection.
- *Fire exit hardware:* Panic hardware that is listed for use on firedoor assemblies.
- *Head:* The horizontal portion of a doorframe above the door opening.
- *Jamb:* The vertical members at the sides of a door opening.
- *Labeled:* Equipment, products, or materials marked with the label, symbol, or other identifying mark of an approved testing organization that indicates compliance with standards for manufacture and testing.
- *Listed:* Equipment, devices, materials, or services included in a list published by a testing agency that have been shown to meet applicable standards for use in fire-rated assemblies or that have been tested and found suitable for use for a specified purpose.
- *Panic hardware:* A door-latching assembly incorporating a device that releases the latch upon the application of a force in the direction of egress travel.
- *Power-assisted door:* A door with a mechanism that helps to open the door or to relieve the opening resistance of the door.
- *Prehung door:* Door and frame combination fabricated and assembled by the manufacturer and shipped to the site.
- *Sill:* The horizontal members at the bottom of a door opening.
- *Subcasing:* The finish frame components that support and guide the door.
- *Undercut:* The space between the bottom edge of a door and the sill or threshold.

GLAZING CONDITIONS
12.74

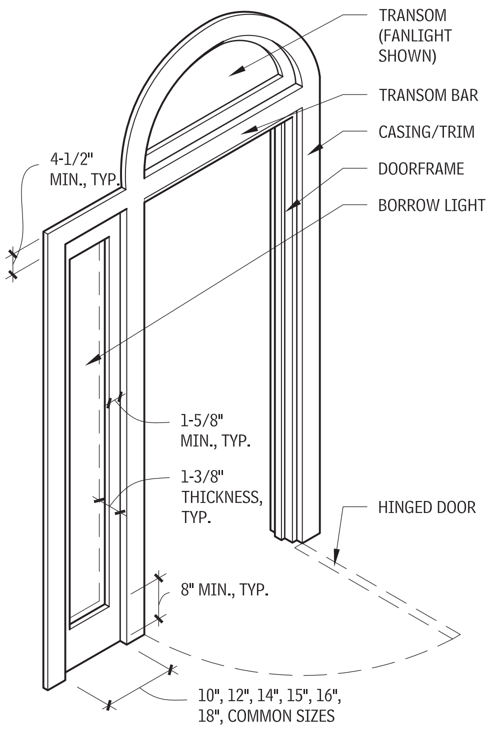


Contributors:
Robert Thompson, AIA, Creative Central, Tigard, Oregon; Jana Gunsul, AIA, DES Architects & Engineers; Redwood City, California.

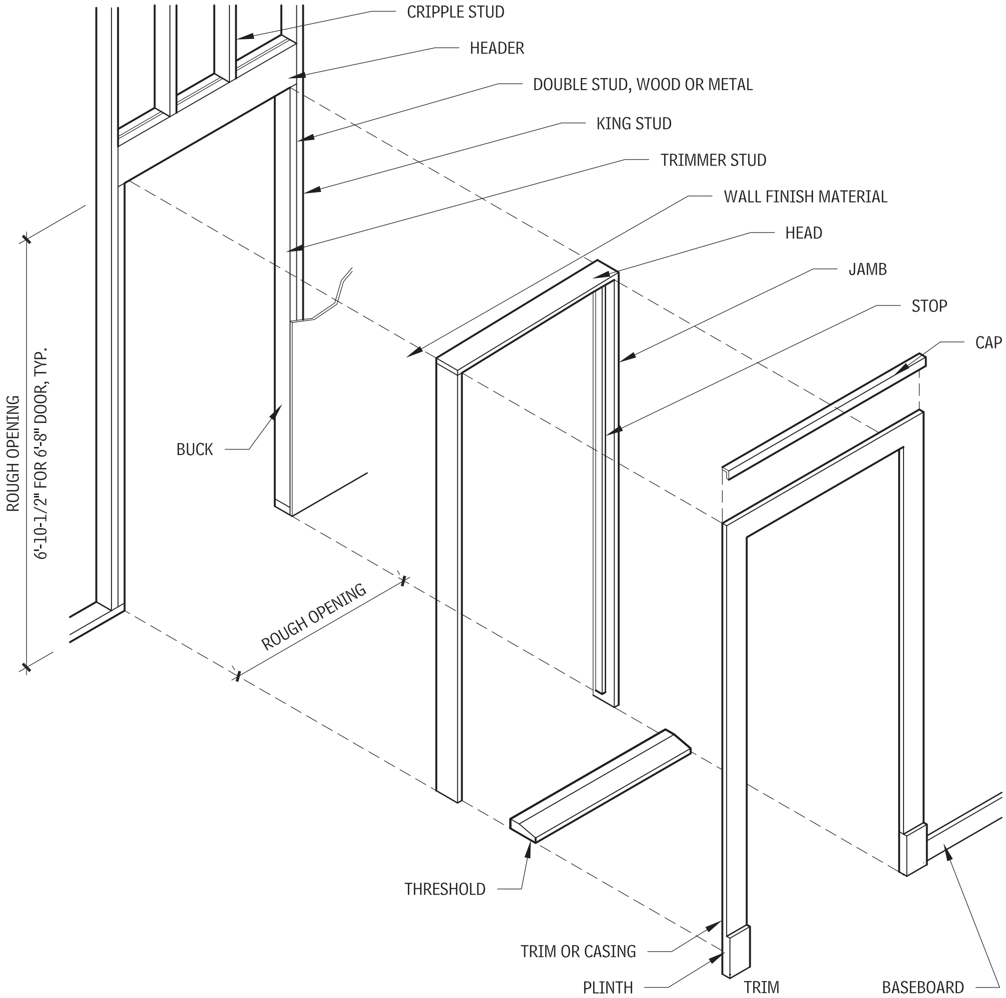
PARTS OF A DOOR
12.75



DOOR NOMENCLATURE
12.76



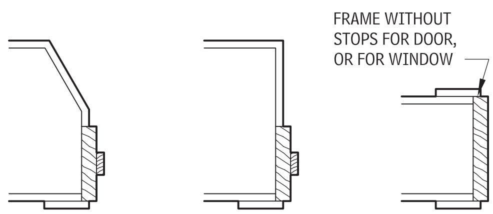
DOOR OPENING COMPONENTS
12.77



WOOD STOPS
12.78

PLANTED STOP (OR DOUBLE-RABBETED STOP) **RABBETED STOP**

FRAME OPENING TYPES



SPLAY **REVEAL** **CASED**

TYPES OF DOORS/MATERIALS/CORES/VENEERS

DOOR TYPES

This section discusses these common types of doors:

- Wood
- Hollow metal
- Glass
- Overhead coiling
- Coiling fire
- Floor, wall, and ceiling access

WOOD DOORS

Wood doors are available with face materials of wood veneer, composite veneer, high-density plastic laminate, medium-density overlay, and hardboard. Wood veneer on manufactured doors is available only in the species offered by the manufacturer, but custom doors may be faced with any veneer available on the world market. Both reference standards listed later in this discussion require face veneers of at least 1/50 in., but thicker veneers may be specified. Veneers may be rotary cut, plain sliced, quarter-sliced, or rift cut, and may be matched with random, slip, and book-matched methods.

- Composite veneers are manufactured by slicing sustainably grown hardwoods, and then vat-dying and pressing them into new, composite "logs." The composite logs are then sliced to form new veneers that replicate other natural woods. By using various colors of natural veneers and slicing angles of the composite log, a nearly unlimited number of simulated wood species and veneer patterns can be created. These veneers can be applied to doors in the same way as natural veneers.

- Plastic laminate veneers provide a durable surface and are available in hundreds of available colors and patterns.
- Medium-density overlay (MDO) faces are used to provide a smooth, paintable surface that resists grain raising and moisture. For this reason, they are often used for exterior doors.
- Hardboard is used with three-ply construction for interior doors that are to be painted, and as a lower-cost option for MDO.

WOOD DOOR STANDARDS

The two main wood door standards are WDMA, I.S. 1-A, "Wood Flush Doors," published by the Window and Door Manufacturers Association, and the "AWI Architectural Woodwork Quality Standards," published by the Architectural Woodwork Institute. Generally, the WDMA standard is used to specify standard manufacturers' doors, while the AWI standards are used to specify custom doors. The Woodwork Institute of California also publishes standards in its *Manual of Millwork*.

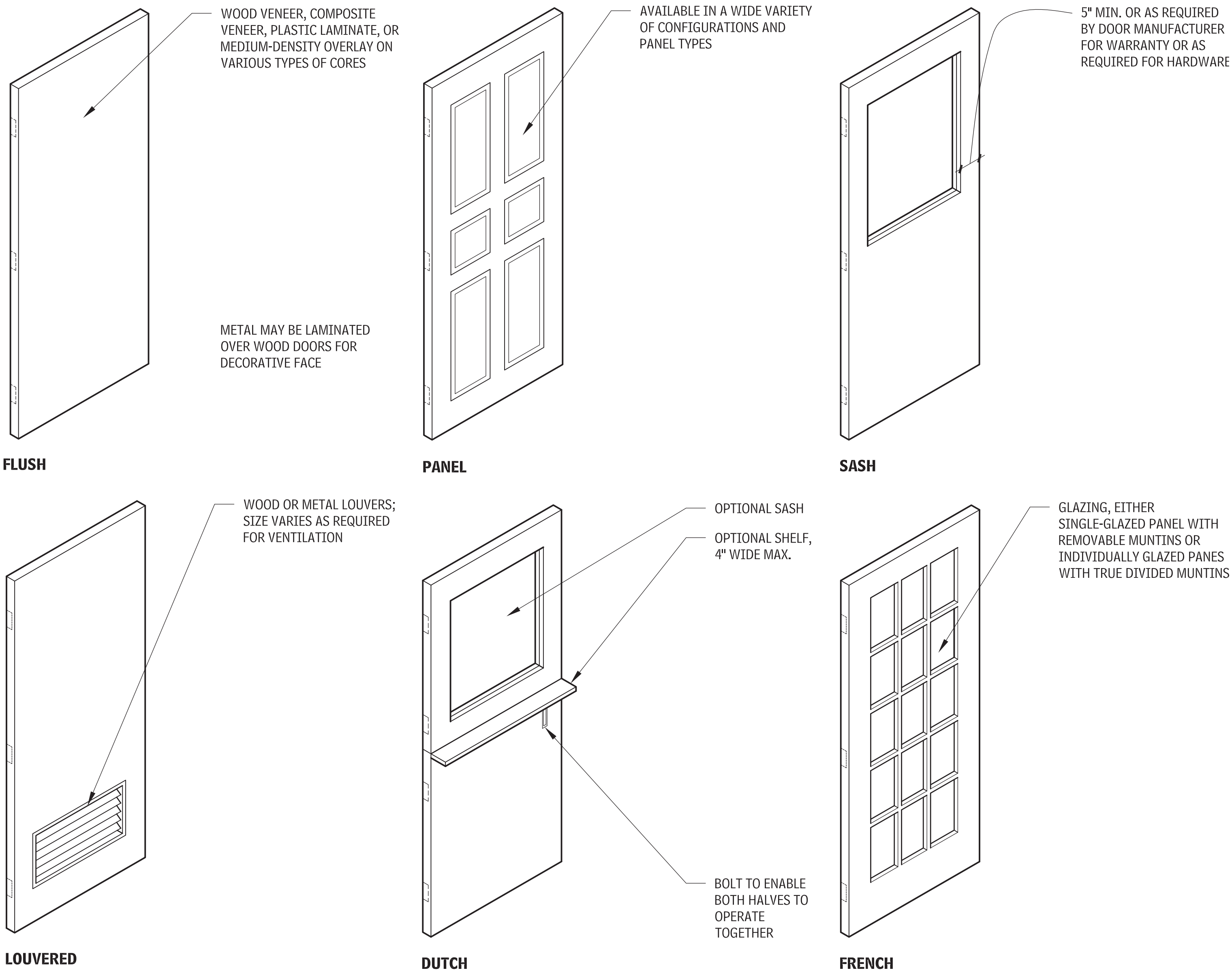
WOOD DOOR GRADES

Both WDMA and AWI standards classify doors into three grades: Premium, Custom, and Economy.

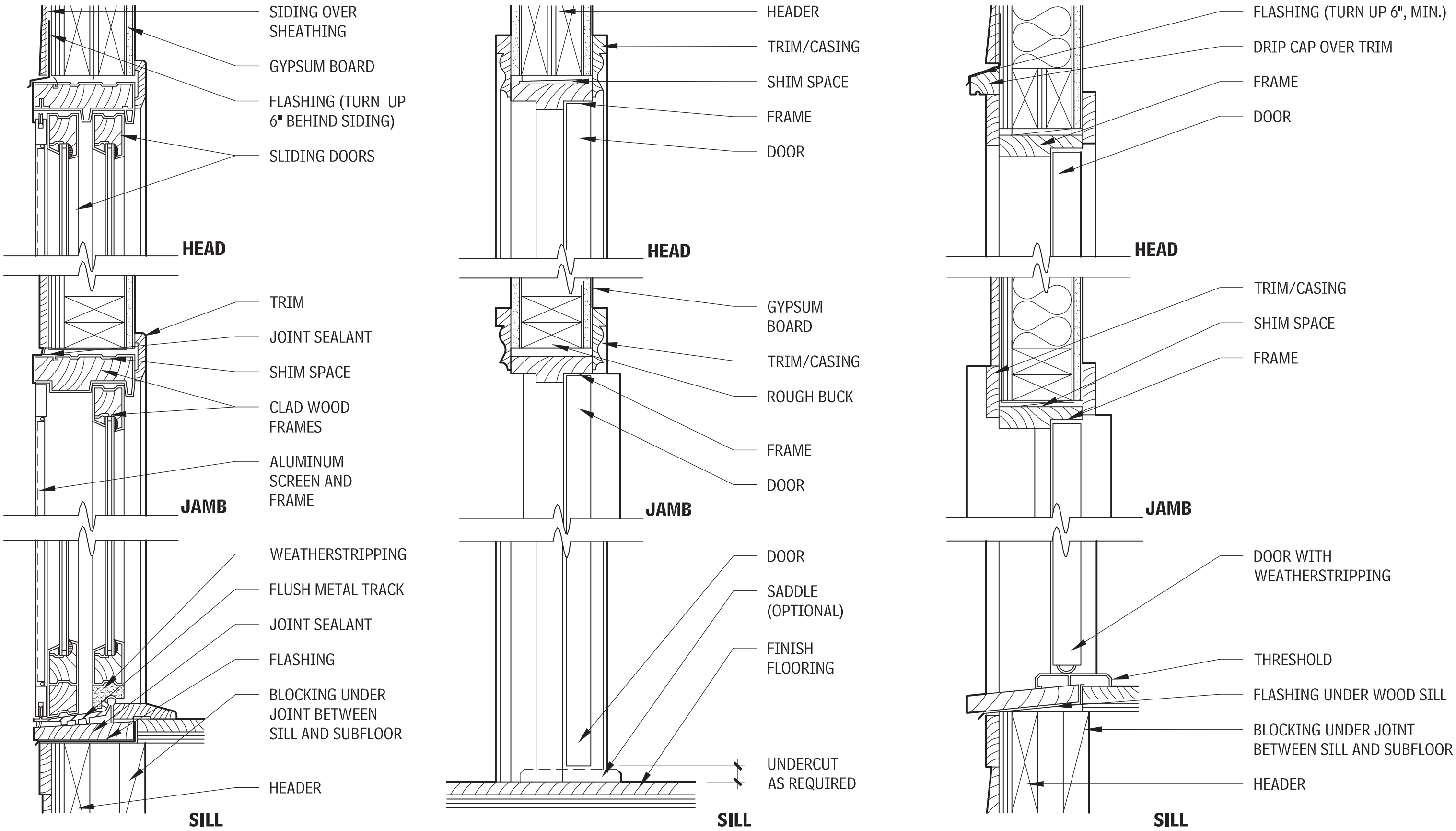
- *Premium grade* is specified when the highest level of materials, workmanship, and installation is required.
- *Custom grade* is suitable for most installations and is intended for high-quality work.
- *Economy grade* is the lowest grade and is intended for work where price is a primary factor.

Despite these common grade names, however, there are some differences between the WDMA and AWI standards, which should be recognized during project design.

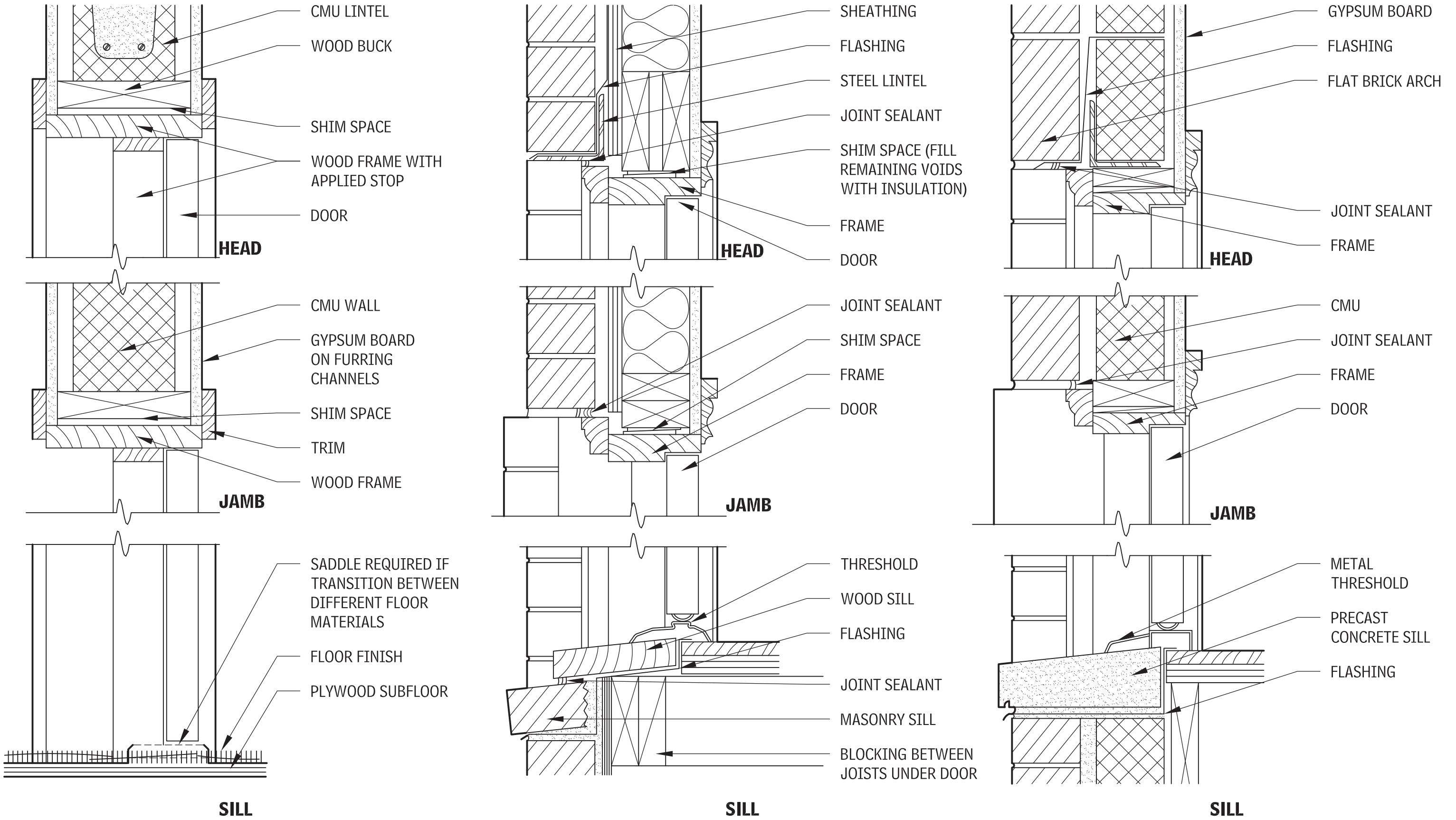
WOOD DOORS
12.79



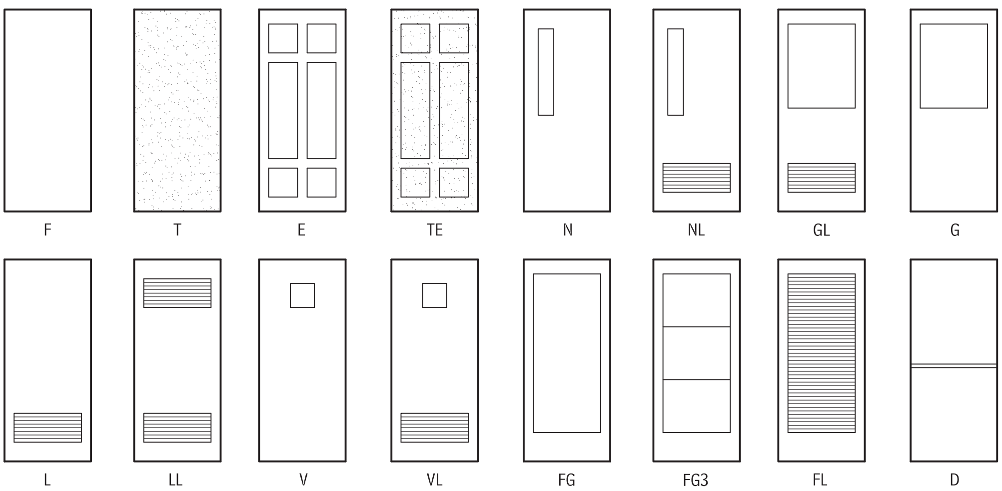
FRAME DETAILS IN WOOD WALL CONSTRUCTION
12.80



FRAME DETAILS IN MASONRY WALL CONSTRUCTION
12.81



STEEL DOOR TYPES ACCORDING TO SDI
12.82



NOMENCLATURE LETTER SYMBOLS AND THEIR MEANING ARE:

F: FLUSH
T: TEXTURED
E: EMBOSSED
TE: TEXTURED AND EMBOSSED
L: LOUVERED (TOP OR BOTTOM)
LL: LOUVERED (TOP AND BOTTOM)
V: VISION LITE
VL: VISION LITE AND LOUVERED
N: NARROW LITE
NL: NARROW LITE AND LOUVERED
GL: HALF GLASS AND LOUVERED
G: HALF GLASS (SEVERAL OPTIONS AVAILABLE)
FG: FULL GLASS
FG3: FULL GLASS, THREE PANES
FL: FULL LOUVERED
D: DUTCH DOOR

HOLLOW METAL DOORS

Hollow metal doors are doors constructed from sheet steel attached to various types of cores. They are generally used in steel frames, also constructed of sheet steel bent into various profiles.

To identify each of the several types of steel doors, the Steel Door Institute (SDI) uses a standard door design nomenclature. Many of these are shown in the accompanying Figure 12.83. Refer to SDI 106, "Recommended Standard Door Type Nomenclature," by the Steel Door Institute for a complete listing and for more information on door nomenclature and construction.

STANDARD STEEL DOOR GRADES AND MODELS
12.83

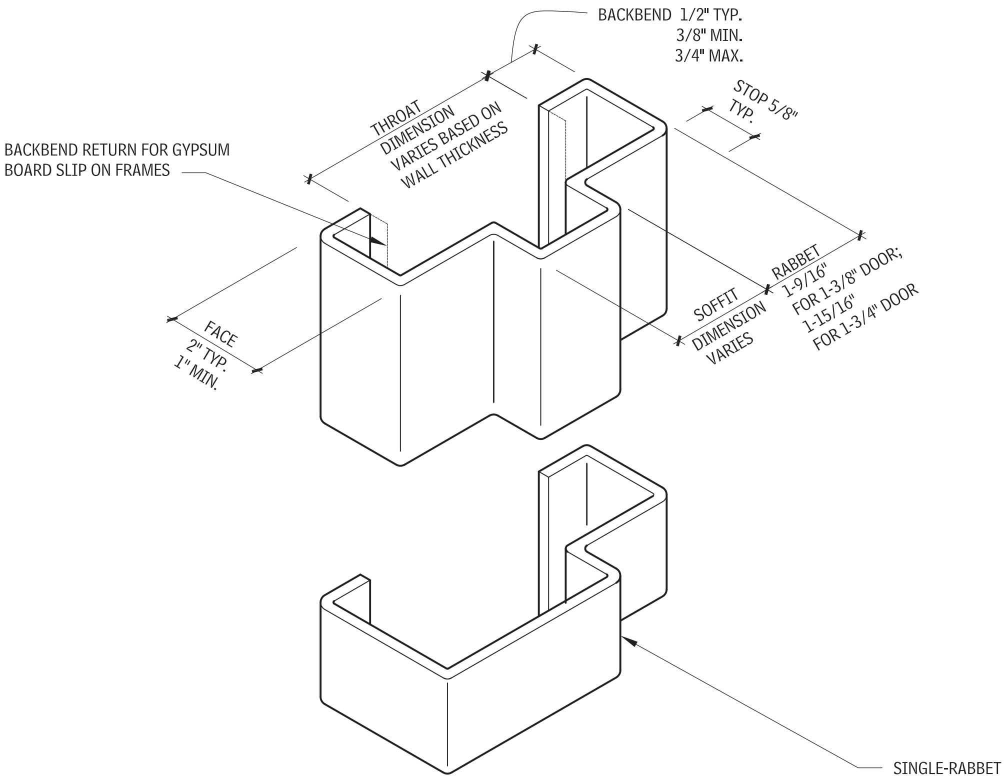
LEVEL		MODEL	FULL FLUSH OR SEAMLESS		
			GAUGE	IN.	CONSTRUCTION
I	Standard duty	1	20	0.032	Full flush
		2			Seamless
II	Heavy-duty	1	18	0.042	Full flush
		2			Seamless
III	Extra-heavy-duty	1	16	0.053	Full flush
		2			Seamless
		3			Site and rail[a]
IV	Maximum duty	1	14	0.067	Full flush
		2			Seamless

Source: Steel Door Institute, SDI-108, Cleveland, Ohio.

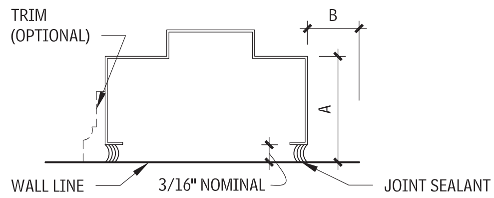
NOTE

12.83 a. Stiles and rails are 16-gauge; flush panels, when specified, are 18-gauge.

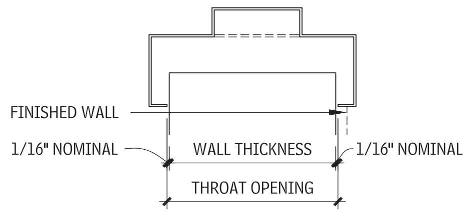
STANDARD HOLLOW METAL FRAMES
12.84



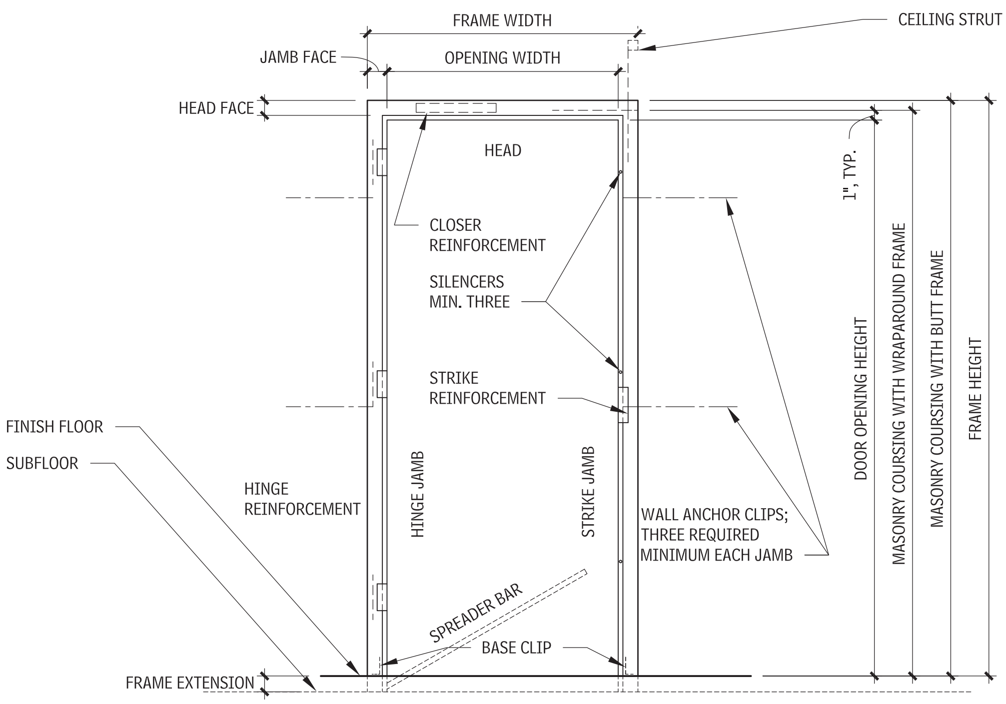
FLUSH FRAME
12.85



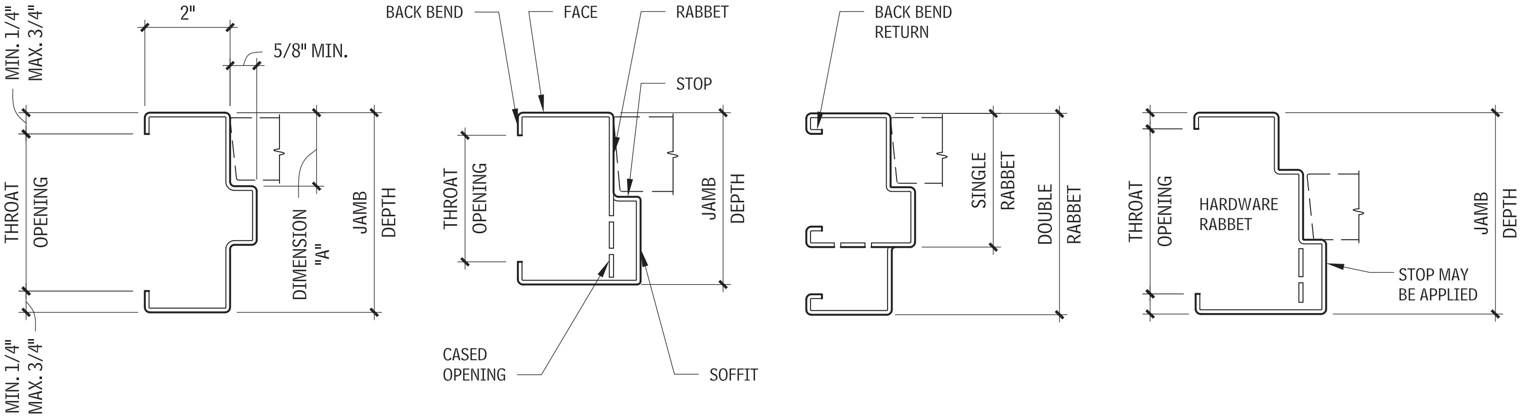
WRAPAROUND FRAME
12.86



STANDARD STEEL FRAME
12.87



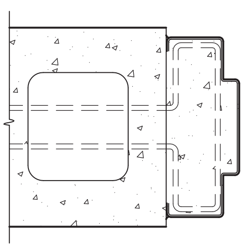
STANDARD PROFILES
12.88



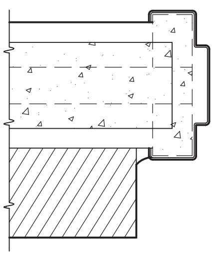
DOUBLE RABBET **SINGLE RABBET** **SLIP-ON DRYWALL** **DOUBLE EGRESS**

DOOR THK.	DIM. "A"
1-3/8"	1-5/8"
1-3/4"	2"

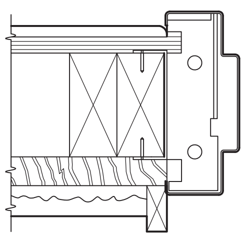
COMMON WALL CONDITIONS
12.89



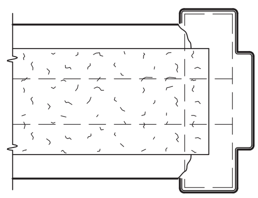
BUTTED MASONRY, BRICK TILE OR CONCRETE BLOCK



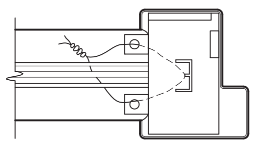
4" BLOCK AND BRICK COMBINATION



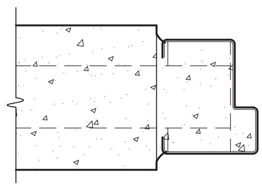
STUCCO – 2 x 4 WOOD STUD WITH GYPSUM BOARD & PLASTER



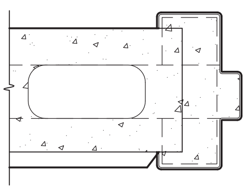
3" PRECAST GYPSUM TILE WITH PLASTER



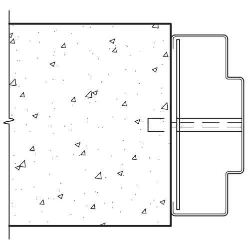
2" SOLID PLASTER WITH GYPSUM BOARD CORE



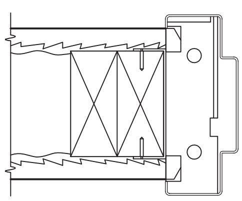
BUTTED MASONRY, TILE OR CONCRETE BLOCK



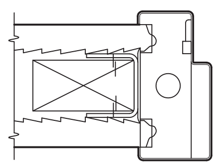
4" BLOCK WITH PLASTER



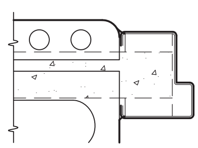
EXISTING MASONRY OR CONCRETE



2 x 4 WOOD STUD WITH PLASTER ON METAL LATH

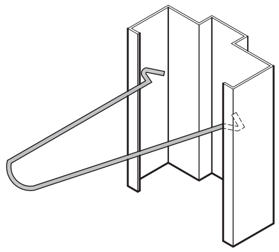


2 x 4 WOOD STUD WITH PLASTER ON METAL LATH

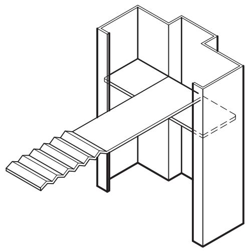


2" CORNER TILE AND 4" BLOCK COMBINATION

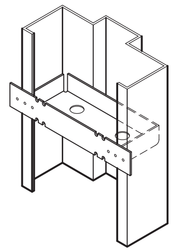
ANCHOR DETAILS
12.90



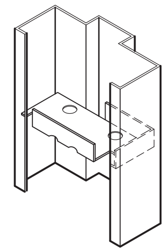
MASONRY WIRE ANCHOR



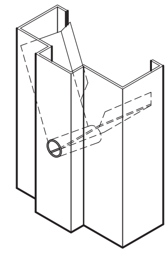
MASONRY TEE ANCHOR



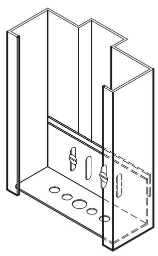
WOOD STUD ANCHOR



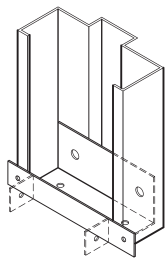
STEEL STUD ANCHOR



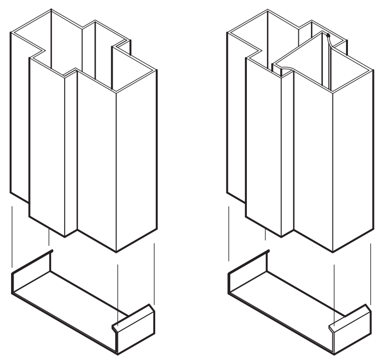
EXISTING WALL ANCHOR



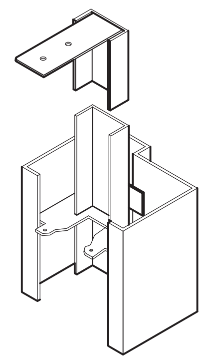
ADJUSTABLE BASE ANCHOR



WOOD STUD BASE ANCHOR



TYPICAL MULLION SECTIONS WITH BASE ANCHOR



PLASTER PARTITION ANCHOR (CEILING STRUT OPTIONAL)

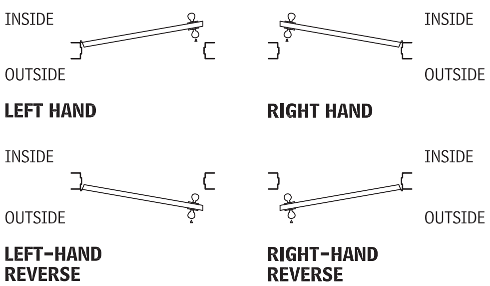
DESIGN CONSIDERATIONS

DOOR HANDING

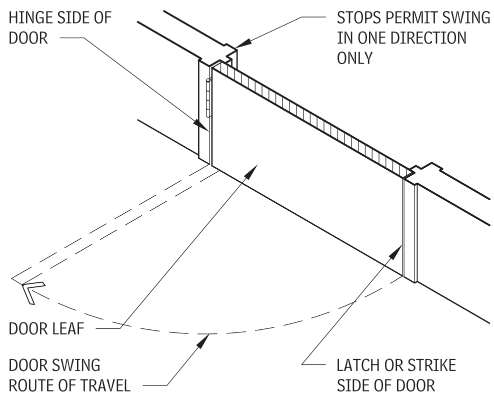
The hand, or the handing, of a door refers to the standard method of describing the way a door swings. Handing is used in the industry to communicate how a door swings and the kind of hardware that must be supplied for a specific opening. Some hardware is specific to the hand of the door due to the bevel on the strike side of the door. Hardware that works on any hand of door is called reversible or non-handed. Handing is determined by standing on the outside of the door looking at the door. If the door hinges on the left and swings away, it is a left-hand door.

The corridor side is considered the outside of a room door, as is the lobby side of a door opening into a room or the room side of a closet door. When the distinction between outside and inside is not clear, the outside is considered the side of the door where the hinge is located.

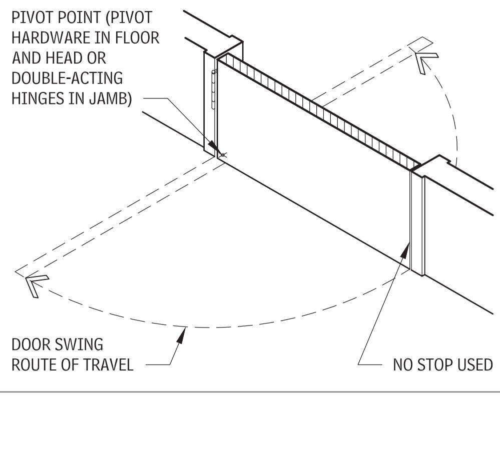
HANDS OF DOORS
12.91



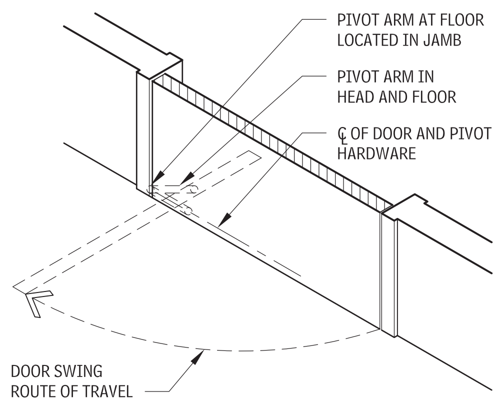
SINGLE-ACTING DOOR
12.92



DOUBLE-ACTING DOOR
12.94



BALANCED DOOR
12.93



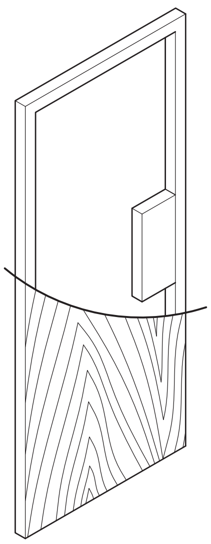
DOOR CORES

Working with door cores requires an understanding of these concepts:

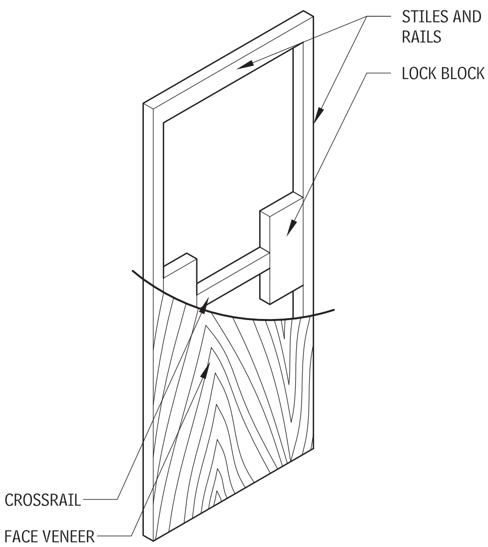
- *Hollow-core versus solid-core doors:* Hollow-core doors are typically used in residential construction and for commercial doors subject only to light use. Institutional hollow-core doors, with heavier stiles and rails and with additional blocking, have increased strength and resistance to warping, but may cost as much as some solid-core doors. Solid-core doors are more secure, more durable, more resistant to warping, and allow less acoustic transmission. They are used in most institutional and commercial projects.
- *Door bevel:* Doors are beveled to allow the door to open past the jamb without binding. The standard bevel is 1/8 in. in 2 in. Generally, unit locksets are only available with the standard bevel; cylindrical locksets are available with either flat or standard bevel, and mortise locksets are available with bevels adjustable from flat to standard.

- *Bonded versus nonbonded cores:* Solid-core doors can either be bonded or nonbonded. With a bonded core, the stiles and rails are glued to the core material and the whole assembly is sanded as a unit before the faces are applied. This reduces the likelihood of telegraphing. With a nonbonded core, the elements can vary slightly in thickness and can telegraph noticeably through the faces. Five-ply doors are typically made with a bonded core, whereas seven-ply doors are made with a nonbonded core.

HOLLOW CORE
12.95

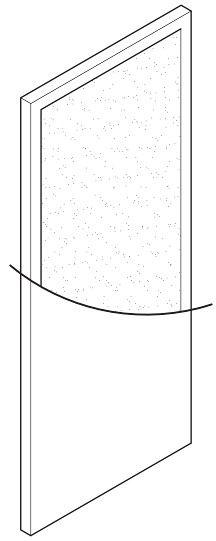


STANDARD

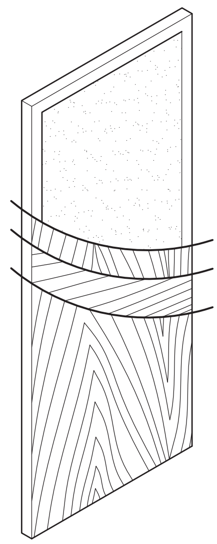


INSTITUTIONAL

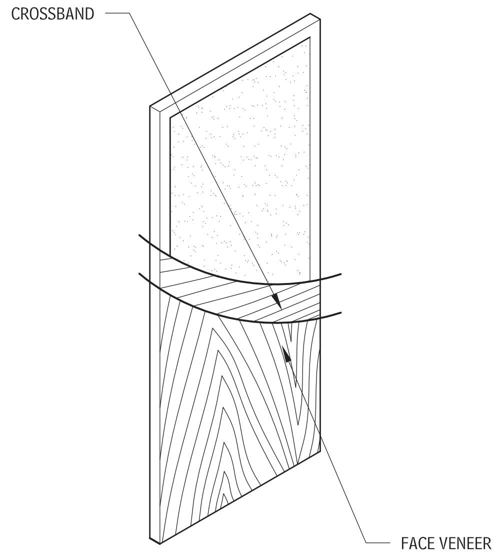
PARTICLEBOARD CORE
12.96



THREE-PLY WITH LAMINATE



SEVEN-PLY



FIVE-PLY

Figures 12.95 through 12.98 show the most common core types. Other options are available, including structural composite lumber (or laminated strand lumber). The following are specialized cores that may be desired, dependent on the project requirements:

- *Sound-insulating core:* A special core available in thicknesses of 1-3/4 in. and 2-1/4 in. The 1-3/4-in. core can provide a Sound Transmission Class (STC) rating of 36; the 2-1/4-in. core can achieve an STC of 42. Barrier faces are separated by a void or damping compound to keep the faces from vibrating in unison. Special stops, gaskets, and threshold devices are also required.
- *Lead-lined core:* A special core consisting of 1/32-in. to 1/2-in. continuous lead sheeting edge-to-edge inside the door construction. This material may be reinforced with lead bolts or glued.

DOOR SIZES

Both wood and hollow metal doors are available in a variety of standard widths. Custom doors can be fabricated in any size, but it is generally best to design around standard door sizes.

PANELS

Flat panels are typically three-ply hardwood or softwood. Raised panels are constructed of solid hardwood or softwood built up of two or more plies. Doors 1 ft-6 in. wide or less are one panel wide.

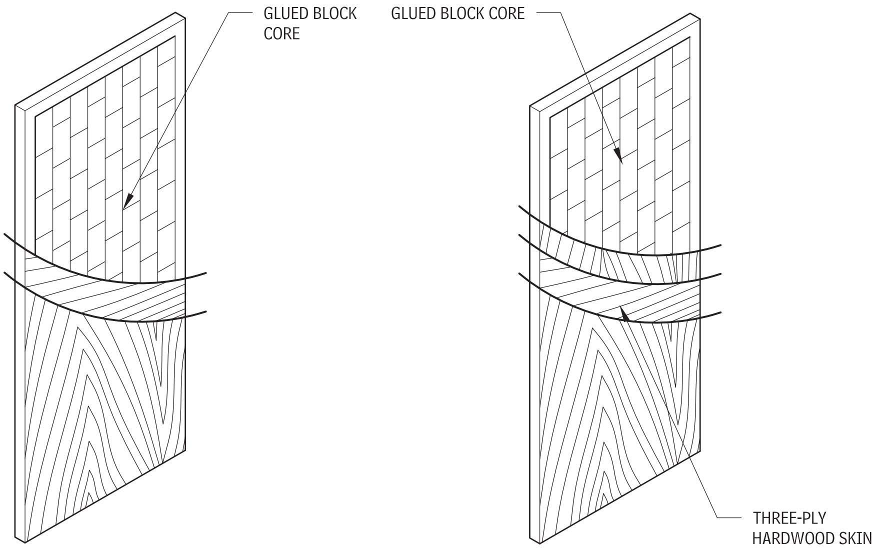
STILES AND RAILS

Panel doors consist of a framework of vertical (stile) and horizontal (rail) members that hold solid-wood or plywood panels, glass lights, or louvers in place.

The doors are made of solid or built-up stiles, rails, and vertical members (muntins), typically doweled per applicable standards. Dependent of location, common species include ponderosa pine,

Contributor:
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland.

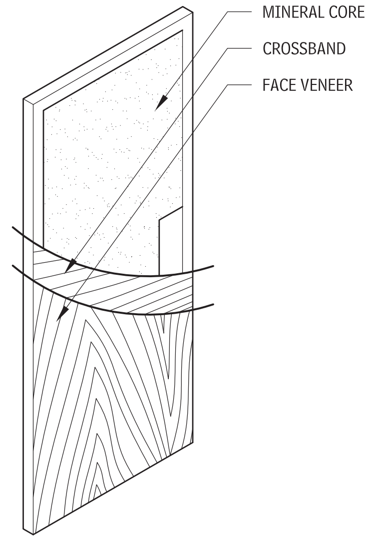
STAVED LUMBER CORE
12.97



FIVE-PLY

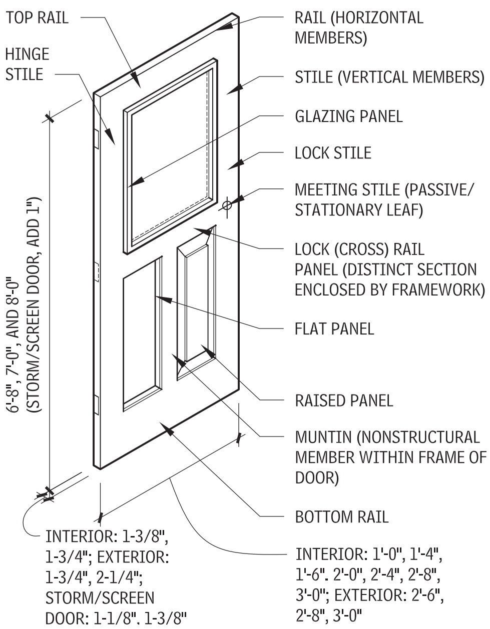
SEVEN-PLY

MINERAL COMPOSITION CORE
12.98

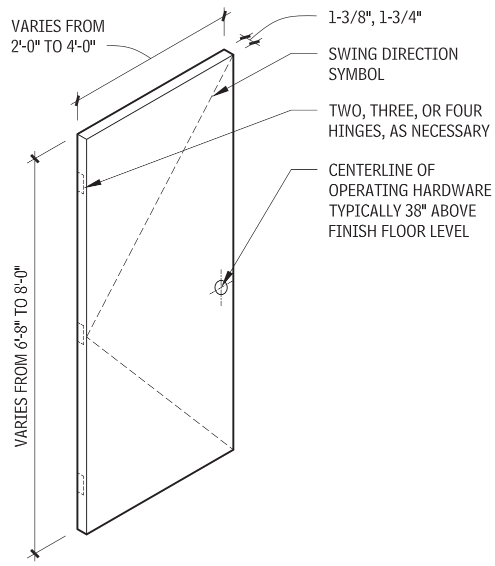


FIVE-PLY

STILE AND RAIL TERMINOLOGY
12.99



STANDARD DOOR SIZES
12.100



fir, hemlock, or spruce and hardwood veneers. Hardboard, metal, and plastic facings are available in various patterns.

GLAZING

Most building codes require all glass in doors to be safety glazed. Insulated safety glazing is available for increased thermal or acoustic performance.

BUILT-UP MEMBERS

The core and edge strip materials are similar to those used in flush doors. Face veneer is typically hardwood at 1/8-in. minimum thickness.

GLASS STOPS AND MUNTINS

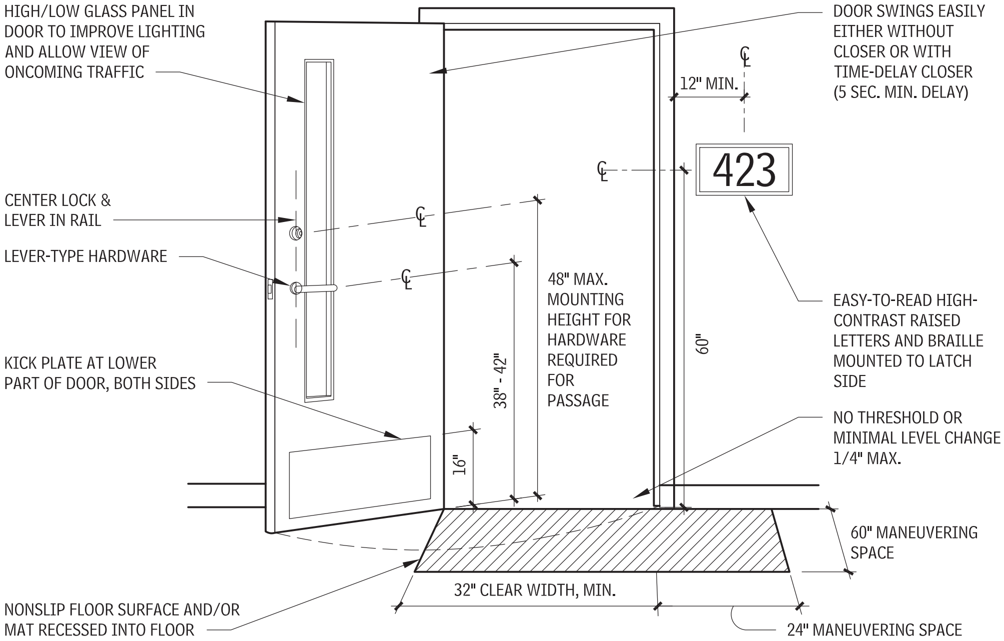
Typical profiles used for trim work include cove, bead, or ovolo.

GLASS DOORS

Glass doors are constructed primarily of glass, with fittings to hold the pivots and other hardware. Their strength depends on the glass rather than the framing. Glass doors are generally constructed of 1/2-in. or 3/4-in. tempered glass.

Glass doors may be installed within an opening or as part of an all-glass entrance system. If used alone, glass doors may be set within a wall opening with or without a frame, or they can be installed between glass sidelights. The same type of fitting used on the door is generally used for sidelights. Although jamb frames of aluminum, wood, or ornamental metal can be used, they are not necessary, and the glass sidelights can be butted directly to the partition.

ACCESSIBLE DOOR
12.101



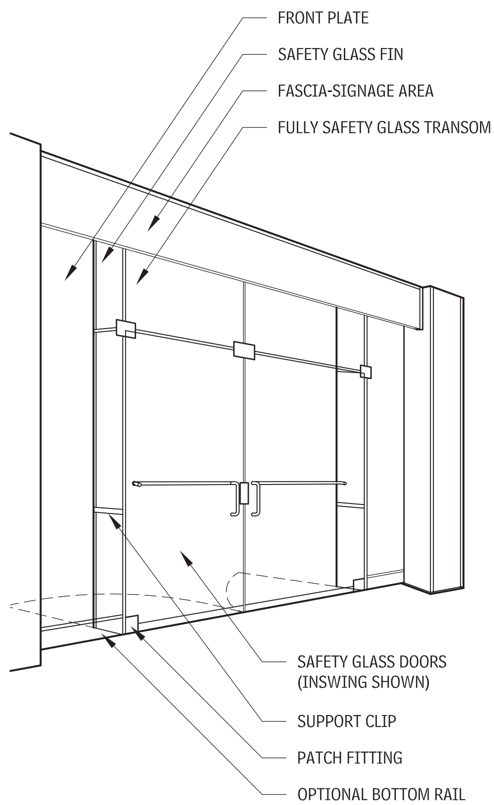
The minimum configuration for a glass door requires some type of door pull and a corner fitting at the top and bottom (sometimes called the shoe) to hold the pivots. Some manufacturers provide hinge fittings that clamp on the glass and support the door in much the same way as a standard hinged door.

If the door is used for egress, the local building code may require the use of special hardware that allows the door to be locked from the outside but still allows the door to be unlatched and opened from the inside with a single push on a push bar. Glass doors are heavy and may require a power operator or a balanced door system.

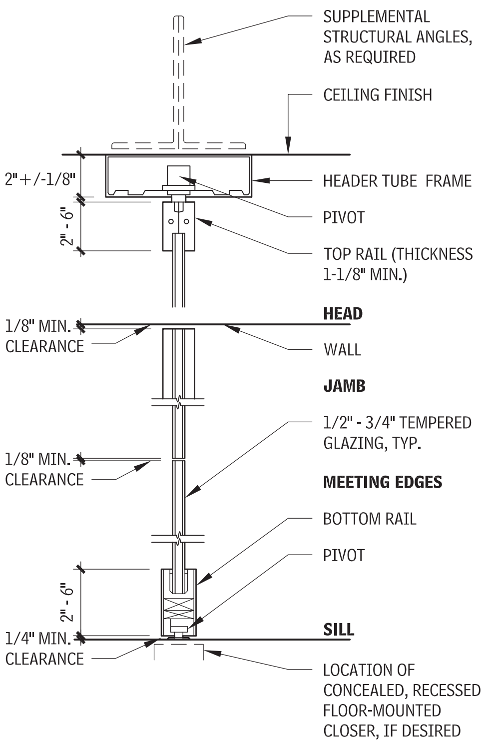
ALL-GLASS ENTRANCES

All-glass entrances, commonly used for interior storefronts, include glass doors and surrounding glazing that does not use visible framing members. Instead, special fittings are used to clamp adjacent glass pieces together and to support the glass doors. The glass, typically 1/2-in.- or 3/4-in.-thick, is installed in channels set in the floor and above the ceiling. Glass fins, for additional lateral support, may be placed perpendicular to the main glass plane and attached with silicone joint sealant.

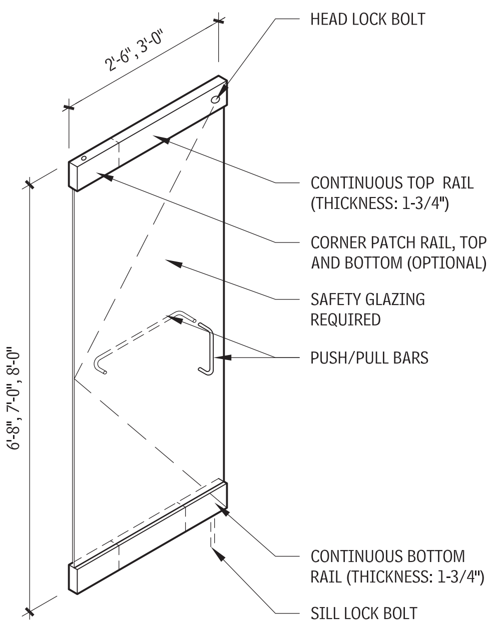
TYPICAL ALL-GLASS ENTRANCE
12.104



GLASS DOOR SECTION
12.102



GLASS DOOR PARTS
12.103



NOTE

12.102 Wire anchors can be tied around a dowel inserted vertically into stone.

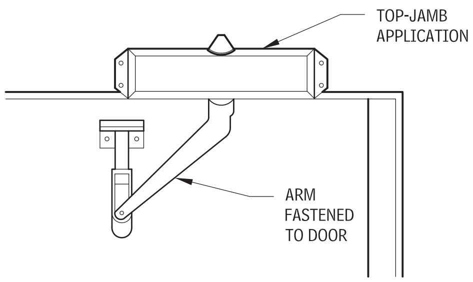
INTERIOR HARDWARE

DOOR HARDWARE

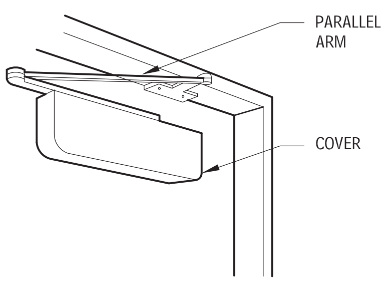
Following are common terms used when discussing and defining door hardware:

- *Coordinator:* A device used on a pair of doors to ensure that the inactive leaf is permitted to close before the active leaf.
- *Cylinder (of a lock):* The cylindrical-shaped assembly containing the tumbler mechanism and the keyway, which can be actuated only by the correct keys.
- *Cylinder lock:* A lock in which the locking mechanism is controlled by a cylinder.
- *Deadbolt (of a lock):* A lock bolt having no spring action or bevel, and which is operated by a key or turnpiece.
- *Door bolt:* A manually operated rod or bar attached to a door, providing means of locking.
- *Doorstop:* A device to stop the swing or movement of a door at a certain point.
- *Electric strike:* An electrical device that permits releasing of the door from a remote control.
- *Exit device:* A door-locking device that grants instant exit when someone presses a crossbar to release the locking bolt or latch.
- *Flush bolt:* A door bolt set flush with the face or edge of the door.
- *Lockset:* A lock, complete with trim, such as handles, escutcheons, or knobs.

MODERN-TYPE SURFACE-MOUNTED DOOR CLOSER 12.105

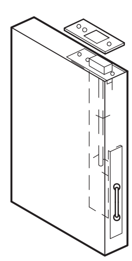


MODERN TYPE

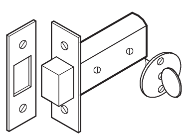


MODERN TYPE WITH COVER

BOLT MECHANISMS 12.106



EXTENSION FLUSH BOLT



MORTISE BOLT

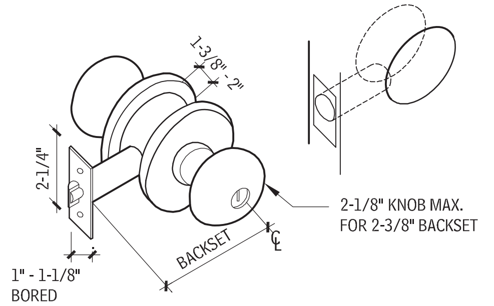
HARDWARE FINISHES 12.107

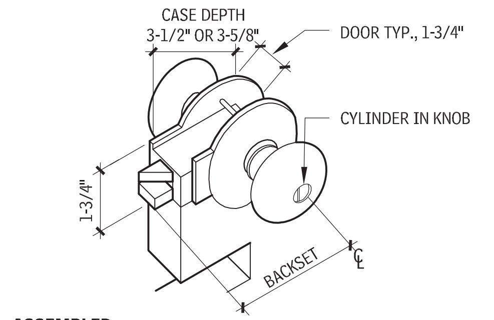
NEAREST U.S. EQUIVALENT	BUILDERS' HARDWARE MANUFACTURERS ASSOCIATION (BHMA) CODE	FINISH DESCRIPTION	BASE MATERIAL
USP	600	Primed for painting	Steel
US1B	601	Bright japanned	Steel
US2C	602	Cadmium plated	Steel
US2G	603	Zinc plated	Steel
US3	605	Bright brass, clear coated	Brass*
US4	606	Satin brass, clear coated	Brass*
US9	611	Bright bronze, clear coated	Bronze*
US10	612	Satin bronze, clear coated	Bronze*
US10B	613	Oxidized satin bronze, oil rubbed	Bronze*
US14	618	Bright nickel plated, clear coated	Brass, bronze*
US15	619	Satin nickel plated, clear coated	Brass, bronze*
US19	622	Flat-black coated	Brass, bronze*
US20A	624	Dark oxidized, statuary bronze, clear coated	Bronze*
US26	625	Bright chromium plated	Brass, bronze*
US26D	626	Satin chromium plated	Brass, bronze*
US27	627	Satin aluminum, clear coated	Aluminum
US28	628	Satin aluminum, clear anodized	Aluminum
US32	629	Bright stainless steel	Stainless steel 300 series
US32D	630	Satin stainless steel	Stainless steel 300 series
—	684	Black chrome, bright	Brass, bronze*
—	685	Black chrome, satin	Brass, bronze*

*Also applicable to other base metals under a different Builders' Hardware Manufacturers Association code number.

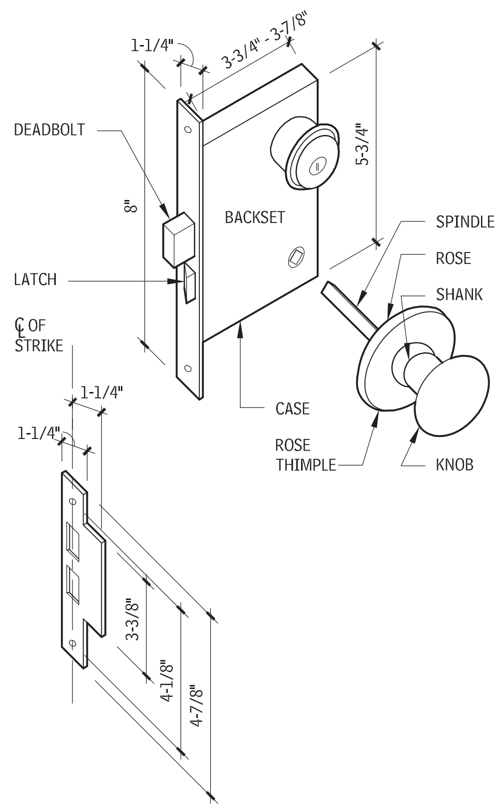
- *Mortise:* A cavity made to receive a lock or other hardware; also the act of making such a cavity.
- *Mortise lock (or latch):* A lock designed to be installed in a mortise rather than applied to the door's surface.
- *Rabbet:* The abutting edges of a pair of doors or windows, shaped to provide a tight fit.
- *Reversible lock:* A lock that, by reversing the latch bolt, may be used by any hand. On certain types of locks, other parts must also be changed.
- *Rose:* A trim plate attached to the door under the handle; sometimes acts as a handle bearing.
- *Shank (of a handle):* The projecting stem of handle into which the spindle is fastened.
- *Spindle (of a handle):* The bar or tube connected with the knob or lever handle that passes through the hub of the lock or otherwise engages the mechanism to transmit the handle action to the bolt(s).
- *Stop (of a lock):* The button or other small device that serves to lock the latch bolt against the outside handle or thumb piece, or unlock it if locked. Another type holds the bolt retracted.

LOCK TYPES 12.108





ASSEMBLED



MORTISE

- *Strike:* A metal plate or box that is pierced or recessed to receive the bolt or latch when projected; sometimes called the keeper.
- *Three-point lock:* A device sometimes required on three-hour fire doors to lock the active leaf of a pair of doors at three points.

NOTES

12.108 a. Installation requires notch cut in lock side of door to suit case size. Complete factory assembly eliminates much adjustment on the job.
b. Installation requires mortise opening in door.
c. See American Standards Association Lock Strikes A-115V-1959 for metal door frames. To determine lip length, measure from centerline of strike to edge of jamb and add 1/4 in. Outside strike dimensions standard for all lock types shown.

Contributor:
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland.

DOOR HANDLES, PLATES, LOCKS, STOPS, AND HOLDERS

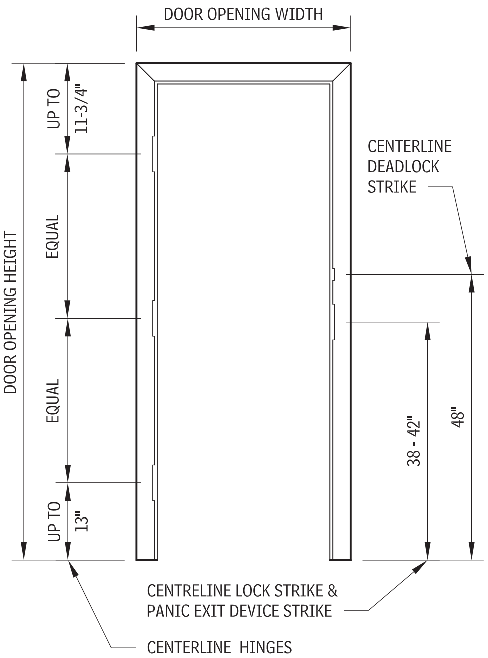
Based on use characteristics, there are four main types of latches and locks:

- *Passage:* Latches can be operated by a handle from either side at all times.
- *Privacy:* The outside handle is locked by a push-button inside (or if a deadbolt latch, by a turn) and unlocked by an emergency key outside.
- *Entry:* The outside handle is made inoperative by mechanical means, other than a key, on the inside. The latch bolt is operated by a key on the outside handle or by manual means at the inside handle.
- *Classroom:* The outside handle is locked from the outside by a key.

When the outside handle is locked, the latch bolt may be retracted by a key from the outside or by rotating the inside handle.

In all cases, the latch bolt can be operated by a handle from either side.

DOOR HARDWARE LOCATIONS
12.109



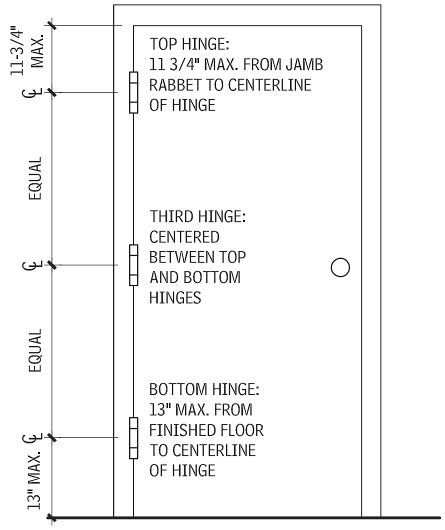
DOOR HINGES

Use three hinges for doors as tall as 7 ft-6 in. Add one hinge for each additional 30 in. in height.

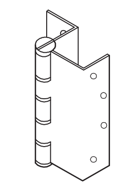
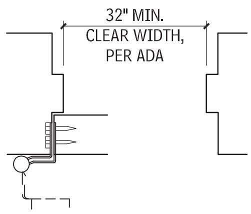
In specifying hinges, these design criteria are important:

- Door material, weight, and dimensions
- Hinge weight (standard or heavy), material, finish, and special features (e.g., swing clear, spring hinge, etc.)
- "Clearance" (i.e., distance between door and frame when door is opened 180°)
- Frequency of use, conditions of use (e.g., exterior, corrosive atmosphere, potential for abuse or vandalism, etc.)
- Type of pin tips
- Type of screws

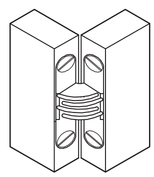
HINGE LOCATION
12.110



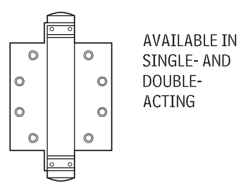
SPECIALTY HINGES
12.111

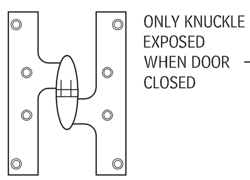
SWING CLEAR



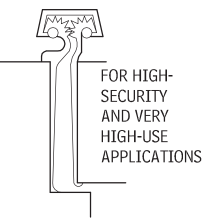
INVISIBLE



SPRING

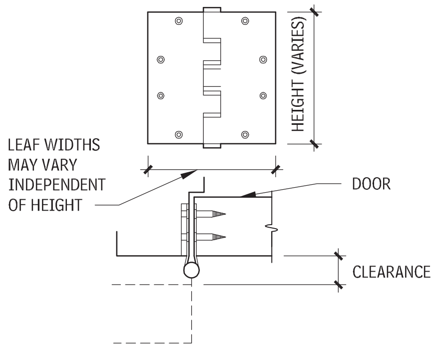


OLIVE KNUCKLE

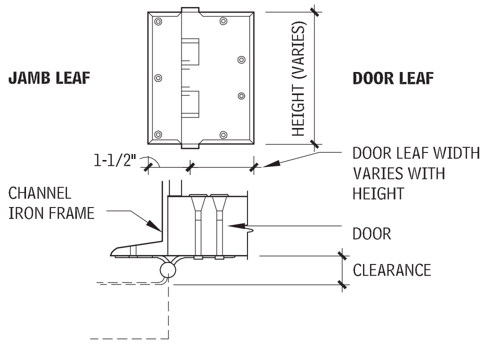


CONTINUOUS GEAR

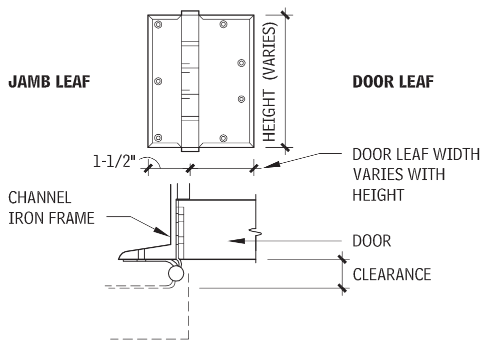
TYPES OF HINGES
12.112



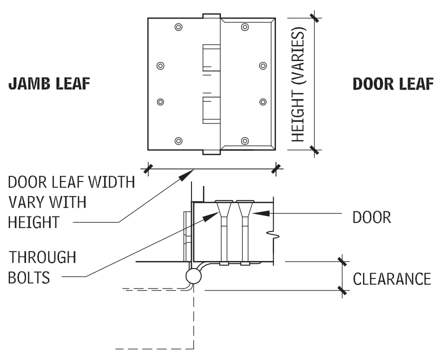
FULL MORTISE



HALF-MORTISE



FULL SURFACE



HALF-SURFACE

PIVOT HARDWARE

Pivot hardware, either center or offset, is recommended for use when the appearance of hinges is unacceptable. Pivot hardware is used most often with frameless, nonrated door assemblies (i.e., glass doors). Pivots are used in pairs, with the bottom pivot concealed in the floor and the top pivot concealed within the door head. This arrangement also allows the closer hardware to be concealed at either of these locations.

Center-pivot hardware allows the door to swing in either direction, unless restrained by the closer mechanism or a stop. Offset-pivot hardware allows the door to swing in one direction. Tall, heavy doors require offset pivot hardware, as intermediate pivots must be included for additional support on heavy doors or to prevent door deflection and consequent warping on tall doors.

DOOR CLOSERS

When properly installed and adjusted, a door closer should control the door throughout the opening and closing swings. It combines three basic components:

- A power source, to close a door
- A checking source, to control the rate at which the door closes
- A connecting component (an arm that transmits the closing force from the door to the frame)

In all modern closers, the power source is a spring, and the checking source is a hydraulic mechanism. The spring and checking mechanisms are connected to a common shaft, and arms attached to this shaft act as a linkage to communicate movement between the door and mechanism. In addition to serving as linkage, the arms, through leverage, can amplify the power of the spring, providing maximum power at the latch point.

Additional features for safety and convenience also are available in many types of closers. These include back check, delayed action, adjustable spring power, and a variety of hold-open functions (regular, fusible link, and hospital).

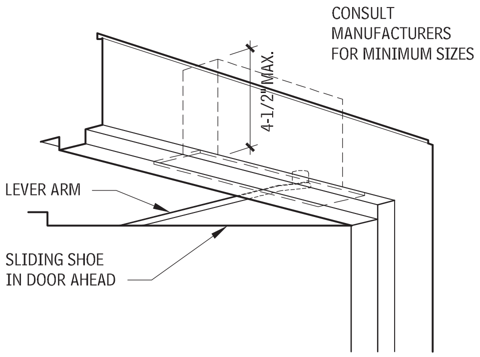
A full range of closer sizes are available to suit various door dimensions, locations, and job conditions. The manufacturer's recommendations should be considered carefully.

Closers with delayed-action features give a person more time to maneuver through doorways. They are particularly useful on frequently used interior doors such as entrances to toilet rooms. The ADAAG requires a closing speed of at least three seconds; ANSI requires five seconds.

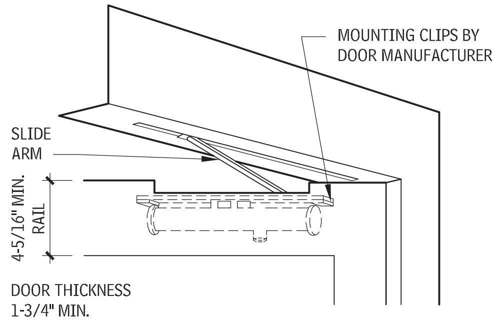
DOOR HOLDER, CLOSER, DETECTOR

A combination fire and smoke detector, door holder, and closer is available. Ionization, photoelectric, or heat-sensing devices detect

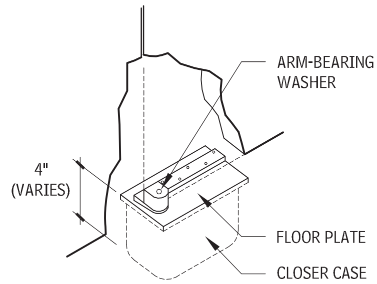
CONCEALED DOOR CLOSERS
12.113



IN FRAME AHEAD

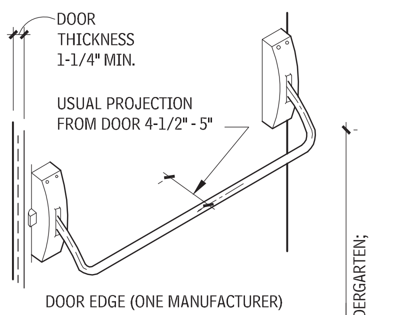


IN DOOR AHEAD

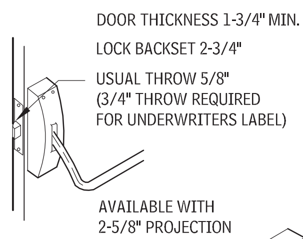


IN FLOOR

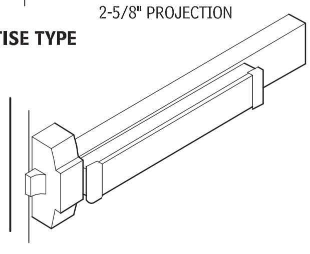
EXIT DEVICES PANIC HARDWARE
12.114



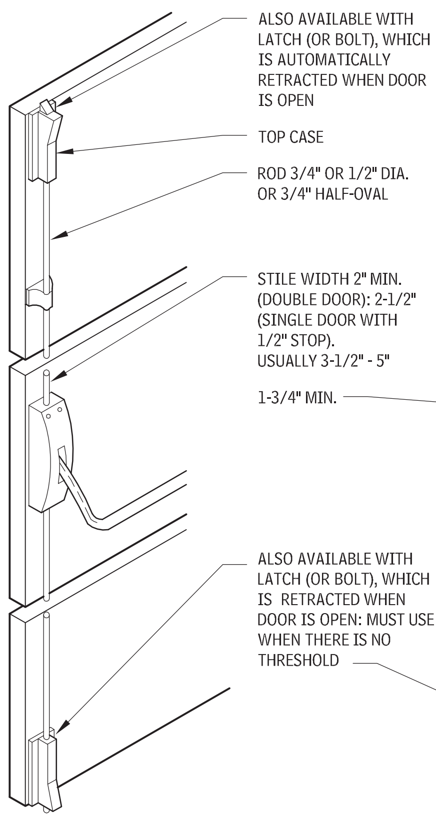
RIM TYPE (SURFACE)



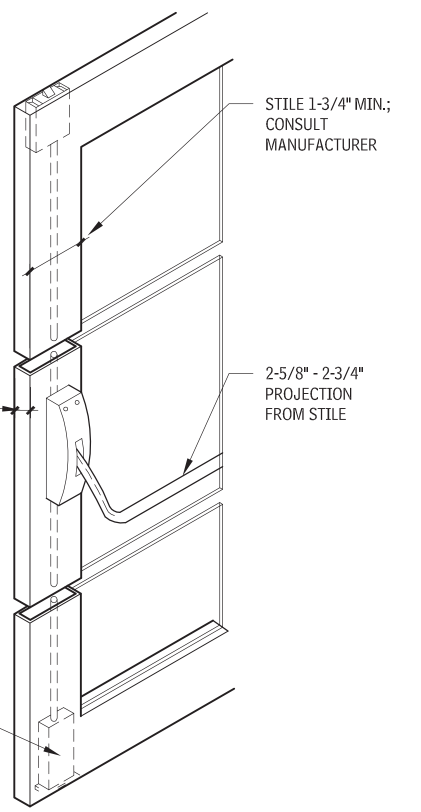
MORTISE TYPE



TOUCH BAR



SURFACE VERTICAL ROD TYPE



CONCEALED VERTICAL ROD TYPE (HOLLOW METAL DOORS)

smoke or any combustion products, and either hold open or close the door. Smoke and fire doors are most commonly held open by electromagnetic or pneumatic devices and are released and closed manually or by means of smoke- or fire-detection devices. Most jurisdictions do not allow the old-fashioned fusible-link door closer in areas of human occupation, except for overhead doors. Some hold-open devices incorporate an electric switch that allows building maintenance staff to turn off the hold-open feature; however, such a switch should never shut off the detector. Requirements for closers and detectors vary by code and governing jurisdiction. Refer to local building codes, the life-safety code of the National Fire Protection Association (NFPA), and other applicable regulations.

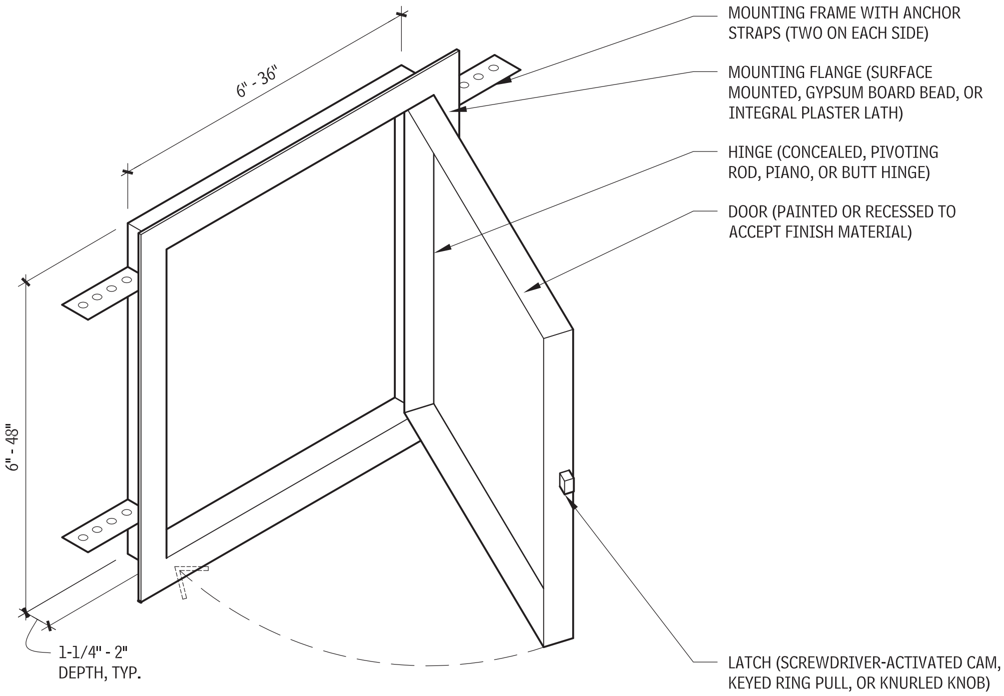
COMBINATION CLOSER AND HOLDER

A combination closer and holder will hold the door in the open position when incorporated with an independent detector or when wired into any type of fire-detecting system. This type of unit has unlimited hold-open from 0° to approximately 170°, or limited hold-open from 85° to 170° for cross-corridor doors.

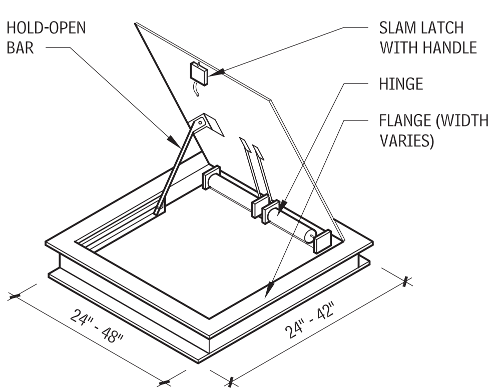
ACCESS PANELS

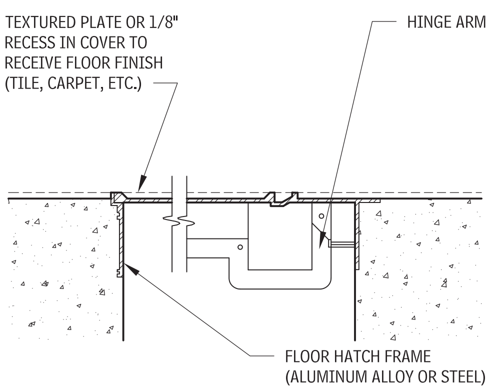
FLOOR, WALL, AND CEILING ACCESS DOORS

WALL OR CEILING ACCESS DOOR CHARACTERISTICS
12.115



DOOR IN FLOOR
12.116





DETAIL

Contributor:
Daniel F. C. Hayes, AIA, Washington, DC.

INTERIOR FLOOR CONSTRUCTION

RAISED FLOOR CONSTRUCTION

ACCESS FLOORING

Access flooring creates a chase underneath the floor for wires, cables, and sometimes an air distribution plenum. Access flooring systems are often used in general offices, data centers, computer rooms, and clean rooms. Multilevel access flooring systems are available that incorporate two or more continuous cavities beneath the floor panels to house wireways and an air distribution plenum. Access flooring consists of panels and an understructure system.

UNDERSTRUCTURES

There are two types of access flooring understructures: low-profile systems and pedestal systems.

- Low-profile systems provide a low-height access floor (typically less than 4 in. high that does not significantly encroach on space height. In these systems, closely spaced plastic or metal supports incorporate cable management systems and provide support at regular intervals across the panel.
- Pedestal systems are composed of either a threaded rod or a telescoping tube, which support the panel at the corners (or at the edge at the floor perimeter). It is considered good practice to adhere pedestal bases to the subfloor to resist horizontal forces.

There are two basic types of pedestal systems: stringerless and stringer systems.

STRINGERLESS SYSTEMS

Stringerless systems consist of pedestals located so that each pedestal head supports four panels at their corners. Stringerless systems provide maximum access to the underfloor cavity. Stringerless understructures can be less stable laterally than those with stringers and are less capable of withstanding lateral forces from earthquakes and other sources; consequently their use is limited to lower finished floor heights. Two-panel types are available for stringerless pedestal systems: gravity-held and bolted-down panels.

Gravity-Held Panel Systems

Gravity-held panels are secured in place by nesting on an interlocking connection formed in both the panel and the pedestal head. This system provides the quickest access because no tools other than a panel lifter are required to remove panels.

Bolted-Down Panels

Bolted-down panels are directly connected to pedestal heads by fasteners located in panel corners. Because the fasteners must be accessible to remove panels, floor coverings must be either removable or permanently attached to panels and of a type that can accommodate exposed countersunk fasteners. Carpet tile is generally selected for the former condition, and either high-pressure plastic laminate or resilient tile for the latter. Bolting panels to pedestals improves the entire system's lateral stability and adds resistance to rocking and overturning. The latter effect can result where partitions are fastened to panels and are subject to unbalanced loads that are not resisted by ceiling connections or other means.

STRINGER SYSTEMS

Stringer systems are offered with either bolted or snap-on (nonbolted) stringers. The purpose of stringers is to provide additional lateral support, particularly where panels are frequently removed or where finished floor heights or earthquake loads exceed those that can be accommodated by stringerless systems. Two panel types are available for stringer systems: bolted and snap-on stringers.

Bolted Stringer

Bolted stringer systems consist of main stringers, usually two to three modules long, and cross stringers, one module long, which are bolted to pedestals. These stringers may or may not support panel edges.

Snap-on Stringer

Snap-on stringer systems consist of stringers, each one module in length, located under the edge of each panel and interlocking with pedestal heads without using threaded fasteners; this makes the removal of grid members more convenient because no tools are needed. The disadvantage of snap-on stringers is that with frequent use they do not provide the same degree of restraint as bolted stringers.

FLOOR AND BASE FINISHES

WOOD FLOORING

Wood flooring consists of solid or engineered wood products and is available in strip, plank, and parquet. All wood floors require regular maintenance to preserve their appearance. Wood flooring industry organizations and suppliers provide detailed information on product specifications.

SOLID WOOD FLOORING

Solid wood flooring is available in many hardwood and softwood species. It can be refinished multiple times. It should not be installed below grade, due to the possibility of moisture damage to the wood floor.

WOOD STRIP FLOORING

Wood strip flooring for normal use is typically a nominal 3/4-in. thick, with an actual thickness of 25/32 in., in widths ranging from 1-1/2 to 2-1/4 in. Lengths are random.

WOOD PLANK FLOORING

Wood plank flooring is also typically a nominal 3/4-in. thick, in widths ranging from 3 to 10 in., and is available in random lengths.

SELECTION OF WOOD FLOORING

Wood flooring should be selected after considering pedestrian and vehicular (cart) traffic, durability required, and potential damage to floors; typical usage, exposure to moisture and sunlight, maintenance, wood floor appearance expectations, and other criteria specific to the project.

The majority of woods specified for commercial flooring are hardwoods such as oak or maple. Best overall appearance, uniformity of color, limited amounts of character marks, and minimal sap marks indicate the most desirable wood flooring.

Figure 12.118 lists the typical grades and sizes of boards by species or regional group. Grade classifications vary, but in each case it can be assumed that the first grade listed is the highest quality and that the quality decreases with each succeeding grade. The best grade typically minimizes or excludes features such as knots, streaks, spots, checks, and torn grain, and will contain the highest percentage of longer boards. Grade standards have been reduced in recent years for most commercially produced flooring, hence a thorough review of exact grade specifications is in order when selecting wood flooring.

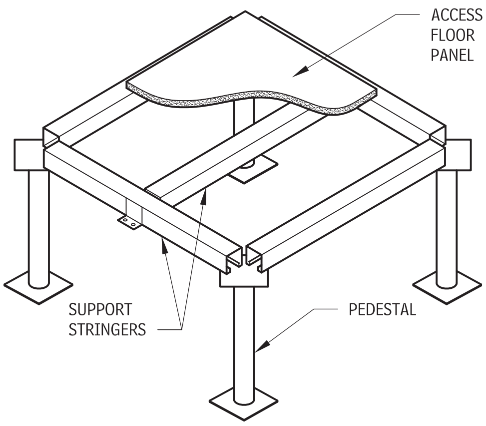
ENGINEERED WOOD FLOORING

Engineered wood flooring is available in strip, plank, or parquet tiles. Hardwood face veneers are laminated to a dimensionally stable, multiple-ply substrate. Engineered wood floors are not as susceptible to moisture as solid wood flooring, and may be used in below-grade areas, with the proper installation techniques.

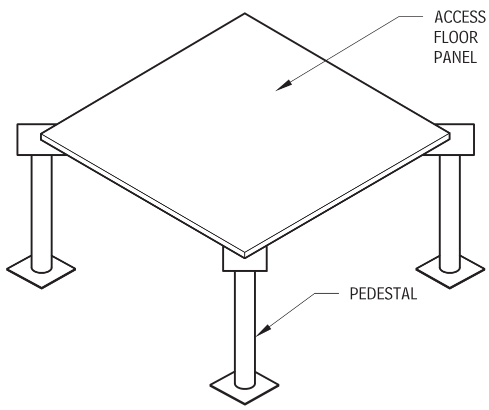
BAMBOO FLOORING

Bamboo is a grass product (not a wood product, strictly defined). The bamboo is harvested, cut into strips, boiled in water with a

ACCESS FLOORING UNDERSTRUCTURE SYSTEMS 12.117



STRINGER SYSTEMS



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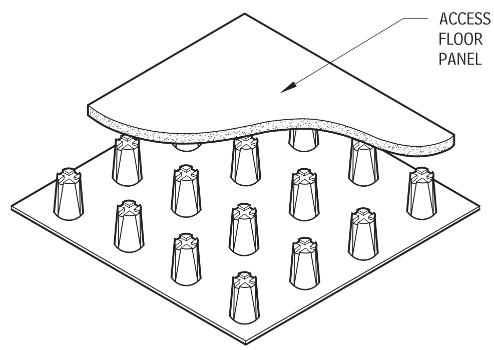


LOW-PROFILE SYSTEMS

TYPICAL GRADES AND SIZES OF BOARDS BY SPECIES OR REGIONAL GROUP
12.118

GROUP	INDUSTRY ORGANIZATION	GRADE	THICKNESS (IN.)	WIDTH (IN.)	NOTES
Oak, ash, black cherry, and walnut; also beech, birch, hard maple, pecan, and hickory	National Oak Flooring Manufacturers Association (NOFMA), Memphis, Tennessee: (901) 526-5016; www.nofma.org	Oak, ash, black cherry, and walnut	Strip	Face	Factory-finished oak flooring is available in Prime, Standard, and Tavern grades, 3/4″ thick with a face width of 1-1/2″ or 2-1/4″. NOFMA grades hickory/pecan as first grade, first grade red, first grade white; second grade, second grade red; and third grade.
		Clear	3/4″	1-1/2″, 2″	
				2-1/4″, 3-1/4″	
		Select	1/2″	1-1/2″, 2″	
		Common (Nos. 1 and 2)	Maple, beech, birch only		
		Beech, birch, and hard maple	3/4″, 25/32″	1-1/2″, 2″	
		First (including red and white)	33/32″	2-1/4″, 3-1/4″	
		Second	Plank	3″, 4″, 5″, 6″, 7″	
		Third	3/4″	8"	
		(See notes in last column for other species.)			
Hard maple (*Acer saccharum*, not soft maple); also beech and birch	Maple Flooring Manufacturers Association, Northbrook, Illinois: (847) 480-9138; www.maplefloor.org	First, Second, and Better Third	25/32″, 33/32″	Face	The Maple Flooring Manufacturers Association states that beech and birch have physical properties that make them fully suitable as substitutes for hard maple. Consult manufacturers for available width and thickness combinations.
				1-1/2″	
				2-1/4″	
				3-1/4″	
Southern pine	Southern Pine Inspection Bureau, Pensacola, Florida: (850) 434-2611; www.spib.org	B and B	3/8″, 1/2″, 5/8″	Nominal Face	Grain may be specified as edge (rift), near-rift, or flat. If not specified, manufacturer will ship flat or mixed-grain boards. Check with manufacturers for available width and thickness combinations.
		C	1″, 1-1/4″, 1-1/2″	2″ 1-1/8″	
		C and Better		3″ 2-1/8″	
		D		4″ 3-1/8″	
		No. 2		5″ 4-1/8″	
				6″ 5-1/8″	
Western woods (Douglas fir, hemlock, Englemann spruce, Idaho white pine, incense cedar; lodgepole pine, ponderosa pine, sugar pine, western larch, western red cedar)	Western Wood Products Association, Portland, Oregon: (503) 224-3930; www.wwpa.org	All but Idaho white pine	2″ and thinner	Nominal	Flooring is machined tongue-and-groove, and may be furnished in any grade. Grain may be specified as vertical (VG), flat (FG), or mixed (MG). Basic size for flooring is 1″ × 4″; standard lengths are 4′ and longer. The moisture content of these grades is 15% MC, with 85% of the pieces less than 12% MC.
		B and Better Select		3″	
		C Select		4″	
		D Select		6″	
		Idaho white pine	Supreme		
			Choice		
			Quality		

Source: National Oak Flooring Manufacturers Association, Memphis, Tennessee.

preservative, and pressed flat. The strips are dried and laminated vertically into solid boards. Because bamboo matures in just three years, this product is an excellent renewable resource. The bamboo flooring is manufactured in tongue-and-groove strips approximately 3-1/2 in. wide, 3/4 in. thick, and in lengths up to 6 ft.

A 3/8-in.-thick material is available for glue-down application. It is available in vertical grain and flat grain. Bamboo flooring is very durable; hardness tests indicate similarity to red oak floors.

INSTALLATION

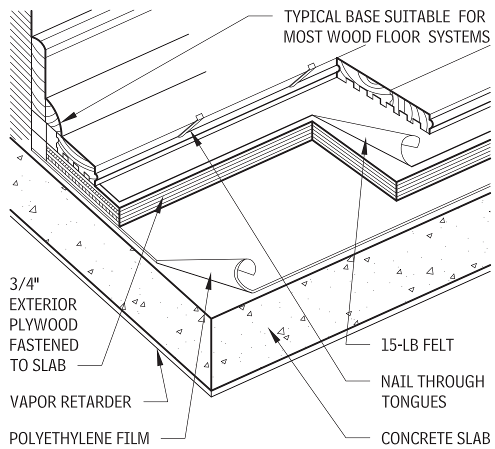
Wood flooring requires particular care in handling and installation. Prior to installation, the wood flooring should be allowed to acclimate to the space in which it is to be installed, at the humidity level of the final occupancy. Minimize moisture damage to wood floors by avoiding installation in close proximity to wet areas. In addition, to ensure constant temperature and humidity, install wood floors after all "wet" jobs have been completed and after the heating plant and all permanent lighting have been installed.

Wood flooring is subject to expansion and contraction; therefore, perimeter base details that allow for movement and ventilation are recommended. Wood structures require adequate ventilation in basements and crawl spaces. Under a slab on or below grade, moisture control can be further enhanced by use of a vapor barrier; this provision should be carefully considered for each installation.

Wearing properties of wood flooring vary from species to species and should be considered along with appearance when specifying wood floors. In addition, grain pattern affects the durability of a given species. For example, industrial wood blocks are typically placed with the end grain exposed because it presents the toughest wearing surface. The thickness of the wood above the tongues in tongue-and-groove flooring may be increased for extra service.

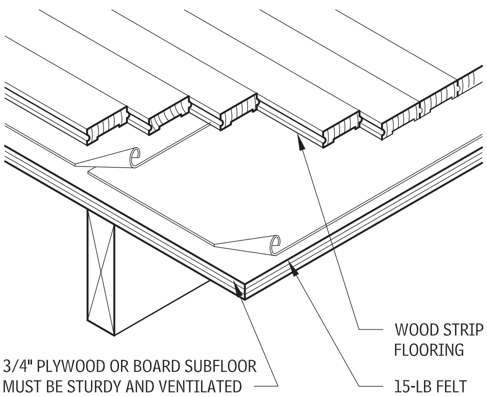
Wood floors are installed over a plywood subfloor or over wood sleepers. Strips or planks are blind-nailed in tongue-and-groove installations and face-nailed in butt-jointed installations; parquet floors are commonly set in mastic. Vapor barriers are installed when the installation is slab-on-grade or below grade. Ventilation is required in certain installation conditions where moisture is a concern. Special conditions require additional detailing for proper installation.

STRIPS OVER PLYWOOD UNDERLAYMENT
12.119

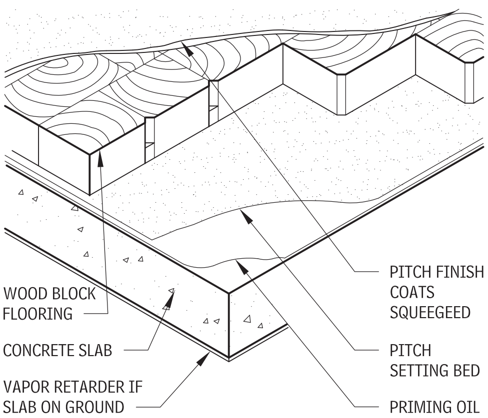


Contributors:
Trey Klein, AIA, Crayfish Design, Belmont, Massachusetts; Jason Dickerson, Rhode Island School of Design, Providence, Rhode Island; John C. Lunsford, AIA, Varney, Sexton Syndor Architects, Phoenix, Arizona.

STRIPS OVER SUBFLOOR ON WOOD JOISTS
12.120



INDUSTRIAL WOOD BLOCK
12.121



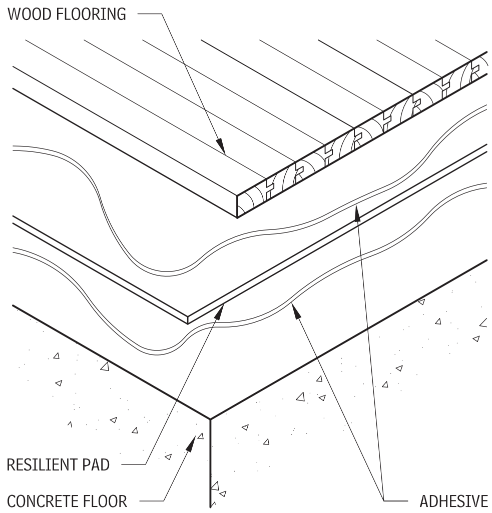
RESILIENT WOOD FLOORING

Resilient wood flooring is commonly used in athletic facilities. The typical wood flooring species for sports facilities is maple, preferred for its density, fineness of grain, and no splintering qualities. Beech and birch are also used by some manufacturers for resilient wood floors. Finishes are typically transparent, and supplemental markings may be added with approved materials and techniques for floor striping and logos.

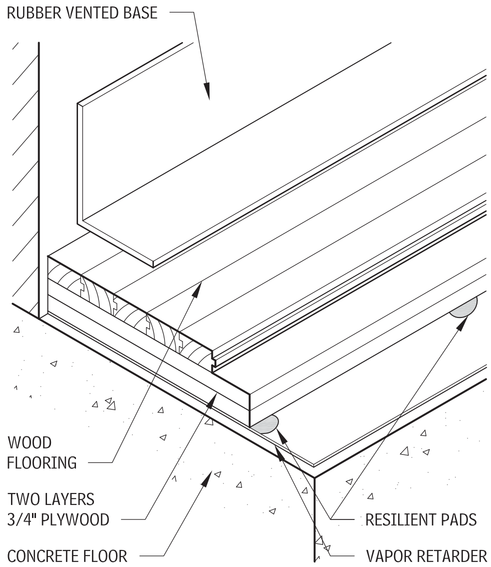
The Maple Flooring Manufacturers Association (MFMA) provides detailed information on the features, installation, and maintenance for maple flooring. Wood sports floor systems vary from one manufacturer to another, and some are engineered for specific purposes, such as aerobics use. Some systems are proprietary and protected by patents. The information contained in this section refers to typical resilient wood flooring systems. Consult manufacturers for specific information.

Resilient wood flooring is commonly milled into tongue-and-groove-shaped strips of random length. Typical thickness is 25/32 in. for most general-purpose resilient wood flooring. An 11/32-in. thickness is available from selected manufacturers when additional loads are anticipated and where usage is expected to be more severe than normal. Widths range from 5-1/2 in. to 3-1/4 in.

RESILIENT WOOD FLOORING—ADHESIVE APPLIED ASSEMBLY
12.122



RESILIENT WOOD FLOORING—CUSHIONED ASSEMBLY
12.123



STONE AND TILE

TILE FLOOR FINISHES

Many types of tile are used as floor finishes including: ceramic, quarry, glass mosaics, plastic, and metal. Ceramic tile is fabricated from clay or a mixture of clay and ceramic materials. Natural clay is most commonly used, but porcelain is also available. Porcelain tile is fine-grained and smooth and can be formed into sharply detailed designs. Tile dimensions are typically nominal. Refer to manufacturers' data for specific tile and trim piece dimensions.

TILE COMPOSITION AND GLAZE

Ceramic tile is made from either natural clay or porcelain, and is glazed or unglazed.

- Porcelain tile is a ceramic mosaic or paver tile generally made by the dust-pressed method. It is dense, impervious, fine-grained, and smooth, with a sharply formed face.
- Natural clay tile is a ceramic mosaic or paver tile with a distinctive, slightly textured appearance. It is made by the dust-pressed or plastic method from clays that have a dense body.
- Glazed tile has an impervious facial finish of ceramic materials that is fused to the body of the tile. The body may be nonvitreous, semivitreous, vitreous, or impervious.
- Unglazed tile is a hard, dense tile of uniform composition that derives color and texture from the materials used in its fabrication.

TILE TYPES

There are a variety of tile types, including ceramic mosaic, quarry, paver, decorative, mounted, and conductive tile.

WATER ABSORPTION OF CERAMIC TILE
12.124

TYPE	WATER ABSORPTION	CERAMIC MATERIAL	USE
Nonvitreous	More than 7.0%	Natural clay	Not for use in continually wet locations
Semivitreous	More than 3.9%, but not more than 7.0%	Natural clay	Not for use in continually wet locations
Vitreous	0.5% to 3.0%	Natural clay	For use in continually wet locations
Impervious	0.5% or less	Porcelain	For use in continually wet locations; superior wear resistance

CERAMIC MOSAIC TILE
Ceramic mosaic tile is formed either by the dust-pressed or the plastic method. Usually 1/4- to 3/8-in. thick with a facial area of less than 6 sq. in., it may be made of either porcelain or natural clay and may be plain or have an abrasive mixture throughout.

QUARRY TILE
Quarry tile is glazed or unglazed tile made by the extrusion process from natural clay or shale. It usually has a facial area of 6 sq. in. or more. Quarry tile may be specified with abrasive grit embedded in the surface, for use in areas where slip resistance is a concern.

PAVER TILE
Paver tile is glazed or unglazed porcelain or natural clay tile formed by the dust-pressed method with a facial area of 6 sq. in. or more.

DECORATIVE THIN-WALL TILE
Decorative thin-wall tile is a glazed tile with a thin body that is usually nonvitreous. It is suitable for interior decorative residential use when breaking strength is not a requirement.

MOUNTED TILE
Mounted tile is assembled into units or sheets to facilitate handling and installation. Tile may be face-mounted, back-mounted, or edge-mounted.

Material applied to the face of the tile is usually easily removed, but material bonded to the back is integrated to the tile installation.

NOTE

12.124 ANSI A 137.1, "Specification for Ceramic Tile," quantifies the four levels of water absorption for tile. The density and porosity of the tile determine its capability to absorb moisture. In general, the lower the water absorption level, the better the stain resistance of the tile.

Contributors:
Rippeteau Architects, PC, Washington, DC; Tonn Lensment, Rhode Island School of Design, Providence, Rhode Island; Rippeteau Architects, PC, Washington, DC; Annica S. Emilsson; Rippeteau Architects, PC, Washington, DC; National Oak Flooring Manufacturers Association, Memphis, Tennessee; National Wood Flooring Association, Manchester, Missouri.

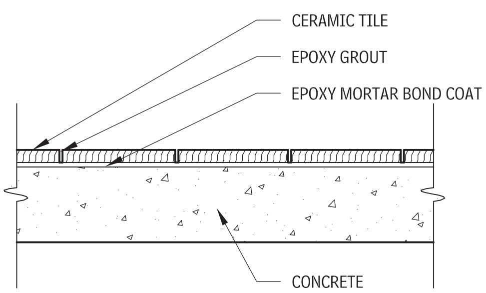
CONDUCTIVE TILE

Conductive tile has specific properties of electrical conductivity but retains other normal physical properties of tile.

SETTING MATERIALS 12.125

TYPE	DESCRIPTION	FEATURES
CEMENTITIOUS		
Portland cement mortar	Portland cement and sand, in proportions of 1:5 for floors; portland cement, sand, and lime, in proportions of 1:5:1/2 to 1:7:1 for walls	Most surfaces, ordinary installations
Dryset mortar	Portland cement with sand and additives imparting water retentivity, which is used as a bond coat for setting tile	Thinset installations
Latex–portland cement mortar	Portland cement, sand, and special latex additive, which is used as a bond coat for setting tile	Latex additives improve adhesion, reduce water absorption, and provide greater bond strength and resistance to shock and impact. Required for large-unit porcelain-bodied tile.
NONCEMENTITIOUS		
Epoxy mortar	Epoxy resin and epoxy hardeners	Chemical-resistant
Modified epoxy emulsion mortars	Emulsified epoxy resins and hardeners with portland cement and silica sand	High bond strength; little or no shrinkage; not chemical-resistant
Furan resin mortar	Furan resin and furan hardeners	Chemical-resistant
Epoxy adhesives	Epoxy resin and epoxy hardeners	High bond strength and ease of application; less than optimal chemical resistance
Organic adhesive	For interior use only; ready to use (no addition of liquid); cures by evaporation	Not suitable for continuously wet applications or temperatures exceeding 140°F

THINSET-CHEMICAL-RESISTANT EPOXY MORTAR AND GROUT INSTALLATION 12.126



EPOXY MORTAR AND GROUT

EPOXY MORTAR AND GROUT

Epoxy mortar and grout are used where moderate chemical exposure and severe cleaning methods are used, such as in food processing plants.

MOVEMENT JOINTS

Movement in the structure and the substrate must be accommodated by the ceramic tile installation. For quarry tile and paver tile, a movement joint width should be the same as a grout joint, but not less than 1/4 in.; for ceramic mosaic tile and glazed wall tile, a movement joint should be not less than 1/4 in. In addition to expansion joints, there are several types of movement joints, as follows:

- Control joints or contraction joints are formed, sawed, or tooled grooves in the concrete substrate, used to create a weakened location where the controlled cracking of the concrete can occur.
- Construction joints are located where two separate placements of concrete meet and where reinforcement may be continuous.
- Isolation joints are installed where adjoining areas of a concrete substrate may move in three directions and where the formation of cracks is to be avoided.
- Cold joints are formed when the size of a concrete slab is too large for one pour and successive pours are required. Cold joints may crack with movement of the slab. Some slabs are saw-cut at regular intervals to provide controlled cracking locations.

MOVEMENT JOINT MATERIALS

Backup strips are flexible and compressible types of closed-cell foam polyethylene, butyl rubber, or open-cell and closed-cell polyurethane. These strips should be rounded at the surface that comes in contact with the sealant.

Sealants used are silicone, urethane, or polysulfide. Silicone sealants are used on interior vertical tile surfaces. Mildew-resistant silicone sealants are useful in wet areas. Urethane sealants are used in interior horizontal tile installations. Sealants should comply with ASTM C 920, "Standard Specification for Elastomeric Joint Sealants."

MOVEMENT JOINT LOCATIONS

All expansion, control, construction, cold, and seismic joints in the structure should continue through the tile work, including such joints in vertical surfaces. Joints installed through tile work directly over structural joints must never be narrower than the structural joint. Expansion joints should be installed in the following circumstances:

- 24 to 36 ft. in each direction
- Tile work exposed to direct sunlight or moisture, 12 to 16 ft. in each direction
- Where tile work abuts restraining surfaces such as perimeter walls, dissimilar floors, curbs, columns, pipes, ceilings, and where changes occur in backing materials

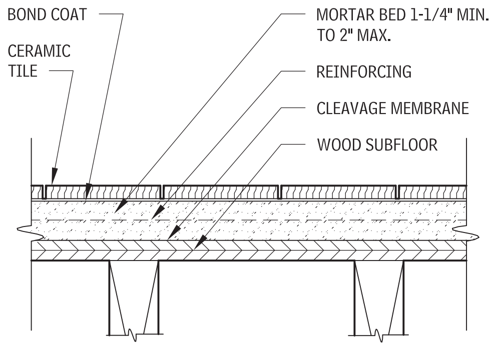
STONE FLOORING

Stone flooring is available in two basic types: dimension stone, which is installed in a thick mortar bed, and dimension stone tiles, which are installed in a thick mortar bed or in a thinset installation, similar to ceramic tile installations.

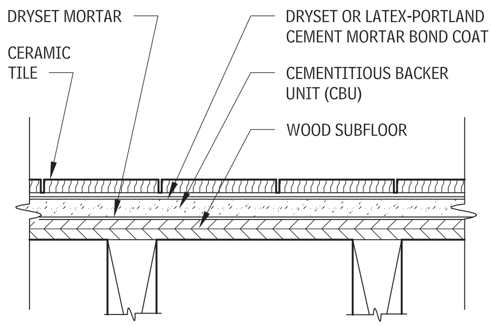
STONE TILE AND PAVER INSTALLATION

Joint width should always be specified; 1/16 to 1/8 in. is considered standard. When installing stone flooring over a wood subfloor, the floor should be reinforced to ensure against deflection.

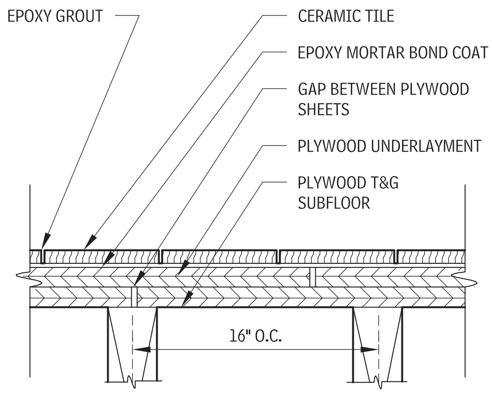
FLOORING DETAILS—WOOD SUBSTRATE 12.127



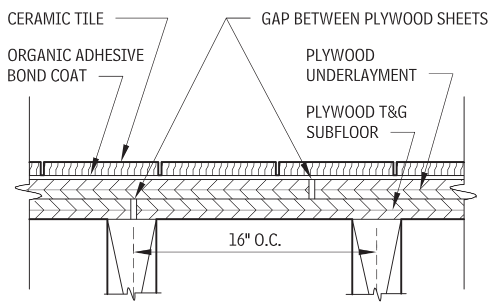
CEMENT MORTAR



DRYSET MORTAR



EPOXY MORTAR AND GROUT



ORGANIC ADHESIVE

NOTE

12.125 Copyrighted work of USG Corporation, *USG Gypsum Construction Handbook*, 6th ed., p. 52, R.S. Means Company, Inc., Kingston, Massachusetts, 2009.

Lippage is a condition that occurs when tiles are installed with a thin bed over an uneven surface. Tiles may "lip" one edge higher than adjacent tiles, presenting a ragged appearance on the finished surface. In some conditions, a certain amount of lippage is unavoidable. As a general rule, the recommended maximum variation of the finished surface should be no more than 3/16 in., cumulative over a 10-ft lineal measurement, with no more than 1/32-in. variation between individual tiles.

DIMENSION STONE

Dimension stone is defined as quarried stone with usually one or more mechanically dressed surfaces. These are thick slabs of stone that are marked as they are cut for matched-pattern installations, such as book-match or end-match configurations.

Dimension stone tiles are less than 3/4 in. thick. They provide the natural beauty of a stone floor without the weight, depth, and expense of dimension stone. However, their thinness makes stone tiles more prone to cracking from impact or normal floor deflection. Stone tiles are installed either by the thick-bed or the thinset installation method.

Stone flooring can vary in sizes from large paver units with face areas up to 48 sq. in. by 3/4, 1-1/4, or 2 in. thick to small stone tiles. Sizes and shapes are limited by the specific stone's characteristics.

Stone tile modules are typically 12 to 24 sq. in. by 1/4, 3/8, or 1/2 in. thick, and typically are furnished with a protective backing to improve the tile strength. Dimension stone for stair and threshold applications are typically custom-sized.

STONE FINISHES

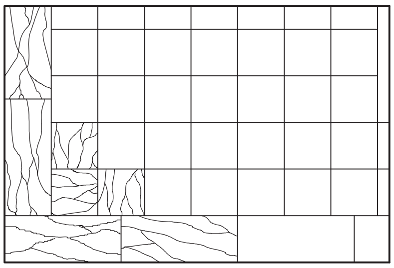
Stone finishes affect the perception of the color and the slip resistance of stone flooring. Common stone finishes are polished, honed, and thermal.

- Polished finishes are the most reflective. These high-maintenance finishes should be selected with care. For high-traffic public areas, such as lobbies, polished floor finishes are often eventually hidden under nonskid mats.
- Honed finishes have a dull sheen. These satin-smooth surfaces are often good choices for commercial floors because of their slip resistance.
- Thermal finishes, sometimes called flamed finishes, are achieved by the application of intense flaming heat to the surface of the stone. Thermal finishes are usually applied to granite.
- Waterjet is a newer type of finish for granite, which is between honed and thermal finishes. Created by high water pressure, the waterjet finish brings out the color of the stone, making it slightly darker than the thermal finish.

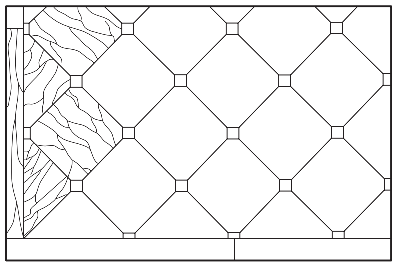
TYPICAL FINISHES AND COMMON SIZES OF STONE TILES AND PAVERS
12.128

STONE	FINISH	MINIMUM THICKNESS (IN.)	MAXIMUM FACE DIMENSION (IN.)	HA[a]
Granite	Polished	3/8, 1/2 (tiles)	12 × 12 (tiles)	N/A
	Honed	1-1/4 to 4 (pavers)	15 × 30 (pavers)	
	Thermal			
Marble	Polished	1/4 to 1/2 (tiles)	12 × 12 (tiles)	10
	Honed	1-1/4 (pavers)	24 × 24 (pavers)	
Limestone	Smooth	1-3/4 to 2-1/2 (pavers)	24 × 36 (pavers)	10
Slate	Natural cleft	1/4 to 1	12 × 12 to 24 × 54	8
	Sand-rubbed			
Flagstone	Natural cleft	1/2 to 4	12 × 12 to 24 × 36	8
	Semirubbed			

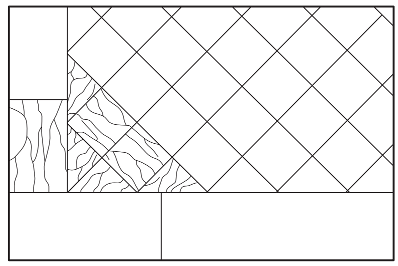
MARBLE AND GRANITE PATTERNS
12.129



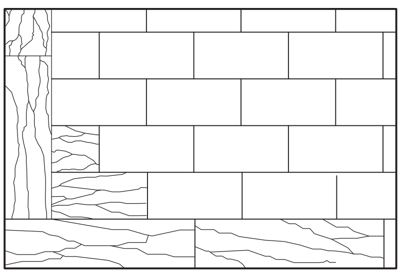
SQUARES



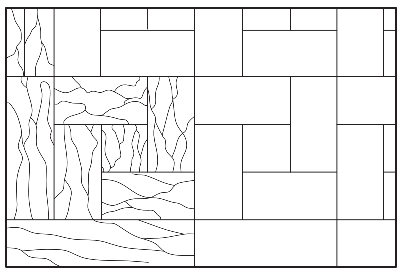
OCTAGON SQUARE



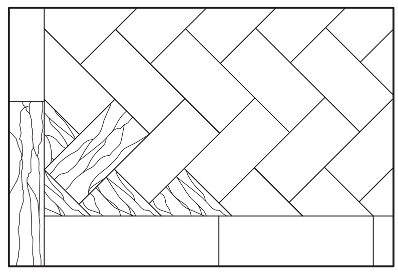
DIAMOND



COURSED



GEOMETRIC



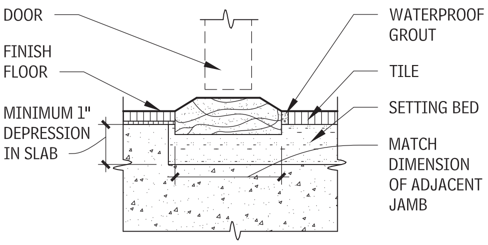
HERRINGBONE

NOTE

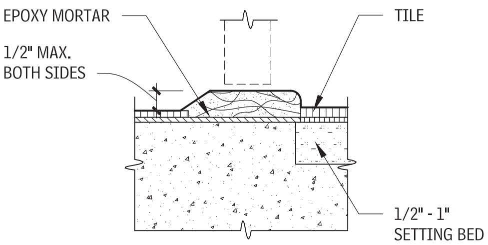
12.128 Abrasive Hardness (HA) value, is the reciprocal of the volume of the material abraded multiplied by 10. A minimum value of 10 is recommended for flooring. Stones with a difference of 5 or more in HA should not be used together because they will wear differently.

Contributors:
Karen K. Lindblad, Chicago, Illinois; Jim Swords, HOK Sports Facilities Group, Kansas City, Missouri; Connor/AGA Sports Flooring Corporation, Amasa, Michigan; Robbins Sports Surfaces, Cincinnati, Ohio; Exerflex, Indianapolis, Indiana; Maple Flooring Manufacturers Association, Northbrook, Illinois.

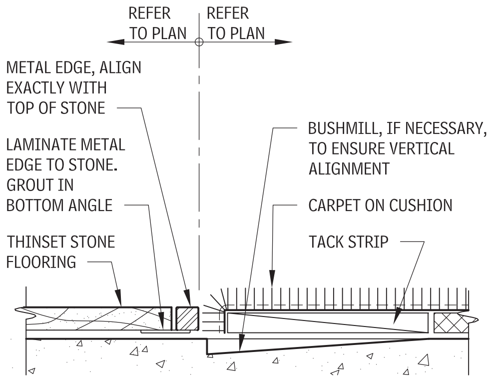
STONE THRESHOLDS AND TRANSITIONS
12.130



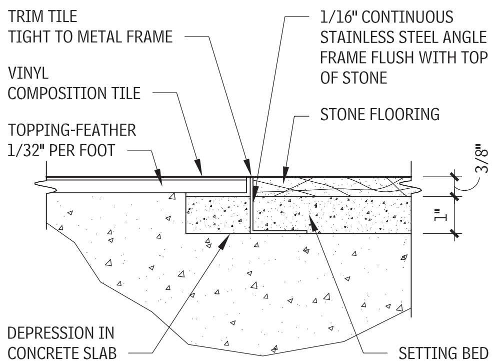
THRESHOLD DEPRESSED



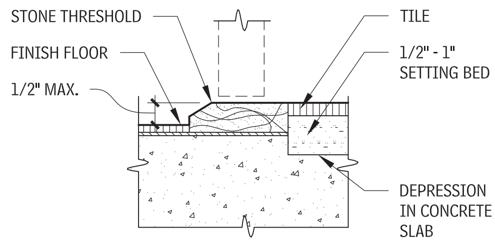
THRESHOLD THINSET



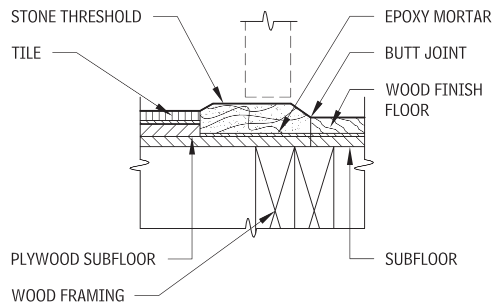
THINSET STONE TO CARPET ON CUSHION



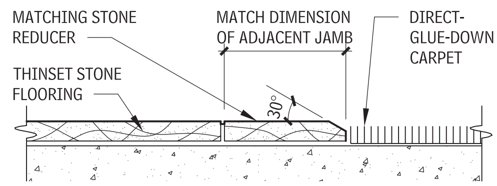
STONE TILE TO VINYL COMPOSITION TILE



THRESHOLD-THINSET

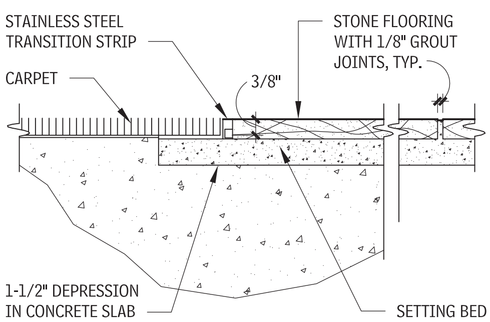


CERAMIC TILE TO WOOD FLOOR

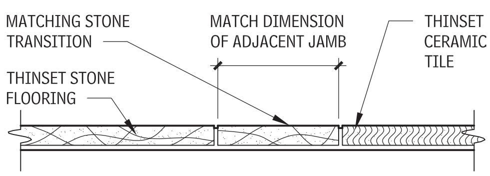


MORTAR-BED SET STONE TO DIRECT GLUE CARPET

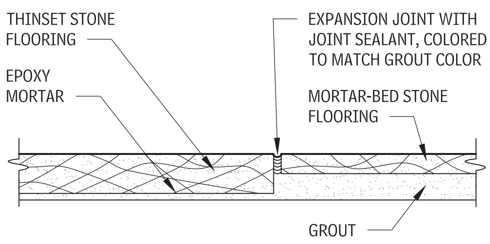
STONE THRESHOLDS AND TRANSITIONS
12.131



STONE TO CARPET



THINSET STONE TO THINSET CERAMIC TILE

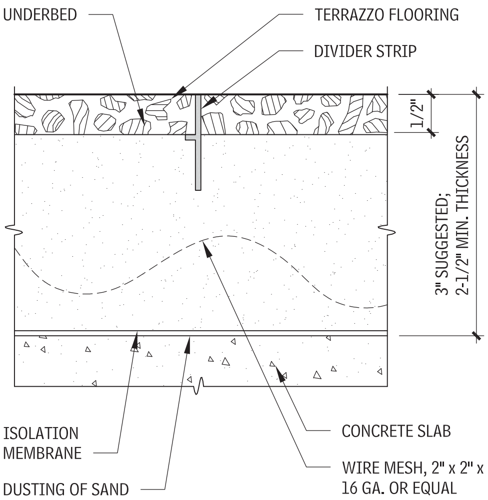


MORTAR-BED SET STONE TO THINSET STONE

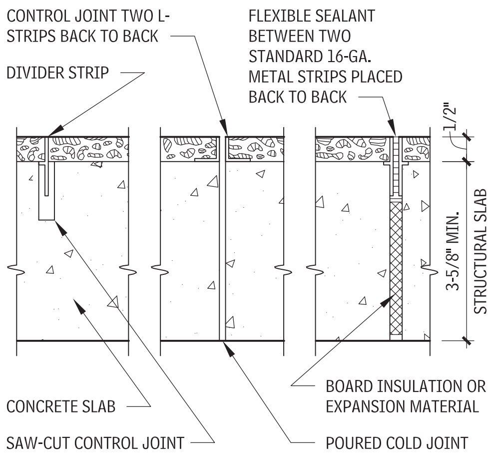
INTERIOR TERRAZZO SYSTEMS
12.132

SYSTEM	DESCRIPTION	ADVANTAGES	TOTAL THICKNESS	WEIGHT PSF
Sand cushion	1/2″ terrazzo topping over 2-1/2″ underbed, reinforced with wire mesh, over an isolation membrane over 1/16″ of sand, on a concrete slab. For interior use only.	The best available cement terrazzo system, because it is the only system that completely separates the finish from the subfloor. This protects against minor substrate defects telegraphing through to the finish surface.	3″, including 1/2″ terrazzo topping	30
Bonded	1/2″ terrazzo topping over 1-1/4″ underbed, on a concrete slab. Interior use only.	Requires less thickness than sand cushion. Can be used for walls.	1-3/4″ to 2-1/4″, including 1/2″ terrazzo topping	18
Monolithic	1/2″ terrazzo topping on a concrete slab. Performance dependent on the quality of the substrate. A level concrete slab must be provided.	Most economical system, ideal for large areas such as shopping malls, schools, and stores.	1/2″ terrazzo topping	7
Thinset (Epoxy)	1/4″ to 3/8″ terrazzo topping over a concrete slab. Thinnest and, typically, most expensive system. Considered to be a resinous flooring type. Epoxy or polyester matrix is used.	Good for renovation work. Both epoxy and polyester resist many types of chemicals, making them suitable for labs, hospitals, and manufacturing facilities.	1/4″ to 3/8″	4
Precast	Fabricated custom units for steps, bases, planters, benches, and wall panels.	Variety of uses	Custom	Varies

TERRAZZO
12.133



SAND CUSHION TERRAZZO



MONOLITHIC TERRAZZO

TERRAZZO

TERRAZZO FLOOR FINISHES

Terrazzo is a very low-maintenance, seamless floor finish with the luxurious look of stone mosaic and durability comparable to that of concrete. Often selected for its decorative possibilities, terrazzo artistry can produce striking medallions or intricate inlaid patterns.

Terrazzo is a mixture of a binder and crushed aggregate, typically marble. Other aggregate types, such as glass, are available to vary the appearance of the terrazzo. Divider strips of brass, white alloy of zinc, or plastic, are used functionally as control joints, and aesthetically as design elements, to separate fields of color.

AGGREGATE

Aggregate, or stone chips used in terrazzo, includes all calcareous serpentine and other rocks capable of taking a good polish. Marble and onyx are the preferred materials. Quartz, granite, quartzite, and silica pebbles are used for rustic terrazzo and textured mosaics not requiring polishing.

CARPET

CARPET FLOORING

The specification of carpet and carpet tile requires evaluation of the following:

- Carpet construction, which includes tufted, fusion-bonded, woven, hand-tufted, knitted, and needle-punched processes
- Carpet fiber
- Carpet performance characteristics, including face and total weight, pile density, and appearance retention
- Density
- Thermal and acoustic considerations
- Installation
- Carpet cushion

CARPET CONSTRUCTION

Carpet construction refers to the carpet manufacturing method. The three most popular construction methods for commercial carpet construction are tufting, weaving, and fusion bonding. Knitted and needle punched carpets are available but less often specified.

- Tufted carpets account for as much as 95 percent of the carpet produced in the United States.
- Woven carpets are made on a loom using the original carpet construction method.
- Knitted carpets use more face yarn than tufting.
- Needle punched carpets are formed by hundreds of barbed needles punching through blankets of fiber.

TUFTED CARPET

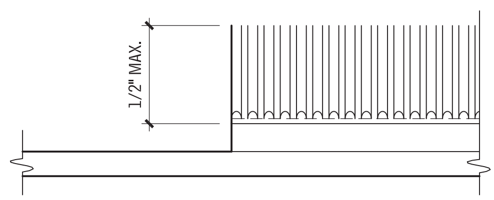
Since its introduction in the early 1950s, tufting has transformed the carpet industry. Compared to other carpet construction methods, tufting does not require skilled labor and requires less expensive equipment to manufacture. It is also far less expensive and faster to produce than woven carpet. This process has enabled the mass production of an affordably priced, wide-width textile floor covering.

The tufted construction process is similar to sewing. Hundreds of needles stitch simultaneously through a backing material. To hold the tufted loops in place, the underside of the primary backing is coated with latex backing adhesive, a rubbery substance that dries hard but remains bendable. A secondary backing material is then applied.

- Primary backing materials are the woven or nonwoven fabrics into which the tufts are inserted. They are typically olefin-based, either plain-woven or spun bonded. A thin polymer coating is often applied to bond the warp and weft threads and to minimize unraveling. Spun bonded olefin is inherently resistant to fraying or unraveling. During the tufting process, the olefin fibers are pushed aside, minimizing the distortion of the backing. This helps ensure a uniform pile height. Backings made of olefin are impervious to moisture and are mildew-resistant.
- Adhesives used in tufted carpet are usually synthetic latex, although molten thermoplastic compounds are also used. Adhesives permanently anchor the tufts to the primary backing, preventing snags and unraveling.
- Secondary backing materials, sometimes referred to as scrims, provide dimensional stability to the finished tufted carpet. A secondary backing is added for strength and stability. Secondary backing materials are often made of polypropylene, which is popular because it is moisture-resistant. Alternatives to secondary backings are attached carpet cushions, solid vinyl composites, and coatings referred to as unitary backings.

The standard dimension of most manufactured tufted carpet is a 12-ft width, although some manufacturers provide 6 and 15-ft widths for special applications.

ACCESSIBLE CARPET PILE THICKNESS
12.134



CARPET TILE

Carpet tiles provide ready access to a raised floor or easy replacement when soiled or worn. Carpet tile backing systems provide moisture barriers from the base of the pile yarn to the floor, preventing spills from penetrating to the subfloor. Backing materials include polyvinyl chloride (PVC), amorphous resins, and polyurethane cushion. The "hard backs" (PVC and amorphous resin) offer dimensional stability and seam and edge integrity for easy pattern matching. PVC backings are used most often for modular tiles.

Carpet tiles are installed with standard adhesives, releasable adhesives, and mill-applied peel-and-stick adhesives. Carpet tile installation is easier and causes less downtime and productivity loss than traditional carpet installation. Systems furniture divider panels and office furniture do not have to be removed, but are simply lifted with a "jack" system. The tiles are then installed underneath the furniture while it remains in place.

NOTES

12.132 Reprinted courtesy of the National Terrazzo and Mosaic Association (NTMA). The NTMA, an association of terrazzo contractors, material suppliers, and distributors, publishes the *NTMA Technical Manual*, which contains complete specifications for all terrazzo systems.
12.133 Tile Council of North America, Inc., Anderson, South Carolina.

Contributor:
National Terrazzo and Mosaic Association, Inc., Leesburg, Virginia.

WOVEN CARPET
Weaving, the traditional carpet construction method, produces carpet on a loom, integrating the pile and backing yarns during the carpet construction. Most woven carpet is dimensionally stable as a result of the weaving process and does not require a secondary backing, as tufted carpet does. Weaving accounts for less than 2 percent of the carpet market in the United States. Its primary use is in the hospitality industry, where long-term durability and intricate pattern detail are primary considerations. The three basic types of weaving processes are velvet, Wilton, and Axminster.

KNITTED CARPET
As in the construction of woven carpet, the knitting process integrates pile and backing yarns in one operation. Needles are used to interlace yarns in a series of connecting loops, similar to the hand-knitting process. Knitted carpets are known for their plush piles, because there is more yarn in the wear surface than tufted carpets. Knitted carpet has a tendency to stretch, however, especially on the diagonal, and is difficult to seam during installation. Knitted carpet represents a very small percentage of the carpet produced in the United States.

NEEDLE PUNCHED CARPET
Needle punching is achieved by layering thick fiber batts, typically polypropylene, over a support fabric. Hundreds of barbed needles punch through the support fabric, compressing and entangling the fibers. Needle punched carpets are permeable, which presents a problem when liquids are spilled on a wall-to-wall interior installation. The most common application of needle punched carpet is outdoor carpet.

CARPET FIBER TYPES
Several types of carpet fibers are used.

ACRYLIC
Acrylic was one of the first synthetic fibers to be used successfully in the production of carpet. However, because the color and texture of acrylic fiber can be glossy and harsh, and because acrylic carpet pile crushes easily, it is no longer recommended for use as a commercial carpet fiber.

NYLON
Nylon is the most popular carpet fiber. It has excellent wearability, abrasion resistance, and resilience, and solution-dyed nylon is also resistant to harsh cleaning chemicals and sunlight fading. However, because of nylon's excellent durability, appearance retention is a concern. Long before a nylon carpet wears out, its appearance may be permanently ruined.

POLYPROPYLENE
Polypropylene is the lightest commercial carpet fiber. Polypropylenes are known for their excellent stain and mildew resistance, low moisture absorbency, excellent colorfastness in sunlight, and high strength. They also minimize static electricity. Olefin is a polypropylene. Polypropylene is commonly used in outdoor carpeting.

POLYESTER
Polyester fibers are known for their color clarity and their capability to retain color. More popular for residential carpet applications than for commercial uses, polyester has a luxurious feel.

WOOL
Used for centuries in the manufacturing of carpet, wool is still the standard against which other carpet fibers are judged. It is generally the most expensive carpet fiber and is commonly used in woven carpets. When exposed to flame, wool chars, rather than melting like most synthetic fibers, making it naturally flame-resistant. It also dyes well and has good resistance to soil and wear.

SISAL
Sisal is a strong, woody fiber produced from the leaves of the agave plant, which is found in Central America, the West Indies, and Africa. Used mostly in twine and rope, it has become a popular contemporary flooring fiber.

CARPET DENSITY
Density, the amount of pile yarn in unit volume of carpet, is influenced by gauge—stitches per inch across the width—yarn size or thickness, and pile height. A larger yarn can be tufted at a wider gauge and receive the same density as a fine yarn at a small gauge. For areas where heavy foot traffic is likely, a density of 5000 to 7000 or more may be necessary. Office spaces with moderate traffic require a density of 4000 to 6000. Because of the fundamental differences in the manufacturing processes, different terms are used to describe carpet density for each type of carpet construction.

CARPET TRAFFIC CLASS RECOMMENDATIONS 12.135

AREA	TRAFFIC CLASS
AIRPORTS	
Administrative offices	I
Corridors, all public and ticket areas	III
BANKS	
Executive offices	I
Lobbies	II–III
Corridors	II–III
Teller windows	III
CONVENTION CENTERS	
Auditoriums	II–III
Corridors and lobbies	III
PLACES OF WORSHIP	
Churches, synagogues, mosques, and others	I–II
Meeting rooms	II
Lobbies	II–III
GOLF CLUBS	
Locker rooms, pro shops	III
Other areas	II–III
HEALTHCARE AREAS	
Executive/administrative offices	I–II
Patient rooms, lounges	II
Lobbies, corridors, nurses stations	III
HOTELS, MOTELS, APARTMENTS	
Rooms	I
Corridors	II
Lobbies	III
LIBRARIES, MUSEUMS, ART GALLERIES	
Administrative offices	I
Public areas	II–III
OFFICE BUILDINGS	
Executive or private offices	I
Clerical areas	II
Corridors	II–III
Cafeterias	III
RESTAURANTS	
Dining areas/lobbies	III
RETAIL STORES	
Windows and display areas	I
Minor aisles, boutiques, specialized departments	II
Major aisles, checkouts, supermarkets, and so on	III
SCHOOLS AND COLLEGES	
Administrative offices	I
Classrooms/dormitories	II
Corridors, cafeterias	III

Source: BASF, Dalton, Georgia.

CARPET TRAFFIC CLASSIFICATIONS 12.136

CLASS	TRAFFIC	WALK-ONS PER DAY	DESCRIPTION	EXAMPLES
I	Light	Up to 500	Areas that undergo a limited amount of traffic and where there is some soiling	Executive offices, hotel bedrooms
II	Heavy	500–1000	Areas that undergo frequent traffic flowing in the same direction and where there is heavy dirt, grit, twisting, turning, and spillage	Hotel corridors, auditoriums, school classrooms
III	Extra Heavy	More than 1000	Areas that are subject to extremely frequent and concentrated traffic flowing in the same direction and where there is severe dirt, grit, twisting, turning, heavy rolling, and spillage	Airports, bank teller window areas

Source: BASF, Dalton, Georgia.

CARPET INSTALLATION
There are two types of carpet installation: stretch-in and adhesive. For broadloom carpet, there are three types of adhesive installation: direct glue-down, double glue-down, and the newest installation type, self-stick. Releasable adhesives can facilitate carpet repair or replacement.

STRETCH-IN INSTALLATION
Stretch-in installation is the traditional method of carpet installation, whereby the carpet is stretched over a cushion and attached at the perimeter with a tack strip. This is the most common installation method for residential applications, and is used commercially for woven wool carpets and in areas where underfoot comfort and luxury are required (e.g., hotel lobbies and boardrooms). Stretch-in applications allow for easy removal and replacement of the carpet and cushion. Because stretch-in carpet is secured only around the perimeter, such installations can ripple, causing accessibility problems, hence they may not be appropriate for large areas and heavy commercial or rolling traffic.

Power stretchers are used to put the carpet in tension and stretch it drum-tight. The carpet should be stretched to its fullest to withstand changes in temperature and humidity and other stresses. Cushion selection should be coordinated with the carpet manufacturer to ensure that the carpet warranty is not voided.

ADHESIVE INSTALLATION
Common methods of adhesive installation include:

- Direct glue-down: The most common method of commercial installation, direct glue-down is economical and practical. The carpet is glued directly to the floor without a cushion. This is the most dimensionally stable installation method and is often required for stair or ramp applications, even if different installation methods are specified for other areas of the project. Proper substrate conditions are imperative for a successful glue-down installation. Uneven substrates can cause irregular wear patterns.
- Double glue-down: This installation method combines the underfoot comfort of stretch-in installation with the stability of the direct glue-down method. The carpet cushion is adhered to the floor, and then the carpet is glued to the cushion. With either the direct or the double glue-down method, admitting traffic

before the adhesive has had time to cure can cause the installation to fail. Hardboard or plywood is typically recommended as protection for an adhesive installation, because covering a new adhesive installation with plastic sheeting may prevent proper curing and cause mold or mildew to develop.

- Self-stick: This is the latest development in carpet installation techniques. A flexible adhesive layer is applied to the carpet backing and is covered with a protective plastic film. The labor involved in adhesive application and the time required to ensure the proper tackiness are eliminated. This carpet type typically comes in smaller widths, about 6 ft., for ease of manipulation during layout and installation.

CARPET TILE INSTALLATION

There are three methods of carpet tile installation: free-lay, full glue, and with a tile that has a pre-applied pressure-sensitive adhesive coating. In free-lay installations, a strip of adhesive is applied about every 15 ft. and around the room perimeter. Tiles in those areas are anchored in place, and surrounding tiles are butted snugly against each other. Full-glue installations should be specified where heavy or wheeled traffic is anticipated. In this case, tiles are typically installed with a "stair-step" technique. The installation "grows" from the center of the room.

RESILIENT FLOORING

Resilient flooring provides a dense, nonabsorbent, pliant surface that is generally quiet, comfortable to walk on, and easy to maintain.

VINYL FLOORING

The five basic ingredients used in the manufacture of vinyl flooring are:

- Polyvinyl chloride (PVC), which imparts wear resistance and durability. PVC is the basis of the binder, which constitutes most of the wear surface. The binder consists of PVC compounded with plasticizers and stabilizers.
- Plasticizers, which increase flexibility.
- Stabilizers, which provide color permanence and stabilize the pigments against heat and light deterioration.
- Fillers, which are added to supplement the bulk and thickness of the flooring. Mineral fillers, the most common, improve fire resistance. Natural fillers increase slip resistance.
- Pigments, which are used for color.

SHEET VINYL

Sheet vinyl flooring, either solid vinyl or backed, forms a continuous finished floor covering. Because sheet vinyl flooring has fewer joints, it is used for applications where spills, dirt, or bacterial growth are of concern. It is commonly specified in hospital operating rooms or other areas where resistance to bacterial growth or water penetration is required.

There are two types of seams for sheet vinyl installations: heat welded and chemically welded.

- Heat-welded seams are formed by melting a vinyl rod between sheets. Solid-color or patterned welding rods can either accent or camouflage seams. Heat welding requires special equipment and trained installers.
- Chemical welding is accomplished with the application of a one- or two-part solvent that is mixed on-site. This softens the edges of the vinyl, essentially melting them together. Chemical welding is more economical than heat welding.

VINYL TILE

Two types of vinyl tile are solid vinyl tile and the less expensive vinyl composition tile (VCT). Solid vinyl tile, or homogeneous vinyl tile, contains much more PVC than VCT, making it more resilient and resistant to abrasion. Homogeneous vinyl tile has superior indentation and rolling/load resistance. Because the pattern is continuous through the thickness of the flooring, its appearance will remain consistent when worn.

Three classes of VCT are defined by ASTM F 1066, "Standard Specification for Vinyl Composition Floor Tile": Type 1, solid-color tiles; Type 2, through-pattern tiles; and Type 3, surface-pattern tiles.

RESILIENT FLOORING SIZES
12.137

TYPE	COMPONENTS	THICKNESS (IN.)	SIZES
Vinyl sheet	Vinyl resins with fiber back	0.065–0.160	6′, 10′, 12′
Solid vinyl tile	Vinyl resins	1/16–1/8	9″ × 9″
			12″ × 12″
Vinyl composition tile	Vinyl resins with filler	0.050–0.095	9″ × 9″
			12″ × 12″
Rubber tile	Rubber compound	3/32–3/16	9″ × 9″
			12″ × 12″
Cork tile	Raw cork and resins	1/8–1/4	6″ × 6″
			9″ × 9″
Cork tile with vinyl coating	Raw cork with vinyl resins	1/8–3/16	9″ × 9″
			12″ × 12″

RUBBER FLOORING

Rubber sheet or rubber tile flooring is composed of natural rubber or synthetic rubber (styrene butadiene), mineral fillers, and pigments. Two types of rubber floor tile are homogeneous and laminated.

- Homogeneous rubber tile has coloring uniform throughout the tile thickness.
- Laminated rubber tile has coloring or patterning in the wear layer only.

LINOLEUM

Linoleum (derived from the Latin terms for "flax," linum, and "oil," oleum) is composed primarily of linseed oil, obtained from the flax plant. The oil is oxidized and mixed with a natural resin, such as rosin tapped from pine trees, and combined with powdered cork for flexibility and limestone for strength and hardness. Wood flour and pigments are added for color and colorfastness. For dimensional stability, this mixture is bonded to a fiber backing (typically burlap) for linoleum sheets, or to a polyester backing for tile. Felt backings are used for linoleum countertop or tack surface sheets.

CORK FLOORING

Cork flooring is harvested from the outer layer of cork oak trees grown in Mediterranean regions. When the bark becomes loose, approximately every nine years, it is cut away. Composition cork is the most common form of cork flooring. The bark material of the cork oak is granulated, pressed with binders such as synthetic resins, and then baked. The quality of composition cork varies according to the quality and size of granules, the type and quantity of the binder, and the density (compression) of the mix.

RESILIENT FLOORING PERFORMANCE ATTRIBUTES
12.138

ATTRIBUTE	RESILIENT FLOORING TYPE
Resilience and quietness	Cork tile, rubber tile
Resistance to indentation	Solid vinyl tile
Stain resistance	Vinyl sheet and tile
Alkali resistance	Vinyl sheet and tile
Grease resistance	Vinyl sheet and tile, cork tile with vinyl coating
Durability	Vinyl sheet and tile

MATERIALS

Resilient wall base and flooring accessories are available in three materials:

- Vinyl can be susceptible to shrinking when exposed to heat.
- Thermoplastic rubber is a vinyl compound with a comparatively small amount of rubber added for flexibility. Because of the high vinyl content, it performs similarly to vinyl, but is more flexible. It is commonly more expensive than vinyl but less expensive than vulcanized, thermoset rubber.
- Thermoset rubber is vulcanized natural rubber. It is the most flexible resilient base material and thus is easier to install and better at hiding surface imperfections in walls and floors. Thermoset rubber base is susceptible to color degradation due to UV exposure; however, it can be specially manufactured with UV inhibitors. White and dark-colored thermoset rubber base tends to hold color best. Lighter colors, especially gray, tend to be prone to color degradation. Thermoset rubber base also tends to be more vulnerable to scuffing than vinyl or thermoplastic rubber. Lighter colors tend not to show scuff marks as much as darker colors.

Although most building codes do not have flammability requirements for wall trim that constitutes less than 10 percent of the wall surface, the flame-spread ratings and the smoke generated from burning resilient flooring accessories differ among the three materials. Thermoset rubber, when burned, generates less smoke and toxic fumes than vinyl or thermoplastic rubber.

RESILIENT BASE MATERIALS
12.139

	RESPONSE TO HEAT	FLEXIBILITY	RESISTANCE TO GREASE AND OIL	RELATIVE COST
Vinyl	Shrinks	Good	Excellent	$
Thermo-plastic Rubber	Expands	Better	Good	$$
Thermoset Rubber	Expands	Best	Fair	$$$

WALL BASE

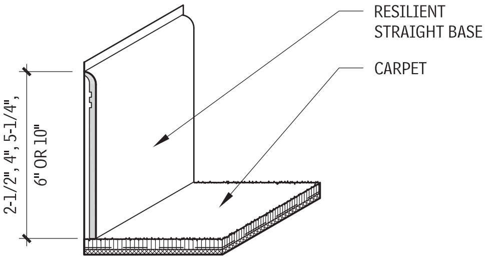
Wall base conceals the joint where the wall meets the floor. Premolded inside and outside corners are available from some manufacturers, but they may differ in texture and color from straight sections. Straight sections of resilient wall base are available in precut lengths (4 ft. long) and coils (approximately 100 ft. long). Coils minimize the number of joints and may reduce installation costs.

There are three basic wall base profiles:

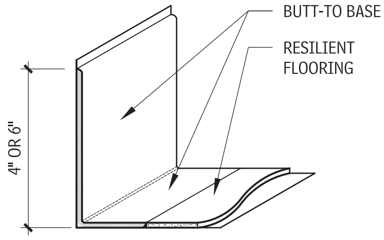
- Straight base is meant to be used with carpet.
- Cove base is meant to be used with resilient flooring.
- Butt-to-base, sometimes referred to as sanitary base, is available from a limited number of manufacturers. It is installed prior to the finish floor covering. The finish floor covering must be of the same thickness as the butt-to-base flange.

The base is sealed to the floor and wall, creating an easy-to-clean, more sanitary joint, which is popular for healthcare applications. Cove moldings support sheet vinyl, sheet linoleum, or other flexible floor coverings when coved up the wall. Cap moldings help to finish the exposed edges of coved floor coverings, ceramic tile, or wood paneling.

WALL BASE
12.140



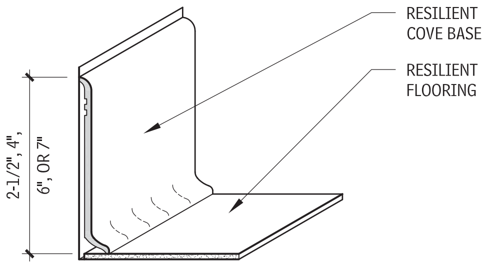
STRAIGHT BASE



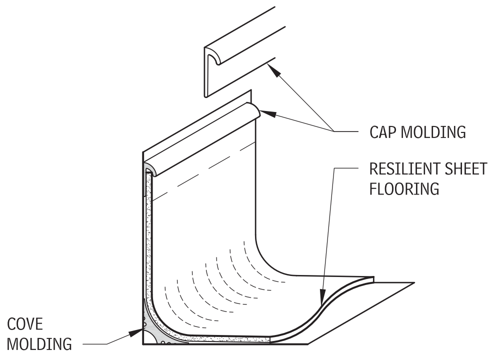
INSTALLED POSITION

SHIPPED POSITION

BUTT-TO BASE

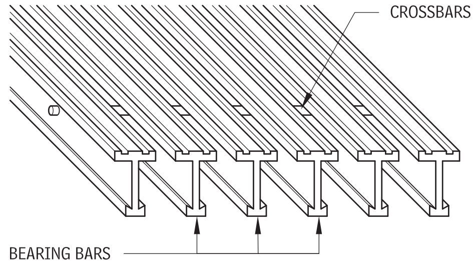


COVE BASE



CAP AND MOLDING

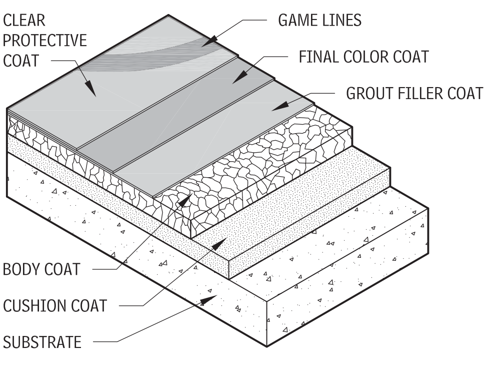
T-BAR GRATING
12.142



POURED FLOORING

Fluid-applied flooring systems provide seamless, durable coatings over concrete and other rigid substrates for commercial, industrial, and institutional applications. They are usually installed with an integral self-cove base. Consult with manufacturers for final selection of products for specific applications. These systems must be applied by trained, experienced installers who have been recommended or approved by the components' manufacturers.

FLUID-APPLIED ATHLETIC FLOORING
12.141



WALK-OFF GRILLES AND GRATES

Floor grille and grating systems, available in a wide range of styles, are used in an increasing variety of building applications. A recessed built-in system is a more permanent way to catch and hold dirt particles, providing protection at the building entrance.

- Recessed systems are generally less than 1 in. deep.
- Shallow pit systems are 1 to 3 in. deep.
- Deep pit systems are more than 3 in. deep.

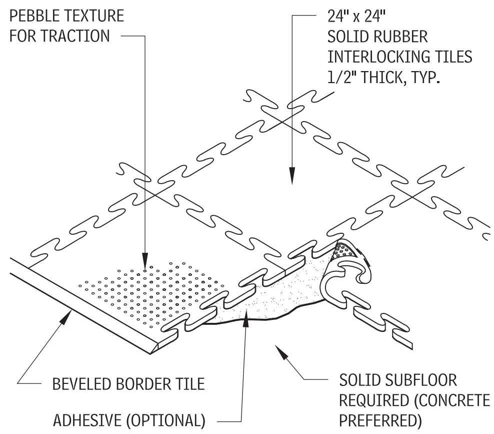
A typical grille or grate system is made up of a series of interlocking rails that run perpendicular to the traffic direction. Types of tread surfaces include serrated aluminum, abrasive or nylon carpet, and rubber or vinyl filled. Rails should be able to handle heavy rolling loads. Continuous drainage between rails allows dirt and moisture to fall into the recess. Failure to routinely maintain the system will create an uneven recess, resulting in an unstable surface and causing a potential tripping hazard and possible damage to the system. Most systems contain recycled content.

Grating types include plank, bar, expanded, extruded, and molded; materials include steel, aluminum, and fiberglass. Where structural strength is paramount, steel is the prevalent material; where corrosion and high-impact resistance is important, fiberglass grating is often used.

FLOOR MATS

A wide range of interlocking resilient floor grid systems are available for wet and high-impact areas such as weight rooms, aerobics studios, and other athletic facilities, as well as kennels and stables. Systems are available for both indoor and outdoor applications. Increasingly, flooring construction is specialized to specific athletic applications; for example, air-supported martial arts flooring is available. In addition, individual removable mats ranging from 4 to 6 ft. wide are available in a variety of lengths for particular athletic applications.

FLOORING FOR HIGH-IMPACT AREAS
12.143

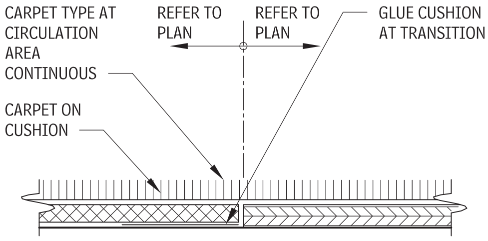


NOTE

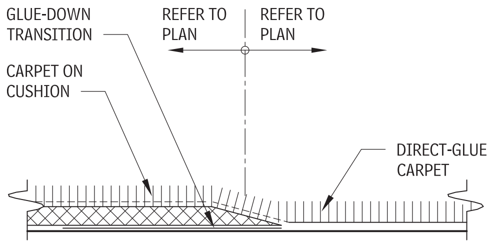
12.143 Source: Balco Inc., Wichita, Kansas.

Contributors:
Faith Baum, AIA, IIDA, Faith Baum Architect, Lexington, Massachusetts; Mia Alwen, Rhode Island School of Design, Providence, Rhode Island; Lerlux Sophonpanich, Rhode Island School of Design, Providence, Rhode Island; Ted Kollaja, AIA, GENSLER, Dallas, Texas.

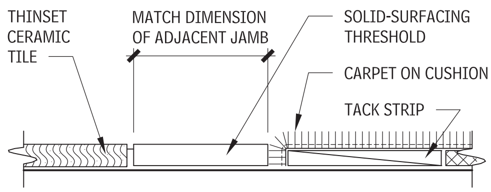
CARPET TRANSITION DETAILS
12.144



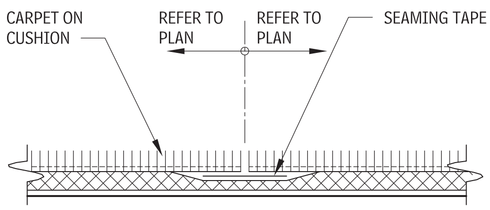
CARPET ON CUSHION TO CARPET ON PLYWOOD



CARPET ON CUSHION TO DIRECT GLUE-DOWN CARPET



THINSET CERAMIC TILE TO CARPET ON CUSHION



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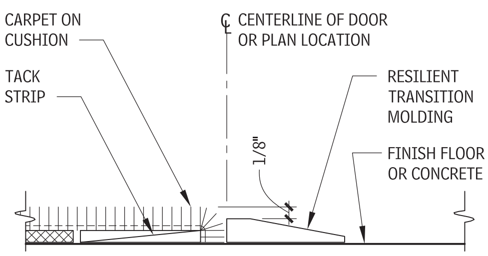
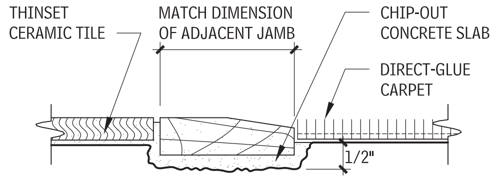
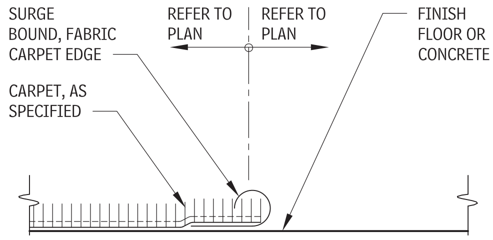


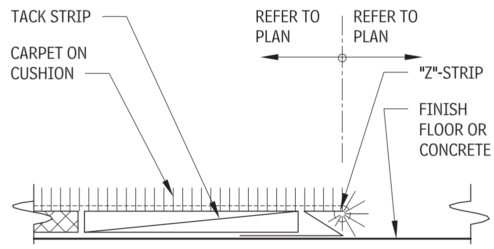
CARPET ON CUSHION TO EXPOSED CONCRETE FLOOR



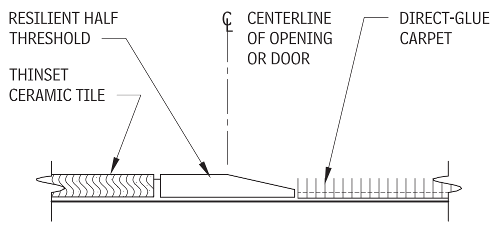
THINSET CERAMIC TILE TO DIRECT GLUE-DOWN CARPET, STONE TRANSITION



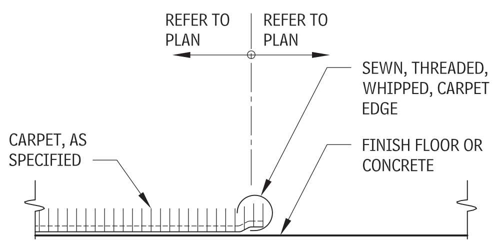
CARPET ON FINISH FLOOR, SURGED EDGE



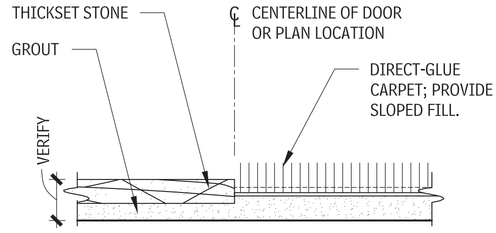
CARPET ON CUSHION TO FINISH FLOOR



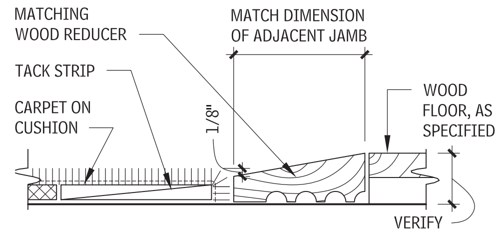
THINSET CERAMIC TILE TO DIRECT GLUE-DOWN CARPET, RESILIENT TRANSITION



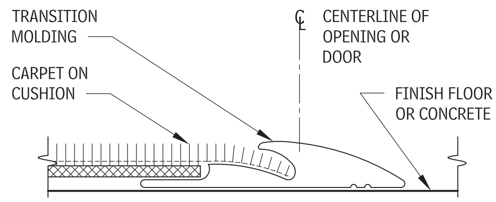
CARPET TO FINISH FLOOR, SEWN EDGE



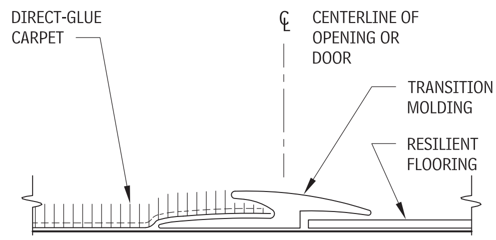
THICKSET STONE TO DIRECT GLUE-DOWN CARPET



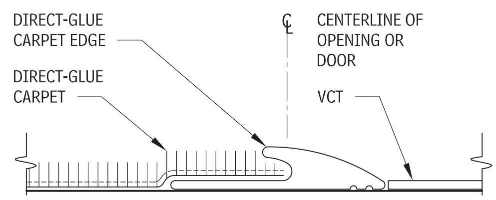
CARPET ON CUSHION TO WOOD



CARPET ON CUSHION TO FINISH FLOOR



DIRECT-GLUE CARPET TO RESILIENT FLOORING, TRANSITION MOLDING



DIRECT-GLUE CARPET TO VCT

INTERIOR CEILING CONSTRUCTION

SUSPENDED CEILING CONSTRUCTION

ACOUSTIC PANEL CEILINGS

Acoustic panel ceilings are composed of manufactured units, installed in a metal suspension assembly. They are used where sound attenuation and accessibility to the above-ceiling interstitial or plenum space are desired. Acoustic ceilings are large visual elements within a space, and so are considered design elements as well as acoustic features. Partitions, light fixtures, ceiling diffusers, sprinklers, and other devices are attached to or installed within these ceilings, so coordination with the ceiling layout is critical.

Acoustic panels are installed on an exposed metal grid system suspended from the underside of the structure above. In contrast, acoustic tiles are inserted to a concealed suspension system and are generally 12 by 12 in. and 24 by 24 in. Common acoustic panel sizes range from 24 by 24 in. to 24 by 48 in. up to 60 by 60 in., and are available in rectangular and square shapes. Thicknesses range from 5/8 in. to 3/4 in. to 1 in., with other thicknesses available for special applications. Most manufacturers provide hard metric-size acoustic panels to address global needs for their products.

Acoustic panel ceiling products are available to meet special project requirements, including the need for greater durability, light reflectance, and humidity resistance. Fire-resistant acoustic ceiling assemblies are available, when used with applicable UL designs.

SOUND ABSORPTION AND SOUND ISOLATION

In open office areas, the installation of an acoustic panel ceiling will improve the amount of privacy between partial-height partitioned workstations. Within closed areas, an acoustic panel ceiling can improve the transmission of noise from one room to another, if used with appropriate partition types. Manufacturers of acoustic tile ceilings categorize the acoustic features of their products according to industry standard designations for the ratings of sound absorption. Ceiling Attenuation Class (CAC) and Noise Reduction Coefficient (NRC) both rate sound absorption.

- CAC (formerly known as CSTC, Ceiling Sound Transmission Class) rates a ceiling's efficiency as a barrier to airborne sound transmission between adjacent spaces and from above-ceiling elements. Shown as a minimum value, a ceiling with a high CAC may have a low NRC.
- NRC rates the average sound absorption coefficient measured at four frequencies: 250, 500, 1000, and 2000 Hz, and rates the capability of a ceiling to absorb sound, measured from 0.0 to 1.00. The higher the number, the greater the capability of the tile to absorb sound.
- AC rates the listener's ability to understand the spoken word within a space, expressed as a decimal, with 1.0 being perfectly intelligible. The AC rating measures the sound attenuation of a ceiling in open office areas with partial-height partitions and workstation furniture panels, without the use of a sound-masking system.

LIGHT REFLECTANCE

The quantity of light reflected by a surface, defined in ASTM E 1477, "Standard Test Method for Luminous Reflectance Factor of Acoustical Materials by Use of Integrating-Sphere Reflectometers," is known as light reflectance. Illuminance is measured in foot-candles, or lux (metric measure). One foot-candle is approximately 10 lux. A foot-candle is the average illumination resulting when one lumen of light falls on 1 sq. ft. of surface. The total number of lumens on a surface divided by the area of the surface equals foot-candles.

High-light reflectance (LR) acoustic tiles provide greater reflected light from the ceiling plane. LR is measured in values from 0.00 to 1.00. High LR ceiling tiles are particularly effective in open office areas with indirect light sources, where glare is reduced at the work plane and where spaces incorporate daylight as a light source. Usable light is increased and is more evenly distributed.

Acoustic ceilings that have a light reflectance above 0.83 are considered to be high light-reflectance ceilings, but some products are available that exceed this number and reflect more light.

After review of the planned illumination levels, it may be possible to reduce the number of light fixtures within a space, thereby reducing initial installation costs and long-term energy costs.

Light-reflectance values are generally lower for those acoustic tiles with textured and embossed patterns. Integrally colored tiles may affect the LR value. Unless the ceiling surface is to be used as a distributor of illumination, lower LR values may not be of concern.

CEILING TYPES

ASTM E 1264, "Classification for Acoustical Ceiling Products," provides a classification system for ceiling panels that describes various attributes of the panels; this is a very useful standard when using the descriptive method of specifying.

CEILING PANEL COMPOSITION

Several of the same types of acoustic tile are also employed as acoustic panels: water-felted, cast, or molded and nodular. Special acoustic panels composed of a ceramic and mineral fiber composite are used where increased durability, cleanliness, and resistance to humidity and fumes are required. Mylar-faced acoustic panels are used in cleanroom areas, food service, and other applications where cleanability is important.

Fiberglass panels are processed from a molten state into fibrous glass strands, then formed into sheet/board stock. A separate dimensionally stable facing material is laminated to the fiberglass core to provide texture and pattern. Backings are available to improve acoustic qualities of the fiberglass panels. The availability of recycled content is increasing within acoustic panel manufacturers' product lines, depending on the product selected. To address the issue of sustainability within the manufacturing process many manufacturers are now recycling old ceiling panels.

EDGE DETAILS

Common edge details are square or reveal shapes. Acoustic panels with these edge details are easily dropped in place within the suspension system and are pushed up to access the ceiling plenum.

SQUARE EDGE

Square-edge acoustic panels are economical and are installed on the exposed ceiling suspension grid flanges. Square-edge panels do not conceal the suspension grid.

REVEAL EDGE

Reveal edge acoustic panels allow the panels to extend below the suspension system, partially concealing the metal grid. Tegular edges can be square, angled, beveled, stepped, or other special shapes, and are generally selected for their aesthetic appearance. When installed within an exposed tee suspension system, the acoustic panels "read" as modular elements, due to the reveals between the panels. Other suspension system profiles fill the tegular-edge reveal, providing a more flush, monolithic appearance to the ceiling.

BEVELED EDGE

Beveled edges, often found on reveal-edged units, form an eased edge condition, which softens the line of the perimeter of the panel. When moving panels after the initial installation, beveled edges can minimize edge damage due to accidental bumping of the panel on the grid.

SPECIAL-USE PANELS

Acoustic ceiling panels are available to address special needs. Food service areas often require products that are accepted by the USDA for food preparation areas. Nonperforated mylar-faced or vinyl-faced acoustic panels with appropriate suspension systems can be installed in food service areas as well as in cleanrooms of certain classes. Acoustic properties of these mylar- or vinyl-faced products are less than those of nonfaced products; therefore, a check of the local regulations for these installations is recommended.

Composite ceramic and mineral fiber panel products perform well in areas such as indoor pool areas, hydrotherapy areas, laboratories, and other spaces where corrosive materials may be present. The suspension system grid and hangers should be of a corrosion-resistant material such as aluminum or stainless steel, to minimize deterioration.

SUSPENSION SYSTEMS

Exposed acoustic ceiling panel suspension systems are composed of main and cross-tee components, installed at the desired height by hanger wires. The suspension system is typically fabricated from factory-coated steel. Additional types include galvanized steel systems for improved resistance to moisture, and aluminum and stainless steel for other special installation requirements. Fire-rated suspension systems are available, with prenotched expansion relief segments to resist suspension system failure resulting from heat expansion of the grid.

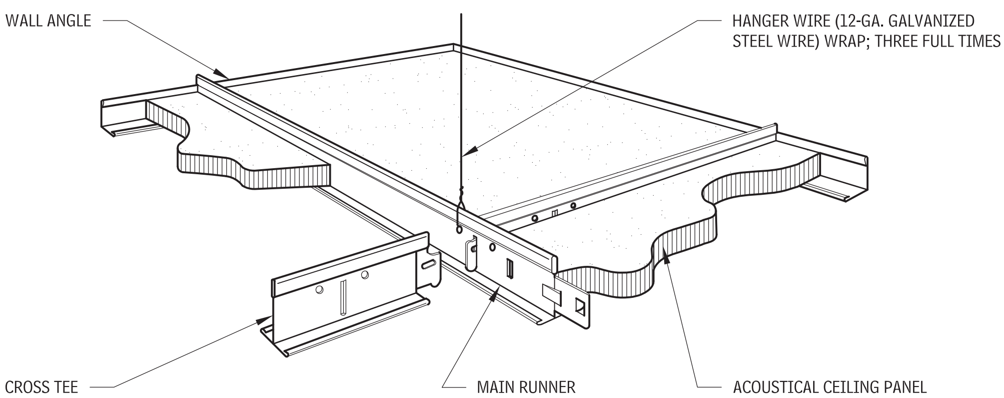
COMPONENTS

The visible components of an exposed ceiling suspension system include interlocking main beams and cross tees, installed in a prescribed grid to accept the acoustic panels. Main beams are typically installed on hanger wires spaced at 4 ft. o.c. along the beam. Angle or channel-shaped moldings are used for perimeter acoustic panel support.

Hanger wires support the main and cross tees from the structure above and are spaced per the manufacturer's recommendations and as project conditions require.

Other special accessory components of the exposed suspension system include stiffeners, clips, spacers, covers, and adapters. Although it may be difficult to identify all of the specific accessory components, the major items anticipated on a project, such as hold-down clips, stiffening braces, partition clips, and so on, should be identified, if possible. Specifications should cover accessories as well as the overall suspension system and acoustic panels.

ACOUSTIC PANEL CEILING ASSEMBLY
12.145



FIRE-RESISTANCE-RATED SUSPENSION SYSTEMS

Fire-resistance-rated suspension systems conform to the UL design for fire-rated performance. Expansion points are provided at specific intervals to alleviate stresses on the grid in case of fire. Cross-tee end clips and other devices must be used as required by UL and local codes. The acoustic panels installed within the fire-resistance-rated suspension system must also be of a fire-resistive nature.

SEISMIC DESIGN

For the installation of an acoustic panel ceiling with seismic design requirement locations, review suspension systems with cross-tee end details that accommodate lateral movement. Check with ceiling suspension system manufacturers to determine the seismic capabilities of a particular system.

CEILING FINISHES

ACOUSTIC CEILINGS

ACOUSTIC TILE CEILINGS

Acoustic tile ceilings are composed of prefabricated ceiling units, which are installed in a concealed or semi-exposed metal suspension system. Also known as concealed spline ceilings, they are directly installed on a substrate by stapling or adhesive bonding. Although acoustic tile installations provide a monolithic ceiling surface, installation can be more costly, and maintenance of the tile ceiling is more difficult than with acoustic panel installations. An acoustic tile ceiling is not as easily accessible to above-ceiling areas as acoustic panel ceilings with lay-in units. If accessibility is not an issue, an acoustic tile ceiling is an option when the aesthetics and other conditions of the installation are appropriate for the project.

Acoustic tiles are typically 12 by 12 in.; however, larger sizes are available. Thicknesses range from 1/2 in. to 5/8 in. to 3/4 in. Hard metric sizes are available on a more limited basis from manufacturers. Acoustic panels are generally larger than 12-by-12-in. ceiling tiles, and are installed in exposed or semiconcealed grids.

Fire-resistant acoustical tile assemblies are available when used with applicable UL design criteria. Consult a manufacturer's product information for specific recommendations on acoustic panel ceiling data.

CEILING TILE COMPOSITION

Composition of the various acoustic tile types used in commercial construction include mineral fiber base and glass fiber base. Cellulose base, used primarily in residential construction, is not as durable as the commercial-grade panel construction. Construction of the mineral fiber base acoustic panels is cast, wet-felted, and nodular, and is available in a number of textures and acoustic properties.

WATER- OR WET-FELTED TILES

Water- or wet-felted tiles are fabricated from mineral wool, perlite, fillers, and binders, which are mixed into a loose slurry that is formed into sheets by draining, compressing, drying, and cutting to size. Fissured, perforated, or stippled textures are added to the tiles prior to painting the units.

CAST OR MOLDED TILES

Cast or molded tiles are fabricated from mineral fibers, fillers, and binders, then mixed into a pulp and poured into paper or foil-lined molds of the desired size. Surface textures are created by the manipulation of the surface of the molds. Integral colors can be added for a through-color product. The tiles are oven-dried, trimmed, and then painted.

NODULAR TILES

Nodular tiles are fabricated from mineral fibers wound into balls, combined with perlite, fillers, and binders, then mixed into a slurry. The mixture is formed into sheets, oven-dried, and cut to size. The tiles, which are inherently porous, are then textured with fissures and painted.

SUSPENSION SYSTEMS

Concealed acoustic tile ceiling suspension systems are installed at the desired height by hanger wires, which support the metal T- or Z-shaped grid components. The suspension system is typically fabricated from factory-coated steel or as galvanized steel systems for improved resistance to moisture.

Concealed suspension systems for acoustic tiles integrate above-ceiling access areas into the system. Access is upward or downward, depending on the system. Care should be taken to prevent damage to the ceiling tile during installation and maintenance of the system and above-ceiling elements.

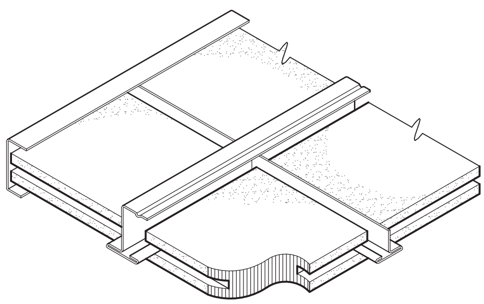
STRUCTURAL PERFORMANCE

Ceiling suspension systems for acoustic tiles are designated as light-, intermediate-, or heavy-duty. Light-duty systems are used where there will be no additional loads other than the acoustic tiles; therefore, these systems are typically used only in residential and light commercial applications. Intermediate-duty systems are capable of supporting a moderate amount of additional load, such as light fixtures and ceiling diffusers. Intermediate-duty systems are commonly used in standard commercial applications. Heavy-duty systems can accommodate additional loads suspended from or installed within the ceiling system. Prior to specifying a suspension system, the anticipated loads on the ceiling should be reviewed to determine the most suitable type.

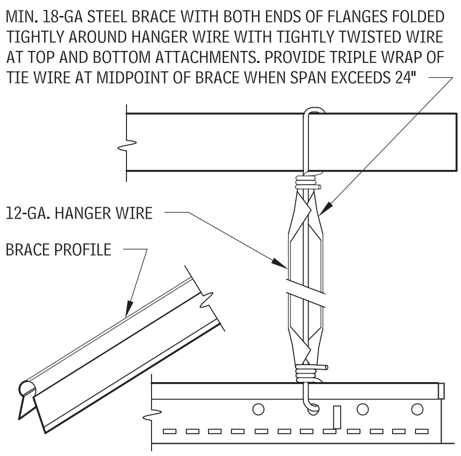
COMPONENTS

The concealed suspension system is composed of interlocking 15/16-in.-wide double-web main beams and cross tees. Main beams are typically installed on hanger wires spaced at 4 ft. on center along the beam. Angle or channel-shaped moldings are used for perimeter acoustic tile support. Hanger wires support the main and cross tees from the structure above and are spaced per the manufacturer's recommendations and as project conditions require. Accessory components such as clips and concealed angles are available to allow access to the plenum space above the ceiling.

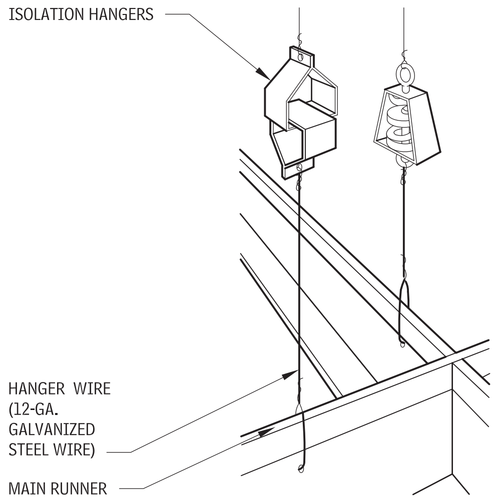
KERFED-EDGE ACOUSTIC CEILING TILE
12.146



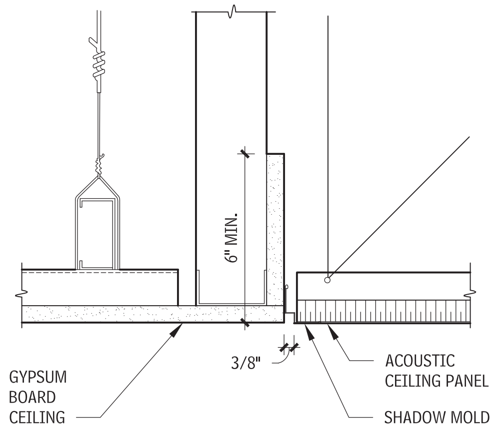
STIFFENING BRACE
12.147



ISOLATION HANGER
12.148



GYPSUM BOARD–ACOUSTIC CEILING FLUSH CONDITION
12.149



ISOLATION HANGERS

Isolation hangers isolate ceilings from noise traveling through the building structure. Hangers are also available for isolating ceiling systems to shield spaces from mechanical equipment and aircraft noise.

When it is necessary to isolate a high-noise area from a building, or a "quiet room" from a high surrounding noise level, floors, walls, and ceilings should be built free of rigid contact with the building structure, to reduce sound and vibration transmission.

SEISMIC DESIGN

For the installation of an acoustical tile ceiling with seismic design requirement locations, review suspension systems with cross-tee end details that accommodate lateral movement. Check with ceiling suspension system manufacturers to determine the seismic capabilities of a particular system.

WOOD CEILINGS

WOOD AND WOOD PRODUCT CEILINGS

There are a variety of wood products used for ceilings, including beadboard, wood decking or planks, and wood-finished ceiling panels.

Beadboard, 5/16 in. thick and around 3-1/2 in. wide, can be used for ceilings. A routed groove down the center of each plank creates the illusion of two narrow planks when installed. Beadboard is installed at right angles to the ceiling joists. Edges at walls are easily trimmed with molding.

Wood decking or planks span beams to form the structural platform of a floor or roof. The underside of the planks may be left exposed as the finished ceiling. Wood planks are typically 5-1/4 in. wide and have V-shaped tongue-and-groove joints. Channel groove, striated, and other machined patterns are available. There is no concealed ceiling space with such a system.

Wood ceilings are often finished with stains and varnishes. A dark ceiling finish, especially a shiny one, may appear lower than it actually is. Combined with a dark-colored floor, it can create the illusion of a flat, horizontal space.

Wood ceilings made from light-colored or highly patterned woods, like knotty pine, can add warmth and character to a space. In some cases, wood ceilings are painted, either to reflect more light or to obscure unattractive wood.

Wood ceilings are usually highly sound reflective. Sometimes designers use lattices or baffles of wood in an attempt to improve sound absorption. Such efforts may improve sound diffusion but must be topped with acoustically absorbent materials in order to significantly increase sound absorption.

Ceiling panels with wood veneer finishes are also available. Perforated wood-finished panels can have acoustically absorbent material inside. The panels are edge banded and some open downward for ease of access.

Manufacturers of ceiling panels provide wood and faux wood options. Standard 2 by 2 ft. metal ceiling panels can be inexpensively powder coated with realistic printed images of wood.

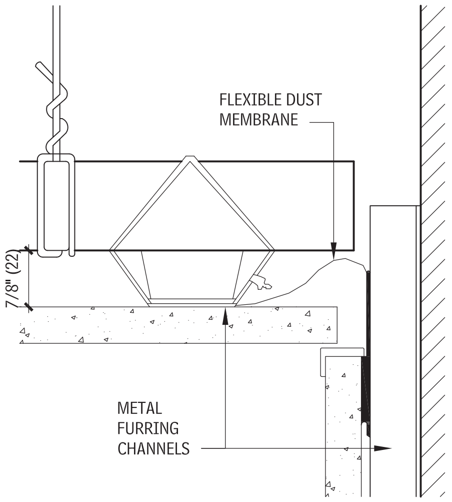
Suspended wood linear ceilings are attached with clips to a rail. They are available in a variety of wood species, including oak, ash, maple, poplar, and red cedar, with factory-applied finishes.

GYPSUM BOARD CEILINGS

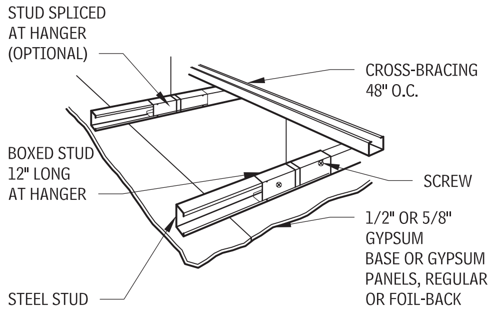
CEILING FRAMING

Suspended drywall and plaster ceilings can be framed with conventional framing materials or with a drywall suspension system. Metal framing typically includes the use of a carrying channel and furring or hat channel suspended by 8- or 9-gauge hanger wire. Steel stud framing typically includes the use of metal studs suspended by 8- or 9-gauge hanger wire.

CEILINGS—EXTERIOR WALL FINISHES
12.151

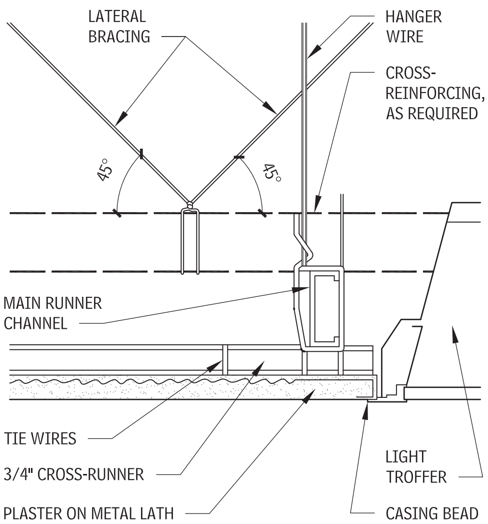


STEEL STUD FRAMING SYSTEM
12.152

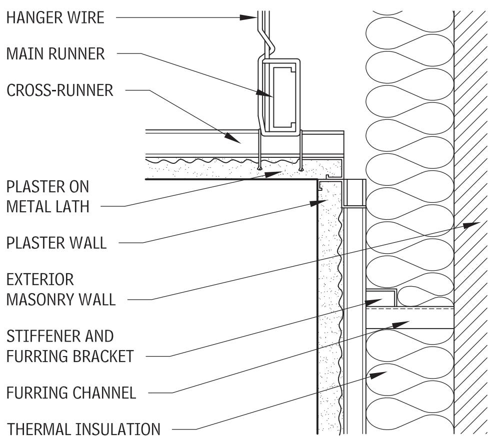


PLASTER CEILINGS

SUSPENDED PLASTER CEILING DETAILS
12.150



SOFFIT



NOTES

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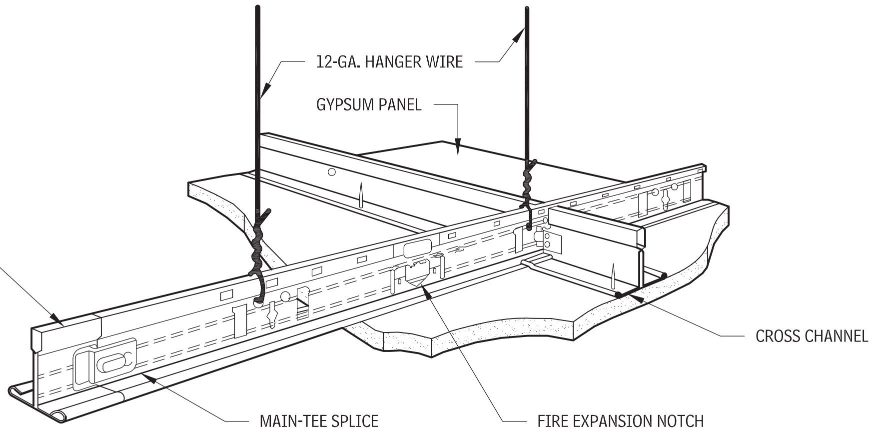
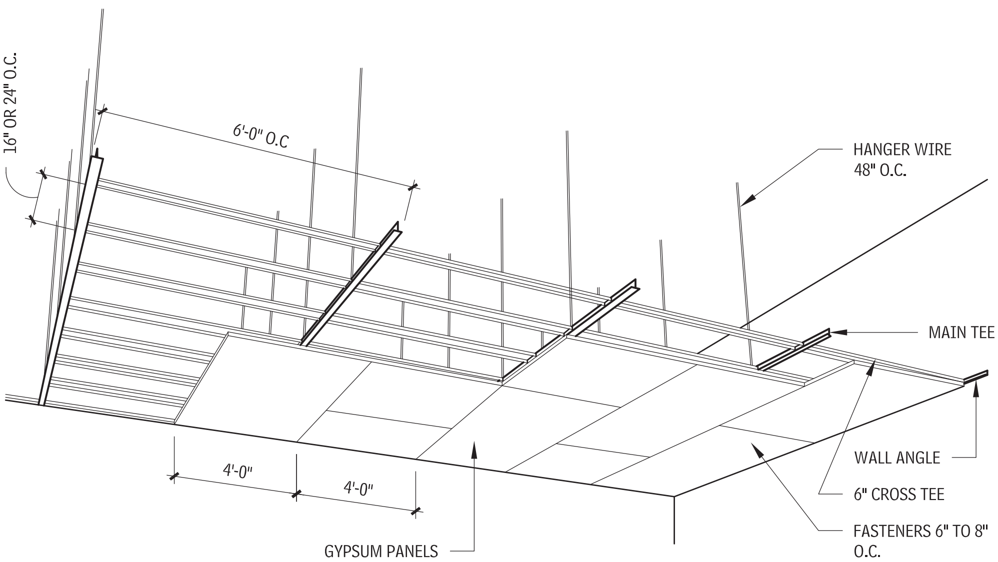
DRYWALL SUSPENSION SYSTEM WITH CROSS TEE
12.153



FLAT CEILINGS
12.154



METAL CEILINGS

LINEAR METAL CEILINGS

Linear metal ceilings are distinctive in appearance and are used where strong linear aesthetic, durability, and ease of maintenance are desired. Metal surfaces are available with many finishes and colors, which allow for a number of design options for the metal ceiling. Special suspension systems allow custom radius configurations, as well as flat horizontal ceilings, to be installed. Linear metal ceilings are typically installed as snap-in units on a concealed suspension system, and some can accept companion integrated light fixtures.

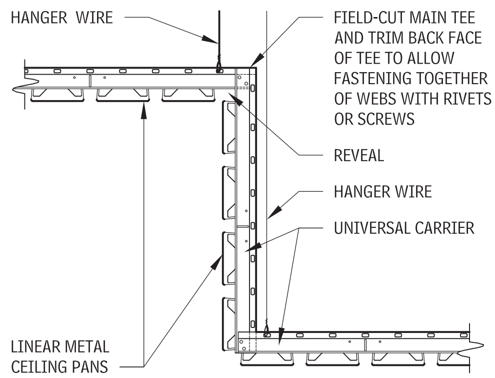
CEILING TYPES

Linear metal ceilings are fabricated from aluminum, steel, or stainless steel. Options include metal panel (slat) sizes, metal coating types, colors, textures, and acoustic insulation. Linear baffle ceilings are also available, but typically are not installed with acoustic insulation.

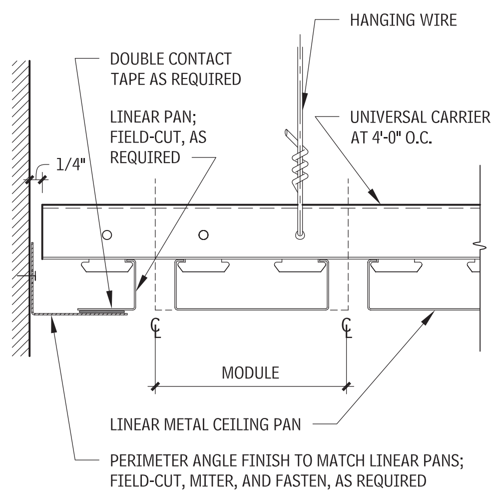
MATERIALS

The most common material for linear metal ceilings is roll-formed aluminum, with typical thicknesses of 0.020 in., 0.025 in., and 0.032 in. Aluminum linear panels are preferred for high-humidity areas and in spaces where the environment fluctuates, as well as for exterior applications. Roll-formed steel linear panels are available, and they can be more economical than aluminum, but are not as commonly used due to concerns about maintenance over time. Stainless steel also performs well but is typically more costly than aluminum or steel panels.

LINEAR METAL CEILING AND FASCIA ASSEMBLY
12.155



LINEAR METAL CEILING PERIMETER CONDITION
12.156



NOTES

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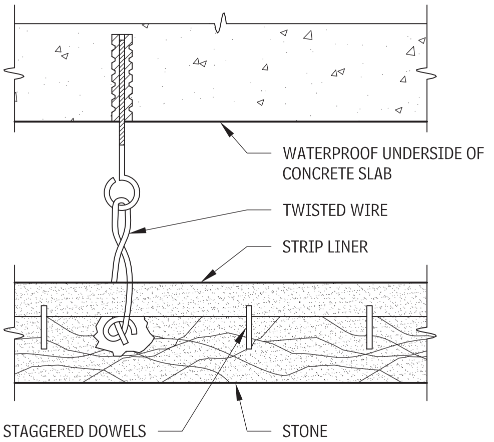
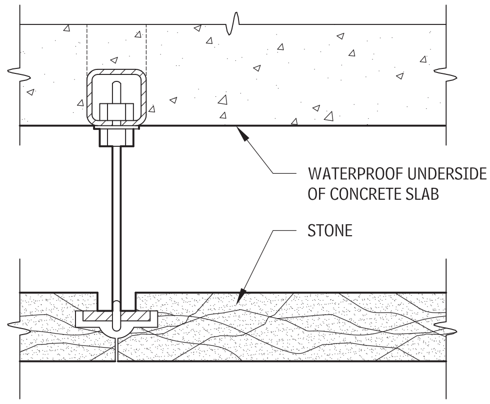
Contributors:
Keith McCormack, CSI, CCS, RTKL Associates, Baltimore, Maryland; USG Interiors, Inc., Chicago, Illinois; Setter, Leach & Lindstrom, Inc., Minneapolis, Minnesota.

STONE CEILINGS

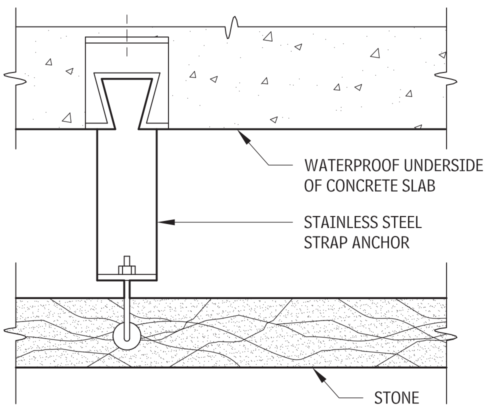
TYPICAL ASSEMBLIES FOR HANGING INTERIOR VENEER STONE
12.157



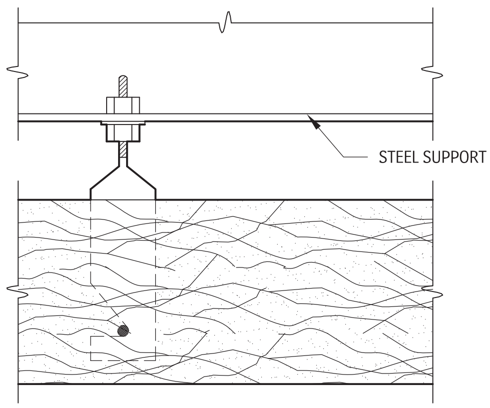
THREADED INSERT AND EYEBOLT



EYEBOLT AND DOWEL BOLTED TO THREADED CONCRETE INSERT



DOVETAIL STRAP WITH HOOK ROD ANCHOR



FLAT HOOK ANCHOR AND DOWEL

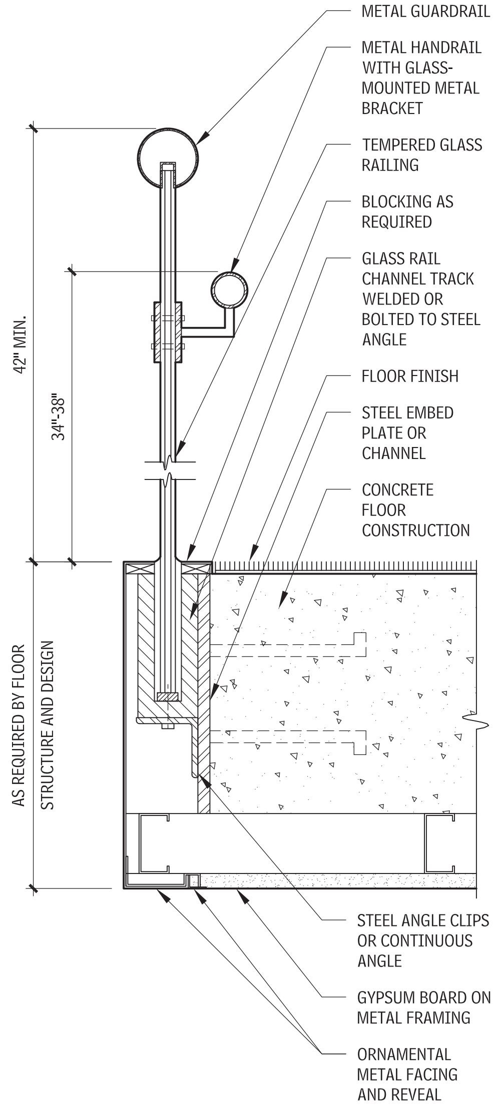
INTERIOR SPECIALTIES

INTERIOR RAILING

INTERIOR BALUSTRADES AND SCREENS, INTERIOR RAILINGS

Guardrails act as fall protection and are required adjacent to any elevation drop of 2 ft-6 in. or greater. The required height of any guardrail is 3 ft-6 in., minimum. If the rail has openings, the spacing must be such that a 4-in. diameter sphere cannot pass through the openings. If there were a danger of objects falling from the floor level, then a toe kick would also be required to prevent this occurrence. A handrail incorporated with the guardrail is only required on stairs or ramps. The guardrail design must meet the required design stresses of rails, posts, and panels. The structural value of fasteners and anchorage to the building structure for both vertical and horizontal forces must be verified.

GLASS AND METAL GUARDRAIL
12.158

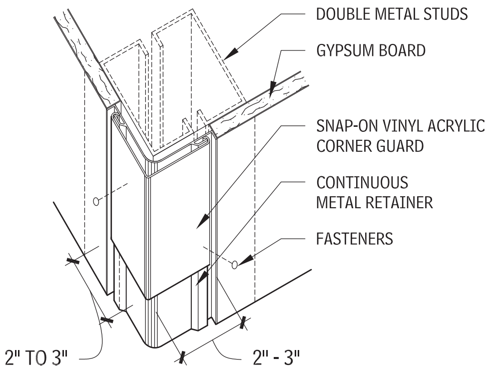


WALL AND DOOR PROTECTION

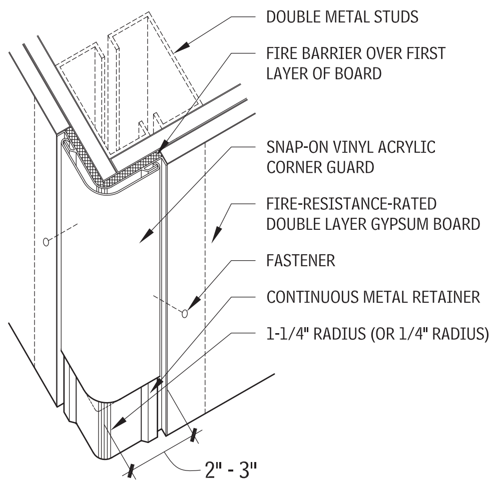
WALL AND CORNER GUARDS

Wall guards, panels, and trim are typically attached to a finished wall surface with adhesive or screws. For all wall and corner guard installations, it is important to provide backup blocking behind areas where fasteners are attached, particularly for handrail-type guards.

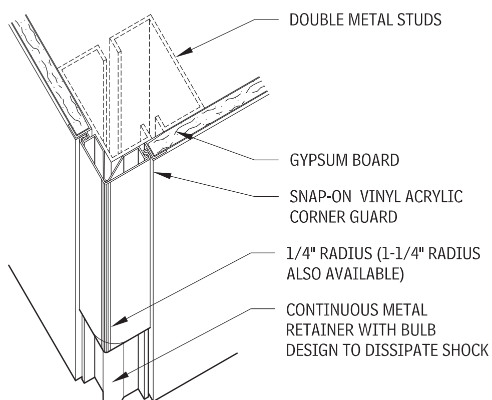
FLUSH-MOUNTED CORNER GUARDS
12.159



STANDARD-RECESSED

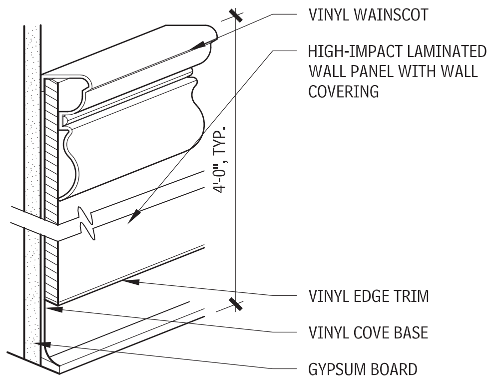


FIRE-RESISTANCE-RATED-RECESSED



CUSHIONED-RECESSED

WAINSCOT PANEL WALL GUARD
12.160



TOILET COMPARTMENTS AND TOILET ACCESSORIES

This section discusses interior construction for toilets and baths, locker rooms, and showers.

COMPARTMENTS AND CUBICLES

When selecting toilet enclosures, screen types, and mounting styles, consider requirements for maintenance, vandal and moisture resistance, supporting construction, and methods for repairing damaged units.

PANEL MATERIALS

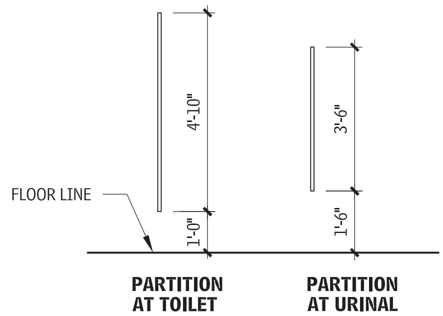
Toilet compartments are often categorized by finish or construction. Common materials from which compartments and cubicles are fabricated include:

- Metal, which includes stainless steel and steel with a baked enamel finish.
- Polymers, including plastic laminate, phenolic core, melamine faced particleboard cores; fiberglass-reinforced panels (FRP) with particleboard cores; and solid-surfacing veneers
- Stone

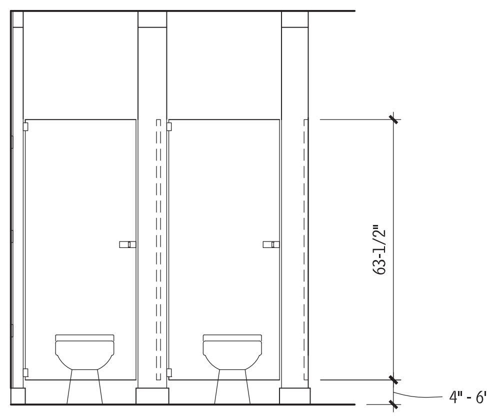
Factory-finished hardwood units, which are generally used exclusively for high-end installations, are also available. Moreover, materials may be combined—for example, compartments may have plastic-laminate doors and panels with stainless-steel pilasters. Baked enamel and plastic laminate panels are also available with stainless steel edge strips.

Taller-than-average doors and panels may be required to help ensure privacy. Assemblies that incorporate a lap joint at doors and pilasters to eliminate vertical sight lines into compartments are available from an increasing number of solid-polymer and phenolic-core unit manufacturers. Some metal units can be modified to include stops and fillers, to eliminate vertical sight lines at doors.

STANDARD PARTITION MOUNTING HEIGHTS
12.161



INCREASED-PRIVACY COMPARTMENTS
12.162



Contributors:
BFS Architectural Consulting and Interior Design; YMCA of the USA, Chicago, Illinois; Frederick C. Krenson, AIA; Rosser Fabrap International, Atlanta, Georgia.

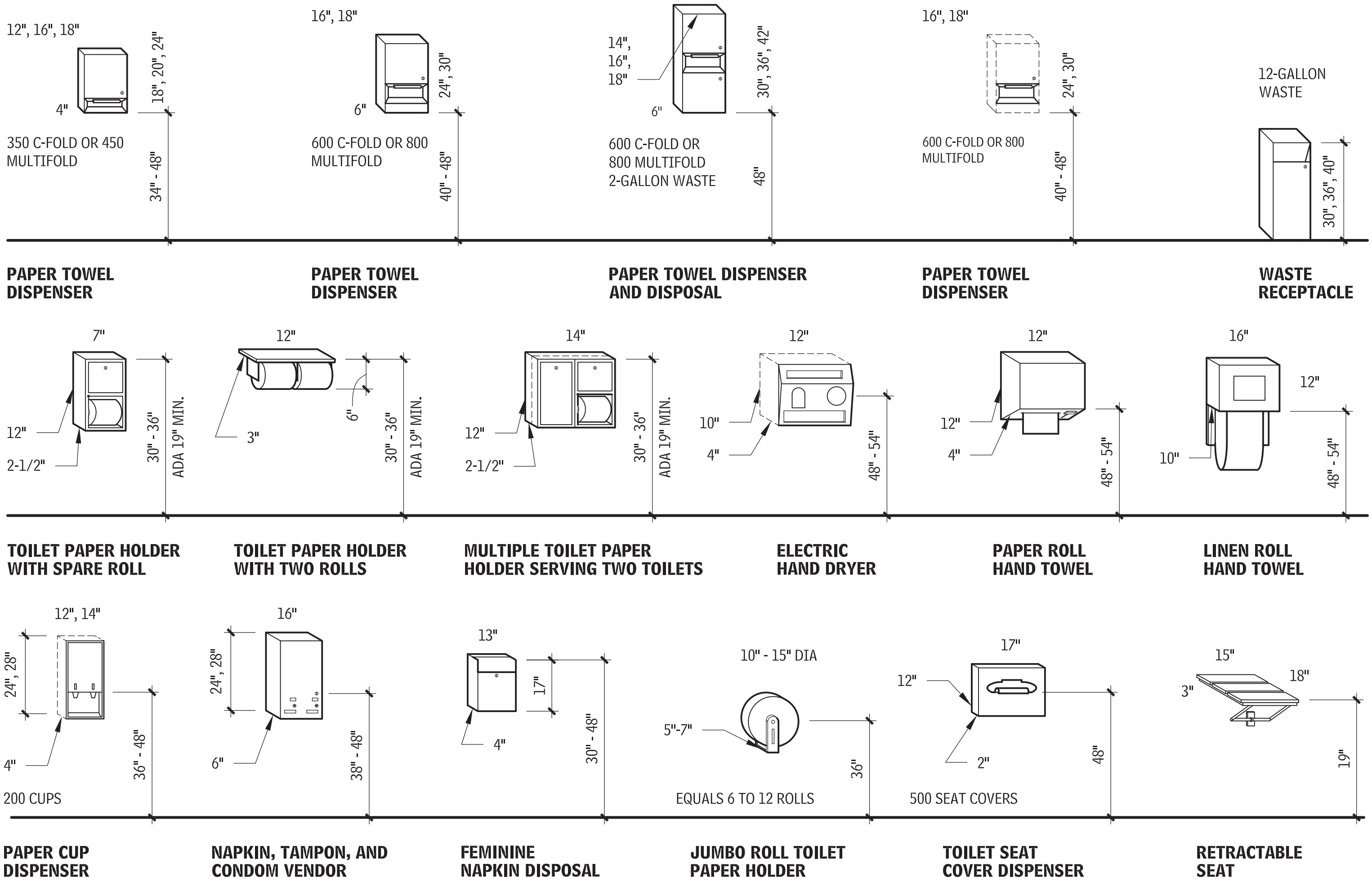
TOILET AND BATH ACCESSORIES

Working with toilet and bath accessories requires adherence to this guideline, unobstructed reach ranges may not exceed 48 in.

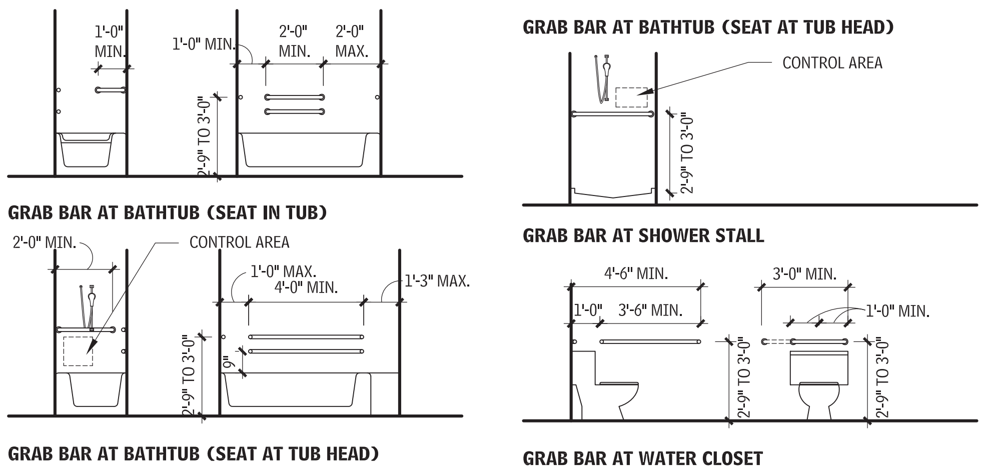
All dispensers and disposals may be recessed, semirecessed, or surface mounted, as long as they do not obstruct the clearances for accessibility.

Refer to applicable codes, standards, and regulations for accessibility requirements.

COMMERCIAL TOILET AND BATH ACCESSORIES
12.163



GRAB BAR HEIGHTS
12.164



INTERIOR SIGNAGE

Interior signage is a critical element in the success of interior spaces. Signage is used as a means of wayfinding, where users are provided with a system of navigational cues to guide them through an architectural environment. Interior signage is the most important component of this navigation system, used for information, direction, destination identification, and depiction of regulatory conditions and emergency locations, such as stair exits. Emergency exit signage, generally covered under base building interior construction and governed by code requirements, is not included in this discussion.

Interior signs may be visual, tactile, digital, or a combination of multiple information techniques. Local codes and ADA/ABA Accessibility Guidelines provide information on regulated sign types.

Interior signs may be freestanding, wall mounted, floor mounted, or suspended from overhead ceilings or structures. Signs may be framed or unframed, custom designed, and fabricated or specified from a premanufactured modular sign product line.

ACCESSIBLE SIGNAGE

The ADA/ABA Accessibility Guidelines establish guidelines for accessible signage. All signage required to be accessible must meet these requirements, as well as any applicable local or state accessibility standards.

ACCESSIBLE SIGN CATEGORIES

Accessible signs must be provided in permanent rooms and spaces. Directional, informational, and overhead signs do not require tactile and Braille lettering, but they must meet ADA/ABA Accessibility Guidelines criteria.

- Signs identifying rooms and spaces, whose function will not easily or readily change, must include tactile and Braille text. An office identification sign with a temporary room occupant may include a nonaccessible name plaque in addition to the accessible room identification sign.
- Wall-mounted signs that provide direction to or information about functional spaces are not required to include tactile and Braille lettering. However, they must meet requirements for character proportion and height, sign finish, and contrast.
- Signs that are projected or suspended overhead must meet requirements for clearance, character proportion and height, sign finish, and contrast.
- Building directories, menus, and all other signs that provide temporary information about rooms and spaces, such as the current occupant's name, are not required to comply with ADA/ABA Accessibility Guidelines.

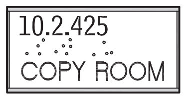
FIREPLACES

The fireplace and chimney are usually large elements in residences, but their scale can be adapted to any architectural style. Although the purpose of the residential fireplace has changed over the years from heating to decoration, increasing public interest in renewable forms of energy has instigated a new demand for fireplaces for heating homes.

Fireplace design and construction are governed by building and mechanical codes. The fireplaces shown in Figure 12.368 indicate the required parts and their vertical organization. The main function of the fireplace and chimney is to sustain combustion and carry smoke away safely. Their design is based on empirical data proven with years of safe performance.

IDENTIFICATION—ROOM SIGN
12.165

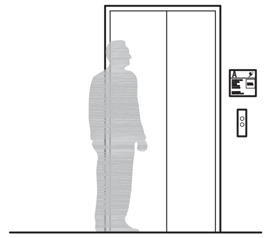
IDENTIFICATION: ROOM SIGN



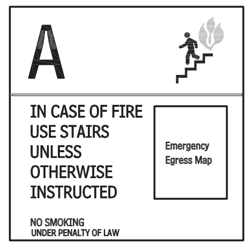
SIGN ELEVATION

SIGN SECTION

REGULATORY—FIRE AND LIFE SAFETY SIGNS
12.166



REGULATORY:
FIRE/LIFE SAFETY SIGN



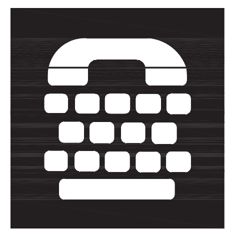
SIGN ELEVATION

SIGN SECTION

INTERNATIONAL ACCESSIBILITY SYMBOLS
12.167

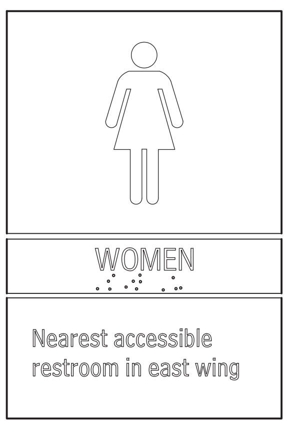
INTERNATIONAL SYMBOL OF ACCESSIBILITY

INTERNATIONAL SYMBOL OF ACCESS FOR HEARING LOSS

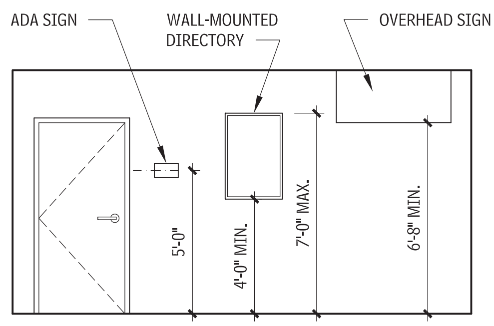


INTERNATIONAL TDD SYMBOL

TYPICAL RESTROOM SIGN
12.168



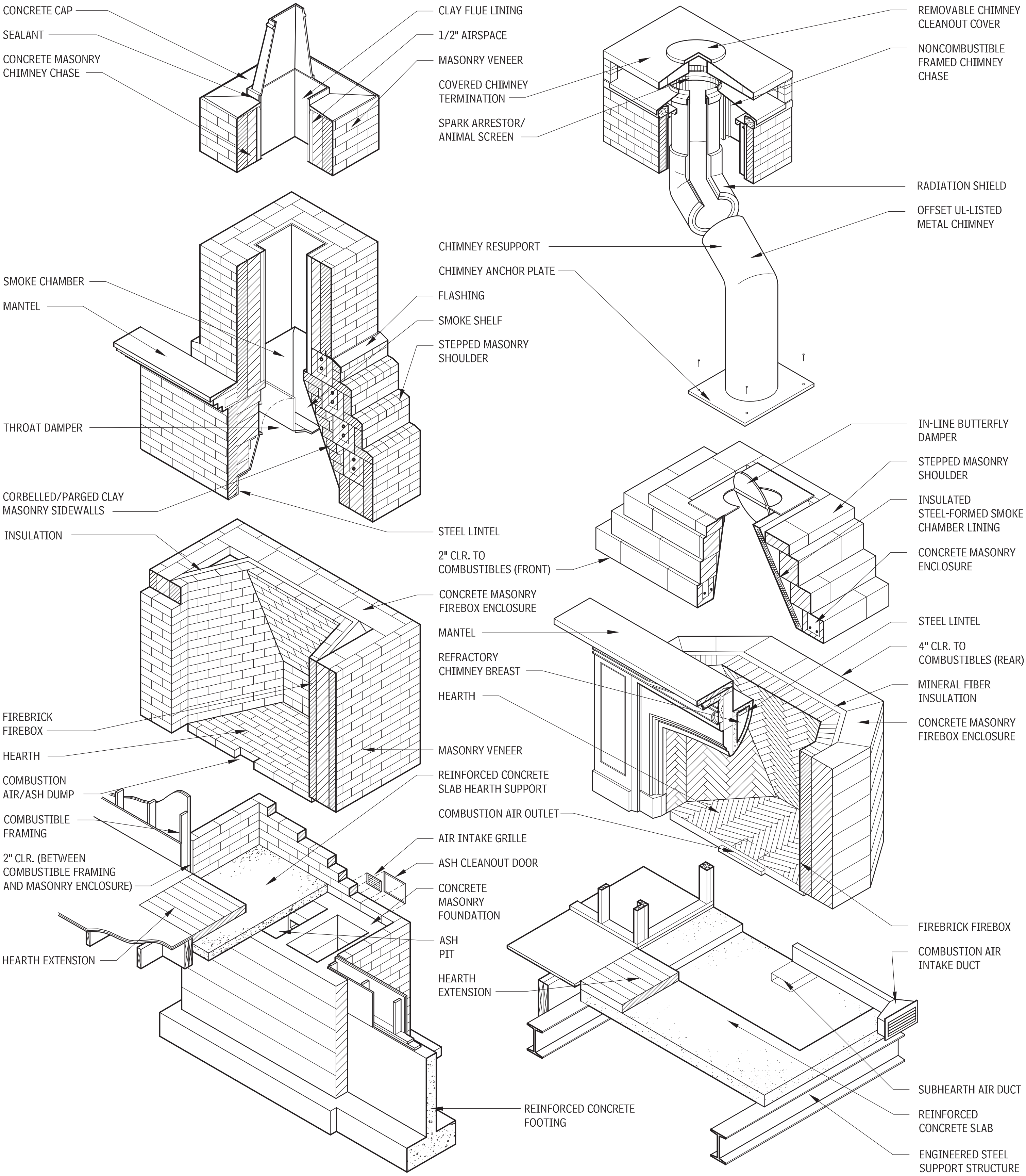
SIGNAGE MOUNTING HEIGHTS
12.169



NOTES

12.167 Society for Environmental Graphic Design, Washington, DC.
12.168 ASI-Modulex, Dallas, Texas.
12.169 ASI-Modulex, Dallas, Texas.

MASONRY FIREPLACE CONSTRUCTION
12.170



TRADITIONAL CONSTRUCTION TECHNIQUE **MODERN CONSTRUCTION TECHNIQUE**

ELEMENT D: SERVICES 13

CONVEYING

Conveying equipment may include elevators, escalators, and moving walks; dumbwaiters, lifts, turntables, scaffolding, conveyors, facility chutes, and pneumatic tube systems.

Conveying equipment is used to move people, equipment, and freight along horizontal and vertical paths. Conveying equipment makes access within large buildings practical by minimizing effort and travel time and can also be used to control access for privacy and security. The physical area and typical expense for conveying equipment usually impact the basic planning of a building and may control some aspects of the overall design. The speed at which these systems operate must be balanced against the occupants' waiting time in conjunction with potential physical unease caused by rapid or jerky movement.

Conveying systems are also important elements of universal access for occupants of differing physical abilities and so must comply with relevant accessibility standards. Safety is critical, in particular where shafts, openings, or operating parts may pose a danger to occupants; therefore maintenance procedures involve frequent inspection and, potentially, regular recertification by building authorities. Regulations are especially critical for elevators.

Other general design factors relate to matching equipment size, speed, and capacity with occupant type, demand load, and level of convenience.

DESIGN CONSIDERATIONS

Mechanized movement of occupants and materials within a building enables designers to organize, divide, and compartmentalize areas into distinctly separate zones that are accessible only through controlled portals employing elevators or escalators. Such separation can increase security, provide individual occupancies, and structure circulation sequences, such as arrival, greeting, and destination. These systems are typically surrounded by public physical space such as landings, foyers, and lobbies.

Conveying equipment also permits large plan areas to be folded upon themselves so that the shortest distance between two points is not a straight line from one area of a floor to another area of the same floor, but rather a mechanized path between adjacent or widely dispersed floor levels. In very large facilities such as airport terminals and high-rise buildings, conveying equipment facilitates rapid and easy communication between widely separated points that might otherwise be impractical to traverse, such as the sequence of passenger dropoff, baggage conveying, ticketing, passenger loading bridges, and departure lobbies.

CONFIGURATIONS

Elevators are generally used for longer-distance trips, while escalator trips are normally limited to five or fewer adjoining floor levels. Sky lobbies can be used to divide buildings into vertical sub-buildings, and smaller elevators, escalators, stairs, or any combination can provide circulation among the divisions.

CONTROLS

Careful and expert consideration is required in the strategic design and automated operation of conveying equipment; therefore appropriate consultants should be engaged early in the design process.

INTERFACES

Conveying equipment interfaces directly with the general circulation system and planning organization of a facility. Mechanized passenger pathways should be supplemented by modes of emergency egress. To the extent that vertical conveyance equipment permits high-rise building designs, the same equipment may also impact site planning and building utilization. High-volume circulation situations may require close coordination between various elements of conveying systems (such as between passenger elevators, service elevators, and escalators).

ELEVATORS

Components of an elevator system include a hoistway, a machine room, an elevator car, and waiting lobbies for passenger, equipment, or freight loading.

HOISTWAY

The hoistway is an open vertical shaft for the travel of one or more elevator cars. It includes a pit and usually terminates at the underside of the machine room in a traction assembly, and at the underside of the roof over the hoistway in a hydraulic assembly. Typically, access to the elevator car and hoistway is through hoistway doors at each floor, serviced by the elevator. Hoistway design is determined by the characteristics of the elevator system selected, along with requirements for fire separation, ventilation, soundproofing, and nonstructural elements.

MACHINE ROOMS

Both electric traction and hydraulic elevators require a location for elevator operating machinery. Due to current technology advances, operating machinery for hydraulic elevators has become smaller and often can be located within the hoistway. When a designated machine room is required, for either electric traction or hydraulic systems, fire separation, adequate ventilation, and soundproofing are required, along with self-closing and self-locking doors. The machine room for an electric traction elevator is usually located directly above the hoistway, but could also be situated below, to the side, or to the rear of the hoistway; this room contains elevator hoisting machinery and electronic control equipment. Machine rooms for hydraulic elevators, normally located near the base of the hoistway, contain a hydraulic pump unit and electronic controls. Codes may forbid placement of equipment not associated with the elevator in the machine room.

ELEVATOR CAR

Guided by vertical rails on each side, the elevator car conveys passengers or freight between floors. It is constructed within a supporting platform and frame. Design of the car focuses on ceiling, wall, floor, and door finishes and accompanying lighting, ventilation, and elevator signal equipment.

The car and frame of a hydraulic elevator are supported by a piston or cylinder. The car and frame of an electric traction elevator are supported by cables draped over the hoist machine. The elevator and its counterweight are connected with steel ropes or belts.

LOBBIES

Elevator waiting areas are designed to allow free circulation of passengers, rapid access to elevator cars, and clearly visible elevator signals. Elevator lobbies may be required to be enclosed—depending upon facility design and codes.

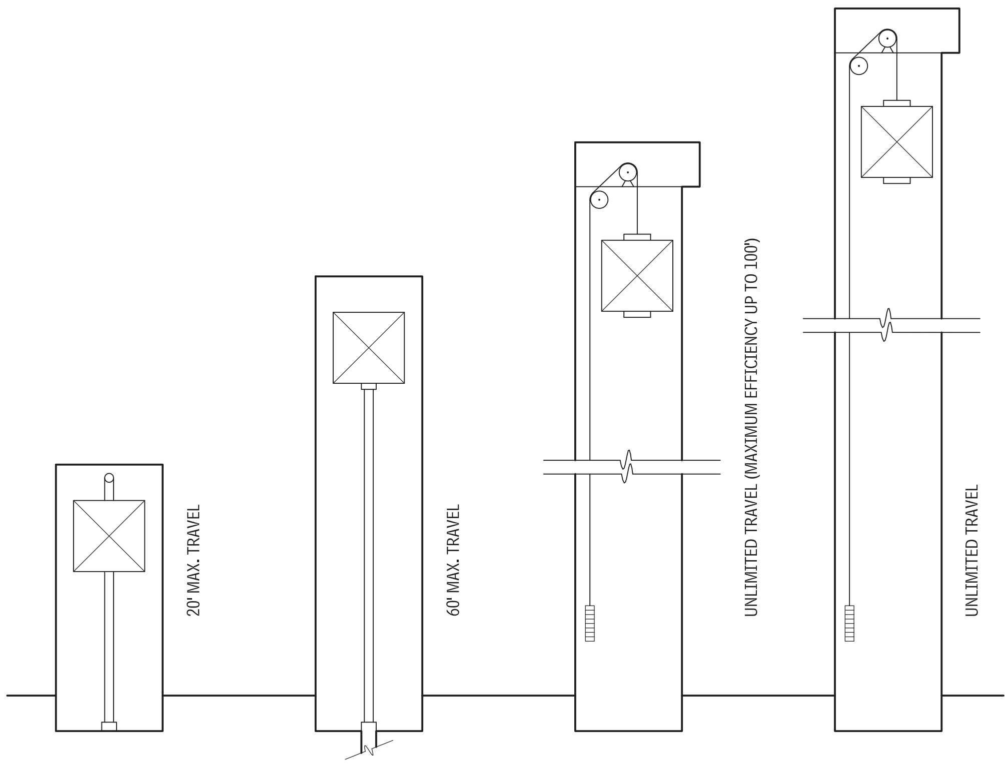
ELEVATOR TYPES AND USES

Generally there are two types of elevators, hydraulic and electric traction. Both of these elevator types can be used for various applications in a range of building types—including passenger, freight, and residential applications.

ELEVATOR TYPES

- *Hydraulic elevators:* Use a hydraulic oil-driven machine to raise and lower the elevator car and its load. Lower speeds and piston length restrict the use of this type. Travel distances vary

ELEVATOR TRAVEL DISTANCES
13.1



NOTE

13.1 These dimensions are general guidelines for selecting an elevator, using height as a criterion.

Contributor:
Dr. Lee E. Gray, Senior Associate Dean College of Arts & Architecture UNC Charlotte.

between 35 and 60 ft. dependent upon configuration and capacity. Although generally requiring the least initial installation expense, this elevator type requires more power to operate and will cost more over the lifecycle.

- *Electric traction elevators:* Elevators in which the energy is applied by means of an electric motor. Medium to high speeds and virtually limitless rise allow this elevator type to serve high-rise, medium-rise, and low-rise buildings. Electric traction elevators can be further divided into geared and gearless categories.
  - *Geared traction elevators:* Designed to operate within the general range of 100 to 450 ft./min, restricting their use to medium-rise buildings.
  - *Gearless traction elevators:* Available in units with speeds of 500 to 1200 ft./min. They offer the advantages of a long life and a smooth ride.

ELEVATOR USE TYPES

- *Passenger elevators:* Used to convey people from floor to floor. Elevator cars are available in standard and custom designs.
- *Service elevators:* In industrial, residential, and commercial buildings, service elevators are often standard passenger elevator packages modified for service use.
- *Freight elevators:* Usually classed as general freight, motor vehicle, industrial truck, or concentrated loading elevators. General freight loading elevators may be electric drum type or traction or hydraulic elevators.
- *Residential elevators:* Installed only in a private residence or to serve a single unit in a building with multiple dwelling units. By code, elevators in private residences are limited in size, capacity, rise, and speed.

ELEVATOR PLANNING

BUILDING CHARACTERISTICS

Physical building characteristics such as building height and hoistway location are considered in conjunction with population characteristics to determine the size, capacity, speed, type, and location of elevator components. These characteristics in particular affect elevator design:

- *Height:* The distance of elevator travel from lowest stop to uppermost stop, the total number of stops, and the distance between stops.
- *Building use:* The location of heavily used entrance areas, such as those leading to cafeterias, restaurants, auditoriums, and service areas. Typically, plan a facility so that no prospective passenger must walk more than 200 ft. to reach an elevator.

The elevator selection process begins with a thorough analysis of how people will occupy the facility. Four issues are pertinent:

- *Total population and density:* Determine these figures for each floor or for a portion of floors.
- *Peak loading:* Identify the periods when elevators will carry the highest traffic loads.
- *Waiting time:* This is the length of time a passenger is expected to wait for the next elevator to arrive.
- *Demand for quality:* Smooth operation may be as important as fancy finishes.

ELEVATOR TRAFFIC

Elevator traffic is typically defined in terms of critical or "peak" periods of elevator usage during a typical day. Traffic is thus discussed in terms of up-peak and down-peak, which refer to the direction of high traffic demands. While they are traditionally used to refer to the start and end of a business day (up-peak in the morning and down-peak in the early evening), they may also extend to lunch hour traffic (if all employees have the same designated lunch hour) or may be impacted by flexible work hours where employees set their own work schedules.

Another key factor is passenger "wait time." This is the length of time a passenger waits for an elevator to arrive after they have pushed the call button. In a building with good elevator service the average wait time is less than 30 seconds.

Some settings require the separation of elevators into distinct banks (groups of two or more elevators) that serve specific sections of a building. This may result in the designation of elevators as either local or express elevators. Local elevators serve a designated group of floors within a building, stopping at every floor. Express elevators typically transport passengers between specific floors, bypassing the intermediate floors.

Additional factors that impact traffic design include travel distance, operating speed, and the number of stops assigned to each elevator.

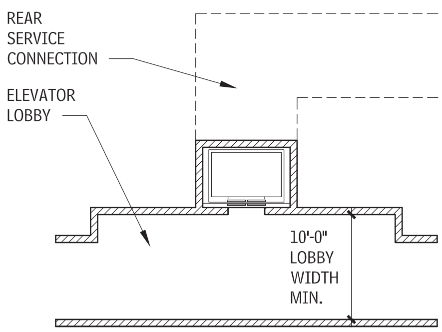
The traffic analysis of elevators required for a large or complex building should always be performed by a qualified elevator consultant.

ELEVATOR TYPES BY USE
13.2

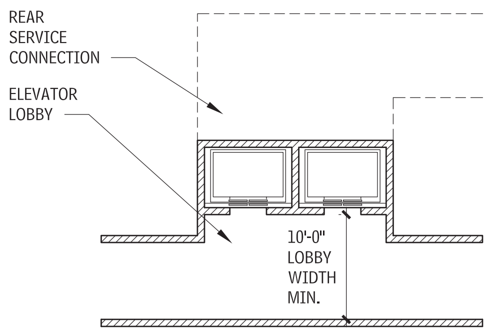
NEED/USE	ELEVATOR TYPE: PRIVATE RESIDENTIAL	HYDRAULIC	GEARED TRACTION	GEARLESS TRACTION
Private houses	X			
Low-rise, low speed		X		
Medium-rise, moderate speed			X	
High-rise, high speed				X
Low initial cost		X		
No penthouse, lightweight construction		X		
Freight, low-rise		X	X	
Freight, high-rise			X	

ELEVATOR LOBBY PLANNING
13.3

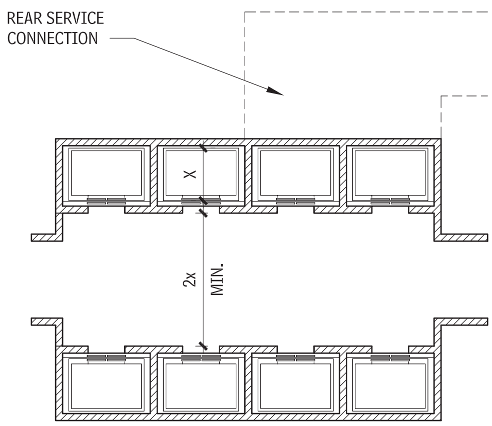
Passenger elevators should be centrally located, near the main entrance, and easily accessible on all floors. Groups of elevators should be arranged to minimize walking distance between cars. Lobby space must be sufficient to accommodate group movement. In general, elevators may not open into a corridor. The largest practical grouping of elevators in a building is eight cars. One row of more than four cars is generally not recommended. With groupings of four or six cars, lobbies may be closed at one end, forming an alcove, or open at both ends. In buildings with several elevator groupings, one group may serve lower floors, while others serve as express elevators to upper floors. When four or more elevators serve all or the same part of a building, they must be located in a minimum of two hoistways, but no more than four elevators can be located in any one hoistway. The use of elevators with front and rear openings may provide an option for building service applications.



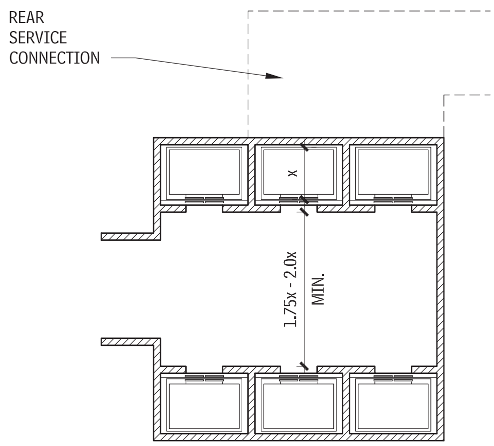
SINGLE CAR



PAIRED CARS



FOUR–EIGHT CAR ARRANGEMENT



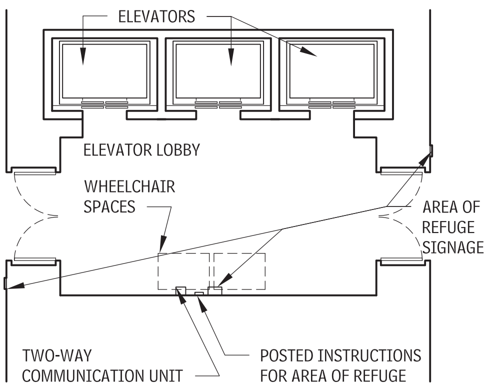
THREE–SIX CAR ARRANGEMENT

Contributor:
Rippeteau Rollins Architecture + Design, Washington, DC.

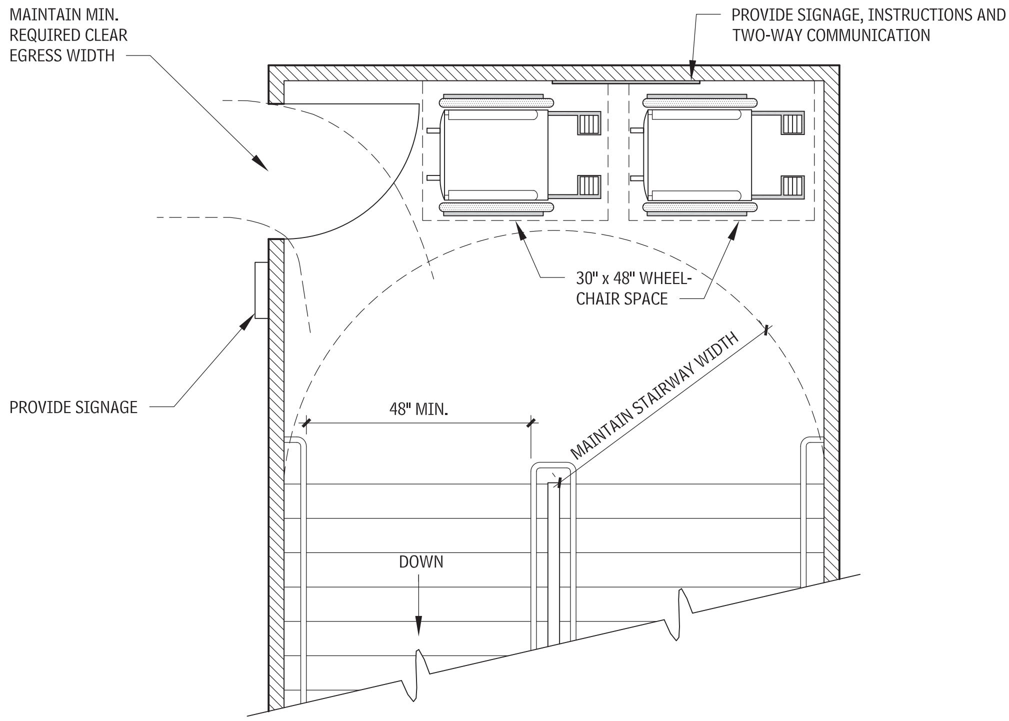
EMERGENCY EGRESS

In buildings without full automatic fire sprinkler systems, areas of refuge are required at a designated elevator (provided with emergency power) and at fire stairs—above the ground floor. The area of refuge concept may also apply to egress from the ground floor of a building where and when accessible egress is a challenge due to terrain, traffic, or snow and ice. A building that is fully sprinklered does not need to have structural areas of refuge—but will have identified assistance-waiting areas. Signage and communication requirements for areas of refuge are specified in the applicable codes.

ELEVATOR LOBBY DESIGNED AS AN AREA OF REFUGE
13.4



EXAMPLE OF AREA OF REFUGE AT FIRE STAIR
13.5



FACILITY TYPE AND SIZE

Facility type and size will dramatically affect the selection of an appropriate elevator system and components. An owner's requirements for service (along with budget constraints) will influence the design process. The mix of these considerations makes generalizing about elevators difficult. Hospitals can be particularly challenging as visitors, staff, patients on gurneys, and portable equipment vie for rapid access to other floors. Courthouses face population separation issues. Requirements for freight (service) transport capabilities vary from building to building. High-rise building elevator systems are normally zoned to allow for acceptable performance. Elevators can be teamed with escalators to increase vertical access capacity. Some general patterns regarding elevator system sizing are provided in Figure 13.6.

TYPICAL ELEVATOR REQUIREMENTS
13.6

BUILDING TYPE	NUMBER OF SHAFTS	ELEVATOR CAR CAPACITY
Apartment Building	1 per 75 units; plus 1 service elevator for 300 or more units in a high-rise building	2000 to 2500 lbs.
Hotels	1 per 75 rooms; plus 1 service elevator for up to 100 rooms, with 1 additional service elevator for each 200 additional rooms	2500 to 3000 lb.
Office Buildings	1 per 35,000 sq. ft. of area served; plus 1 service elevator per 265,000 sq. ft. of area served	2500 to 3500 lb.

For passenger service in a multistory building, the elevator system acts as a common flow path for the majority of occupants and visitors. It is important that the performance and ambience of this path match the context of the building. Several design criteria interact to determine elevator system performance—and thus user perceptions of the system's adequacy. Appropriate values for each criterion should be set by the design team—and will, along with car capacity, car speed, zoning, the number and location of main lobbies, and system control logic, determine elevator system requirements.

Handling capacity is the percentage of the building population that can be handled by the elevator system in a defined time period (normally 5 minutes); if actual handling capacity is too low, waiting times will increase along with user dissatisfaction. Typical design targets for handling capacity are shown in Figure 13.7.

MINIMUM HANDLING CAPACITIES
13.7

BUILDING TYPE	PERCENT OF POPULATION (IN 5-MIN PERIOD)
OFFICE BUILDINGS	
Center city	12–14
Investment	11.5–13
Single-purpose	14–26
RESIDENTIAL BUILDINGS	
Prestige apartments	5–7
Other apartments	6–8
Dormitories	10–11
Hotels—first tier	12–15
Hotels—second tier	10–12

Lobby waiting time is the average amount of time a passenger spends between arriving in the lobby (and pushing a call button) and leaving the floor in an elevator car; this is a direct indicator of elevator system performance in the eyes of users; long waiting times cause irritation. Typical design targets for waiting time are presented in Figure 13.8.

RECOMMENDED LOBBY WAITING TIMES
13.8

BUILDING TYPE	WAITING TIME (SEC)
OFFICE BUILDINGS	
Excellent service	9–14
Good service	15–17
Fair service	18–23
Poor service	24–29
Unacceptable service	30 and up
RESIDENTIAL BUILDINGS	
Prestige apartments	30–42
Middle-income apartments	36–48
Low-income apartments	48–72
Dormitories	36–48
Hotels—first tier	18–30
Hotels—second tier	30–42

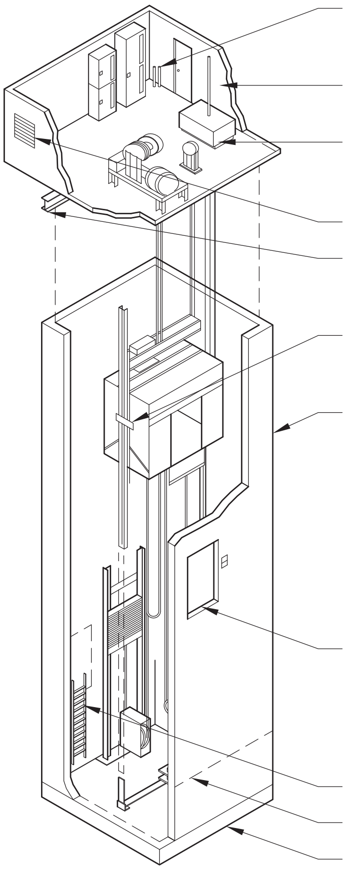
Average trip time is the average amount of time a passenger spends between pushing a lobby call button and departing the car at an upper floor; this is also perceived by users as an indicator of elevator system quality. In a commercial building, a trip time of less than 60 seconds is desirable; 75 seconds is bearable; 120 seconds is not acceptable. In residential buildings, longer trip times may be tolerated (depending upon context).

NOTES

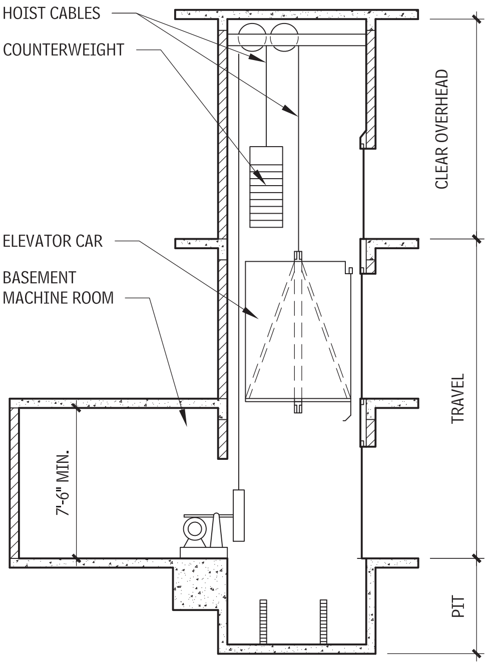
13.4 a. Refer to applicable codes, standards, and regulations for specific area of refuge requirements.
b. The elevator lobby and shaft must be pressurized for smokeproof enclosure, as required by the authority having jurisdiction.
c. The pressurization system must be activated by smoke detectors in locations approved by the authority having jurisdiction.
d. The system's equipment and ducts must be enclosed within 2-hour fire-resistance-rated construction.
13.5 Source: International Code Council.
13.6 Source: *Architect's Studio Companion*, 5th edition by Edward Allen, John Wiley and Sons, Inc.
13.7 Source: *Mechanical and Electrical Equipment for Buildings*, 12th edition by Walter Grondzik and Alison Kwok, John Wiley and Sons, Inc.
13.8 Source: *Mechanical and Electrical Equipment for Buildings*, 12th edition by Walter Grondzik and Alison Kwok, John Wiley and Sons, Inc.

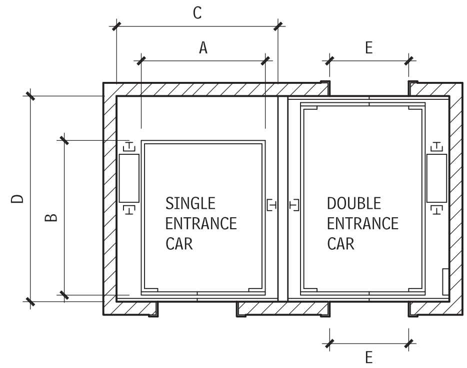
Contributor:
Walter Grondzik, Ball State University, Muncie, Indiana.

ELEVATOR PLANNING DETAILS
13.9

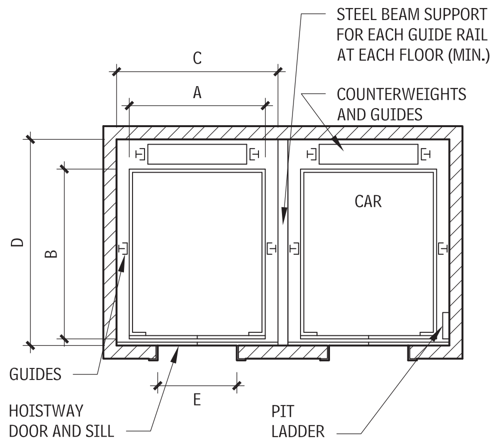


ELEVATOR HOISTWAY TYPES
13.10





SIDE-MOUNTED COUNTERWEIGHT



REAR-MOUNTED COUNTERWEIGHT

ELECTRIC TRACTION ELEVATORS

Electric traction elevators may be either geared or gearless systems. The main differences between the two systems lie in travel speed and travel height. General design considerations involving hoistway, machine room, and elevator planning are similar.

Both geared and gearless drive units are governed by electronic controls, which coordinate car leveling, passenger calls, collective operation of elevators, door operation, car acceleration and deceleration, and safety applications. A broad range of control systems is available to meet individual facility requirements.

Structural requirements call for the total weight of the elevator to be supported by the machine beams and transmitted to the building (or hoistway) structure. Coordination with elevator consultants and structural engineers is important for proper design.

Keep the following in mind when designing for traction elevators:

- Pit depths, clear overhead dimension, and machine room penthouse sizes should be in accordance with American Society of Mechanical Engineers Safety Code for Elevators and Escalators (ASME A17.1). Local codes may vary from these requirements along with requiring fire-resistance-rated enclosures.
- Minimum clear overhead dimensions are based on manufacturer standard car heights.
- Capacity may be expressed in passengers or pounds, depending upon what will be moved.
- Elevator configuration will be dependent upon capacity and also entrance size and location.
- Travel distance, speed, and number of stops will affect the design of the elevator and associated equipment.
- The machine room for traction elevators is usually located directly above the hoistway in a penthouse, but may be located in other spaces adjacent to the hoistway. Space must be provided for the elevator drive, electronic control equipment, and governor; provide sufficient clearance for equipment installation, repair, and removal. Adequate lighting, heating, ventilation, and sound control should be provided. An elevator consultant can be a valuable asset to the design team during the early phases of a project.

ELECTRIC TRACTION ELEVATOR DIMENSIONS (FT-IN.)
13.11

RATED LOAD (LB)	A	B	C	D	E
2000	5–8	4–3	7–4	6–11	3–0
2500	6–8	4–3	8–4	6–11	3–6
3000	6–8	4–7	8–4	7–5	3–6
3500	6–8	5–3	8–4	8–1	3–6
4500	5–8	7–10	8–2	10–5	4–0

HYDRAULIC ELEVATORS

Hydraulic elevators are used primarily in low- and mid-rise installations, where moderate car speed (up to 150 ft. per minute) is acceptable. A car is connected to the top of a piston that moves up and down in a cylinder. The car moves up when hydraulic fluid is pumped into the cylinder from a reservoir, raising the piston. The car is lowered when the hydraulic fluid returns to the reservoir.

NOTES

13.10 Side-mounted counterweights allow an optional rear entrance door.
13.11 Indicated dimensions should be used only for preliminary planning. Actual dimensions are dependent upon mounting location of counterweights and manufacturer standard elevator dimensions.

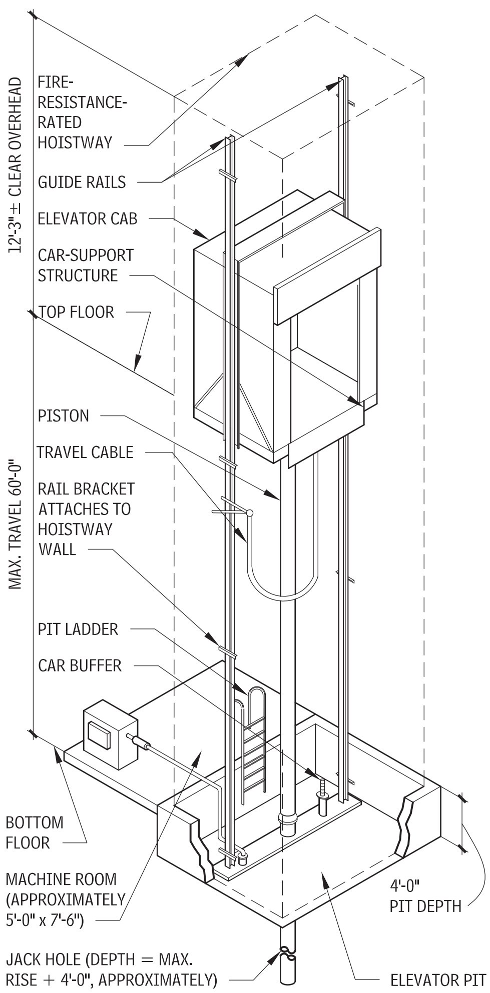
The up and down motions of the elevator car are controlled by the hydraulic valve.

The main space planning elements of a hydraulic elevator are the machine room, usually located at the base, and the hoistway, which serves as a fire-protected, ventilated passageway for the elevator car. Adequate structure must be provided at the base of the hoistway to bear the load of the elevator car and its supporting piston or cylinder.

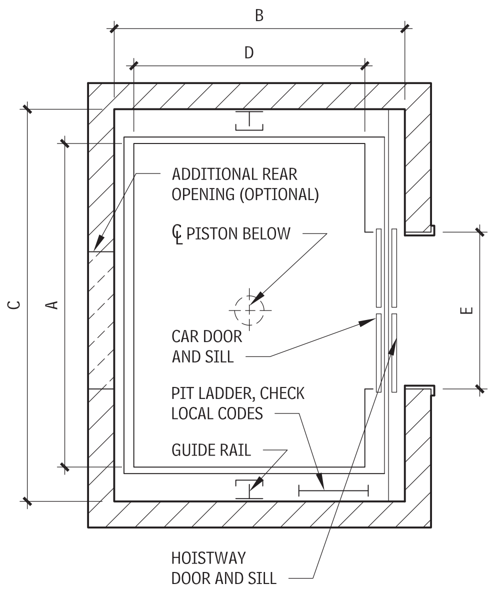
There are three configurations of hydraulic elevators: holed, holeless, and roped hydraulic. The cylinder in a holed hydraulic elevator is centered below the car and bored into the earth. The cylinder depth will be approximately equal to the travel distance plus the pit depth. Holeless hydraulic elevator cylinders are located on one or both sides of the car and do not penetrate below the elevator pit. Holeless hydraulic elevators have substantially less travel than holed types. With roped hydraulic elevators, a plunger moves the cables or ropes, which then moves the elevator car. All three configurations can be used in commercial applications, but holed and holeless are the most common types.

When designing for hydraulic elevators, follow these guidelines:

- Ensure that pit depths and overhead clearances are in accordance with ASME A17.1 requirements; note that local codes may vary from these requirements.
- Use car and hoistway dimensions of units for reference purposes only. A variety of units are available. Consult with manufacturers for specific dimensions.
- Hoistway walls serve primarily as fire-resistant enclosures. Check local codes to determine required fire-resistance ratings.
- Guide rails extend from the floor of the pit to the top of the hoistway to guide the car inside the hoistway.
- Rail brackets attach the guide rails to the hoistway walls and typically are located at each floor level. A bracket is required at the top of the hoistway, and an intermediate bracket may be required for excessive floor-to-floor heights.
- Holed hydraulic applications require a jack hole in the floor of the pit.

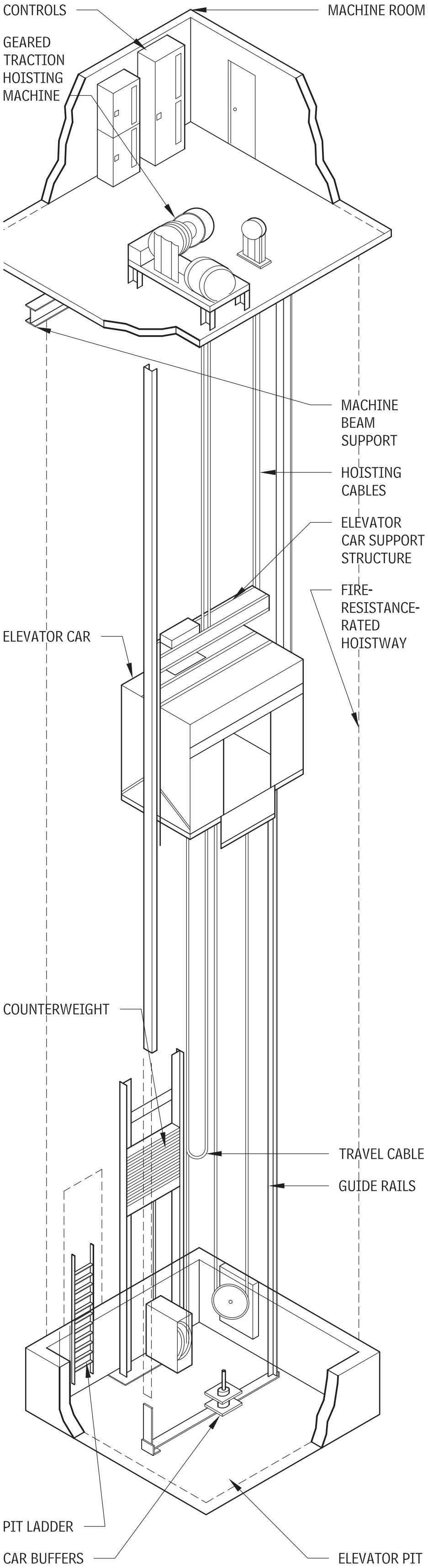


HOLED HYDRAULIC ELEVATOR
13.13



HOLED HYDRAULIC ELEVATOR DIMENSIONS (FT-IN.)
13.14

RATED LOAD (LB)	A	B	C	D	E
2000	5–8	4–3	7–4	5–11	3–0
2500	6–8	4–3	8–4	5–11	3–6
3000	6–8	4–7	8–4	6–3	3–6
3500	6–8	5–3	8–4	6–11	3–6
4500	5–8	7–10	7–5	10–0	4–0



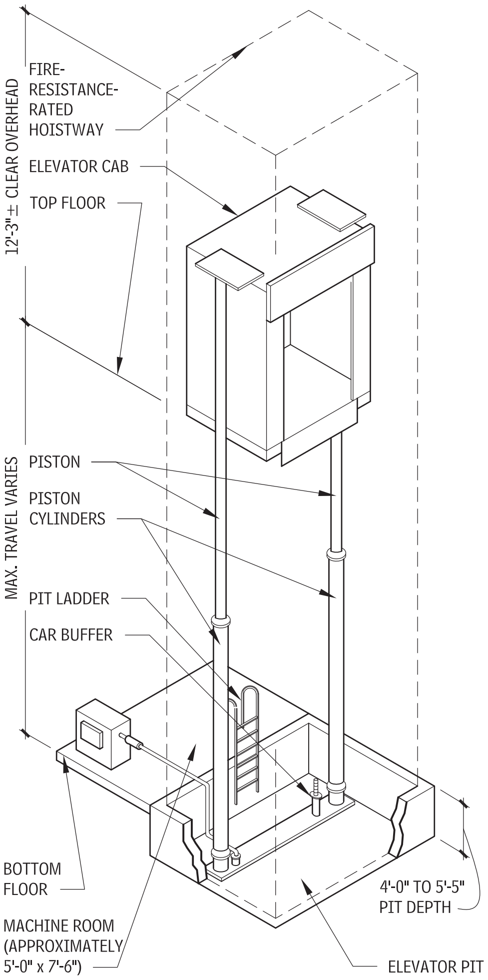
TRACTION ELEVATOR (GEARED)
13.12

NOTES

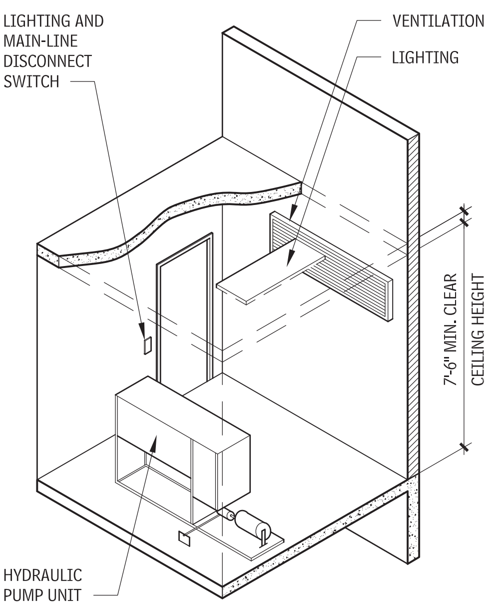
13.14 a. A and B dimensions are "clear inside."
b. Indicated dimensions should be used only for preliminary planning. Actual dimensions are dependent on mounting location of counterweights and manufacturer standard elevator dimensions.

Contributor:
Rippeteau Rollins Architecture + Design, Washington, DC.

HOLELESS HYDRAULIC ELEVATOR
13.15



MACHINE ROOM
13.16



PASSENGER ELEVATORS

Passenger elevators are primarily intended to transport people from floor to floor in multistory buildings. A passenger elevator system consists of one or more elevator cars arranged to meet building needs. Elevator cars are rated by loading capacity (expressed in pounds) and by system speed. Cars intended for passenger use are normally outfitted with amenities (interior finishes and lighting) appropriate to the building context. Passenger elevators can also be used to move light freight (within the limits of the car's loading capacity) and may be provided with removable pads to protect wall surfaces when used for other than incidental freight.

There are three common types of passenger elevators: traction—gearless, typically used in high-rise applications; traction—geared, used in mid- to high-rise residential buildings and mid-rise commercial; and hydraulic, limited to low-rise to mid-rise applications. Traction elevator speeds can vary to suit the project needs and may be quite high. Hydraulic elevator speeds are lower.

Passenger elevator car layout, access, and exterior control elements will comply with the accessibility requirements of the ADA. In multistory buildings, one or more cars may need to be arranged to provide accessible emergency egress.

ELEVATOR DRIVES

- *Hydraulic elevators:* Use a hydraulic oil–driven machine to raise and lower the elevator car and its load. Lower speeds and piston length restrict the use of this type. Travel distances vary between 35 and 60 ft. dependent upon configuration and capacity. Although generally requiring the least initial installation expense, this elevator type requires more power to operate and will cost more over the lifecycle.
- *Electric traction elevators:* Elevators in which the energy is applied by means of an electric motor. Medium to high speeds and virtually limitless rise allow this elevator type to serve high-rise, medium-rise, and low-rise buildings. Electric traction elevators can be further divided into geared and gearless categories.
  - *Geared traction elevators:* Designed to operate within the general range of 100 to 450 ft./min, restricting their use to medium-rise buildings.
  - *Gearless traction elevators:* Available in units with speeds of 500 to 1200 ft./min. They offer the advantages of a long life and a smooth ride.

ELEVATOR APPLICATIONS

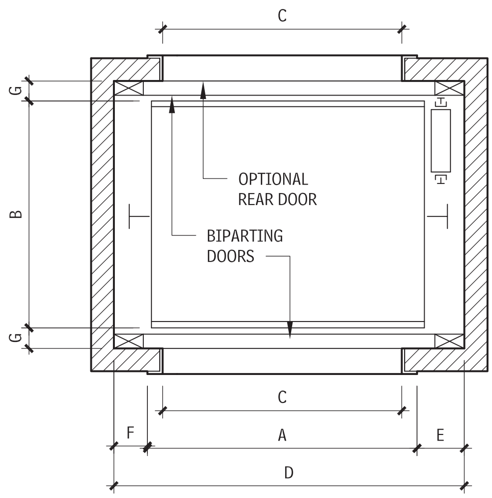
- *Passenger elevators:* Used to convey people from floor to floor. Elevator cars are available in standard and custom designs.
- *Service elevators:* In industrial, residential, and commercial buildings, service elevators are often standard passenger elevator packages modified for service use.
- *Freight elevators:* Usually classed as general freight, motor vehicle, industrial truck, or concentrated loading elevators. General freight loading elevators may be electric drum type or traction or hydraulic elevators.
- *Residential elevators:* Installed only in a private residence or to serve a single unit in a building with multiple dwelling units. By code, elevators in private residences are limited in size, capacity, rise, and speed.

FREIGHT ELEVATORS

General freight elevators with capacities of 2000 to 8000 lb. satisfy a variety of material-handling requirements. Industrial truck freight elevators require special design considerations to handle truckloads of 10,000 to 20,000 lb. or more.

General freight or industrial truck elevators may have either hydraulic or traction drive systems, similar to those of other elevators. The units are, however, usually custom-designed with vertical bipart doors and special structural support to accommodate heavy loads and eccentric loading conditions. Freight elevators usually have simple control systems and operate at slower speeds than other elevators. Their capacity must be sized for the largest expected load.

FREIGHT ELEVATOR KEY PLAN
13.17



TRACTION FREIGHT ELEVATORS
13.18

CAPACITY (LB)	DIMENSIONS (FT-IN.) A	B	C	D	E	F
2500	5–4	7–0	5–0	7–10	1–7	0–11
4000	6–4	8–0	6–0	8–10	1–7	0–11
8000	8–4	10–0	8–0	10–10	1–7	0–11
12,000	10–4	14–0	10–0	13–6	1–7	0–11
20,000	12–4	20–4	12–0	16–6	1–7	0–11

NOTES

13.16 a. A machine room, meeting code requirements and ventilated for temperatures between 65°F and 100°F, must be provided for all elevators. It is usually located next to the hoistway at or near the bottom terminal landing. Room size may vary depending on the number of cars, capacity, and speed.
b. Machinery consists of a pump and motor drive unit, hydraulic fluid storage tank, and electronic control panel. Adequate ventilation, lighting, and entrance access (recommended 3 ft-6 in. wide) should be provided.

13.17 For regular counterbalanced hoistway doors, G = 5 in.; for pass-type counterbalanced hoistway doors, 6–3/4 in. Pass-type doors are required when floor heights are less than 11 ft. for 7-ft openings, and less than 12 ft-6 in. for 8-ft openings.
13.18 Indicated dimensions should be used for preliminary planning. Consult elevator manufacturer for specific sizes and load capacities.

Contributor:
Rippeteau Rollins Architecture + Design, Washington, DC.

ESCALATORS

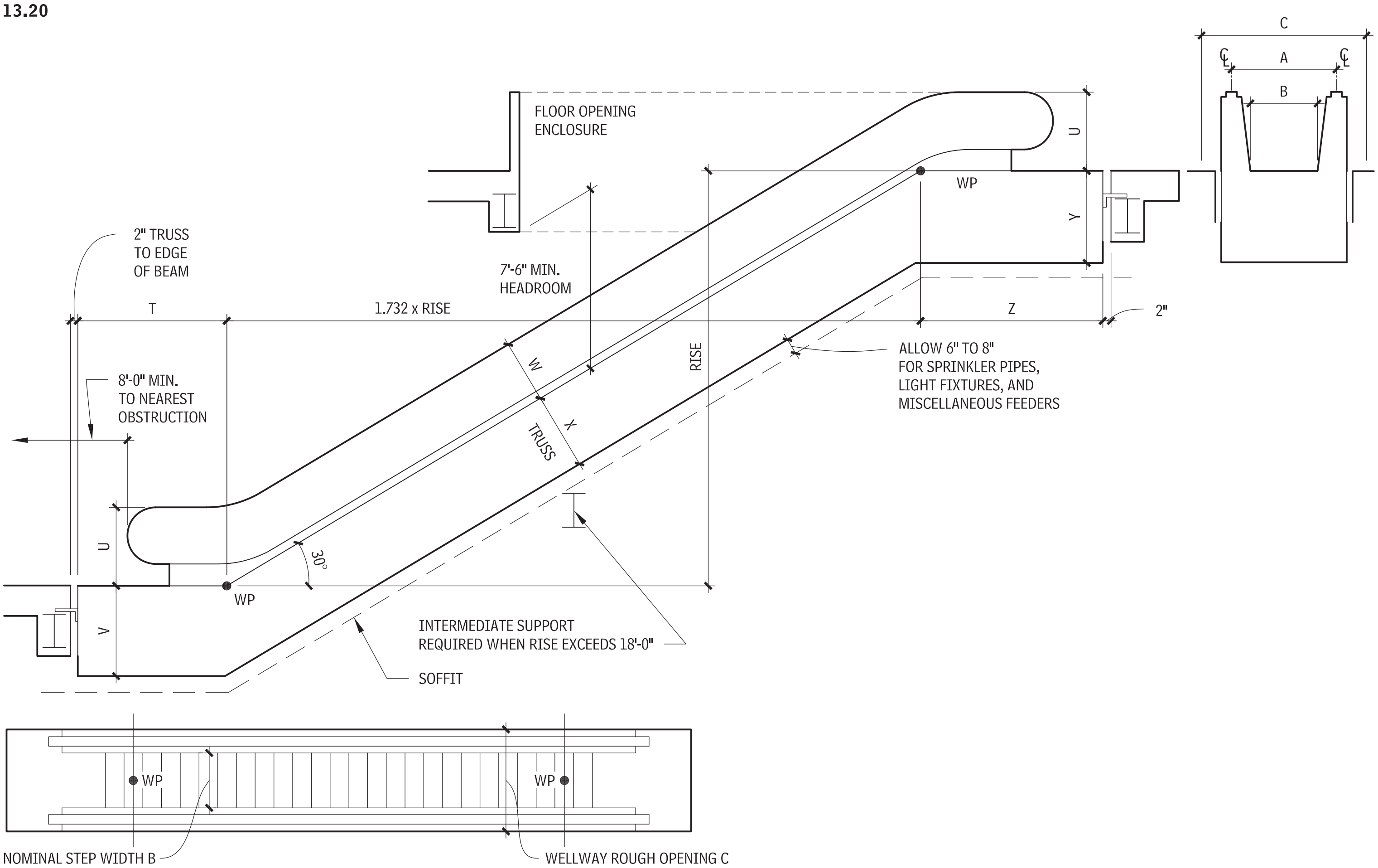
Escalators are a very effective form of vertical transportation for very heavy traffic where the number of floors served is limited (normally a maximum of five or six floors). Escalators are not usually accepted as a required exit and are not allowed as part of an accessible route.

Dimensions indicated in Figure 13.19 are typical for commercial-type escalators with two flat steps; dimensions will vary with the manufacturer and alternative configurations. Consult manufacturers for structural support, electrical supply, and specific dimensional requirements.

ESCALATORS
13.19

SYMBOL	DESCRIPTION	MANUFACTURER DIMENSIONS								
	NOMINAL ESCALATOR WIDTH	KONE			OTIS			SCHINDLER		
		32″	40″	48″	32″	40″	48″	32″	40″	48″
A	Centerline to centerline of handrail	2′-10-1/8″	3′-5-7/8″	4′-1-11/16″	N/A			2′-9″	3′-4-7/8″	4′-3/4″
B	Nominal step width	24″	32″	40″	24″	32″	40″	24″	32″	40″
C	Wellway rough opening	4′-1-1/16″	4′-8-7/8″	5′-4-5/8″	4′-3/16″	4′-8-3/16″	5′-4-1/8″	3′-11-1/4″	4′-7-1/8″	5′-3″
T	WP to end of lower truss	7′-0-11/16″			7′-8-3/4″			7′-1/2″		
U	Top of handrail	3′-3-3/8″			3′-3-3/8″			3′-3-3/8″		
V	Depth of lower pit	3′-8-7/8″ Min.			3′-5-5/8″			4′-0″		
W	Top of handrail	2′-10-1/8″			2′-9-1/8″			2′-7″		
X	Depth of truss	3′-0-13/16″			3′-2-11/16″			2′-11-3/8″		
Y	Depth of upper pit	3′-5-3/16″			3′-5-5/8″			3′-3-3/4″		
Z	WP to end upper truss	8′-2-1/2″			8′-5″			8′-3″		

ESCALATOR PROFILE
13.20



PLUMBING

DESIGN CONSIDERATIONS

A plumbing system is used to safely transfer liquids and gases to and from a building and its site. Water supply, plumbing fixtures, and waste piping may be the most common type of plumbing system within a building. However, other types of plumbing systems may be required, including plumbing for gas service, and, depending on the facility type, services such as medical gases in a hospital.

Plumbing design usually will affect the overall design of a facility. Determining the fixture count, space requirements, and location of toilet rooms within the building should be an early planning consideration of the design team. When sustainable design is a concern, addressing rainwater and site drainage issues should also be part of the early planning process. Existing utility conditions and infrastructure (storm drainage, water utilities, and sanitary sewage utilities) need to be considered. These utilities may need to be addressed on a site, facility, or campus basis, or at a municipal scale when services do not exist. Spacing and location of plumbing fixtures and toilet rooms should respond to occupant needs and code requirements. The design professional should be aware of how water is piped to plumbing fixtures, how waste is plumbed from fixtures, along with general venting requirements. Even during preliminary design, the design team should begin to address the requirements for accumulation and flow of waste through horizontal and vertical piping.

Other issues that should be considered in the design of the facility plumbing system include the control of noise, vibration, and piping condensation.

- *Noise* is a factor of high-velocity liquid flow in pipes or of fixture noise (such as flush valves).
- *Vibration* is the result of mechanically coupling pipes to moving equipment (such as pumps), as well as the manner in which piping is physically isolated from the building structure. Structure-borne noise can propagate very efficiently.
- *Condensation* occurs when exposed or insufficiently insulated pipes cooled by their contents pass through warm, moist air and the exterior of the pipe reaches the dew point temperature.

The potential flow of unhealthy and dangerous sewer gases back into the building requires the use of water-filled traps at each fixture, as well as a system of venting to open air. Exterior openings of these vents should be placed away from direct view, and must be remote from any outdoor air intakes to the building. Additionally, there are code requirements for the location in relationship to roofs.

Plumbing fixtures provide the most visible design elements in this system; they are the parts of the building that occupants actually touch and feel. Most other plumbing components are concealed within the building construction.

The basic components of a plumbing installation (water distribution and sanitary waste drainage system) are as follows:

1. Service tap
2. Meter
3. Shutoff valve
4. Service entry
5. Fixture supply tree
6. Fixture
7. Trap
8. Drain
9. Venting
10. Waste piping
11. Cleanouts
12. Building trap
13. Sewer connection

INTERFACES

Plumbing and piping connect to a building structure and may require vibration isolation to avoid structure-borne noise transmission. Acoustic considerations are necessary when routing of plumbing or piping near occupied spaces. Fixture noise (such as flush valves) is also a design consideration in buildings. Other design issues that must be considered include coordination of plumbing fixture location with toilet compartments and urinal screens, toilet and bath accessories, and tub and shower doors.

CODES AND STANDARDS

Plumbing codes establish minimum acceptable standards for the design and installation of plumbing systems and selection of the components they comprise. Model building codes and the plumbing codes associated with them have found general acceptance in large areas of the country. However, some jurisdictions have adopted their own codes or modifications of one or more of the model codes. Verify the plumbing code used by the authority having jurisdiction and any amendments for each specific project.

Requirements for plumbing system design should be based on the adopted code(s) used by the jurisdiction of the project. Tables and charts provided in this chapter are for preliminary planning purposes and should not be used for actual design.

The word "approved" is often used in conjunction with components and devices that come in contact with potable water and products used for human consumption or use. Nonetheless, a responsible code official or agency must examine and test these items to determine whether they are suitable for a particular intended use. Only materials and devices approved by the local jurisdiction can be used in plumbing systems. Plumbing design drawings and utility services also must be examined and found to be in compliance with local codes, rules, and regulations.

ACCESSIBILITY

The U.S. Department of Justice has developed, in the ADAAG (Americans with Disabilities Act Accessibility Guidelines), wide-ranging and detailed technical requirements for accessibility in new construction and renovations. Since then, ANSI A117.1 has been adopted into building codes. ANSI A117.1 provides specific dimensioned layouts for various design features (such as wheelchair turning space and clearances) for plumbing fixtures (including water closets, bathtubs, shower enclosures, and drinking fountains).

SUSTAINABILITY

Physical sustainability concerns (as distinct from economic and equity considerations) related to plumbing system design will normally focus on three areas: (1) water conservation, (2) conservation of material resources, and (3) energy efficiency.

Plumbing systems design is heavily dictated by code requirements that have evolved over time to protect the health, safety, and welfare of building users and the public. Although plumbing codes are beginning to consider water conservation as a social benefit to be encouraged (similar to energy codes), they provide a lowest common denominator for sustainability. Designers will need to reach beyond code to engage sustainability.

The fundamental building block of a plumbing system is the fixture. A fixture is a device that requires water or produces sanitary drainage. Most fixtures do both. Common fixtures include: lavatories (bathroom sinks) with faucets, bathtubs with faucets, showers with faucets, water closets (toilets) with flush mechanism, service sinks, drinking fountains, hose bibbs (exterior faucets), washing machines, dishwashers, and often refrigerators.

Water conservation: Design guidance regarding water conservation is fairly well developed. Prevalent thinking about the potential to conserve water is embodied in any of several well-known green building evaluation and rating systems. Minimum expectations for a green plumbing system are typically expressed in rating systems via prerequisites. Higher aspirations for greenness are engaged via optional credits. A desire for sustainability will surpass such green building credits—perhaps embracing net-zero water use.

Water conservation may be accomplished by selecting fixtures that use less water than conventional (code-minimum) fixtures. These include:

- Reduced-flow water closets
- Flow-restricting shower heads
- Aerating faucets
- Water-conserving dishwashers
- Water-conserving clothes washers

Water conservation may also be accomplished by fixtures that use less water per operation/cycle than conventional (code-minimum) fixtures. These include:

- Multicycle dishwashers
- Multicycle clothes washers

In addition, water conservation may be accomplished by fixtures that use no water or an alternative source of water. These include:

- Waterless urinals
- Composting toilets
- Graywater supplies
- Rainwater cistern supplies

Water conservation may also be accomplished by modifying human behavior (usage patterns). The most common examples of this are municipal water-use restrictions on hose bibb use and parental supervision of teenager shower lengths.

Materials conservation: This is an area that is not being formally pursued in most green building rating systems. Building code requirements for hygienic and healthful materials tend to restrict recycled content potentials for fixtures. Local sourcing of fixtures, piping, and accessories should be considered (when possible) to reduce energy and pollution associated with transportation of system components.

Energy conservation: There are two main sides to conserving energy in plumbing systems operation. The first is to reduce the use of potable water, which consumes energy in its processing and delivery and again in its treatment at a sewage plant. The second is to reduce the energy required for water heating. This may be accomplished by:

- Using water-conserving fixtures that use less water
- Reducing hot water temperatures (within the limits set by codes)
- Using more energy-efficient heating systems (high-efficiency combustion and/or instantaneous heaters)
- Using solar thermal water heaters (shifting from fossil fuels to renewable energy)

Sustainability from an equity perspective may be addressed by ensuring that designs allow for equal outcomes across the genders—as opposed to simply providing equivalent fixture counts. This has been referred to as "potty parity."

DOMESTIC WATER DISTRIBUTION

A building service is that portion of the supply piping on private property that extends below frost depth from the public utility main into the building. It includes the connection to the main, valves, pressure-reducing devices, backflow prevention devices, meters, and other requirements specific to the individual utility company.

Because of different requirements the water supply service for commercial buildings is often divided into two separate services at the public main: potable water and fire protection water. However, a single, combined service is sometimes used.

BACKFLOW PREVENTION

It is extremely important for a utility company to protect the public water supply from contamination flowing from any building to which it is supplying water. The device used to accomplish this is the backflow preventer (BFP), which prevents contaminated water from flowing backward into the potable water supply.

There are four types of BFP, and the degree of hazard in a particular situation determines which type to select and install:

- *Air gap:* This BFP provides a physical separation between the supply of potable water and the storage tank or piping distribution network. This is a passive method and is considered the only absolutely safe concept.
- *Reduced-pressure zone (RPZ):* This type of BFP is a mechanical device used when a high hazard is present. Liquids attempting to flow in reverse discharge out of the BFP instead. When installed in a building water supply, the RPZ backflow preventer should be located as close to the public water main as is practical.
- *Double check valve:* This is a mechanical device often used on fire protection water supplies and for smaller-size piping that supplies equipment that has a back pressure and is not considered a high hazard.
- *Vacuum breaker:* This mechanical device is used when there is no back pressure, such as for a submerged water supply to a water closet. It uses a flexible diaphragm that allows water to flow through in only one direction; it closes on itself, stopping flow in the reverse direction.

After connecting a plumbing system to the public water main, it is necessary to provide a method to shut off the water supply to the building without entering it. A curb valve installed close to the property line is used to serve this function. A second shutoff valve is provided inside the building at the service entrance.

For high hazard occupancies, a reduced-pressure zone BFP should be installed as close to the public main as is reasonable to protect the public water supply from contamination. Because of the potentially large discharge of water, an aboveground, heated enclosure is recommended. For less hazardous locations, a double check valve assembly may be permitted. No water is discharged from a double check valve.

Water meters are necessary to measure the amount of water used in a facility. The arrangement of the water meter assembly is specific to each utility. The meter could be located in an outside pit or exposed inside the building. The meter used should be selected for accuracy. A compound meter, consisting of separate sections for low and high flows, is often used for applications such as multiple dwellings and dormitories.

A strainer may be required before the meter, if solids are present in the water supply. A second backflow preventer may be required on individual water branches supplying specific equipment inside a building.

POTABLE WATER DISTRIBUTION SYSTEM

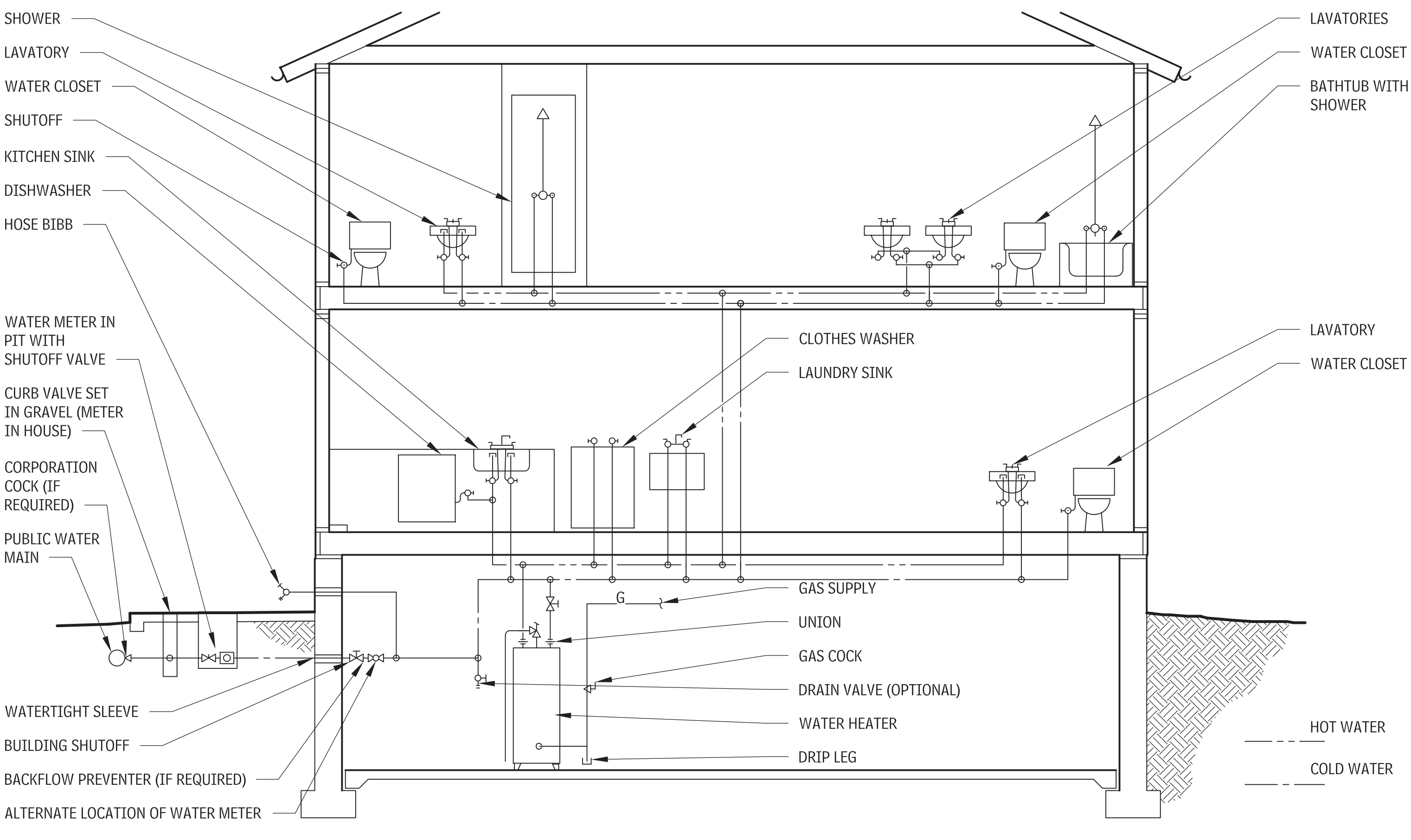
A potable water system delivers water suitable for human consumption at appropriate pressure and volume to all plumbing fixtures and equipment. Three types of systems and their appropriate uses include the following:

- A *street pressure system* is suitable when the water pressure supplied from a public water main is sufficient to supply all fixtures and equipment in a building without the use of a booster pump. This generally requires that the static pressure in the public main be no less than 50 lb. per square inch (psi).
- A *hot water system* heats raw water from ambient temperature to a desired higher temperature and delivers the heated water to all plumbing fixtures and equipment requiring hot water. The recommended hot water temperature at the heater is 140°F. A booster hot water system can be used to heat primary service hot water to a higher temperature for a specific purpose.
- A *hot water recirculation system* ensures hot water is quickly available to plumbing fixtures. Generally accepted practice requires that hot water delivered to terminal points of the system reach utilization temperature in 20 seconds or less. Some codes also require a form of temperature maintenance if the distance of a fixture from the heater exceeds a set distance (often, 50 ft.).

DESIGN CONSIDERATIONS FOR A POTABLE WATER SYSTEM

- *Estimating maximum water demand:* Maximum instantaneous water demand is estimated using water supply fixture units (WFU) converted to gallons per minute (gpm). The supply demand curve converts WFU to gpm using "Hunters Curve," which is derived from a statistical method of estimating how often various fixtures would be used simultaneously. The conversion of WFUs is separated into two categories, one for flush valves and one for flush tanks. Since the flush valve has a much higher flow rate, its conversion from WFUs shows a larger flow rate of water.
- *Water velocity:* Generally accepted practice limits the velocity of water in piping to 8 ft. per second (fps) to avoid excessive noise and prevent erosion of the piping. The velocity should be

WATER SUPPLY PIPING
13.21



lowered to 4 fps to avoid corrosion when softened water is used and to avoid water hammer when any quick-closing valves are installed. All branches containing a flush valve or quick-closing valve should have shock absorbers installed downstream of the last fixture.

- *Factors affecting design of a public water main:* It is necessary to obtain the location, elevation, and size of the water main from the local water purveyor. Also helpful is a topographical map showing the relative ground elevations and any obstructions (trees, boulders, curbs, etc.) that would interfere with the run from the main into the building. If possible, find out the frost depth for the project site. When this information is unavailable, generally a dimension of 5 ft.-0 in. to the centerline is considered a safe figure for depth of bury.
- *Static and residual water pressure:* The actual water pressure in the water main is critical to the design of the water supply system. The static pressure is the water pressure in the main when no water is flowing in an immediate connection adjacent to the project site. The residual pressure is the water pressure available in the main when a considerable amount of water is flowing from any connection (usually a fire hydrant) close to where the building water supply will be connected to the public main. This information is obtained by means of a flow test, often called a *hydrant flow test*. The residual (lower) pressure is used to size the project water supply distribution network.
- *Minimum fixture operating pressure:* Various plumbing fixtures and devices require a minimum pressure to ensure proper operation. Generally accepted values are given in Figure 13.22, but should be verified by the fixture or equipment manufacturer.

MINIMUM OPERATING PRESSURES FOR SOME FIXTURES
13.22

FIXTURE	PRESSURE (PSI)
Lavatory faucet	8
Lavatory faucet, self-closing	12
Bathtub faucet	5
Dishwasher	15
Hose bib with 50 ft. of hose	30
Service sink cock, 1/4 in.	5
Shower	12
Sink faucet, 3/8 in.	10
Sink faucet, 1/2 in.	5
Urinal flush valve	15
Water closet, ball cock	15
Water closet, flush valve	15–25
Water closet, one-piece floor mounted	30–40
Water closet, pressure tank	20–30

PRESSURE-BOOSTING SYSTEMS

Water pressure in a building may be increased by means of these pressure-boosting systems:

- Booster pumps
- Elevated water tanks
- Hydropneumatic tanks

A combination of two such systems, called a hybrid system, may be used when a single type is impractical or not economical.

PUMPS USED FOR WATER SYSTEMS

The pump most often used for water service is the baseplate-mounted centrifugal pump. This type of pump should be directly installed on an equipment pad with proper grouting or with vibration isolation devices separating the pump base and the building structure. This arrangement helps prevent noise caused by the transfer of vibration from the pump to the building structure. Vibration isolation devices installed between the pump suction and discharge connections and the distribution piping will prevent transfer of vibration to the connected piping.

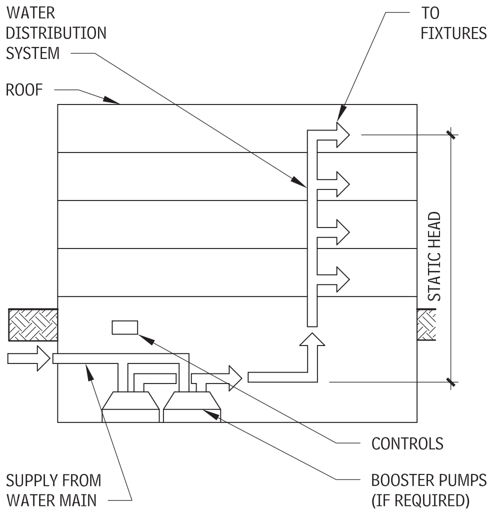
BOOSTER PUMP

A booster pump is utilized when there is insufficient pressure from the water. A control system senses variations in the distribution system and adjusts either the speed of the pump or a flow regulator to maintain constant pressure of acceptable value.

Two types of booster pump controls are available for adjusting pressure and flow in the water distribution system:

- Constant speed
- Constant pressure

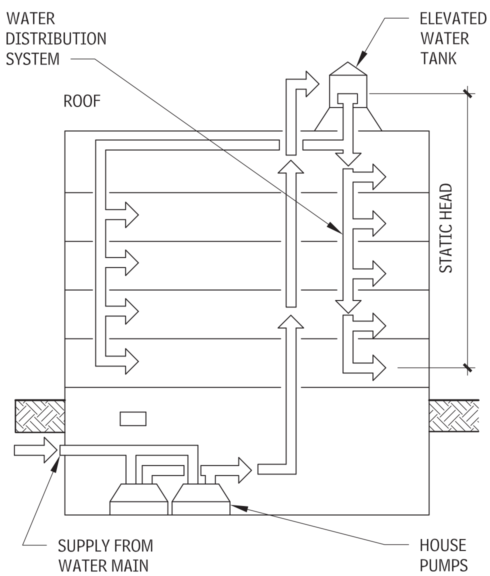
UPFEED WATER SUPPLY SYSTEM
13.23



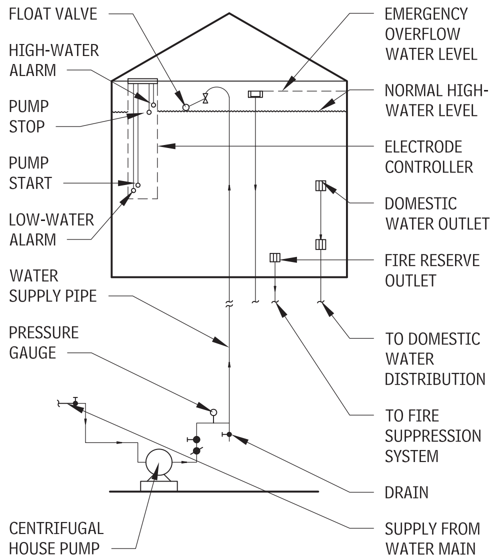
ELEVATED WATER TANK

In an elevated water tank system, water is pumped from the level where the building water service enters the building up to an elevated water storage tank, commonly called a *gravity tank* or a *house tank*. The pump most often used is the *centrifugal pump*, and it is commonly called a *house pump* when used for this service.

DOWNFEED WATER SUPPLY SYSTEM
13.24



ELEVATED WATER TANK PIPING ARRANGEMENT
13.25



The house tank is located above the highest and most hydraulically remote point in a building water supply system. The height of the tank provides additional static head, increasing the pressure in the water distribution system.

The advantages of the elevated water tank system are as follows:

- It is less complex than either of the other two systems.
- Fewer components are required to control and operate the system.
- It is more efficient and costs less to operate than the other systems.
- It may use a smaller pump.
- Pressure fluctuations in the system are small.
- Maintenance requirements are minimal.

Disadvantages of the elevated water tank system are:

- An exposed tank, or the enclosure around it, may be considered unsightly.
- The building structure may require reinforcement to support the additional weight.
- Tank and piping may be subject to freezing if exposed.
- Water pressure on the upper floors may be inadequate for some fixtures.
- A catastrophic tank failure could flood the roof.

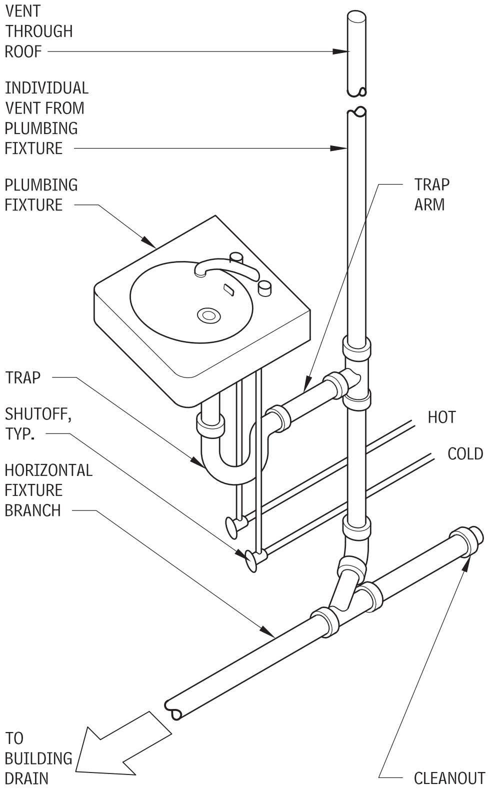
The capacity of the house tank depends on the type of facility it will serve. To determine an approximate size for the domestic storage volume for a multiple-dwelling gravity tank:

- Determine the number of people the system will serve. If this figure is not available, estimate by counting two people per bedroom or four people per apartment, whichever is larger.
- Multiply the number of people by the gallons required per person to find the total domestic storage capacity. Add to this figure constant uses of water (such as HVAC makeup and fire protection water storage, if any).
- Finally, select a standard storage tank size equal to or larger than the required amount of stored water.

The capacity of the house pump(s) is determined by the quantity of water stored for domestic use. In general, a house pump should be capable of replacing the domestic reserve in about one-half to two hours; one hour is a generally accepted value. A duplex pump arrangement (two pumps in parallel), with each pump full size, should be provided so the system is not impaired if one pump is out of service.

A common problem with the gravity tank system is the lack of adequate water pressure on the upper floors of a building unless the tank is elevated to an impractical height. Under these conditions, a hybrid system composed of an elevated tank plus a small booster pump or small hydropneumatic system, used only for the top several floors, is suitable.

TYPICAL WATER SUPPLY AND DRAINAGE FROM A PLUMBING FIXTURE
13.26



TYPICAL PLUMBING FIXTURE/PIPE SIZE SCHEDULE
13.27

	DRAINAGE				WATER		
		SIZE (IN.)			SIZE (IN.)		FLOW (GPM)
PLUMBING FIXTURE	DFU[a]	TRAP	VENT	WFU[b]	COLD	HOT	
Automatic clothes washer	3	2	1–1/2	2	1/2	1/2	5
Bathroom group (WC, LAV, SH/BT) FV	8			8			
Bathroom group (WC, LAV, SH/BT) tank	6			6			
Bathtub (BT), with or without SH	2	1 1/2	1–1/2	2	1/2	1/2	5
Dishwasher, domestic	2	1–1/2	1–1/2	1	1/2	1/2	3
Drinking fountain (DF, EWC)	1/2	1–1/4	1–1/4	1/2	1/2		1–1/2
Floor drain (FD)	5	3	1–1/2				
Kitchen sink and tray, single 1.5 trap (KS)	2	1 1/2	1 1/2	2	1/2	1/2	3
Kitchen sink and tray, multiple 1.5 traps	3	1–1/2	1–1/2	2	1/2	1/2	3
Lavatory, private (LAV)	1	1–1/4	1–1/4	1	3/8	3/8	2
Lavatory, public (LAV)	2	1–1/4	1–1/4	2	3/8	3/8	2
Laundry tray, 1 or 2 compartments	2	1–1/2	1–1/2	2	1/2	1/2	5
Shower (SH) per head or stall	2	2	1–1/2	2	1/2	1/2	3
Service sink (SS)	3	3	1–1/2	3	3/4	3/4	4
Sink, pot, and scullery (SK)	2	1–1/2	2	2	1/2	1/2	4–1/2
Sink, wash fountain, per faucet	2	1–1/2	1–1/2	2	1/2	1/2	2–1/2
Urinal (UR)	4	2	1–1/2	5	3/4		10–20
Water closet private flush valve (WC)	6	3	1–1/2	10	1		15–40
Water closet private tank type	4	3	1–1/2	5	1/2		3–5
Water closet private pressure tank	4	3	1–1/2	4	1/2		3–5
Water closet public flush valve	6	3	1–1/2	10	1		15–40
Water closet public tank type	4	3	1–1/2	5	1/2		3–5
Water closet public pressure tank	4	3	1–1/2	4	1/2		3–5
Wall hydrant, hose bib						3/4	3

SANITARY WASTE

Sanitary waste systems convey waterborne effluent from plumbing fixtures and other equipment to an approved point of disposal that discharges into a facility sanitary sewer. The sanitary sewer system receives all liquid waste (sanitary waste), except stormwater or unacceptably treated process or chemical waste. Effluent that contains bodily waste is referred to as *soil*. Clear water waste, such as that from equipment, sinks, or showers, is referred to as *waste*. Untreated waste containing chemical effluent must be treated before discharge into the sewer system or the environment. Treatment can be carried out either by a public utility or on-site with a private treatment plant approved by the local jurisdiction.

The building drain is the lowest portion of the drainage system inside a building; it is the main line that carries effluent outside the building. The building sewer is a continuation of the building trap that runs from outside the building to the point of disposal. A stack is a vertical pipe more than three stories high. A branch line is any drainage line connecting to a stack or the building drain.

A number of design requirements apply.

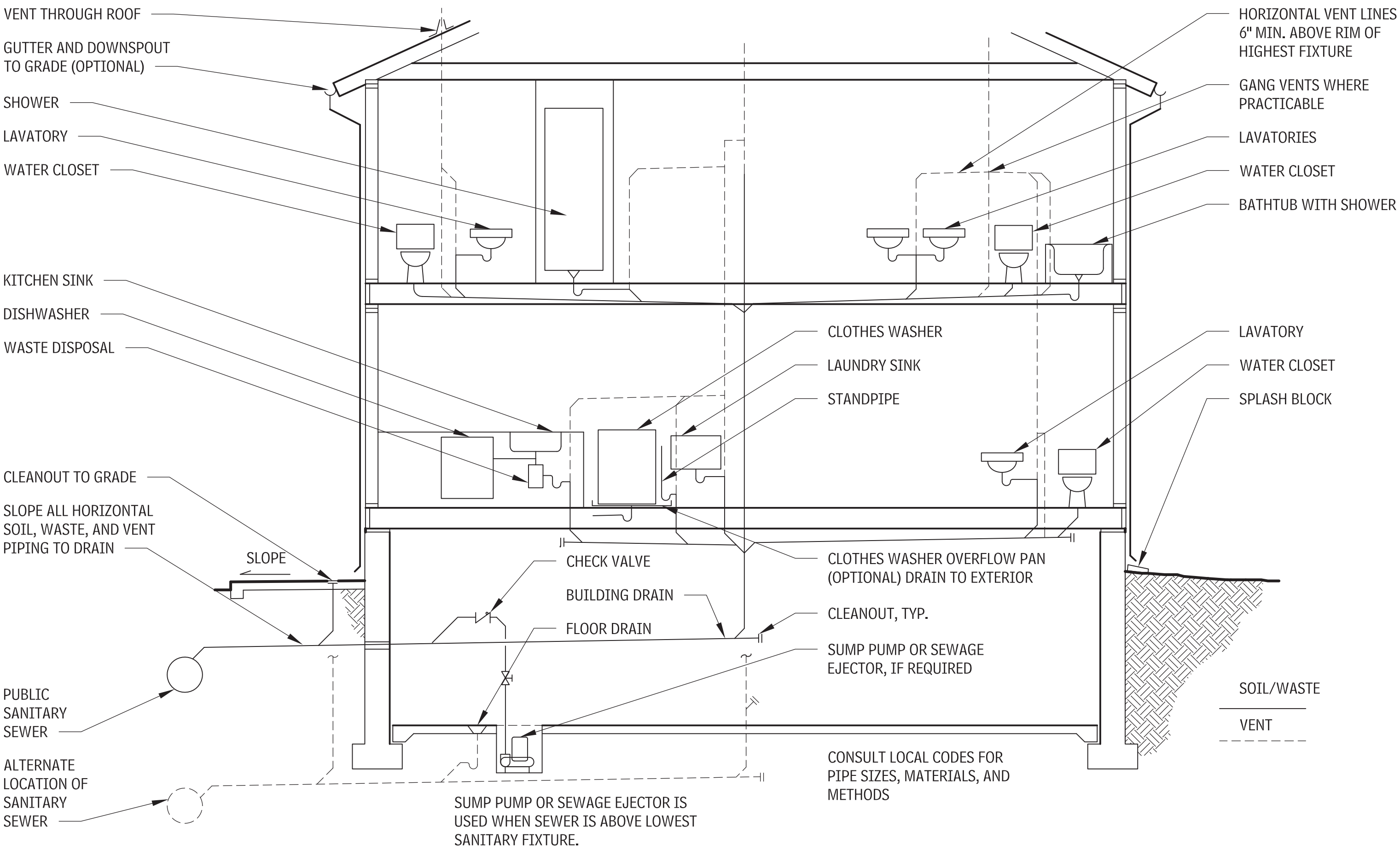
- Plumbing codes require that any substance harmful to the building drainage system, the public sewer, or the municipal sewage treatment process be prevented from entering the public sewer system by the installation of an approved sanitary waste interceptor. Such materials include grease, flammable liquids, sand, or other substances local authorities determine are objectionable.
- Where public sewers are available, connect the building sewer to the public sewer. Plugged outlets, called laterals, are often provided for future connections to the public sewer. If no laterals are available, a direct connection is made.
- In the absence of public sewers, a private sewage disposal system must be provided. The most commonly used is a facility septic tank, which depends on bacterial action to change most solids into a liquid, which is then discharged into an underground absorption field. The basic principle is to have the volume of effluent conditioned by the septic tank and the discharge from the tank absorbed into the ground as quickly as it is discharged. Laundry appliances should be routed to separate drywells since the soap and other chemicals retard or stop bacterial action in a septic tank. Grease should be disposed of separately. The design, selection, and location of septic tank components are strictly governed by local codes, requirements of which vary widely.

NOTES

13.27 a. DFU: drainage fixture units
b. WFU: water fixture units

Contributors:
American Society of Plumbing Engineers, Westlake, California; Michael Frankel, CIPE, Utility Systems Consultants, Somerset, New Jersey.

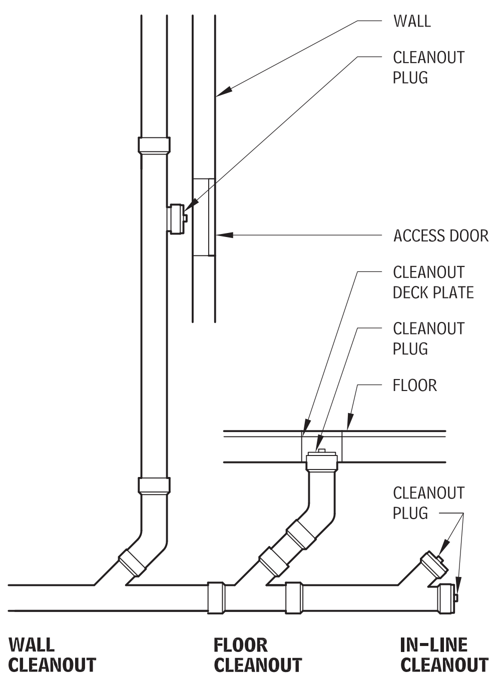
DRAINAGE AND VENT PIPING
13.28



BUILDING DRAINS AND SEWERS[a]
13.29

MAXIMUM NUMBER OF FIXTURE UNITS THAT MAY BE CONNECTED TO ANY PORTION OF BUILDING DRAIN OR BUILDING SEWER[b]	SLOPE PER FOOT			
DIAMETER OF PIPE (IN.)	**1/16″**	**1/8″**	**1/4″**	**1/2″**
2			21	26
1–1/2			24	31
3			42[c]	50[c]
4		180	216	250
5		390	480	575
6		700	840	1000
8	1400	1600	1920	2300
10	2500	2900	3500	4200
12	2900	4600	5600	6700
15	7000	8300	10,000	12,000

TYPICAL CLEANOUT INSTALLATION
13.30



SIZING DRAINAGE AND WASTE LINES

The sizing of drainage and waste lines from fixtures is based on total DFUs, the pitch of the drainage pipe, and the classification of the line as a branch, stack, or building drain.

The fixture schedule shows the minimum-size line permitted from a fixture. At each design point, add all DFUs together. Utilize Table 13.31, based on line classification and the pitch of the pipe, and find a figure equal to or greater than the DFUs calculated. Read horizontally to find the pipe size.

The minimum pitch for branches 3 in. and smaller is 1/4 in./ft. For lines 4 in. and larger, it is 1/8 in./ft. A branch interval is the rough equivalent of one floor level. The minimum pitch for building drains (main lines inside the building) and building sewers (main lines outside the building that connect with the public sewer) is 1/16 in./ft.

NOTES

13.29 a. On-site sewers that serve more than one building may be sized according to current standards and specifications of the administrative authority for public sewers.
b. Consult local building codes for exact requirements.
c. No more than two water closets or two bathroom groups (except in single-family dwellings, where no more than three water closets or three bathroom groups) may be installed.
13.30 Facility drainage piping cleanouts are typically used for ferrous or plastic drainage pipe only.

Contributors:
American Society of Plumbing Engineers, Westlake, California; Michael Frankel, CIPE, Utility Systems Consultants, Somerset, New Jersey.

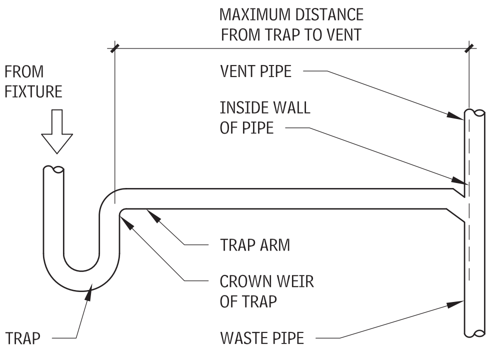
DRAINAGE BRANCHES AND STACKS
13.31

MAXIMUM NUMBER OF FIXTURE UNITS THAT MAY BE CONNECTED TO VARIOUS BRANCHES[a]				
			STACKS WITH MORE THAN THREE BRANCH INTERVALS	
DIAMETER OF PIPE (IN.)	ANY HORIZONTAL FIXTURE BRANCH[b] (DFU)	ONE STACK OF THREE OR FEWER BRANCH INTERVALS (DFU)	TOTAL FOR STACK[c] (DFU)	TOTAL AT ONE BRANCH INTERVAL (DFU)
1–1/2	3	4	8	2
2	6	10	24	6
2–1/2	12	20	42	9
3	20d	48d	72d	20d
4	160	240	500	90
5	360	540	1100	200
6	620	960	1900	350
8	1400	2200	3600	600
10	2500	3800	5600	1000
12	3900	6000	8400	1500
15	7000			

FIXTURES TRAPS

A *fixture trap* is a U-shaped section of pipe deep enough to prevent the passage of sewer gas into a fixture. Traps must be self-cleaning, provide a liquid seal of at least 2 in. (larger when required), conform to local code requirements regarding minimum size, must have an accessible cleanout, and are capable of draining a fixture rapidly. All traps must be vented, unless waived by local codes. All fixtures directly connected to the sanitary drainage system must be trapped and vented.

TRAP ARM
13.32



MAXIMUM LENGTH OF TRAP ARM
13.33

DIAMETER OF TRAP ARM (IN.)	DISTANCE FROM TRAP TO VENT (FT)
1–1/4	3–1/2
1–1/2	5
2	8
3	10
4	12

VENT PIPING

A vent equalizes the pneumatic pressures (both positive and negative) within a facility sanitary sewage system. The purpose of a vent system is to limit the pneumatic pressure to plus or minus 1 in. of water column. Vent systems terminate in the outside air and connect indirectly to every fixture trap.

Vent lines are sized using three factors:

- Drainage fixture units
- Size of the drainage line (or stack) to which the fixtures are connected
- Developed length of the vent line from the fixture to the vent stack

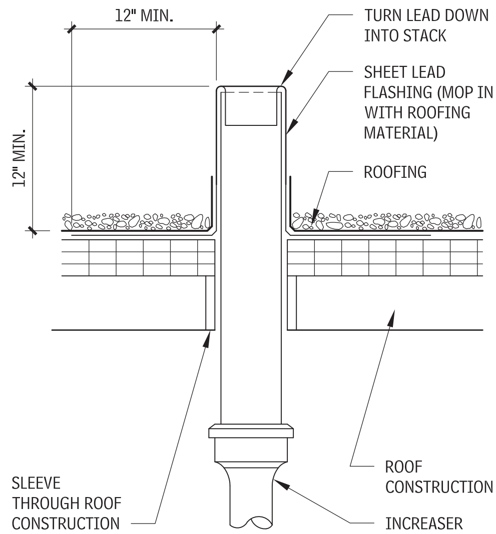
Applicable design requirements are:

- The size of a vent stack should be a minimum of one-half the size of a soil or waste line. The size of a branch vent should be a minimum of one-half the size of the branch drainage line it serves.
- Each individual fixture vent must rise above the flood level of the fixture served before it is connected to another vent line, so as not to act as a waste line in the event the drain line becomes blocked.
- To size a vent stack, use the drainage fixture unit (DFU) load for the entire drainage stack and the full, developed length of the vent from the lowest connection up to the roof. Vent stacks must be undiminished in size for the entire length.
- For branch vents, use the longest developed length, from the point where the size is being determined to the farthest connection to a branch drainage line.
- Building traps, where installed, should have a vent called a *fresh air inlet*. The inlet should be one-half the size of the building drain, with a minimum size of 4 in.
- Vent pipes that pass through a roof must remain open under all circumstances. The two most common causes of blockage in exposed pipes are frost closure and snow closure. Local codes and authorities will provide the minimum height needed to avoid closure by accumulated snow on a roof. This dimension is often 2 ft.

In the absence of specific code requirements, use the following as a guide for locating vent extensions:

- Do not locate the vent extension under or within 10 ft. of any window, door, or ventilating opening, unless it is 2 ft. above that opening.
- If the terminal is through a building wall, locate it a minimum of 10 ft. from the property line, a minimum of 10 ft. above grade, and not under any overhang.

ROOF VENT DETAIL
13.34



NOTES

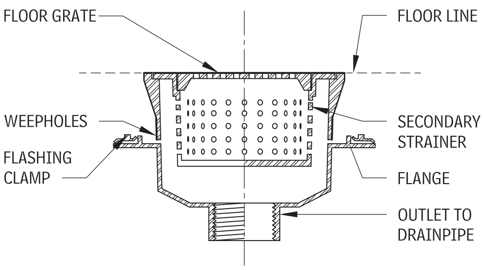
13.31 a. Consult local building codes for exact requirements.
b. Does not include branches of the building drain.
c. Size stacks according to the total accumulated connected load at each story or branch interval. Stacks may be reduced in size as this load decreases to a minimum diameter of half the largest size required.
d. No more than two water closets or bathroom groups within each branch interval and no more than six water closets or bathroom groups on the stack.

Contributors:
American Society of Plumbing Engineers, Westlake, California; Michael Frankel, CIPE, Utility Systems Consultants, Somerset, New Jersey.

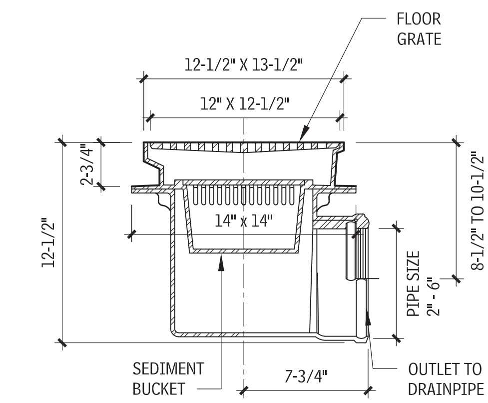
FLOOR DRAINS

A floor drain removes liquids from interior, normally occupied areas of a building and discharges them into either the sanitary or an industrial waste drainage system. A commonly cited standard for floor drains is ANSI A112.21.

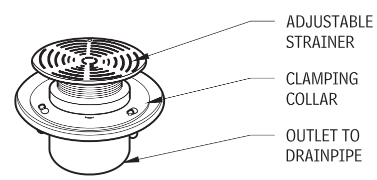
FLOOR AND SHOWER DRAINS
13.35



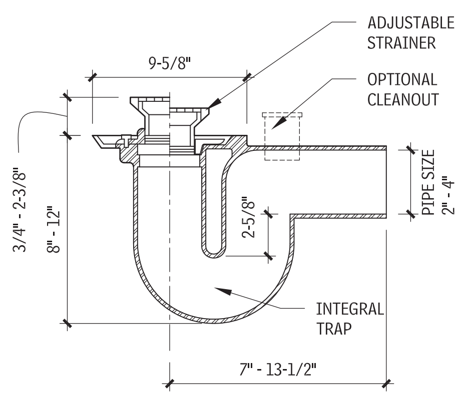
FLOOR DRAIN (BOTTOM OUTLET)



FLOOR DRAIN (SIDE OUTLET)

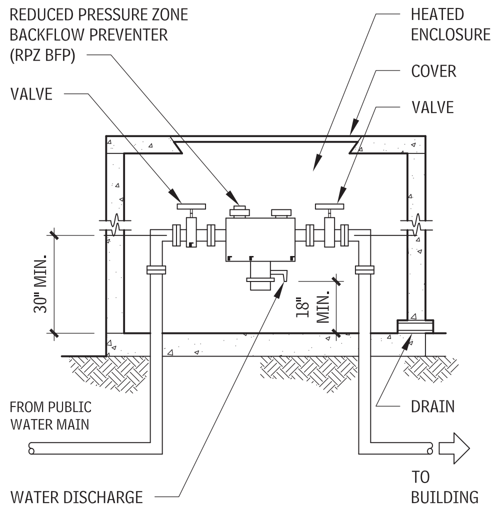


SHOWER DRAIN ISOMETRIC



SHOWER DRAIN SECTION

TYPICAL BACKFLOW PREVENTER
13.36



DOMESTIC WATER HEATERS

There are three primary types of water heaters: automatic storage heaters, instantaneous demand water heaters, and combination water heaters, the most common of which is the automatic storage heater.

Warm and moist environments will support the growth of bacteria and in some cases disease has been traced to domestic hot water distribution systems. It is highly recommended that water for domestic purposes be heated initially to a temperature of 140°F and lowered to the final temperature with a mixing valve. The final temperature of the water should be high enough to meet the minimum requirements of the connected equipment.

MINIMUM HOT WATER TEMPERATURE FOR PLUMBING FIXTURES AND EQUIPMENT
13.37

USE			MINIMUM TEMPERATURE (°F)
Lavatory	Hand-washing		105
	Shaving		115
Showers and tubs			110
Commercial and institutional laundry			180
Residential dishwashing and laundry			140
Commercial spray-type dishwasher	Single- or multitank hood or rack type	Wash	150
		Final rinse	180–195
	Single-tank conveyor type	Wash	160
		Final rinse	180–195
	Single-tank rack or door type	Single-temperature wash and rinse	165
Laboratory glass-washer		Wash	140
		Rinse	180

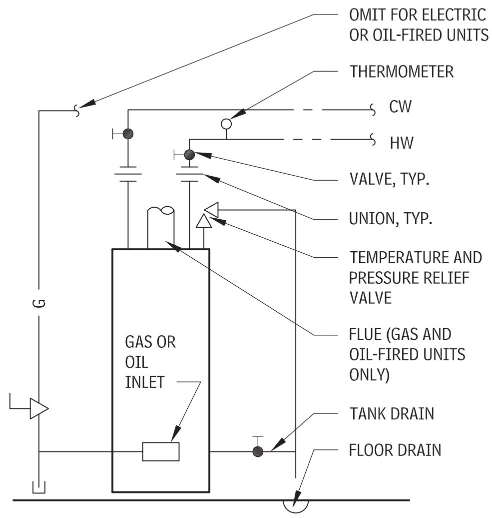
HOT WATER SYSTEM SIZING

Hot water usage and flow rates are characterized by intermittent periods of peak, sustained, and low-to-zero flows. The pattern of usage varies widely, depending on the building type and use, time of day, time of year, population, and connected equipment and fixtures.

TYPICAL TANK SIZES
13.38

CAPACITY (GAL)	HEIGHT (IN.)	DIAMETER (IN.)
30	48	22
50	60	24
75	60	26
100	74	28
120	76	30

TYPICAL RESIDENTIAL WATER HEATER
13.39



STORAGE-TYPE WATER HEATER SIZING

Storage-type heaters are sized using the total volume of hot water required for the estimated duration of maximum demand. This total volume can be provided by any combination of hot water storage capacity and water heater recovery (makeup) rate. The required storage and recovery values depend on the project type. The major advantage of using a storage-type water heater instead of an instantaneous demand water heater is that they use considerably less energy.

Use Figure 13.40 to provide preliminary estimates for hot water demand on a project:

- Select the facility type.
- Determine the number of each fixture type and find the hot water demand for each fixture using the figure.
- Multiply the gallons-per-hour value for each fixture by the total number of individual fixtures.
- Add together the resulting figure for all fixture types to determine the total connected (demand) load for the building in gallons of water per hour.
- Find the actual hourly demand for the facility by multiplying the total connected load by the demand factor shown at the bottom of Figure 13.40. This will yield the total volume of hot water to be used by the facility during a one-hour period.

NOTES

13.37 Temperatures required by National Sanitation Foundation.
13.39 a. Electric water heaters have the lowest initial cost and the highest operating cost.
b. Consult manufacturers for makeup capacity.

Contributors:
American Society of Plumbing Engineers, Westlake, California; Michael Frankel, CIPE, Utility Systems Consultants, Somerset, New Jersey.

HOT WATER DEMAND IN GALLONS PER HOUR AT 140°F
13.40

PLUMBING FIXTURES	APARTMENT HOUSE	CLUB	GYM	HOSPITAL	HOTEL	INDUSTRIAL PLANT	OFFICE BUILDING	PRIVATE RESIDENCE	SCHOOL	YMCA
Basins, private lavatory	2	2	2	2	2	2	2	2	2	2
Basins, public lavatory	4	6	8	6	8	12	6	—	15	8
Bathtubs	20	20	30	20	20	—	—	20	—	30
Dishwashers	15	50–150	—	50–150	50–200	20–100	—	15	20–100	20–100
Foot basins	3	3	12	3	3	12	—	3	3	12
Kitchen sinks	10	20	—	20	30	20	20	10	20	20
Laundry tubs, stationary	20	28	—	28	28	—	—	20	—	28
Pantry sinks	5	10	—	10	10	—	10	5	10	10
Showers	30	150	225	75	75	225	30	30	225	225
Service sinks	20	20	—	20	30	20	20	15	20	20
Hydrotherapeutic showers				400						
Hubbard baths				600						
Leg baths				100						
Arm baths				35						
Sitz baths				30						
Continuous-flow baths				165						
Circular wash sinks				20	20	30	20		30	
Semicircular wash sinks				10	10	15	10		15	
DEMAND FACTOR	0.30	0.30	0.40	0.25	0.25	0.40	0.30	0.30	0.40	0.40
STORAGE CAPACITY FACTOR	1.25	0.90	1.00	0.60	0.80	1.00	2.00	0.70	1.00	1.00

In addition to the total hourly demand, a certain amount of hot water should be stored. The recommended volume for storage is a function of the actual hourly demand. The storage requirement is found by multiplying the total hourly demand by the storage capacity factor found at the bottom of Figure 13.40. This figure is the usable volume of hot water required to be stored.

The recovery requirement and the storage requirement represent one hour's peak use of hot water. There may be occasions when the duration is longer than one hour.

Refer to Figure 13.41 to determine whether the facility should have more than a one-hour peak usage duration. If so, multiply the actual hourly demand by the number of hours of peak duration to find the total volume in gallons of hot water required for the entire peak period. Select a recovery rate and storage tank capacity combination to cover the total number of gallons. For example, if the actual hourly demand is 1000 gal/hr for a duration of three hours, the total volume of hot water required will be 3000 gallons. If the usable storage volume is 1000 gal, the recovery rate required for the three-hour period will be 2000 divided by 3, or 670 gal/hr. The total of 1000-gallon storage + 2010-gallon makeup (670 GPH × 3) will equal slightly more than the 3000 gallons required.

DURATION OF PEAK USE
13.41

BUILDING TYPE	PEAK DURATION (HR)
Motel	2
Hotel	3
Apartment house	3
Nursing home	3
Office	2
Food service	1–4 (varies with type)

SUMP PUMP SYSTEMS

Sanitary sewage pumps and packaged, submersible sewage pump units (ejector pumps) are intended to transport sanitary waste with large suspended solids. Packaged, wastewater pump units transport turbid, sanitary effluent with small, suspended solids.

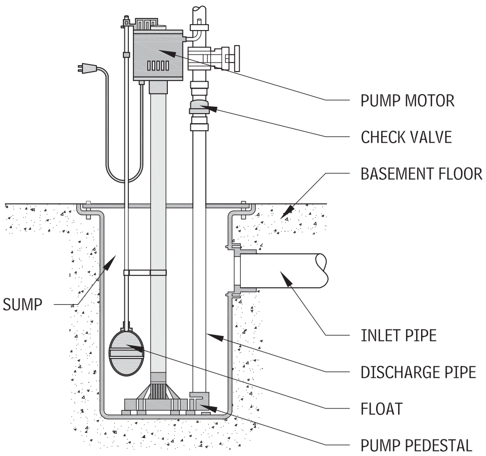
A sump pump is used to remove water from a sump (a naturally occurring or intentionally designed low area that collects water). Sump pumps are installed when accumulation of water in a sump is unacceptable (as in a building basement) and gravity flow is not possible (usually due to the elevation of the sump relative to drainage lines). Sump pumps commonly operate intermittently (as needed) and discharge to the ground surface or to a code-acceptable drainage pipe.

There are two primary types of sump pumps: pedestal and submersible. The difference between the two refers to the location of the pump motor—above the sump or in the sump—which affects appearance and service. Common components of a sump pump system include: (1) a motor (usually centrifugal and between 1/4 and 1 hp in building applications); (2) an impeller, which creates a low-pressure region at the intake and a higher-pressure region at the discharge; (3) a discharge pipe with check valve to lead water to its point of disposal; and (4) controls, often based upon a float switch that senses water level in the sump pit. Minimum recommended pump running time is one minute, for optimum reliability.

To find the depth for sewage pump basin and pits, use the following approximate dimensions as a guide, assuming duplex pumps and starting from the invert of the inlet pipe.

- From the invert of the inlet pipe, allow 6 in. to the high water alarm.
- From the high water alarm, allow 6 in. to pump 2 start in a duplex installation.
- From pump 2 start, allow 6 in. to pump 1 start.
- Below pump 1 start, the dimension of the liquid capacity depends on a 1- to 5-minute operating period of the selected pump. The lower level of the storage portion is the pump stop. Figure 13.153 gives the storage capacity of different-sized basins.
- Allow 6 in. from pump stop to the inlet of the pump.
- Allow 1 ft. to the basin bottom from the inlet of the pump. This dimension varies according to manufacturer.
- Sewage and waste effluents have the same hydraulic characteristics as water. Ejector discharge lines should be a minimum of 3 in., and sump discharge lines should be a minimum of 2 in., to prevent stoppages. The pump head is found by adding the distance from the bottom of the basin to one foot higher than the point of discharge and the friction loss of water through the discharge pipe.
- Duplex pumps generally require a minimum diameter of 4 ft.

TYPICAL SUMP PUMP INSTALLATION
13.42



PIPE MATERIALS

Common materials used in pipes are described in this section.

CAST-IRON PIPE

Cast-iron (CI) pipe and fittings are manufactured in two weight classes: standard and extra heavy. Each class is available either with hub and spigot ends (ASTM A74) or hubless (CISPI 301 pipe and CISPI 310 fittings).

High-silicon (acid-resistant; ASTM A861) hub-and-spigot cast-iron pipe and fittings are manufactured for laboratory drainage service. Hub-and-spigot pipes are joined with caulked or compression gasket joints and hubless pipe with compression couplings.

Cast-iron pipe is used for nonpressure, sanitary, and storm gravity drainage service above and below grade. The most commonly used pipe above grade is hubless, service-weight cast-iron; below grade it is service-weight, hub-and-spigot pipe with compression gaskets. High-silicon pipe uses caulked joints aboveground and sealing sleeves below grade. Some codes require extra-heavy class pipe below grade.

Contributor:
Michael Frankel, CIPE, Utility Systems Consultants, Somerset, New Jersey.

STEEL PIPE

Carbon steel (CS) pipe is available in a variety of alloys, the most common being ASTM A53, for general service, and ASTM A106, for high-pressure, high-temperature service. Stainless steel (SS) pipe encompasses a variety of alloys and is widely used in the chemical, pharmaceutical, and food processing industries. The most commonly used pipe types are type 304 and 316.

Steel pipe is manufactured either seamless (extruded) or welded. Wall thickness, known as "schedule," ranges from schedule 5 (thinnest) to schedule 160 (thickest). Steel pipe can be joined by welding or with flanges or threaded joints.

COPPER TUBE

Available as either hard (annealed) or drawn (soft) temper, seamless copper (CU) tube can be joined by soldering, brazing, flared joints, and flanges. It is manufactured for specific applications in the following types:

- ASTM B88: Types K, L, and M (thickest to thinnest wall) are used primarily for potable water service and noncritical laboratory gases. Type L, hard temper, is often used aboveground, and type K, soft temper, underground.
- ASTM B819: Similar to ASTM B88, this tubing is cleaned for laboratory and healthcare facilities, and is available only in types K and L hard temper. It is joined most commonly by brazing.
- ASTM B75: Termed *capillary tubing*, this is available only in small diameters and soft temper, and is generally used to connect instruments in laboratory service. It is joined with flare joints and by soldering.
- ASTM B280: Type ACR is available only in small diameters and soft temper, and is generally used for air-conditioning and refrigeration service. It can be joined with flared fittings or by soldering.
- ASTM B306: Known as DWV, for drainage, waste, and vent, this tubing is used for drainage service and is joined by soldering. It has the thinnest wall of any copper product.
- ASTM B837: Type G is primarily used for fuel gas service. It is joined by using soldering and flare fittings.

BRASS PIPE

Brass pipe (BR) is made of an alloy of copper and zinc that conforms to ASTM B43. The proportion of copper varies from 85 percent (in red brass) to 67 percent (in yellow brass). Brass pipe is joined by threading, soldering, brazing, or using flanged fittings.

Larger brass pipes are used for potable water, and sometimes for branch drainage lines. Fittings and castings made from an alloy different from the pipe may not be suitable for potable water service.

GLASS PIPE

Glass pipe (GL) is made from a low-expansion borosilicate glass with a low alkali content. It is used for laboratory gravity waste service and is available in sizes up to 6 in. in diameter. Glass pipe must conform to ASTM C599.

PLASTIC PIPE

Plastic (PL) has become the material of choice for piping systems used to convey a variety of liquids, including chemical drainage, pharmaceuticals, sewage, water, liquid fuel, and fuel gases. To convey potable water, plastic pipe must be listed by the National Sanitation Foundation (NSF) International.

Plastic materials used for pipe are either *thermoplastic* or *thermoset*. Thermoplastics (the most commonly used pipe materials) soften when heat is applied and reharden when cooled, so the pipe can be extruded or molded into shapes. Thermoset plastics must be cured by heating or with a curing chemical to achieve permanent shapes; once shaped, they cannot be reformed.

Subclassifications of plastic pipe are based on the pipe material; the two most common are *polyolefins* and *fluoroplastics*.

It is important to understand the definitions of the terms used in various consensus standards for plastic pipe:

- *Standard dimensional ratio (SDR):* The SDR is found by dividing the average outside diameter of a pipe by the wall thickness. This designation has yielded a series of preferred industry standard numbers that are constant for all sizes of pipe.
- *Dimensional ratio (DR):* Often incorrectly used interchangeably with SDR, the DR is found in the same way as the SDR, and means the same thing, but is used when a product does not have the preferred SDR number established by prevailing standards.
- *OD controlled:* This designation is used when the *outside diameter* of a pipe is the controlling factor in its selection.
- *ID controlled:* This designation is used when the *inside diameter* of a pipe is the controlling factor in its selection.
- *Pressure rating (PR):* This designation is used when the pressure rating is the controlling factor in the selection of a pipe.
- *Schedule:* This designation is used to match the standard dimensions for metallic pipe sizes. The pressure rating of the pipe varies with pipe size. Some standards use iron pipe size (IPS) in lieu of schedule to keep a wall thickness consistent with iron pipe.

Plastic pipe can be joined with heat fusion (either butt or socket fusion), flanged joints, solvent cement, or threaded pipe of schedule 80 wall thickness or greater. Consult manufacturers for specific recommendations.

PIPE FITTINGS

Fittings are used to connect some pipes to one another, to change the direction of flow of fluids within a pipe, and to change the size of a pipe run. Often one fitting is used to provide all these features. An alternative to changing direction with fittings is to bend the pipe itself, but this method is rarely used except for soft-temper copper tubing.

Drainage pipe requires special long-radius Y-type fittings to achieve the best flow characteristics. These fittings are called *sanitary* or *drainage-type fittings*.

In general, fittings are made of the same material as the pipe to which they are attached, with the following exceptions:

- Fittings for copper tubing are either of a cast copper alloy that conforms to ANSI B16.18, or wrought copper that conforms to ANSI B16.22.4.
- Threaded fittings for steel pipe are generally cast-iron pressure fittings that conform to ANSI B16.4, or malleable iron-banded fittings that conform to ANSI B16.3.

PIPE JOINTS

A joint is required to connect pipe to other pipe, a fitting, or a piece of equipment. The joint type selected for a particular application depends on the pipe material and wall thickness, pipe contents, system pressure, system temperature, disassembly requirements, and the applicable plumbing code.

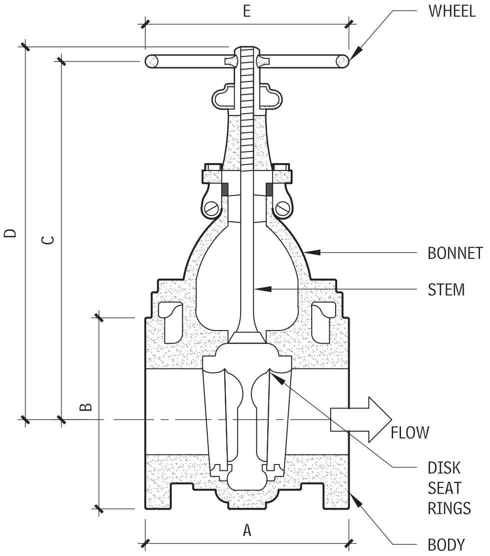
VALVES

Valves are used to turn on or off, control the flow of, prevent the reverse flow of, and adjust the pressure of fluids in a piping system. Operation can be linear (straight up and down) or rotary (multiturn or quarter turn). Valves are classified by the shape of their closure member. Plastic valves, which are suitable for use in most utility services, are rapidly replacing metallic valves because of their increased corrosion resistance and lower cost. Valves are selected according to resistance to flow; throttling capability; system working pressure; intended service, such as WOG (water, oil, gas), WWP (water working pressure), or WSP (working steam pressure); and jointing method.

Valve types include the following:

- *Gate valves:* Gate valves have a wedge-shaped closure member seated into a metal recess. Used for on-and-off controls, generally for liquids, they are available in a wide variety of sizes, body shapes, stem configurations, body and internal materials, and pressure ranges. They are not recommended for throttling service, and they have low resistance to flow.
- *Globe valves:* Globe valves, named for the round shape of their body, have a closure member that is generally a disk sealed on a resilient seat. Body types include straight-through and angle configurations. Used primarily for throttling service, they have a high resistance to flow because of the diverted passage of fluid around the seat.
- *Plug valves:* Plug valves are named for the tapered, cylindrical closure member, which has a port through it that seals tightly on a resilient seat when turned. Classified as a quarter-turn valve, they are available either lubricated (larger sizes) or nonlubricated. They are used primarily for fuel gas service but also for both throttling and shutoff service. They have low resistance to flow and are well suited for power actuation.
- *Check valves:* Check valves prevent the reverse flow of fluids. The most commonly used check valves are lift and swing types, although ball closures are also available. When used for sanitary drainage service, check valves are referred to as *backwater valves*.
- *Butterfly valves:* Butterfly valves use a thin, rotating disk in the flow path as the closure member, seating on a resilient seal at the perimeter of the valve body. Classified as a quarter-turn valve, they are used for both throttling and shutoff service. When no leakage is desired, a "bubble-tight" seat is used. Butterfly valves have low resistance to flow and are well suited for power actuation.
- *Ball valves:* Ball valves are named for the round closure member that consists of a round port drilled through the valve and sealed tightly on a resilient seat when turned. Classified as a quarter-turn valve, the body is available in one-, two-, or three-piece construction. Used for throttling and shutoff service, ball valves are suitable for liquids and gases. They are well suited for power actuation and have low resistance to flow. They are often used for medical gas service when specifically cleaned and packaged for healthcare facilities.

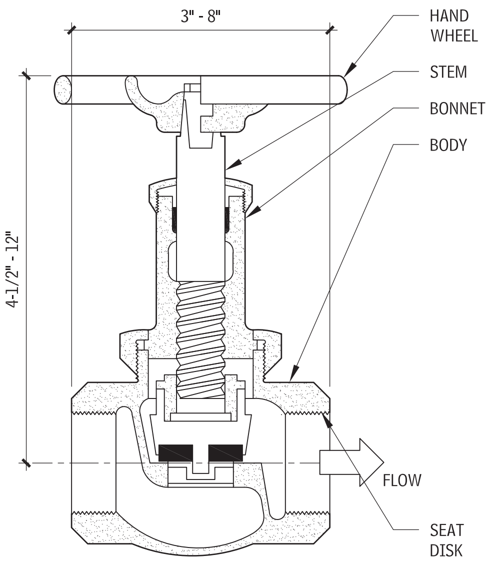
GATE VALVE
13.43



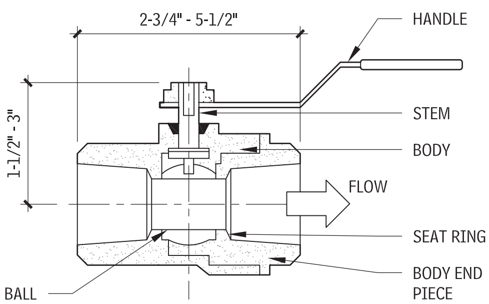
TYPICAL GATE VALVE DIMENSIONS (IN.)
13.44

NOMINAL SIZE	A	B	C	D	E
2	7	6	11–3/4	14–3/8	6
2–1/2	7–1/2	7	12–3/4	16–1/16	6
3	8	7–1/2	14–1/16	18–1/8	8
3–1/2	8–1/2	8–1/2	15–1/4	19–7/8	8
4	9	9	16–7/8	21–3/4	10
5	10	10	20–3/4	26–7/8	12
6	10–1/2	11	23–1/2	30–9/16	12
8	11–1/2	13–1/2	29–3/4	39	14
10	13	16	35–3/4	46–7/8	16
12	14	19	41–1/4	55	18

GLOBE VALVE
13.45

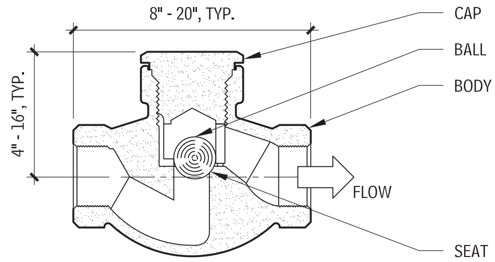


BALL VALVE
13.47

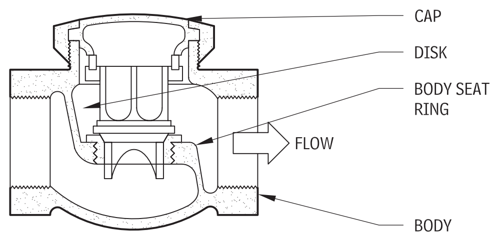


TWO-PIECE BODY

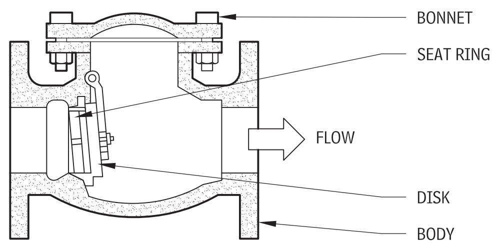
CHECK VALVES
13.46



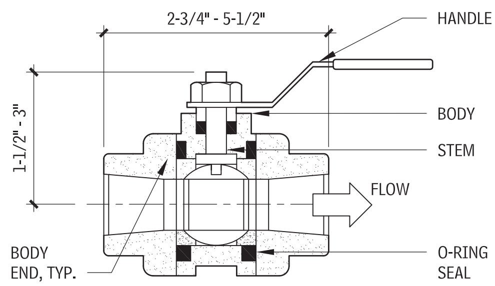
BALL CHECK



LIFT CHECK



SWING CHECK

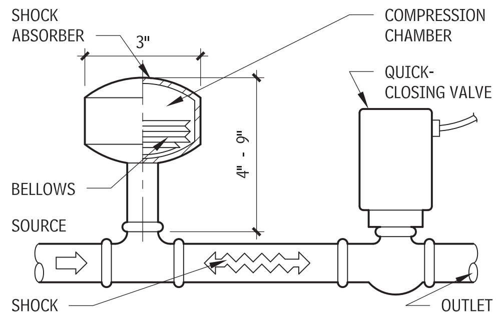


THREE-PIECE BODY

SHOCK ABSORBER

Whenever a water control valve closes very quickly in normal operation (such as those installed on water closets and clothes- and dish-washing machines), the sudden stopping of water starts a shock wave. This shock wave (commonly called *water hammer*) greatly increases pressure in the piping that over a period of time could cause the pipe or joint to fail. A shock absorber, installed in the water line between the source and the equipment, will lower the pressure to acceptable levels. The absorber size is based on line size, flow rate, and water pressure.

SHOCK ABSORBER
13.48



PIPING INSULATION

The primary purpose of insulation is to retard the flow of heat and water vapor from pipes, ducts, and equipment. An insulation system consists of the insulation itself, a jacket to cover it, and, if needed, an additional jacket to provide specific characteristics (such as weather protection or the ability to be repeatedly cleaned). Code limitations for flame spread and amount of smoke developed established for components in fireproof and noncombustible buildings apply to these insulation system elements.

COMMON INSULATION TYPES

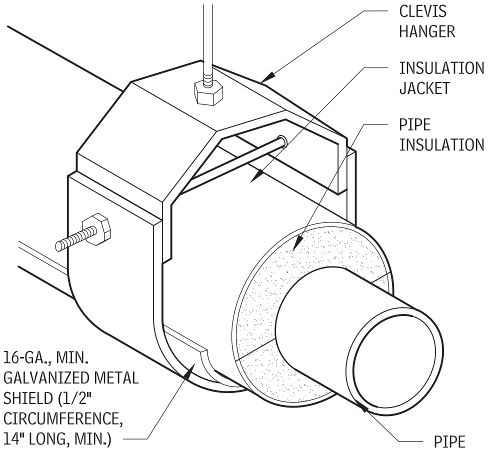
The insulation materials described here are identified by generic names rather than manufacturers' trade names.

JACKETS

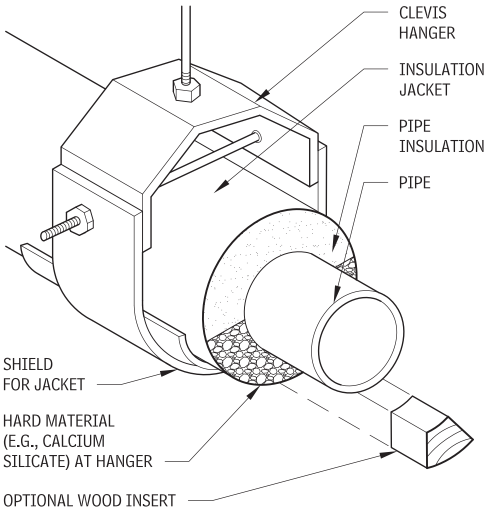
A jacket is any material (excluding cement and paint) that can be directly applied to insulation on a pipe, or vessel to cover or protect the insulation. The type of jacket chosen depends on the application. Jackets come in various forms and types, which can be divided into three general categories: rigid (plastic, aluminum, or stainless steel), membrane (glass cloth, coated papers, treated papers, and foil- or cloth-laminated papers), and mastic. The most common jacket for fiberglass insulation is an all-service jacket (ASJ), which comprises laminated kraft paper, fiberglass cloth (skrim), and either aluminum foil or metalized film as a vapor barrier. This jacket type is sometimes called an FSK jacket, for foil, skrim, and kraft. When plumbing piping is exposed and aesthetics need to be considered, the design professional may choose specific jackets that are able to be painted.

Contributors:
American Society of Plumbing Engineers, Westlake, California; Michael Frankel, CIPE, Utility Systems Consultants, Somerset, New Jersey.

METAL SHIELD SUPPORT
13.49



HARD MATERIAL SUPPORT
13.50



PLUMBING FIXTURES

A plumbing fixture is a device or appliance that is designed to supply water or receive waterborne waste, and may discharge into a sanitary waste system. Ideal fixture materials should be nonabsorbent, nonporous, nonoxidizing, smooth, and easy to clean.

Plumbing codes usually mandate the number and type of fixtures that must be provided for specific occupancy based on the capacity. Provisions for people with disabilities have been made an integral part of code requirements, mandating the quantity and design of spaces using plumbing fixtures.

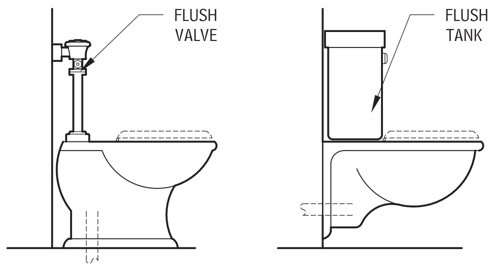
FIXTURE UNITS

Every plumbing fixture is assigned a value known as a fixture unit (FU). FU values represent the probable flow of water the fixture will discharge into a sanitary waste system or use (demand) from a potable water supply system. The base value of 1 is assigned to a lavatory for both water demand and waste discharge; other fixtures are assigned comparative values as they relate to the lavatory. Waste discharge and water demand FUs are different; therefore the designations DFU, for drainage fixture units, and WFU, for potable water fixture units, can be used to differentiate them.

WATER CLOSETS, URINALS, AND BIDETS

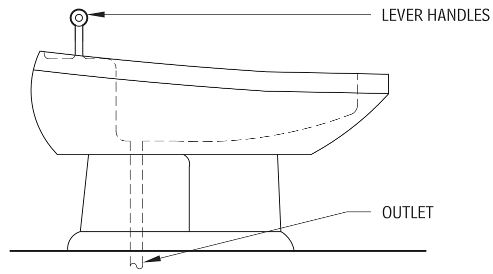
Water closets, urinals, and bidets generally have two parts—a receptor for waste, which includes the drain trap and a flushing or water supply mechanism. Most are made of vitreous china. These plumbing fixtures are generally grouped according to their flushing action, which affects the bowl type, flushing mechanism, and mounting method.

WATER CLOSET MOUNTING TYPES
13.51

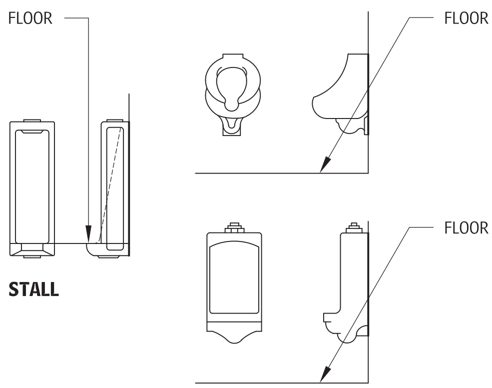


FLOOR MOUNTED **WALL HUNG**

BIDET
13.52



URINALS
13.53



STALL

WALL-HUNG

NOTES

13.51 a. Flush valves and tanks can be installed on either floor-mounted or wall-hung water closets.
b. For rough-in dimensions for water supply and sanitary waste, refer to fixture manufacturer.
13.52 The bidet is often designed to sit next to a water closet, which it resembles, but is a form of lavatory.
13.53 a. Urinals require flush valves as the water supply source.
b. If used, urinal tanks should be 92 to 94 in. above the floor.
c. Install urinals 21 to 24 in. on center, except accessible units.
d. For styles and rough-in dimensions, refer to manufacturer.

Contributors:
American Society of Plumbing Engineers, Westlake, California; Michael Frankel, CIPE, Utility Systems Consultants, Somerset, New Jersey; Jacqueline Jones, American Standard, Piscataway, New Jersey; Philip Kenyon, Kohler, Kohler, Wisconsin.

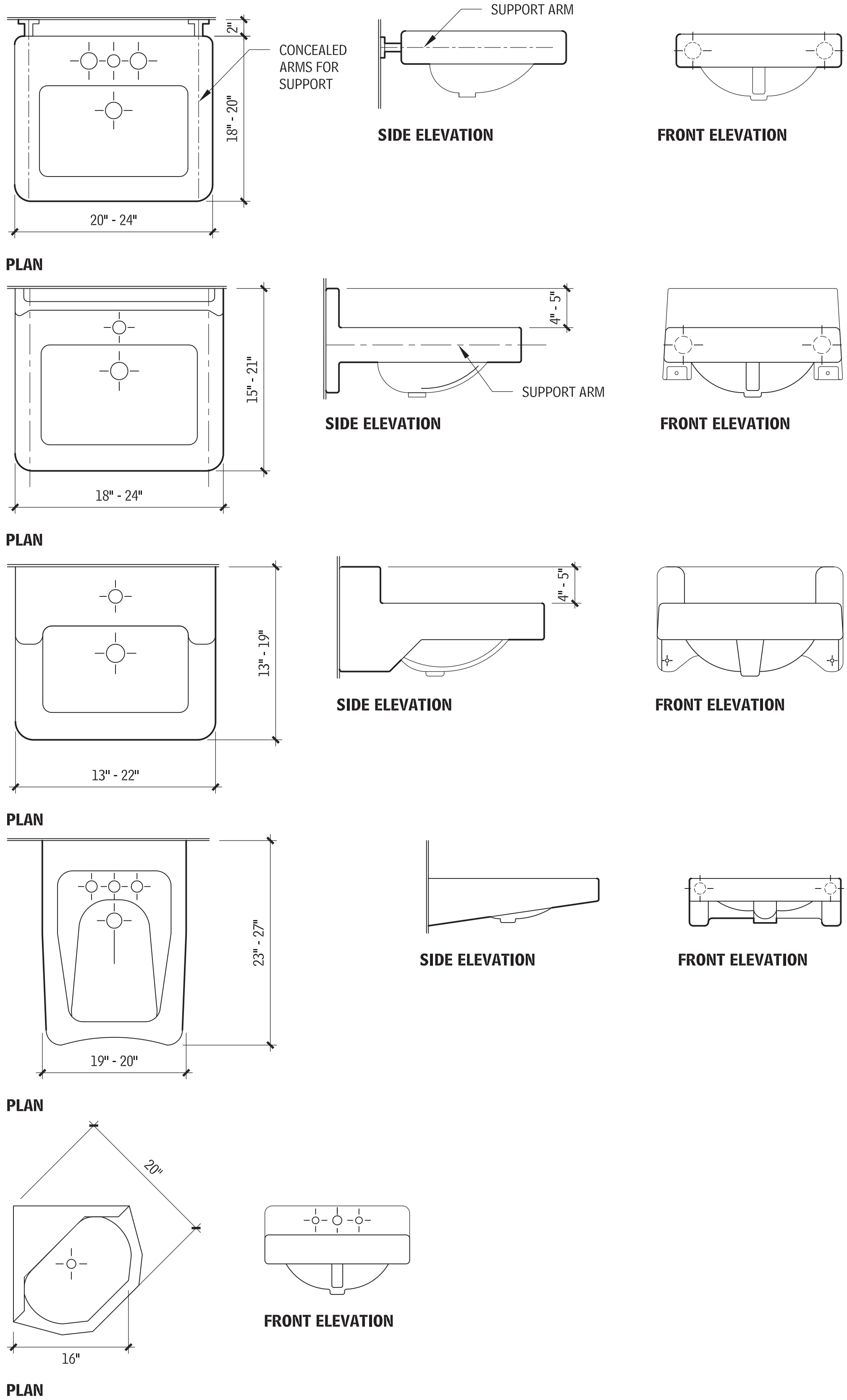
LAVATORIES AND SINKS

Lavatories have a shallow receptor designed primarily for washing hands, arms, and face; sinks are generally deeper and designed for general washing and disposal of liquid waste. Sinks can include residential, commercial, and service applications.

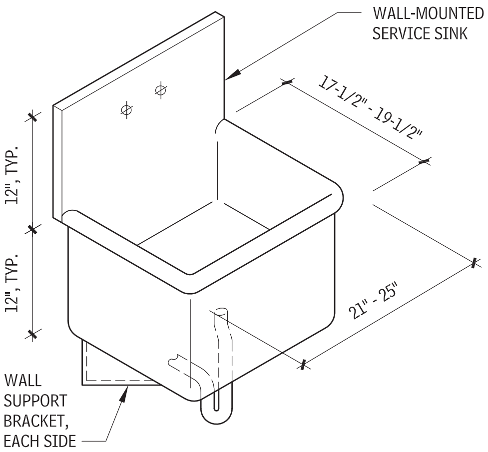
Lavatories are generally one of three types: wall-hung, installed in or as a part of a countertop, and pedestal. Vitreous china is the most common material used in lavatories, though they are also available in cast acrylic resin and enameled cast iron, enameled steel, stainless steel, and other metals.

Sink materials include stainless steel, enameled iron or steel, and cast resin. The underside of stainless steel sinks typically is coated with a sound-deadening material. Sink accessories may include pull-out faucets, instant hot or chilled water dispensers, soap dispensers, and disposers.

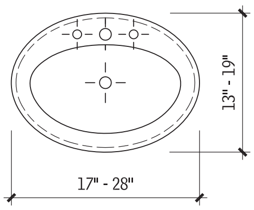
WALL-HUNG LAVATORIES
13.54

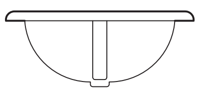


WALL-HUNG SERVICE SINK
13.55



BUILT-IN LAVATORY
13.56

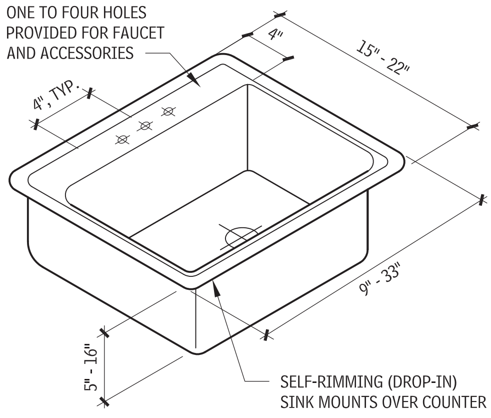




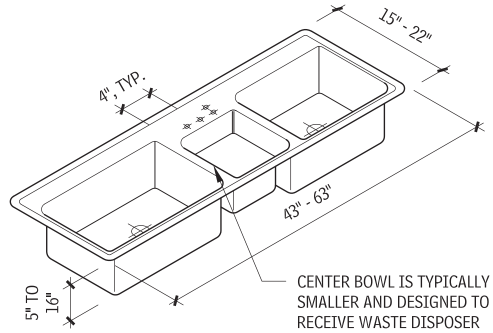
FRONT ELEVATION

PLAN

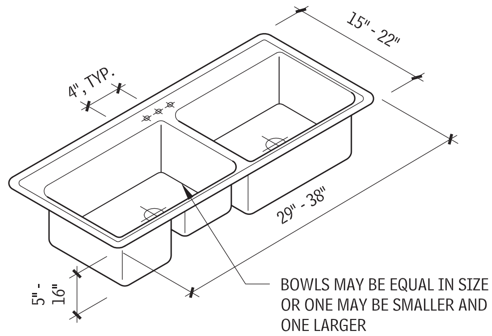
BUILT-IN SINKS
13.57



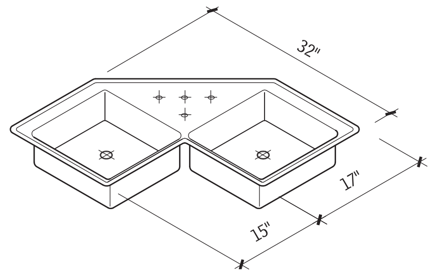
SINGLE BOWL OR BAR SINK



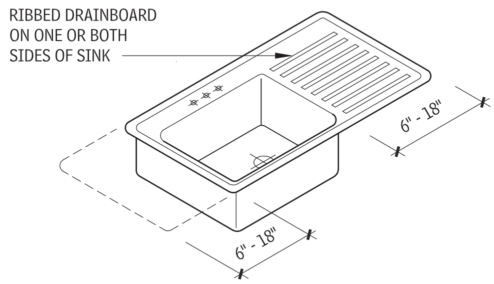
TRIPLE BOWL SINK



DOUBLE BOWL SINK

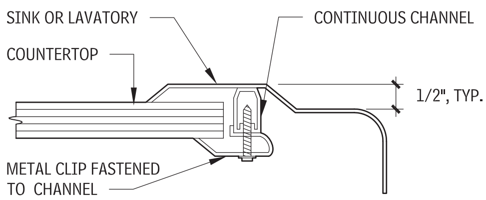


CORNER BOWL SINK

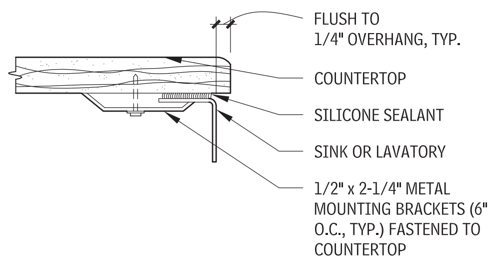


SINK WITH DRAINBOARD

BUILT-IN SINK AND LAVATORY MOUNTING DETAILS
13.58



**DROP-IN OR
SELF-RIMMING MOUNTING**



UNDER COUNTER MOUNTING

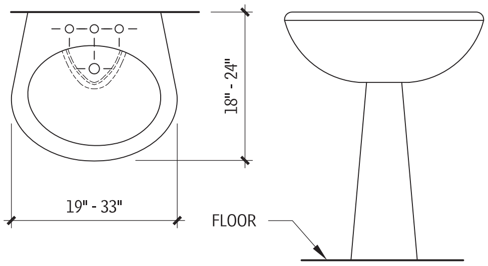
NOTE

13.57 Drainboard area may be used with single-, double-, and triple-bowl sinks. Institutional kitchen sinks may have longer drainboards. Consult manufacturers for exact dimensions, configurations, and options.

PEDESTAL PLUMBING FIXTURES

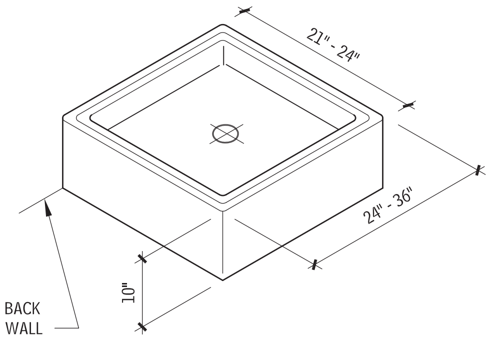
PEDESTAL LAVATORY
13.59

Pedestal lavatories may be either wall-mounted or freestanding. Consult manufacturers for specific designs, forms, and dimensions.



PLAN

FLOOR SERVICE SINK
13.60



BATHTUBS AND SHOWERS

BATHTUBS

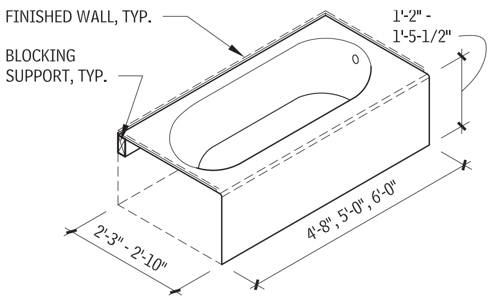
Bathtubs are available in many shapes, sizes, and styles including, rectangular, corner, and oval. Three types of installation are common including recessed, drop-in, and freestanding. Bathtub surrounds can be various materials, for example, ceramic tile, solid surfacing, molded fiberglass, or acrylic one-piece units. The surround material is important for coordination purposes during installation. Bathtubs are available in the following materials, though the fiberglass and acrylic units are the most common.

- *Fiberglass:* An economical and common choice, gel-coated fiberglass (also known as FRP) is lightweight and easy to install. Because the material can be molded, fiberglass tubs are available in a variety of shapes. Although not as durable as cast iron or acrylic, fiberglass can easily be repaired.
- *Acrylic:* Fiberglass reinforced acrylic is more durable than units constructed solely of fiberglass. Because acrylic is light and easily formed into various shapes, it is a good choice for whirlpools and other large tubs that would be too heavy in cast iron. Acrylic is a good insulator and, thus, keeps water warm longer.
- *Cast iron:* Very heavy and extremely durable, traditional enamel-coated cast iron resists staining and scratching. It cannot be molded as freely as acrylic or fiberglass, so there are fewer shapes and styles from which to choose.
- *Enameled steel:* Because enameled steel is lighter weight it is a less expensive alternative to cast iron.

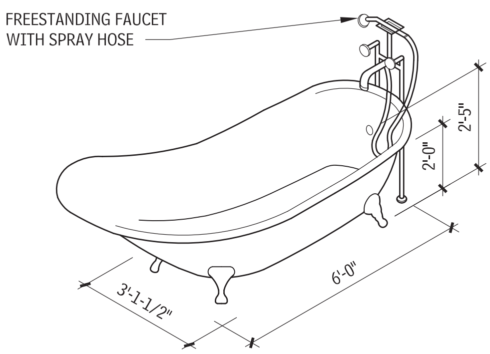
Whirlpool bathtubs are usually made of fiberglass-reinforced acrylic, which can be fabricated in a variety of shapes. Air mixed with water streams through jets in the side of the tub, giving the whirlpool its soothing, therapeutic character. Models may have 3 to 10 jets, including some aimed to massage feet, back, and neck. Jet direction can usually be adjusted; some jets can also be adjusted to deliver a pulsating or steady stream or to regulate intensity. Pumps range from 1/2 to 3 horsepower, and the intensity of the flow varies accordingly. In-line heaters are recommended to keep the water warm without refilling the tub.

Built-in bathtubs have an integral apron and tiling flange, for installation in a 3-wall alcove. Drop-in designs are intended for deck-mounted installations and typically have integral feet that support the weight of the unit. Many whirlpool bathtubs are drop-in units, though manufacturers may offer built-in units with a removable apron for access to the pump.

BUILT-IN BATHTUB
13.61



FREESTANDING BATHTUB
13.62

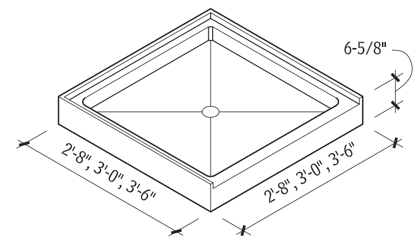


SHOWERS

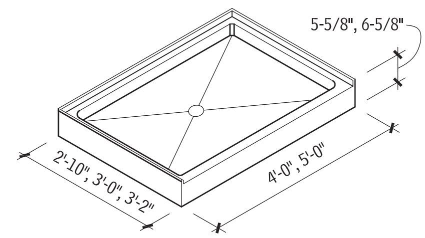
Showers may be tub showers, shower stalls, or emergency showers. Tub showers are showers installed over a bathtub and usually share its water supply valve. The shower surround may be integral to the bathtub or site-built. Site-built shower enclosures are generally three-sided with an impervious finish with either a shower door or curtain completing the enclosure.

Shower stalls consist of a floor receptor topped by water-resistant walls, either self-supporting or attached to the wall framing. Receptors slope to a drain and may be manufactured or site-built. Manufactured shower stalls may also be one-piece plastic units with integral grab bars, seat, and other accessories.

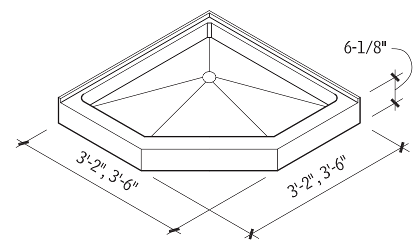
SHOWER RECEPTOR
13.63



SQUARE

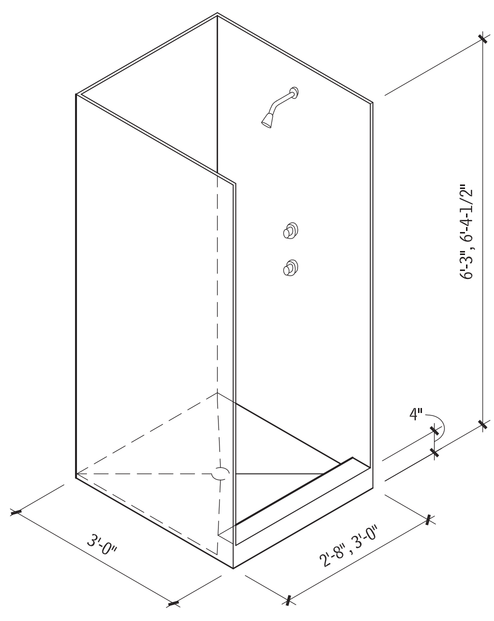


RECTANGULAR



CORNER

MANUFACTURED ONE-PIECE SHOWER STALL
13.64

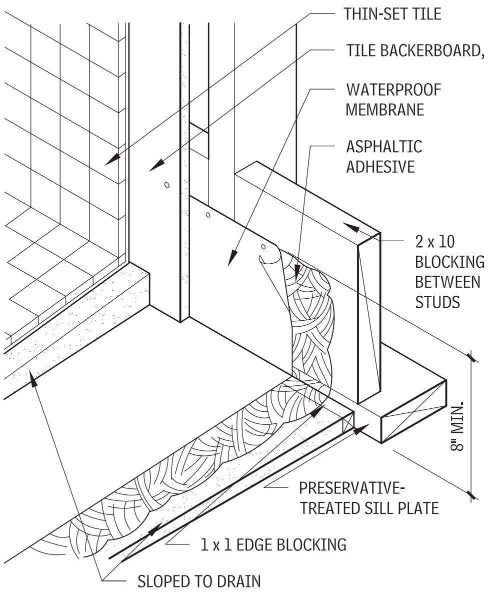


NOTES

13.60 Floor service sinks are available in stainless steel and terrazzo.
13.63 Materials for bases include acrylic with fiberglass reinforcement, enameled steel, and terrazzo.
13.64 Variations in shapes and designs are prevalent in one-piece shower units; consult manufacturers.

Contributors:
American Society of Plumbing Engineers, Westlake, California; Michael Frankel, CIPE, Utility Systems Consultants, Somerset, New Jersey.

TYPICAL SITE-BUILT SHOWER CONSTRUCTION
13.65

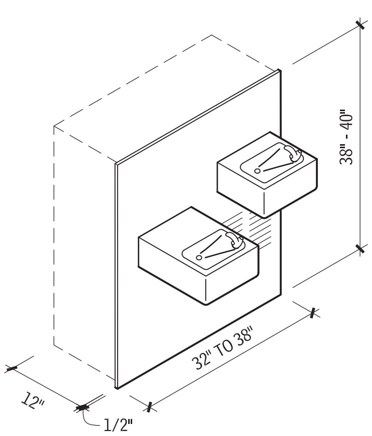


DRINKING FOUNTAINS AND ELECTRIC WATER COOLERS

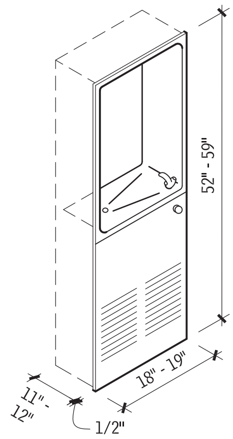
Drinking fountains (DF) only use water at ambient temperatures; electric water coolers (EWC) use an integral or remote chiller to cool water for drinking. Some design guidelines are listed below.

- Use air-cooled condensers for normal room temperatures and water-cooled units for high room temperatures and larger capacities. Many models are available with hot and cold water supplies, a cup-filling spout, or refrigerated compartments.
- Install half of required fountains or water coolers as accessible, but design the layout so accessible fountains do not obstruct movement of the visually impaired.
- Explosion-proof electric water coolers are recommended for use in hazardous locations. Corrosion-resistant fountains are available for harsh environments.
- Consult local building codes for the number of drinking fountains or water coolers required.

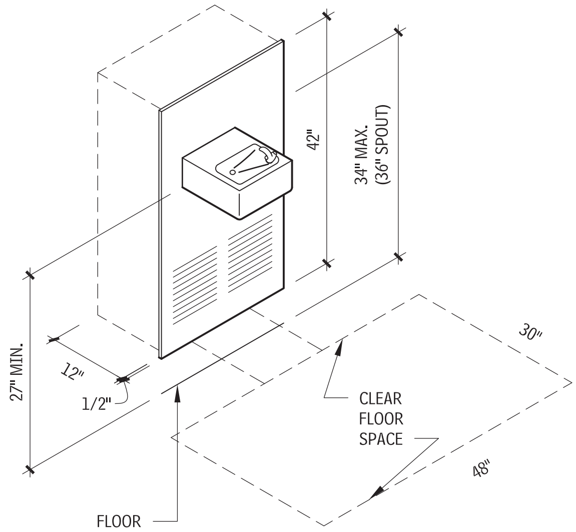
TYPICAL INTERIOR ELECTRIC WATER COOLERS
13.66



BILEVEL

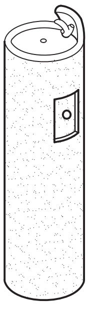


FULLY RECESSED

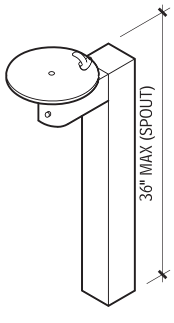


SEMIRECESSED ACCESSIBLE

TYPICAL EXTERIOR DRINKING FOUNTAINS
13.67



EXTERIOR CONCRETE PEDESTAL



METAL PEDESTAL

PLUMBING FIXTURE COUNTS

MINIMUM NUMBER OF REQUIRED PLUMBING FIXTURES 13.68

FACILITY TYPE	WC (PEOPLE)	WC (FIXTURE)	UR	LAV	DF	SH	SS	NOTES
Stadiums, arenas, convention halls, terminals	1–100	1						
	101–200	2	Note 1	Note 2	1/100			Note 4
	201–400	4						
	Addl. 300	1						
Churches, auditoriums, theaters	1–50	1						
	51–300	2	Note 1	Note 2	1/1000			Note 4
	Addl. 300	1						
Restaurants	1–50	2						
	51–100	3	Note 1	Note 2	1/200			
	101–200	4						
	Addl. 200	1						
Sports clubs	1–40	1	Note 1	Note 2	1/75	15/1		Up to 150
Country clubs	Addl. 40	1				30/1		More than 150
Industrial facilities (with lockers)	1–10	1						
	11–25	2						
	26–50	3	Note 1	Note 2	1/15	1/10	1/floor	
	51–75	4						
	76–100	6						
	Addl. 50	1						
Stoes, malls, office buildings—employees	1–15	1						
	16–40	2	Note 1	Note 2	1/100		1/floor	
	41–75	3						
	Addl. 60	1						
Stores, malls, office building—customers	1–15	1						
	16–40	2	Note 1	Note 2				
	41–75	3		Note 3	1/1000		1/floor	
	Addl. 60	1						
Dormitories	1–20	2						1 laundry tray
Boardinghouses	Addl. 20	1	Note 1	Note 2		1/unit	1/floor	Addl. 10 people

RAINWATER DRAINAGE

Facility storm drainage systems remove rainwater from all exposed portions of a building for discharge to an approved point of disposal. Roof drains and gutters are used to convey the stormwater. Other areas that require stormwater drainage include balconies, walkways, canopies, and areaways. Rainwater enters the stormwater drainage system by means of drains.

There are two classifications of roof drainage: *conventional* and *controlled flow* (also called *limited discharge*). Only the conventional roof drainage system, which removes stormwater as quickly as it falls, is discussed here. Information on controlled flow systems can be obtained from manufacturers of roof drains and/or standard engineering references.

Following are important design requirements:

- Most codes require a fail-safe method of removing excess rainwater from a roof before water accumulates to the point at which structural damage will occur. The preferred method is use of rectangular holes through the parapet (called *scuppers*) to allow water to drain down the side of the building. Another method places secondary drains immediately adjacent to the primary drain, but with a water inlet elevation about 3 in. higher than the roof. The applicable plumbing code must be consulted for the size, location, and routing of the secondary roof drainage system; the same is true for scuppers with the exception of routing.
- The final point of disposal into a public sewer system may be either a stormwater sewer that accepts only stormwater, or a combined stormwater and sanitary sewer into which both types of effluent are drained.
- When no public sewers are available, stormwater is discharged into dry wells, site gullies, watercourses, and recharge basins, which are large storage basins that allow water to both evaporate and be absorbed into the ground.

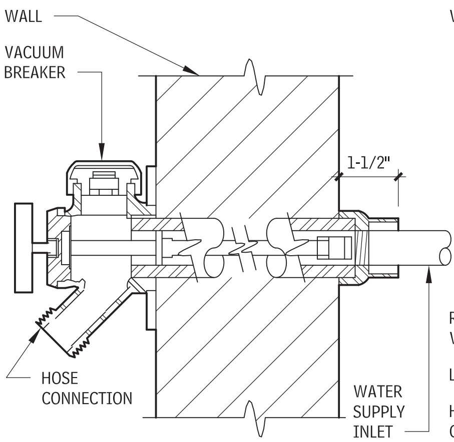
Obtain this information before designing a stormwater drainage system:

- *Ultimate point of disposal:* Find out whether stormwater on the site will drain to a storm sewer, a combined sewer, a watercourse, a street, or a gully on the site.
- *Restrictions:* Find out whether any stormwater management programs or restrictions are in effect for the project site.
- *Jurisdiction:* Find out which authorities are responsible for approval of plumbing plans and installations at the site.

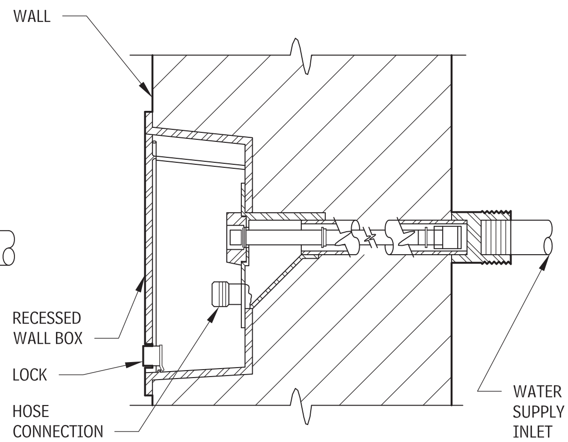
HOSE BIBBS AND WALL HYDRANTS

Hose bibbs and wall hydrants are water supply fixtures on the exterior of a building used to attach hoses for cleaning and maintenance purposes, such as washing walkways. Hose bibbs are typically exposed fixtures, while wall hydrants are concealed within a recessed wall box. If freezing conditions are even a remote possibility, a non-freeze-type fixture should be installed. To prevent backflow, wall hydrants should be provided with an integral vacuum breaker.

HOSE BIBB AND WALL HYDRANT 13.69



HOSE BIB



WALL HYDRANT

NOTES

13.68 WC—water closet; UR—urinal; LAV—lavatory; DF—drinking fountain; SH—shower; SS—service sink.
1. Half of the water closets can be urinals.
2. Half of the lavatories can be water closets.
3. If employee facilities are accessible to customers, no additional fixtures are necessary.
4. Some codes require double or triple the number of water closets for women.
5. General guidelines. Consult local plumbing codes for exact requirements.
13.69 The figures in this chart are based on a maximum rate of rainfall of 4 in./hr.

Contributors:
Michael Frankel, CIPE, Utility Systems Consultants, Somerset, New Jersey; K. Shahid Rab, AIA, Friesen International, Washington, DC; American Society of Plumbing Engineers, Westlake, California; Michael Frankel, CIPE, Utility Systems Consultants, Somerset, New Jersey.

FACILITY STORM DRAINAGE PIPING

The size of storm drainage lines is based on the area (in square feet) to be drained, the pitch of the pipe, and the rate of rainfall in inches per hour.

To design a storm drainage system for a project:

- Begin by locating the roof or area drains and designing the piping network.
- Establish the rainfall rate, and calculate the area contributing rainwater to each drain, including the side wall area (half of the area, in square feet, of any two adjacent vertical walls).
- At each design point, add all of the area (in square feet) for all drains together. In Figure 13.70, for sizing horizontal storm drainage piping, look under the pitch established for the piping in a project to find the figure that equals or exceeds the drainage area calculated. Find the applicable pipe size in the column labeled "Diameter of Piping." Use Figure 13.72 for sizing vertical storm drainage piping.

SIZING HORIZONTAL STORM DRAINAGE PIPING, SINGLE RAINFALL RATE
13.72

	MAXIMUM ALLOWABLE ROOF AREA PER DRAIN					
	1/8″ PIPE SLOPE		1/4″ PIPE SLOPE		1/2″ PIPE SLOPE	
DIAMETER OF PIPING (IN.)	SQUARE FEET	GPM	SQUARE FEET	GPM	SQUARE FEET	GPM
3	822	34	1160	48	1644	68
4	1880	78	2650	110	3760	156
5	3340	139	4720	196	6680	278
6	5350	222	7550	314	10,700	445
8	11,500	478	16,300	677	23,000	956
10	20,700	860	29,200	1214	41,400	1721
12	33,300	1384	47,000	1953	66,600	2768
15	59,500	2473	84,000	3491	119,000	4946

SIZE OF VERTICAL STORM DRAINAGE PIPING[a]
13.70

DIAMETER OF PIPING[b] (IN)	MAXIMUM ALLOWABLE ROOF AREA PER DRAIN (SQ FT)	GPM
2	544	23
2–1/2	987	41
3	1610	67
4	3460	144
5	6280	261
6	10,200	424
8	22,000	913

DRAINAGE CAPACITY OF PIPING (FLOW CAPACITY IN GAL/MIN)
13.71

PIPE DIAMETER (IN.)	VERTICAL PIPING	HORIZONTAL PIPING (SLOPE IN IN./FT)		
		1/8	1/4	1/2
2	30	—	—	—
2–1/2	54	—	—	—
3	92	36	51	80
4	192	77	110	174
6	563	220	315	449
8	1208	494	696	987
10	2600	943	1302	1800
12	6000	1526	2154	2800
15	—	2973	3500	4950

FACILITY STORM DRAINS

Facility storm drains include roof, area, and trench drains. A roof drain removes rainwater from roofs. Drains in other areas exposed to the weather such as balconies or canopies are called area drains. Both types of drain discharge the effluent into the storm drainage system. Specialized drain types are available for installation in specific exposed or interior locations; consult drain manufacturers for details.

- *Grate or dome:* This is the component that allows liquid into a drain body while excluding larger solids. Grates are available in a wide variety of shapes, slot configurations, materials, and load-bearing capability, from light to extra heavy. The high dome on the drain allows rainwater to enter the drain if some debris accumulates at the bottom. A generally accepted practice has the open area of a grate twice that of the discharge pipe. Generally, an adjustable grate allows the grate top to be adapted to the finished level.
- *Flange:* This is the part of the drain body that anchors the drain into the roof or walking surface.
- *Flashing ring:* This is provided to secure any flashing directly to the drain body, to prevent leakage around the drain. Often, roof drains are provided with an integral gravel stop to prevent gravel from ballasted roofing from entering the drain.
- *Under-deck clamp:* This is used to secure the drain body to a slab through an opening prior to the installation of any roof, slab finish, or piping.

RAINWATER HARVESTING SYSTEMS

Rainwater harvesting is experiencing a renewed interest due to the following:

- Escalating environmental and economic costs of providing water by centralized water systems or by well drilling
- The relatively pure, soft, low-sodium water source that rainwater harvesting offers
- Health concerns over the source and treatment of polluted waters
- A perception that there are cost efficiencies associated with reliance on rainwater

Collecting rainwater is not only a way to conserve water but also to conserve energy, as the energy input required to operate a centralized water system designed to treat and pump water over a vast service area is bypassed. Rainwater harvesting also lessens local erosion and flooding caused by runoff from impervious cover such as pavement and roofs, as some rain is instead captured and stored.

CONCEPTS

Rainwater quality almost always exceeds that of ground or surface waters: It does not come into contact with soil and rocks, where it dissolves salts and minerals, and it is not subject to many of the pollutants that often are discharged into surface waters such as rivers, and which can contaminate groundwater. However, rainwater quality can be influenced by where it falls, as localized industrial emissions affect its purity. Thus, rainwater falling in nonindustrialized areas can be superior to that in cities dominated by heavy industry, or in agricultural regions where crop dusting is prevalent.

NOTES

13.70 a. Based on a maximum rate of rainfall of 4 in./hr and on the hydraulic capacities of vertical circular pipes flowing between a third and one-half full at terminal velocity, computed by the method of NBS Mono. 31.
b. The area of rectangular piping should be equivalent to that of the circular piping required, while the ratio of width to depth of rectangular piping should not exceed 3 to 1.

PRIMARY WATER QUALITY CRITERIA: HEALTH CONCERNS

Once rain comes in contact with a roof or collection surface, it can wash many types of bacteria, molds, algae, protozoa, and other contaminants into the cistern or storage tank. Health concerns related to bacteria, such as salmonella, E coli, and legionella, and to physical contaminants, such as pesticides, lead, and arsenic, are the primary criteria for drinking water quality analysis.

If the rainwater is intended for potable uses such as drinking and cooking or for nonpotable uses including showering and toilet flushing, appropriate filtration and disinfection practices should be employed. If the rainwater is to be used exclusively for outside landscape irrigation, the presence of contaminants may not be of major concern, thus treatment requirements may be less stringent.

SECONDARY WATER QUALITY CRITERIA: AESTHETIC CONCERNS

Concerns such as color, taste, smell, and hardness comprise the secondary testing criteria used to evaluate publicly supplied water. When assessed according to these characteristics, rainwater often proves to be of better quality than well or municipal tap water. Inorganic impurities such as suspended particles of sand, clay, and silt contribute to the water's color and smell. Proper screening and removal of sedimentation help to decrease problems caused by these impurities.

Rainwater is the softest natural occurring water available, with a hardness of zero for all practical purposes. It naturally contains almost no dissolved minerals and salts, and is near distilled-water quality. The pH of rainwater would be 7.0 if there were nothing else in the air. However, as rain falls, it dissolves carbon dioxide that is naturally present in the air and, thus, becomes slightly acidic. The resultant pH is 5.6; however, any sulfates or nitrates dissolved from the air can lower this number.

COMPONENTS

Rainwater harvesting systems are composed of six basic components:

- *Catchment area/roof:* The surface upon which the rain falls
- *Gutters and downspouts:* The transport channels from catchment surface to storage
- *Leaf screens and roof washers:* The systems that remove contaminants and debris
- *Cisterns:* Where collected rainwater is stored
- *Conveying:* The delivery system for the treated rainwater, either by gravity or pump
- *Water treatment:* Filters and equipment, and additives to settle, filter, and disinfect

CATCHMENT AREA/ROOF

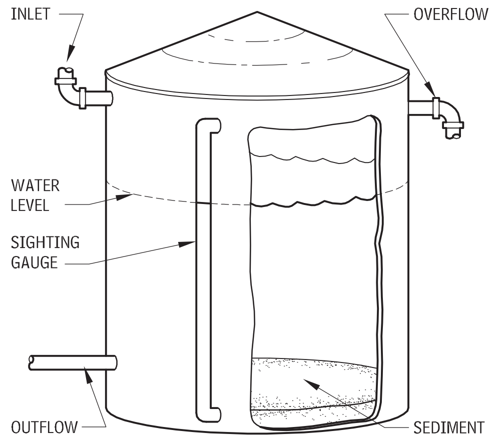
The catchment area is the surface on which the rain that will be collected falls. Although this discussion focuses on roofs as catchment areas, it's important to point out that channeled gullies along driveways or swales in yards can also serve as catchment areas, collecting and then directing the rain to a French drain or bermed detention area. Rainwater harvested from catchment surfaces along the ground should only be used for lawn irrigation because of the increased risk of contamination. For potable use, the roofs of buildings are the primary catchment areas, which, in rural settings, can include outbuildings such as barns and sheds.

For systems intended as potable water sources, no lead should be used as roof flashing or as gutter solder. The slightly acidic quality of rain can dissolve the lead and, thereby, contaminate the water supply. Existing houses and buildings should be fully examined for any lead content in the planning stages of any rainwater harvesting project.

CISTERNS

Other than the roof, which is an assumed cost in most building projects, the cistern represents the largest investment in a rainwater harvesting system. To maximize the efficiency of a system, the building design should reflect decisions about optimal placement, capacity, and material selection for the rainwater storage.

TYPICAL CISTERN
13.74



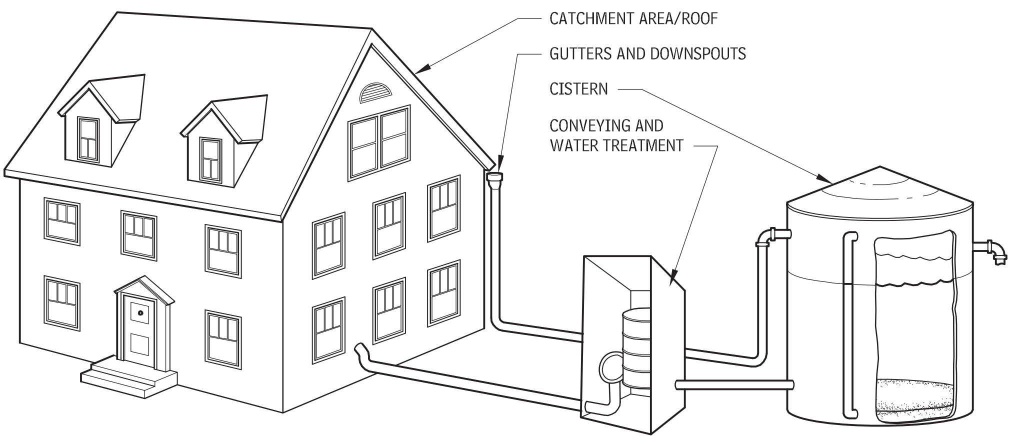
Cisterns are placed both above and below ground. While aboveground installations avoid the costs associated with excavation and certain maintenance issues, cisterns that are below ground benefit from the cooler year-round ground temperatures. To maximize efficiency, cisterns should be located as close as possible to both the supply and demand points. And to facilitate the use of gravity or lower stress on a pump, the cistern should be placed on the highest level that is practical.

Although the catchment area should not be shaded by trees, the cistern can benefit from the shade, as direct sunlight can heat the stored rainwater in the tank, which encourages algae and bacterial growth, which, subsequently, can lower water quality.

To ensure a safe water supply, cisterns should be sited at least 50 ft. away from sources of pollution, such as animal stables, latrines, or, if the tank is below ground, from septic fields. Cistern placement should also take into consideration the possible need to add water to the cistern from an auxiliary source, such as a water truck, in the event that the water supply is depleted due to overuse or drought conditions.

Regardless of the type of cistern material selected, the cistern should have a durable, watertight exterior, and a clean, smooth interior, sealed with a nontoxic joint sealant. If the water is intended for potable use, the tank should be labeled as approved by the Food and Drug Administration (FDA), as should any sealants

RAINWATER HARVESTING SYSTEM—MAIN COMPONENTS
13.73



or paints used inside the tank. A tight-fitting cover is essential to prevent evaporation, mosquito breeding, and to keep animals, children, and insects from entering the tank.

This is because two smaller tanks of, for example, 1500 gallons each are generally more expensive than a single 3000-gallon tank. The primary benefit of a multitank system is that the system can remain operational if one tank must be shut down because of maintenance or leaking.

Regardless of the cistern type chosen, regular inspection and proper maintenance are imperative to ensure reliability and safe, efficient operation. Remember that water is heavy: a 500-gallon tank of water will weigh more than 2 tons, so a proper foundation and support are essential.

ROUND CISTERN CAPACITY 13.75

DEPTH (FT)	6′ DIAMETER (GALLONS)	12′ DIAMETER (GALLONS)	18′ DIAMETER (GALLONS)
6	1266	5076	11,412
8	1688	6768	15,216
10	2110	8460	19,020
12	2532	10,152	22,824
14	2954	11,844	26,628
16	3376	13,536	30,432
18	3798	15,228	34,236
20	4220	16,920	38,040

CONVEYING

Water pressure for a gravity system depends on the difference in elevation between the storage tank and the faucet. Water gains 1 lb. per square inch of pressure for every 2.31 ft. of rise or lift. Many plumbing fixtures and appliances require 20 psi for proper operation, while standard municipal water supply pressures are typically in the 40 to 60 psi range. To achieve comparable pressure, a cistern would have to be 92.4 ft. ($2.31 \text{ ft.} \times 40 \text{ psi} = 92.4 \text{ ft.}$) above the home's highest plumbing fixture. That explains why pumps are frequently used much in the same way they are used to extract well water. To approximate the water pressure from a municipal system, pressure tanks are often installed with the pump. Pressure tanks have a pressure switch with adjustable settings between 5 and 65 psi.

WATER TREATMENT

Before making a decision about what type of water treatment method to use, water should be tested by an approved laboratory.

FILTERING

Filtration can be as simple as the use of cartridge filters or those used for swimming pools and hot tubs. In all cases, proper filter operation and maintenance, in accordance with the instruction manual for that specific filter, must be followed to ensure safety. Once large debris is removed by screens and roof washers, other filters are available that help improve rainwater quality.

Screening, sedimentation, and prefiltering occur between catchment and storage, or within the cistern. The most common filter used for rainwater harvesting is a cartridge sediment filter that traps and removes particles of 5 microns or larger. Sediment filters used in series, referred to as *multicartridge* or *in-line filters*, sieve the particles from increasing to decreasing size. These sediment filters are often used as a prefilter for other treatment techniques such as ultraviolet light or reverse osmosis filters, which can become clogged from large particles. Unless something is being added to the rainwater, there is no need to filter out something that is not present.

When a disinfectant such as chlorine is added to rainwater, an activated carbon filter at the tap may be used to remove the chlorine prior to use. However, activated carbon filters are subject to becoming sites of bacterial growth, therefore chemical disinfectants such as chlorine or iodine must be added to the water prior to the activated carbon filter. If ultraviolet light or ozone is used for disinfection, the system should be placed *after* the activated carbon filter. Many water treatment standards require some type of disinfection after filtration with activated carbon. Ultraviolet light disinfection is often the method of choice. All filters must be replaced per the recommended schedule, rather than when they cease to work; failure to do so may result in the filter contributing to contamination of the water.

DISINFECTION

Private systems do not disinfect to the extent of public water systems where the threat of a pathogenic organism such as E coli can affect many households. If the harvested rainwater is used to wash clothes, to water plants, or to carry out other tasks that do not involve direct human consumption or contact, treatment beyond screening and sedimentation removal is optional. However, if the water is plumbed into the house for general indoor use such as for drinking, bathing, and cooking, disinfection is needed. Whereas filtering is quite common in private water systems, disinfection is less common, for two reasons:

- The Safe Drinking Water Act is neither enforced nor applicable to private systems.
- Chlorine is disliked because of taste, fear associated with trihalomethanes (THMs), and other concerns.

Common disinfection systems include:

- *Ultraviolet radiation* (UV): This type of water disinfection (a physical process) kills most microbiological organisms that pass through them. Because particulates offer a hiding place for bacteria and microorganisms, prefiltering is necessary for UV systems. To determine whether the minimum UV exposure is met, units should be equipped with a light sensor. Either an alarm or shutoff switch is activated when the water does not receive the adequate level of UV radiation. The UV unit must be correctly calibrated and tested after installation to ensure that the water is being disinfected.
- *Ozone:* This is the disinfectant of choice in many European countries, but until recently it had not been used in American water treatment facilities. Ozone is a form of oxygen (O_3) produced by passing air through a strong electric field. Ozone readily kills microorganisms and oxidizes organic matter in the water into carbon dioxide and water. Any remaining ozone reverts back to dissolved oxygen (O_2) in the water. Recent developments have produced compact ozone units for home use. Since ozone is produced by equipment at the point of use, with electricity as the only input, many rainwater catchment system owners use it to avoid handling chlorine or other chemicals. Ozone can also be used to keep the water in cisterns "fresh." When used as the final disinfectant, it should be added prior to the tap, but after an activated carbon filter, if such a filter is used.
- *Chlorine or iodine for disinfecting:* Chlorine is the most common disinfectant because of its dependability, water solubility, and availability. Granular or tablet form is available (calcium hypochlorite), but the recommended application for rainwater disinfecting is in a liquid solution (sodium hypochlorite). Chlorine-feed pumps that release small amounts of solution while the water is being pumped can also be used. Chlorine-metering pumps inject chlorine into the water only at the time of use. Chlorine is more effective than iodine at higher water temperatures and lower pH levels. Prolonged presence of chlorine where organic matter may be present may cause the formation of chlorinated organic compounds. If chlorine is used as a disinfectant, it is essential to screen all organic material from the tank.
- *Iodine:* This water disinfectant is less soluble than chlorine, although it is effective over a pH range of 5 to 9 and displays greater antibacterial activity in water temperatures of 75°F to 98.6°F.

BUFFERING

Baking soda is often used for buffering. The composition and pH of rainwater differs from chemically treated municipal water and mineral-rich well water. Controlling the pH of rainwater by buffering can be easily accomplished by adding one level tablespoon of baking soda to the cistern for each 100 gallons of water collected. (This amounts to about 4 ounces by weight of baking soda for every 1000 gallons of water collected.) An easy method is to mix this amount of baking soda in a jar of water and pour it into the tank. Mixing will occur naturally over a day or two; or a clean paddle may be used to hasten the process, but avoid disturbing materials that have settled at the bottom of the cistern.

OTHER TREATMENT

Some alternate types of treatment available include reverse osmosis (RO), nano-filtration, and several other "membrane" processes and distillation equipment that are designed primarily to remove dissolved materials such as salts or metals. However, rainwater contains extremely low levels of dissolved salts and is very soft.

GRAYWATER SYSTEMS

The use of graywater would typically be considered under one of three project circumstances: (1) an arid environment where water resources are substantially constrained; (2) a green building project where reduced water use is a part of an environmentally responsive solution; or (3) when a project objective is net-zero annual water use.

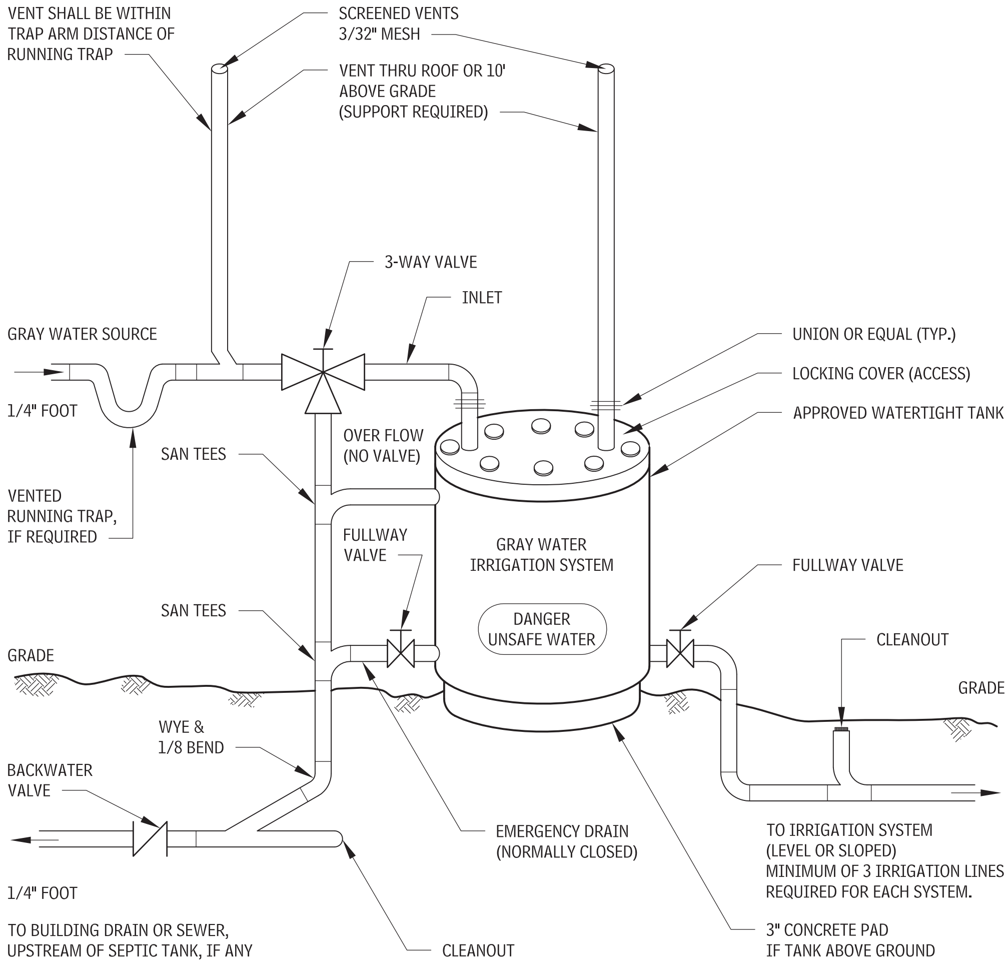
Blackwater is biologically active, constitutes a health risk, and must be appropriately treated before discharge into the environment. Such treatment occurs in a central sewage system or via local processing (such as a septic system). Graywater, by comparison, is much less of a health hazard and potentially can be used for nonpotable water demands before final diversion into a treatment system. A graywater system seeks to use some portion of supplied potable water twice before releasing it to the final treatment system. It does so by diverting specific wastewater flows to storage (and light treatment) and then to a secondary use (such as irrigation or flushing toilets). When used for flushing toilets, graywater eventually ends up in the sewage waste stream; when used for irrigation, graywater ends up supporting plant growth or infiltrating into the ground.

Graywater (or grey water) is generally defined as building wastewater that does not include human waste or substantial organic material. This definition is typical—but not universal—and will vary from jurisdiction to jurisdiction. In many locales, graywater sources include showers, bathtubs, and bathroom lavatories (sinks). Washing machines and laundry sinks are considered graywater sources in some jurisdictions. Wastewater from water closets (toilets), urinals, kitchen sinks, dishwashers, and wash water from diapers is termed blackwater. Because plumbing systems are highly regulated by codes, local regulations regarding graywater must be understood—both in terms of what is considered graywater and in terms of potential uses for graywater.

Some jurisdictions permit the use of graywater only for exterior irrigation (potentially constrained to subsurface and/or surface delivery). Some permit the use of graywater only for interior uses. Universally, graywater systems must be clearly identified by color coding/signage, must lightly treat (normally involving filtration, disinfection, and perhaps dying) the collected water before reuse, and must be installed to prevent any cross connection with a potable water system.

Sizing a graywater system involves four generic steps. Step 1: Estimate expected graywater flows. Step 2: Estimate the desired capacity of graywater uses (irrigation needs; toilet flushing). Step 3: Balance resources and needs to develop an economical system arrangement. Step 4: Comply with all applicable codes.

GRAYWATER SYSTEM SCHEMATIC: IRRIGATION
13.76



NOTE

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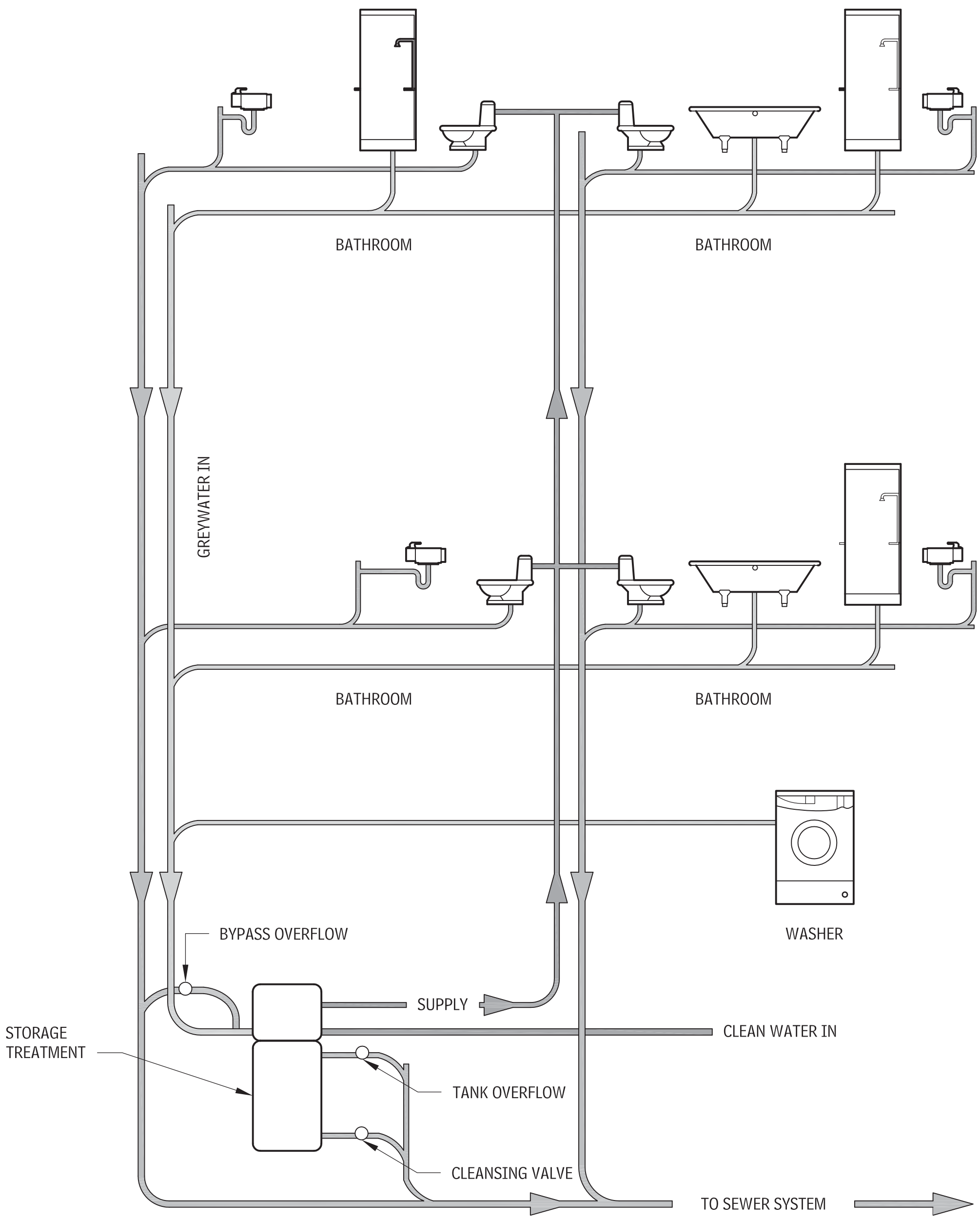
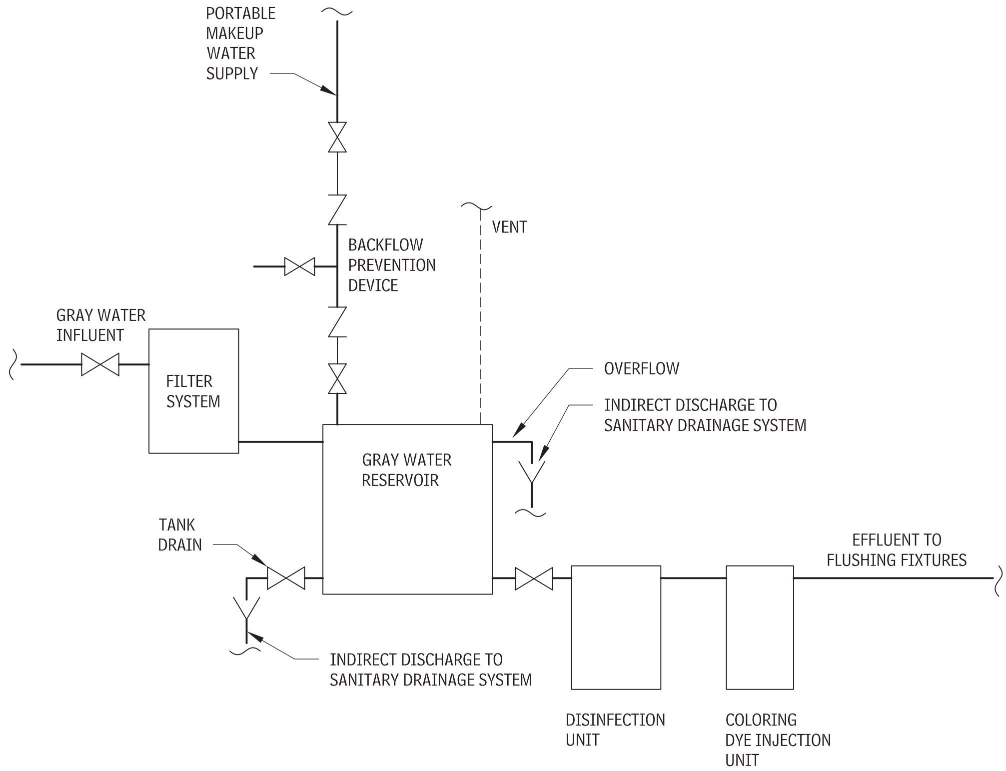
Contributor:
Peter Pfeiffer, Barley & Pfeiffer Architects, Austin, Texas.

GRAYWATER SYSTEM SCHEMATIC: INTERIOR USE
13.77



GRAYWATER SYSTEM STORAGE/TREATMENT
13.78



HEATING, VENTILATING, AND AIR-CONDITIONING (HVAC)

DESIGN CONSIDERATIONS

An HVAC system is an active climate control system that includes heating/cooling source equipment, distribution and delivery components, and controls. Thermal comfort and acceptable indoor air quality are the primary system objectives. Energy efficiency techniques are commonly applied to HVAC systems.

Although shelter from the weather and protection from harsh climates are historic reasons for constructing buildings, the mere act of building does not in itself result in desirable and acceptable interior environments. Thus, climate control is a critical performance attribute of a successful building, and the creation of a comfortable, healthy environment for occupants is an important goal of the design process. HVAC systems may also include refrigeration for manufacturing, processing, and storage.

An HVAC system is a requirement in virtually all types and sizes of buildings. Second only to structural makeup, HVAC represents a technical area of design that must be generally understood and properly coordinated during the design process.

HVAC systems have a significant impact on the budget and space allocations for a facility because they:

- Represent a substantial percentage of the construction budget for most facility types
- Can consume up to 10 percent of the floor area of a building
- Reach into and affect aesthetically most building spaces
- Contribute greatly to facility energy use and operating expense
- Account for the majority of occupant complaints
- In processing, manufacturing, and storage facilities, HVAC may be critical to the basic function and operation of the facility.

HVAC has a major impact on occupant satisfaction, on facility construction and operating costs, and, often, on building layout and spatial efficiency.

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) definition of HVAC describes a system that must be able to simultaneously control:

- Temperature
- Relative humidity
- Air speed
- Quality of air in occupied spaces

These four factors generally overlay the factors that define thermal comfort and indoor air quality—mean radiant temperature (MRT) being the critical exception.

Increasing demands for control of indoor air quality tend to require the design and installation of quality HVAC. Of the three primary means of mitigating indoor pollutants—source control, filtration, and dilution—dilution (through ventilation and exhaust) and filtration (through system and equipment selection) are directly related to HVAC design, installation, and operation.

NOTE

13.78 Source: International Code Council.

Contributor:
Ayush Vaidya, M. Arch, University of Oregon, Eugene, Oregon, with Walter Grondzik, Ball State University, Muncie, Indiana.

INDUSTRY STANDARDS

ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers) standards and guidelines dominate the design of HVAC systems. AHRI (Air-Conditioning, Heating, and Refrigeration Institute) standards dominate equipment certifications. Federal requirements establish minimum equipment efficiency thresholds. A series of *Advanced Energy Design Guides* (available through ASHRAE) provide recommendations for designing a variety of building types to substantially exceed code-mandated energy performance. HVAC systems will play a key role in achieving green building certification under LEED or Green Globes. Key standards affecting the design of most commercial/institutional projects include:

- ASHRAE Standard 90.1, "Energy Standard for Buildings Except Low-Rise Residential Buildings"
- ASHRAE Standard 55, "Thermal Environmental Conditions for Human Occupancy"
- ASHRAE Standard 62.1, "Ventilation for Acceptable Indoor Air Quality"
- ASHRAE Guideline 0, "The Commissioning Process"

SUSTAINABILITY

HVAC (active climate control) systems are installed to provide interior environments that occupants will judge to be thermally comfortable and to provide indoor air quality that will be healthful and acceptable. These fundamental objectives behind HVAC system design must be remembered when addressing sustainability. Safe and equitable system outcomes are as much a part of sustainable design as energy and resource conservation. HVAC systems must be effective as well as efficient. A system can be highly effective, but very inefficient; or very efficient, but dismally ineffective. A reasonable middle ground between efficiency and effectiveness is the goal.

HVAC systems can account for half the annual energy consumption in many building types—especially as the energy demands of lighting are reduced through skillful daylighting. The design team for a building striving for greater sustainability must consider the impact of HVAC systems on energy consumption. Secondarily, the impact on water and materials consumption should be addressed.

Energy efficiency and conservation: An HVAC system consists of four functional subsystems: (1) source components—which produce heating and cooling effect, including chillers and boilers; (2) distribution components—which convey heating/cooling and ventilation effects to the zones in a central system; (3) delivery components—which introduce heating/cooling/ventilation effects into the various spaces/zones; and (4) controls.

Source components are critical when considering energy efficiency (increasing output—heating or cooling effect—while decreasing energy input). A large percentage of the energy used by HVAV systems passes through the source components, placing them on a critical path toward efficiency. The federal government sets minimum efficiency standards for HVAC source equipment, which are embedded in energy codes. These are legally minimum efficiencies. There is almost always one or more higher efficiency alternatives. In addition, efficiency standards apply to specific equipment—and not to whether that equipment is the most efficient choice for a given task. Alternative source types should be considered, as well as efficiency within a type.

Controls are also on the critical path to energy efficiency and conservation. Control schemes should turn off equipment when not needed (conservation) and optimize equipment operation when in use (efficiency). Proportional control approaches (such as variable air volume distribution/delivery, variable frequency motor drive controllers, and variable flow rate distribution arrangements) offer great promise for higher efficiencies at part-load operation.

The energy intensity of distribution subsystem designs should be considered. This includes fans, pumps, duct and pipe sizing, and the fundamental decision of whether to use air or water to distribute heating/cooling effect. Delivery components can affect energy efficiency via pressure drop requirements—but the main focus on these components is effectiveness.

Displacing fossil-fuel energy consumption through the use of renewable energy can be very effective in conserving energy. Passive solar heating can displace gas/electricity use; natural ventilation can displace electricity. In many climates, passive systems cannot provide comfort or acceptable air quality in extremes of weather—nevertheless during the times when they are effective they reduce the use of nonrenewable energy resources and reduce carbon emissions.

Materials and water conservation: This is an area not being addressed for HVAC systems in most green building evaluations. Local sourcing of products should be considered (when possible) to reduce energy and pollution associated with transportation of system components. Opportunities for water reclamation and selection of low-water-demand equipment (such as condensers) may be considered.

CLIMATE AND HVAC SYSTEMS

Technically, the term "HVAC" refers to an active climate control system. Climate affects the design of an HVAC system in several ways, including the following.

- It determines building code envelope requirements, which affect heat gains and losses.
- It will influence system selection by making a heating-focused or cooling-focused system a more appropriate choice.
- It will influence the selection and placement of delivery devices (such as baseboard radiators or diffusers).
- It will determine the feasibility of an air-side economizer system.
- It will influence the selection of condensing units (air-cooled versus water-cooled).
- It will determine the feasibility of heat/energy recovery ventilators.

Expanding the concept of HVAC to passive climate control systems, climate is the deciding factor in establishing the feasibility of such systems—including passive solar heating, natural ventilation, and other passive cooling approaches.

DESIGN PROCESS

The design process for an HVAC system is similar to that used for the overall building design. The first steps in the design process are nontechnical and generally independent of the system solution eventually chosen. Active involvement of the project architect in these first steps is critical to a successful design.

DESIGN INTENT

HVAC design should begin with a clear and explicit statement of what the system is expected to do. Design intent should ideally be defined during the programming phase of a project but certainly no later than the early stage of schematic design. Design intent should examine the operation of HVAC under all possible conditions (weekdays, weekends, emergencies, and predictable renovations). The process of defining the intent will lead to explicit design criteria—measurable targets for system performance—that can be used to select an appropriate system.

ZONING

An HVAC zone is an area of a facility (not necessarily coincident with a room or rooms) that requires a separate controller to provide conditions amenable to thermal comfort. Such control is typically provided by a thermostat that senses room air temperature. Thus, each thermal zone has its own thermostat.

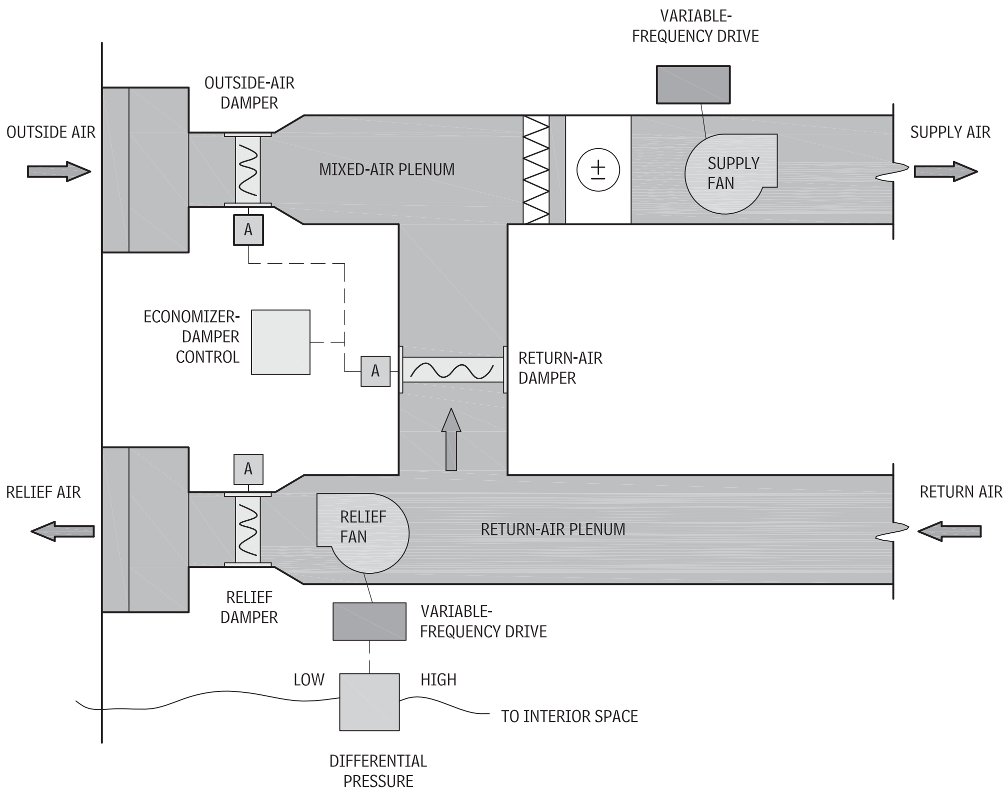
Ideally, any area of a facility that responds to loads differentially across time from other areas should be considered for separate control. Such differential response usually is caused by the timing of loads, with solar orientation, fenestration, occupant use, and equipment loads affecting this timing. For example, an office with east-facing glazing should not be controlled from a thermostat in an office (even if adjacent) with south-facing glazing. A conference room should not be controlled from an office, even if solar exposures are the same, as the occupancy schedules and loads are different.

Zoning is a critical part of the HVAC design process and should involve the active participation of the design professional. Providing too many zones wastes money, while providing too few may cause discomfort. Establishing appropriate zones is as much a qualitative as a quantitative process, one that requires a clear understanding of facility function and owner expectations. Zones are so critical to HVAC success that many systems are defined primarily by their zoning capabilities. As zoning depends on building layout, it should occur during schematic design.

BUILDING AND SPACE PRESSURIZATION

Nonresidential buildings will typically be pressurized (maintained at a positive pressure relative to the outdoors) as a means of controlling airflow through the building envelope—in order to improve occupant comfort, promote indoor air cleanliness, and (to some extent) reduce degradation of building enclosure assemblies. Such pressurization is established by balancing the volume of outdoor air intake to the HVAC system against exhaust airflows (such as from bathroom, kitchen, and lab hood exhausts) and leakage (exfiltration) through the building envelope.

TYPICAL OUTDOOR AIR-RELIEF AIR ARRANGEMENT
13.79



The outdoor airflow rate for most buildings is established by ventilation airflow requirements related to acceptable indoor air quality. Minimum outdoor airflow requirements (in ASHRAE Standard 62.1) are expressed in cfm per occupant plus cfm per unit area of floor. Air change rates are not commonly specified—with the critical exception of healthcare facilities (where room air change rates are a measure of air turnover for control of pathogens) and residential occupancies (where outdoor air change rate is a figure of merit for air tightness).

Pressurization of interior spaces relative to other interior spaces is critical, and code mandated, in healthcare facilities; it is also important in laboratory buildings, and for some typical building spaces such as bathrooms and shops.

SYSTEM SELECTION

HVAC selection is a sophisticated process. Normally, several system types could function adequately in a given building context. Careful matching of system characteristics to design criteria can help achieve the best match for the system intent. The earlier in the design process that a system can be selected, the greater the opportunity for system coordination.

Characteristics to consider during the selection process include: lifecycle cost (including purchase, installation, and operating costs), energy consumption, space and volume requirements, noise, vibration, locational flexibility, operational flexibility, adaptability to changes in occupancy and/or room layout, ventilation capabilities, smoke control capabilities, aesthetics, reliability, maintainability, appropriateness to owner/operator personnel resources, and capability to provide thermal comfort. The relative importance of these characteristics, as well as system capabilities, will vary from project to project. Use of a project-specific, weighted selection matrix can assist in the selection process.

DETAILED DESIGN

The specifics of HVAC design are normally assigned to a mechanical engineer with the appropriate expertise. The detailed design, normally conducted during the design development phase, involves selection of a number of manufactured equipment items (such as chillers, cooling towers, air-handling units, and diffusers) to meet load and performance requirements, as well as design of numerous field-fabricated components (such as ductwork and piping) to connect and support the major equipment items.

In a typical building, most of the HVAC components are hidden from view behind mechanical room walls or above suspended ceilings. Thus, detailed design is driven by considerations of functionality and economics. Two exceptions to this "no-see" situation are the air supply and return devices (and/or water terminal units) and the exterior condenser.

DESIGN COORDINATION

HVAC systems may place substantial space and volume demands on a building and tend to interact with virtually all other building elements; key activities for coordinating these elements include the following:

- Ensuring HVAC design intent supports overall facility design intent
- Coordinating HVAC zones with other system zones (fire protection and alarm, lighting, and smoke control)
- Locating major equipment components to minimize distribution length and size, and to minimize negative aesthetic impacts
- Locating major equipment components to minimize negative impacts on room acoustics, circulation patterns, and facility flexibility
- Coordinating air distribution with elements of other systems, such as structural beams and columns, lighting fixtures, and plumbing and fire protection piping
- Locating terminal devices (such as VAV or mixing boxes) and control devices (such as valves, dampers, and actuators) so they are accessible for regular maintenance
- Giving more than rudimentary consideration to selection of air supply and return devices, such as diffusers, registers, and grilles. (These devices can have a dramatic effect on thermal and acoustic comfort and on aesthetics.)
- Coordinating controls with design intent. Although controls are highly technical in implementation, failures are often conceptual.
- Providing operations and maintenance manuals and procedures to assist the owner in operating the HVAC system

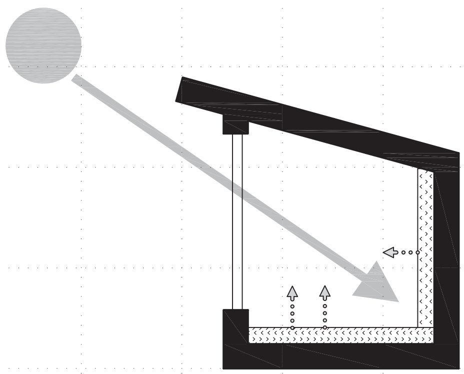
PASSIVE SOLAR HEATING

A passive solar heating system can displace all, a substantial part of, or some portion of annual heating demands—depending upon system design and project climate. Even where a passive heating system cannot reasonably handle all heating needs—necessitating installation of a backup active heating system—the passive system can contribute to efforts to reach net-zero energy status without the installation of a larger-than-necessary PV or wind system and, perhaps more importantly, reduce carbon emissions related to building heating. There are three basic passive heating system configurations: direct gain, indirect gain, and isolated gain. A direct gain system is essentially south-facing glazing coupled with interior thermal mass, with appropriate solar and heat loss control mechanisms. There are three distinct forms of indirect gain systems: Trombe walls, water walls, and roof ponds. Isolated gain systems typically take the form of a sunspace.

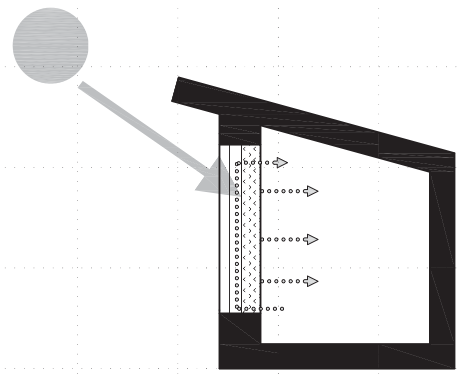
NOTE

13.79 Taylor, S.T. (2000, September). Comparing economizer relief systems. ASHRAE Journal, pp. 33–40, 42.

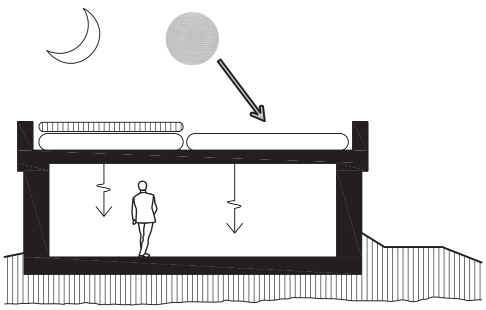
PASSIVE SOLAR HEATING TYPOLOGIES
13.80



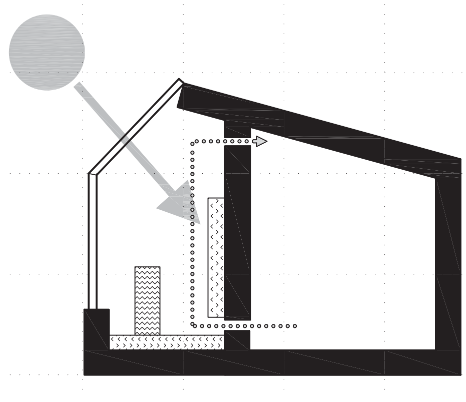
DIRECT GAIN



INDIRECT GAIN

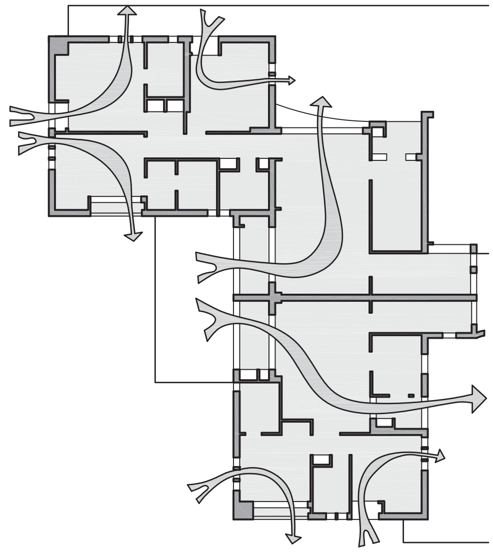


ROOF POND

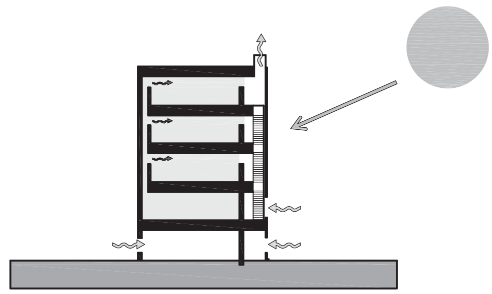


ISOLATED GAIN

NATURAL VENTILATION TYPOLOGIES
13.81



CROSS VENTILATION



STACK VENTILATION

PASSIVE COOLING

A passive cooling system uses an exterior condition (such as dry-bulb air temperature, soil temperature, or night sky temperature) as a heat sink where heat from a building interior can be dumped. As opposed to a passive heating system that obtains substantial heat flow from one source—solar radiation, passive cooling systems typically seek appropriate heat sinks in the face of challenging exterior conditions. The capacity of most heat sinks is inversely proportional to cooling demands—the greater the need for cooling, usually the lower the capacity of passive cooling systems. Nevertheless, a passive cooling system can reduce climate control energy consumption and carbon emissions associated with space cooling.

There are a number of passive cooling systems in use in a range of building types. These are commonly classified as direct, indirect, or isolated loss systems; alternatively, they are described as convective, radiative, conductive, or evaporative cooling systems on the basis of the primary heat flow mode. Typical system types include: cross ventilation, stack ventilation, cool towers, evaporative systems, and earth tubes. Of these, natural ventilation (cross and stack) systems are the most common.

Key factors in the success of a natural ventilation system include:

- Exterior (heat sink) conditions—both dry-bulb temperature and relative humidity; an interior space can be ventilated no lower than the ambient outdoor air temperature and/or relative humidity, and usually only within a differential (outdoor minus indoor) temperature of around 3°F.
- Aperture size, which controls the volume of air that can enter (or exit) the building; the smallest aperture in the line of airflow will control the system capacity.
- Driving force—wind speed for cross ventilation and buoyancy (as a result of height and temperature difference) for stack ventilation; the greater the wind speed or buoyancy, the greater the ventilation airflow.
- Interior obstructions will block or constrain airflow; the path for ventilation air must be essentially unobstructed from inlet aperture to outlet aperture; this is a serious design challenge in many building types.

NOTE

13.80 ©ASHRAE, www.ashrae.org. 2015 Fig. 1, Chapter 8, ASHRAE Handbook Online: HVAC Applications.

Contributor:
Walter T. Grondzik, Ball State University, Muncie, Indiana.

HVAC SYSTEM TYPES

Climate control systems are fundamentally either active or passive. Passive systems use no purchased energy resources, normally are assembled of "architectural" building elements doing double duty (such as glazings, walls, floors, finishes), and require design coordination.

Active climate control (HVAC) systems use purchased energy resources and employ task-specific, single-purpose elements (such as pumps, fans, ducts, and diffusers). Although mechanical engineers usually design an HVAC system, its interactions with the building must be coordinated with the entire project team.

HVAC systems are categorized by scale and by means of energy transfer to and from occupied spaces of a facility:

- *Local system:* Serves only a single space, and all of the system components are usually located in or directly adjacent to the space being conditioned. Distribution and delivery elements are bundled with the source equipment.
- *Central system:* Serves multiple spaces, and the major components are usually located in a dedicated mechanical room or rooms. Distribution and delivery elements are separate from the source equipment—and may be air or water based.
- *District system:* Serves multiple buildings (as in a campus or central business district heating-cooling loop), with major components located in a dedicated plant.

LOCAL SYSTEMS

Local systems are typically smaller-capacity systems intended to provide climate control for a single space/room in a building. Examples include window air conditioners, through-the-wall air-conditioners, unit heaters, ductless mini-split systems, fireplaces, wood stoves, electric baseboard heaters, and the like. Architectural coordination for local systems involves placement of a device within a space—with due consideration for aesthetics, noise, and control capabilities.

ELECTRIC HEATING SYSTEMS

Electric energy is ideally suited for local space heating because it is simple to distribute and control. Electric heating systems are widely used in residences and schools, as well as commercial and industrial facilities. Heating units are placed in individual rooms or spaces, but may be combined into zones with automatic temperature controls. Electric in-space heating systems may use natural convection, radiant, or forced-air units.

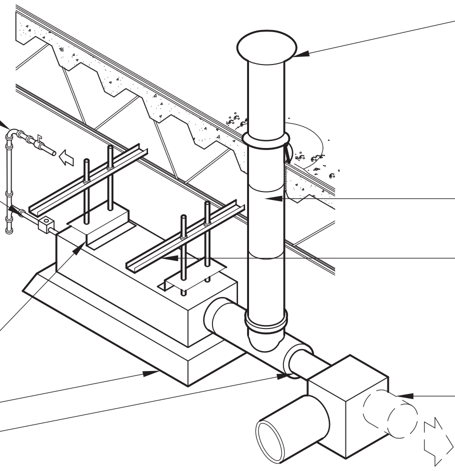
NATURAL CONVECTION UNITS

Natural convection units for wall or floor placement (and surface or recessed installations) have elements of bare incandescent wire, bare low-temperature wire, or sheathed wires. A liner or reflector is usually placed between elements so that part of the heat output is distributed by radiation and part by convection. Small-capacity units (up to about 1650 W) operate at 120 V; higher-capacity units operate at 208 V or more. Because natural convection air currents are critical to the distribution of heat from these units, they must be installed so that airflow across the resistor element will not be impeded.

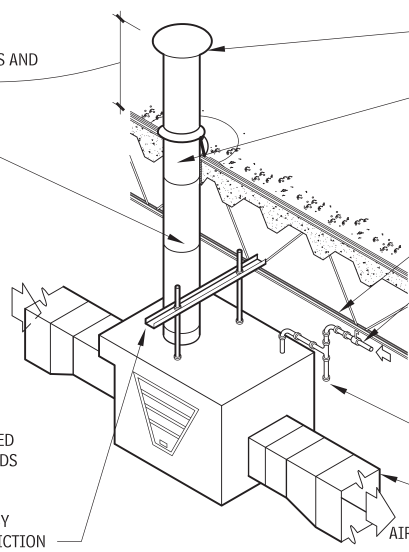
INFRARED HEATING UNITS

Infrared heating units are designed primarily to heat objects, rather than space. Current flowing through a high-resistance wire heats up the element or surface of the unit. Heat is transferred from the unit to surfaces or occupants primarily by radiation. Manufacturers' recommendations for installation clearance should be followed. For an effective system, it is important to locate radiant heating units carefully in relation to the objects being heated.

GAS-FIRED HEATERS
13.82



LOW-INTENSITY POWER-VENTED HEATER



DUCT FURNACE

FORCED-AIR UNITS

Forced-air units combine convection heating with fan-powered air circulation. Such units are available in a wide range of capacities to suit a variety of heating loads and occupancy types. Unit ventilators are commonly located on an outside wall, where they have access to outdoor air intake and can prevent cold-air downdrafts from window areas.

GAS-FIRED HEATERS

Gas (natural gas or propane) is well-suited for local and central space heating because it is often readily available and provides an economic alternative to electric resistance heating. Gas heating systems are widely used in a range of building types. In a local system, heating units are placed in individual rooms or spaces (but may be combined into zones with automatic temperature controls). Because gas heating is a combustion process, gas-heating devices must be provided with a flue to remove products of combustion and with outdoor air to support the combustion process.

NOTES

13.82 a. If venting of gases is not required, and code approves, vent piping and power vent may be eliminated.
b. For the duct furnace, a unit heater would be similar, but without ducts.

DIRECT-EXPANSION SYSTEMS

Most local cooling systems are direct expansion (DX) systems. The term "direct expansion" means that a refrigerant flows through the system cooling coil to remove heat from a space. Direct-expansion systems come in cooling only or heat pump configurations; a heat pump can provide either heating or cooling.

The most common direct-expansion system is a unitary or packaged unit installed through the wall or in a window. These can also be floor-mounted in or out of the air-conditioned space, or located on the roof.

Another type of direct-expansion system is the "split" system, in which the heat rejection components (the condenser) and the compressor are packaged separately and located remotely from the evaporator and fan, which must be in the air-conditioned space. The two subassemblies, which are attached to the system with refrigerant piping, may be as close as on opposite sides of a wall or separated by up to 100 ft.

CENTRAL SYSTEMS

Central systems are categorized by the means of heat transfer used to convey heat to and from the spaces served by the system. Two primary media are used for this purpose: water and air.

Water is a very effective means of transferring heat, requiring substantially less volume to move a given quantity of heat than is possible with air as a medium. For the same heating or cooling load, the water distribution piping will be several times smaller than an equivalent air distribution duct. On the other hand, air distribution is convenient, because the air used to transport heating or cooling from a central location can simply be skillfully dumped into the space. Water distribution systems require some type of terminal device to exchange heat between the water and the air in the space to be cooled.

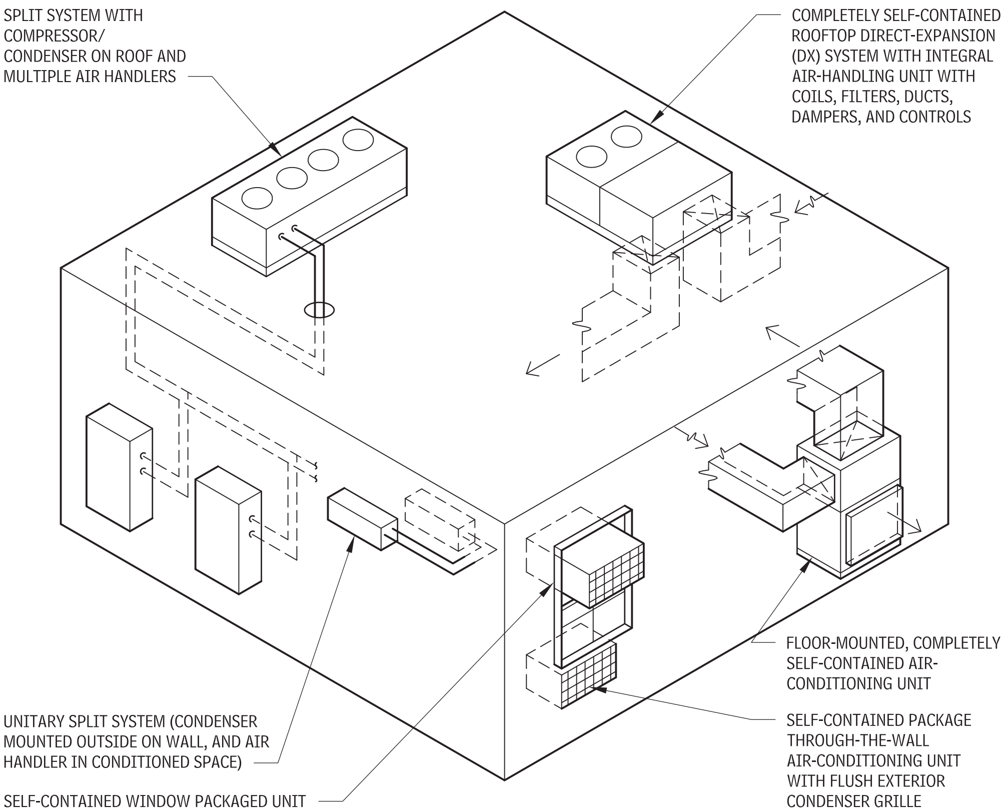
Those central systems that use only air to distribute heating and cooling effects to the occupied spaces are called all-air systems, and require a ductwork distribution tree. An all-water system uses only water to supply and remove heat from the spaces; such a system requires a piping distribution network. Air-water systems deliver both air and water to the occupied spaces and require both ductwork and piping distribution networks.

CENTRAL SYSTEM COMPONENTS

Central system components are distributed throughout a facility, with a range of equipment choices available for most systems. HVAC system components can be grouped into subsystems, including source, distribution, delivery, and control components.

- *Source subsystem:* Source components involve the generation of a heating or cooling effect and typically include chillers (vapor compression or absorption), boilers (electric, gas, oil, coal), cooling towers or air-cooled condensers, heat pumps, and solar collectors.
- *Distribution subsystem:* Distribution components involve transfer of a heating/cooling effect from the source to occupied spaces, and typically include ductwork, piping, air-handling units (with fans, filters, coils, and accessories), pumps, standalone fans, and air terminal units.
- *Delivery subsystem:* Delivery components are used to introduce a heating/cooling effect into the occupied spaces, and typically include baseboard radiators, unit heaters, convector cabinets, fan-coil units, induction units, diffusers, and radiant panels.
- *Controls subsystem:* Controls provide for the safe, effective, and efficient operation of an HVAC system.

DIRECT-EXPANSION SYSTEM
13.83



HEAT GENERATION

BOILERS

Boilers produce hot water or steam for use in space conditioning, heating of domestic hot water, and/or process requirements. A boiler may be electric or combustion (with a variety of fuel types available). Key considerations in selecting a boiler (beyond fuel type) include: capacity and efficiency. Applications include single-family residences, buildings of all scales, and district systems.

A combustion boiler will require makeup air and a flue (or breeching). Burner efficiency depends on the proper combustion of fuel (air-fuel ratio) and the maintenance (annual tune-up) of the burner. To handle a boiler properly and efficiently, the maintenance staff must be trained to operate the unit and to conduct efficiency tests, which include testing for CO_2, stack temperature, smoke, and draft. Air pollution regulations must be considered for larger installations.

RATINGS

Boiler capacity ratings are expressed as:

- Gross rating = input in Btu/hr. (found on equipment plates)
- Net rating = output in Btu/hr. = gross rating × efficiency (found on equipment plates)

FUEL RATINGS
13.85

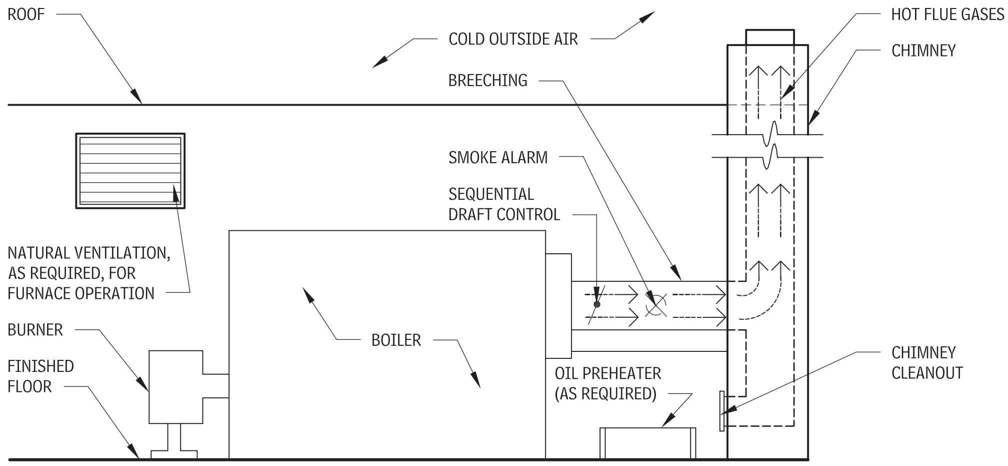
FUEL	HEAT VALUE	EFFICICENCY (%)
Anthracite coal	14,600 Btu/lb.	65–75
No. 2 oil	140,000 Btu/gal	70–80
No. 4 oil	145,000 Btu/gal	70–80
No. 6 oil	150,000 Btu/gal	70–80
Natural gas	1052 Btu/cu ft.	70–80
Electricity	1 W = 3.4 Btu/hr.	95–100

For example, if the boiler-burner combination is 80 percent efficient, No. 2 fuel oil is burned, and the total heat load is 168,000 Btu/hr., what is the required firing rate?

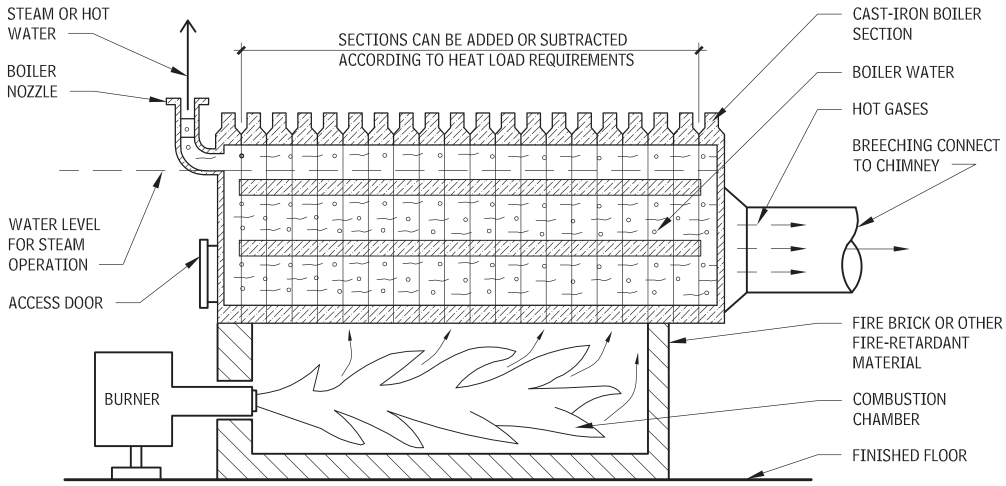
$$\text{Firing rate} = \frac{\text{gross rating}}{\text{fuel rating} \times \text{efficiency}}$$

$$\frac{168{,}000\ (\text{Btu/hr})}{140{,}000\ (\text{Btu/gal}) \times 80\%\ (.8)} = 1.5\ \text{gal./hr}$$

TYPICAL BOILER EQUIPMENT
13.84



CAST-IRON BOILER
13.86



BREECHINGS, CHIMNEYS, AND STACKS

CHIMNEY CONSTRUCTION

A chimney should be supported on a foundation of masonry, reinforced concrete, or other noncombustible material having a minimum fire-resistance rating of three hours. When installed on a boiler (or other appliance), the chimney should be supported so that it does not place excessive stress on the appliance. The base of the chimney should be secured to prevent movement of the chimney; anchor lugs should be used for this purpose whenever possible. A cleanout section may be used in the chimney assembly but must not be used above the chimney inlet.

CHIMNEY CLEARANCES

Chimneys of the medium-heat appliance or commercial industrial incinerator type are not intended to be enclosed in walls of combustible materials. These chimneys should be placed in fire-resistive or noncombustible shafts, where they extend through any floor–ceiling assembly above the location of the connected appliance.

An enclosed chimney may be placed adjacent to walls of combustible material with the following minimum clearances:

- 10 to 15 in. I.D. requires 16 in. clearance
- 15 to 21 in. I.D. requires 18 in. clearance
- 21 to 27 in. I.D. requires 20 in. clearance
- 27 to 36 in. I.D. requires 22 in. clearance

Where the chimney passes through a roof of combustible material, it must be installed with an insulated thimble and flashing. This insulated thimble may be installed at 0-in. clearance to combustibles. The chimney should extend at least 3 ft. above the highest point where it passes through the roof, and 2 ft. higher than any ridge within 10 ft.

VENT STACKS

The purpose of a vent stack is to conduct the products of combustion to a point of safe discharge (atmosphere). Forced-draft design eliminates the need for a stack designed to create a draft. An offset type of stack connection to the stub vent on the boiler is preferred.

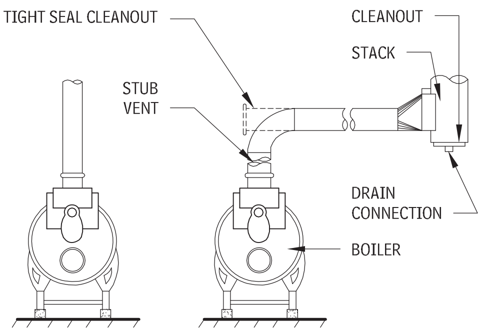
Contributors:
Kelly Sacher & Associates, Architects Engineers Planners, Seaford, New York; Joe H. Shaw, Everett I. Brown Company, Indianapolis, Indiana.

A direct vertical connection can also be made when boiler vent outlets can withstand the direct vertical load of the stack, including the effect of wind and guy wires.

VENTING OTHER GAS-FIRED EQUIPMENT

Refer to state and local codes and ordinances and manufacturers' literature for requirements governing installation, maintenance, clearances, gas piping, combustion air, and venting in specific situations.

VENT STACKS
13.87



VERTICAL CONNECTION **OFFSET CONNECTION (RECOMMENDED)**

CONDENSING FURNACES

Condensing furnaces are high-efficiency units that extract heat from exhaust gases to the point at which water and combustion by-products are condensed out of the gases. The condensed water is typically disposed of in a floor drain. These furnaces contain a multipass heat exchanger that recovers enough heat from the flue gas to yield annual fuel utilization efficiencies (AFUEs) in the range of 90 to 97 percent. Because the resulting flue gases are at a very low temperature, they can be vented directly through a roof or sidewall via plastic pipe and do not require a chimney.

Condensing furnaces can reduce heating costs when compared to noncondensing furnaces with typical AFUEs (in the range of 60 to 80 percent). As such, a condensing furnace is highly recommended for colder climates where heating costs are a major portion of the annual utility bill.

SOLAR ENERGY SYSTEMS

Solar energy reaches the earth's surface in the form of electromagnetic radiation in the wavelength band between approximately 0.3 and 3.0 micrometers (μm). Outside the earth's atmosphere, at the mean earth-sun distance (about 93 million miles) the radiant flux density on a surface normal to the sun's rays is about 437 Btu/hr.-sq. ft. This solar flux varies annually by about plus or minus 3 percent due to the earth's elliptical orbit, and is also subject to minor variations due to solar flares.

At the earth's surface, the solar irradiance falling on a horizontal surface varies from 0 at sunrise and sunset to a maximum of about 330 Btu/hr.-sq. ft. at solar noon on a clear day at sea level. This value varies with altitude and with latitude. The National Renewable Energy Laboratory (NREL) website provides valuable data on average daily solar radiation on various surfaces by month of year including the following:

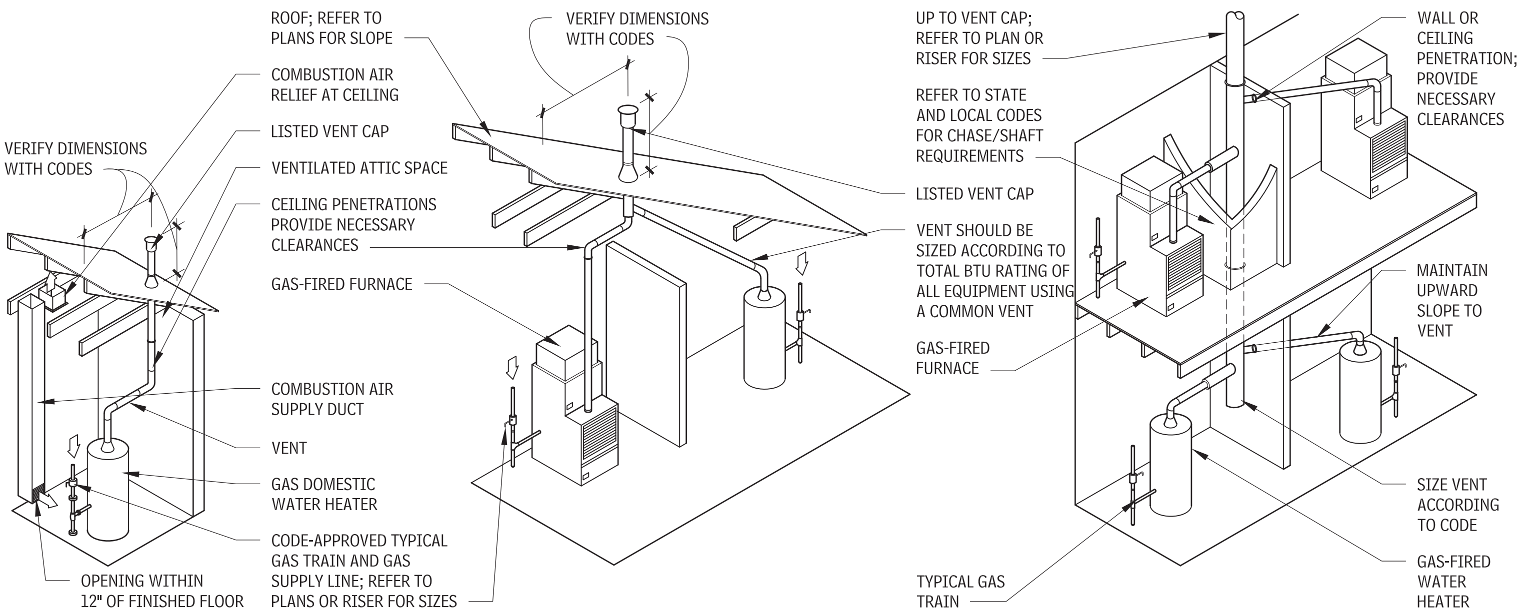
- http://rredc.nrel.gov/solar/old_data/nsrdb/1961–1990/bluebook/state.html: In the *Solar Radiation Data Manual for Buildings*, data is listed by city and are given for global diffuse, and for clear-day global. "Global" refers to the sum of direct (beam) radiation and diffuse radiation on a surface.
- http://rredc.nrel.gov/solar/pubs/redbook/: In the *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors*, global data are provided for flat-plate collectors at varying orientations; and direct (beam) radiation is provided for tracking, concentrating collectors.

SOLAR THERMAL COLLECTORS

Four types of thermal collectors are commonly used:

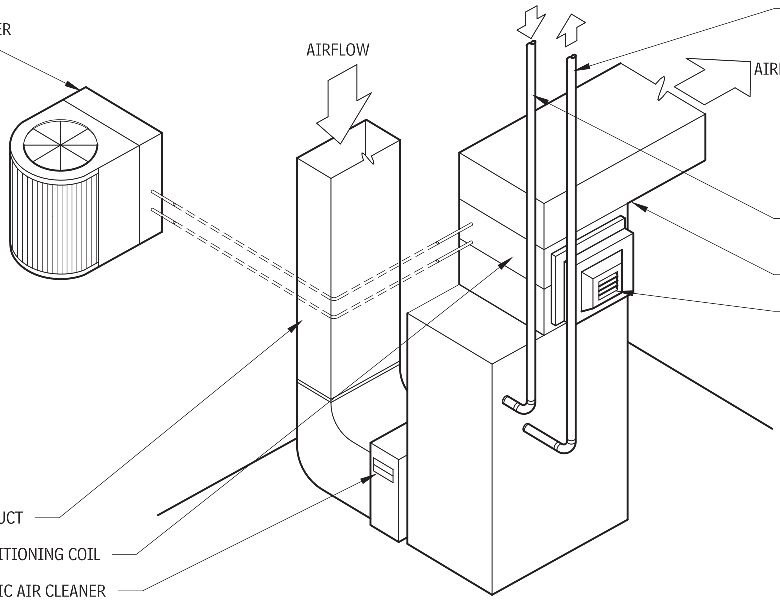
- Flat-plate collectors
- Concentrating collectors
- Compound parabolic concentrators (CPCs)
- Evacuated tube collectors

GAS APPLIANCES WITH VENT ARRANGEMENTS
13.88

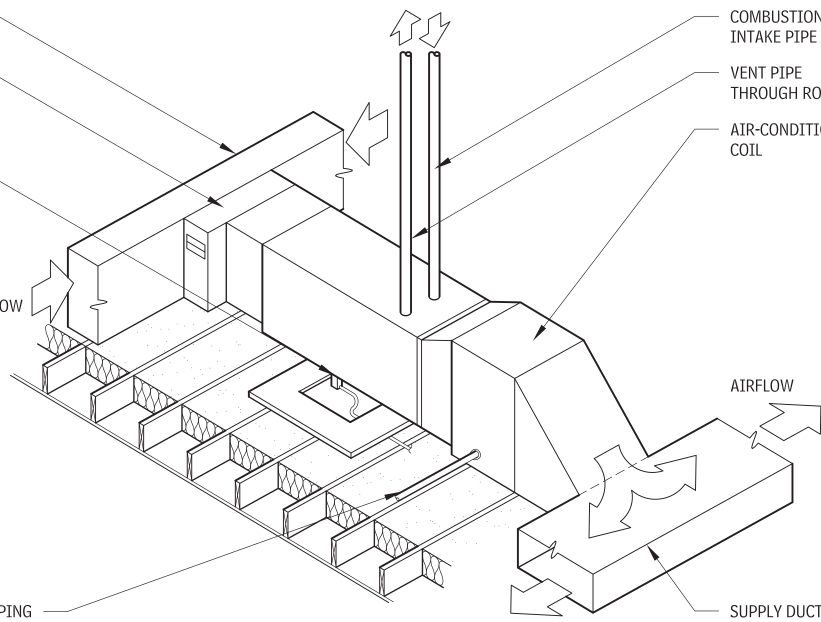


SINGLE APPLIANCE **MULTIPLE APPLIANCES–ONE LEVEL** **MULTIPLE APPLIANCES–MULTIPLE LEVELS**

UPFLOW BASEMENT FURNACE ARRANGEMENT
13.89



HORIZONTAL FURNACE
13.90



FLAT-PLATE COLLECTORS

Solar energy can be put to use at low and moderate temperatures by flat-plate collectors in which a blackened surface is used to absorb the incoming radiation and convert it to heat. This heat is then conducted to a fluid that passes through tubes or passages integral with or attached to the absorber surface. To minimize loss of heat from the absorber, glazing (single or double, of glass or a heat-resistant plastic) is used to reduce convection losses and to suppress long-wave radiation exchange with the sky. The rear side of the absorber is insulated, typically with glass fiber or foam insulation that can stand the relatively high temperatures (300°F to 400°F) that can exist under "stagnation" conditions. Stagnation occurs when the collector is exposed to full sunshine with no heat transfer fluid flowing through it. The entire unit is contained within a weatherproof box, and connecting pipes or ducts are provided to bring the fluid to the collector and to carry it away after being heated. The inlet and outlet ports are at diagonally opposite corners of the collector to provide even flow through the parallel passages.

Details of many types of flat-plate collectors are given in Chapter 35 of the *ASHRAE Handbook: HVAC Applications* (2015). The Solar Rating & Certification Corporation (SRCC; www.solar-rating.org) performs independent testing and certification of collectors and systems.

For swimming pool heating applications, which involve relatively low collection temperatures, collectors are often unglazed, and the absorber surface may be metal or plastic. However, for most applications the absorber surface is a metal such as copper, which has the good heat conduction properties desired of absorbers.

CONCENTRATING COLLECTORS

When high temperatures are required for industrial process heat- or power-generation applications, concentrating collectors must be used. These reflect or refract solar radiation onto a relatively small absorber surface, thus reducing the surface available for heat loss and enabling the fluid to attain temperatures that can exceed 1000°F. Such collectors must "track the sun" because they can only use the direct beam radiation from the sun. Some concentrating collectors can remain essentially fixed, but these are limited to concentration ratios of less than about 3:1, and thus moderate collection temperatures.

CPC AND EVACUATED TUBES

There are two collector designs that fall between the flat-plate and common concentrating collector: the compound parabolic concentrator (CPC) and the evacuated tube collector. Each of these designs permits collection in the moderate temperature range of about 150°F to 400°F. The evacuated tube design achieves better performance at higher temperatures by enclosing the absorbers in evacuated tubes, thus reducing losses. The CPC design achieves this by a novel type of concentration.

SOLAR ENERGY UTILIZATION SYSTEMS

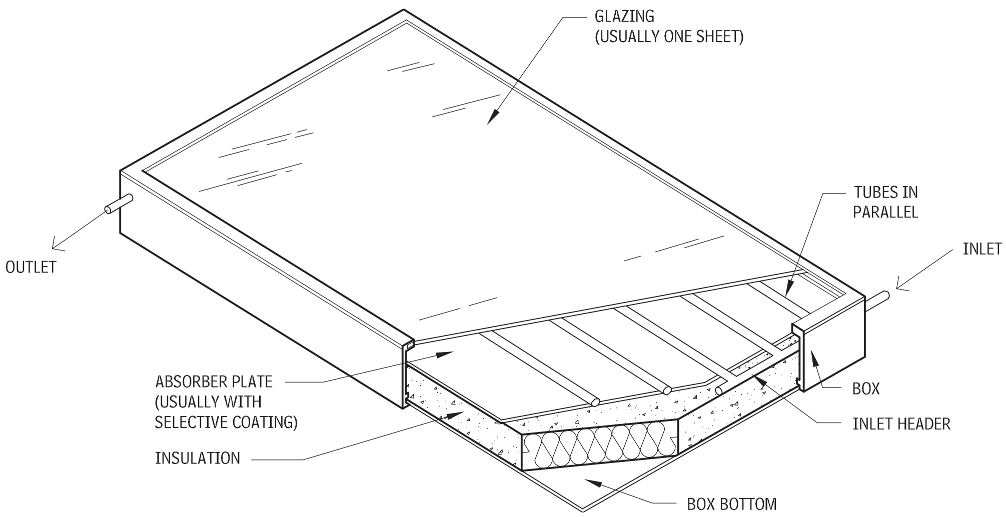
A system for using solar energy consists of an array of collectors; a thermal storage unit; and piping or ducting to distribute fluid between the collectors, storage, and the load. Pumps or blowers are used to circulate the heat transfer fluid, and control devices are used to actuate the circulators. Auxiliary or standby heat sources are generally needed to carry part of the load when demand is heavy and/or the weather has been unfavorable.

NOTE

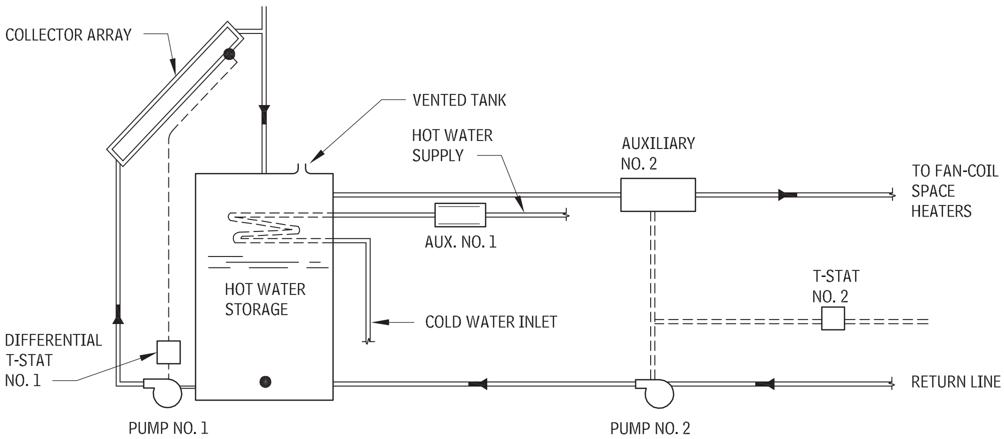
13.90 This configuration may also be used in a crawl space with the system suspended on hangers from the floor joists.

Contributor:
Larry O. Degelman, PE, Texas A&M University, College Station, Texas.

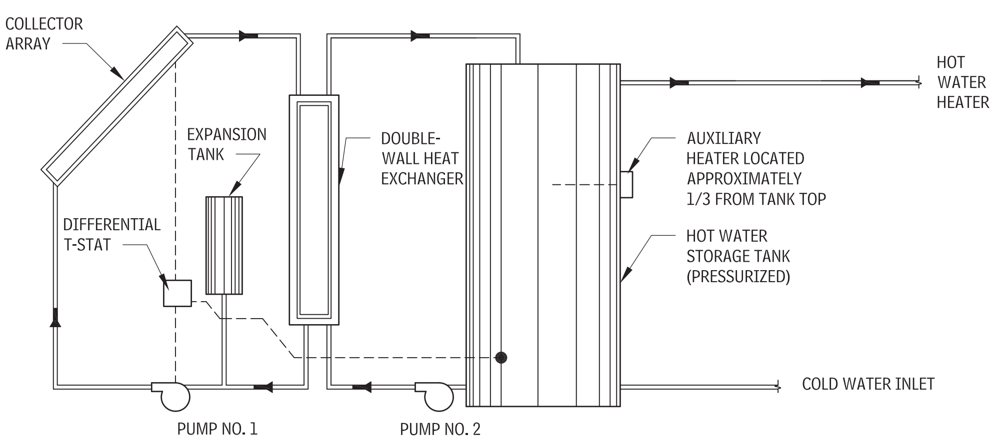
TYPICAL FLAT-PLATE SOLAR THERMAL COLLECTOR
13.91



DRAIN-DOWN SPACE HEATING AND DOMESTIC HOT WATER SOLAR SYSTEM
13.92



SOLAR DOMESTIC HOT WATER SYSTEM WITH COLLECTOR LOOP HEAT EXCHANGER
13.93



SOLAR ENERGY HEATING SYSTEMS

Figure 13.92 shows a simple system for providing space heating and domestic hot water, using a drain-down design in which the collectors are emptied to the storage tank whenever Pump No. 1 stops. A controller senses the temperature difference between the collector plate and the tank water and starts the circulation in Pump No. 1 when this difference exceeds a set value. This set difference is such that negligible thermal energy is collected for values below the set value.

Since solar thermal collectors work more efficiently when the temperature difference between the collector and the ambient air is low, fan-coil units with large areas of finned-tube heat transfer surface are generally selected for the space heating assignment. These can be used with water temperatures as low as 90°F. The auxiliary heat source in solar installations could be electricity, fuel oil, or natural gas.

SOLAR DOMESTIC HOT WATER SYSTEMS

Solar hot water (by itself) is one of the most attractive and cost-effective of solar applications. Figure 13.93 depicts a closed-loop design with an external heat exchanger, which isolates the domestic water from the collector loop fluid. In this case, antifreeze is likely the collector loop fluid, and an expansion tank is incorporated as appropriate. Other designs incorporate a smaller drain-down tank in the collector loop, which permits water, instead of antifreeze, to be used in the collector loop.

Domestic hot water is typically provided by an immersed coil located near the top of the main storage tank. The domestic hot water system operates under full line pressure, whereas the main tank is at essentially atmospheric pressure. Because of the remote possibility of a backflow from the main tank into the public water supply, some plumbing codes require a double-walled heat exchanger in isolating the collector loop fluid from the potable water. An auxiliary heater is provided to ensure an adequate supply of domestic hot water at all times.

For systems using electric auxiliary heating, an electric element is typically located about one-third from the tank top, as shown in Figure 13.93, and the reentry line from the collector issues slightly below this element. The element thermostat is typically set at about 135°F to keep the upper third of the tank heated. The lower two-thirds of the tank is reserved for solar, and if solar input is high and/or demand is low, the auxiliary element remains off and demand is met entirely by solar. For the case where gas is the auxiliary, it is necessary to use a two-tank design, wherein the gas heats a small tank and a second tank is heated by solar; and this serves as a preheat for the supply water to the gas water heater.

Scaling due to calcium carbonate or silica in some waters may be a serious problem. In such cases, a conventional closed loop system (Figure 13.93) can be used; but rather than the external heat exchanger, better options are a wraparound tank heat exchanger, a mantle-tank heat exchanger, or heat exchanger coil immersed in the tank. The system is simplified because Pump No. 2 is eliminated. When scaling occurs, it is on the inside of the tank wall or outside of the immersed coil, and though it may slightly reduce performance, it does not clog and impede flow.

INTEGRATED COLLECTOR-STORAGE

While the solar domestic hot water systems described here are all active systems (i.e., they have pumped fluid circulation) and have the collector located on the roof and the tank below, the integrated collector-storage (ICS) system is a fairly common design. In such systems, the solar storage vessel is typically a horizontal vessel integrated with the collector and located at its upper end. Heat is transported by natural circulation from the collector to the vessel. Some designs are open-loop (no heat exchanger in the vessel) and others are closed-loop (a heat exchanger in the vessel). The vessel serves as a preheater to the conventional water heater located in the semiconditioned space below. Such designs are very common in temperate locations such as Hawaii and South Florida.

NOTES

13.91 a. The design shown is an example of a typical liquid-cooled collector. Air-cooled collector design varies somewhat.
b. For further information on collector design and performance, see manufacturers' specifications.
13.92 Differential T-Stat No. 1 is outside the tank. There are two sensors, one on the collector (dot) and one in the tank near the bottom (dot).

Contributors:
John I. Yellott, PE, and Gary Yabumoto, College of Architecture, Arizona State University, Tempe, Arizona; Gary Vliet, PE, Mechanical Engineering, University of Texas at Austin, Austin, Texas.

It is becoming fairly common for domestic hot water systems to incorporate a PV-powered circulation pump in place of the common AC-powered pump. The pump operates when the sun shines, eliminating the differential thermostat; it also circulates water faster the higher the solar input, a desirable feature.

FREEZE PROTECTION FOR LIQUID SYSTEMS

When water is used for the heat transport fluid, freeze protection must be provided for essentially all locations within the continental United States. The drain-down system shown in Figure 13.92 is a fail-safe method to provide such protection, but it has certain disadvantages that, in many applications, make the use of an antifreeze fluid advisable. Figure 13.93 shows a widely used system in which water plus ethylene glycol or propylene glycol, or some similar antifreeze fluid, is circulated through the collector array by Pump No. 1. A double-walled heat exchanger is used to transfer the collected heat to the service hot water, which is under full line pressure.

SOLAR SWIMMING POOL HEATING SYSTEMS

A swimming pool heating application is a low-temperature one (80°F to 90°F) and, as such, can use a much simpler collector for use during the spring through fall months. As noted, the collectors are often unglazed with a plastic absorber, and are much less expensive than glazed collectors. The pool serves as the storage vessel, and the collector pump controls are similar to those described previously, except that there is an upper-limit temperature control to prevent the pool from overheating.

SOLAR ENERGY COOLING SYSTEMS

There are several means for providing cooling by solar power, including absorption cooling, desiccant cooling, and vapor compression cooling. Most installations have used the absorption or desiccant concepts. In general, solar cooling has not seen much success. The primary reasons are that these systems require relative high-performance collectors and the systems themselves are complex, making them generally less cost-effective than space heating and domestic hot water applications. Additionally, the duration of the cooling season tends to reduce cost-effectiveness in many applications. Of course, for commercial applications where cooling demand may be year-round, this doesn't apply.

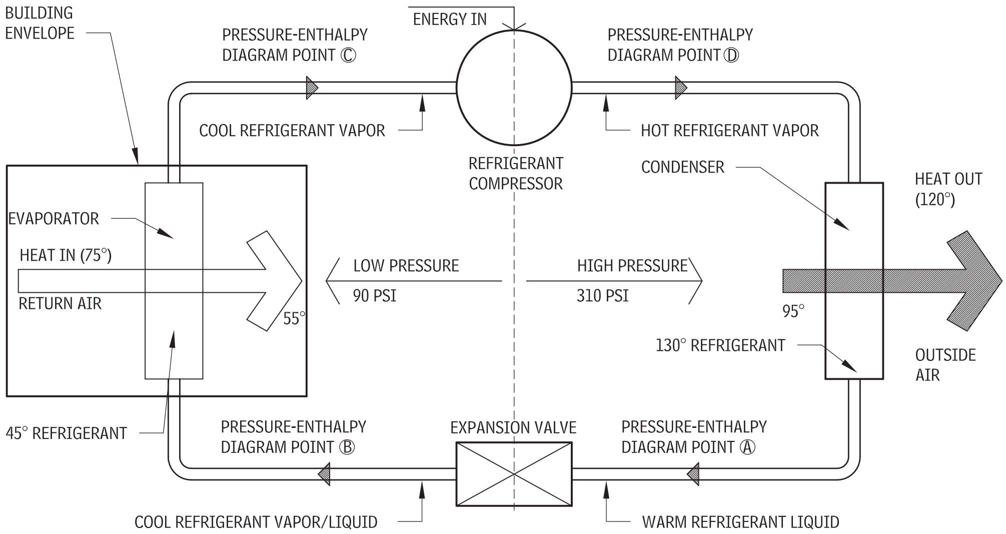
REFRIGERATION

A building cooling system moves heat from interior rooms to the outdoors. The efficiency of residential air-conditioning equipment is indicated by a seasonal energy efficiency rating (SEER), a measure of heat moved per watt of electrical input energy. The higher the SEER, the more efficient and less costly a piece of equipment is to operate. Larger cooling system efficiency is indicated by COP (coefficient of performance)—again the higher the COP, the higher the efficiency.

A large quantity of heat is required to boil or evaporate a liquid. This latent heat is the key to moving large quantities of heat with a small amount of refrigerant. To move heat from an area of low temperature to an area of high temperature (e.g., a building at 75°F to its surrounding environment at 95°F), refrigeration equipment uses a fluid that boils and condenses within a limited range of temperatures and operating pressures.

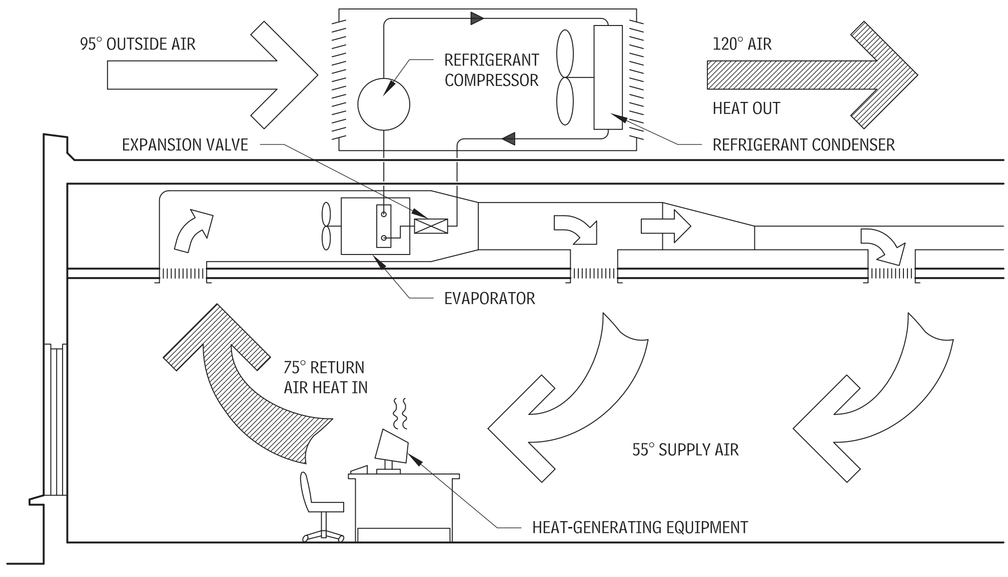
REFRIGERATION CYCLE

TYPICAL COOLING CYCLE TEMPERATURES AND PRESSURES
13.94



During the cooling process, refrigerant (as in a direct expansion evaporator coil in a split-system air-conditioning unit) absorbs heat from the building interior. This heat is absorbed by the refrigerant as it changes from a low-pressure liquid to a vapor. The low-pressure refrigerant vapor is then drawn into a package compressor and condenser unit, where it is compressed into a high-pressure vapor at high temperature. The resulting high-pressure refrigerant vapor is discharged into a condenser coil, where it gives up the latent heat absorbed in the evaporator and the heat added during compression and returns to a high-pressure liquid state. This high-pressure liquid is forced through an expansion device in which the pressure and temperature are rapidly decreased, making it possible for the evaporator to again absorb heat from the building.

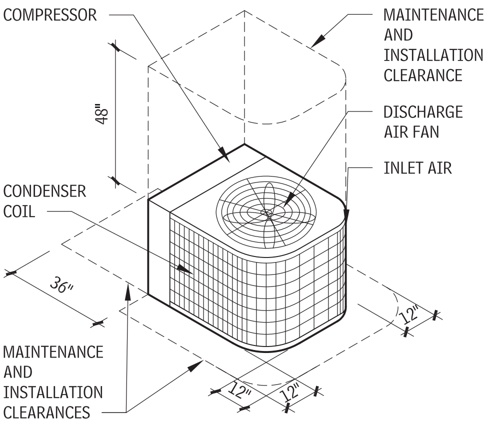
TYPICAL BUILDING APPLICATION
13.95



Contributor:
Jeff Haberl, Ph.D., PE, Texas A&M University, College Station, Texas.

The cooling cycle may be reversed to extract heat from a low-temperature source, such as outside air, to heat a building. The basic equipment is unchanged, with the exception of the addition of a four-way reversing valve and controls that permit the condenser and evaporator to exchange functions. A heat pump is more efficient than electric resistance heating because the only action required is to pump the refrigerant from a low-pressure vapor to a high-pressure vapor. The efficiency of a heat pump, measured as a coefficient of performance (COP), is a function of the temperature of the heat source.

CONDENSING UNIT
13.96



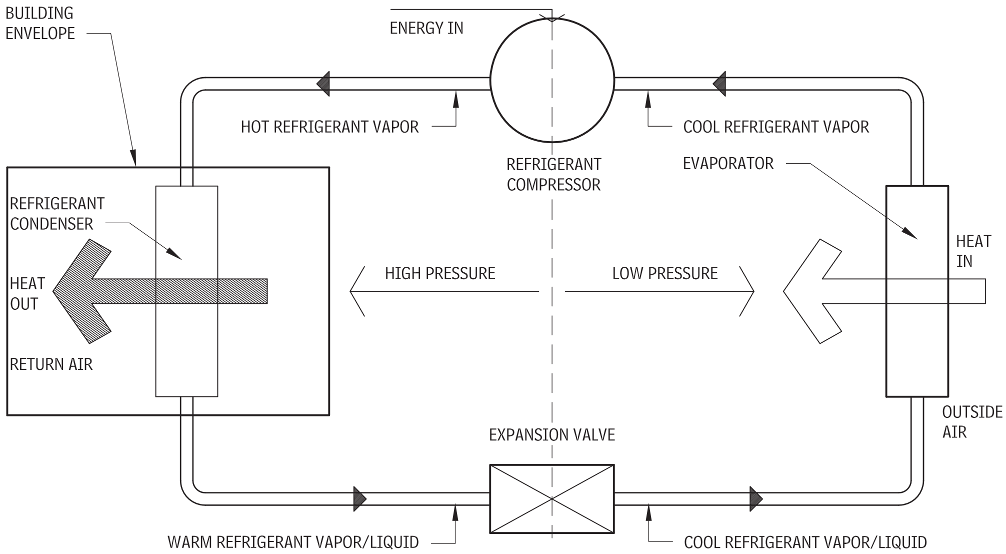
A large building air-conditioning system typically includes a packaged water chiller, cooling tower, and one or more air-handling units. The arrangement shown in Figure 13.203 offers substantial flexibility in equipment location and distribution. Chilled water is generated in a chiller (vapor compression or absorption) and circulated to air-handling units strategically located in the building. Condensing water from the chiller is circulated to an exterior cooling tower, where heat from the building is rejected to the outside environment. The chiller and air handler(s) may be located virtually anywhere in the building, and the cooling tower at an appropriate exterior location.

In an absorption cooling cycle, cooling is generated by absorbing and desorbing water in a salt solution. Just as common table salt absorbs water on a damp day, a strong salt solution (e.g., lithium bromide) will draw water out of moist air when it is sprayed into an enclosed tank (absorber). If this moist air is connected to another tank that contains water that is evaporating, it will transfer water vapor to the absorber tank to replace the water that was drawn into the lithium bromide solution. Eventually, this strong lithium bromide solution becomes diluted and is pumped into a generator tank, where excess water is boiled off. The strong solution is then cooled in a heat exchanger and expanded back into the absorber, where it can absorb more water. The water that was driven off in the generator is passed into a condenser, where it cools, condenses, and is then expanded back into the evaporator.

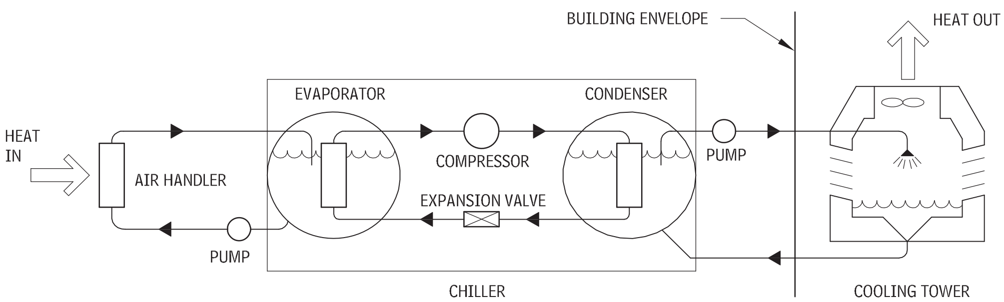
The refrigeration effect then draws off the (low-pressure) evaporator at 45°F to 55°F to produce chilled water. The absorption cycle accomplishes cooling without compressing a vapor, so it can operate with reduced amounts of electricity as long as adequate amounts of heat are available for the generator, and cooling for the condenser and absorber, and a reduced amount of electricity for the solution pumps.

Because an absorption cooling cycle does not use a mechanical compressor, it is quieter and vibrates less than a vapor compression chiller. It also uses less electricity for solution pumps than a vapor compressor uses to do its work. Absorption refrigeration is ozone-friendly and can be configured to operate in systems with limited or no electricity (e.g., recreational vehicles).

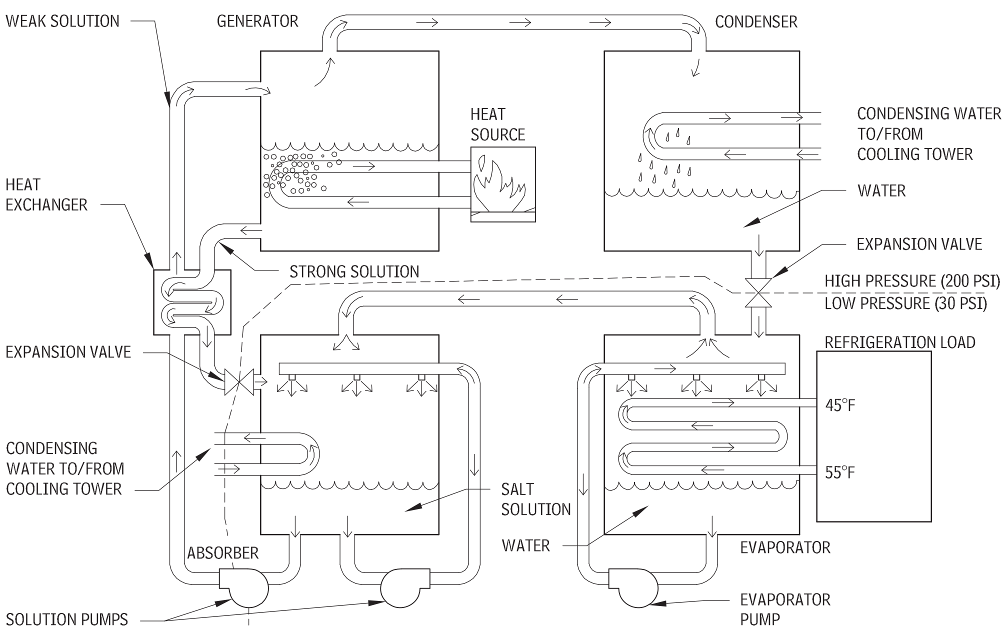
HEAT PUMP REFRIGERATION CYCLE
13.97



PACKAGED WATER CHILLER AND COOLING TOWER
13.98



ABSORPTION CYCLE
13.99



Contributor:
Jeff Haberl, Ph.D., PE; Texas A&M University; College Station, Texas.

WATER CHILLERS

Chilled water is the most common medium for transferring heat from any type of cooling equipment, such as cooling coils and heat exchangers, to some source of refrigeration.

A chilled water system is a closed-circuit system that recirculates water between a mechanical refrigeration water-chilling unit and remote cooling equipment, usually operating with water temperatures in the range between 40ºF and 55ºF. There are six types of refrigeration units used in chilled water systems:

- Centrifugal chiller, with electric motor or steam turbine drive
- Reciprocating water chiller, with electric motor drive
- Rotary-screw chiller, with electric drive
- Indirect-fired absorption chiller
- Direct-fired absorption chiller, using fuel oil or gas for firing
- Scroll chiller

When a chilled water piping system also is used to circulate hot water for winter heating, it is called a dual-temperature water system. The design water temperature of chilled water systems usually falls in a rather narrow range because of the necessity for dehumidification and to avoid a possible freeze-up in the chiller. Chilled water supply temperatures usually range from 42ºF to 60ºF for normal comfort applications.

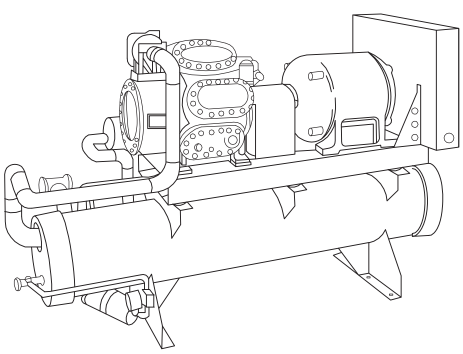
Design flow rates depend on the type of terminal apparatus and the supply temperature. In general, a higher temperature rise (or a greater temperature difference between supply and return temperatures) reduces the initial cost and the operating cost of the distribution system, as well as pumps required, and increases the efficiency of the chillers. In a given chilled water system, the selection of the design flow rate and the supply temperature, therefore, are closely related.

Although lower chilled water temperatures permit higher rises (or greater temperature difference), lower chiller efficiencies result. Water treatment may be required in chilled water systems to control corrosion rate, scaling, or algae growth.

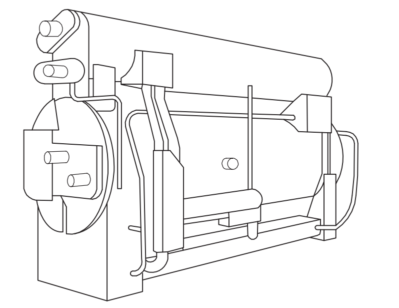
Layout of piping for chilled water distribution varies greatly depending on system capacity, extent of distribution, type of terminals used, and control scheme to be employed.

Refrigerants that attack the ozone layer above the earth are being phased out and replaced with refrigeration systems that do not degrade the ozone layer, such as R-123, R-134A, and ammonia. Ozone depletion potential (ODP) is a measure of this effect. Concern for ODP has expanded the consideration of absorption chillers, both indirect (steam) and direct-fired types. A related, but independent, concern is the effect of refrigerants on climate change. Global warming potential (GWP) is a measure of this effect. Concern for GWP has changed considerations regarding refrigerants.

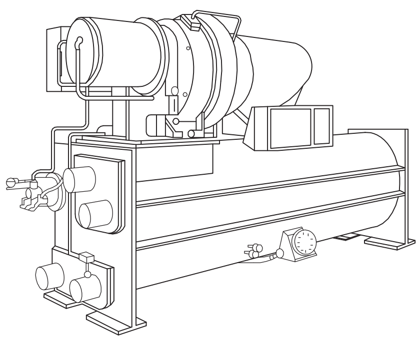
RECIPROCATING WATER CHILLER
13.100



ABSORPTION WATER CHILLER
13.101



CENTRIFUGAL WATER CHILLER
13.102



COOLING TOWERS

Cooling towers reject heat from water used in refrigeration condensers or other heat exchangers. Standard ratings are in tons of refrigeration when cooling 3 gal/min per ton from 95ºF to 85ºF with ambient air at 78°F wet bulb. Cooling tower design should be based on performance at local conditions. Packaged cooling towers operate with fans moving air horizontally (crossflow) or upward (counterflow) against water falling and wetting the fill or packing to expose maximum water surface to the air. Reduced airflow reduces tower performance. Architectural enclosures should minimize obstruction to airflow.

Warm water is distributed at the top of the cooling tower by spray nozzles or basins with multiple orifices, and cooled water is collected in a basin at the bottom and pumped to condensers. Water is cooled by evaporating a very small portion. Water droplets may also be carried out by the airstream. Minerals and impurities present in all water increase concentration as pure water evaporates, so a little water is "bled" and chemicals are added to minimize scaling, corrosion, or biological fouling of condenser tubes. Towers for critical or large systems should be multicell, for maintenance without shutdown.

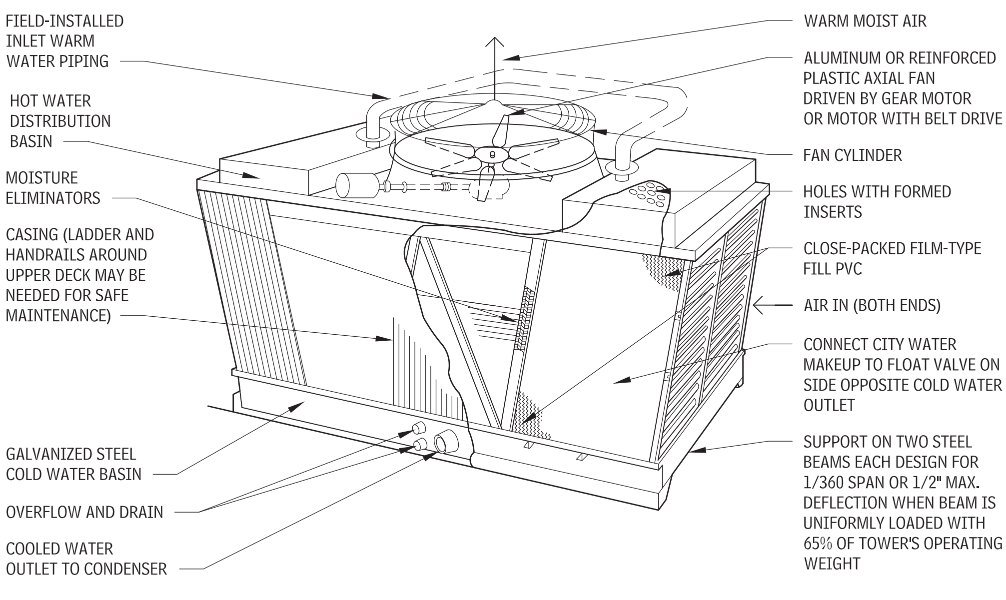
It is usually desirable to maintain condenser water temperature above a predetermined minimum, so return water is partially bypassed around the tower through a control valve to maintain desired supply water temperature. The required water flow rate depends on the refrigeration system used and the available temperature of the condenser water. Lower condenser water supply temperature results in increased refrigeration machine efficiency.

In a cooling tower system, air is continuously in contact with the condenser water. Special consideration is required for chemical treatment and allowance for impurities, scale, and corrosion in the condenser and piping system.

Fan, motor, and water-splashing noise may be a nuisance. Fan noise is reduced by two-speed motors (about 8 decibels [dB] at half speed, 15 percent power, and 60 percent capacity) and by intake and discharge attenuators (about 12 dB) with 10 percent power increase. Tower noise is louder in line with fan discharge and intake than in other directions. Each doubling of distance decreases sound pressure level by about 6 dB. Barriers can reflect some noise from critical directions. For design purposes:

- Locate towers for free air movement.
- Avoid hot air recirculation, long piping from pumps and condensers, and inadequate substructures.
- Locate cooling towers so that noise and water droplet carryover and fog at air discharge in cold weather will not be a nuisance.
- Consider seismic and wind load in anchoring tower to supports; towers are usually designed to withstand 30 psf wind load. The basin may be heated for winter use.

CROSSFLOW, INDUCED-DRAFT, PACKAGED COOLING TOWER
13.103



NOTES

13.100 Reciprocating water chillers are ideally suited to smaller jobs requiring less than 200 tons of cooling. Rotary screw chillers also operate in this capacity range.
13.101 Absorption water chillers are steam-powered for production of 200 to 800 tons of cooling.
13.102 A centrifugal chiller with a flooded cooler and condenser; typically will produce 150 to 1200 tons of cooling.
13.103 a. 200 to 700 ton capacity; pumps available in dual cells with twice the capacity.
b. Field-erected custom-designed cooling towers with casings of masonry or concrete used to enhance building aesthetics.

Contributor:
Joseph R. Loring & Associates, Inc., Consulting Engineers, New York, New York.

ENCLOSURE CONSIDERATIONS

Provide liberal wall openings on the air inlet side and mount towers so that the air outlet is at the top of the enclosure. Consider the effect of wind on nearby structures and enclosures to minimize recirculation of hot, moist discharge air into the inlet.

EVAPORATIVE CONDENSERS

A closed-circuit evaporative cooler and a cooling tower both operate on the principle of evaporative cooling, which depends on the wet bulb temperature of the air. Closed-circuit evaporative coolers are used when contamination of the condenser water by direct contact with outdoor air cannot be tolerated; they are available in sizes up to 300 tons.

Evaporative condensers combine the functions of a cooling tower and a water-cooling condenser. Latent heat transfer is more effective as a means of heat dissipation. This permits a smaller-sized unit than an equivalent tonnage air-cooled unit and considerable energy savings in fan horsepower.

Installations can be either within an equipment room with appropriate ducts or ground- or roof-mounted outdoors. Adequate protection from freezing must be provided for exterior installations.

For sizing of condensing units, the manufacturer's rating is the only reliable method of determining unit capacity.

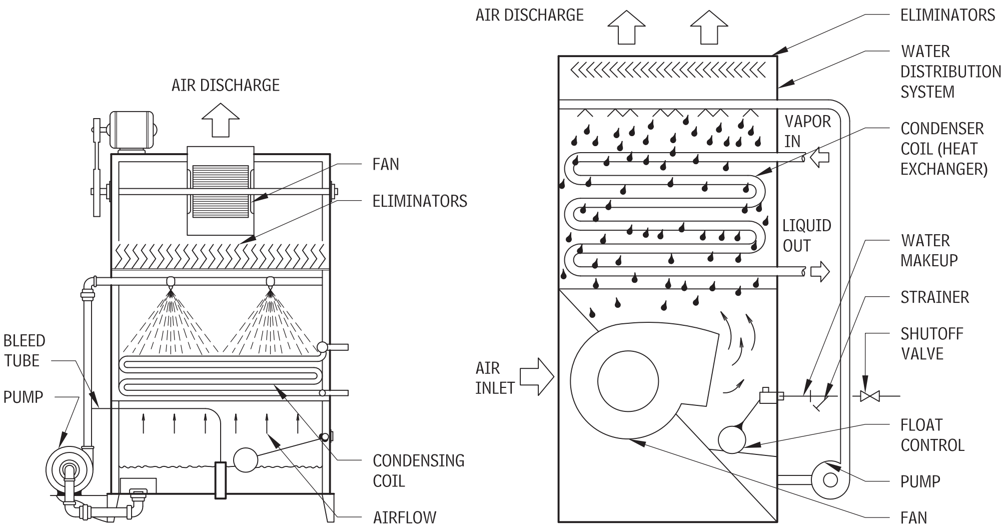
Multiple evaporative condensers may be connected in parallel, or an evaporative condenser may be connected in parallel with a shell-and-tube condenser. Proper piping and traps must be installed in these cases to prevent unequal loading or overloading.

The condenser water is circulated inside the tubes of the unit's heat exchanger. Heat flows from the condenser water through the heat-exchanger tubes to the spray water outside, which cascades downward over the tubes. Air is forced upward through the heat exchanger, evaporating a small percentage of the spray water, absorbing the latent heat of vaporization, and discharging the heat to the atmosphere.

The remaining water falls to the sump to be recirculated by the pump. The water consumed is the amount evaporated plus a small amount that is bled off to limit the concentration of impurities in the pan.

The condenser water circulates through the clean, closed loop of the heat exchanger and is never exposed to the air stream or the spray water outside the heat-exchanger tubes.

EVAPORATIVE CONDENSERS
13.104



DRAW-THROUGH TYPE **BLOW-THROUGH TYPE**

HVAC DISTRIBUTION ARRANGEMENTS AND COMPONENTS

RESIDENTIAL SYSTEMS

ELECTRIC HEATING SYSTEMS

Electric resistance can be used as a heat source in a variety of central heating systems. An electric boiler with an immersion heating element can provide hot water for a heating-only system with radiator or convector terminal units, or for an all-water or air-water HVAC system. An electric furnace, with a heating coil, fan, and air filter, can provide warm air for a central all-air HVAC (or heating-only) system. This type of system is essentially a small-capacity version of a single-zone, all-air system. Electric resistance elements can also be inserted in ductwork or at terminal boxes to provide heating capability in central HVAC systems. Heat pumps are another means of heating with electricity.

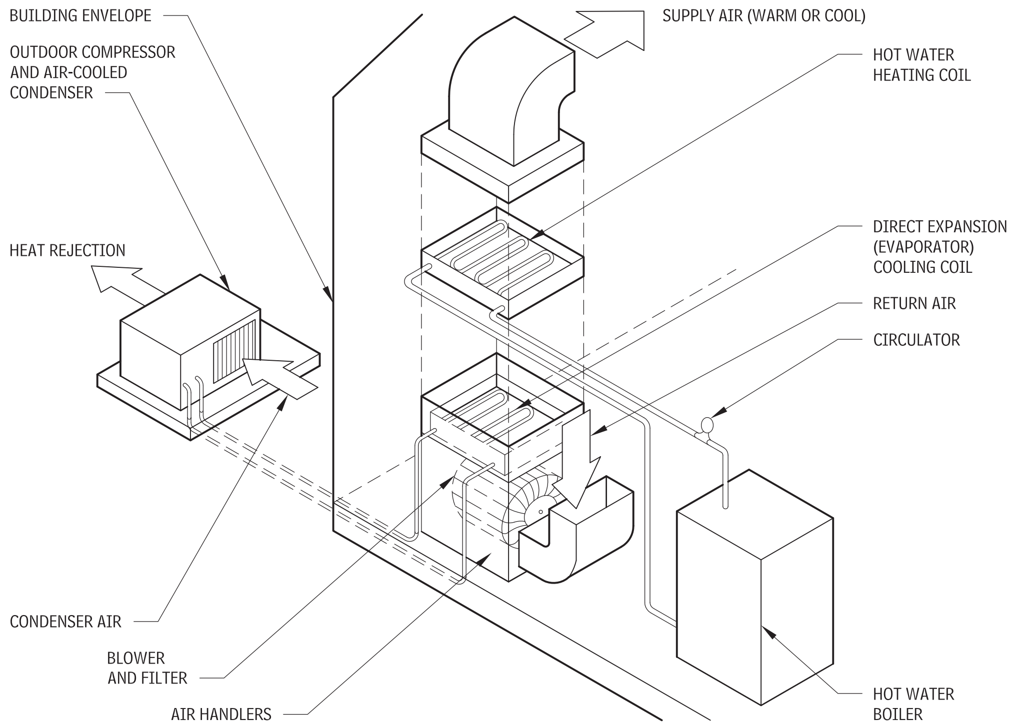
WARM-AIR FURNACES

Warm-air furnace units—using either electric resistance or gas as the heat source—are designed primarily for residential, small commercial, or classroom heating. Cooling can be added to these units by installing a cooling coil downstream from the furnace, with refrigerant compressor and condenser located remotely outside the building.

Ductwork from the furnace can be installed above the ceiling or in a furred-down soffit. Distribution systems above the ceiling are usually the radial type with high wall registers. Ductwork also may be installed below living spaces, in a crawl space, or a basement.

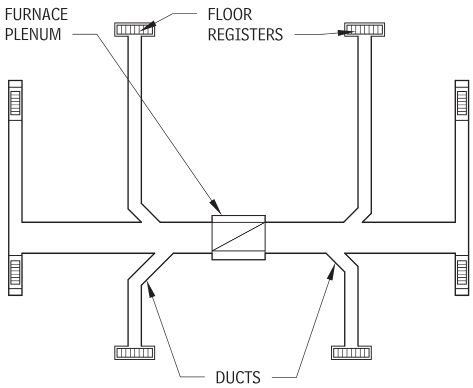
Two- or three-story buildings using similar warm-air furnace and cooling-coil combinations are centrally air-conditioned via a vertical extension of the branch ductwork through walls and partitions. All variations of warm-air heating and cooling systems recirculate air within the building envelope, making it crucial to leave adequate return air passage opportunities from each space back to the furnace room.

OVERHEAD AIR SYSTEM WITH DUCTED RETURN
13.105

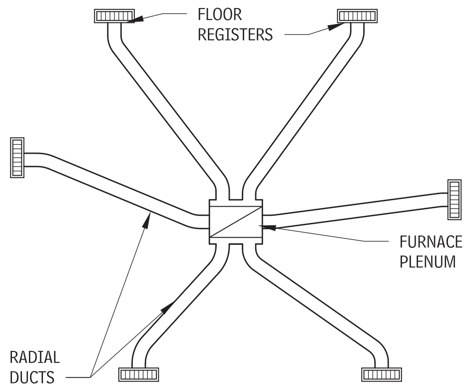


Contributors:
Walter T. Grondzik, PE, Ball State University, Muncie, Indiana; Jeff Haberl, PhD, PE, Texas A&M University, College Station, Texas.

COMMON DUCT SYSTEM LAYOUTS
13.106



EXTENDED PLENUM SYSTEM



PERIMETER RADIAL SYSTEM

NONRESIDENTIAL SYSTEMS

The distribution system in central and district HVAC systems connects primary source elements (chillers and boilers) and/or secondary source elements (air-handling units) to the various zones in a building requiring conditioning. Interbuilding distribution in district systems is always via water (hot or chilled) or steam. Intrabuilding distribution can be via air, water, or (less commonly) steam. Central system distribution classifications include: all-air, all-water, and air-water.

ALL-AIR SYSTEMS

In a central all-air system, the heating and refrigerating plants may be located in a central mechanical room some distance from the conditioned space, or may be provided as packaged units in the air-conditioned spaces or on the roof. The air-handling unit is designed to mix outdoor and return air as desired; then to filter, heat, cool, and humidify the air before it is delivered to conditioned spaces. It may also exhaust portions of the return air based on the balance between outdoor and return air.

All air temperature/humidity control functions do not have to occur within the air-handling unit. Depending on the specific design criteria and space conditions, some air temperature/humidity modification components (such as a reheat coil) may be remote from the air-handling unit.

Common all-air systems include: single-duct, constant or variable volume airflow; dual duct (rarely used); multizone; single-duct with powered terminal and either constant or variable volume airflow; and a single-duct system with self-contained airflow volume controls and thermostats in each diffuser in the conditioned space. The use of terminal reheat, previously a go-to approach for space control, is severely restricted by energy codes.

Components of a basic all-air system include:

- *Minimum outside air damper:* Usually two positions.
- *Variable outside air damper:* Closed when only minimum outside air is desired (e.g., when outside air temperature is extremely high or low). Designed to open in response to the capability of outside air to contribute to mitigation of a building's heating or cooling needs. Exhaust and return air dampers are controlled to operate in accordance with the setting of the variable outside air damper.
- *Preheat coil (PHC):* Required only if the temperature and distribution of the return air mixture could cause freezing temperatures within the casing.
- *Air-handling unit (AHU):* May be field- or factory-fabricated. Pitch the floor of the AHU casing between components, as required, and provide piped floor drains to remove any moisture that develops.
- *Cooling coil:* Cooling coil may be a direct-expansion (DX) coil or a chilled water coil.
- *Humidifier (H):* May use steam or water as the humidification medium.
- *Reheat coil (RHC):* Used in the air-handling unit only when a fixed discharge air temperature is to be supplied to all areas served by the duct system. If different spaces require varying temperatures, a separate reheat coil may be placed (in conformance with codes) in each duct serving a different temperature zone.

TERMINAL CONTROL UNITS

Air terminal control units are a key element of many common HVAC systems, including variable-air volume (VAV) and dual-duct systems. These devices—which regulate airflow volume—are usually located adjacent to the zones they serve and require space/volume for transitions and connections to the central air distribution network and to the supply air devices. Terminal boxes should be installed in readily accessible locations to permit adjustment and maintenance.

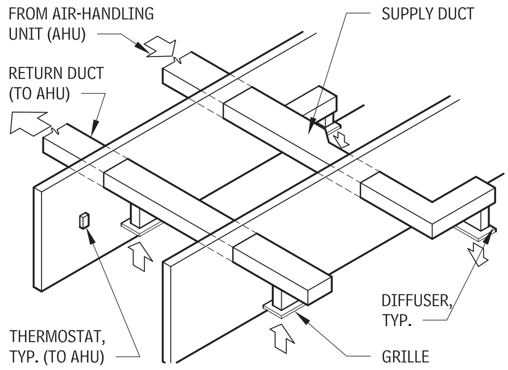
Several HVAC distribution system configurations are commonly used in medium to large buildings, including constant-volume single duct, variable-volume single duct, dual duct, and multizone.

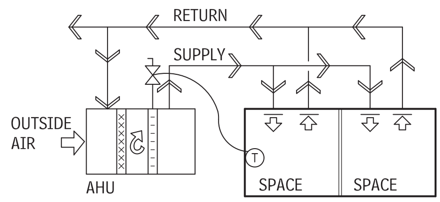
CONSTANT-VOLUME SYSTEMS

SINGLE-ZONE ALL-AIR SYSTEMS

Single-zone all-air systems have only one point of control (one thermostat for the system, equals one zone). The system operates with a constant airflow from the air-handling unit and through the diffusers, with the thermostat controlling supply air temperature in response to load. Any number of diffusers may be provided to meet air distribution needs. Numerous air-handling unit configurations are available. This type of system may be found in residential, retail, and industrial buildings, and in interior (core) spaces of complex buildings. Multiple systems may be used to provide multiple zones.

SINGLE-ZONE AIR DISTRIBUTION
13.107



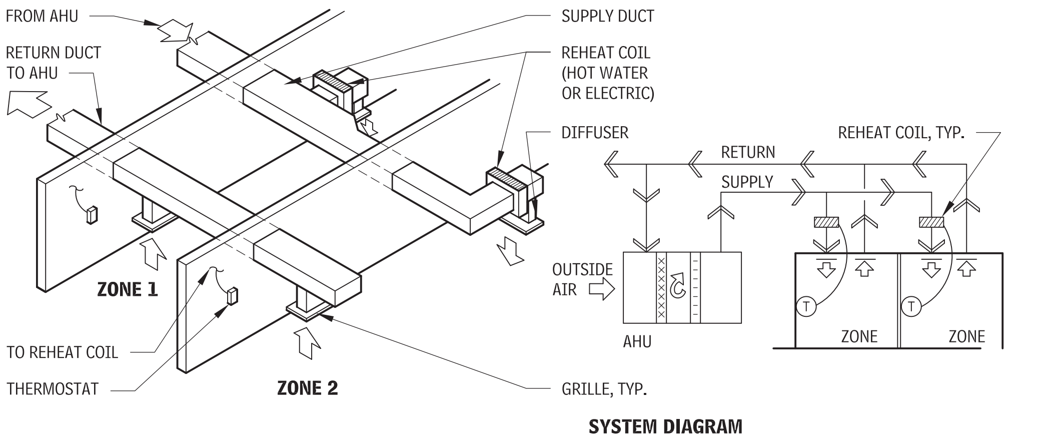


SYSTEM DIAGRAM

TERMINAL REHEAT AIR DISTRIBUTION

A terminal reheat air distribution system can serve virtually an unlimited number of zones. The system meets loads by varying the supply air temperature through the diffusers in each zone under the control of zone thermostats. The system is very flexible because zone control occurs at coils (electric or hot water) located near the conditioned spaces. A terminal reheat system can provide excellent comfort conditions (by providing constant airflow and humidity control) and simultaneous heating and cooling. Unfortunately, the reheat approach wastes substantial energy and is generally to be avoided unless the reheat comes from renewable energy sources (waste or reclaimed heat or solar energy). Terminal heating may be combined with variable volume air delivery.

TERMINAL REHEAT AIR DISTRIBUTION
13.108



CONSTANT-VOLUME SINGLE-DUCT WITH TERMINAL REHEAT

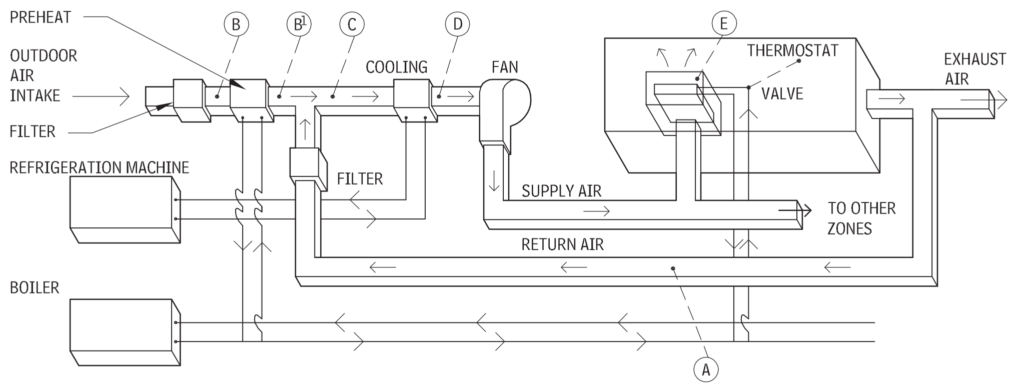
This system provides a constant flow of air to the system zones. Zone temperature is maintained by reheating (as necessary) the constant-supply airflow to each zone. Cooling and dehumidification is provided by a cooling coil located in the air-handling unit. Heating is provided in the outside air preheat coil and in the reheat coil, using hot water from a boiler or electric resistance. Normally, the amount of outside air provided corresponds to the ventilation required to maintain indoor air quality.

Winter and summer operation of the system is best understood by extracting the system state points from a psychrometric chart. Assume summer outdoor conditions of 95°F, 50 percent relative humidity (RH), with desired space conditions of 78°F and 50 percent RH; system operation points of 10 percent outside air, cooling coil set point of 55°F, and a maximum reheat coil set point of 110°F. The preheat coil is assumed to be inactive in the summer, and the cooling coil to be inactive in the winter when the mixed air is less than 55°F.

ADVANTAGES
- Can provide heating and cooling as needed.
- Provides good dehumidification.
- Boiler and chiller can be installed at a central plant.
- Air-handling unit runs continuously, providing good ventilation.
- Equipment life is long.
- An economizer can be added to take advantage of free cooling during appropriate conditions.

DISADVANTAGES
- There is no humidification, so this type of system may produce very dry conditions indoors during the winter.
- Requires distribution ductwork to each zone.
- Air-handling unit runs continuously, which can cause excessive energy consumption.
- Reheat coils require piping to run to each zone or electric resistance heating.
- Use of reheat during dehumidification uses unnecessary heating in the summer.
- Chiller and boiler both must operate except in extreme winter conditions.

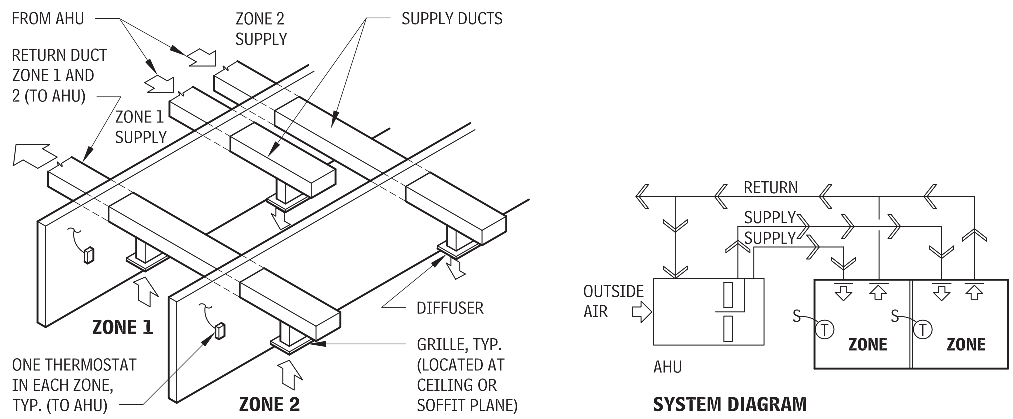
CONSTANT-VOLUME SINGLE-DUCT SYSTEM WITH TERMINAL REHEAT
13.109



MULTIZONE AIR DISTRIBUTION

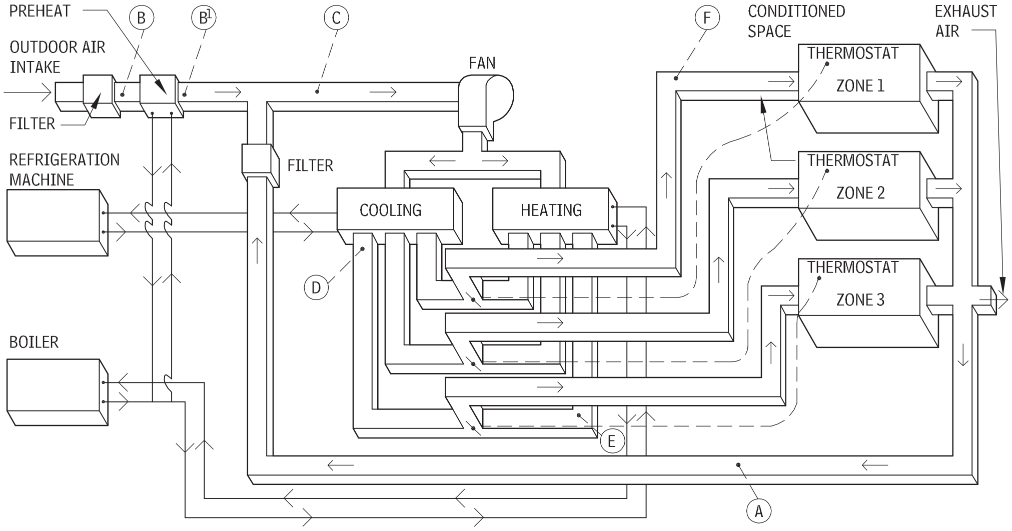
A multizone air distribution system can serve approximately 10 zones per air-handling unit (depending upon equipment manufacturer). The system operates with constant airflow from the air-handling unit and through the diffusers; zone thermostats control the supply air temperature delivered to each zone in response to load. A dedicated supply air duct serves each zone. This system can provide good control of space conditions at moderate energy cost. Because zone control occurs at the air-handling unit, this is not a flexible system. The numerous supply ducts make system layout and coordination critical. Multiple air-handling units may be used to provide additional zoning capability.

MULTIZONE AIR DISTRIBUTION
13.110



Contributor:
Alfred Greenberg, PE, CEM, Murray Hill, New Jersey.

CONSTANT-VOLUME MULTIZONE SYSTEM
13.111



CONSTANT-VOLUME MULTIZONE

A constant-volume multizone system provides a constant flow of air to the zones served by the system. Zone temperature is maintained by changing the temperature of the zone supply air leaving the air-handling unit. Dehumidification is provided by the cooling coil. The system shown in Figure 13.111 does not provide humidification, but a dehumidification device can be added just after the main heating coil for each zone. Cooling is provided by a direct-expansion or chilled water-cooling coil. Heating is provided in the outside air preheat coil and in the main heating coil, typically using hot water from a boiler (or electric resistance). Normally, a fixed amount of outside air is provided corresponding to indoor air quality needs. Hot and cold air are both always available to each zone. Varying amounts of hot and cold air are mixed according to the required cooling or heating load in each zone. The temperature of the air leaving the cooling coil is between 45°F (winter) and 55°F (summer). Air leaving the heating coil is at 110°F; or it can be moderated by an outside reset thermostat.

Summer and winter operation of the system is best understood by extracting system state points from a psychrometric chart. Assumptions for summer and winter conditions are those described above for the constant-volume single-duct system.

ADVANTAGES

- Can provide heating and cooling as needed.
- Provides good dehumidification.
- Boiler and chiller can be installed at a central plant.
- Air-handling unit runs continuously, providing good ventilation.
- Equipment life is long.
- Multizone systems can be equipped with variable-volume fans for reduced energy use.

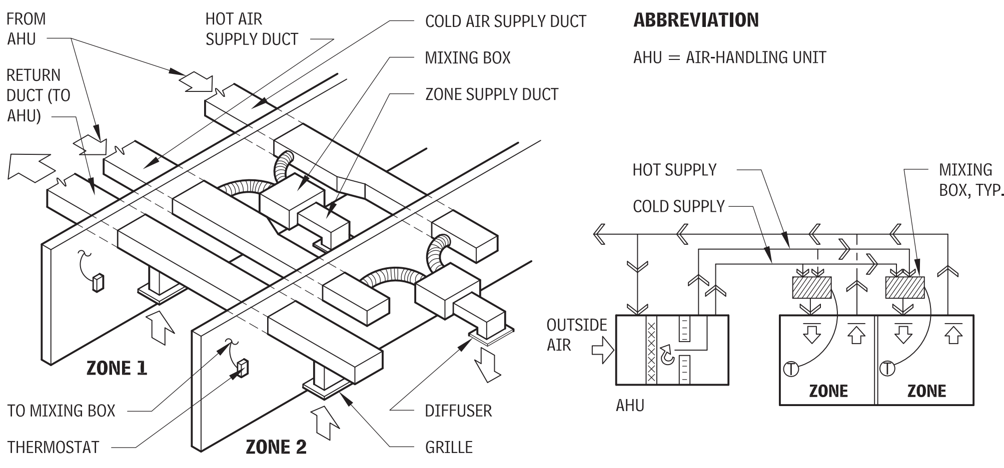
DISADVANTAGES

- There is no humidification, so this type of system may produce very dry conditions indoors during winter.
- Requires distribution ductwork to each zone.
- Air-handling unit runs continuously, which can cause excessive energy consumption.
- Use of reheat during dehumidification uses additional energy in the summer.
- Chiller and boiler both must operate except in extreme winter conditions.

DUAL-DUCT AIR DISTRIBUTION

A dual-duct air distribution system can serve a virtually unlimited number of zones. The system meets loads in the various zones by mixing hot and cold airstreams from the air-handling unit in response to zone thermostats. The system is very flexible because zone control occurs in mixing boxes located near the conditioned spaces. A dual-duct system provides good comfort and air quality conditions at reasonable energy cost. The need for two separate supply air distribution ducts, however, requires excellent coordination between air distribution and other services. Dual-duct systems may be designed with either a constant- or variable-volume air supply.

DUAL-DUCT AIR DISTRIBUTION
13.112



ABBREVIATION

AHU = AIR-HANDLING UNIT

SYSTEM DIAGRAM

CONSTANT-VOLUME DUAL-DUCT

A constant-volume dual-duct system provides a constant flow of air to system zones. Zone temperature is maintained by changing the temperature of the airflow leaving the terminal mixing box for each zone. Dehumidification is provided by the cooling coil. Humidification is not shown in Figure 13.113, but can be added by inserting a humidification device immediately after the main heating coil. Cooling is provided by a direct-expansion or chilled water-cooling coil. Heating is provided in the outside air preheat coil and in the main heating coil, using electric resistance or hot water from a boiler. Normally, the amount of outside air provided corresponds to the indoor air quality needs of the anticipated occupancy. In a dual-duct system, both hot and cold airstreams are always available to each terminal mixing box. Varying amounts of hot and cold air are mixed in the terminal boxes to meet the required cooling or heating load. The temperature of the air leaving the cooling coil is between 45°F (winter) and 55°F (summer). Air leaving the heating coil is fixed at 110°F or can be moderated by an outside reset thermostat.

Winter and summer operation of the system is best understood by extracting system state points from a psychrometric chart. Assumptions for summer and winter conditions are the same as those for the constant-volume single-duct system above.

ADVANTAGES

- Can provide heating and cooling as needed.
- Provides good dehumidification.
- Boiler and chiller can be installed at a central plant.
- Air-handling unit runs continuously, providing good ventilation.
- Equipment life is long.
- Dual-duct systems do not require piping to run to each zone.

DISADVANTAGES

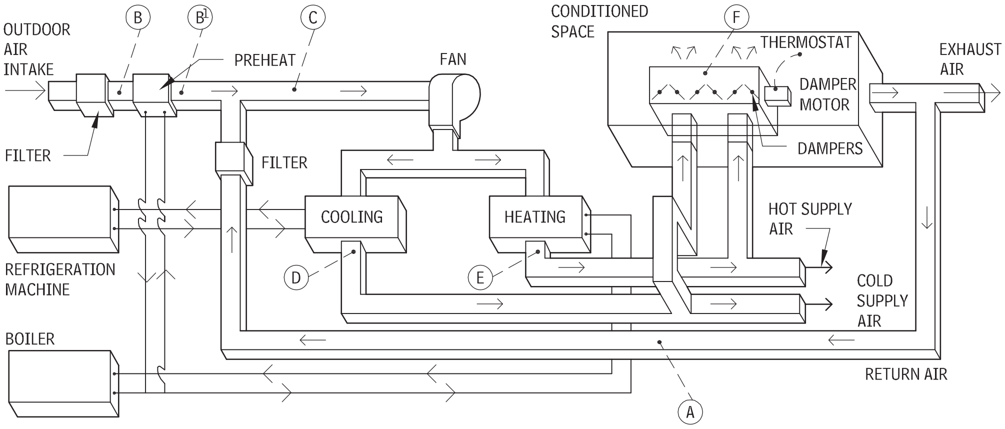
- There is no humidification, so this type of system may produce very dry conditions indoors during winter.
- Requires routing of two ductwork elements to each zone.
- One main heating coil may cause hot interior zones when internal loads require year-round cooling.

VARIABLE-VOLUME DUAL-DUCT

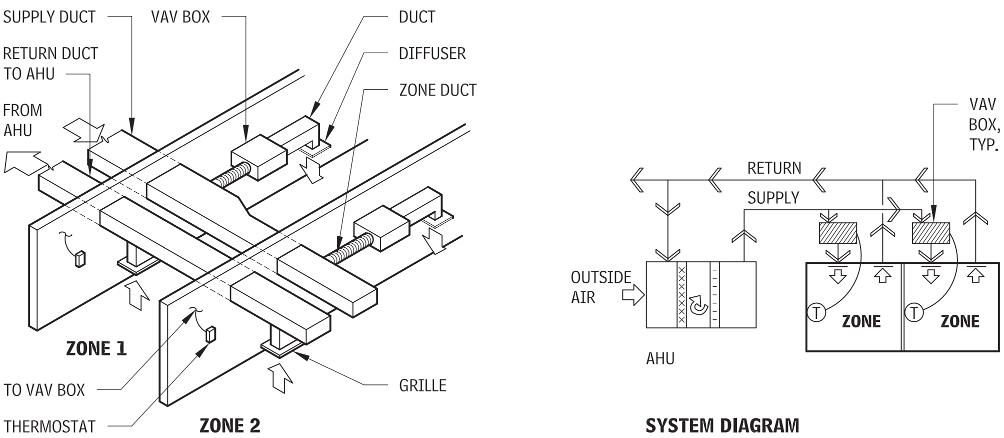
This system can easily be modified to make a variable-volume dual-duct system, by installing a variable-speed controller on the main fan and modifying the terminal mixing boxes to allow for varying airflow rates.

Contributors:
Jeff Haberl, PhD, PE, Texas A&M University, College Station, Texas;
Walter T. Grondzik, PE, Ball State University, Muncie, Indiana.

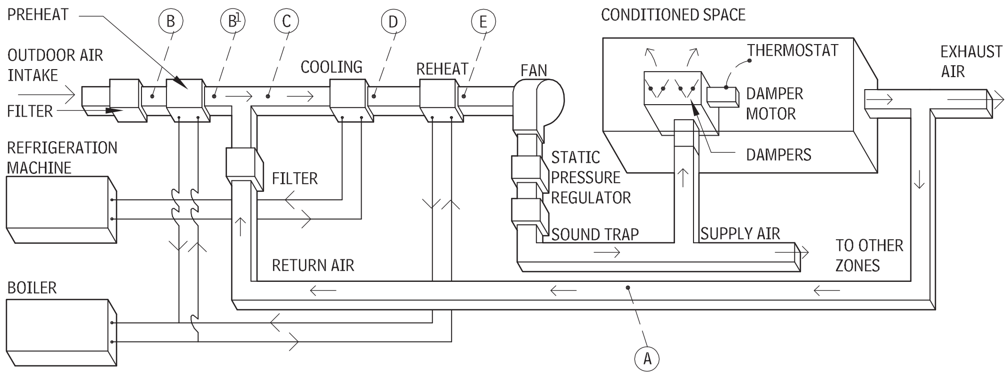
CONSTANT-VOLUME DUAL-DUCT SYSTEM
13.113



VARIABLE AIR VOLUME (VAV) AIR DISTRIBUTION
13.114



VARIABLE-VOLUME, SINGLE-DUCT SYSTEM WITH REHEAT
13.115



VARIABLE-VOLUME SYSTEMS

VAV SYSTEM

A variable air volume (VAV) system can serve a virtually unlimited number of zones. The system meets loads by providing a varying rate of airflow through the diffusers in each zone under the control of zone thermostats. The resulting reduction of airflow at the air-handling unit (under all but full-load conditions) permits serious savings in fan energy compared to other control approaches. VAV systems are very flexible and can accommodate changes in space usage because zone control occurs at VAV boxes located near the conditioned spaces. A VAV system, however, is essentially a cooling-only system, so some means of space heating must be provided (an independent heating system, such as a hot water baseboard radiator; fan-powered or induction terminals with electric or hot water heating). VAV systems can provide excellent comfort with good energy efficiency, but air quality issues must be examined during system design. Several fan and air supply control options are available to minimize system energy use at part loads.

VARIABLE-VOLUME SINGLE-DUCT WITH REHEAT

This system provides a variable flow of air to the zones. The amount of air is regulated by control boxes serving each zone that act as flow-regulating valves. Static pressure is maintained by varying the fan speed. For zone cooling, the temperature in each zone is maintained by changing the supply airflow rate. In the winter, a thermostat in each zone regulates the reheated airflow to meet the zone load. Dehumidification is provided by the cooling coil. Humidification is not provided, but can be added by inserting a humidification device immediately after the fan. The cooling coil can be either direct expansion or chilled water. Electric resistance or hot water from a boiler provides heating at the outside air preheat coil and in the reheat coils. Normally, a fixed amount of outside air is provided, corresponding to the ventilation air appropriate for anticipated occupancy levels.

Winter and summer operation of the system is best understood by extracting the system state points from a psychrometric chart. Assume summer conditions of 95°F and 50 percent RH outdoors, space conditions of 78°F and 50 percent RH, and system operating points of 10 percent outside air, cooling coil set point of 55°F, and a maximum reheat coil set point of 110°F. The preheat coil is assumed to be inactive in the summer.

ADVANTAGES

- Can provide heating and cooling as needed.
- Provides average dehumidification.
- Boiler and chiller can be installed at a central plant.
- Air-handling unit runs continuously at variable volume, which can provide adequate ventilation.
- Equipment life is long.
- An economizer can be added to take advantage of free cooling during appropriate exterior conditions.
- Does not require piping into individual zones.

DISADVANTAGES

- There is no humidification, so this type of system may produce very dry conditions indoors during winter.
- Requires distribution ductwork to each zone.
- Volume of air moved by air-handling unit varies, which can result in inadequate ventilation if not properly balanced.
- One main reheat coil for the entire system can result in a very cold building in extremely humid climates. Could require humidity sensor to moderate supply air temperature, to maintain humidity at or below 60 percent RH.
- Use of reheat for dehumidification requires unnecessary heating energy in the summer.
- One main heating coil may cause hot interior zones when internal loads require year-round cooling.

Contributor:
Jeff Haberl, PhD, PE, Texas A&M University, College Station, Texas.

AIR-WATER SYSTEMS

An air-water system combines the most beneficial characteristics of air-based and water-based central distribution systems. The key benefit of a water system is reduced volume of distribution components (pipes versus ducts) as a result of water's thermal efficacy. The key benefit of an air system is the ability to reliably deliver conditioned and filtered outdoor air to spaces as part of the indoor air quality mitigation strategy. An air-water system can provide the best of both distribution worlds.

In a central air-water system, the heating and refrigerating plants will be located in a mechanical room some distance from the conditioned spaces. One or more air-handling units will supply tempered and filtered outdoor air to the spaces. The volume of air supplied is typically just what is needed for appropriate air quality control.

Air-water systems involve an air side—usually a constant-volume, unzoned system, with air introduced to the spaces via conventional diffusers/registers or (less commonly) through the water-side terminal unit; and a water side, where heating/cooling effect is introduced to the spaces via a terminal device (heat exchanger).

SYSTEM ARRANGEMENTS AND COMPONENTS

The induction system was historically a high-end air-water system; it has essentially been replaced by fan-coil systems. Fan-coil units, which may be used in both air-water and all-water HVAC systems, are a very common terminal device (available in a wide range of configurations). Radiant panels may serve as the terminal device, for both heating and cooling systems; in cooling applications the panel is often called a chilled beam.

DEDICATED OUTDOOR AIR SYSTEM

The term "dedicated outdoor air system" (DOAS) refers to an HVAC design approach where control of thermal conditions is disassociated from control of air quality. A separate system provides centralized delivery of outdoor air for air quality control. Another system (either air or water) provides for thermal control. The dedicated outdoor air approach removes conflicts that may occur between air quality and thermal comfort demands.

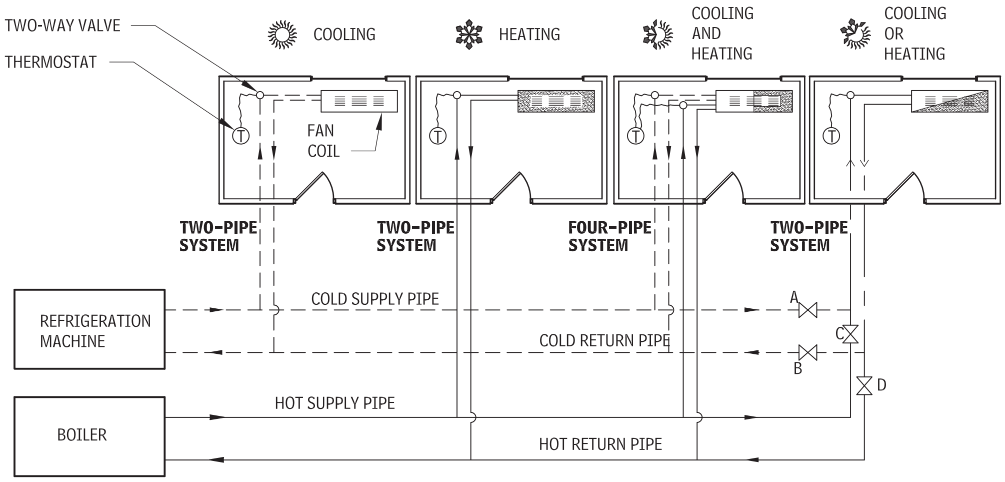
ALL-WATER SYSTEMS

All-water HVAC systems circulate only hot or chilled water to spaces. No central air supply is provided. All-water systems may use fan coil or radiant panel terminal units as the means of conveying heating/cooling effect from the water to room air.

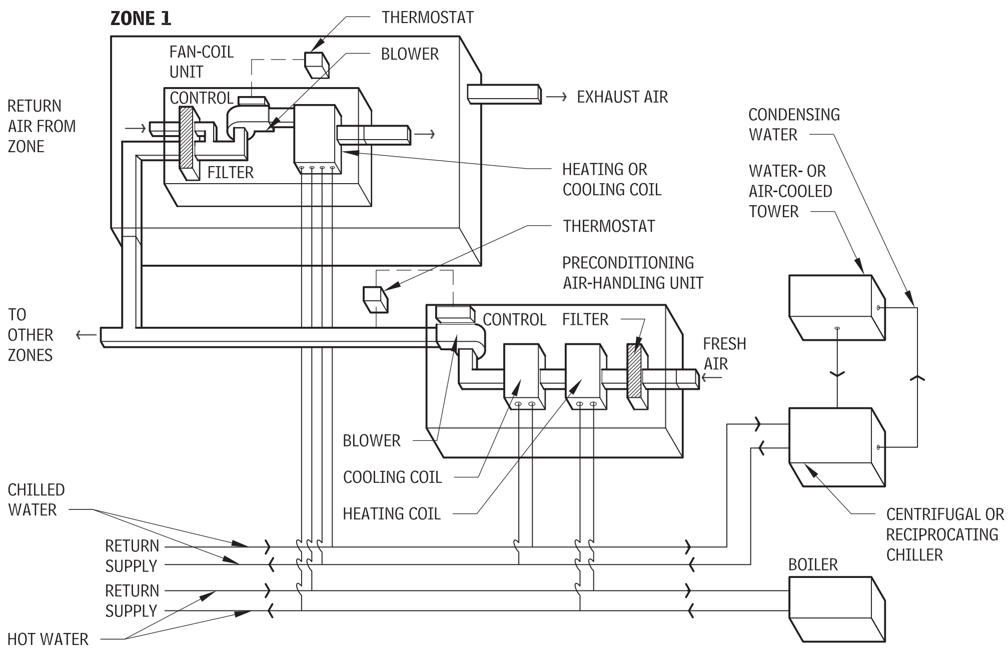
Two-, three-, and four-pipe configurations are used for the water distribution network. In a two-pipe system, each terminal unit is connected to a single supply pipe and a single return pipe. The entire system operates in either cooling or heating mode; the supply pipe provides either cold or hot water. This arrangement is economical, but not operationally flexible because one space cannot be heated while another space is cooled.

In a four-pipe system, each terminal unit is connected to two supply pipes (one hot, one cold) and two return pipes (one hot, one cold). These independent heating and cooling water networks permit complete flexibility of operation from zone to zone. A four-pipe system is more expensive to install than a two-pipe system. A three-pipe system is a hybrid arrangement that provides two supply pipes to each fan-coil unit (one hot and one cold) but only a single return pipe. Hot and cold return water streams are mixed and returned to the chiller and boiler at some intermediate temperature. The three-pipe arrangement is seldom used because it is difficult to operate properly and is inherently very inefficient.

ALL-WATER SYSTEM CONFIGURATIONS
13.116



FOUR-PIPE FAN-COIL UNITS
13.117



NOTES

13.116 a. Valves A and B are closed during the heating season.
b. Valves C and D are closed during the cooling season.
c. A majority of existing buildings with central heating and cooling use the two-pipe distribution system.

Contributors:
Alfred Greenberg, PE, CEM, Murray Hill, New Jersey; Jeff Haberl, PhD, PE, Texas A&M University, College Station, Texas.

FAN-COIL SYSTEM

A fan-coil unit is commonly used as a water-to-air heat exchange component of an all-water (or air-water) HVAC system. In an all-water system, all space-conditioning needs are handled by one or more fan-coil units. In an air-water system, the fan-coil units carry the majority of space loads, while a separate central air system handles ventilation requirements.

A complete all-water fan-coil system consists of several fan-coil units (one for each thermal zone), a chiller, an air-cooled condenser or cooling tower, a boiler (if central heating is required), a piping distribution network, and necessary circulation pumps.

FOUR-PIPE FAN-COIL SYSTEM

Fan-coil units in each zone provide heating or cooling for that zone. Each fan-coil unit contains a blower, filter, and heating/cooling coil. Chilled water and hot water are simultaneously provided to the fan-coil units. Chilled water is provided by a chiller located in a central mechanical room and hot water is provided by a boiler (which is often located in the same mechanical room). The unit fans can either operate continuously or turn on and off as needed to satisfy the zone thermostat. More expensive units may contain a variable volume fan that regulates the airflow depending upon zone loads.

Each fan-coil unit (which defines a zone) is controlled by a thermostat, which changes the temperature of the supply air to meet heating or cooling loads. The temperature of the chilled water and hot water supplied to the units may be controlled with an outdoor reset thermostat.

ADVANTAGES

- The system provides all-season heating and cooling at each unit.
- The boiler and chiller are installed at a central location.
- Chiller efficiency is higher than that of individual heat pumps.
- A fan-coil unit can be shut down for maintenance without affecting adjacent areas.
- No summer/winter changeover is required.
- This system is simpler than other system options for multiple interior-zone buildings.
- The only ductwork needed—in an air-water configuration—is for preconditioned air (approximately 10 to 20 percent of fan-coil air); cooling of preconditioned air may not be required in climates with hot, dry summers.

DISADVANTAGES

- Four-pipe systems are slightly more expensive to install than two-pipe systems.
- The hot water and chilled water loop must operate when only one zone needs heating or cooling.
- Noise from individual units may be a problem.
- This system may use more energy than other options because of frequent operation of the water loop.
- Decentralized maintenance of fan-coil units can require additional maintenance time.
- Fan-coil units need a sanitary sewer connection to drain condensate. These drains can be a maintenance concern.
- The system has no humidification capability.

TWO-PIPE DUAL-TEMPERATURE SYSTEM

In a two-pipe dual-temperature system, hot water is circulated through the terminal units during cold weather and chilled water is circulated during hot weather. The distribution system may be divided into macro-zones, each of which is capable of changeover from heating to cooling, independent of the other zones.

HVAC SYSTEM APPLICATIONS

This section describes HVAC systems commonly found in K–12 schools and small commercial office buildings.

SINGLE-ZONE AIR-HANDLING UNITS

Small air-handling units (AHUs) provide heating and cooling for specific zones. Each AHU has a blower, filter, and heating and cooling coils. A fixed amount of fresh air to the units is pretempered to 55°F in a preconditioning unit. Both chilled and hot water are provided to carry the loads on the cooling and heating coils. Chilled water is provided by a chiller located in a central mechanical room and hot water is provided by a boiler (usually located in the same mechanical room). Some single-zone AHUs run continuously. Better-quality units may have a variable volume fan that regulates airflow according to zone loads. The chiller or boiler must operate when any single zonal unit requires cooling or heating.

Each unit is controlled by a zone thermostat that adjusts the supply-air temperature to meet heating or cooling loads. The preconditioning unit is controlled to maintain 55°F by preheating air in the winter and precooling it in the summer. The temperatures of the chilled water and hot water supplied to the units may be controlled with an outdoor reset thermostat.

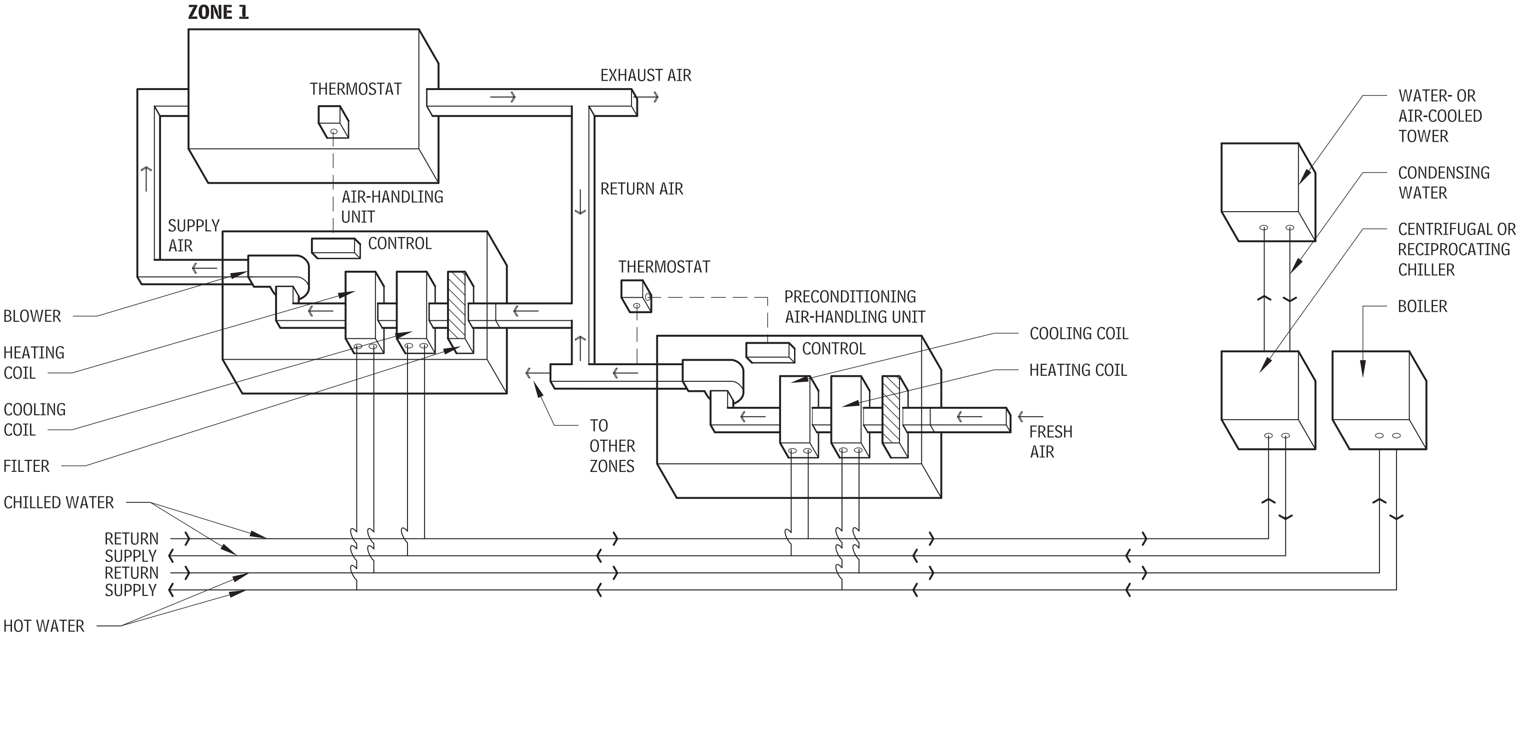
ADVANTAGES

- This system can provide heating and cooling as needed.
- The system offers good dehumidification.
- The boiler and chiller are installed at a central location.
- The system operates with minimal distribution ductwork.
- Zonal air-handling units can be shut down without affecting adjacent areas.
- Chiller efficiency is higher than for individual heat pumps.
- The boiler and chiller have a long life (25 years).

DISADVANTAGES

- The hot water and chilled water loop must run even if only one zone needs heating or cooling.
- The entire system is shut down if the loop fails.
- The temperature is higher in an air-cooled condenser than a water-cooled condenser, making chillers less efficient; but a water-cooled condenser (cooling tower) needs frequent service and water quality checks.
- This system may require more energy than others because of the energy needed to run a four-pipe central loop.
- The system, as shown in Figure 13.118, has no humidification capability.

FOUR-PIPE, SINGLE-ZONE AIR-HANDLING UNIT
13.118



Contributor:
Jeff Haberl, PhD, PE, Texas A&M University, College Station, Texas.

PACKAGED SPLIT SYSTEM WITH INDIVIDUAL HEAT PUMPS

This system provides heating and cooling for individual zones with separate heat pumps. Each heat pump unit contains a blower, filter, and heating/cooling coil. A fixed amount of fresh air to the units is pretempered to 55°F in a preconditioning heat pump unit. Each heat pump has its own heat rejection (or ambient air heat source during cold weather). Emergency electric resistance heating is often provided for severe conditions.

The zone heat pump cycles on and off when the zone thermostat calls for heating or cooling. Airflow to the zones also cycles on and off according to zone demand. In general, the heat pump that preconditions outside air must run continuously to provide adequate fresh air.

ADVANTAGES

- Installation, system operation, and maintenance are simple.
- No mechanical room is required.
- Ductwork is only required for fresh air.
- The initial cost is low.
- This system is well-suited to spaces that require many zones of individual temperature control.

DISADVANTAGES

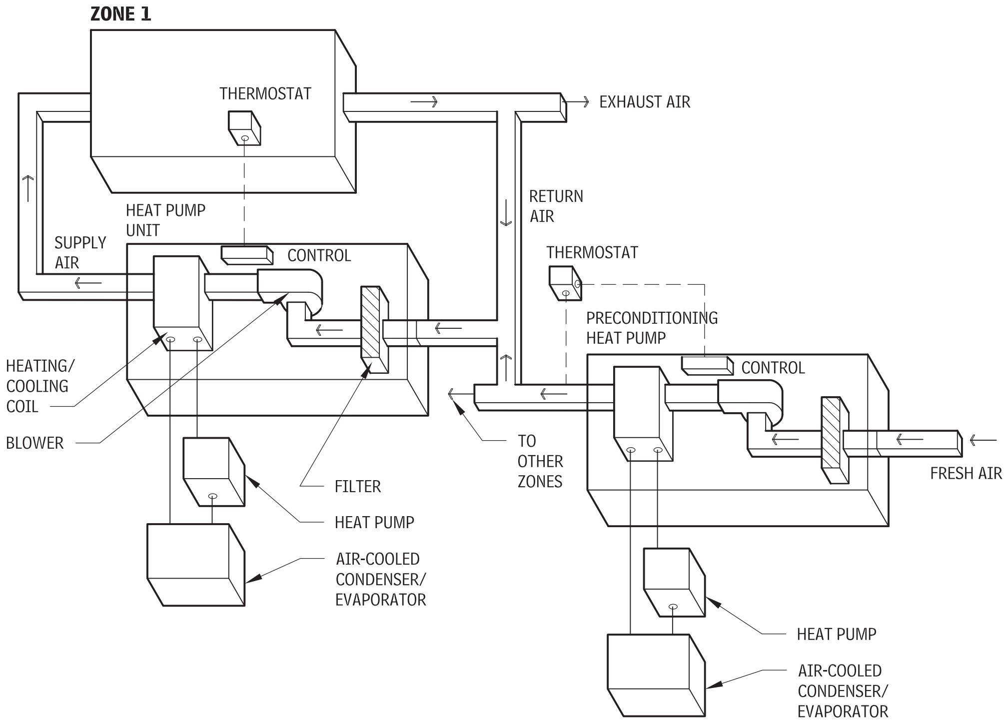
- The noise level of this system is generally high.
- Maintenance costs are high.
- Overall efficiencies of individual heat pumps are less than that of one large chiller.
- The system needs electric resistance heating when the outside air temperature is below 35°F.
- Humidity control can be problematic if there is no preconditioning unit and zone heat pumps are oversized.
- Wall penetration is required for refrigerant lines to and from the condenser/evaporator.
- Equipment life may be relatively short (typically, 10 years).
- The system has no humidification.

TWO-PIPE WATER LOOP HEAT PUMP WITH PACKAGED SPLIT SYSTEM

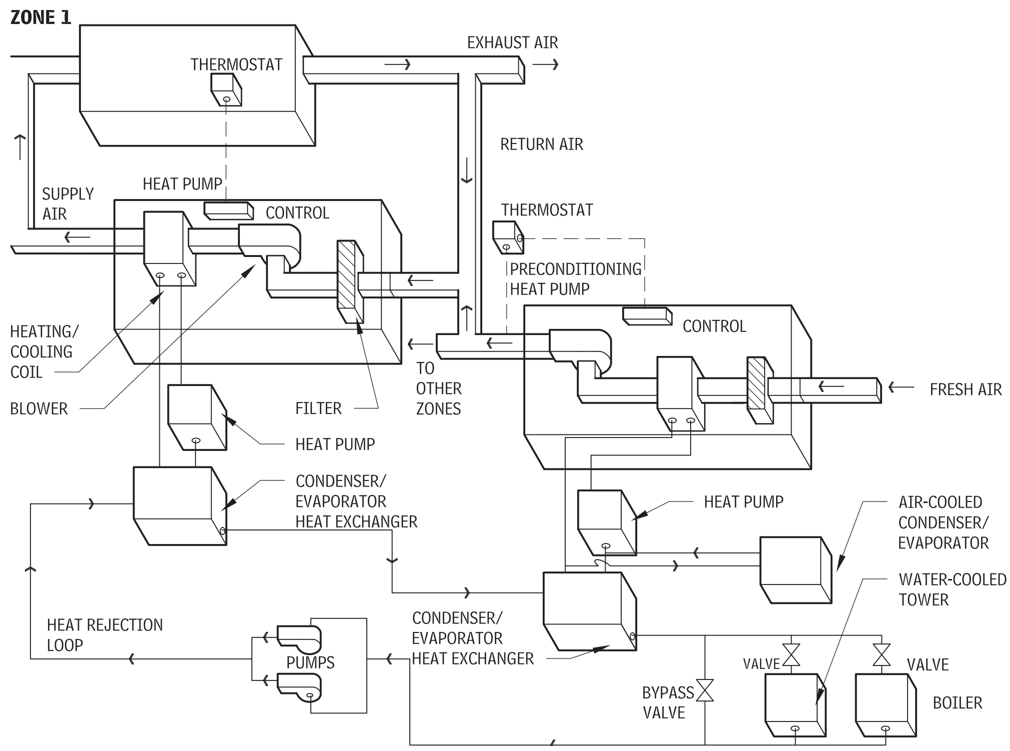
In this system, separate heat pumps provide heating and cooling for individual zones. Each heat pump unit has a blower, filter, and heating/cooling coil. A fixed amount of fresh air to the units is pretempered to 55°F in a preconditioning heat pump unit. The system has a heat rejection loop, and each heat pump is connected to it with a heat exchanger. The heat rejection loop is maintained within a preset temperature range (e.g., 40°F to 100°F) using a central boiler in the winter and one or more cooling towers in the summer. Usually, this type of system does not need emergency electric resistance heating for severe conditions. The heat rejection loop must operate whenever a heat pump is running. In some cases, a variable speed water loop pump can be used, although care must be taken to provide adequate flow to keep the heat pump heat exchangers from freezing up and/or to avoid heat transfer problems in the boiler caused by low flow.

The zone heat pumps cycle on and off when the zone thermostat calls for heating or cooling. Airflow to the zones also cycles on and off according to zone demand. In general, to provide an adequate source of preconditioned fresh air, the outside air preconditioning heat pump must run continuously. An air-cooled condenser can be provided for the preconditioning units to allow for the main loop to be shut down during unoccupied periods.

PACKAGED SPLIT SYSTEM WITH INDIVIDUAL HEAT PUMPS
13.119



TWO-PIPE WATER LOOP HEAT PUMP WITH PACKAGED SPLIT SYSTEM
13.120



Contributor:
Jeff Haberl, PhD, P E, Texas A&M University, College Station, Texas.

TWO-PIPE, GROUND-COUPLED WATER LOOP HEAT PUMP WITH PACKAGED SPLIT SYSTEM

This system is similar to the system with heat pumps and packaged split system described above. However, in contrast to the water loop system with an auxiliary boiler and cooling tower, this water loop rejects heat in a series of wells or trenches that establish contact with soil temperatures. This heat rejection loop is also maintained within a preset temperature range (e.g., 40°F to 100°F) using the thermal mass of the earth to improve performance. Emergency electric resistance heating for severe conditions is not required. The ground-coupled heat rejection loop must operate when a heat pump is running. A variable speed heat rejection loop can be used.

Zone heat pumps cycle on and off in response to zone thermostat calls for heating or cooling. Airflow to the zones also cycles on and off to match zone demand. In most cases, the outside air preconditioning heat pump runs continuously to provide an adequate source of preconditioned fresh air. An air-cooled condenser can be provided for the preconditioning units to allow for the main loop to be shut down during unoccupied periods.

Advantages and disadvantages, respectively (unless otherwise noted), that apply to the water loop heat pump systems described above include:

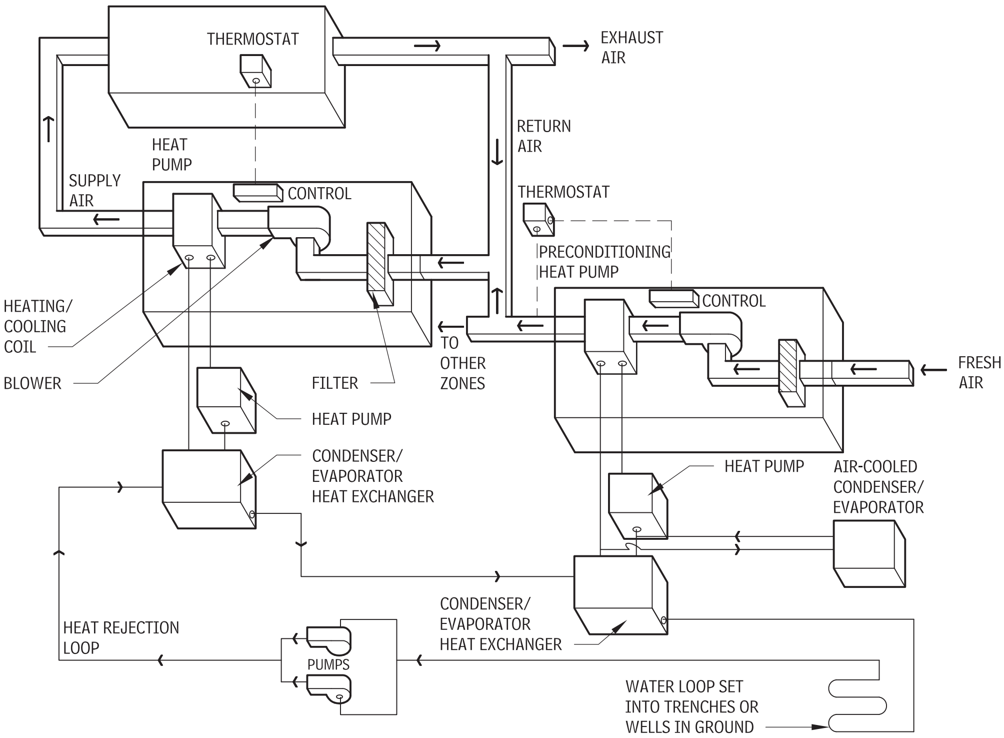
ADVANTAGES

- They conserve energy by recovering heat from interior zones and/or waste heat.
- They do not require wall penetrations to provide for the rejection of heat from air-cooled condensers.
- Air-cooled preconditioning allows fresh air to be supplied without running the main loop.
- The noise level may be lower than that of air-cooled equipment because individual condenser fans are eliminated and the compression ratio is lower.
- The systems can usually be maintained locally, as specialized maintenance technicians are not required for the heat pumps (they may be required for the boiler).
- Units have a longer service life than air-cooled heat pumps.
- The entire system does not shut down when a single zone unit fails.
- Ground-coupled systems normally do not need a boiler and cooling tower. The size of the mechanical room for the loop pumps can be minimized.
- The lifecycle cost of the two-pipe water loop heat pump with packaged split system (without ground coupling) compares favorably with that of central systems when lifecycle costs are considered.

DISADVANTAGES

- The initial cost for these systems may be higher than for systems that use multiple unitary HVAC equipment.
- Cleanliness of the piping loop must be maintained.
- The cooling tower needs frequent service and water quality checks (this does not usually apply to the ground-coupled system).
- If air-cooled preconditioning is not used, the loop must run 24 hours/day when any zone needs cooling or heating.
- The entire system shuts down when the loop fails.
- More maintenance will be required than for some other systems since the heat-pump equipment and air-handling units are decentralized.
- These systems have no humidification.
- In the ground-coupled system, soil type, moisture content, composition, density, and uniformity affect the success of the heat exchange.

TWO-PIPE, GROUND-COUPLED WATER LOOP HEAT PUMP WITH PACKAGED SPLIT SYSTEM
13.121



- In the ground-coupled system, the pipe material and the corrosiveness of the local soil and groundwater may affect heat transfer and service life.
- In the ground-coupled system, a large area is needed in which to drill wells or dig trenches.
- Zone heat pumps and preconditioning heat pumps need a sanitary sewer connection to drain condensate. These drains can be a maintenance concern.

MULTIZONE SYSTEM WITH COLD DECK BYPASS

Multizone air-handling units (AHUs) provide heating and cooling for several zones (typically between 4 and 10 per AHU). Each AHU contains a blower, filter, heating coil, cooling coil, and bypass dampers. Chilled water and hot water are simultaneously provided to the cooling and heating coils. Chilled water is provided by a chiller and hot water is provided by a boiler. The multizone units operate continuously. The chiller or boiler must operate when any unit (including the preconditioning unit) requires heating or cooling. Variable volume fans may be used to regulate airflow according to the zone loads.

Each zone is controlled by a zone thermostat that changes the temperature of the supply air to meet heating or cooling loads. The supply air temperature is controlled by an arrangement of dampers that allows air either to flow across or to bypass the cold deck (coil). A reheat coil can be provided for locations with extremely humid conditions. A preheat coil can be provided for extreme winter conditions. The temperature of the chilled water and hot water supplied to the units may be controlled with an outdoor reset thermostat.

ADVANTAGES

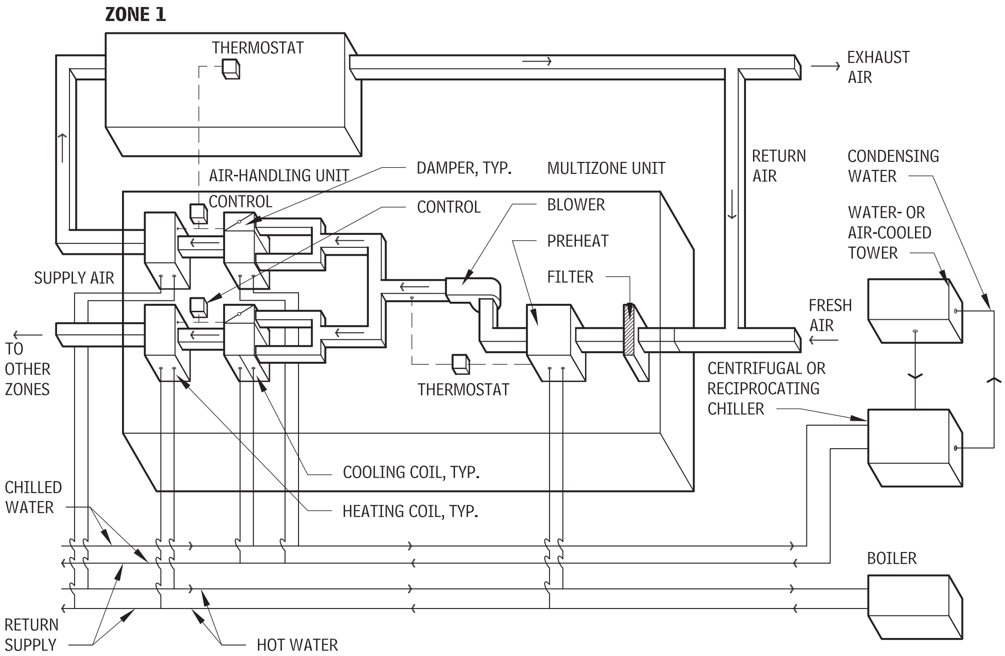
- The system supplies several zones from centrally located AHUs.
- No pipes that could leak are required in occupied zones.
- The system can provide heating and cooling as needed.
- The boiler and the chiller are centrally located.
- Chiller efficiency is often higher than that of individual heat pumps.
- The system offers good dehumidification. Much of the year, this can be provided with the cooling coil bypass damper.

DISADVANTAGES

- The hot water and chilled water loop must run even when only one zone needs heating or cooling.
- The chiller and boiler require service by specially trained technicians.
- A cooling tower needs frequent service and water quality checks.
- Additional space is required for distribution ductwork (since each zone requires a separate duct).
- The system has no humidification.

Contributor:
Jeff Haberl, PhD, PE, Texas A&M University, College Station, Texas.

MULTIZONE SYSTEM WITH COLD DECK BYPASS
13.122



HVAC DUCTS AND CASINGS

Ducts must be permanent, rigid, nonbuckling, and nonrattling. Joints in ducts should be airtight. Steel or aluminum sheets are the most common materials used in the construction of ducts, which are generally round, flat, oval, or rectangular in cross section.

Supply ducts should be constructed entirely of noncombustible material in commercial construction. Single-family residential ducts need not meet this requirement, with the exception of the first 3 ft. from the unit, provided they are used in conjunction with listed heating units, are properly constructed from a base material of metal or mineral, and are properly applied. Ducts passing through unconditioned spaces or located in exposed walls should have 1 to 2 in. of insulation.

Ducts must be securely supported by metal hangers, straps, lugs, or brackets. No nails should be driven through duct walls, and no unnecessary holes should be cut in them.

HVAC DELIVERY COMPONENTS

DIFFUSERS, REGISTERS, AND GRILLES

Diffusers, registers, and grilles are components of an air-based delivery system. These devices ensure that air is supplied to and returned from a space in a manner that is effective, thermally and acoustically comfortable, and aesthetically acceptable (if not pleasing). A diffuser is a fairly sophisticated air delivery device, which should (in conjunction with ductwork layout) provide control over supply air volume, direction, throw, velocity, and sound power. The objective is to deliver air into a space with adequate mixing, no drafts, no dumping, and no noise. A register is typically used as a less-sophisticated supply air device (or as a return air device). A grille is basically just a louvered cover (visual screen) for a return air duct or opening.

Air supply devices should be selected and located so that they can introduce supply air without adverse effects (drafts, noise). This will influence the number of devices required per room and their arrangement in the ceiling. Most diffusers interact with the ceiling plane in order to obtain their rated performance characteristics; this must be considered in exposed duct applications. Return air devices should be located to avoid short-circuiting of room airflows and to mitigate noise transfer to/from adjacent spaces. They should be installed so that they actually do provide visual screening.

Diffusers, manufactured of steel or aluminum, are available in a wide range of shapes, sizes, surface appearances, finishes, and installation detailing. Registers come in a more restricted range of shapes and sizes. Grilles are generally square or rectangular in shape.

Underfloor air distribution (UFAD) may be considered as a desirable delivery approach. This system uses an underfloor plenum and floor-mounted diffusers. Proponents argue that indoor air quality and thermal comfort are improved by a floor-level delivery.

FAN-COIL UNITS

Fan-coil units may be installed as part of an air-water or all-water HVAC system. In an air-water system the fan-coil unit would be supplemented with an independent central air supply system (with air-handling units, ductwork, and air-supply devices) to provide ventilation air. Often the quantity of supply air is small enough that it can be exhausted without need for a return air system. Although fan-coil units can be provided with outside air intakes (if installed at a wall), adequate control and conditioning of outside airflows in such a configuration is problematic.

A fan-coil air distribution system, either all-water or air-water can serve a virtually unlimited number of zones. The system meets loads in the various zones by controlling the flow of chilled or hot water to the fan-coil unit in response to zone thermostats (often located integral to the fan coil). Design coordination must address the location of units within (or directly adjacent to) occupied spaces. All-water configurations are not true air-conditioning systems, and their use will generally be limited to exterior spaces; with a separate central air supply, however, the system can provide control of conditions as expected on full air conditioning, and be used in both interior and exterior zones.

INDUCTION UNITS

An induction unit serves as the room delivery device in an air-water HVAC system. This type system can provide a virtually unlimited number of zones. The system meets loads in the various zones by controlling the flow of chilled or hot water to the induction unit in response to zone thermostats (often located integral to the unit). Air supply from a central conditioning system deals with indoor air quality concerns. Design coordination must address the location of units within (or directly adjacent to) occupied spaces. An induction system can provide the control of space conditions expected of an "air-conditioning" system. The use of coupled central air and water networks attempts to reduce the overall building volume required for distribution while providing adequate outdoor air.

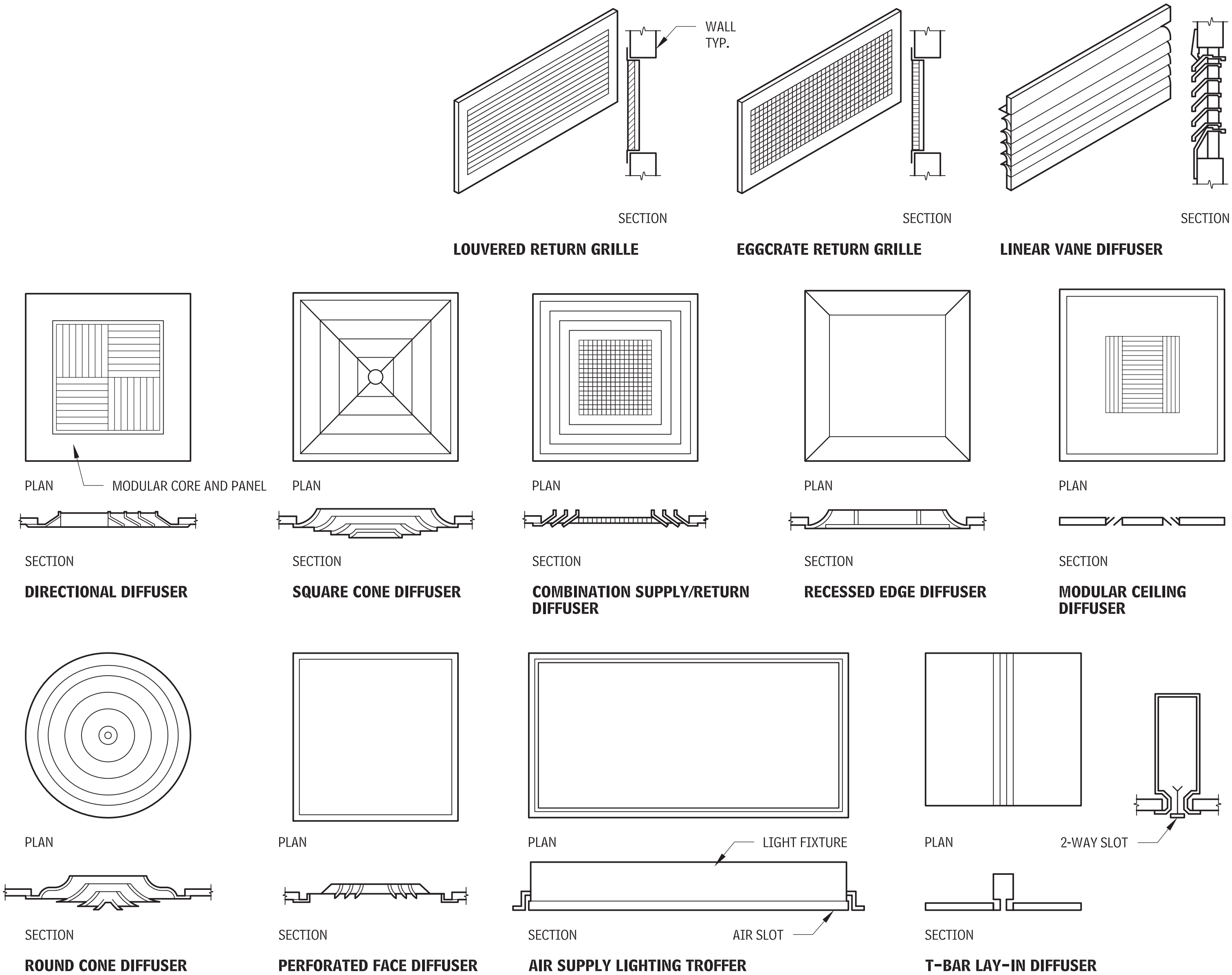
RADIANT HEATING ELEMENTS

Radiant heating systems transfer heat from hot water tubing (or electric cables) embedded in the floor or ceiling to a surface that will then distribute heat to the space. The tubing or cables are laid out to maximize heat distribution to the areas of greatest heat loss. The choice of hot water or electric heat is made based on installation, energy, and total lifecycle costs and code constraints.

For appropriate applications, properly designed and operated radiant heating systems will provide greater comfort at lower operating costs than other heating systems because of the inherent nature of the human body's thermal functions. About 70 percent of the body's heat exchange is via radiation (electromagnetic waves),

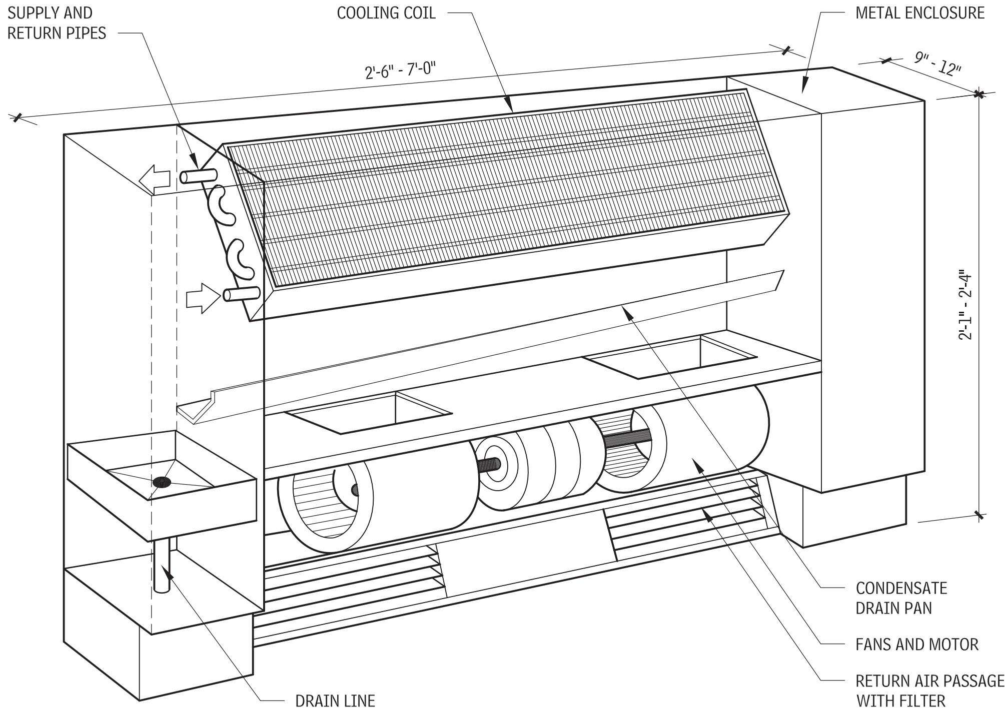
Contributor:
Jeff Haberl, PhD, PE, Texas A&M University, College Station, Texas.

COMMON AIR DISTRIBUTION DEVICES
13.123



Contributor:
Walter T. Grondzik, PE, Ball State University, Muncie, Indiana.

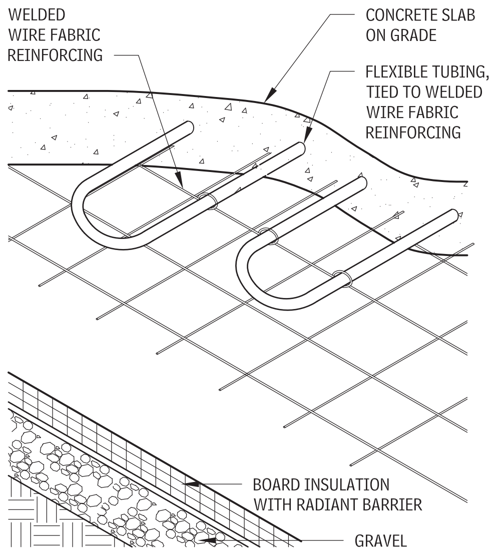
COMPONENTS OF A FAN-COIL UNIT
13.124



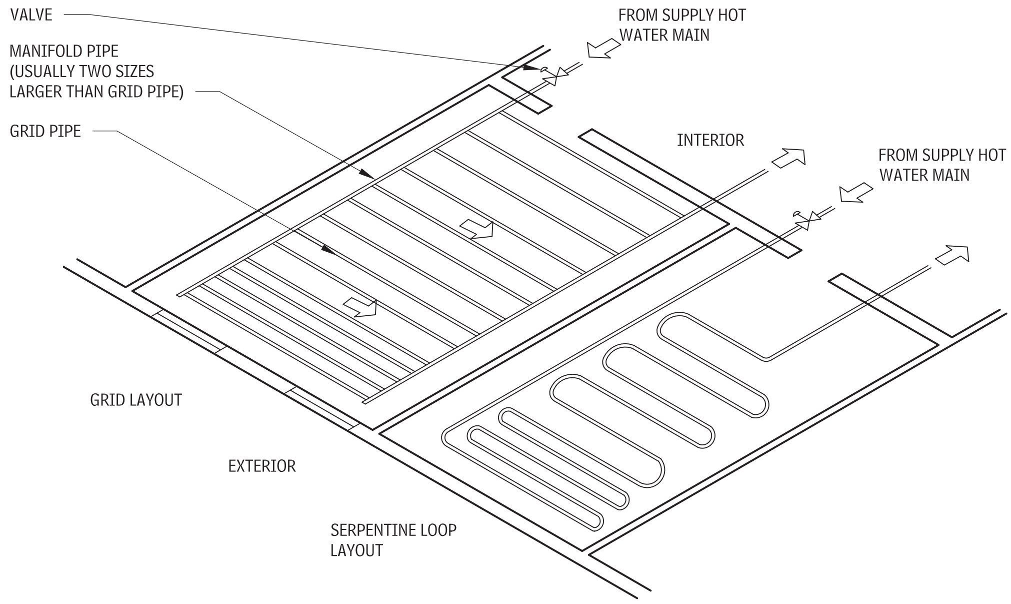
25 percent by convection (via air or water), and 5 percent by conduction (via physical contact).

In terms of overall system configuration, a radiant floor, wall, or ceiling is equivalent to a radiator, convector, or any other terminal-heating element. The primary caveat is that a suitable control system must be provided to ensure that floor surface temperatures do not rise above 75°F or, if ceiling systems are used, above 120°F. Thermostats for radiant systems can generally be set several degrees lower for heating than thermostats for other types of systems. Finish floor should not be of a thermal insulating material; ceramic tile or wood flooring would be suitable.

HEAT TRANSFER IN SLAB ON GRADE
13.125



RADIANT HEATING LAYOUTS
13.126



NOTES

13.126 a. Spacing for grid pipes is closer (3 to 4 in.) at exterior walls than in interior spaces (12 to 18 in. apart).
b. Grid pipe layouts have a lower pressure drop than serpentine pipe layouts. Serpentine layouts are generally easier to install and less costly to fabricate, but because of the higher pressure drop they are more expensive to operate.

Contributor:
Alfred Greenberg, PE, CEM, Murray Hill, New Jersey.

HVAC CONTROL SYSTEMS

HVAC controls have historically been of three principal types: electric (line voltage), electronic (low voltage), and pneumatic. Direct digital controls (DDC) are the norm today. Wireless controls are becoming common. Controls are either manual or automatic; although both types may be found in modern buildings, automatic controls dominate in all building types and scales. The networked interconnection of individual equipment and device controls is the norm for most larger buildings. Such interconnection, variously called an energy management system (EMS), building automation system (BAS), or building management system (BMS), allows for sophisticated decision making, fault detection, and performance tracking.

ENERGY MANAGEMENT SYSTEMS

Energy management and control systems can dramatically reduce building energy use and improve occupant comfort and health. Primary strategies involve turning the right equipment on/off at the correct times, optimizing the operation of HVAC equipment, controlling room comfort, and recording HVAC system performance as stored data.

Most EMS manufacturers offer similar functionality. Their systems will have either proprietary or open-systems protocols for interconnectability. Proprietary systems will not usually interface with another vendor's equipment. BACnet, an open system from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), requires that systems pass certification tests to verify that the communications and data formats meet the minimum interoperability standards. The LonMark open system requires vendors using their label to comply with LonMark requirements. Vendors can add features or extensions to the minimum requirements; these features may not be interoperable with other vendors' equipment.

- *Local equipment controller (LEC):* The LEC directly connects to HVAC equipment, with the controller designed for specific HVAC equipment. These controllers work with terminal boxes (VAV boxes and others), air-handling units, pump and fan motors, chillers, boilers, and even non-HVAC devices like access controls. The controllers usually issue commands to the physical controls and communicate upward to building-level controllers. Often the equipment controllers will have backup functionality so that the facility continues to operate in the event of communication failure or a dysfunctional building-level controller. Various manufacturers use differing names to refer to these LEC panels.
- *Building-level controllers (BLC):* The next level up from the LEC is the BLC, which are often called *supervisory controllers*. The BLCs generally use a personal computer with custom software to provide direct communication and control of the controllers tied to specific equipment. They maintain the equipment control schedules, run the building control applications, and store data logs containing measurements from sensors and actuators. If a local control fails, the BLC alarm sounds, and after the equipment controller is repaired, the BLC updates the internal schedules and control strategies in the LEC.
- *Enterprisewide systems (ES):* Enterprisewide systems allow communication and control over as large a network as the user requires. ES communications typically route to various systems using normal Internet protocols. ES software can also enable one central location to control and monitor multiple building sites.

Specific supervisory control applications for EMS include timed start/stop, optimum start/stop, demand control, chiller control, boiler control, air-handling unit control, and, often, custom controls needed to interface to a particular mechanical system.

Timed controls simply turn equipment on and off at specified times. Care needs to be taken to ensure that overcycling of equipment, which would lead to a higher equipment failure rate, does not occur.

Optimum start provides additional savings over simple timed functions and can determine the "on" time for equipment such that the indoor conditions meet requirements just before the occupancy time. Optimum stop allows the building to "coast" off, typically no more than 15 minutes to a half hour before the end of occupancy. Applying a variable-speed drive to an air handler enhances these controls.

Demand control minimizes peak demand charges by limiting peaks in electrical power use. Utilities have a variety of billing methods, including fixed-window, sliding-window, and instantaneous demand measures. These billing methods can have different rates and peak demand costs for different seasons and time of day. New, evolving billing methods include differing versions of real-time pricing where the kWh price changes hour by hour. A facility can receive a price signal indicating the price for a specified time during the next few hours to a day. Prices have ranged from a few cents per kWh to over a dollar per kWh in current real-time pricing offerings. Demand control programs have the highest level of errors of any of the EMS programs, because of the complexity of matching the billing methods with an acceptable load-dropping sequence for the facility.

COMBUSTION EQUIPMENT CONTROLS

Boiler controls also include sequencing, water temperature, and reset controls. Boiler water reset controls adjust the supply water to reduce the energy consumption, whenever possible. Before applying any controls to either chillers or boilers, make certain that all safety controls are operating correctly. Also, with combustion boilers, keep the flue gas temperature high enough to inhibit acids from condensing out and eroding the flue ducts.

Automatic fuel-burning equipment requires a control system that will provide a prescribed sequence of operating events and will take proper corrective action if failure occurs in the equipment or its operation. The basic requirements for oil burners, gas burners, and coal burners (stokers) are the same. The controls can be classified as operating controls, limit controls, and interlocks.

Operating controls initiate the normal starting and stopping of the burner in response to the primary sensor acting through appropriate actuators. Because the heat output of a burner may be widely distributed, the location of the primary sensor is important.

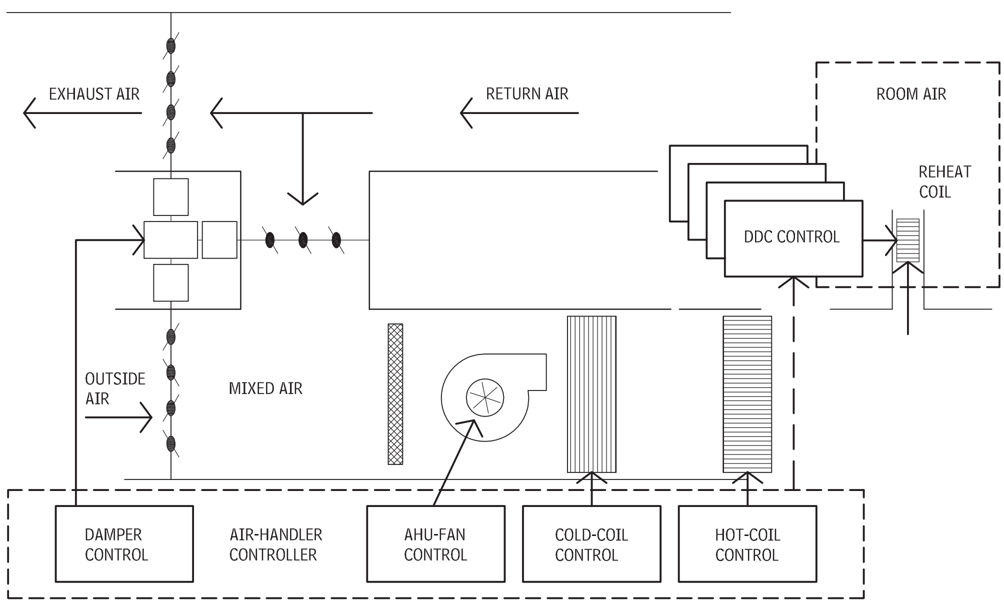
Examples of primary sensors are:

- A room thermostat for a residential furnace
- A pressure-actuated switch for a steam boiler
- A thermostat for a hot water heater

An actuator is defined as a device that converts the control system signal into a useful function. Actuators generally consist of valves, dampers, or relays.

Ignition for oil or gas burners is achieved by an electric spark or by a pilot gas flame, all supervised by a flame safeguard system,

ENTERPRISE BUILDING-LEVEL CONTROL—LOCAL EQUIPMENT CONTROL CONNECTION
13.127



which must meet legal and insurance underwriters' requirements. After ignition is proved, the flame safeguard system then permits the main fuel (gas or oil) to enter the burner for on-line combustion.

Separate limit and operating controls are always recommended. Limit controls and interlocks function only when the system exceeds prescribed unsafe operating conditions. They actuate electric switches that will close the fuel valve in the event of an unsafe condition, such as:

- Excessive temperature in the combustion chamber or heat exchanger
- Excessive pressure in a boiler or hot water heater
- Low water level in a boiler and in larger commercial and industrial burners
- High or low gas pressure
- Low oil pressure
- Low atomizing media pressure
- Low oil temperature when firing residual fuel oil

CHILLER CONTROLS

Chiller control typically includes chiller sequencing, water temperature supervisory controls, and chilled water and condenser water reset controls. The selection controls need to be set up to minimize the on/off cycling of chillers. The reset controls adjust the water setpoints of the chilled and condenser water to optimize the energy efficiency of the chiller.

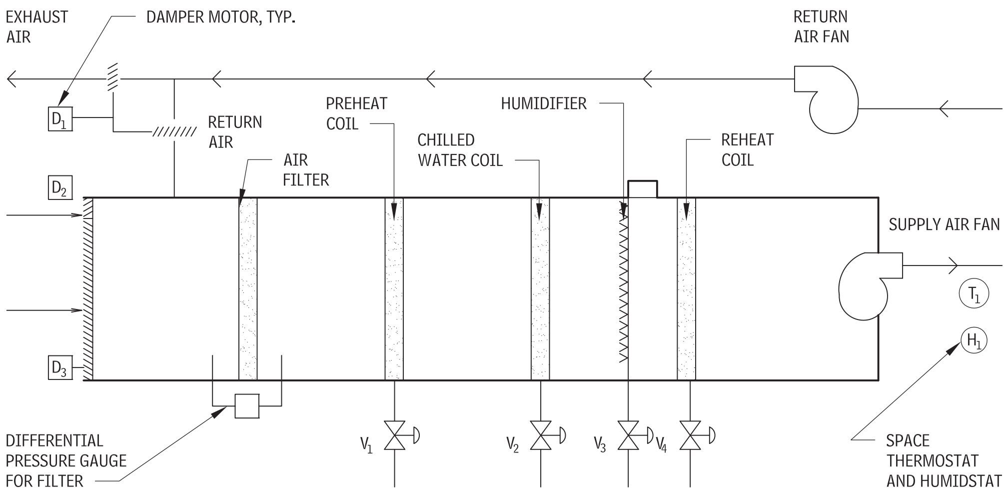
AIR SYSTEM CONTROLS

Air-handler unit supervisory-type controls include start/stop control (either timed or optimum), supply air temperature adjustment, fan control, and hot and cold deck temperature control. These controls also link to the controls on the terminal control "boxes" located in the room supply air path. Figure 13.128 shows a typical air-handler controller (a specific-function local equipment controller) and its connection to multiple direct-digital controllers (DDC). The DDCs can interconnect through a variety of communications protocols.

A typical sequence of operation for an air-handling system is as follows (see Figure 13.128):

1. When the supply air fan has been turned on but the motor is not yet turning, minimum outside air damper D2 and exhaust air damper D1 open, the latter to its minimum position to match the amount of incoming air. The exhaust air and return air dampers are interlocked: When the exhaust air damper is shut, the return air damper is fully open; when the exhaust air damper is fully open, the return air damper is minimally open.
2. When dampers are in proper open positions, the supply air fan starts running and the return air fan is turned on, either manually or electrically. This sequence is necessary to prevent the supply air fan from sucking air out of the air-handling unit and collapsing the casing and to keep the return air fan from blowing excess air into the casing and "bursting the bubble."
3. Space thermostat T1 and humidistat H1 control the system. If humidification is required, H1 controls the operation of control valve V3 at the humidifier in the air-handling unit. If heating is required, T1 controls the operation of reheat coil control valve V4. If cooling is needed, T1 controls the cooling coil control valve V2. At this time, control valves V1, V3, and V4 are closed. Control valve V1 for the preheat coil is controlled by a thermostat on the discharge side of the coil.
4. Many control system variations are possible to improve comfort and conserve energy. In one commonly used variation, an "economizer cycle" is established in which an outdoor thermostat is added to the control system. This permits the system to decide whether T1 should open the heating or cooling coil control valve damper to initiate heating or cooling, depending on the season, or whether heating or cooling can be accomplished by proportionally opening variable outside air damper D3.
5. On a balmy spring or autumn day, it may be possible for full space conditioning needs to be supplied by fully open outdoor air dampers. In this case, damper D1 would be fully open for exhaust air and fully closed for return air. D2 and D3 would be fully open, and V1 through V4 fully closed.

TEMPERATURE AND HUMIDITY CONTROLS FOR ALL-AIR SYSTEMS
13.128



OTHER HVAC SYSTEMS AND EQUIPMENT

DEHUMIDIFICATION

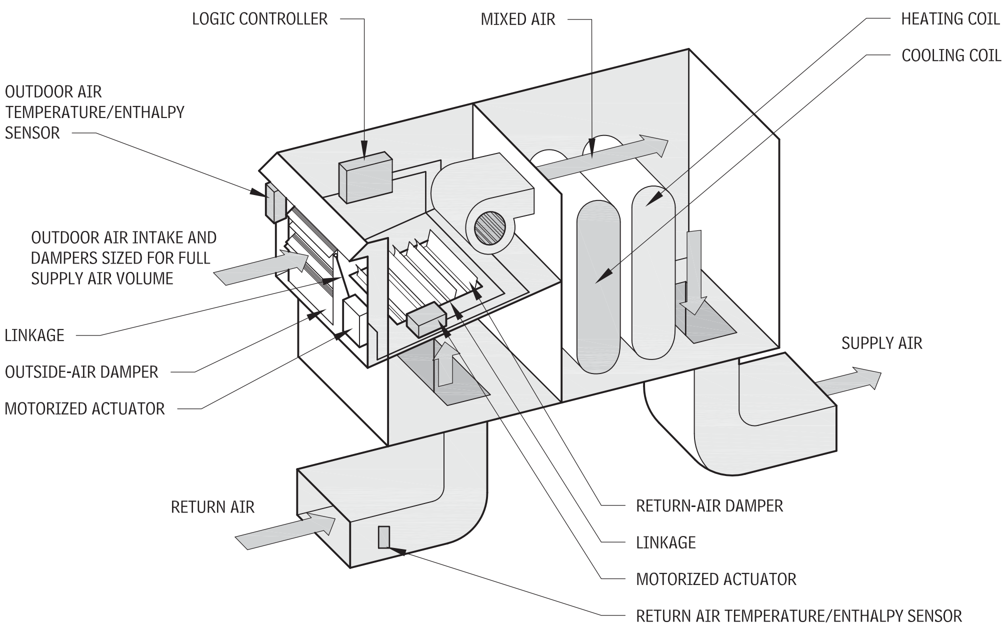
A cooling system is typically required to reduce the temperature of room air (called sensible cooling) while reducing the humidity of the air (called latent cooling—or dehumidification). A conventional HVAC system provides dehumidification by cooling air below its dew point temperature, causing condensation on the cooling coil, and the removal of water from the supply air stream. This approach can cause control problems in typical building spaces because of overcooling on the sensible side (requiring reheating or some other air-warming technique to ensure thermal comfort). In situations where the sensible building load is reduced without a proportional reduction in the latent building load (such as an energy-efficient building), providing appropriate dehumidification can become a serious challenge. The same is true for applications with inherently high latent loads (such as dense occupancy spaces).

ECONOMIZERS

The term "economizer" in this application describes a system arrangement that allows for differential flow paths (for air, water, refrigerant) to be selected so as to provide the lowest cost of operation under different load/weather conditions. An air-side economizer in an HVAC system is simply an arrangement of ductwork, dampers, and controls that allows outdoor air to cool a building via the HVAC system when conditions permit. Essentially an economizer is a mechanized natural ventilation system.

Implementing an air-side economizer requires sizing the outdoor air intake mixing box and mixing dampers to accommodate more-than-minimum airflows. Minimum outdoor airflow is usually that required for indoor air quality control. Relief (exhaust) air capability must

COMPONENTS OF AN ECONOMIZER CYCLE
13.129



Contributor:
Alfred Greenberg, PE, CEM, Murray Hill, New Jersey.

also be considered. A control system will compare the conditions of the return air with those of the outdoor air—and admit more outdoor air when it has a lower energy content (for cooling) than the return air; thus reducing energy use for cooling. The comparison can be based on temperature difference (sensible heat) or enthalpy difference (sensible and latent heat) depending upon the climate.

COMPUTER ROOM AIR-CONDITIONING

Computers generate great quantities of heat in concentrated areas. To ensure proper operation, a precise temperature and humidity environment is required. The range of control may be as narrow as 72°F (±2°F) temperature and 50 percent humidity (±5 percent).

The air-conditioning equipment should be able to meet the changing conditions created by relocation of equipment, facility expansion, and changes in heat output. Hot spots can result if flexibility is not built into the system.

DOWNFLOW AND UPFLOW SYSTEMS

Downflow systems are preferable for a number of reasons. Air is returned through the top of the unit and supplied out through the bottom into a raised floor, thereby permitting high quantities of air without disturbing the occupants. Perforated floor outlets can easily be moved, providing flexibility in room layout. The units themselves also form part of the floor grid and can easily be moved.

Upflow systems are used in areas where there is no raised floor (often the case in retrofit situations). They are also used in large rooms when the air is distributed by a ductwork system. Upflow systems are not as flexible as downflow systems for reorganizing equipment in a room.

REDUNDANCY

All systems should be designed with redundancy to provide full, continuous cooling. The degree of redundancy should be weighed against the consequences of downtime of the equipment. A minimum of 25 percent redundancy is recommended, but 100 percent may be warranted, depending on future expansion and the degree of backup required.

VAPOR RETARDERS

It is difficult and costly to maintain a computer room at a relative humidity of 50 percent (±5 percent) throughout the year without a vapor retarder. In addition, room partitions should extend beyond the ceiling to help prevent migration of moisture to and from adjoining spaces.

TYPES OF SYSTEMS

Common types of systems include:

- *Spot coolers:* Direct forced air can be located at ceiling in return air plenum or on the floor; short ducting can be used. Capacity: 1 to 3.5 tons.
- *Local units for small systems:* Forced air can be used for direct spot cooling; it can be ducted or installed in pressurized raised floor. Capacity: 3 to 5 tons.
- *Local units for large systems:* Forced air can be used with pressurized raised-floor installation. Capacity: 6 to 25 tons.
- *Mainframe cooling systems:* Independently generated chilled water is circulated to the computer's coolant distribution unit (CDU), an intertwined coiled heat exchanger that distributes special coolant directly to the computer in a closed loop system. Capacity: 2.5 to 15 tons.

STANDARDS FOR UNITARY SYSTEMS

The applicable standard is ANSI/ASHRAE Standard 127, "Method of Testing for Rating Computer and Data Processing Room Unitary Air Conditioners."

METHODS OF HEAT REJECTION

There are six methods of heat rejection.

- *Self-contained air-cooled:* Uses air within the building return air plenum; limited to small-capacity units.
- *External air-cooled:* Uses outdoor condenser unit; refrigerant lines generally are limited to 100 ft. above, 30 ft. below, or 200 ft. total from the computer room to the outdoor unit.
- *Water-cooled:* Uses closed-loop condenser water pumped to an external cooling tower to remove heat from the condenser within the computer room fan-coil unit. The distance from the cooling tower to the computer room can be longer than that in an external air-cooled system.
- *Glycol-cooled:* Uses closed-loop glycol to carry rejected heat to an external dry cooler or cooling tower, which allows greater separation of the computer room from outside air. With additional coils, the system can provide "free cooling" during colder weather. This system is preferred in areas where ambient air temperature is below −10°F.
- *Chilled water:* Chilled water is pumped from a remote chilled water plant to a local fan-coil unit.
- *Combination unit:* May use two or more means of heat rejection to service the system during certain hours of operation or as a backup in case of primary system failure.

PLANNING ISSUES

When planning, it is essential to:

- Evaluate the availability of building services and systems, mechanical chases, and electrical power capacities.
- Determine the overall heat load and plan size of the system with the client and engineer. Design for built-in redundancy with multiple circuits.
- Use qualified engineers to design and engineer the systems and to supervise testing and certification.
- Detail the construction of walls, ceiling, and floors to provide a complete vapor seal and adequate airflow.
- Evaluate energy-efficiency ratios (EERs) of various kinds of proposed equipment.
- Select a system with high reliability and low noise level.
- Do not ventilate the space when unoccupied.

GUIDELINES FOR ESTIMATING COOLING LOADS

- Room design conditions: temperature 72°F (±2°F); relative humidity 50 percent (±5 percent)
- Sensible heat ratio: 0.85–0.98
- Sensible heat gain: 115–200 Btu/sq. ft.
- Total heat gain: 120–240 Btu/sq. ft.
- Load density (SF/ton): 50–100
- Air quantity (CFM/ton): 600–900
- Ventilation rate (CFM/person): 15–20 maximum
- Humidification (lb. moisture/100 CFM of outside air): 3

HEAT-RECOVERY SYSTEMS

Heat-recovery systems may consist of a direct or indirect heat transfer from airstreams, liquids, refrigerants, water, or gases. Waste heat sources for heat-recovery systems include:

- Flues of fuel-burning heating boilers and furnaces
- Refrigeration systems' hot gas and condenser water
- Exhaust gases from diesel engine and gas-turbine-driven electric-power-generating equipment
- Cooling water from diesel engine cooling jackets and air compressor aftercoolers
- Exhaust steam and condenser water from steam-turbine-driven electric generators and refrigeration units
- Exhaust air from toilet rooms, mechanical equipment rooms, transformer vaults, kitchen range hoods, laundries, laboratory hoods, hospital operating rooms, locker rooms, shower rooms, and swimming pools
- Wastewater from washing machines and dishwashers
- Internal heat gain from lights, people, and appliances

Applications for waste heat-recovery systems include:

- Building space heating
- Preheating ventilation outdoor air intake
- Air-conditioning systems supply air reheat
- Preheating domestic hot water and boiler feed water

THERMAL WHEEL
13.130

Sensible heat-absorbing aluminum or stainless steel mesh. Desiccant impregnated for latent heat transfer. Leakage 4 to 8 percent between opposing airstreams. Added purging section reduces cross-contamination to less than 1 percent. Speed variations or face and bypass damper capacity control. Efficiency 70 to 80 percent. Sizes to 144 in. diameter.

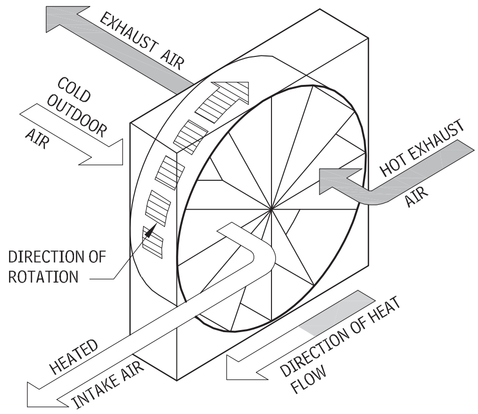
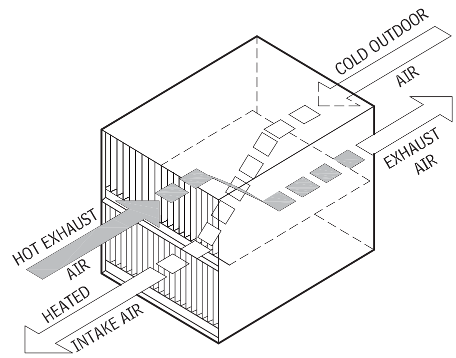


PLATE-TYPE HEAT EXCHANGER
13.131

Counterflow, direct air-to-air type heat exchanger. Sensible heat transfer only. No leakage between airstreams. Corrugated aluminum or stainless steel construction. Wash down spray manifold for dirty exhaust airstreams. Bypass damper temperature control. Modular sizes to 10,000 cfm. Efficiency 60 to 80 percent.



FIRE PROTECTION

DESIGN CONSIDERATIONS

The purpose of fire protection is to extinguish or mitigate the effects of a fire. Selection of the extinguishing medium most appropriate for a project is based on availability, compatibility, cost, and code requirements.

CODES AND STANDARDS

Most model, state, and local codes have a separate fire-protection section that mandates certain types of fire-suppression systems based on occupancy types, potential fire hazards, height, and area of the structure. Insurance companies, such as Factory Mutual, American Risk Insurers, and American Risk Management, have developed design standards to be followed by the clients they insure. In addition, the National Fire Protection Association (NFPA) has developed consensus standards for various suppression systems that are referenced by most building codes.

BASIC DEFINITIONS

Although the exact nature of fire and the combustion process is still not completely understood, it is known that three components are necessary for a fire to be maintained: fuel, oxygen, and a temperature high enough to start ignition or maintain combustion. All fire-extinguishing methods remove one or all of these components, causing the fire to be extinguished.

Fires are classified as:

- Class A fires, which occur in solid, combustible materials (such as wood and paper).
- Class B fires, which occur in combustible liquids (such as oil and gasoline).
- Class C fires are electrical in nature (such as a short circuit that causes a spark capable of igniting other substances).
- Class D fires occur in metals with their own fuel supply.

Building occupancy and other specific areas within a building are classified as follows, according to the potential for fire:

- *Light hazard* occurs in office buildings, schools, and public buildings.
- *Ordinary hazard* is similar to warehouses and stores with large amounts of combustible material.
- *Extra hazard* occurs where there is considerable potential for easily started, large fires.

The term "automatic" is often used when referring to fire-suppression systems. In this context, "automatic" means operation of the system without human intervention when fire conditions occur.

SYSTEM TYPES

Three general types of systems are used for suppression and extinguishing of fires: water-based, chemical-based (either liquid or powder), and gas-based.

- *Water-based fire-suppression systems:* These use either water mixed with chemicals, which add fire-extinguishing characteristics, or undiluted water, to cool the fire below ignition temperature or deprive it of oxygen.
- *Gas-based fire extinguishing systems:* These interfere with the combustion process and deprive the fire of oxygen.
- *Chemical-based fire extinguishing systems* (either liquid or powder): These interfere with the combustion process and deprive the fire of oxygen.

WATER-BASED FIRE-SUPPRESSION SYSTEMS

The medium most often used to extinguish fires is water. It is readily available, inexpensive, and easy to apply. The most important factor in the use of water-based fire-suppression systems is adequate water pressure. When pressure from the building water supply is inadequate to supply fire standpipe and sprinkler systems, fire pumps, manufactured and installed specifically for fire-suppression systems, are used to increase water pressure. The fire pump is installed in strict conformance with NFPA-20.

GAS-BASED SYSTEMS

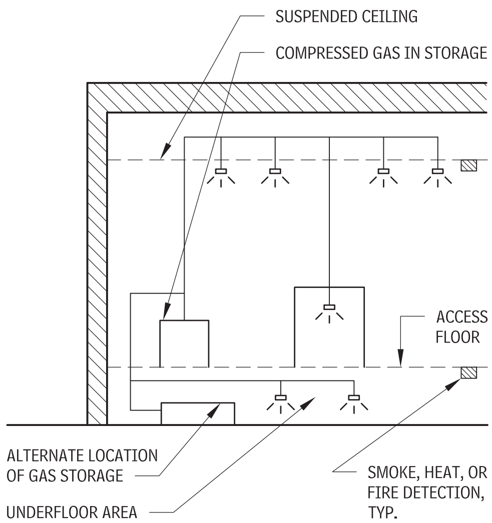
Some gas-based systems use inert gases, and others use chemical gases.

INERT GASES

These systems are used when chemicals that may react to water are present or when water will cause unacceptable damage. The gases (generally carbon dioxide or nitrogen) are discharged either directly onto a fire or are used to reduce the oxygen level in a room or area to a point below that required to sustain combustion. (Note, however, that this low level will not sustain life.)

The gas is stored compressed in high-pressure cylinders or tanks and is connected to a piping system with open heads. A quick-opening valve at the storage location detects heat, fire, or smoke at the hazard being protected, then opens to allow gas to enter the piping system and discharge out all of the heads.

TYPICAL GAS SYSTEM
13.132



OTHER GASES (HALON ALTERNATIVES)

Chemical gases interfere with the combustion process, and chemical gas systems are often used to protect computer and electronic equipment and areas. The systems operate in the same way as inert gas systems, but a lower concentration of gas is usually required. Halon is no longer permitted because of environmental concerns. Many halon alternatives are available, but authorities having jurisdiction must approve their use.

Because of the force exerted by the discharging gas, hung ceilings should be reinforced in areas where heads are located and the heads mounted so they can resist the force of discharge.

CHEMICAL SYSTEMS

Both wet and dry chemical fire-extinguishing systems require extensive cleanup after a fire has been extinguished.

DRY-CHEMICAL FIRE-EXTINGUISHING SYSTEMS

This system is used to protect areas for which water is not a suitable extinguishing medium, such as chemical storage areas and cooking areas with exhaust ductwork that vents grease. A powdered chemical is stored in high-pressure cylinders or tanks connected to a piping system with open heads. Upon detecting heat, fire, or smoke at the hazard being protected, a quick-opening valve at the storage location opens, allowing the powder to enter the piping system and discharge from all of the heads simultaneously.

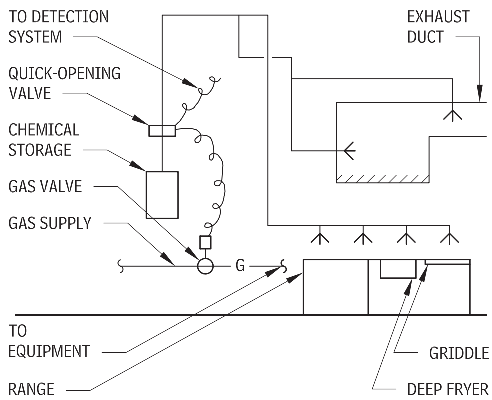
WET-CHEMICAL FIRE-EXTINGUISHING SYSTEMS

The recent shift from animal fats to vegetable fats for cooking required a different medium for fighting fires in kitchens. This medium is a wet chemical, which operates in the same manner as the dry-chemical system.

SPRINKLERS

A fire-suppression sprinkler system uses water distributed through a network of valves, piping, and nozzles, whose primary purpose is to set off an alarm and mitigate the effects of a fire, not necessarily to extinguish it. When a fire condition is present, the heat of the fire melts the element of a closed sprinkler head, allowing water to discharge automatically onto the fire.

DRY- OR WET-CHEMICAL SYSTEM FOR KITCHENS
13.133



The sprinkler piping system is sized using one of two methods:

- The *schedule method* uses pipe sizes based on a minimum available water pressure and the number of heads connected to the piping, given in NFPA-13.
- The *hydraulic method* uses a remote area (that farthest from the water supply source) based on occupancy type, flow of water over the remote area, flow of water at each design point, and pressure available in the system.

MAJOR SYSTEM COMPONENTS

The major operating components of a sprinkler system are the operating valve assembly, piping, and nozzles (referred to as *heads* for some systems).

The operating valve assembly admits water to or sends an alarm upon the flow of water in the system. There are many types of operating valves; the type of system installed determines the type of valve used.

Heads or nozzles distribute water in a special, predetermined pattern based on the requirements of the system. They are available in a wide variety of configurations, including upright, pendant, or sidewall, and can be closed or open. They have different temperature ratings to open the head, various orifice diameters for the discharge of water, standard or quick response, and standard or extended coverage. They can be installed in a hung ceiling as concealed, flush, or exposed fixtures.

Contributors:
Michael Frankel, CIPE, Utility Systems Consultants, Somerset, New Jersey; American Society of Plumbing Engineers, Westlake, California.

SPRINKLER OCCUPANCY HAZARD CLASSIFICATIONS

Occupancy hazard is determined by the quantity and combustibility of room contents, the expected heat release rate, the total potential for energy release, the height of stockpiles, and the presence of flammable/combustible liquids. Occupancy hazard determines the appropriate sprinkler head type, protection area per head (affecting spacing), and sprinkler head flow density. For details, refer to NFPA 13, "Standard for the Installation of Sprinkler Systems."

- *Light hazard:* Light (Low) hazard occupancies have combustibles expected to produce fires with relatively low heat release rates. Light hazard areas may include offices, classrooms, and meeting rooms.
- *Ordinary hazard:* Ordinary (Moderate) hazard occupancies have combustibles with low combustibility content and relatively moderate heat release rates. Group 1 occupancies may have stockpiles not exceeding 8 ft. in height, while Group 2 may have stockpiles below 12 ft. Ordinary hazard locations may include offices, malls, light manufacturing or research operations, parking garages, workshops, or maintenance/service areas.
- *Extra hazard:* Extra (High) hazard occupancies have contents with dust and lint and other materials introducing rapidly developing fire with high heat release rates. Group 1 occupancies have little to no combustible or flammable liquids, while Group 2 occupancies may have substantial amounts of combustible liquids. Shielding of combustibles also comes into consideration in determining the extra hazard group. High hazard locations may include car repair shops; aircraft and boat servicing; painting, dipping, and coating operations; and tank/container storage areas.

Occupancy hazard dramatically affects the required water flow density to be provided by a sprinkler system. In essence, it affects system sizing.

TYPES OF FIRES

Fire is an oxidation (or combustion) process that requires three distinct elements: a fuel, oxygen, and heat. These three elements are depicted in the "fire triangle" as the necessary ingredients for combustion. Remove any one of the three and a fire will be extinguished. Various types of fire prevention and extinguishment strategies operate to remove one or more of these ingredients.

Unimpeded, a fire will typically progress through four stages of development. The incipient stage comes first, with products of combustion being emitted, but no visible smoke or appreciable heat. This is followed by the smoldering stage, with visible smoke production, but no heat or flames. The flame stage follows, with visible flame but modest heat. The final stage is the heat stage where the fire is fully engaged and producing substantial heat.

In the building context, fires often progress (unless interrupted by fire-protection efforts) through three phases. A nonexplosive fire typically starts as a fire in a room (such as a trash can fire). If not extinguished but allowed access to additional fuel, a fire in a room will progress to the room fire phase—where elements of room finishes and furnishings become involved in the fire. If not contained by fire barriers or a sprinkler system, a room fire will spread to other rooms and eventually become a building fire.

Different fuels create different types of fires and require different types of fire-extinguishing agents. Categorizing fires makes it easier to choose the most appropriate extinguishing medium (such as water or dry chemical).

- *Class A—Ordinary Combustibles:* These fuels are involved in the most common type of fire, involving materials such as wood, rubber, paper, cloth, trash, and some plastics. Class A fires are probably the easiest to extinguish as spraying them with water will cool the fire, thus removing the heat supply that is essential for the fire to burn. Water-based or foam fire extinguishers are appropriate for putting out Class A fires.
- *Class B—Flammable Liquids and Gases:* Liquids such as gasoline, petroleum oils, or paints, and flammable gases such as propane and butane can fuel Class B fires. A key concern with extinguishment is containment of the fuel (water is a bad agent as many of these fuels will float on water and spread). Foam and dry powder fire extinguishers are appropriate for putting out Class B fires.
- *Class C—Electrical:* These fires involve energized electrical equipment such as motors, transformers, and appliances. Water is not an acceptable extinguishing agent due to its electrical conductivity. Carbon dioxide and dry powder fire extinguishers are recommended.
- *Class D—Combustible Metals:* Metals such as potassium, sodium, aluminum, and magnesium can burn when in contact with air and water. Specially formulated powder-medium fire extinguishers can be effective on type D fires. It is critical that the extinguisher match the metal likely to be involved.
- *Class K—Combustible Oil and Grease (Kitchen):* Fires involving unsaturated cooking oils are difficult to extinguish due to the high temperatures involved. Wet-chemical Class K extinguishers contain an extinguishing medium that cools the fire and then emulsifies to seal the surface and prevent re-ignition.

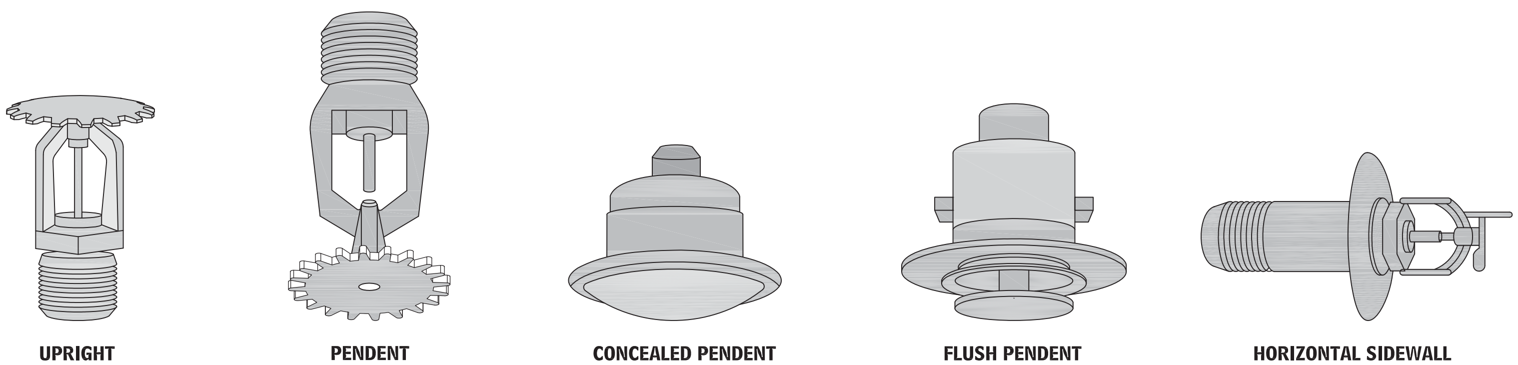
SPRINKLER HEADS

Sprinkler heads come in a variety of styles and performance characteristics. Selection of heads on a project is based upon architectural and engineering needs—including appearance, flow rate, water distribution pattern, and response time.

A standard upright sprinkler head is mounted above a sprinkler supply pipe, usually in a room without a suspended ceiling and where it is desirable to partially protect the sprinkler head by not suspending it downward. The head is characterized by a slightly curved deflector—a serrated metal plate designed to direct and distribute water downward from the sprinkler.

A standard pendent sprinkler is mounted below the sprinkler supply pipe, usually below the surface of a suspended ceiling and is characterized by a flat serrated deflector. Concealed pendent sprinkler heads, used where clean ceiling aesthetics are important, are recessed into the ceiling plane and covered with a decorative cap. The cap falls away when temperatures are about 20°F below the activation temperature of the sprinkler head. Once the sprinkler reaches its rated activation temperature, the head will drop below the ceiling and discharge. Flush pendent heads are

SPRINKLER HEAD TYPES
13.134



similar to concealed heads, but without the cap and with a partial projection below the ceiling plane.

Sidewall sprinkler heads have a deflector designed to ensure that the sprinkler discharges water toward the floor surface from a wall-mounted position. The deflector directs some water back toward the wall so that it is also protected. Sidewall heads are used when sprinklers cannot be located in the ceiling (typically due to exposed concrete slab construction). Room dimensions are limited with sidewall sprinklers.

Dry sprinklers are thermosensitive sprinkler heads designed for use in areas subject to freezing. These heads may be used with dry-pipe and preaction systems where it is necessary to prevent water or condensation from entering the supply nipple before sprinkler operation. They can also be used in unheated spaces adjacent to heated rooms equipped with wet-pipe sprinkler systems.

A conventional sprinkler head is activated by heat (expressed as temperature). The head opens when a triggering action occurs—a frangible bulb breaks (the norm in current head design) or a fusible link melts. This action opens the head and allows water to flow. The water flow persists until the water supply is shut off. An activated head must be replaced to reset the system.

SPRINKLER HEAD TEMPERATURE RATINGS, CLASSIFICATIONS, AND COLOR CODING 13.135

SPRINKLER HEAD ACTIVATION TEMPERATURE (°F)	TEMPERATURE CLASSIFICATION	COLOR CODING	GLASS BULB COLORS
135–170	Ordinary	Uncolored or Black	Orange or Red
175–225	Intermediate	White	Yellow or Green
250–300	High	Blue	Blue
325–375	Extra High	Red	Purple
400–475	Very Extra High	Green	Black
500–575	Ultra High	Orange	Black
625	Ultra High	Orange	Black

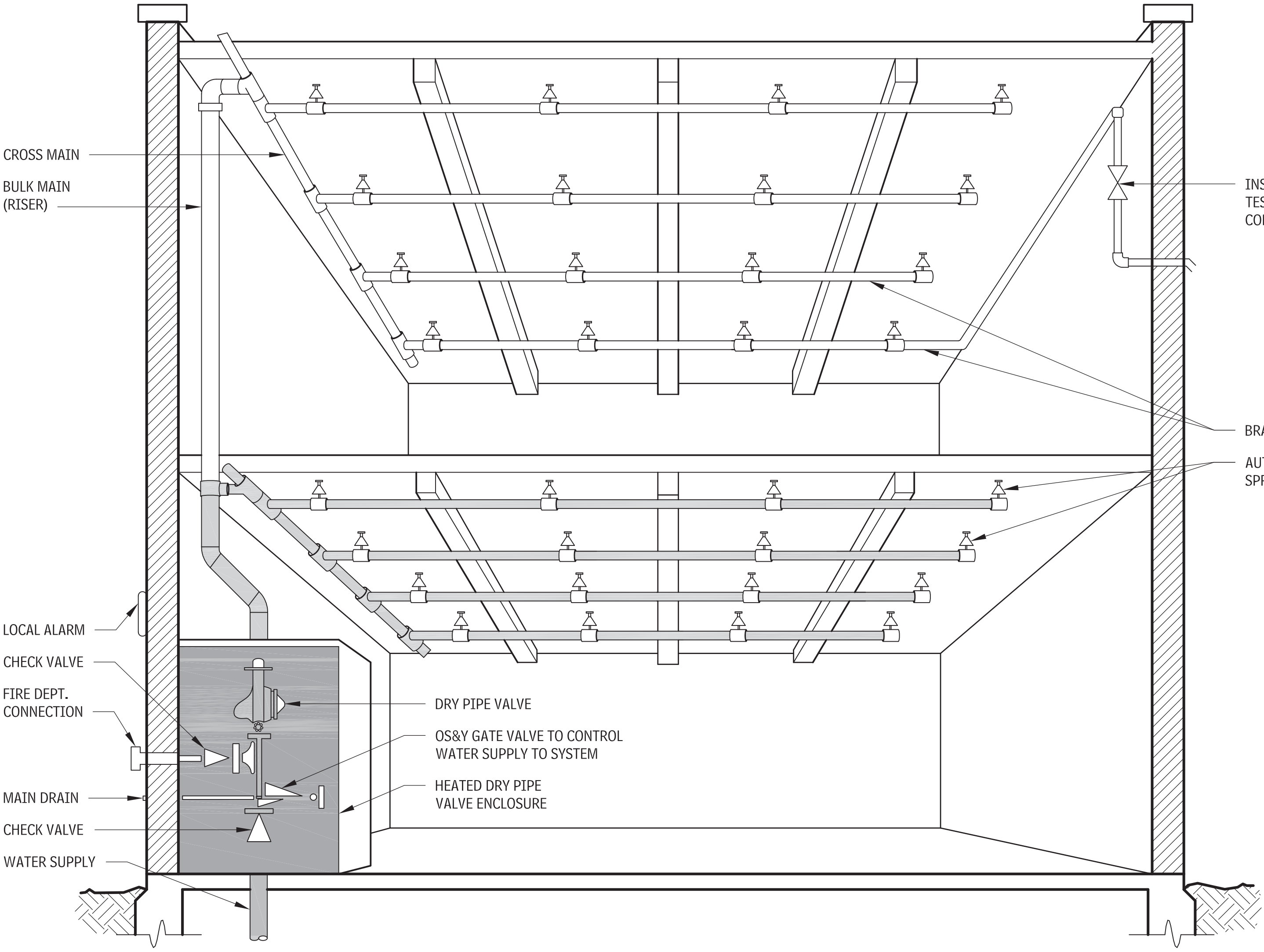
Despite their advantages, dry pipe sprinklers have separate maintenance, testing, and installation requirements to ensure proper performance. Unlike a wet pipe system, dry sprinklers are free of water until a fire is detected, but they need to be periodically tested. The challenge with these systems is that once you fill them with water during a test, you need to completely drain the system upon completion of the test.

SPRINKLER SYSTEM TYPES

There are six common types of fire-suppression sprinkler systems.

- *Wet-pipe sprinkler systems:* This automatic system uses piping filled with water under pressure and closed heads. The operating valve assembly, called an *alarm check valve*, initiates an alarm when water flows and prevents the reverse flow of water into the building service if the system is supplied with water from a fire department connection. When a fire condition exists the heat melts (fuses) a temperature-sensitive element in the head, causing the head to open and water to flow.
- *Dry-pipe sprinkler systems:* This automatic system uses piping filled with air under pressure and closed heads. The operating valve assembly is called a *dry pipe valve*. An air compressor is required to make up air lost through leakage. Both water and compressed air are supplied only up to the dry pipe valve. When a head fuses due to a fire condition, it lowers the air pressure, opens the valve, and permits water to enter the piping; the water then flows only from the open heads.
- *Preaction sprinkler systems:* This automatic system uses closed heads and piping filled with air under atmospheric pressure. Water is supplied to the operating valve assembly, called a *preaction valve*. An ancillary smoke- or fire-detection system initiates a signal upon detection of heat, fire, or smoke. The signal causes the preaction valve to open, allowing water to enter the piping system. Water will not flow out of the heads unless they open due to a fire condition.
- *Deluge fire-suppression sprinkler systems:* Used to protect high-hazard areas and specific equipment, this automatic system uses piping filled with air under atmospheric pressure and open heads. Water is supplied to the operating valve assembly, called a *deluge valve*. An ancillary smoke- or fire-detection system is required to initiate a signal upon detection of heat, fire, or smoke at the hazard being protected. This signal will open the deluge valve, admitting water throughout the piping system and allowing water to discharge out of all the heads connected to the piping network.
- *Antifreeze sprinkler system:* A wet-pipe automatic system is filled with an antifreeze solution instead of water to protect areas subject to freezing but too small for a dry-pipe system. Operations are similar to those of the standard wet-pipe system.
- *Water spray fixed system:* This automatic system uses high-pressure water flowing through nozzles designed to discharge very small droplets of water directly onto a fire. A water pump is required to produce the high system pressure. Water is supplied to the pump, which is activated by ancillary heat, fire, or smoke detectors adjacent to the hazard protected.

SPRINKLER SYSTEM TYPES
13.136



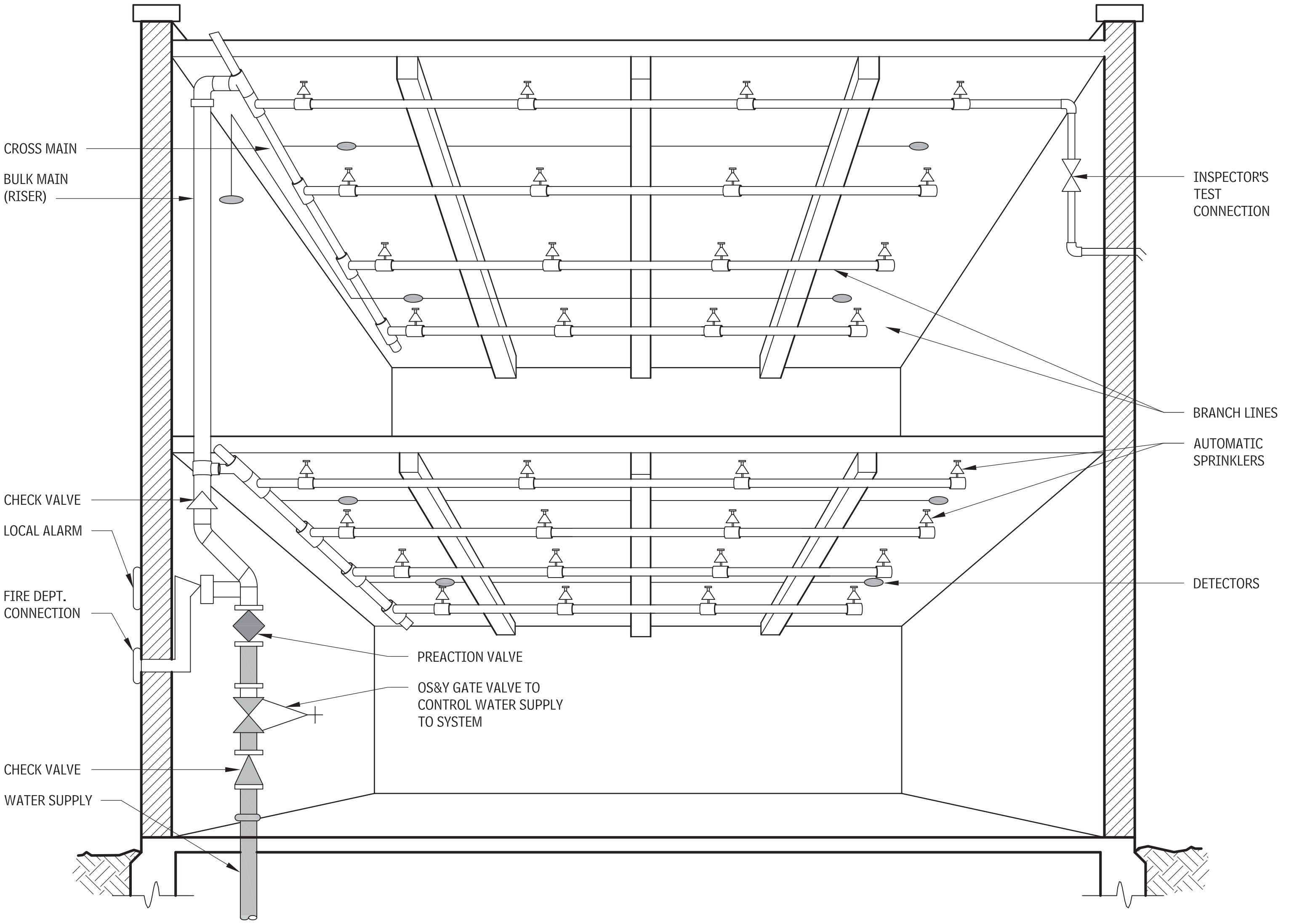
HYPOTHETICAL DRY PIPE SYSTEM

NOTE

13.136 Coverage varies with mounting height and water pressure.

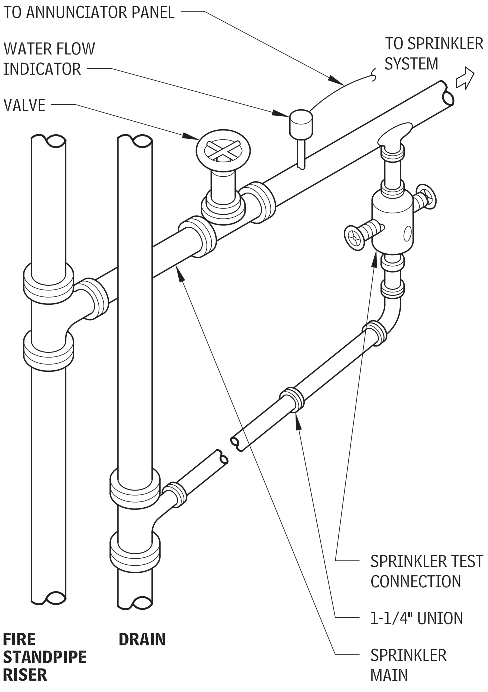
Contributor:
Ayush Vaidya, M. Arch, University of Oregon, Eugeane, Oregon, with Walter Grondzik, PE, Ball State University, Muncie, Indiana.

SPRINKLER SYSTEM TYPES
13.136 (continued)



TYPICAL PREACTION SPRINKLER SYSTEM

TYPICAL SPRINKLER CONNECTION
13.137



WALL-MOUNTED FIRE DEPARTMENT CONNECTION
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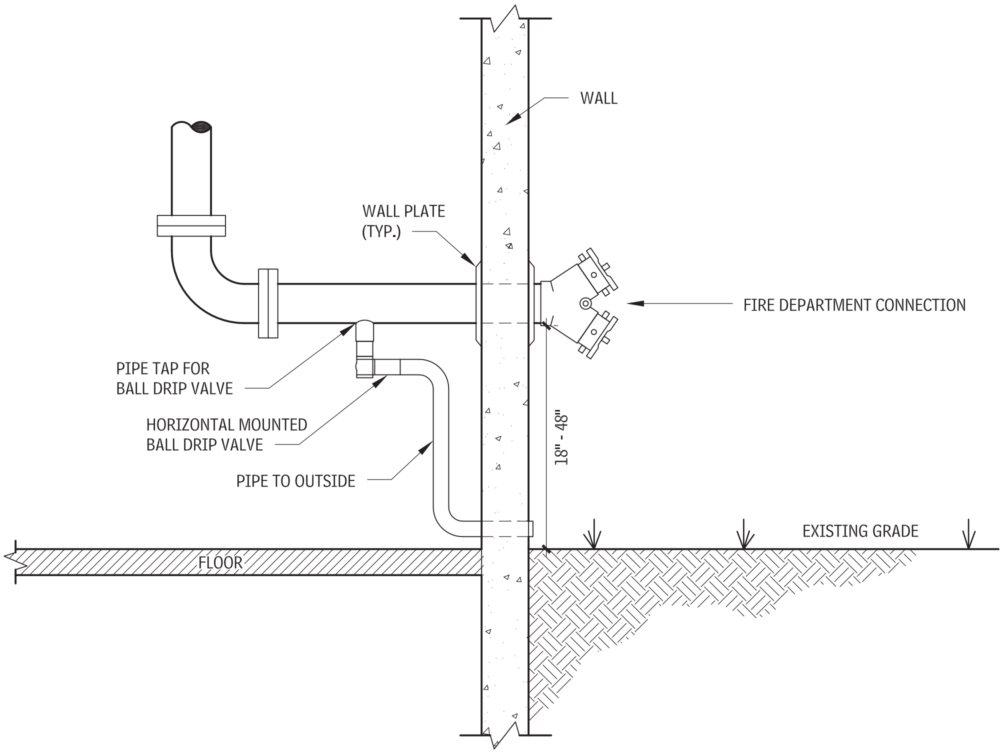


STANDPIPES

Fire-suppression standpipes are a network of water-filled pipes, hose valves, and fire hose that allows the direct application of water onto a fire. The most common system configuration has hose valves only, which are connected to system piping to allow fire department personnel to connect their hose to the system. Mains are installed in high-fire-rated areas such as stairwells. Hose valves are located so that all parts of the building can be reached with a 100-ft length of hose and a 20-ft water stream from the hose nozzle.

It is accepted practice to supply sprinkler heads from standpipes in various areas throughout a building. Each connection point is provided with a flow alarm. A test connection is installed at each point to permit authorities to visually verify that the water discharged from one sprinkler head is actually flowing and will initiate an alarm. This test connection is combined with a drain line to permit the entire branch to be drained for maintenance and repair.

FDC CONNECTION

A fire department connection (FDC) is a means of providing an auxiliary water supply for a water-based suppression system—including automatic sprinkler systems and standpipe systems. This assembly, located outside of the building enclosure, allows the fire department to supplement a building's fire protection water supply by connecting hose lines from a pumper truck to the fire department connection. The FDC can also serve as an alternative source of water should there be a problem with the primary (building) water supply. NFPA 13, "Standard for the Installation of Sprinkler Systems" requires FDCs in all automatic sprinkler systems.

An FDC (also called a Siamese connection) consists of the fire hose connections, a check valve, and piping that connects to the sprinkler or standpipe riser or main. To prevent water from collecting in the piping between the check valve and the inlet body, an automatic drip is installed at the lowest point of the FDC piping. High-rise buildings with vertically zoned fire protection risers will have a designated FDC for each zone.

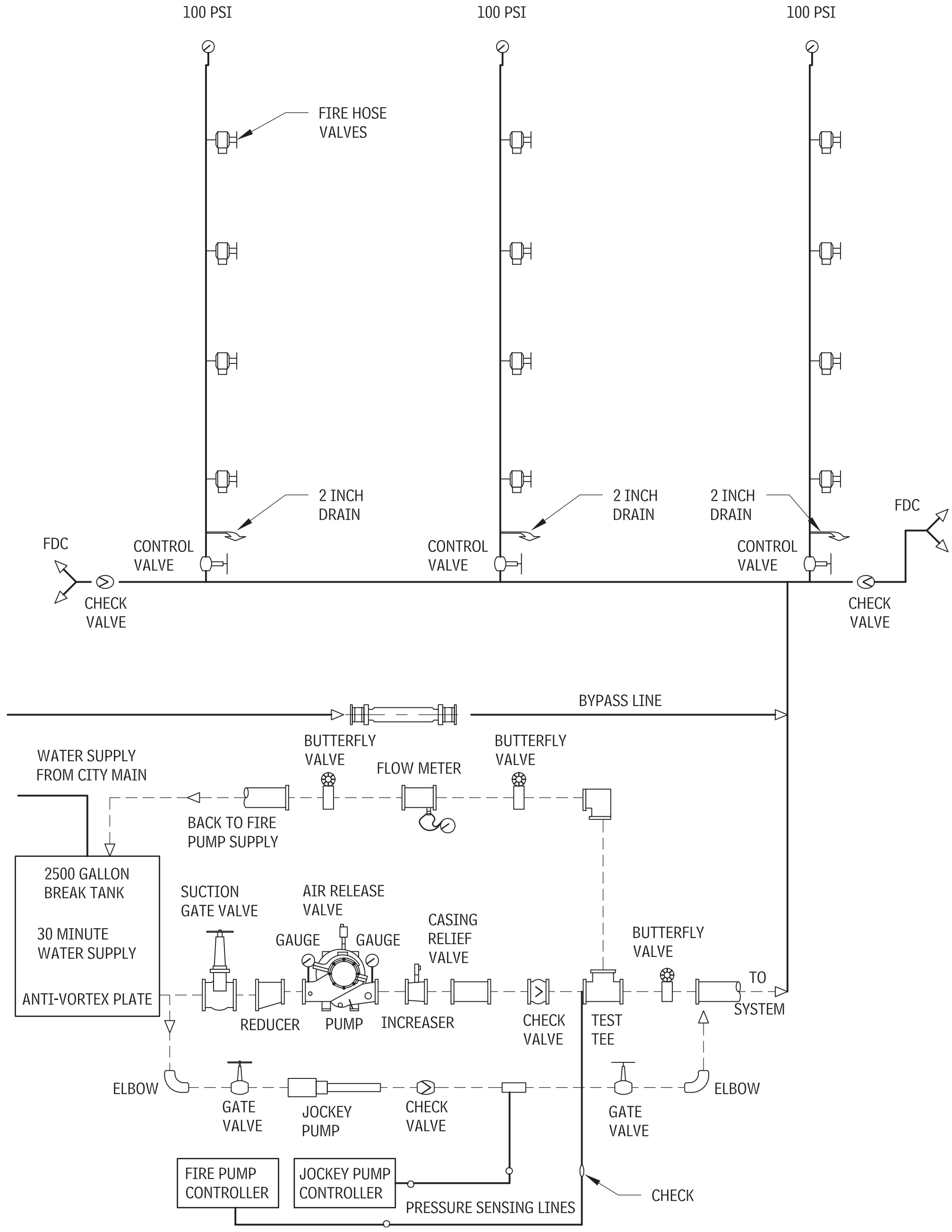
An FDC must be positioned on the street side of the building and be fully visible and recognizable from the street or the point of fire department vehicle access. The FDC should be positioned such that the hose run between the pumper truck and the FDC is no greater than 100 ft. FDCs come in various sizes—from $1^1/_2$ in. for residential systems, $2^1/_2$ in. for most other buildings, and up to 4 to 5 in. for very large buildings. The FDC should be no less than 18 in. and no more than 48 in. above grade.

FIRE-PROTECTION PUMPING SYSTEMS

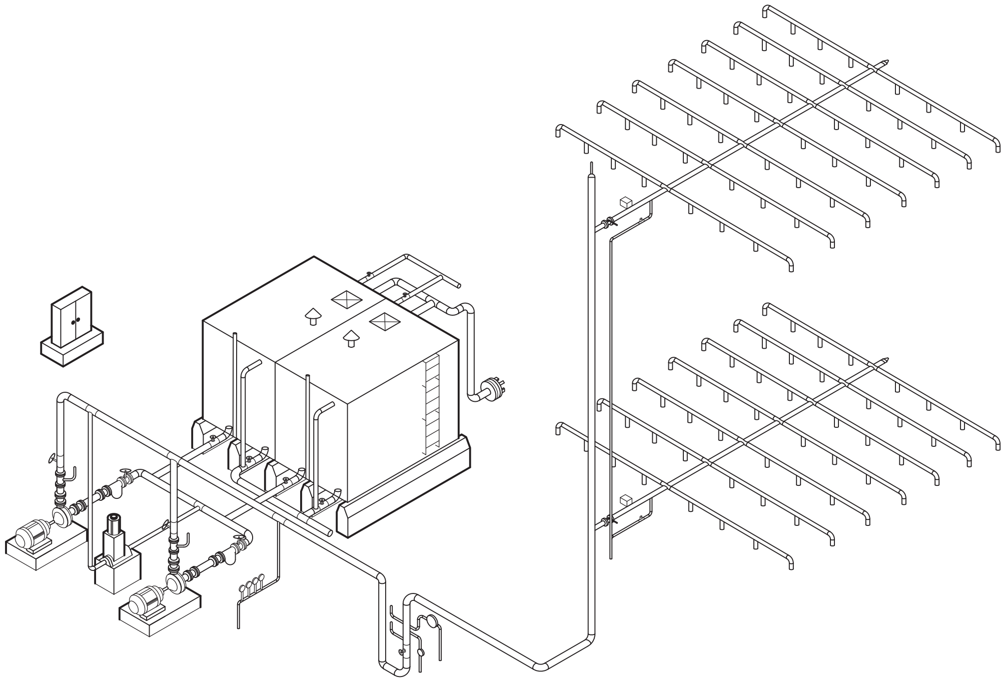
Water-based central fire-protection systems (standpipes and automatic sprinklers) depend upon adequate water supply during the duration of an emergency. Initial water supply will be building-based; extended water supply may be provided by fire trucks and fire department connections. Requirements for a building-based water supply are project specific (involving hazard classification, protected floor area, building height, and municipal water supply characteristics). Dedicated fire pumps are often required to provide adequate protection. A building-based water supply source (storage) may be required depending upon project context. See NFPA documents for details.

Contributors:
Ayush Vaidya, M. Arch, University of Oregon, Eugene, Oregon, with Walter Grondzik, PE, Ball State University, Muncie, Indiana.

PUMPING DIAGRAM FOR STANDPIPE SYSTEM
13.139



PUMPING ARRANGEMENT FOR AUTOMATIC SPRINKLER SYSTEM
13.140



FIRE-SUPPRESSION HOSES, RACKS, AND CABINETS

Recommended hose size for use with building fire-suppression standpipes should not exceed 1–1/2 in. in diameter and 100 ft. in length. A larger hose used by amateurs is likely to tangle and cause excessive water damage and possible injuries.

A connection for a 2–1/2-in. hose should be available to each station for the use of firefighters. Many codes require 2–1/2-in. outlets at all standpipes.

By using a reducing coupling, a 1–1/2-in. hose can be attached. When a 2–1/2-in. stream is required, the coupling may be removed. Industrial installations use 2–1/2-in. hoses and train personnel in the use of the heavier equipment. Valves may be located 5 ft-6 in. above floor (check local code).

Lined synthetic fiber plastic hoses are recommended for use on standpipe installations. Cotton-rubber-lined hoses are standard for fire department and heavy equipment use.

RATED/NONRATED CABINETS

If a cabinet containing fire extinguishing equipment (such as a fire hose or a portable fire extinguisher) is surface mounted there is no effect on the fire rating (if so required) of the mounting wall. A non-fire-rated cabinet may be used. A recessed or semi-recessed cabinet installed on a rated wall will, however, affect the fire rating of the affected wall. In such circumstances, use of a rated cabinet may be a logical design solution (as opposed to modifying the wall construction).

The primary difference in rated versus nonrated cabinet dimensions (whatever the overall size) is the addition of roughly 1–1/8 in. to the required wall opening dimensions to accommodate the extra thickness of the rated cabinet walls.

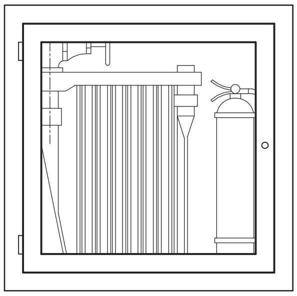
FIRE-PROTECTION SPECIALTIES

FIRE EXTINGUISHERS

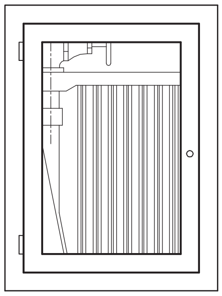
Portable fire extinguishers can serve as a first line of defense against fires of limited size, even property equipped with automatic sprinklers or other fixed protection equipment. The following are criteria for selecting fire extinguishers:

- Type and severity (size, intensity, and speed of travel) of potential fire hazard
- Environmental conditions of potential fire hazard (ambient air temperature conditions, presence of fumes, etc.)
- Effectiveness of extinguisher on potential fire hazard
- Ease of use
- Suitability for its environment
- Any anticipated adverse chemical reactions between the extinguishing agent and the burning materials
- Any health and operational safety concerns (exposure of operators during fire control efforts)
- Training and physical capabilities of available personnel to operate extinguisher
- Upkeep and maintenance requirements

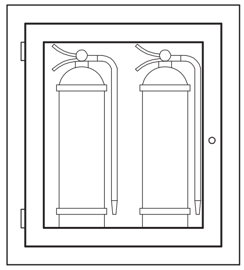
FIRE HOSE AND EXTINGUISHER CABINETS
13.141



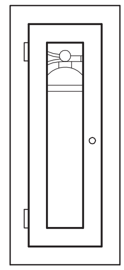
75'-1-1/2" LINED HOSE, RACK, AND ANGLE VALVE; 2-1/2 GAL EXTINGUISHER
2'-9" x 2'-9" x 8-1/2" TO
2'-11" x 2'-11" x 9"



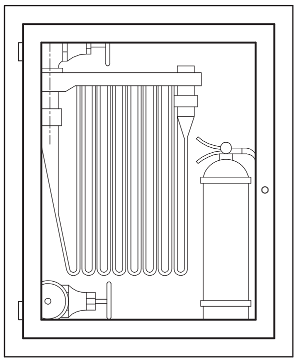
75'-1-1/2" LINED HOSE, RACK, AND ANGLE VALVE
1'-9" x 2'-5" x 8" TO
1'-4" x 2'-7" x 8-1/2"



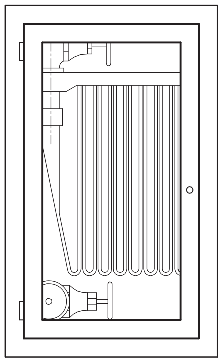
TWO 2-1/2 GAL EXTINGUISHERS
1'-11" x 2'-9" x 7" TO
2'-2" x 2'-11" x 8"



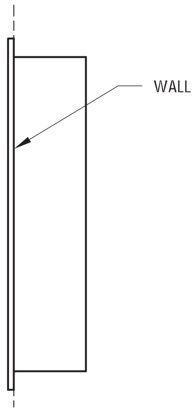
ONE 2-1/2 GAL EXTINGUISHER
1'-0" x 2'-6" x 8" TO
1'-4" x 2'-7" x 8-1/2"
RESIDENTIAL EXTINGUISHER CABINET 1'-5" x 7" x 2"



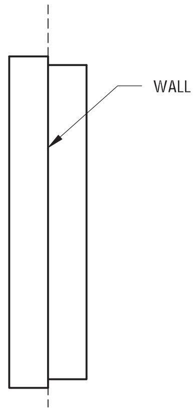
75'-1-1/2" LINED HOSE AND RACK; 1-1/2" AND 2-1/2" ANGLE VALVE; 2-1/2" GAL EXTINGUISHER
2'-9" x 3'-4" x 8-1/2" TO
2'-10" x 3'-7" x 9"



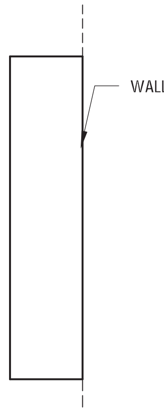
75'-1-1/2" LINED HOSE AND RACK; 1-1/2" AND 2-1/2" ANGLE VALVE
1'-11" x 3'-3" x 8-1/2" TO
2'-4" x 3'-4" x 9"



RECESSED



SEMIRECESSED



SURFACE-MOUNTED

General guidelines for fire extinguishers state that:

- Fire extinguishers on accessible routes must be configured so that they do not protrude more than 4 in.
- The authority with jurisdiction over the location dictates the number, type, and placement of fire extinguishers and fire-extinguisher cabinets.
- All extinguishers without wheels must be installed on hangers or brackets, mounted in cabinets, or set on shelves. Extinguishers weighing up to 40 lb. should be no more than 5 ft. above the floor. The top of extinguishers with a gross weight greater than 40 lb. should be no more than 3 ft-6 in. above the floor. All operable parts must be within accessible-reach ranges.

It's also important to note that halon-type extinguishers are no longer manufactured as a result of an international environmental agreement.

These standards and classifications are taken from the National Fire Protection Association Publication 10, "Portable Fire Extinguishers". Always check local code requirements before specifying fire extinguishers.

LOCATING PULL STATIONS AND EXTINGUISHERS

Manual fire alarm pull stations generally must be located within 5 ft. of each exit doorway on a floor. Additionally, they should be placed within a building at intervals not greater than 200 ft. apart. The design intent is for manual fire alarm pulls to be encountered while following an emergency egress path to safety. Manual fire alarm pull stations are not required by code if a building is fully sprinklered and smoke detection with alarm verification is provided. Differential requirements will apply to specific occupancies.

The process of locating portable fire extinguishers is influenced by several variables, including the type of extinguisher (fire type), the extinguisher rating (capacity), the occupancy hazard, and the size of the building. Examples of extinguisher location requirements are presented below. See NFPA 10, "Standard for Portable Fire Extinguishers" for more detailed information.

DISTRIBUTION OF FIRE EXTINGUISHERS

Fire extinguishers rated for Class B fires are placed a maximum travel distance of 50 ft. from the hazard (smaller rated extinguishers are placed no more than 30 ft. from the hazard). Fire extinguishers rated for Class C fires are required in locations with energized electrical equipment that would require a nonconducting extinguishing medium. For Class D fires, extinguishers are located not more than 75 ft. from the Class D hazard.

NOTES

13.141 a. Cabinets are #18-gauge steel with glass doors, as shown, or with doors of metal, wood, mirror, and others.
b. Consult manufacturers' literature for cabinets with special features such as revolving door, twin doors, pivoting door with attached extinguisher, and curved door.
c. Cabinets are obtainable for 25-, 50-, 75-, and 100-ft hose racks. Rough dimensions are shown.

Contributor:
William G. Miner, AIA, Architect, Washington, DC.

OSHA EXTINGUISHER LOCATION REQUIREMENTS 13.142

TYPE OF FIRE	FIRE EXTINGUISHER PLACEMENT
Class A	One extinguisher for every 3000 sq. ft., with access to an extinguisher within a 75-ft travel distance. An automatic sprinkler system can be used in lieu of portable fire extinguishers.
Class B	Access to an extinguisher within a 50-ft travel distance
Class C	Access to an extinguisher within a 50-ft travel distance
Class D	Extinguishers not more than 75 ft. from the hazard
Class K	Extinguishers not more than 30 ft. from the hazard

FIRE CLASSIFICATIONS FOR SELECTING FIRE EXTINGUISHERS 13.143

LETTER SYMBOL AND COLOR	PICTURE SYMBOL	DESCRIPTION
Green A		Class A: Fires involving ordinary combustible materials (such as wood, cloth, paper, rubber, and many plastics) that require the heat-absorbing (cooling) effects of water or water solutions, or the coating effects of certain dry chemicals that retard combustion.
Red B		Class B: Fires involving flammable or combustible liquids, flammable gases, greases, and similar materials that are best extinguished by excluding air (oxygen), inhibiting the release of combustible vapors, or interrupting the combustion chain reaction.
Blue C		Class C: Fires involving energized electrical equipment where safety to the operator requires the use of electrically nonconductive extinguishing agents.
Yellow D		Class D: Fires involving combustible metals (such as magnesium, titanium, zirconium, sodium, lithium, and potassium).

ELECTRICAL

Building electrical systems are designed and installed to provide power to building loads. Loads may be hard-wired fixed loads (such as fan, pump, and elevator motors) or plug loads that access the electrical system via convenience receptacles. Building electrical systems consist of three main subsystems: a service subsystem that brings power into the building and provides high-level safety and control oversight; the loads subsystem that defines the need for electricity and the locations of those needs; and the distribution subsystem that delivers power from the service to the various points of need while providing secondary safety and control functions.

INDUSTRY STANDARDS

The design and installation of electrical systems is highly regulated by code. Building electrical systems are governed by NFPA 70, "The National Electrical Code." Electrical devices are regulated by Underwriters Laboratories (UL) listings. Although highly code-based, the design of electrical systems should consider that codes provide minimum societally acceptable requirements for design—an owner's project expectations may demand more than code minimum, particularly in the areas of flexibility in distribution and access to receptacles.

SUSTAINABILITY

The design of electrical systems is heavily dictated by code requirements that have evolved over time to protect the health, safety, and welfare of building users and the public. In general, these code requirements do not interfere with efforts to make buildings more sustainable. Physical sustainability concerns (as distinct from economic and equity considerations) related to electrical system design will normally focus on two areas: (1) energy efficiency and (2) energy conservation. These are conceptually and practically different concerns.

The majority of energy consumed in a modern building passes through the building electrical system. This includes energy consumed by plug loads, fixed power loads (motors), electric lighting systems, and HVAC systems. Domestic hot water and elevator loads may also be included. The exception to the electrical pass-through pattern is gas-fired equipment.

Energy Efficiency: If there is a desire to advance sustainability on a project, it would be reasonable to specify high-efficiency electrical distribution equipment (such as transformers and switchboards). A 1/2 percent increase in efficiency here affects all power in the building (whereas a 5 percent increase in a motor's efficiency affects only the driven equipment). Consider the operating environment for distribution equipment—it can affect efficiency. Building wiring should be designed to minimize losses (via rational routing and sizing). Premium quality motors should be selected to improve equipment efficiency.

Plug loads and electric lighting can account for half the energy consumption in commercial/institutional buildings. These must be considered in any attempt to improve sustainability. Electric lighting devices have greatly improved over the past decades; very efficient lighting equipment options are readily available and should be used. In the cooling season (all year long in many buildings) heat gain from electric lighting adds to cooling loads in a cascading fashion. No building striving for sustainability can be designed around business-as-usual plug loads. The design team must engage these loads, through dialog with the owner/client, in an effort to reduce energy consumption via efficiency.

Energy Conservation: As opposed to efficiency (maximizing output per unit of input), conservation focuses on not using energy. This may be accomplished by:

- Turning off equipment (including lighting) when not needed
- Using proportional control devices and schemes (such as variable frequency drive controllers and dimming ballasts)

If the idea of conservation is extended to basic resources, displacing fossil-fuel energy inputs through the use of renewable energy (solar, wind) can be effective. Daylighting displaces electricity use; solar thermal hot water systems displace gas or electricity.

Materials Conservation: This is an area that is not being formally pursued for electrical systems in most green building rating systems. Yet there is a lot of metal in electrical systems—which may already be substantially manufactured using recycled materials. Local sourcing of products should be considered (when possible) to reduce energy and pollution associated with transportation of system components.

Sustainability from a social perspective may be addressed by ensuring that designs do not sacrifice equitable outcomes for efficiency.

TRANSFORMERS

A transformer changes voltage in an electrical system—typically reducing voltage in one or more increments in or adjacent to a building. The need for transformers on a project is related to decisions about utilization voltages and service voltages. Service transformers may be located outside of the building envelope or inside the building in a suitable room. Distribution transformers are often distributed throughout a building in electrical closets.

TYPICAL DIMENSIONS OF PAD-MOUNTED TRANSFORMERS 13.144

FLOOR AREA OF COMMERCIAL BUILDING	NUMBER OF RESIDENTIAL UNITS	PAD SIZE
18,000 ft^2	50	52 × 44 in.
(1,700 m^2)		(1.3 × 1.2 m)
60,000 ft^2	160	52 × 50 in.
(5,700 m^2)		(1.3 × 1.3 m)
180,000 ft^2	–	96 × 96 in.
(17,000 m^2)		(2.4 × 2.4 m)

NOTE

13.142 Source: www.osha.gov/SLTC/etools/evacuation/portable_placement.html

TYPICAL SIZES OF TRANSFORMER VAULTS AND SWITCHGEAR ROOMS
13.145

FLOOR AREA OF COMMERCIAL BUILDING	FLOOR AREA OF RESIDENTIAL BUILDING	SIZE OF COMBINED ROOM FOR TRANSFORMERS AND SWITCHGEAR	SIZE OF TRANSFORNMER VAULT	SIZE OF SWITCHGEAR ROOM
150,000 ft^2	300,000 ft^2	30 × 30 × 11 ft		
(15,000 m^2)	(30,000 m^2)	(9.14 × 9.14 × 2.44 m)		
100,000 ft^2	200,000 ft^2		20 × 20 × 11 ft	30 × 20 × 11 ft
(10,000 m^2)	(200,000 m^2)		(6.0 × 6.0 × 3.35 m)	(9.0 × 6.0 × 3.35 m)
300,000 ft^2	600,000 ft^2		20 × 40 × 11 ft	30 × 40 × 11 ft
(30,000 m^2)	(60,000 m^2)		(6.0 × 12.0 × 3.35 m)	(9.0 × 12.0 × 3.35 m)
1,000,000 ft^2	2,000,000 ft^2		20 × 80 × 11 ft	30 × 80 × 11 ft
(100,000 m^2)	(200,000 m^2)		(6.0 × 24.0 × 3.35 m)	(9.0 × 24.0 × 3.35 m)

SUBSTATIONS, MOTOR STARTERS, SWITCHBOARDS, AND BUSWAYS

SECONDARY UNIT SUBSTATION

A secondary unit substation, sometimes called a *power center*, is a close-coupled assembly consisting of three-phase power transformers, enclosed high-voltage incoming line sections, and enclosed secondary low-voltage outgoing sections encompassing these electrical ratings:

- *Transformer kVA:* 112.5 through 2500 (self-cooled rating) liquid-filled, dry-type, or cast coil
- *Primary voltage:* 2.4 kV thru 34.5 kV
- *Secondary voltage:* 208, 240, 480, or 600 V (maximum)

For information on aisle space, ventilation, servicing area, and special building condition requirements, refer to the National Electrical Code.

MOTOR STARTERS

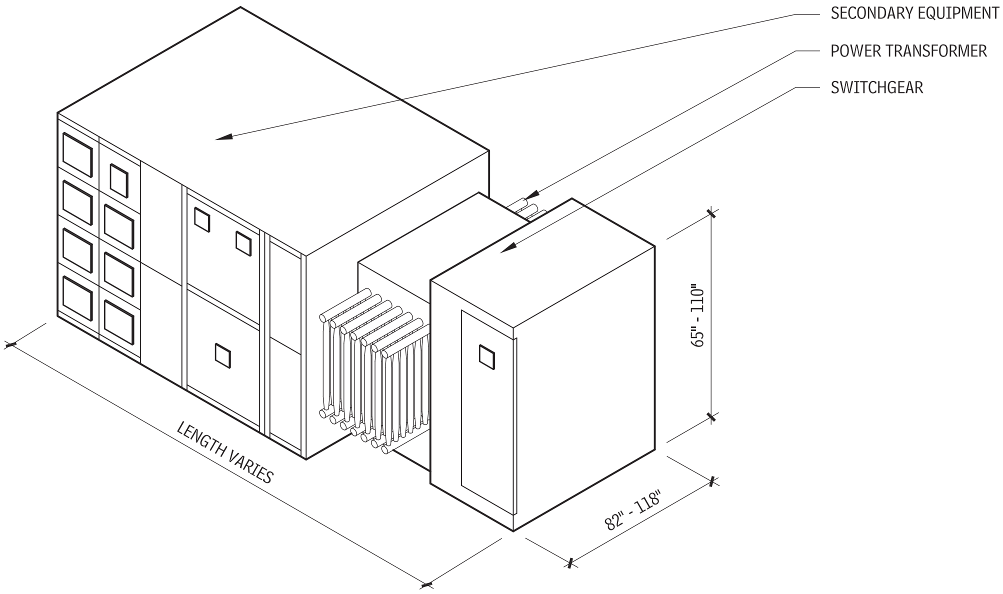
Four types of starters are described here: manual single-phase starters, magnetic motor starters, magnetic combination starters, and solid-state units.

- *Manual single-phase starters* are designed to give positive, accurate, trouble-free overload protection to single-phase motors rated up to 1 HP. Typical applications are fans, machine tools, motors, HVAC, and so on. Maximum voltage is 240 V AC.
- *Magnetic motor starters* are designed for across-the-line control of squirrel cage motors or as primary control for wound rotor motors. Starters can be furnished for nonreversing, reversing, and two-speed applications. Maximum voltage is 600 V AC; maximum horsepower is 200 HP.
- *Magnetic combination starters* are designed for across-the-line control of squirrel cage motors, or as primary control for wound rotor motors. In addition, they provide a disconnect means and short-circuit protection. They are available for nonreversing or reversing applications.
- A *solid-state unit* is a reduced voltage motor starter, used to reduce starting current and high starting torque. Typical applications for controllers are in motors used in cranes, belt-driven equipment, conveyors, materials-handling facilities, compressors, and woodworking equipment. These units are available for AC motors in 5 to 900 HP.

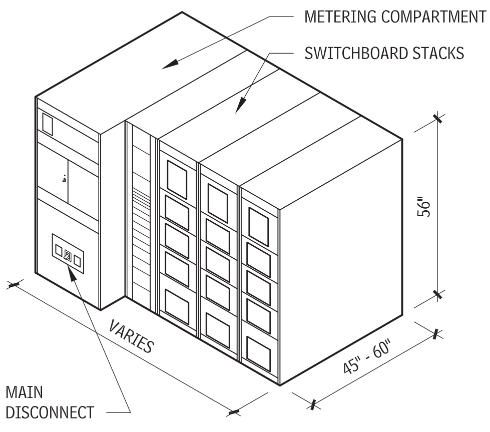
SWITCHBOARDS

Figure 13.147 shows a metering compartment, a main disconnect, check meters, and a low-voltage distribution section. See manufacturers' literature for type, size, and arrangements; and refer to the National Electrical Code for required aisle space, servicing area, and room layout.

SECONDARY UNIT SUBSTATION
13.146



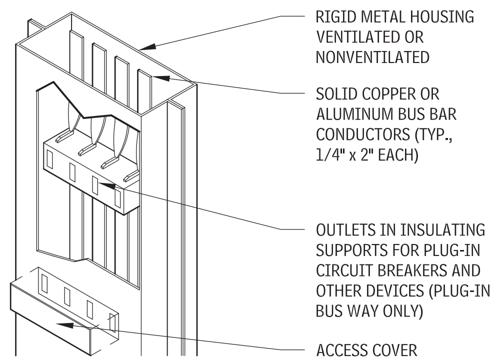
SWITCHBOARD
13.147



BUSWAY SYSTEMS

Plug-in and feeder busways carry current from 50 to 5000 amps. They are used when large blocks of low-voltage power (up to 600 V) must be transmitted over long distances, or when taps must be made at various points, as in vertical risers in office buildings. Codes limit locations in buildings where different types of busways may be installed. Consult an electrical engineer before using this system. Busway housing may be hung from an overhead support, mounted to a wall, or braced to the structure in vertical riser installations.

BUSWAY SYSTEM
13.148



Contributor:
Charles B. Towles, PE, TEI Consulting Engineers, Washington, DC.

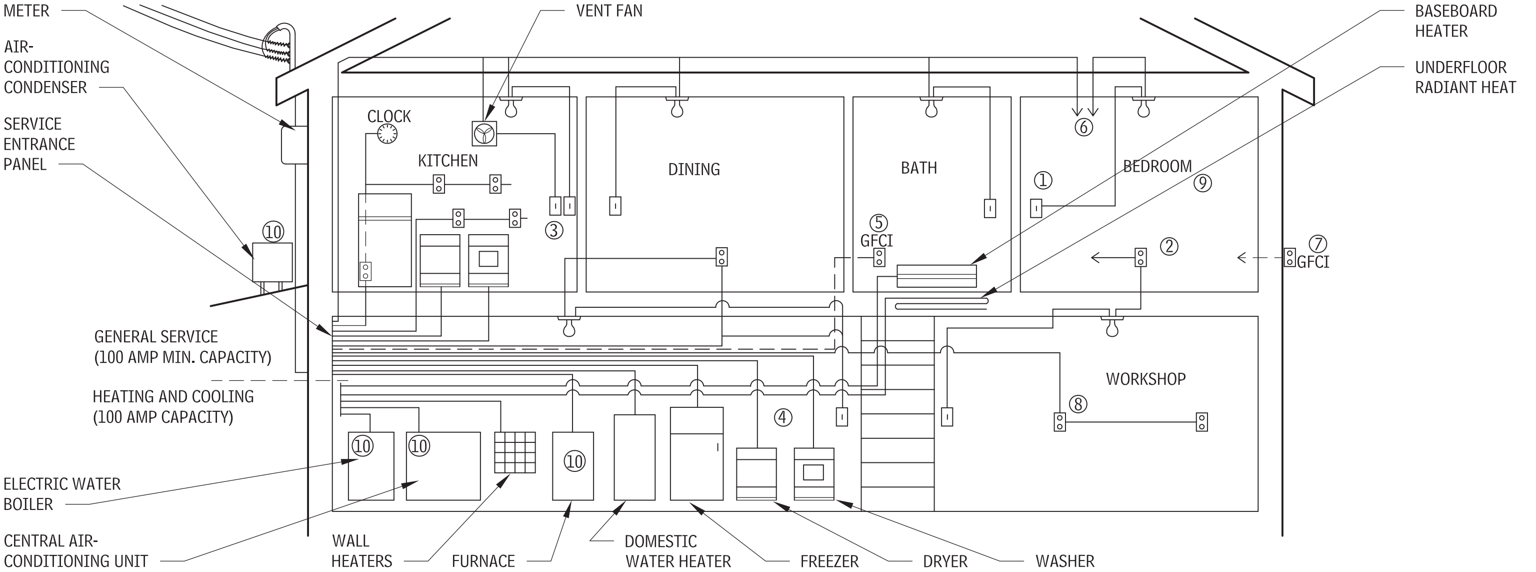
LIGHTING AND BRANCH WIRING

RESIDENTIAL ELECTRICAL WIRING

The general requirements described here for residential electrical wiring systems are intended to be used in conjunction with Figure 13.149, as the numbers in parentheses following each requirement refer to an aspect of the drawing.

- A minimum of one wall-switch-controlled lighting outlet is required in every habitable room, hallway, stairway, attached garage, and outdoor entrance. An exception is in habitable rooms other than kitchens and bathrooms, where one or more receptacles controlled by a wall switch are permitted in lieu of lighting outlets. (1)
- In every kitchen, family room, dining room, den, breakfast room, living room, parlor, sunroom, bedroom, recreation room, and similar rooms, convenience outlets must be installed so that no point along the floor line is farther than 12 ft. (measured horizontally, from an outlet), including any wall space 2 ft. or more wide, and the wall space occupied by sliding panels in exterior walls. (2)
- A minimum of two #12 wire 20-A small-appliance circuits are required to serve only small convenience outlets, including refrigeration equipment, in the kitchen, pantry, dining room, breakfast room, and family room. Both circuits must extend to the kitchen; the other rooms may be served by one or both of them. No other convenience outlets may be connected to these circuits, except a receptacle installed solely for an electric clock. In kitchen and dining areas, convenience outlets must be installed at each and every counter space wider than 12 in. (3)
- A minimum of one #12 wire 20-A circuit must be provided to supply the laundry receptacle(s), and it may have no other convenience outlets. (4)
- At least one convenience outlet must be installed in the bathroom near the basin and must be provided with ground-fault circuit-interrupter protection. (5)
- Code requires sufficient 15- and 20-A circuits to supply 3 watts of power for every square foot of floor space, not including garage and open porch areas. Minimum code suggestion is one circuit per 600 sq. ft., but one circuit per 500 sq. ft. is desirable. (6)
- A minimum of one exterior convenience outlet is required (two are desirable) and must be provided with ground-fault circuit-interrupter protection. (7)
- A minimum of one convenience outlet is required in the basement and garage, in addition to the one in the laundry. In attached garages it must be provided with ground-fault circuit-interrupter protection. (8)
- Many building codes require a smoke detector in the hallway outside bedrooms or above the stairway leading to upper-floor bedrooms. (9)
- Disconnect switches are required for equipment. (10)

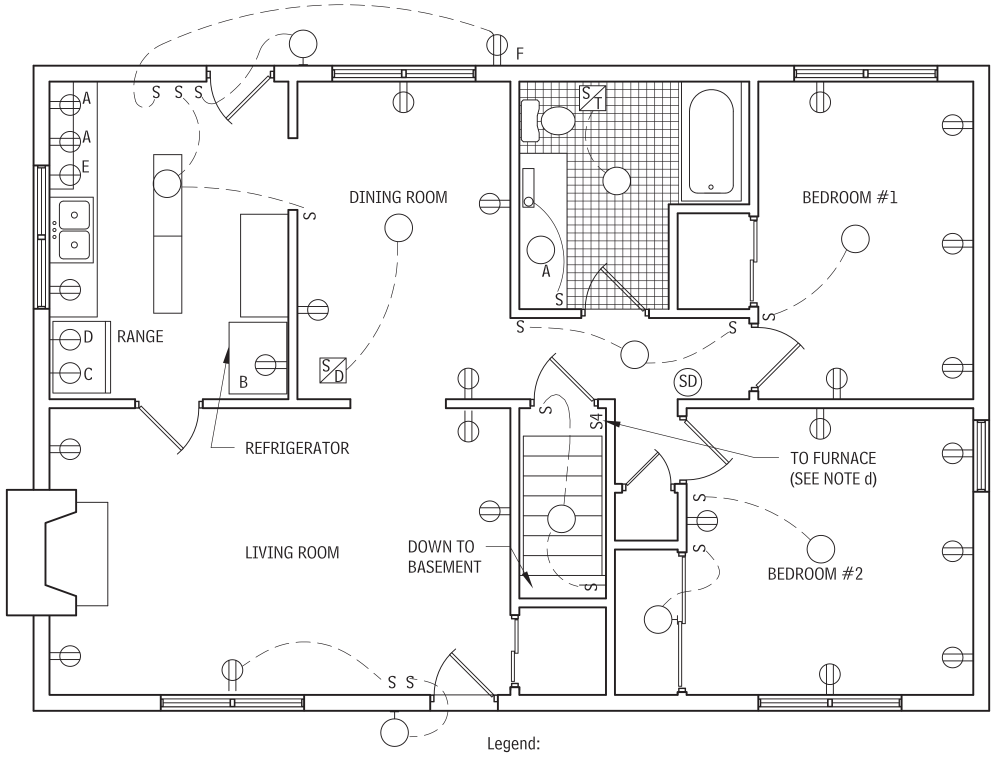
SCHEMATIC DIAGRAM OF TYPICAL RESIDENTIAL ELECTRICAL LAYOUT
13.149



NOTE

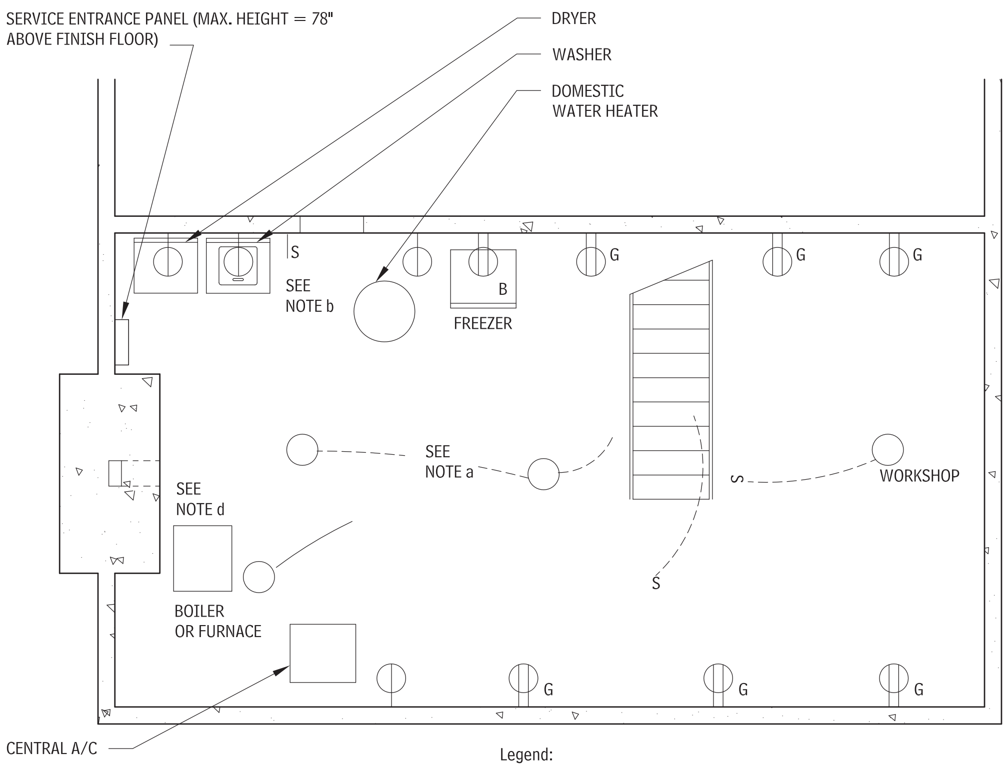
13.149 Refer to the National Electrical Code (NEC) for further information on residential requirements.

FIRST-FLOOR PLAN OF ELECTRICAL EQUIPMENT AND DEVICES
13.150



Legend:
S Switch (S/D with dimmer) ○ Light ⊖ Duplex receptacle

BASEMENT PLAN OF ELECTRICAL EQUIPMENT
13.151



Legend:
S Switch (S/D with dimmer) ○ Light ⊖ Duplex receptacle

LEGEND FOR FIRST-FLOOR AND BASEMENT PLANS

A: Mount convenience outlets at countertop locations 2 in. above backsplash.
B: Mount convenience outlets 48 in. above finish floor (AFF).
C: Range and oven outlet boxes should be wall-mounted, 36 in. AFF. Use flexible connections to units.
D: Switch and outlet for exhaust fan. The switch should be wall-mounted above the sink backsplash, and the outlet blank should be cover-mounted adjacent to the fan wall opening. A separate switch may be omitted if the fan is supplied with an integral switch.
E: Dishwasher outlet is wall-mounted behind unit, 6 in. AFF.
F: Equipped with self-closing waterproof cover with gasket.
G: Mount 42 in. AFF.

AVERAGE WATTAGES OF COMMON ELECTRICAL DEVICES
13.152

TYPE	WATTS
Air-conditioner, central	2500–6000
Air-conditioner, room type	800–2500
Blanket, electric	150–200
Clock	2–3
Clothes dryer	4000–6000
Dishwasher	1000–1500
Fan, portable	50–200
Food blender	500–1000
Freezer	300–500
Frying pan, electric	1000–1200
Furnace blower	380–670
Garbage disposal	500–900
Hair dryer	350–1200
Heater, portable	1000–1500
Heating pad	50–75
Heat lamp (infrared)	250
Iron, hand	600–1200
Lamp, incandescent	10 upward
Lamp, fluorescent	15–16
Lights, Christmas tree	30–150
Microwave oven	1000–1500
Mixer	120–250
Power tools	up to 1000
Projector, slide or movie	300–500
Radio	40–150
Range (all burners and oven)	8000–14,000
Range top (separate)	4000–8000
Range oven (separate)	4000–5000
Refrigerator	150–300
Refrigerator, frostless	400–600
Sewing machine	60–90
Stereo (solid-state)	30–100
Television	50–450
Vacuum cleaner	250–1200
Washer, automatic	500–800
Water heater	2000–5000

BRANCH CIRCUIT PROTECTION
13.153

Lighting (general purpose)	#14 wires	15 A
Small appliances	#12 wires	20 A
Individual appliances	#12 wires	20 A
	#10 wires	30 A
	#8 wires	40 A
	#6 wires	50 A

NOTES

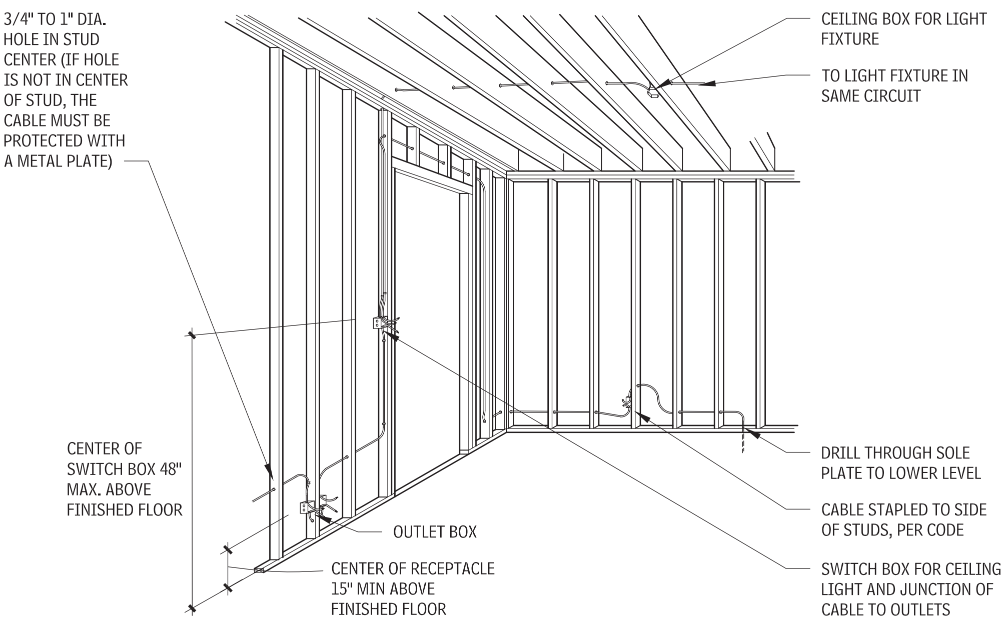
13.149 and 13.150 a. Wiring shown as exposed indicates absence of finished ceiling in basement level. All BX cable is run through framing members. Attachment below ceiling joists is not permitted.
b. Connect to two incandescent porcelain lamp holders with pull chain. Mount two evenly spaced ceiling fixtures in crawl space.
c. Connect to shutdown switch at top of stairs.
d. Boiler wiring safety disconnect switch should have red wall plate, clearly marked "BOILER ON/OFF."

Contributor:
Charles B. Towles, P.E., TEI Consulting Engineers, Washington, DC.

LOADS, CIRCUITS, AND RECEPTACLES FOR RESIDENTIAL ELECTRICAL EQUIPMENT 13.154

APPLIANCE	TYPICAL CONNECTED VOLT-AMPERES[a]	VOLTS	WIRES[b]	CIRCUIT BREAKER OR FUSE[c]	OUTLETS ON CIRCUIT	NEMA[k] DEVICE[d] AND CONFIGURATION
KITCHEN						
Range[e]	12,000	115/230	3 #6	60 A	1	14–60R
Oven (built-in)[c]	4500	115/230	3 #10	30 A	1	14–30R
Range top[c]	6000	115/230	3 #10	30 A	1	14–30R
Dishwasher[c]	1200	115	2 #12	20 A	1	5–20R
Waste disposer[c]	300	115	2 #12	20 A	1	5–20R
Broiler[e]	1500	115	2 #12	20 A	1 or more	5–20R
Refrigerator[f]	300	115	2 #12	20 A	1 or more	5–20R
Freezer[f]	350	115	2 #12	20 A	1 or more	5–20R
LAUNDRY						
Washing machine	1200	115	2 #12	20 A	1 or more	5–20R
Dryer[c]	5000	115/230	3 #10	30 A	1	14–30R
Hand iron; ironer	1650	115	2 #12	20 A	1 or more	5–20R
LIVING AREAS						
Workshop	1500	115	2 #12	20 A	1 or more	5–20R
Portable heater[g]	1300	115	2 #12	20 A	1	5–20R
Television[g]	300	115	2 #12	20 A	1 or more	5–20R
FIXED UTILITIES						
Fixed lighting	1200	115	2 #12	20 A	1 or more	5–20R
Air-conditioner, 3/4 hp[h]	1200	115	2 #12	20 A or 30 A	1	5–20R
Central air-conditioner[i]		5000	115/230	3 # 10	40 A	1
Sump pump[i]	300	115	2 #12	20 A	1 or more	5–20 R
Heating plant—forced-air furnace[h, j]	600	115	2 #12	20 A	1	
Attic fan[i]	300	115	2 #12	20 A	1 or more	5–20R

TYPICAL WIRING IN WOOD CONSTRUCTION 13.155



FLOOR WIRING SYSTEMS FOR WORKSTATIONS

CELLULAR DECK SYSTEMS

Based on the projected frequency of changes in office furniture layouts, a corporate or government organization may elect to invest in a permanent raceway system, to minimize cost and disturbance to occupants when changes or additions are made. When structural design dictates the use of metal decking, a cellular floor raceway system utilizing trench header ducts is the most likely choice.

Cellular raceways come in a variety of sizes and configurations, ranging from 1–1/2 to 3 in. high, with cells 8 or 12 in. o.c., and two or three cells per section. An overall floor deck can be full cellular, where bottom plates are provided throughout, or blended, as shown in Figure 13.156.

Trench header ducts come in various sizes and configurations. The height is adjustable for slab depths above cells of 2–1/2 to 4 in., and widths vary from 9 to 36 in. Cover plates are 1/4-in. thick, with lengths from 6 to 36 in., and can either be secured with spring clips or flush, flathead bolts.

Two versions of trench design are available: One has a compartmental bottom tray with a grommeted access hole for each cell it crosses; the other has a bottomless trench duct consisting of side rails and a separate wireway in the middle, with grommeted access holes only for the power cells.

When service is needed, the floor is core-drilled above the desired cell; the cell top is drilled into, and an afterset insert with above-floor fitting is attached. If data and communications wiring can occupy the same cell, with power wiring in an adjacent cell, two separate service fittings are required for each workstation.

When it is necessary to eliminate or minimize core drilling, a modular pattern of preset service flush outlets can be provided along the cellular sections before the floor is poured (as shown in Figure 13.156). Upon activation, one flush outlet can serve all the power, communications, and data requirements of a workstation.

The modular grid and frequency of preset locations will determine the convenience of service provisions for the workstations.

NOTES

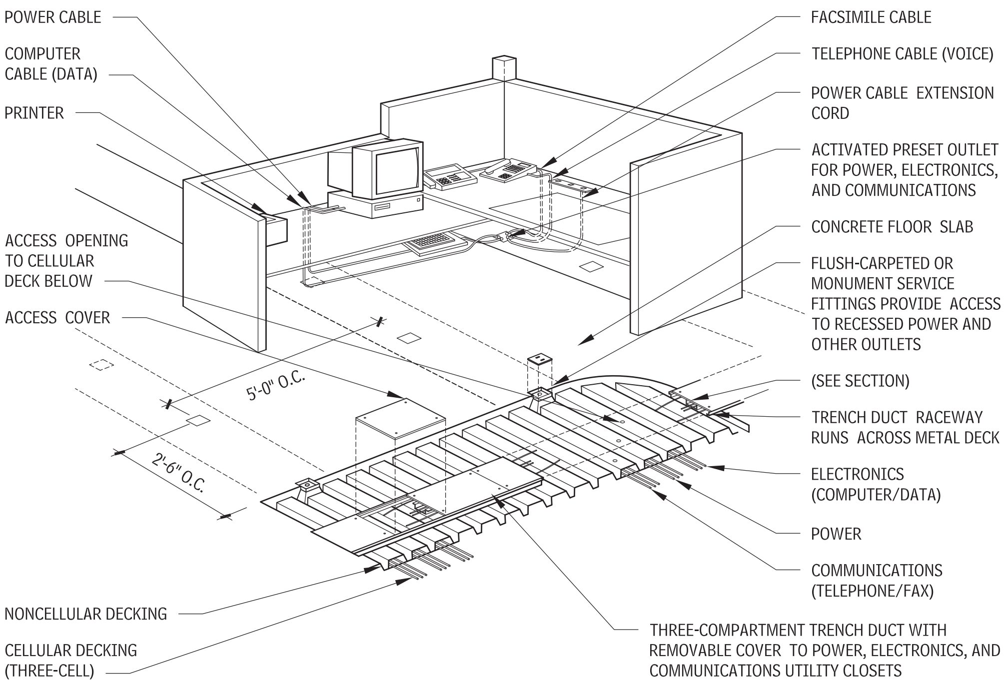
13.154 a. Wherever possible, use actual equipment rating.
b. Number of wires does not include equipment grounding wires. Ground wire is #12 AWG for 20-A circuit and #10 AWG for 30-A and 50-A circuits.
c. May be direct-connected. For a discussion of disconnect requirements, see NEC Article 422.
d. Equipment ground is provided in each receptacle.
e. Heavy-duty appliances regularly used at one location should have separate circuits. Only one such unit should be attached to a single circuit.
f. A separate circuit serving only one other outlet is recommended.
g. Should not be connected to a circuit with appliances or other heavy loads
h. A separate circuit is recommended.
i. It is recommended that all motor-driven devices be protected by a local motor-protection element, unless motor protection is built into the device.
j. Connect through disconnect switch equipped with motor-protection element.
k. National Electrical Manufacturers Association (NEMA).

13.155 In metal stud construction, cables are passed through precut openings in place of field-drilled holes.

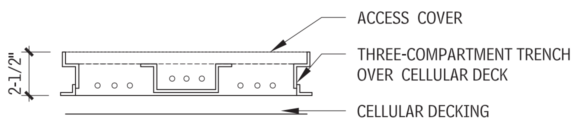
Contributor:
Charles B. Towles, PE, TEI Consulting Engineers, Washington, DC.

CELLULAR DECK SYSTEM WITH TRENCH HEADER DUCTS
13.156

Computer and telephone cabling is often combined as an integrated voice/data cabling system, eliminating the need for three raceways, except when extra capacity is needed.

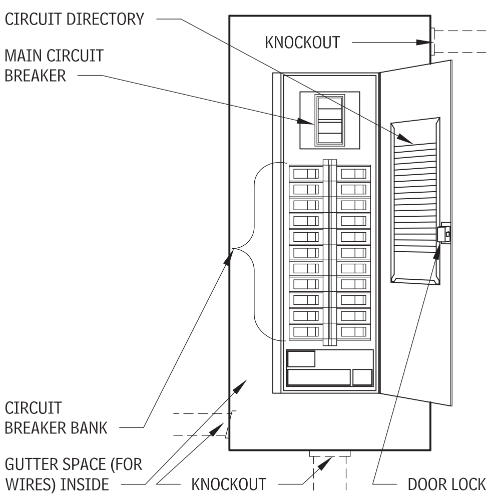


CELLULAR DECK



SECTION

RESIDENTIAL AND COMMERCIAL PANELBOARD
13.157



ELECTRICAL PANELBOARDS AND CIRCUIT BREAKERS

Electrical panels, or panelboards, are cabinet enclosures where a bulk power feed is subdivided into discrete electrical circuits. Branch panelboard cabinets are recessed into, or attached flush on, a wall; they are accessible for routine service only from the front. Panelboards provide a protective fuse or circuit breaker for each circuit. Panels are available in a range of sizes with variations in construction, and may house specialized circuit control elements. Panelboards are commonly described as:

- Lighting (and appliance) branch-circuit panels
- Power panelboards (also called distribution panels)

Panelboards are located to meet the requirements of NFPA 70, "National Electrical Code." In addition, they will be located logically relative to the incoming power feed and outgoing circuit layout. In larger buildings there will usually be one or more panelboards per floor, often organized to separate lighting, plug, and motor loads.

PANELBOARD DIMENSIONS
13.158

MAXIMUM NUMBER OF CIRCUITS	BOX DIMENSIONS (IN.)		
	WIDTH	HEIGHT	DEPTH
12	9–15	13–20	3–3/4–4–5/8
20	9–15	20–1/4 –24	3–3/4–4–5/8
30	12–15	30–33	3–3/4–4–5/8
40	14–15	34–39	4–4–5/8

FUSES
Plug fuses:

- *Rated Voltage:* 125
- *Ampere Rating:* 1–30
- *Fuse Types:* S, T

Knife-blade:

- *Rated Voltage:* 250 and 600
- *Ampere Ratings:* 70–6000
- *Fuse Types:* K1, RK1, K5, RK5, J, H, G, and L

Cartridge fuses:

- *Rated Voltage:* 250 and 600
- *Ampere Rating:* 1/10–60
- *Fuse Types:* K1, RK1, K5, RK5, J, H, and G

Cartridge and knife-blade fuses are available for short-circuit protection up to 200,000 A (RMS).

DISCONNECT SWITCHES
Capacities of multiple meter banks with a main circuit breaker include:

- *Rated Voltages:* 120/240 V, three-wire, single-phase; or 208/120 V, four-wire, three-phase
- Either indoor or outdoor construction
- Number of sockets as required by application

Note that high-pressure contact switches may be top or bottom feed; 600 VAC max; 800–4000 A.

CIRCUIT BREAKERS
Capacities of typical molded-case circuit breakers include:

- *Rated Voltages:* 120 VAC, 240 VAC, 600 VAC, 125 VDC, and 250 VDC
- *Frame Sizes:* 100, 150, 225, 400, 600, 800, 1200 A poles, two or three above 100 A
- Current limiting types with fuses

NOTE

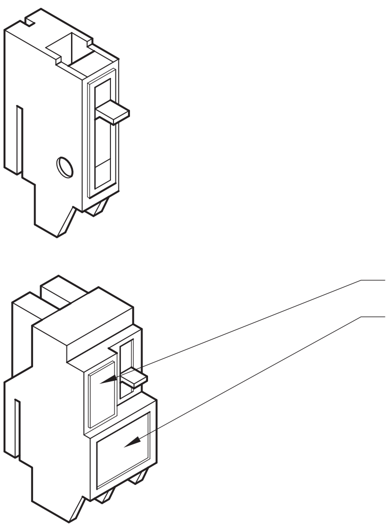
13.157 Knockout holes allow conduit connections from all sides.

Contributor:
Richard F. Humenn, PE, Joseph R. Loring & Assoc., Consulting Engineers, New York, New York.

Capacities of molded-case circuit breakers with ground fault include:

- *Rated Voltages:* 120 VAC or 120/240 VAC
- *Frame Sizes:* 100 A ratings, 15–30 A poles, one or two

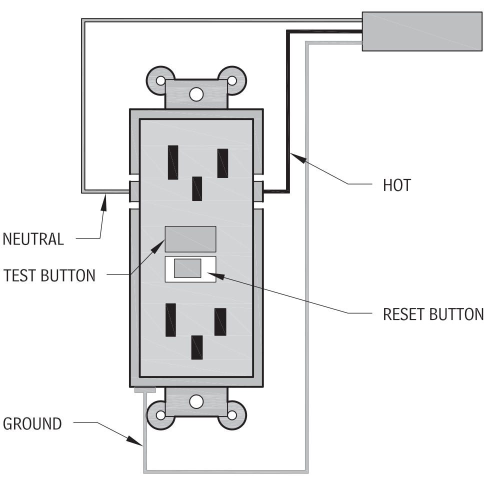
CIRCUIT BREAKERS
13.159



GFCI

A ground-fault circuit interrupter, or GFCI, is a fast-acting circuit breaker designed to shut off electric power to a circuit or receptacle in the event of a ground fault. GFCIs are required in numerous locations defined by the National Electrical Code. These are locations where a device- or appliance-user might encounter a grounding problem in the presence of water (such as in a bathroom, kitchen, garage, laundry room, or on the building exterior, including rooftops). The objective is to reduce the danger of electrocution. Ground-fault protection can generally be provided receptacle-by-receptacle or for an entire circuit. Circuit protection is provided by a ground-fault interrupting breaker.

GFCI RECEPTACLE
13.160



LIGHTING TERMINOLOGY

These terms and concepts are commonly used in the field of lighting and branch wiring:

- *Ballast:* Device providing a controlled electrical current, voltage, and waveform to gas-discharge-type lamps. Ballasts provide the energy necessary to start lamp operation, and limit the current that flows through them during operation afterward. Incandescent and halogen incandescent lamps are resistive-type sources and do not use ballasts; other lamps such as fluorescent and high-intensity discharge (HID) are gas-discharge types and do need ballasts. Low-voltage incandescent and halogen lamps do use a transformer to provide proper voltage, but do not require the level of circuit control provided by ballasts for fluorescent and HID lamps.
- *Blackbody:* An idealized radiator of energy that is at a uniform temperature and whose emitted color spectrum is the maximum that can be emitted by any substance at the same temperature. Blackbody radiation is more simply understood as the characteristic color spectrum emitted from a perfect radiator at a given temperature. Its basic definition is requisite to understanding qualitative measures of color rendering.
- *Bulb* or *Tube:* The glass envelope of a lamp.
- *Color Rendering Index* (*CRI*): Measure of the color shift in the appearance of objects when lit by a light source, as compared to being lit by a reference light source of the same color temperature. CRI is measured in percentage, with higher numbers being closer to color rendering of the reference light source. CRI should not be used to compare color rendering between light sources of different color temperatures. Even among lamps with similar color temperatures, a significant difference takes a 3 to 5 percentage point margin in CRI.
- *Color Temperature:* A standard of light source color that is also referred to as *correlated color temperature* (*CCT*). This is the absolute temperature in degrees Kelvin required for a blackbody to radiate a color spectrum most similar to that of a given light source. As color temperature increases, the general color-rendering effect of light sources moves from red (low color temperature) to blue (high color temperature). The human visual expectation of what looks natural also varies with intensity: Dim lighting scenes seem more natural in low color temperatures (such as firelight), whereas bright lighting scenes appear more natural in high color temperatures (such as the blue sky). Standard T8 fluorescent lamps have a CCT of about 4100°K, which appears cool. Generically, this temperature is seen as desirable in office settings, whereas warmer colored lamps with CCT of 3000°K or less are recommended for residences and hospitality environments. Natural daylight corresponds to a CCT of about 6000°K, an overcast sky to 7000°K, and a blue sky to something between 10,000 and 30,000°K.
- *Efficacy* (*LPW*): Lumens of light output for each watt of electricity consumed. This is a measure of how efficient a lamp is, but not necessarily how efficient a lighting system (including fixtures and room conditions) will be. Total system efficacy should also include the energy of lamp ballasts in systems other than incandescent lighting. Be aware that lumen ratings are much like the EPA's miles-per-gallon ratings on automobiles; that is, rated lumens for a lamp are measured under ideal conditions. Electrical power, waveform, air temperature, operating position, and other conditions are constrained in standard tests so that accurate comparison to other lamps can be made on an equal basis. The ballast used in testing is an extremely sensitive laboratory version and typically produces more light from lamps than commercially available ballasts do. In most cases, installed combinations of lamps and ballasts will not produce as much light as the rated lumens, even under initial conditions.
- *Illuminance:* Density of light on a surface, measured as candela per square foot or *footcandles* (*fc*), and represented by the symbol "E." This is analogous to the gallons of water delivered on a square foot of lawn. Multiply fc by 10.76 to obtain the metric unit, lux.
- *Illumination:* The common term for footcandles of illuminance, but also used in a more general sense to describe the means of lighting a space. For clarity, when used to refer to footcandle levels, the term *level of illumination* is preferred.
- *Lamp:* Lighting source used in a fixture to generate visible energy. Many fixtures use more than one lamp.
- *Luminaire:* Lighting fixture including housing, lamp, ballast, lens, reflectors, and louvers or baffles. Some of these components are optional or may be part of the lamp.
- *Luminance:* Brightness of light transmitted by, reflected from, or transmitted through a surface. Brightness is measured as *footlamberts* (*fL*), though that unit of measure is no longer commonly used. Brightness as *reflected luminance* is the product of incident footcandles on a surface multiplied by the percentage of visible light reflected from it. *Transmitted luminance* is, similarly, the product of incident footcandles on a surface multiplied by the percentage of visible light it transmits. The units of luminance are cd/ft^2.
- *Luminous Flux:* Flow of light from a source, measured in *lumens* (*lm*). This is analogous to the flow rate of water through a garden hose.
- *Luminous Intensity:* Radiant energy emitted by a source, measured in *candela* (*cd*), and represented with the symbol "I." This is analogous to water pressure in a hose.

Organizations to contact for more information in this subject area include:

- *American National Standards Institute* (*ANSI*): ANSI publishes a system of nomenclature for the designation of lamps, including their electrical characteristics, performance, and physical specifications. These designations and specifications help ensure interchangeability among different manufacturers' lamps and ballasts.
- *Illuminating Engineering Society of North America* (*IESNA*): IESNA is an organization of lighting professionals that provides the recognized technical authority on illumination. Its stated mission is "to improve the lighted environment by bringing together those with lighting knowledge and by translating that knowledge into actions that benefit the public." See www.iesna.org/ for more details.
- *International Commission on Illumination* (*CIE*): Promotes international cooperation and information exchange among member countries as a technical, scientific, and cultural organization. See www.cie.co.at/cie/home.html for more details.
- *National Electrical Manufacturer Association* (*NEMA*): NEMA publishes test standards for lamps, bulbs, lamp bases, and holders, as well as for ballasts, as part of its lighting standards program.

LIGHTING DESIGN CONSIDERATIONS

As in most architectural pursuits, lighting design has both quantitative and qualitative objectives, such as whether there is enough light and whether it is of appropriate character. Lighting design also engages both artistic and scientific thinking. Form, texture, and space are rendered by a combination of light and shadow. Color and composition are also direct artifacts of lighting. The methods selected to achieve these results are technical in nature, and are the most rapidly changing technology in buildings.

Technical considerations begin with the following:

- Footcandle (fc) illuminance levels
- Lighting efficacy (lumens per watt, LPW)
- Color Rendering Index (CRI)

These three basic factors correspond to having sufficient light, using energy-efficient lighting sources, and providing a color spectrum from the light source that is broad enough and balanced correctly for the visual task. These three fundamental decisions, therefore, require an understanding of the lighting task being considered and the means of matching the task to appropriate lighting methods.

Contributors:
Charles B. Towles, PE, TEI Consulting Engineers, Washington, DC; Ayush Vaidya, M. Arch, University of Oregon, Eugene, Oregon, with Walter Grondzik, Ball State University, Muncie, Indiana.

LIGHT SOURCE SELECTION GUIDE
13.161

	APPLICATIONS
LAMP CCT[a] (KELVIN, OR °K)	
<2500	Bulk industrial and security (HPS) lighting
2700–3000	Low light levels in most spaces (<10 FC); general residential lighting; hotels, fine dining and family restaurants; theme parks
2950–3200	Display lighting for retail and galleries; feature lighting
3500–4100	General lighting in offices, schools, stores, industry, medicine; display lighting; sports lighting
4100–5000	Special-application lighting where color discrimination is very important; not commonly used for general lighting
5000–7500	Special-application lighting where color discrimination is critical; uncommon for general lighting
MINIMUM LAMP CRI[b]	
<50	Noncritical industrial, storage, and security lighting
50–70	Industrial and general illumination, where color is not important
70–79	Most office, retail, school, medical, and other work and recreational spaces
80–89	Retail, work, and residential spaces, where color quality is important
90–100	Retail and workspaces, where color rendering is critical

Beyond these three basic factors, however, there are a host of related lighting design issues and corresponding features of lighting systems to incorporate. Each lighting situation will prioritize these differently, but following are a few fundamental considerations, some of which are discussed in more detail later in this section.

HUMAN FACTORS

The physiology of human vision and the notion of visual comfort both influence lighting design in several ways.

- The healthy human eye can accommodate to different scene brightness levels by contracting or expanding the pupil, meaning that contrast level is more important in some aspects than is the quantitative illumination level.
- Accommodation is also important in planning for distinctions between day and night illuminance levels because occupants are accommodated to outdoor brightness levels by day, so higher interior illumination levels are needed for their level of adaptation. Nighttime lighting power levels can, therefore, be considerably lower. Dimming devices or stepped switching can help control lighting levels accordingly.
- The perceptive sensitivity of the human eye is essentially a logarithmic response to brightness. Generally, a 50 percent increase of brightness level is required to produce a subjective impression of one order of magnitude level change in illumination. So, for the same lighting situation, the difference between 10 fc and 15 fc of illuminance is perceptually the same as the change from 50 fc to 75 fc and 100 fc to 150 fc.
- Not all brightness is equally perceived. To appear as bright to the human eye as 50 fc from a 3500°K fluorescent lamp or a 2850°K incandescent, a low-pressure sodium lamp would need to produce almost 100 fc; a high-pressure sodium lamp would likewise need to produce about 90 fc; and a mercury lamp around 60 fc. On the other end of the scale, a 6500°K fluorescent would produce the same subjective level of illuminance at only 40 fc; sunlight would be equivalent at 37 fc; and a 7500°K fluorescent lamp would need only 36 fc.
- Vision has a pronounced ability to discriminate detail in shadow within the narrow cone of foveal vision, as opposed to the wider cone of peripheral vision. This means that photographic or virtual representations of space are never quite the same as a direct experience of them.
- The human aging process decays the eye's ability to focus and even to perceive brightness. With aging, the lens inevitably becomes denser and less elastic, so the human ability to focus on objects within 2 ft. is lessened (presbyopia). Presbyopia is progressive between a person's age from the 40s through the 60s. Gradual yellowing of the lens also reduces the amount of light entering the eye. At the age of 60, the average healthy human eye receives only a third of what a 20-year-old eye does. Similar symptoms of aging include loss of acuity in fine details, slower accommodation to sudden changes in light level, degradation of color discrimination, glare caused by lens opacities, and a visual field that narrows some 1° to 3° per decade. Some of these factors of aging can be offset with additional light, of course, but others require high-quality light, proper contrast ratios, and considerate design.
- Enlightened designers and building owners are continually taking a broader perspective and lifecycle economics view of lighting. Quality lighting is now more frequently seen as a design opportunity and an investment in human productivity and occupant comfort.

ENERGY ECONOMICS

Lighting accounts for about 35 percent of the electricity use in a typical commercial building, about 8 percent in the residential sector, and about 10 percent of industrial energy consumption. Relating site energy consumption to the inefficiencies of source energy production involves a ratio of about 3.3 units of source energy used per 1.0 unit of energy consumed. Overall, then, lighting was about 8 percent of the total primary energy used in the United States in 2001, and consumed about 22 percent of all U.S. electricity generated that year.

ENERGY CODES

The ANSI/ASHRAE/IESNA 90.1, "Energy Standard for Buildings except Low-Rise Residential Buildings" is part of the Model Energy Code. It was published in December 2004 and supplements earlier versions. Compliance varies with adoption by state and local jurisdictions, but all code enforcement agencies are required to develop a set of regulations at least as stringent as the 90.1 Model Code. The regulation is based on a maximum power budget of allowable watts of lighting power per square foot, lineal foot, or individual installation. This ratio of watts per square foot is termed the *lighting power density* (*LPD*), or alternately called *unit power density* (*UPD*) or *lighting power allowance* (*LPA*). Allowable LPD under the Model Code is dependent on the building type, occupancy, or area use category. Exceptions are provided as appropriate to critical installations.

BEAM PATTERN

Distribution of light from a bare lamp or a luminaire can basically be thought of as having spot, normal, or flood patterns, depending on the beam spread. This photometric data is usually indicated in the manufacturer's product data as a *candlepower distribution curve* (*CDC*). The CDC is a polar coordinate plot graphically showing the candela output from a fixture at any angle relative to one fixture axis. The CDC also indicates the cutoff angle or shielding angle, above which no light is emitted.

TASK LIGHTING VERSUS AMBIENT LIGHTING

Task lighting and general illumination are often best considered and rendered separately. Task light is provided by direct point-to-point illumination from a fixture or fixtures onto a single point on a surface such as the center of a desk. Ambient light is the uniform level of illuminance provided in a room from a uniformly spaced grid of fixtures. It is generally wasteful to provide task level illuminance with ambient lighting if high footcandle levels are needed only in a small percentage of the space. Sometimes, however, it is acceptable to provide task-level lighting to work surfaces with the general illumination system, and then rely on spill light from these same fixtures to supply a lower level of background ambient light between task surfaces in areas such as circulation paths.

DIRECT VERSUS INDIRECT AMBIENT ILLUMINATION

Indirect lighting comes from suspended luminaires that radiate 90 to 100 percent of their light upward, where it is then reflected around the room. Direct lighting fixtures, on the other hand, radiate 90 to 100 percent of their light down onto the task surface or in the general direction of the surface to be illuminated. Indirect lighting results in a uniform distribution of light with reduced shadowing and glare. It is especially well regarded where the work surface is predominantly computer screens, so that reflected glare from exposed lamps is less likely to be bouncing off the vertical visual task surface. Direct downlighting is more efficient than indirect lighting because it does not rely on the tactic of bouncing light off of multiple room surfaces; but direct lighting is decidedly more prone to create glare. Direct-indirect luminaires, which provide some balance of both techniques, can also be advantageous compromises that capture the best attributes of each.

DAYLIGHT INTEGRATION

Daylighting systems only provide energy savings and cooling load reductions if artificial lighting is switched or dimmed in proportion to received natural light. Photocell-controlled dimming can automate this process, but it is also possible to manually switch electrical lighting in separate rows parallel to the daylighting aperture or window. In either case, electrical lighting should generally be considered as supplemental to natural daylight. Another form of daylight integration is that of blending daylight and electrical light together before they enter the space. Where daylighting is used, it is also necessary to provide adequate illumination for nighttime use.

DIMMING AND CONTROLS

Beyond manual switching and dimming, there is a trend toward more dynamic controls that automate the operation of lighting and allow for the programming and on-demand use of different lighting scenes that might be required in a space. There is also an increasing number of practical ways to conserve energy by way of controls that sense the presence of daylight or the absence of occupants.

GLARE AND CONTRAST CONTROL

Glare is to light as noise is to acoustics. Excess brightness ratios measured between foreground and background surfaces is defined as *glare*. Direct source glare from lamps is controlled by the cutoff angle of the luminaire housing or louvers. Reflected glare is controlled by limiting the geometry of the cone of light that leaves a luminaire and by the absence of glossy or otherwise highly reflective task surfaces. Glare from veiling reflections is experienced when direct glare from a reflective surface is mixed with diffuse reflections from the same surface, such as off a glossy magazine page or from a plate of window glass.

HEAT OF LIGHTING AS A THERMAL COOLING LOAD

All energy used to power electrical lighting is instantly converted to heat. In conditioned spaces during warm months, this means that lighting electricity used inefficiently or excessively is paid for twice: first to power luminaires and then to remove the resulting heat by mechanical cooling. Even in cold weather, where waste heat from lighting might seem useful for warming the interior, it is more economical to provide the same heat with an efficient heating system than with what amounts to a very inefficient electrical resistance heating system of unneeded electrical light.

LAMP LIFE, LAMP REPLACEMENT SCHEDULE, AND FIXTURE MAINTENANCE

These factors are interwoven in a number of ways that impact lighting economics. First, proper maintenance and lamp replacement schedules will allow for the design of a smaller lighting system, as compared to a system that is less well maintained. Second, this resulting smaller system will cost less initially, and less to operate, and may also reduce the size of the cooling system that must be installed and operated to offset the waste heat of light.

LAMP LUMEN DEGRADATION (LLD)

Different lamp types have characteristic degradation curves. In point-to-point task lighting, it is therefore advisable to use average lamp lumen ratings rather than new lamp ratings. For ambient lighting calculations, LLD is one of several factors that make up the overall light loss factor (LLF) used to predict the average maintained level of light over the operation of the system. In either case, it is important to understand that the lighting level attained in a new system is not the same as the average operating conditions of the system.

NOTES

13.161 a. CCT—Correlated Color Temperature
b. CRI—Color Rendering Index

LAMP COLOR STABILITY (OR CONSISTENCY)

Most lamp types will undergo some shift in color temperature over their life of operation. There is also some variation in actual color temperature among a random sample of any one given lamp product.

LIGHTING DESIGN OPPORTUNITIES

The architect is in the best position to integrate light sources within a building's structure. If a lighting consultant or designer is part of a design team, it is the lighting designer's task to assist the architect by recommending the appropriate luminaires to manifest the architect's luminous image. It is also the lighting designer's task to refine the positioning of the luminaires for maximum comfort and efficiency in revealing structure and space and providing appropriate task lighting for activities within the space.

The lighting design process follows a path similar to that of architectural design:

- Programming
- Schematic design
- Design development
- Construction documents
- Construction procurement
- Construction administration

Lighting design can also include the additional finishing steps of final adjustment of adjustable luminaries and the programming of lighting controls after final client move-in and occupation of the space.

The lighting designer should start this process by meeting with the client/owner to determine the functional and aesthetic requirements of the end user of the project. The list should include the overall image (preferences and impressions) desired by the owner and design team, as well as the different tasks that are to be performed within the project's scope. As a result of this exercise, the designer will be able to order the priorities of initial cost, lifecycle cost, energy use, visual comfort, and aesthetics. The exercise should also educate the client about the lighting design possibilities.

Designers have many options in considering how lighting design influences a space:

- Effect: Spot lighting, floodlighting, backlighting, footlighting, and other dramatic or theatrical effects
- Composition of the lighting scene: Focus, balance, sequence, and so forth, as rendered by patterns of brightness and shadow
- Glitter and sparkle: Small points of light used as visual elements without the introduction of source glare
- Beam play and shadow play as figural elements
- Fixture hardware as design elements, furniture, or architectural hardware
- Configurations: Ways in which lighting systems are deployed
- Task lighting: Work surfaces, lighting accents, artworks, retail displays
- Ambient lighting: Background fill light
- Fixture mounting options: Surface, recessed, pendant, cove, valiance
- Applications: General, task, high-bay, display, accent, signage, facade, landscape, emergency, security
- Controls: Ways in which lighting is regulated to match changing requirements
- Local manual on/off switching
- Local manual dimming
- Occupant sensors for automated switching in periodically unoccupied spaces, especially small offices
- Multizone dimming and switching for manual selection of preset lighting "scenes" as set in a programmable scene controller
- Photocell for automated on/off operation tied to natural light levels
- Astronomical time clock for automated on/off tied to sunrise/sunset and time of day

LIGHTING INTERFACES

Lighting systems most commonly connect with other interior systems, especially ceilings. Recessed luminaires must be checked for clearance and for code compliance with fire-rated assemblies that they penetrate, as well as their insulation contact (IC) rating. The size of the lighting system, with some diversity factor, also has a direct impact on the size of the required mechanical cooling system. Most importantly, lighting design is usually a direct response to furniture arrangement, circulation paths, and other occupant use patterns. The luminous zoning of an entire building might be organized around the use of daylight, distance from a window, unfavorable east and west summer sun, and the distinct qualitative and quantitative needs of visual tasks that are performed in different areas.

A significant performance enhancement is achieved by the use of air-handling light fixtures. Fluorescent fixtures are commonly available as either air-handling or static devices. When used as return-air devices, these air-handling fixtures remove some of the waste heat from the fixture before it ever becomes part of the room load, thus reducing the amount of cooling air needed to flush the room. This also keeps the lamp cooler and operating more efficaciously, makes it less prone to dust accumulation, and provides an extended lamp life. Air-handling fluorescent fixtures are estimated to have a 10 percent greater system efficiency than static fixtures, meaning that the standard static luminaire will, on average, provide 10 percent less light-level output across its lifetime than an identically configured and maintained air-handling fixture. Consequently, the two systems would provide the same initial footcandle levels when they were new, but the air-handling system could be sized at 10 percent fewer fixtures to provide the same level of maintained illumination.

LIGHTING DESIGN DETAILS

Definitive lighting design standards are difficult to establish. Continual advances in lighting technology and the consequent rapid updating of lighting products are likely to make this so for the foreseeable future. Color, efficacy, control, and lamp life are the primary measures of lighting technology, and these continue to advance with every product catalog published. The shelf life of printed technical data and product information on lighting is now so short that all but the most current is open to question. Moreover, the voluminous new information being published is difficult to catalog, digest, evaluate, and use. Written guidelines should, therefore, convey something of the dynamic advances and dramatic changes that can be expected to continue, rather than offering up a static picture of one specific point in time.

The architect is well advised to keep in mind how fluid this industry is and to carefully consider the most current available information for a wide range of current products. Today's best decisions may well be different from other recent ones in this area. It is also advisable to use both manufacturer-specific performance data (such as from current catalogs) and independent evaluations of lighting technology (such as those available from relevant government agencies and the IESNA). Because competitive product ranges often use proprietary terms and labeling information, it may also be necessary to consult the appropriate product literature to make comparisons with similar products from other suppliers.

ILLUMINANCE TARGET VALUES FOR VARIOUS INDOOR ACTIVITIES

Selection of footcandle levels (or lux, in the metric system) should be made with several factors in mind:

- Illuminance category of the visual task
- Age of the occupants
- Contrast level of the task
- Duration of the task
- Critical importance level of visual error

ILLUMINANCE TARGET VALUES FOR VARIOUS ACTIVITIES 13.162

ILLUMINANCE CATEGORY	TARGET ILLUMINANCE (FC)	CONTEXT	TYPICAL APPLICATIONS
A	11	Orientation, large-scale awareness tasks	Dark adapted and basic convenience situations
B	23	Orientation, large-scale awareness tasks	Dark adapted and basic convenience situations
C	43	Orientation, large-scale awareness tasks	Slow-paced situations
D	65	Orientation, large-scale awareness tasks	Slow-paced to moderate-paced situations
E	86	Orientation, large-scale awareness tasks	Slow-paced to moderate-paced situations
F	108	Orientation, large-scale awareness tasks	Moderate-paced to fast-paced situations
G	161	Orientation, large-scale awareness tasks	Moderate-paced to fast-paced situations
H	152	Orientation, large-scale awareness tasks	Moderate-paced to fast-paced situations
I	323	Orientation, large-scale awareness tasks	Decision points, some social and commercial situations
J	430	Large and/or high-contrast tasks	Indoor and outdoor commercial situations
K	538	Large and/or high-contrast tasks	Indoor and outdoor commercial situations
L	807	Large and/or high-contrast tasks	Indoor and outdoor commercial situations
M	1076	Large and/or high-contrast tasks	Indoor and outdoor commercial situations
N	1,612	Large and/or high-contrast tasks	Indoor and outdoor commercial situations
O	2152	Large and/or high-contrast tasks	Indoor and outdoor commercial situations
P	3228	Common small-scale or fast-performance tasks	A range of indoor situations
Q	4304	Common small-scale or fast-performance tasks	A range of indoor situations
R	5380	Common small-scale or fast-performance tasks	A range of indoor situations
S	8070	Common small-scale or fast-performance tasks	A range of indoor situations
T	10,760	Fine detail, close inspection, rapid reaction	A range of indoor and outdoor situations
U	16,140	Fine detail, close inspection, rapid reaction	A range of indoor and outdoor situations
V	21,520	Fine detail, close inspection, rapid reaction	A range of indoor and outdoor situations
W	32,280	Visual performance of the highest order	Some sports, industrial, medical situations
X	53,800	Visual performance of the highest order	Some medical procedures
Y	107,600	Visual performance of the highest order	Some medical procedures

NOTE

13.162 Illuminance values converted from lux; targets are for 25–65 age group. Specific target illuminance values for a wide range of very specific design situations are given in the *IES Lighting Handbook*.

Contributor:
Walter Grondzik, PE, Ball State University, Muncie, Indiana.

Use the illuminance category as a center-value guideline and adjust accordingly to accommodate all occupants and tasks of the space. Remember that quality is just as critical as quantity but that the solution should work for all individuals. Consult the most current recommendations for the parameters of any specific application.

RECOMMENDED GENERAL ILLUMINANCE LEVELS 13.163

ACTIVITY	ILLUMINANCE (FC)
Public areas with dark surroundings	2–5
Simple orientation for short visits	5–10
Working areas where visual tasks are only occasionally performed	10–15
Warehouses, homes, theaters, archives	15
Easy office work, classes	25
Normal office work, PC work, study library, groceries, show rooms, laboratories	45
Supermarkets, mechanical workshops, office landscapes	70
Normal drawing work, detailed mechanical workshops, operation theatres	95
Detailed drawing work, very detailed mechanical work	140–185
Performance of visual tasks of low contrast and very small size for prolonged periods of time	185–465
Performance of very prolonged and exacting visual tasks	465–930
Performance of very special visual tasks of extremely low contrast and small size	930–1860

TASK METHOD OF CALCULATING ILLUMINANCE (POINT-TO-POINT LIGHTING)

For estimating lighting from one or more fixtures directly onto the center of a visual task area such as the middle of a desktop, use the inverse square law:

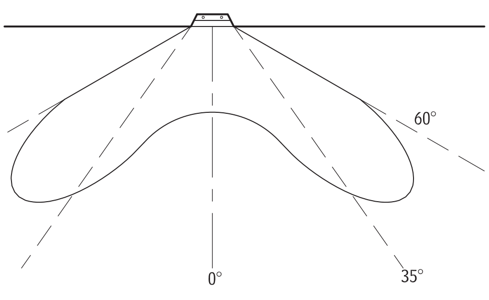
(candela of source) ÷ (distance from source to task)^2 × cos (incidence angle between ray of light from luminaire and line extending normal from task surface), or fc = cd/d^2 × cos(θ)

Note that the candela output from a luminaire varies according to its candlepower distribution curve (CDC) and the aiming angle of the fixture. Lighting of one task point from multiple luminaires is simply the sum of the individual fc levels provided by each fixture.

Task-lighting calculations should be made with the understanding that the initial output of the fixture and its lamp(s) will degrade with age and that room surfaces are not considered as light-reflecting areas that contribute to illumination on the task.

LUMINAIRE LIGHT DISTRIBUTION PATTERN 13.164

Any one of these dimensions may be the cavity height (H), which is the distance from the light fixture to the work plane of interest.



LUMEN METHOD OF CALCULATING ILLUMINANCE (UNIFORM BACKGROUND LIGHTING)

The lumen or zonal cavity method is used to estimate the maintained levels of uniform illumination from a room of uniformly spaced light fixtures. This estimation allows for the contribution of reflected light from room surfaces and, thus, considers the room itself, along with its geometry and reflectance levels, to be part of the lighting system. Maintained illumination is differentiated from initial fc levels by including light loss factors (LLF) for estimated recoverable light loss factors, which include:

- Area dirtiness
- Room surface dirt depreciation
- Lamp percentage burnout
- Lamp lumen depreciation
- Luminaire dirt depreciation

Unrecoverable light loss factors include:

- Luminaire ambient temperature
- Luminaire voltage
- Ballast efficiency factor
- Luminaire surface depreciation

Light loss factors are the mathematical product of all these different maintenance considerations, each of which can be determined by a detailed procedure. LLF usually ranges from 0.6 to 0.8 and can be estimated for very preliminary purposes with some knowledge of the room conditions and the parameters of lighting system operation.

Light output from luminaires in the lumen method is not taken from lamp candela as in the task-lighting method, but rather as the total lumens from the fixture multiplied by the efficiency of the fixture. This fixture efficiency is termed the *coefficient of utilization* (CU) and is determined from manufacturers' photometric test data as published in their product literature.

Generally:

footcandles (fc) = (number of fixtures × lumens per lamp × lamps per fixture × CU × LLF) ÷ (room square feet)

If there is only one lamp in each fixture this simplifies to:

fc = (fixtures × lumens × CU × LLF) ÷ (room square feet)

If the desired illuminance level is known and the number of fixtures is not, then the terms can be rearranged as:

(number of fixtures) = (fc × room square feet) × (lumens per fixture × CU × LLF)

Further, to assure uniform illumination at the task, it is necessary to check the final fixture layout against the allowable spacing ratio given by the manufacturer for the fixture being used. Exceeding the spacing ratio will result in gaps between the fixtures where the task will not be lit to the predicted average fc level. Note also that asymmetric fixtures such as linear fluorescents have two different spacing ratios to indicate the beam spread across the fixture width, as opposed to along the fixture length.

Determination of CU is key to this process, and involves a succession of calculations based on room geometry, fixture mounting height, and room surface reflectances. For very preliminary estimation purposes and typical room conditions, a CU can usually be assumed in the range of 0.5 to 0.8. Note that a CU of 0.6 indicates that only 60 percent of the light generated in the fixture will ever reach the intended task surface. Coupled with a hypothetical LLF of 0.7, this means that only 0.6 × 0.7 = 42 percent of the fixture output would be effectively utilized and that the average operating fc level would only be 70 percent of the illuminance when the system is new. All energy used for light is instantly converted to heat in a room, but light that never reaches the task surface is doubly problematic. It should be apparent that detailed ambient lighting design should never be initiated until CU and LLF values are well established. Equally obvious, better maintenance and quality component design results in higher CU and LLF factors that provide the same maintained illuminance levels with less wasted lighting energy and interior heat gain.

The relation of efficacy and lighting power density can be used in early design stages to estimate maintained uniform footcandles of illuminance provided. Relative lighting power density levels for different uniform maintained illumination levels and lamp efficacies are shown here for an assumed CU of 0.6 and an LLF of 0.7. For other values, use LPD = fc ÷ CU ÷ LLF ÷ LPW. Lighting power density is used in comparing relative lighting energy requirements and has a specified maximum allowance under the Model Energy Code.

BALLASTS

Control of gas discharge lamps during starting and operation requires a ballast device. Many fixtures are available with either 120 V or 277 V ballast options. Higher-voltage fixtures allow for a simplified and more economical building electrical distribution system with smaller (lower ampacity) conductors. Ballasts consume some 10 to 20 percent as much energy as the lamp they control.

For some 50 years the standard ballast was the wire-wound magnetic type. Electronic ballast technology is now commonplace. Electronic ballasts are generally more efficient at operating discharge lamps and also have lower energy losses associated with their own power draw. The more sophisticated electronic ballasts also have other advantages:

- High-frequency ballasts can be used to drive fluorescent lamps at 20,000 Hz or more (40,000 pulses per second) and, thus, eliminate the eyestrain-causing flicker associated with standard 60 Hz (120 pulses per second) ballasts. This high frequency also causes fluorescent lights to operate even more efficaciously than standard electronic ballasts.
- Additionally, electronic ballasts are available in dimmable configurations to allow for control of stepped or continuously variable illuminance levels.

On the downside, electronic ballasts are more heat-sensitive than magnetic ballasts. Electronic ballasts are designed for ambient temperatures below 105°F with an inside temperature of the ballast of less than 167°F. Magnetic ballasts, on the other hand, have a maximum interior temperature of 194°F. Electronic ballasts are fitted with thermal protection circuitry that shuts down when overheating occurs, but repeated overheating can lead to ballast failure.

Another critical factor is that ballast characteristics are tailored to a limited number of lamp applications. Mismatched lamp and ballast combinations can result in more than just poor performance; it can also cause immediate to near-term catastrophic failure. Catastrophic failure can occur because discharge lamps tend to have negative electrical impedance once they reach operating temperature after start-up, and so a mismatched ballast may cause a sudden circuit failure if it is not programmed for the lamp in use.

Dimming electronic ballasts can incorporate low-voltage controls, and can be grouped into custom-sized and independently controlled zones. Low-voltage wiring for this purpose avoids the necessity of expensive conduit and is readily modified when use patterns change. Low-voltage controls also work with other control components such as photocells, occupant sensors, and energy management systems.

LAMPS

This section addresses design considerations for lamps and describes different types of lamps.

DESIGN CONSIDERATIONS

Even though color rendering, lamp life, and efficacy ratings will normally dictate the general choice among incandescent, fluorescent, and HID lamp families, there remain other detailed factors to consider when selecting a specific lamp.

SMALL LIGHT SOURCES

Smaller light sources are much easier to focus, whereas large diffuse sources such as fluorescent tubes are quite difficult to direct. The smallest conventional lamp source is the filament of a low-voltage halogen MR lamp. With a small filament it is much easier to design and build a reflector profile into the lamp bulb or fixture housing that will produce the desired beam spread, from very narrow spot to very wide flood. Small lamps with small filaments are, thus, usually better suited to task-lighting applications where precise control of beam pattern is more important. Larger light sources are more appropriate for ambient background illumination where light levels are fairly uniform.

LUMEN MAINTENANCE AND LAMP LIFE

The typical decline of lumen output from a lamp corresponding to age in operating hours is termed the *lamp lumen depreciation* factor (*LLD*). LLD is measured as a percent of the original lamp lumens and is rated as the percentage of original lumens still remaining at 40 percent of the rated life of the lamp. Lamp life in turn is established by the number of operating hours at which 50 percent of a large sample of lamps will burn out completely. Because lamps have a variety of expected life hours, the LLD degradation cannot be compared directly from one lamp to another. LLD and lamp life are also influenced by various factors depending on the lamp technology being considered; lamp position, operating voltage, operating temperature, and hours per on/off operating cycle also may have a significant impact. Another productive use of dimming is the graduated compensation for lamp lumen depreciation, where lamp power is increased over time to compensate for lumen depreciation.

SPECTRAL COLOR DISTRIBUTION AND PHOSPHOR BULB COATINGS

Gas-discharge lamps rely on a conductive vapor such as mercury, metal halide, or sodium to emit photon energy when subjected to a current flowing through the gases held within the lamp bulb or arc capsule. In the case of mercury, these photons produce mostly invisible ultraviolet energy. As the photons leave the lamp, however, they are intercepted by a phosphor coating on the bulb surface, where they are absorbed and exchanged for photon energy in the visible spectrum. This photon exchange happens very efficiently. Different phosphors emit different spectrums of visible light, and so the lamp color balance can be tailored to specific applications. Halophosphor types are used in warm and cool-white fluorescent lamps. Triphosphor blends contain one phosphate each for reinforcing the red, green, and blue portions of the spectrum. Halophosphor and triphosphor coatings are combined and tuned in the design of lamps to vary color output across the spectrum by adjusting the specific type and amount of selected phosphors.

COMPONENTS

Although the fundamental function of a lamp is to convert electrical energy to visible light, lamp construction can also incorporate reflectors, lenses, and internal ballasts. These additional features allow for the use of less expensive fixtures and more flexible retrofitting of room lighting.

MERCURY CONTENT AND LAMP DISPOSAL

Many lamp types contain the heavy metal mercury, which is a neurotoxin that can impair brain function, fetal health, and child development. Compact fluorescent lamps contain as little as 1.4 milligrams. On the other end of the spectrum, HID stadium lamps can contain as much as 225 milligrams. Linear fluorescent lamps range from 1.4 to 60 milligrams of mercury. Businesses were banned from disposing of lamps that contain mercury in the mid-1980s. In January 2000, the U.S. Environmental Protection Agency reclassified these lamps as "universal waste," a subset of hazardous waste. This reclassification was intended to simplify the recycling of said lamps by anyone who handles them in bulk. Most states already have their own more stringent and detailed methods for dealing with mercury lamps. Each year, however, an estimated 30,000 lb. of mercury waste still makes its way into the U.S. environment, possibly into the groundwater, and potentially then into the food chain. About 1 percent of that mercury is thought to come from discarded lamps.

Designers can mitigate some of this risk by considering the mercury content of the lamps specified and the expected life of the lamp before it needs to be recycled.

LABEL DESIGNATIONS

Selecting a lamp also means interpreting their various label designations. All lamps have a great deal of information coded into their labeling, but different lamp families use different codings. This information may variously include the lamp shape, the wattage, the base type and size, the lamp tube length in inches, the lamp diameter in one-eighth-inch increments, the reflector shape, color temperature, and the beam spread pattern. An incandescent A-19 is just the common 2.375-in. diameter lamp. Likewise, an F25T8SPX30 is a 25-watt fluorescent lamp with a T-pin base and a 1-in. diameter bulb operating at a 3000°K color correlated temperature. A halogen 250PAR38SP designates a 250-watt lamp with a parabolic aluminized reflector, a 4.75-in. diameter, and a spot beam spread pattern, as opposed to an FL flood pattern.

Because manufacturers use slightly different coding, and new products are constantly being introduced, appropriate technical information should always be consulted. Some manufacturers also offer a comparison chart of competing product brand equivalencies.

TYPES OF LAMPS

Examined here are these common types of lamps:

- Incandescent
- Halogen incandescent
- Fluorescent
- High-intensity discharge (HD)
- Mercury vapor (MV)
- Metal halide (MH)
- High-pressure sodium (HPS)
- Low-pressure sodium (LPS)
- Induction
- Light-emitting diode (LED)

INCANDESCENT LAMPS

Incandescent lamps generate light by heating a thin tungsten metal filament with electrical current. To prevent oxidation, the filament is sealed in a bulb of inert gas.

The typical A-lamp incandescent has a color temperature range from 2750 to 3200°K, which is warm and emphasizes reds while dulling blue tints. They have a short life of about 750 to 1500 hours, but are very inexpensive and easy to replace.

Because incandescent lamps have a small point source of light generated at the filament, effective reflector profiles can be designed into a reflective lamp bulb enclosure or into the fixture housing. This ease of control translates into a good match of beam spread and beam pattern for task and display lighting, because light can be put more specifically where it is wanted. Also, because the filament works in proportion to electrical current, incandescents can be readily dimmed. Dimming reduces the efficacy and color temperature of incandescent nonhalogen lamps slightly, but it does greatly increase lamp life. Solid-state dimmers reduce lamp buzz noise, and lamp debuzzing coils (LDC) can be added to the circuit to reduce filament vibration even further.

Incandescent lamps come in several sizes and shapes. Their generic label takes the form WWSDDBB. Other terms may be used for colored lamps, lamp base, or manufacturer-specific features.

- *W:* Watts of power
- *S:* Shape, including general-service A-lamps, reflector lamps, elliptical reflectors, PAR (pressed aluminized reflector), candle, globe, and decorative shapes
- *D:* Diameter of the lamp bulb in eighths of an inch
- *B:* Beam spread characteristic, if applicable: spot or flood

HALOGEN INCANDESCENT LAMPS

Both line-voltage and low-voltage halogen lamps differ from standard incandescent lamps in that they use an iodine or bromine gas within the bulb to protect against tungsten filament burnout and bulb blackening, which contributes to extended lamp life. During lamp operation, the halogen gas combines with tungsten that is evaporated off of the lamp filament. When the lamp is switched off and the gas mixture cools, tungsten is redeposited on the filament rather than on the bulb. This effect greatly retards filament weakening and lamp lumen degradation.

Halogen lamps have a rated life of about 2000 to 3000 hours with a 90 to 95 percent lamp lumen depreciation factor. They offer a CRI of 100 at CCTs of 2600°K to 3200°K. The regenerative halogen evaporation/cooling cycle necessitates a higher operating temperature, which slightly increases efficacy and improves the color rendering, as well as increasing the CCT. The bulb of halogen lamps is usually made of quartz to resist these high internal temperatures. Note, however, that quartz is very sensitive to oil and dirt, so direct handling of the bulb is to be avoided. Premature lamp failure can occur if contamination is allowed to deteriorate the quartz surface.

The most impressive advance in incandescent lighting technology in many years is that of the halogen infrared reflecting lamp (HIR). These lamps encapsulate the lamp filament in a quartz capsule, which is coated with a multilayered infrared reflecting film. Ninety percent of the energy consumed by incandescent lamps is converted to invisible infrared energy, so the energy reflected from the quartz capsule raises the filament temperature without drawing extra power. The added incandescence of the HIR lamp filament raises its efficacy into the 40 LPW range. HIR lamps are considerably more expensive than standard incandescent lamps, however, and with the advent of low-priced compact fluorescent lamps, HIR has a limited popularity.

Like conventional incandescent lamps, halogen lamps have a small filament point source of light that is readily controlled. Halogens are also dimmable, just as conventional incandescents are. Halogen lighting is most appropriate to applications where precise control and ease of dimming are important, such as display and accent lighting. But fluorescent and other gas-discharge lamps have a higher efficacy, so halogen should normally not be used where energy consumption and general room lighting are priorities.

Halogen multimirror reflecting lamps, labeled MR, are popular low-voltage lamps that have a compact filament and precision reflector for excellent beam control such as that required for projection lamps. MR lamps also have a dichroic coating on a faceted glass reflector that allows most infrared energy to pass through the back of the lamp but reflects visible light forward through the lens. The dichroic filtering gives the projected light a cooler hue and lower heat content. Some MR lamps have an infrared reflecting capsule around the filament, which increases efficacy. Typically, MR lamps are rated by center-of-beam candlepower, rather than initial lumens, but MR efficacy is generally around 30 LPW.

FLUORESCENT LAMPS

General fluorescent lamps pass an electrical current through an inert and electrically nonconductive gas by first evaporating a small drop of mercury held within the tube (typically, 10 to 23 milligrams) each time the lamp is started. The evaporation is accomplished by a high-voltage starting current from the fixture ballast. Once the mercury is evaporated and electrical current begins to flow through the lamp, a mostly invisible ultraviolet (UV) spectrum of light is produced. Photons of this UV light are then absorbed by special phosphor coatings on the lamp bulb that replaces them very efficiently by photons of visible light. The ballast then provides reduced current that maintains the discharge of light.

Although fluorescent lamps do not have the control or color-rendering capability of incandescents, nor the efficacy of HID lamps, they do offer good compromises of efficacy, color, and lamp life at a very reasonable first cost. This middle ground of good performance and economy have given fluorescent lamps a strong market advantage. Lamp life ranges from 6000 to 30,000 hours at an industry standard on/off cycle of 3 hours of operation per start. Many fluorescents offer about 20,000 life hours. Color Correlated Temperature ratings are available from 2200°K to 7500°K with a CRI of 50 to 92 and typical CRI of about 80. Efficacy in some fluorescents approaches 100 lumens per watt with typical LPW values ranging from 75 to 90 LPW. The combination of these factors in any single example is highly dependent on the exact lamp and ballast combination selected.

HIGH-INTENSITY DISCHARGE (HID) LAMPS

HID technology includes mercury, metal halide, and sodium-gas discharge lamps. In general, they have high efficacy and low to average color rendering. Their most common applications are industrial, commercial, roadway, and security lighting. HIDs are similar in operation to fluorescent lamps. All of them use a ballast to initiate and control a flow of electrical current through a gas-filled envelope. The gas emits photon energy when excited, just as in fluorescent lamps. Each of the different HID lamp types does, however, have individual efficacy, color, and control characteristics that make each of them better suited to a particular range of applications.

According to the U.S. Department of Commerce, sale of all HID technology lamps increased from 20 million units in 1990 to a peak of 37 million in 1999, and by 2002 was still near 34 million lamps. Despite the continued improvement in some HID lamp efficacy and color rendering, however, the relative share of the HID market by lamp wattage remained unchanged from 1993 to 2001. The total number of HID luminaires shipped has remained constant at about 12 million since 1996, with outdoor fixtures accounting for about 8 million, industrial fixtures for 3.5 million, and commercial fixtures for some 0.5 million. The only trends in fixture shipments indicate a slight increase in the commercial, and a similar small decrease in outdoor fixtures.

HID lamps can be dimmed by either step-level or continuous dimming ballasts. Dimming HID is important for more than daylight harvesting, illuminance flexibility, and energy savings; it also avoids the necessity of switching the lamps on and off. Given the strike and restrike time needed for HID lamps to warm up before reaching or returning to full brightness, dimming can thus help extend HID lamp life by maintaining the 10-hour operating cycle for which they are designed and rated. Note that the efficacy of an HID lamp will decrease when dimmed and that dimming below 50 percent of the lamp's rated power may degrade the life, efficacy, lumen maintenance, color, and warranty coverage.

MERCURY VAPOR (MV) LAMPS

Clear MV lamps have a very low CRI of approximately 15. Generally, even with phosphor coatings the CRI is still low, around 50 at CCTs of 3200 to 6700. Efficacy is also limited, to a low 25 to 32 LPW for small lamps of less than 100 watts to perhaps 50 to 60 LPW for MV lamps of 1000 watts. Efficacy at 40 percent of the lamp life (LLD) is about 75 percent of the initial efficacy. Lamp life is quite long, with 24,000 hours being quite common. Brightness and efficacy tend to slowly degrade over the life of an MV lamp, but they are known to be rugged and durable. Mercury lamps do require a five- to seven-minute warm-up strike time and an equal restrike time.

The bluish cast of uncoated mercury lamps is beneficial to the appearance of green vegetation in night scenes. Generally, however, mercury lighting has few applications where good vision is important. Small MV lamps of around 50 watts contain about 15 milligrams of mercury, and a 1000-watt MV lamp might contain as much as 250 milligrams, so all MV lamps should be recycled and treated as hazardous waste.

Mercury vapor lamps are essentially unchanged since their introduction in the 1930s. The sole development has been the invention of a type B self-ballasted incandescent/mercury hybrid lamp that uses a tungsten filament to regulate current in the absence of ballast control. An arc discharge within the B lamp tube generates light. Next, a filament is heated to incandescence. Together, the arc tube and the filament form a self-regulating series circuit. The B-lamp efficacy is comparable to incandescent lamps of the same wattage. B-lamps have about a three-minute strike time start-up with a five-minute restrike.

Overall, MV lamps have fallen from popularity because of the technical improvements in other lamp families. It is estimated that MV lamp shipments fell from 5.5 million units in 1993 to fewer than 3.0 million in 1999, alone. Projections indicate that this number could decrease to less than 1.0 million by 2008.

METAL HALIDE (MH) LAMPS

MH lamps were developed from mercury vapor lamp technology by the addition of metal halides to the mercury and argon in the arc tube. Continual improvements have made MH technology an excellent match of color, efficacy, and lamp life. CRIs of 70 to 90 are common at CCTs of 2500°K to 5000°K; and lamp efficacies are in the range of 75 to 125 LPW.

Probe-start and pulse-start MH lamps differ in gas pressure within the arc capsule. Pulse-start lamps have improved life (15,000 to 30,000 hours) and lumen maintenance (as much as a 33 percent improvement, from about 65 percent to perhaps 80 percent), as well as higher efficacy (typically, 90 versus 100 LPW; and varying with lamp wattage).

Note that metal halide lamp life is rated at a standard 10 hours per start. Pulse-start lamps start faster than probe-start metal halides, with a strike and restrike time of 1 to 4 minutes and 2 to 8 minutes, respectively, compared to probe-start times of 2 to 15 minutes and 5 to 20 minutes. Pulse-start MH lamps can also be used with electronic dimming ballasts to provide variable illuminance control and energy savings. These ballasts are also compatible with low-voltage control systems for daylight integration and occupancy sensors.

The addition of ceramic arc tube technology, CMH, in lamps under 400 watts improves the small lamp metal halide efficacy to about 90 LPW, with a life of 9000 to 15,000 hours, a CRI approaching 95 at CCTs of 3000°K to 4200°K, and LLD factors of 80 percent.

Metal halide lamps are quickly gaining in popularity and their share of the HID market has basically doubled since 1991. The Department of Energy and the National Electrical Manufacturer's Association estimated that MH lamp sales rose quickly from 5.7 million in 1990 to 18.1 million in 1999 and then increased more slowly to 18.8 million lamps in 2002.

HIGH-PRESSURE SODIUM (HPS) LAMPS

HPS lamps discharge an arc current through a small ceramic arc tube in the center of the lamp. The arc tube is filled with xenon, sodium, and mercury vapor, but the larger outer bulb volume is drawn down to vacuum pressure. Efficacy is dependent on the vapor pressure of sodium in the arc tube, but 35-watt sources are in the range of 65 LPW, 100 watts at 100 LPW, and 1000 watts at 130 LPW. Standard HPS life is 24,000 hours with long-life lamps rated up to 40,000 hours. CCT is normally 2100°K with a very low CRI of 22. Higher color-rendering HPS lamps are also available, but their CRI of 60 to 85 at CCTs of 2200°K to 2700°K come with reduced efficacy, in the range of 50 to 95 LPW. Cold HPS lamps require a three- or four-minute strike time and a one- to three-minute restrike time.

The monochromatic yellow cast of standard HPS restricts its usage; thus, although HPS sales have remained relatively steady, at around 11.0 million lamps per year since 1994, their HID market share has slipped continually since 1991.

As discussed earlier, as for human factors in lighting design, designers are increasingly finding that lower illuminance levels of fuller-spectrum light provided by other sources such as metal halide are more desirable and actually provide greater visual acuity than higher illuminance levels with less color rendering. In technical terms, at low-light levels, human vision shifts to "scotopic visibility function," whereby the spectral distribution and higher CCT of metal halide lamps provide better peripheral visibility, even at lower footcandles. As long as the reduced lighting level is acceptable and compensates for reduced efficacy, this is probably a reasonable tradeoff.

LOW-PRESSURE SODIUM (LPS) LAMPS

Although LPS lamps have very high efficacy, on the order of 100 to 150 LPW, they have no color rendering capability due to their strictly monochromatic light, with a very low CRI at a CCT of 2000°K. LPS ballasts add another 30 or 40 watts of required system power and reduce the overall system efficacy. The most common LPS application might be that of replacement lamps in mercury vapor fixtures, where replacement wattages of 18 to 180 are available and offer life ratings of 16,000 to 18,000 hours, with a maintenance factor LLD of 87 percent. There are other environmental considerations in favor of LPS, however. First, the narrow bandwidth of LPS lamps is easily filtered out by astronomers who have increasing night "skyglow" from unshielded lighting to deal with; second, some animals such as sea turtles are not as attracted to these lamps as they are to full-spectrum lamps. Many animals are accidentally destroyed when leaving their habitat to approach full-spectrum lighting.

INDUCTION LAMPS

Induction lighting is a rapidly emerging and revolutionary lighting technology. It is essentially fluorescent technology without lamp cathodes. Induction lighting provides approximately 100,000 hours of lamp life, which is about 10 times the life of HID sources at about three times the cost. Efficacy is about 75 LPW, and a characteristic LLD of 0.70 means less than 30 percent lumen degradation after 60,000 hours of operation. Induction also features a CRI of 80 or better at CCTs of 3000°K or 4000°K. Due to their high cost and long life expectancy, induction lighting systems should be purchased with a warranty against premature failure.

Induction lamps resemble general-service incandescent A-lamps, but operate like gas-discharge lamps. At the center of the lamp itself is an induction coil, which produces a magnetic field and excites a mercury electron-ion plasma material on an inner glass assembly, producing ultraviolet light. Phosphor coatings on the lamp bulb envelope replace the ultraviolet energy photons with ones of visible light. Induction lamps have no strike or restrike time, no color shift with age, and low sensitivity to operating temperature. Induction lamps do require special fixtures, are not currently dimmable, and may have a pink hue in the first few minutes of operation. At the end of the rated 100,000-hours life, it may be necessary to replace the entire induction system with its lamp, power coupler, and high-frequency generator.

LIGHT-EMITTING DIODE (LED) LAMPS

LED lighting uses the semiconductor diode lamps that have been around since 1962. Originally, gallium arsenide devices were used to produce red light. Developments in new material compounds have recently made other colors possible, but single LEDs emit a narrow spectrum of color. Combining the relatively wide-bandwidth blue gallium nitride LEDs with red and green ones would, in principle, allow for the production of white light. Most full-spectrum LEDs in current production, however, use the blue gallium nitride LED with a yellow phosphor lens coating.

LED lamps operate on direct-current voltage and are polarity-sensitive; improper connection can destroy them. Otherwise, they have an extremely long life, typically about 10 years. LEDs usually fail by gradual dimming rather than sudden burnout. They are also insensitive to vibration and temperature.

As replacements of incandescent and fluorescent lighting, LEDs are termed solid-state lighting (SSL) devices and are clustered in arrays of several semiconductors to form a single lamp. SSLs currently have efficacies of about 32 lumens per watt but are predicted to eventually reach 80 LPW.

LUMINAIRES

Light fixture performance, as an artifact of industrial design, has been greatly augmented by advancements in computer simulation and CAD design. The ability to use ray tracing for the design of reflectors, for example, and the parallel advent of precision manufacturing makes it possible to devise and craft luminaires that have finely controlled photometric performance.

Luminaires have the following functional components. Some of these are optional elements that are not included in every luminaire, or may be incorporated into the lamp used in the fixture. In the case of PAR incandescent lamps, for example (parabolic aluminized reflector lamps), the reflector and a lens are built into the reflective lamp bulb enclosure and a Fresnel lens is pressed into the lamp aperture.

- *Lamp:* The source of light used to convert supplied energy into visible light energy.
- *Reflector:* Interior surface around the lamp used to control the spread of light from the fixture or to diffuse it as widely as possible. Reflector profiles can be designed for converging or diverging patterns of light in parabolic or elliptical shapes. This level of control is only possible where a small lighting filament is used, such as incandescent lamps have. Larger sources such as fluorescent lamps can be diffused easily, but cannot be focused. Most reflectors are of white enamel or an aluminized surface. Cones of various color and material that are inserted into fixtures also fit this function, but cones are often dulled or

darkened to reduce the apparent brightness of the fixture when viewed from the side.

- *Lens:* Optical element used to control the direction and diffusion of light from the fixture; to protect the lamp from physical damage, moisture, or weather; and, optionally, to color the light as it exits the fixture. Lenses can focus or spread a controlled beam or cone of light from the fixture by optical diffraction, and they can also diffuse light by having translucent properties or a diffuse rather than a transparent surface.
- *Louvers and baffles:* Shielding elements used to hide the lamp from direct view and/or to diffuse light from the fixture in a wide pattern.

LIGHTING CONTROL

Controls are an essential part of any lighting system. Controls are integral to energy conservation—allowing light output (energy consumption) to match user needs. Controls can also contribute to spatial ambiance. Controls can be manual (requiring explicit user action for success) or automatic (operable in the absence of user action). Controls can be on/off or dimming—with dimming allowing for a much wider range of system responses (other than light/no-light). Current design practices tend toward manual and on/off controls in business-as-usual buildings. Automatic and dimming controls are common in high-performance buildings (green; net-zero energy).

The purposes for which lighting controls are installed include:

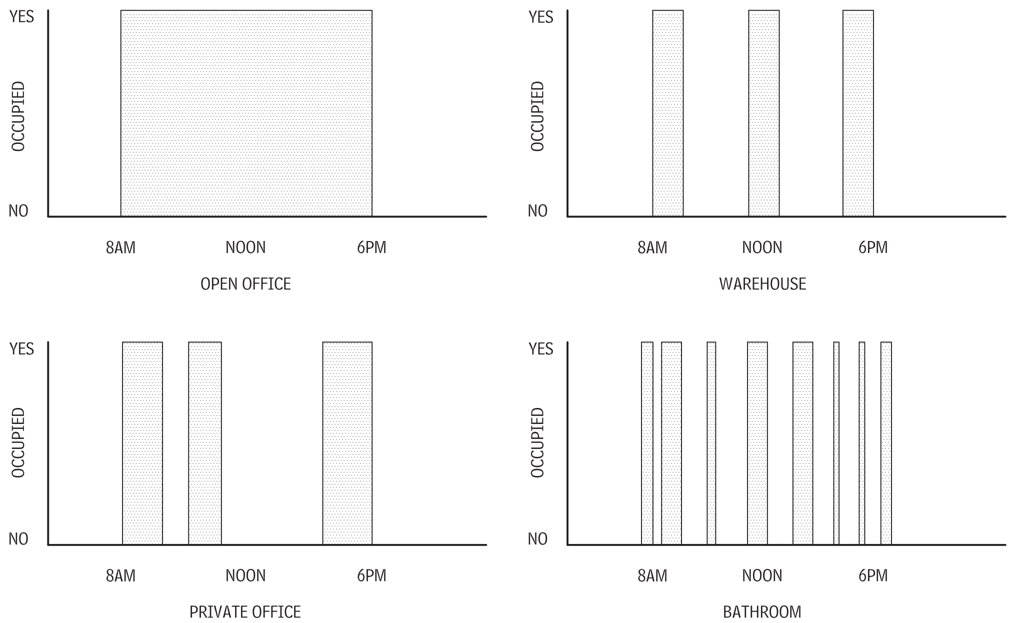
- *Energy use reduction:* Basic manual on/off controls save energy if properly used; automatic occupancy sensor on/off controls can increase off cycles in public spaces with no clear ownership; automatic time switch on/off controls can do the same when the need for lighting is driven by daily cycles and not occupancy status; task tuning controls can allow illuminance to match visual needs in spaces with a range of tasks.
- *Daylight compensation:* Spaces with daylighting will experience a range of illuminance values throughout the year as sky luminance changes; this type of control adjusts the output of the electric lighting system to maintain reasonably constant illuminance in a space.
- *Lumen maintenance:* Lighting system output decreases with time (as a result of lamp depreciation, dirt collection on reflective surfaces, and other factors); an automatic dimming system can reduce light output early in the system lifecycle so that spaces are not over-lit (and energy is conserved).
- *Scene changes:* Preprogrammed lighting controls can simplify switching from one lighting arrangement to another (such as from wall washing to uniform task illuminance in a conference room).
- *Demand control:* In a building with high demand charges (distinct from energy consumption charges) this type of control can be one part of a demand management system.

LIGHT TRESPASS AND LIGHT POLLUTION

Light leaving a site and falling on a neighboring property is termed light trespass. From the culprit building perspective, such light is a wasted resource—increasing energy consumption and adding unnecessarily to carbon emissions. From the neighbor's perspective, trespassing light may decrease quality of life if it enters an area the neighbor desires to be dark. The solution to light trespass for exterior lighting fixtures is careful selection and installation of fixtures with appropriate cutoff characteristics. Light trespass caused by interior lighting transmitted through windows is more of a challenge to control—but not impossible if deemed important.

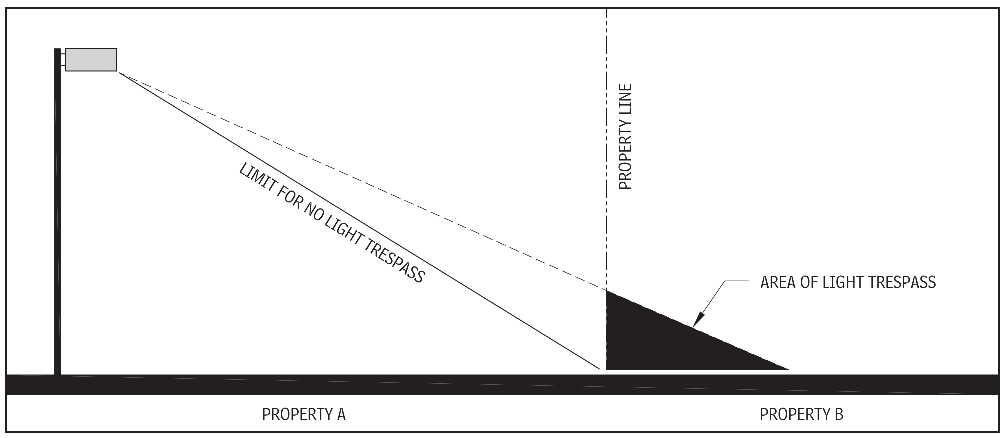
Light illuminating the sky is termed light pollution. As in most cases of pollution, the effects of lighting the night sky impinge on the enjoyment of others (and not just adjacent neighbors). Light pollution also wastes energy. The solution to light pollution from exterior lighting fixtures lies in the selection of fixtures with desirable cutoff characteristics. The surfaces being lit by exterior fixtures will reflect light, some of which will head toward the sky. This effect can be somewhat controlled by selecting moderate exterior surface illuminances. Light trespass caused by interior lighting transmitted through skylights is more of a challenge to control—involving the interaction of interior luminance and glazing transmittance.

OCCUPANCY PATTERNS AFFECT LIGHTING CONTROL SCHEME SELECTION
13.165



TYPICAL PATTERNS OF OCCUPANCY

LIGHT TRESPASS
13.166



FACILITY POWER GENERATION: PV

PHOTOVOLTAIC SYSTEMS

Photovoltaic (PV) systems convert sunlight into direct current (DC) electricity, which can subsequently be "inverted" to AC electricity to meet an AC load. Their rapidly decreasing cost and rising conventional energy costs will likely make these systems competitive with conventional sources of electricity within the decade. They are currently competitive with many off-grid applications where power line extension is costly or use of a diesel generator is undesirable.

The basic collection component of a PV system is the photovoltaic cell, a layered semiconductor that is generally fabricated from crystalline silicon. A group of cells interconnected in series is encapsulated to form a module. An array is an assembly of modules.

The most common PV material is crystalline silicon, and currently the efficiency of commercial cells/modules is somewhat above 15 percent. Significant advances are being made in silicon technology and it is expected that the efficiency of commercial modules will exceed 20 percent in the near future. A variety of other PV technologies (including thin films and amorphous materials) are available, generally with somewhat lower efficiencies than current silicon technology. An important parameter for PV is the cost per watt of energy, and modules of different efficiencies may have comparable dollars per watt. The module efficiency is important to the designer in that the installed capacity (power) for a given area is directly proportional to efficiency.

NOTE

13.165 EPRI: Advanced Lighting Guidelines.

A major component of a grid-connected PV system is the inverter, or power conditioning unit (PCU), which converts the DC power generated by the PV array into AC power used by the load and synchronizes the PV array's power output to make it compatible with the local utility output.

PV MODULE INSTALLATION

PV module installation typically involves one of three forms:

- Standoff or rack-mounted away from the roof or walls, and either parallel or inclined with the mounting surface. The standoff module design is currently the most common in residential applications and has the advantages of allowing convection cooling on the back side, ease of installation (particularly for retrofit), less impact on roof integrity, and ease of service/repair.
- Set directly on the roof sheathing or into the wall and made integral with that surface.
- PV shingles, which may replace conventional roofing. PV shingles have lower efficiencies and are currently much less common.

BUILDING-INTEGRATED PHOTOVOLTAICS (BIPV)

For commercial/institutional structures in particular, the use of building-integrated photovoltaics is becoming rather common. In such cases, PV modules may be sufficiently integrated into the roof or walls of the structure so that they provide the exterior barrier to the elements. Because of this integration of the PV system with the building envelope, it is particularly important that the architect be intimately involved in the design and specification of such a system.

STAND-ALONE (OFF-GRID) SYSTEMS

For residential and commercial buildings the architect will most likely deal with grid-connected systems, since the loads will most likely be AC. However, some applications, such as vacation homes, offshore facilities, and so on, will be off-grid, and loads may be DC. In such cases, there is no need for the inverter; but for the system to be stand-alone, a battery bank must be incorporated. In such systems, the battery bank should provide 5 to 10 "days of autonomy"—that is, have a capacity to meet the load for that many days.

LOCATING AND ORIENTING COLLECTOR ARRAYS

The most optimal orientation for solar collectors, whether thermal or PV, is on a south-sloping structure and inclined approximately at the local latitude or at a slightly greater tilt. For space heating systems, latitude plus about 15° favors the high winter season heating demand. Although these angles are recommended, if within even 10° or 15° for either azimuth or tilt, the collector's performance degradation is small. For locations where electric utility demand peaks in the late afternoons during summer, it may be best to face PV systems approximately to the southwest.

Shading is detrimental to collector performance and, as such, wherever possible collectors should be installed on the least shaded location of the building. Shading can arise from nearby trees and other buildings and from the building itself. For thermal collectors, the degradation is approximately proportional to the fraction of the collector array in shade, and so shading is not as significant a problem. However, for PV arrays, shading is very critical, as in an array possibly all cells are series-connected, and shading of even a few cells out of many hundreds will very seriously degrade performance. A good rule of thumb for PV arrays is that if any portion of a subarray of series-connected cells is shaded, then the output of that subarray will be negligible. Thus, PV modules should not be located proximate to any roof section elevated above it.

MOUNTING AND SUPPORTING COLLECTOR ARRAYS

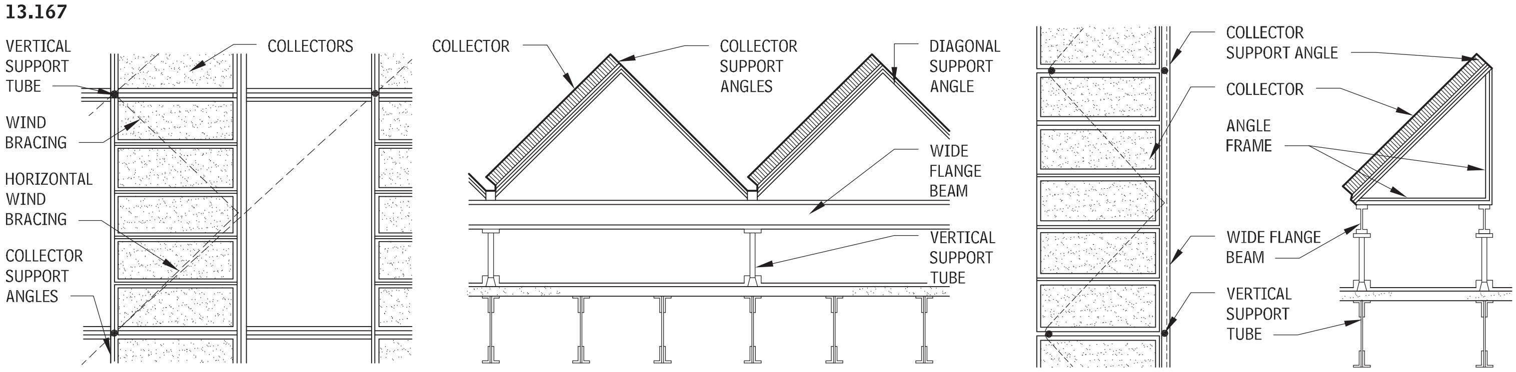
The issues of collector mounting and support for truly BIPV designs are so site-specific that they will not be dealt with here. However, it is possibly even more important for the architect's involvement in BIPV designs than for the applications discussed here, which are restricted to standoff collector arrays.

The design of the support structure of a solar collector array can have an important influence on overall building appearance and design. It is also the aspect of the system that the architect can most easily control. If the collector array is to be selected as part of a total bid package, for example, sizing and coordination problems may result, and the architect may lose control of the array's structural underpinnings and the building's overall appearance. In most cases, collector manufacturers (thermal and PV) will offer one or more support concepts that are compatible with their particular collectors. However, the means for the final anchoring to the structure will be the architect's decision.

When mounting a collector array on a roof or other structure, the underlying supporting structure must be capable of meeting both the downward weight of the array as well as the uplift and sideward forces due to wind loadings. In retrofit applications, this may mean beefing up the substructure and special treatment for roof penetrations. Rooftop collector supports should be anchored directly to structural members, not to wood or metal decking; otherwise, wind-induced uplift forces and point loading may cause roofing and, possibly, structural failure. In steel buildings, vertical collector array supports must be secured directly to joists or beams. In wood buildings, securing the collectors to structural members will normally require the installation of some form of blocking, under the decking and between rafters, to adequately transfer the load.

On flat composition roofs, a fairly common approach is "gravity mounting," where the support posts are anchored to pans filled with sufficient aggregate to overcome wind forces. Of course, this adds to the weight of the system, which must be accommodated in the substructure. If anchored supports are used for a collector array on a light steel-framed roof, the supports should be anchored to the roof beams, and it is not uncommon to increase the capacity of the roof structure. Some roofs cannot support such loads and, thus, must be clear-spanned. However, long-span space-frame structures are invariably costly.

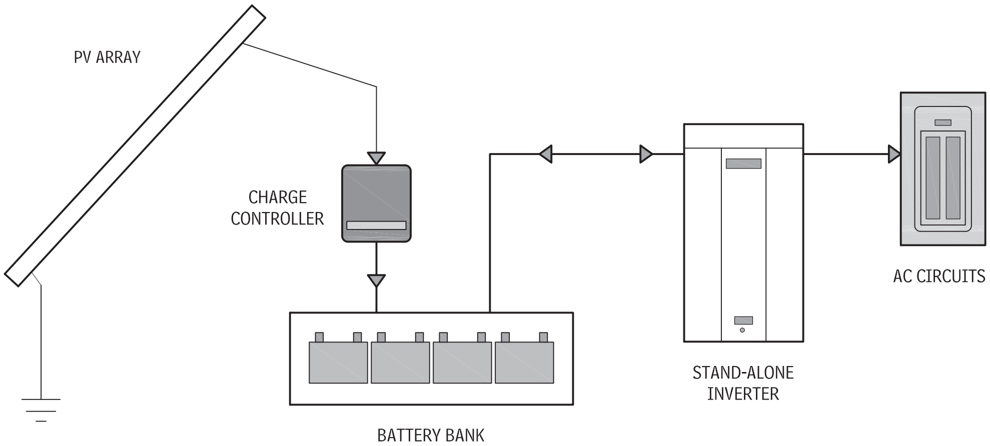
COLLECTOR SPACING AND SUPPORT FOR LARGE ARRAYS AND MULTIPLE ROWS
13.167



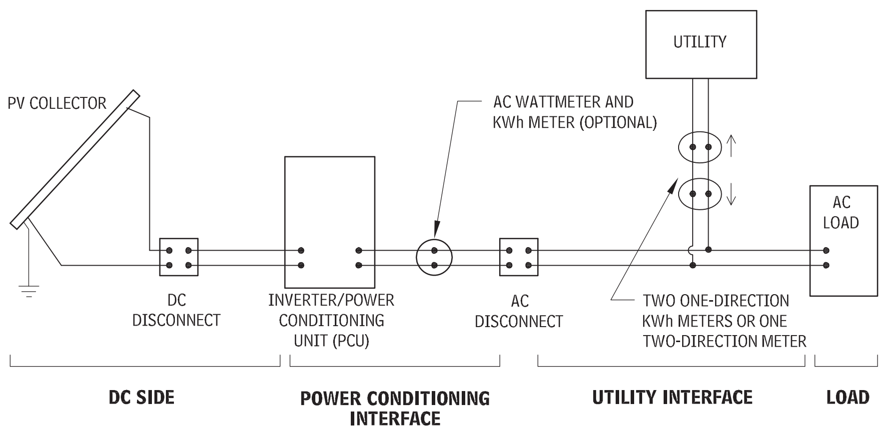
PLAN SECTION PLAN SECTION

Contributors:
Stephen Weinstein, AIA, The Ehrenkrantz Group, New York, New York;
Gary Vliet, PE, Mechanical Engineering, University of Texas at Austin, Austin, Texas.

TYPICAL AC STAND-ALONE PHOTOVOLTAIC SYSTEM
13.168



TYPICAL GRID-CONNECTED PHOTOVOLTAIC SYSTEM
13.169



Photovoltaic (PV) power systems are classified by the nature of the electrical current delivered to the loads (AC or DC) and the system's relationship to the surrounding power grid. All PV modules initially produce DC (direct current) electricity. Some PV systems deliver this DC power directly to DC loads; other systems convert the DC output to AC power for use by AC (alternating current) loads. A PV system may or may not have battery storage. In a grid-connected system, the utility grid assumes the role of the battery backup.

Direct Current System: Direct current systems are the simplest approach to PV power. The system consists of a PV module or array connected directly to a load or loads. Electrical safety, disconnect, and control elements will be located between the array and the load. With no storage capability, these systems can power loads only when adequate solar radiation is available. Common applications include water pumping (including pumping for solar thermal collectors) and ventilation devices. The addition of batteries to this system allows it to provide DC power at night and on cloudy days. Batteries will add to the cost of a PV system and require maintenance and proper location within a building, but may be justified in the context of a particular project.

Stand-alone Alternating Current System: Off-grid or stand-alone systems pair a PV array with batteries for energy storage. An inverter converts the DC electricity from the PV modules or the batteries to AC electricity so that conventional appliances may be used. By definition, a stand-alone system must be power-self-sufficient. This requires careful coordination of PV production, storage capacity, and load patterns to ensure electricity is available at night and during periods of bad weather.

Grid-Connected Alternating Current System: A grid-connected system interfaces with the local power grid—using the grid as a source when the PV system output is inadequate for the connected loads. In similar fashion, the grid accepts excess power production from the PV array and distributes it to other customers. The grid functions like the batteries in a stand-alone system, balancing power production and consumption over time. Regulations regarding grid-connected PV systems are in flux and vary from state to state; the financial arrangements for such interconnections also vary widely.

OTHER ELECTRICAL SYSTEMS

UNINTERRUPTABLE POWER SUPPLY

Uninterruptible power supply (UPS) is designed to provide continuous power with specific electrical characteristics by conditioning utility company power, battery power, or generator-supplied power. UPS systems closely control the power supply voltage and frequency to critical equipment such as computers, communications systems, and medical instrumentation.

UPS systems are either *on-line*, with power routing through them continuously, or *off–line*, with power routed through them only when the incoming power is interrupted or departs from the design characteristics. The time required for an off-line, solid-state UPS to automatically switch on varies with the type of switch selected: The quicker the switch, the more expensive the switching equipment, in general. The time must be matched to the tolerances of the critical equipment being supplied by the UPS to prevent loss of data or other problems.

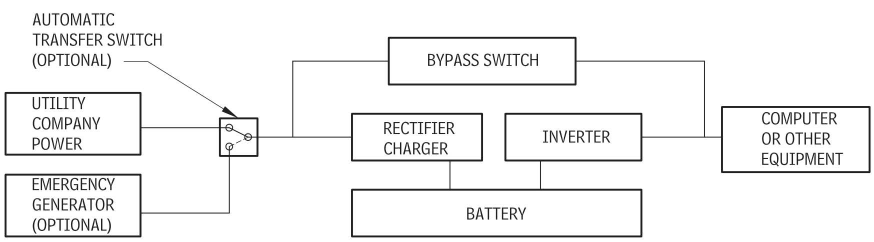
Battery backup time is selected to allow a controlled shutdown of equipment, or to allow a backup generator to be started and to stabilize at full power.

Redundant UPS systems may be required if UPS power loss cannot be tolerated for system maintenance or equipment breakdown.

Some equipment can produce electrical disturbances that are fed back into the electrical circuit. This must be prevented through filtering to maintain clean power to the other equipment being supplied by the UPS.

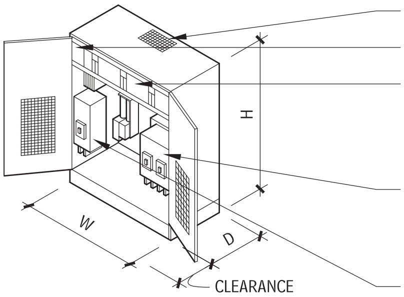
The UPS unit and battery should be placed close together. Some UPS cabinets contain sealed batteries; others require separate batteries.

TYPICAL UNINTERRUPTIBLE POWER SUPPLY SYSTEM DIAGRAM
13.170



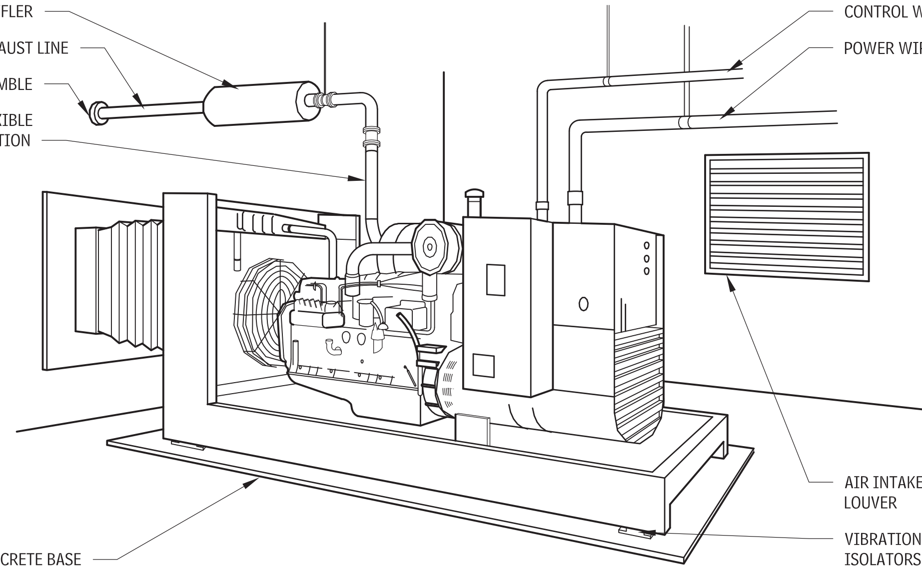
Contributors:
Walter Grondzik, PE, Ball State University, Muncie, Indiana with Ayush Vaidya, M. Arch, University of Oregon, Eugene, Oregon.

SOLID-STATE UPS
13.171



KVA	WIDTH (IN.)	DEPTH (IN.)	HEIGHT (IN.)	WEIGHT (LB)
25	28	32	70	1,400
50	72	36	72	4,000
125	72	36	72	5,600
200	72	36	72	6,000
350	168	32	76	12,700
500	168	40	76	14,600

EMERGENCY ENGINE GENERATOR WITH CONTROL PANEL
13.172



PACKAGED ENGINE GENERATORS AND BATTERY POWER SYSTEMS

EMERGENCY BACKUP SYSTEMS

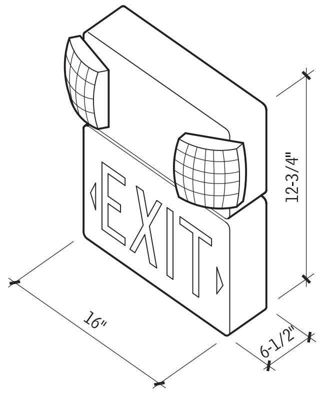
Packaged engine generators provide emergency power during power outages, when life safety lighting and/or critical equipment power requirements are beyond the capacity of battery units, or when required by code (as in hospitals or high-rise buildings). Design requirements are as follows:

- Engines should be located away from main electrical switchgear.
- Engine rooms must have adequate ventilation for engine- and generator-radiated heat and must be protected against extreme environments under all conditions of airflow.
- There must be enough room around a power-generating unit to service it and to remove the unit.
- Packaged engine generators require frequent inspections, tests under load conditions, and maintenance.
- Provisions must be made to prevent vibration transmission to nearby occupied areas.

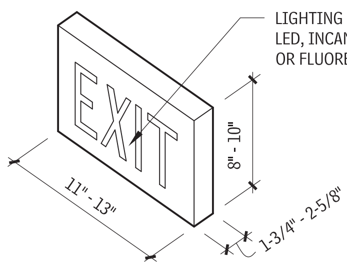
Refer to the National Electric Code for working space requirements and proper application.

Battery-powered lighting equipment provides the minimal emergency illumination required for personnel safety and evacuation in buildings not requiring standby generator power. It is also used in buildings requiring standby generator power for the central control, telephone switchboard, generator, and electrical switchgear rooms to provide lighting for critical operations and troubleshooting if the generator fails to start. The batteries, which require frequent inspection, tests, and maintenance, are available in lead calcium, nickel cadmium, and wet lead acid.

EXIT SIGNS
13.173



WITH EMERGENCY LIGHTING



NOTES

13.171 Sound level approximately 65 to 70 dB. Heat rejection approximately 450 to 700 Btu/hr/kVA at 50 kVA to 250 Btu/hr/kVA at 500 kVA. Maintain room temperature at 70°F to 80°F. Some units require clearance for access.

13.173 Available in solid acrylic, cast aluminum with acrylic letters, steel, or polycarbonate housing, these signs may be side-, top-, or back-mounted or recessed. They can be powered by standard AC or battery pack.

Contributor:
Charles B. Towles, P.E., TEI Consulting Engineers, Washington, DC.

LIGHTNING PROTECTION

A lightning protection system is an integrated arrangement of air terminals, bonding connections, arresters, splicers, and other fittings installed on a structure to safely conduct to ground any lightning discharge to the structure.

Lightning protection systems and components are grouped into three categories (UL classes) based on building height and intended applications.

- Class I equipment and systems are for ordinary buildings under 75 ft. in height.
- Class II equipment and systems are for those over 75 ft. in height.
- Class II Modified is a special group covering only large, heavy-duty stacks and chimneys similar to those used at power plants.

Each of these system types comprises five or six major groups of components:

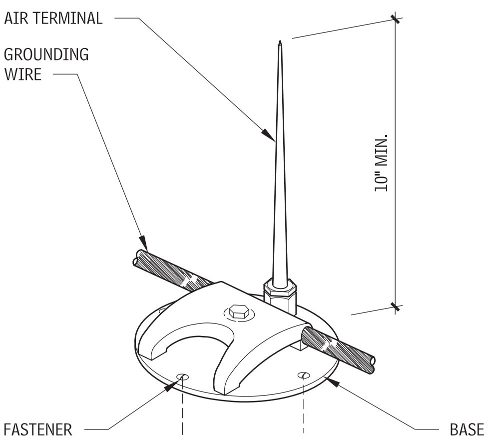
- Air terminals (lightning rods) located on the roof and building projections
- Main conductors that tie the air terminals together and connect them with the grounding systems
- Bonds to metal roof structures and equipment
- Arresters to prevent power line surge damage
- Ground terminals, typically rods or plates driven or buried in the earth
- Tree protection (usually applicable only to residential work)

These types of equipment and the methods for their installation is covered in Figures 13.174 to 13.175.

Beyond these material requirements, other factors to be considered relative to lightning protection systems include:

- Selection of codes for compliance
- Inspection criteria (again, based on code)
- Criteria to evaluate competence of installing personnel
- Requirements for annual inspection and maintenance

TOP-MOUNTED AIR TERMINAL (LIGHTNING ROD) DETAIL
13.174



OVERALL SYSTEMS DESIGN NOTES

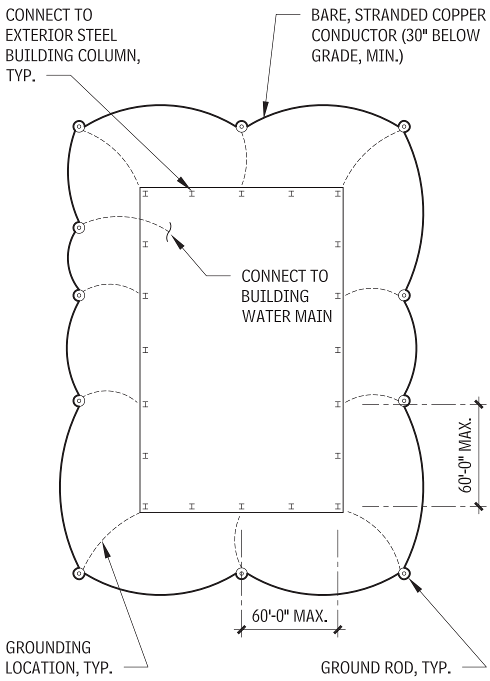
System design guidelines state that:

- Air terminals should be located around the perimeter of flat-roof buildings and along the ridge of pitched-roof buildings spaced at 20 ft. o.c., maximum, and be located not more than 2 ft. from ridge ends, outside corners, and edges of building walls.
- Full-size main conductors should connect all air terminals.
- Additional air terminals should be located in the center of large, open, flat spacings, not to exceed 50 ft.
- Cable runs connecting these center roof air terminals should be no longer than 150 ft. without a lead back to the perimeter cable.
- Gently sloping roofs are classified as flat under these guidelines.
- Downlead cables to ground should be connected to the roof perimeter cable at a maximum spacing of 100 ft. o.c. Buildings with a perimeter of 250 to 300 ft. should have three downleads. For each additional 100 ft. or fraction thereof, add one downlead.
- No building or structure should have fewer than two downleads.
- Arresters should be installed on the electric and telephone services and on all radio and television lead-ins to a structure. Responsibility and jurisdiction for the installation of these devices can vary with locality, so special consideration may have to be given to these items.

Trees adjacent to residences pose a special hazard, therefore it is recommended that all trees larger than an adjacent structure and within 10 ft. of it be fully protected. Consult codes or manufacturer for recommendations on materials and installation requirements.

On-site inspections and certification of completed systems, installer competency certification, and guaranteed inspection/maintenance options are all available under existing standards. Consult codes and standards for specifics.

BUILDING GROUND GRID
13.175



BUILDING GROUND GRID

All buildings and equipment should be grounded to protect people and equipment from fault currents. A complete interconnected system should be installed according to the requirements of the National Electrical Code and the National Electrical Safety Code. The structural steel of the building is connected to a buried "ground grid" to ensure NEC requirements are met. All electrical equipment is connected with this system to provide a direct path to the earth. Specify the number of ground rods and conductor size according to National Electrical Code requirements.

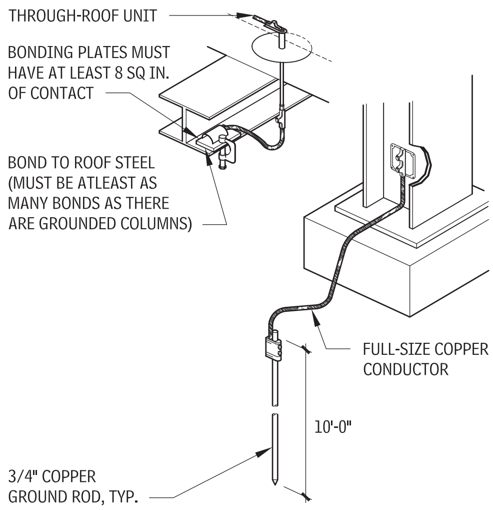
ROOFTOP EQUIPMENT BONDING

Codes vary slightly regarding bonding requirements for metal bodies on rooftops. Generally, if a metal body is in a zone of protection (lower than adjacent air terminals) and within 6 ft. or a calculated bonding distance, it should be bonded to the lightning protection system. Smaller, secondary-size materials may be used for these connections. Metal bodies taller than the air terminals and less than 3/16-in. thick require air terminal protection. Those greater than 3/16-in. thick are protected if adequately bonded.

STEEL FRAME AS CONDUCTOR

In some cases, especially on tall structures, it may be advantageous to substitute the steel frame of a structure for portions of the usual conductor system, normally the downleads. Connections are made to cleaned areas of the building steel, at grade and at roof levels, and the columns serve to connect the roof and ground systems.

STEEL FRAME AS CONDUCTOR
13.176



CODES, TECHNICAL SOURCES, QUALITY CONTROL

The following codes, technical sources, and quality control procedures are standards for lightning protection systems.

- Lightning Protection Institute, "Installation Code LPI–175"
- National Fire Protection Association, "Lightning Protection Code NFPA 780"
- Underwriters Laboratories, Master Label Program under "U.L. Installation Requirements 96A"

NOTE

13.174 Adhesives are typically used for flat-roof installation.

COMMUNICATIONS

DESIGN CONSIDERATIONS

Communications systems cover a wide range of needs and equipment in a modern building. They transfer information between spatially separated points using a suitable medium (typically wired or wireless). Communications systems enhance safety, security, control, and productivity. They are ubiquitous in today's buildings. In general, such systems tend to be low-voltage (if wired), often proprietary (leading to integration and coordination challenges), and prone to rapid renovations and updates. Ease of access for updates is a hallmark design requirement of many communications systems.

The fundamental components in a communication system are: messages, sender, receiver, medium, and protocols. Building control systems typically include a logic element to determine an appropriate action as a result of a signal.

- *Messages:* The message is the information to be communicated. It can be text, numbers, audio, video, or any combination of these.
- *Sender:* The sender is the device that transmits the message. It can be a computer, workstation, telephone handset, video camera, etc.
- *Receiver:* The receiver is the device that receives the message. It can be a computer, mechanical equipment, telephone handset, television, etc.
- *Medium:* The transmission medium is the physical path by which a message travels from sender to receiver. It may be a twisted-pair wire, co-axial cable, fiber optic cable, or electromagnetic waves. Wireless transmission is becoming increasingly popular across all types of communication. This can simplify architectural planning, but the security of wireless transmissions (especially for systems control functions) must be considered.
- *Protocol:* A protocol is a set of rules that govern the data communication. It represents an arrangement between the communicating devices. Without a protocol, two devices may be connected but not able to communicate. Standardized protocols, such as BACnet and LonWorks, have been established for building control networks.

TELECOMMUNICATIONS SYSTEMS

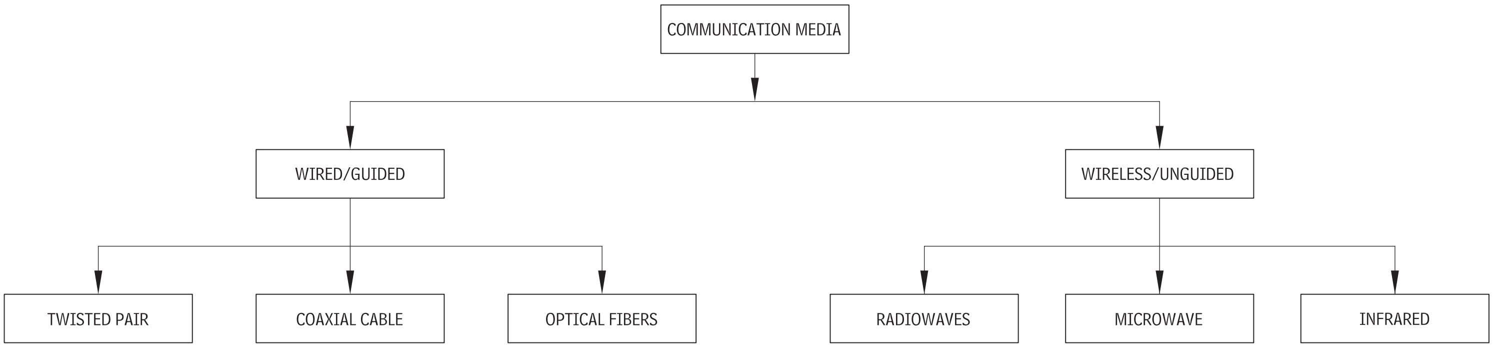
TIA/EIA (Telecommunications Industry Association/Electronics Industry Association) standards should be used to define the minimum architectural requirements for telecommunications spaces. There are three main categories of spaces: service entrances, equipment rooms, and telecommunications rooms. Each of these interrelated space types has a distinct function.

- *Building Service Entrance:* An independent room where voice, data, and video distribution systems enter the building.
- *Equipment Room:* A space dedicated solely to telecommunications systems equipment, such as a voice switching node, backbone network devices, and/or video transmission equipment.
- *Telecommunications Room:* Spaces used to facilitate interconnections between the building backbone (riser) system and stations on a given floor; often located on each floor of a building. These rooms may also be used to house some local electronic equipment.

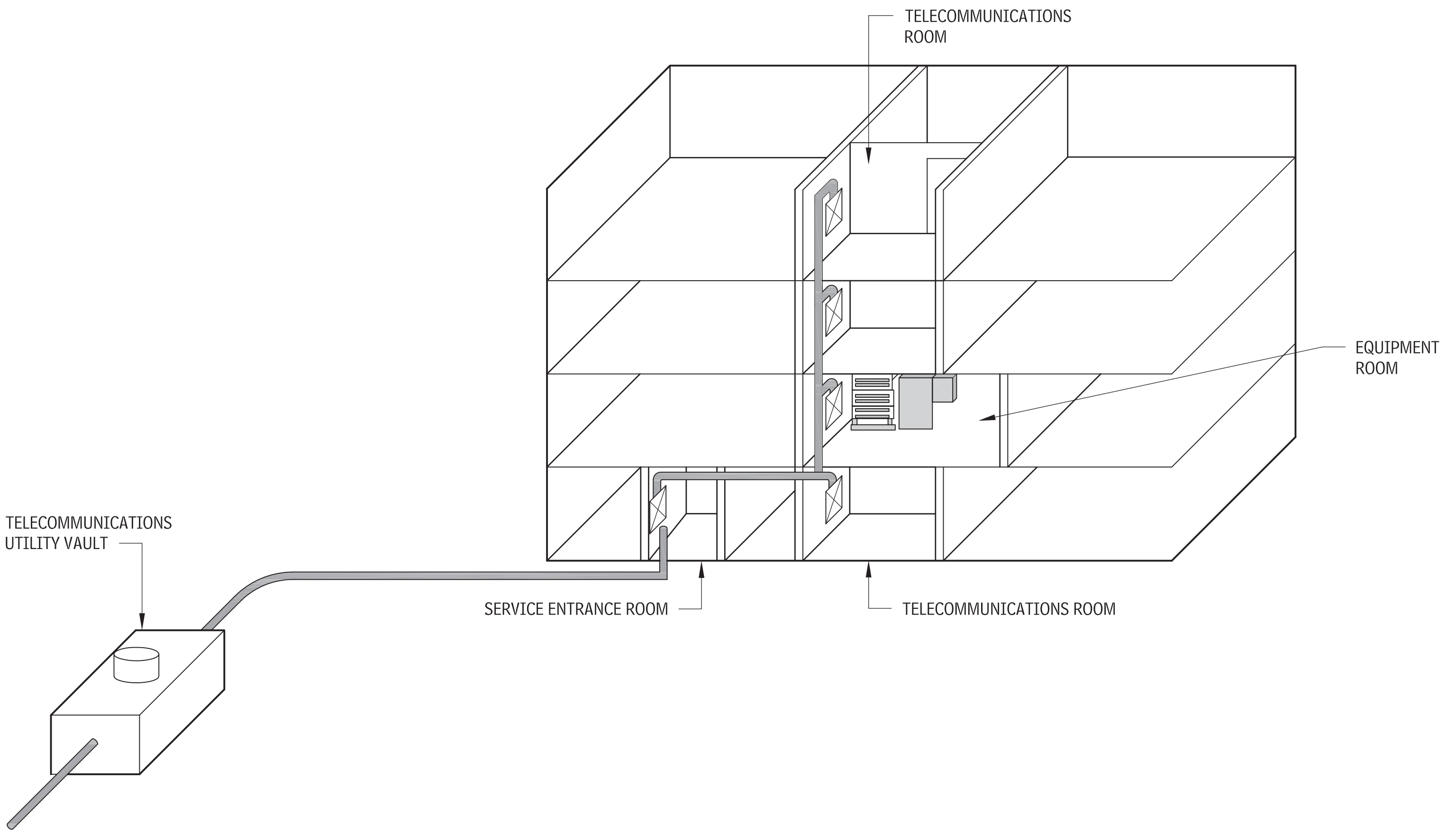
Telecommunications rooms provide the transition points between risers and horizontal cabling and accommodate associated cable termination hardware and transport electronics. Telecommunications rooms should be large enough to accommodate the service area, and meet environmental, lighting, fire protection, security, and cable pathway requirements. Horizontal cabling may not exceed 295 ft. in total length, which will dictate room locations. Carefully managed cable pathways, routing paths to workstations, and ceiling height must be considered for appropriate placement of telecommunications rooms.

Horizontal telecommunications cabling may be routed between telecommunications rooms and workstations via access floors, cellular decks, and ceiling plenums. Access floor distribution facilitates the installation of future cabling as well as the movement of floor boxes and cable feed-throughs to accommodate furniture relocations. Cellular decks provide similar underfloor cable pathways, yet lack the flexibility of relocatable floor boxes. Other distribution approaches include underfloor plenum routing, which requires poke-through fittings for access to workstations, and ceiling routing, which is most appropriate for installations with accessible ceiling plenums.

COMMUNICATION MEDIA OPTIONS
13.177



TELECOMMUNICATIONS SPACES
13.178



TELECOMMUNICATIONS ENTRACE ROOM SPACE REQUIREMENTS
13.179

GROSS BUILDING FLOOR AREA (SQ FT)	MINIMUM ENTRANCE ROOM SIZE
< 5000	4′ × 5′
5000–10,000	5′ × 8′
10,000–30,000	8′ × 8′
30,000–50,000	10′ × 8′
50,000–75,000	12′ × 8′
75,000–125,000	12′ × 12′

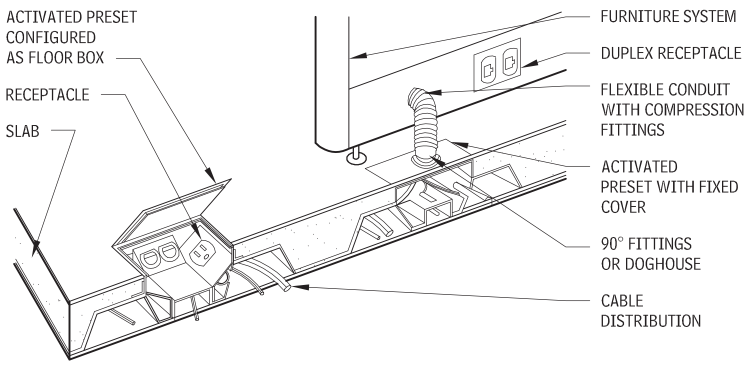
TELECOMMUNICATIONS EQUIPMENT ROOM SPACE REQUIREMENTS
13.180

NUMBER OF WORKSTATIONS	MINIMUM EQUIPMENT ROOM AREA (SQ FT)
Up to 100	150
101 to 400	400
401 to 800	800
801 to 1200	1200

TELECOMMUNICATIONS ROOM REQUIREMENTS
13.181

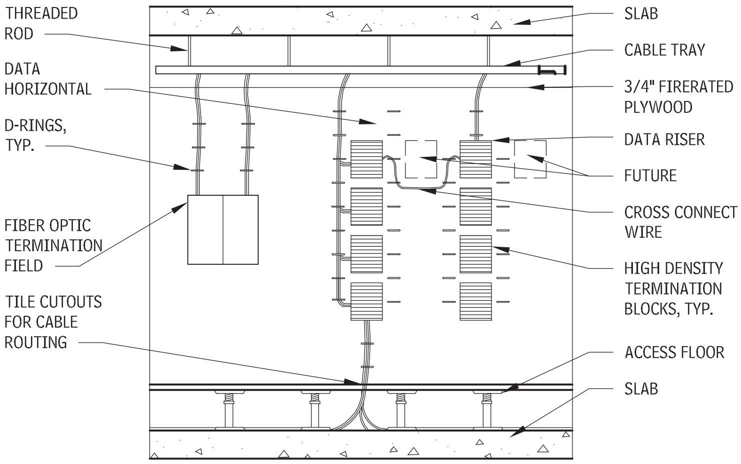
AREA SERVED (SQ FT)	MINIMUM TELECOMMUNICATIONS ROOM FLOOR SIZE
Up to 5000	10′ × 8′
Up to 8000	10′ × 9′
Up to 10,000	10′ × 11′

HORIZONTAL CABLE DISTRIBUTION
13.182

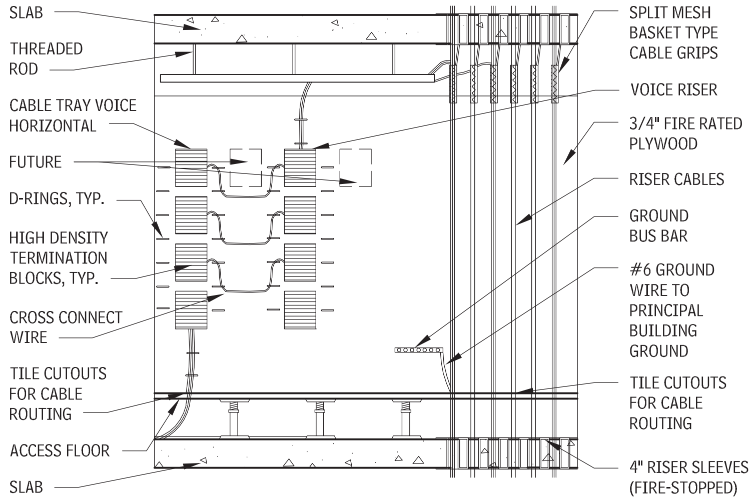


CELLULAR DECKS

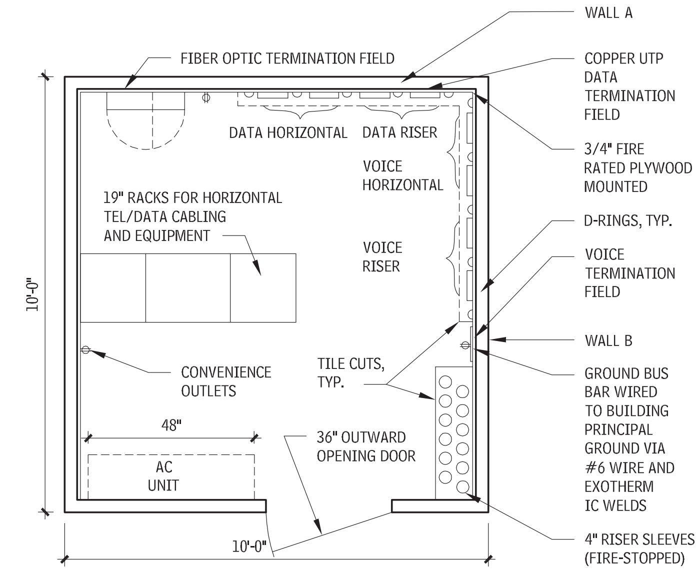
TELECOMMUNICATIONS CLOSET
13.183



ELEVATION A



ELEVATION B



PLAN

LOCAL AREA NETWORKS

A local area network (LAN) interconnects computers within a building. The transmission medium (typically twisted-pair cable or Wi-Fi) is managed within the confines of the building. In contrast, a WAN (wide area network) extends beyond a single building and may involve leased communications elements.

WIRED VERSUS WIRELESS

Key considerations related to a wired LAN include:

- Control, security, reliability, and speed are enhanced by a wired network of connections
- A wired network is relatively cost-effective
- Wire management may be a challenge

Key considerations related to a wireless (Wi-Fi) LAN include:

- Flexibility in device location is enhanced by removing the need for a physical connection point
- Wi-Fi is generally physically neater
- Speeds are typically slower than with wired networks
- Security can be a greater challenge than with defined-connection point networks
- Providing adequate network signal strength can be difficult in some building configurations (and there are no simple rules of thumb for router placement)

Contributors:
Ayush Vaidya, M. Arch, University of Oregon, Eugene, Oregon, with Walter Grondzik, Ball State University, Muncie, Indiana.

BUILDING MANAGEMENT SYSTEMS

Also called building automation systems, a building management system (BMS) provides automated control of some aspect of building operations—typically including HVAC and lighting systems control. Other aspects of building operation may be included in the scope of such a system, including fire detection, security, and access.

Building management systems can be wired, wireless, or hybrid. Control of environmental systems is typically implemented by direct digital controls (DDC). A BMS should provide opportunities for datalogging (trending) and automated fault detection. Such a system would be the foundation for an intelligent building—which could learn from past events as a means of anticipating future actions.

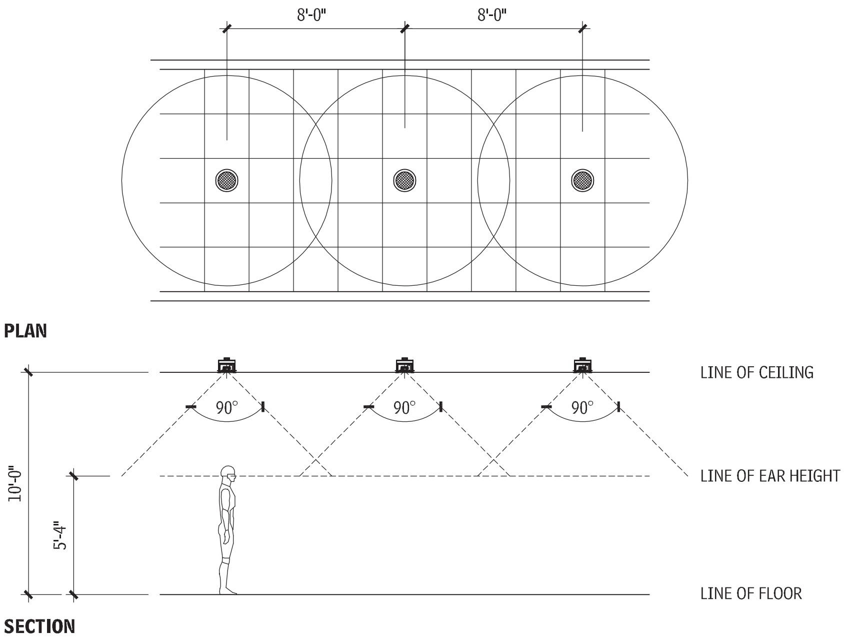
AUDIOVISUAL SYSTEMS

Floor boxes are for shared audiovisual, telecommunications, and electrical (120 VAC) connectivity. Internal audiovisual components (i.e., custom plates and connectors) are furnished and installed by the audiovisual contractor.

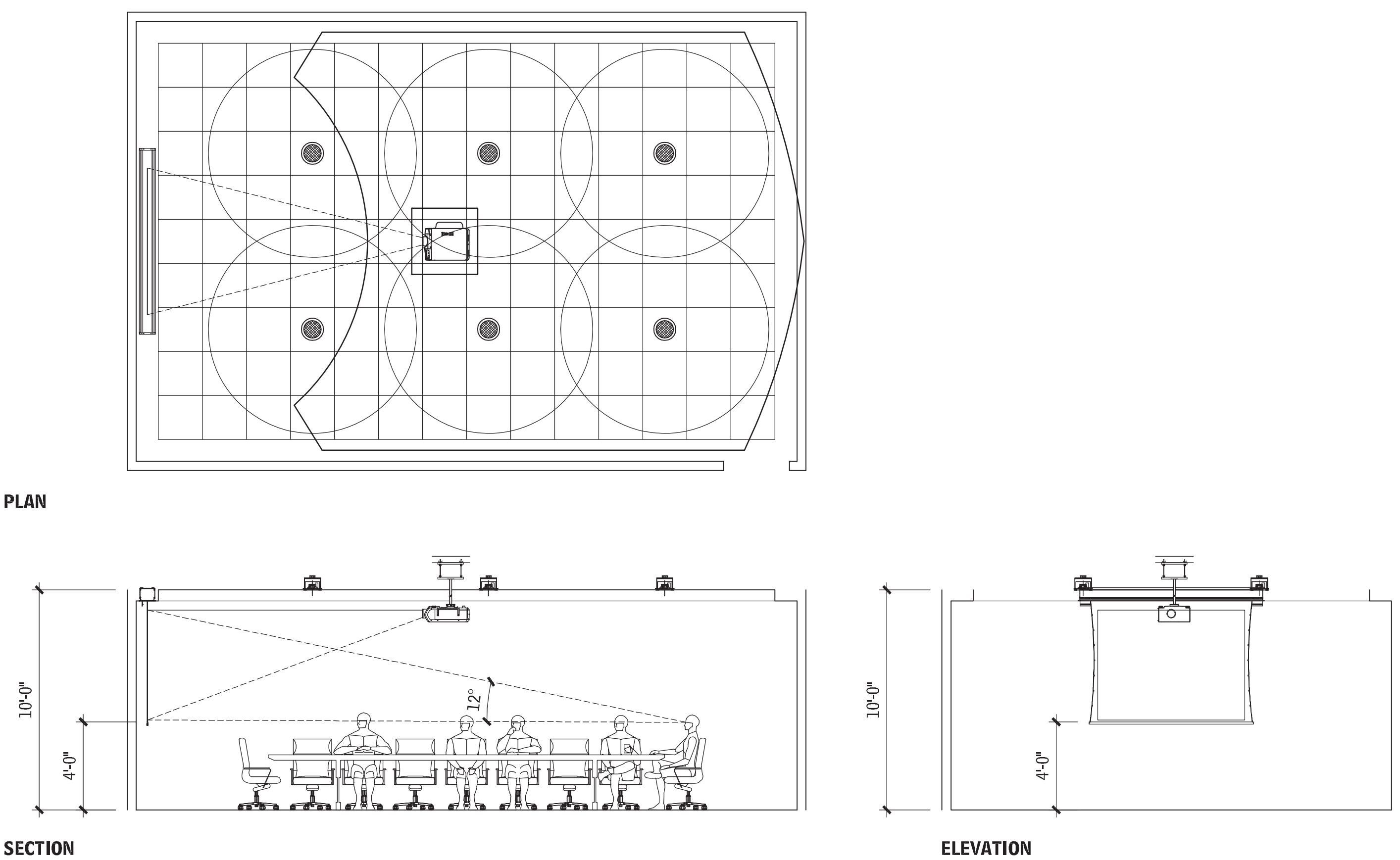
VIDEO SYSTEMS

The major components of a video system are the camera, lens, and mount; lighting system; transmission system; synchronization system; video switching equipment; video recorder; video monitor; and video controller. Digital video systems consist of Internet Protocol (IP) addressable cameras, digital video recorders, network video management systems, monitors, and network video management software. Digital video systems are network-capable, and video can be transmitted across LAN and WAN networks to a centralized location and multiple network workstations.

SPEAKER LAYOUT AND DENSITY
13.184



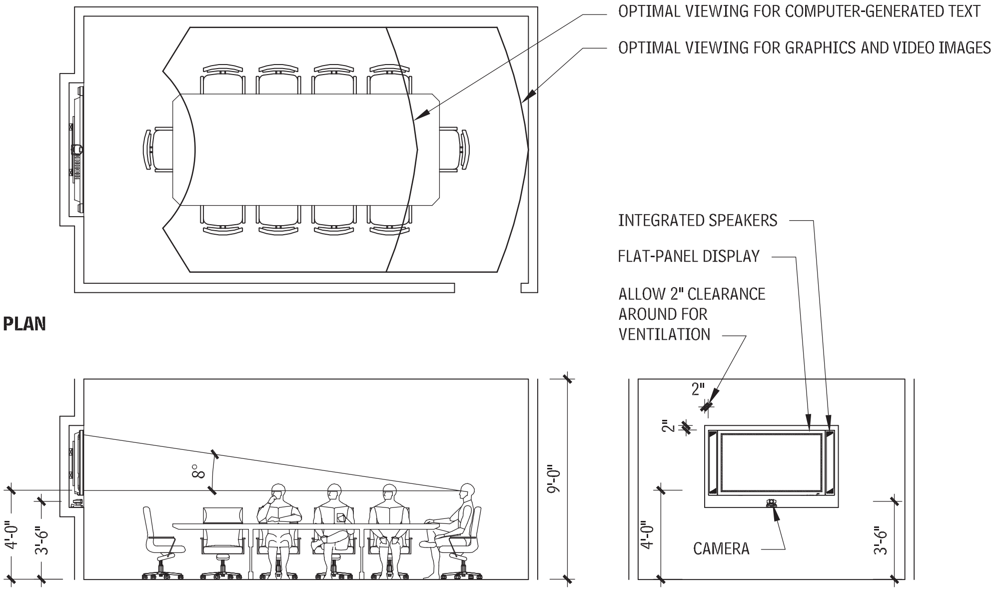
CEILING-MOUNTED PROJECTOR AND SCREEN
13.185



NOTES

13.184 Based on ceiling height and required coverage; lower density for less-critical applications.
13.185 Distance of projector from wall is variable based on screen size and projector/lens selection.

VIDEO TELECONFERENCE COMPONENTS
13.186



PROJECTION SCREENS CHART (MAY BE WALL- OR NICHE-MOUNTED)
13.187

VIDEO (1.33:1) ASPECT RATIO PROJECTION SCREEN SIZES					
DIAGONAL (IN.)	WIDTH (IN.)	HEIGHT (IN.)	MINIMUM VIEWING	MAXIMUM VIEWING COMPUTER VIDEO	MAXIMUM VIEWING COMPOSITE VIDEO
60	48	36	6′–0″	18′–0″	24′–0″
67	53.6	40.2	6′–8″	20′–1″	26′–10″
72	57.6	43.2	7′–2″	21′–7″	28′–10″
84	67.2	50.4	8′–5″	25′–2″	33′–7″
90	72	54	9′–0″	27′–0″	36′–0″
100	80	60	10′–0″	30′–0″	40′–0″
120	96	72	12′–0″	36′–0″	48′–0″
150	120	90	15′–0″	45′–0″	60′–0″
180	144	108	18′–0″	54′–0″	72′–0″
200	160	120	20′–0″	60′–0″	80′–0″

ACCESS CONTROL SYSTEMS

Effective access control systems:

- Cannot be bypassed, but may be zoned and /or scheduled for operation.
- Allow observation by a protective guard force.
- Protect the guard.
- Indicate door status.
- Block passage until access and material control procedures have been performed.
- Provide secondary inspection of those who cannot pass the automated inspection.
- Accommodate peak loads.
- Accommodate vehicles and people.
- Perform access and material control.
- Are under surveillance by a central alarm station.
- Are designed for both entry and exit.
- Are network-capable and can reside on a LAN or WAN.

CARD TECHNOLOGIES

Common card technologies include:

- *Bar code* cards have a series of vertical or horizontal stripes and spaces printed in a manner that represents coded data. The spaces between the stripes are read optically by a photodetector cell.
- *Embossed cards* exhibit pattern codes that are raised or indented in the card's surface and read by their relative position in the card reader.
- *Hollerith cards* have a pattern of small holes punched into the card that presents specific data to the card reader. This card can be read optically or mechanically. The optical reader depends on the light patterns passing through the holes; the mechanical reader uses electric reed, brush, or switch contacts to read the coded patterns.
- *Infrared cards* depend on encoding information with varying density patterns that are read by infrared detectors. The patterns are optically detected and not visible to the human eye.
- *Magnetic slug cards* have magnetic slugs or metal pieces embedded or layered in them; they are read by magnetic sensing devices. Also known as *shim cards*, they are generally limited to a single code, making them most suitable for parking operations.
- *Magnetic stripe cards* have stripes or layers of a magnetic material embedded between layers or on a card's surface in vertical columns or horizontal rows. Areas or patterns on this magnetic material can be magnetized in coded patterns and read by magnetic sensing devices.
- *Optical memory cards* depend on varied transparency densities arranged in rows, columns, or spots. These patterns are read by a system of light sources and photodetectors.
- *Proximity cards* incorporate embedded or laminated resonating frequency (RF) circuits that use electrically tuned circuits that resonate when activated by a transmitter sweeping through the RF range. A receiver picks up the RM and activates the code-deciphering system. Unlike other access cards, the proximity card can be worn or carried and detected at various ranges, depending on the design capabilities of the system.

NOTE

13.186 Keep cameras as close as possible to eye height.

Contributor:
Robert Martino, Shen Milsom & Wilke, Inc., New York, New York.

- *Smart cards* can be either active or passive in design. Active cards contain a lithium power supply for transmission; passive cards are read through powered antennae strategically located. Smart cards can hold a very large amount of data.
- *Watermark magnetic cards* contain small oxide particles physically oriented into zones of varying widths creating an unalterable 10- or 12-digit code number, while leaving another layer of the magnetic stripe available for encoding soft conventional data.
- *Wiegand cards* use magnetically embedded unstable ferromagnetic wires formed in a permanently tensioned helical twist. The wiegand card reader uses a magnetic coil that picks up the flux reversal characteristics of the wires and converts them to binary pulses.

FIRE ALARM SYSTEMS

The simplest fire alarm system is a self-contained, UL-approved residential smoke detector. It senses products of combustion, sounds an alarm, and signals when the battery needs replacement. Most municipalities require the use of smoke detectors in houses, apartments, and motel/hotel rooms. Check local codes for requirements.

More complex systems are needed in buildings where public safety is an issue, such as schools, hospitals, office buildings, and other commercial establishments or institutions. Although there are still applications for small hard-wired and relay-operated alarm signaling systems, the trend is to use microprocessor-based digital multiplex systems that not only signal the presence of a fire but also initiate other measures, including activating fans and dampers for smoke control, closing fire doors and shutters, releasing locked doors, capturing elevators, and transmitting voice messages. Building codes require voice communication in buildings with specific group occupancies. It is also recommended for other large buildings to enhance life safety.

Fire alarm systems can either function alone or be integrated with security and building management functions. Processors and their peripheral equipment are generally located in a manned central command center accessible to firefighters. Depending on the degree of reliability desired, redundancy can be provided in wiring and processors, along with battery backup.

Alarm system control cabinets can be 36 in. wide by 8 in. deep. They must have battery backup, be UL-approved, and conform to NFPA No. 72; they may also require local approval. In small systems where only one cabinet is required, all the functions required of the command center can be incorporated in a cabinet located in the main entrance lobby. In larger systems, remote cabinets are generally located in wiring closets throughout the building and can be programmed to function independently of the central processor, should it fail.

SIGNALING SYSTEM TYPES

Common system types are defined as:

- *Noncoded:* Evacuation signal sounds continuously.
- *Master Coded:* Signal repeats four rounds.
- *Selective Coded:* Same as master coded, except individual and assigned number codes of up to three groups per round.
- *Presignal:* Same as selective coded, except signals sound only at selected areas to prompt investigation. If a hazard is determined, an evacuation signal is initiated by key.
- *Voice:* Direct (by microphone) or automatic prerecorded messages are transmitted over speakers, following an alert signal.

AUDIBLE ALARMS

Audible alarms must have an intensity and frequency that attract the attention of those with partial hearing loss. Such alarms should exceed the prevailing sound level in the space by at least 15 dBA or exceed any maximum sound level with a duration of 60 seconds by 5 dBA, whichever is louder. Sound levels should not exceed 120 dBA.

VISUAL ALARMS

Visual alarm signals should be integrated into the building alarm system. Alarm stations should give both audible and visual signals. Visual alarm signals should have the following characteristics:

- *Lamp:* Xenon strobe type or equivalent.
- *Lamp Color:* Clear or nominal white (i.e., unfiltered or clear filtered white light).
- *Maximum Pulse Duration:* 0.2 sec with a maximum duty cycle of 40 percent. The pulse duration is defined as the time interval between initial and final points of 10 percent of maximum signal.
- *Intensity:* 75 candela minimum.
- *Flash Rate:* 1 Hz minimum, 3 Hz maximum.

Visual alarms are placed 80 in. above the highest floor level within the space or 6 in. below the ceiling, whichever is lower. In any space required to have a visual alarm, generally all areas must be within 50 ft. of the signal (measured horizontally). In large spaces exceeding 100 ft. across with no obstructions over 6 ft. high (such as auditoriums), devices may be spaced a maximum of 100 ft. apart around the perimeter in lieu of suspending devices from the ceiling.

SECURITY SYSTEMS

An interdependent arrangement of physical barriers, technological devices, and response capabilities constitutes a responsive and complete security delivery system.

The physical security components primarily consist of fences, building enclosure elements, interior partitions and doors, and safes and vaults.

The proliferation of electronic security devices and systems, coupled with rapid and substantial advances in the capabilities of these systems, has resulted in a wide array of choices in security technology. To choose effectively among these, architects should understand the principles and applications of crime prevention through environmental design (CPTED), security design, and operational security.

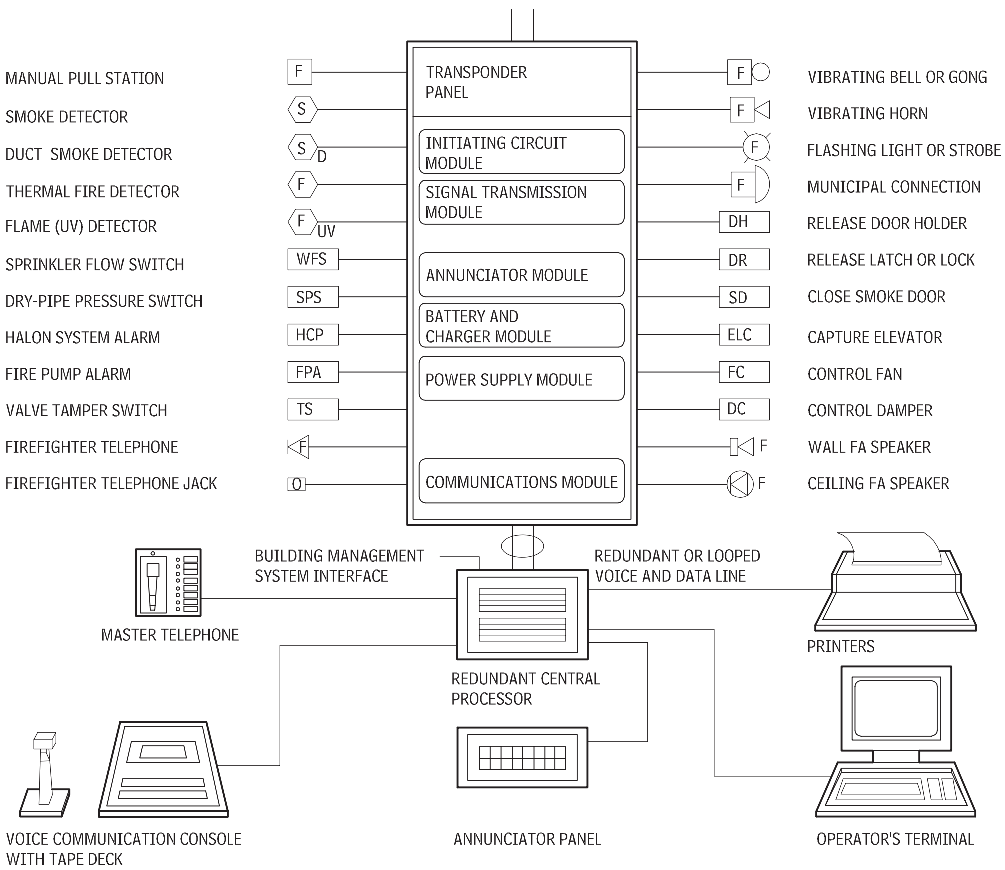
Use of alarmed surveillance systems can greatly reduce property loss. This involves the use of alarms, perimeter protection, and intrusion detection systems. Integrated systems—those that employ the proper procedures, equipment, and people in combination—are the most effective.

In general, the security response capabilities at a particular facility depend on the efforts of the on-site security team. Architects, however, must design buildings that enable security staff to respond efficiently to incidents requiring their action.

SENSOR SECURITY SYSTEMS

Sensor security systems are commonly designed to protect perimeters or to monitor interior space.

ELECTRONIC FIRE ALARM/COMMUNICATION SYSTEM FUNCTION DIAGRAM
13.188



Contributors:
Robert Martino, Shen Milsom & Wilke, Inc., New York, New York; Richard F. Humenn, PE, Joseph R. Loring & Associates, Consulting Engineers, New York, New York; JRS Architect, Mineola, New York.

PERIMETER SENSOR SYSTEMS

Perimeter sensor systems may include the following features:

- Continuous line of detection
- In-depth protection
- Complementary sensors
- Alarm combination
- Priority schemes
- Clear zone
- Site-specific system
- Sensor configuration
- Tamper protection
- Self-test compatibility
- Suitability for physical and environmental conditions
- Integration with video system
- Integration with barrier delay

Physical and environmental conditions that affect exterior sensors include topography, vegetation, wildlife, background noise, climate and weather, and soil and pavement.

Conceptual design of a perimeter sensor system involves identifying targets, defining threats, establishing security requirements, and developing basic security features. Design development requires defining the clear zone surface, determining sensor locations, completing system engineering and specifications, locating perimeter fencing, and designing power and signal distribution. Construction involves procuring materials, performing surveys, installing conduit and wiring, applying surface material, and installing outer fences and sensors. Correct operation requires maintenance, testing, training, and documentation.

INTERIOR DETECTION SYSTEMS

Interior detection systems offer in-depth protection, detect intruders in time for adequate response, detect tampering, and are able to self-test. To be effective, however, they must be properly located, installed, and maintained.

TYPES OF SENSORS AND CONDITIONS OF USE

Descriptions of the most common types of sensors follow. Environmental conditions that affect interior sensors include electromagnetic energy, nuclear radiation, acoustic energy, thermal energy, optical effects, seismic phenomena, and meteorological conditions.

- *Ultrasonic motion detectors* are used when air turbulence is low and when there are external noise sources that could affect a motion detector radiating energy outside of the protected area. Use low-frequency detectors where audible noise is not objectionable.
- *Microwave motion detectors* are used when air turbulence is present in the protected room and when there are no potential false alarm sources outside of the room and in the field of the detector.
- *Passive infrared detectors* are used when air turbulence is present in an area or at a point to be protected. Temperature changes do not affect this type of device, but abrupt changes in light level may cause false alarms.
- *Detectors for room boundaries* are used to give the earliest possible warning of an intrusion. They are used only in conjunction with space detectors for the interior of a room; vibration detectors, acoustic detectors, break beams, magnetic reed switches, and breakwires are suggested.
- *Multiple space detectors* are used jointly when detectors are not affected in the same measure by external noise sources and to reduce false alarms while still maintaining a reasonable probability of detection. Multiple space detectors are used singly when one type of detector can protect one part of a room and another detector can protect another part of a room because external noise sources are specifically located.
- *Vibration detectors* are used when air turbulence, acoustic noises, and motion outside the room are present. These devices are best suited to protecting room boundaries from penetration by drilling or hammering.
- *Acoustic detectors* are used when light air turbulence, vibration, and motion are present outside the room. These devices are most effective in protecting room boundaries from penetration by drilling or hammering.
- *Thermal detectors* are used to detect temperature rises in small enclosures such as vaults (as when an intruder uses a torch or burning bar to gain entrance). This device would normally be used in a system that includes other types of intrusion detectors.

Contributor:
Robert Martino, Shen Milsom & Wilke, Inc., New York, New York.

ELEMENT E: EQUIPMENT AND FURNISHINGS

14

EQUIPMENT

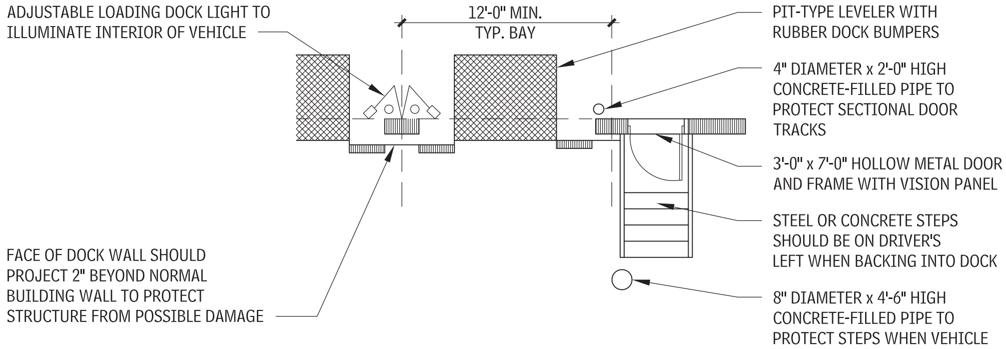
VEHICULAR AND PEDESTRIAN EQUIPMENT

VEHICULAR DETERRENT AND SITE SECURITY BARRIERS

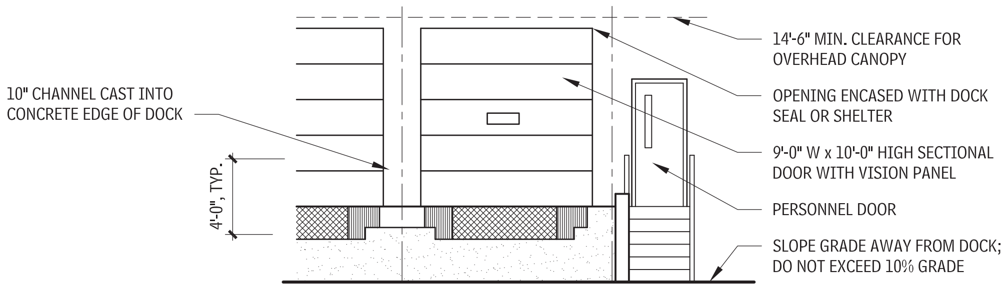
Vehicular security walls include different types of construction, depending on the vehicle size and velocity or anticipated velocity of the vehicle. The U.S. Department of State has developed K Ratings for vehicles by size and velocity to determine criteria by which to construct walls, bollards, or other devices that will prevent a vehicle from penetrating those devices or walls.

LOADING DOCK EQUIPMENT

TYPICAL LOADING DOCK BAY
14.1

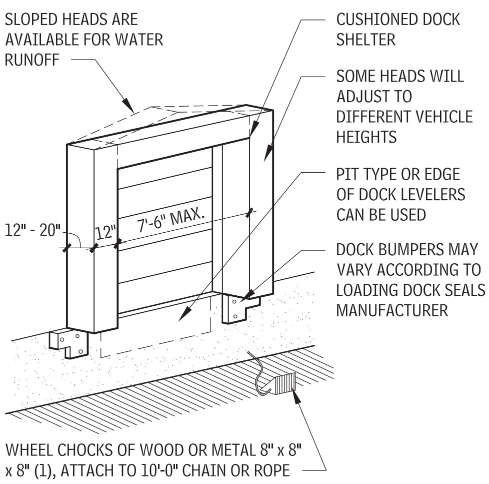


PLAN

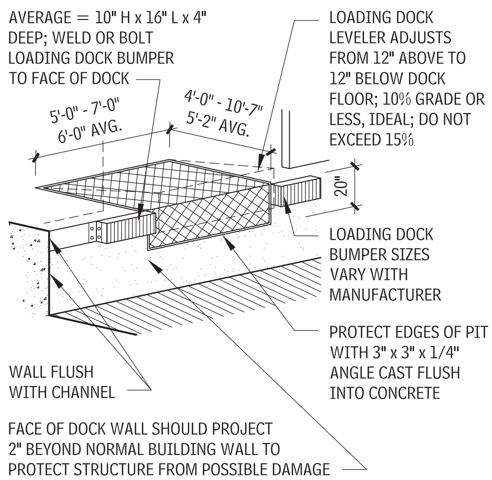


ELEVATION

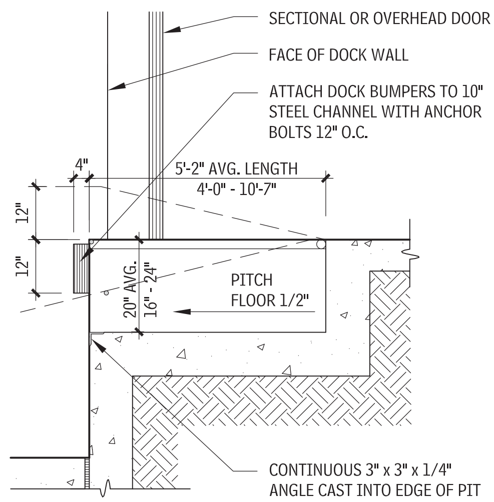
CUSHIONED DOCK SHELTER
14.2



PIT-TYPE DOCK LEVELER
14.3



SILL FOR PIT LEVELER
14.4

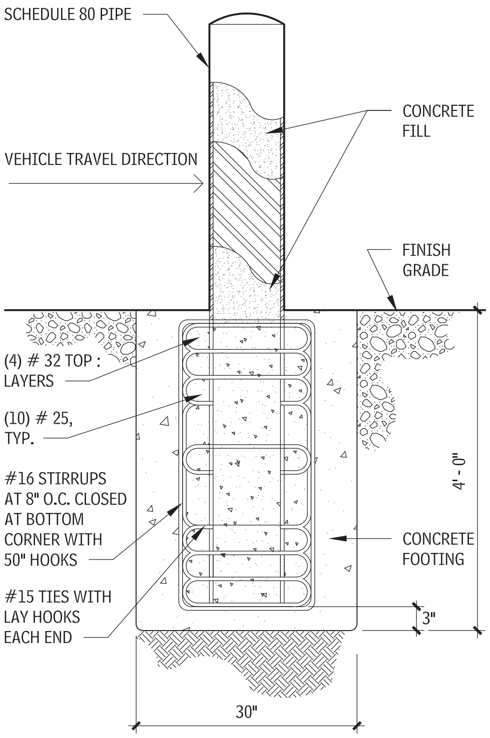


NOTES

14.1 Dock height will vary depending upon the type of truck that will use the facility.
14.2 a. A cushioned dock shelter provides a positive weather seal; protects the dock from wind, rain, snow, and dirt. It also retains a constant temperature between dock and vehicle.
b. Many different types of dock shelters are available.
14.3 a. Dock levelers may be automatic or manually operated, where incoming vehicle heights vary widely.
b. Recessed levelers must be installed in a concrete pit.
c. Levelers vary by manufacturer; contact manufacturer for available dimensions and capacity.

There are several manufacturers of equipment made for operational, movable vehicle arrest devices that can be placed at loading docks, driveways, or entrances to parking areas. These devices are tested by special testing laboratories and witnessed by the U.S. Department of State or other federal officials and then certified for use. Similar to the security criteria mentioned previously, the specific site or building must be assessed for security program and security requirements. As a result of those requirements being developed and agreed to, and if warranted, vehicular arrest devices, wall construction, or similar equipment may be necessary for the site or building perimeter. A typical detail for fixed bollards is shown in Figure 14.5. Although not common, the vehicular arrest device construction may be used in conjunction with a chain linked or other type of wall to prevent and/or deter both pedestrian and vehicular access to a site. Another option to the vehicular bollards or concrete wall construction is the use of two or three steel cables, approximately 1-in. diameter, mounted to "dead-men" (concrete or steel fence post) just behind a pedestrian-type fence. The cable assembly with the dead-men will prevent certain sized vehicles at certain velocities from gaining access to the site, and may provide a more pleasing aesthetic appearance.

VEHICULAR DETERRENT BOLLARD DETAIL
14.5



SITE SECURITY BARRIERS

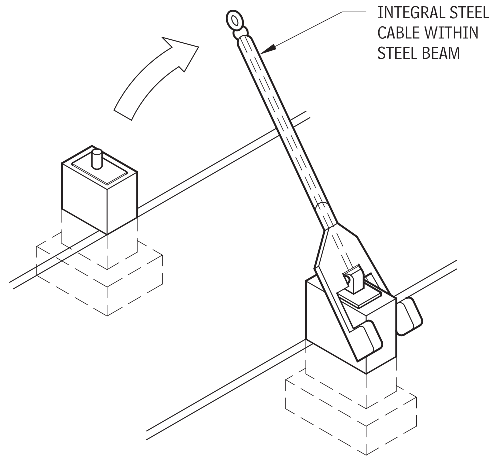
Consistent with the philosophy of crime prevention through environmental design (CPTED), architects use a combination of design and operational tools to address projects requiring site security. These tools include access control of pedestrians on the site, natural and mechanical surveillance of occupants of the property, and clear definition of public and private space through a combination of real and symbolic barriers.

When terrorism, workplace violence, or street crime is possible on a site, the U.S. General Services Administration recommends the following for all government buildings:

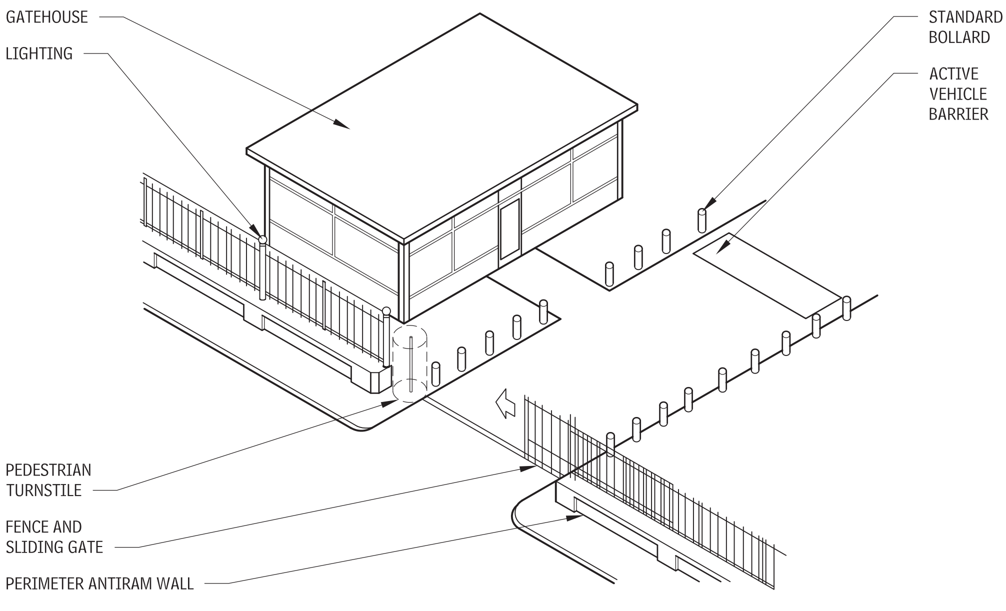
- Eliminate potential hiding places near the facility.
- Provide an unobstructed view around the facility.
- Place the facility within view of other occupied facilities.
- Locate assets stored on-site but outside the facility within view of occupied rooms in the facility.
- Minimize the signage or indication of assets on the property.
- Set the facility a minimum of 100 ft. from the facility boundary, if possible.
- Eliminate lines of approach perpendicular to the building.
- Minimize the number of vehicle access points.
- Eliminate or strictly control parking beneath facilities.
- Locate parking as far from the building as practical, while accommodating accessibility requirements for parking spaces and their proximity to the building. Place parking within view of occupied rooms or facilities.
- Illuminate the exterior of the building and/or exterior sites where assets are located.
- Secure access to power/heat plants, gas mains, water supplies, and electrical and phone service.
- Design elements commonly used to create real and symbolic barriers to increase site security include bollards/planters, curbs, vehicle barriers, gates, security lighting, and signage.

Active barriers at access/egress points in high-security areas should be fully engaged until vehicles are cleared for passage. A visible signal light or drop arm should indicate the status of the barrier to approaching vehicles. Operating time should not exceed three to four seconds. In case of power failure, the barrier system must be capable of maintaining its position to prevent access but be capable of manual operation; it also should be connected to emergency power. Remote controls should include a status indicator.

CABLE CRASH BEAM
14.7



SECURITY CONTROL
14.6



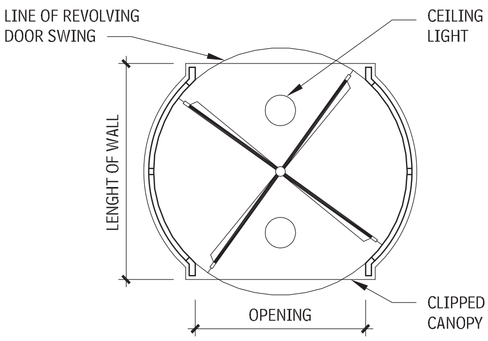
REVOLVING DOORS

These are points to consider when working with revolving doors:

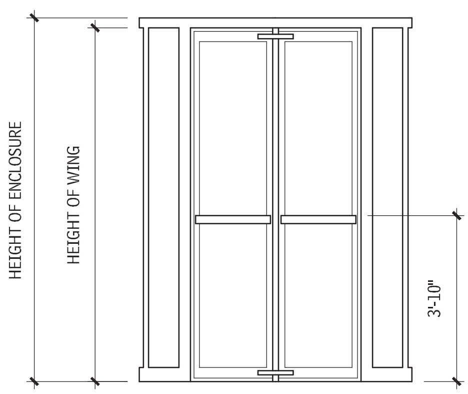
- Circular glass enclosure walls may be annealed 1/4-in. glass. However, this varies with different government bodies. Some jurisdictions require laminated glass. Tempered glass is not available for this use. Refer to the Consumer Products Safety Commission's standards for glazing.
- Practical capacity equals 25 to 35 people per minute.
- Doors fabricated from stainless steel, aluminum, or bronze sections are available. Stainless steel is the most durable; lead times vary with construction techniques. Stainless steel is available in a number of satin and polished finishes. Aluminum is the most common and economical. It is available in anodized or painted finishes. Bronze is most difficult to maintain; satin, polished, or statuary finishes must have a protective lacquer coating. Doors are available with only top and bottom stiles to be used with all-glass storefront doors. Wall enclosures may be all metal, all glass, partial glass, or housed-in construction.
- Optional heating and cooling source should be placed immediately adjacent to the enclosure.
- For general planning, use 6-ft-6-in. diameter. For hotels, department stores, airports, or other large traffic areas, use 7-ft or greater diameter.
- Codes may allow 50 percent of legal exiting requirements by means of revolving doors. Some do not credit any, and require hinged doors adjacent to revolving doors. Verify with local authorities.

Swing doors may be required in addition to revolving doors by code or for good practice to provide egress, to meet accessibility requirements, or for off-hours security operation.

TYPICAL REVOLVING DOOR
14.8



PLAN

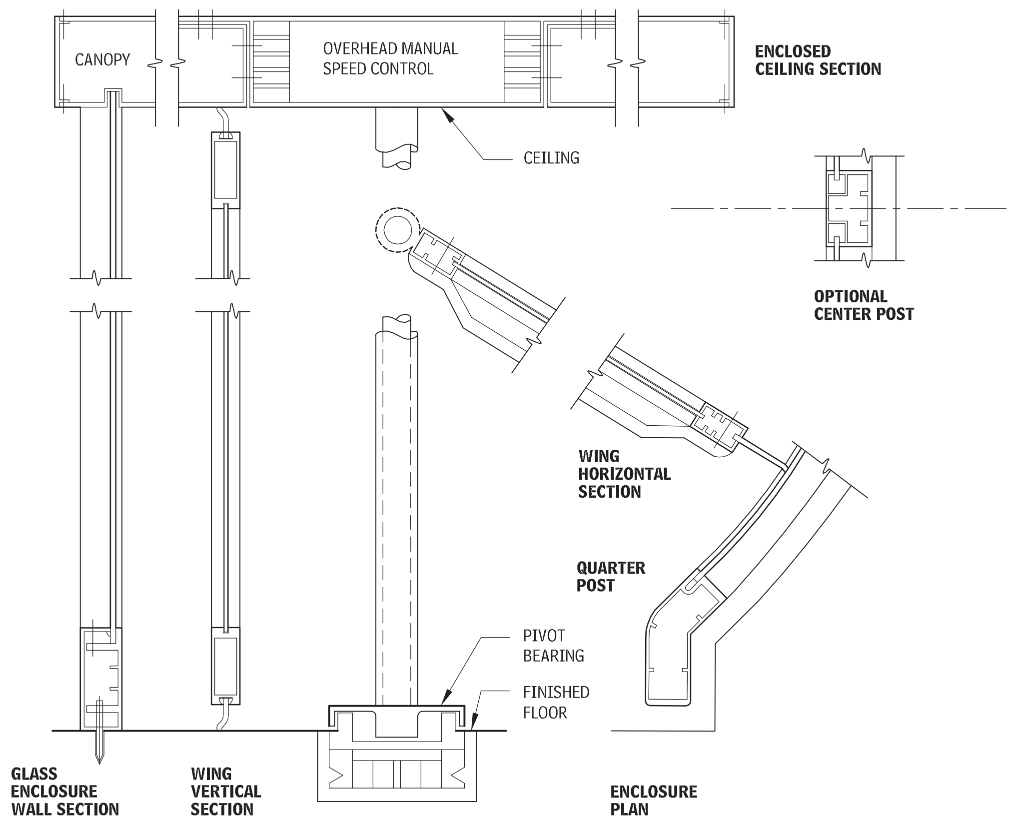


ELEVATION

REVOLVING DOOR ENCLOSURE DIMENSIONS
14.9

DIAMETER	OPENING FOUR-WING	OPENING THREE-WING	WALL LENGTH FOUR-WING	WALL LENGTH THREE-WING	RECOMMENDED MAXIMUM HEIGHT
6′–0″	4′–1″		4′–7–5/8″		10′–0″
6′–2″	4′–2–1/2″		4′–9–1/8″		9′–10″
6′–4″	4′–3–7/8″		4′–10–1/2″		9′–8″
*6′–6″	*4′–5–1/4″	3′–1/4″	*4′–11–7/8″	6′–1/4″	9′–6″
6′–8″	4′–6–5/8″	3′–1–1/4″	5′–1–1/4″	6′–2–1/32″	9′–4″
6′–10″	4′–8–1/8″	3′–2–1/4″	5′–1–1/4″	6′–3–3/4″	9′–2″
*7′–0″	4′–9–1/2″	*3′–3–1/4″	5′–4–1/8″	*6′–5–1/2″	9′–0″
7′–6″	5′–1–3/4″	3′–6–1/4″	5′–8–3/4″	6′–10–11/16″	8′–6″
8′–0″	5′–6″	3′–9–1/4″	6′–5/8″	7′–3–7/8″	8′–0″
9′–0″		4′–3/4″		8′–2–1/8″	8′–0″
10′–0″		4′–9–1/4″		9′–9/16″	8′–0″
14′–0″	9′–8–7/8″	6′–9–1/4″	10′–3–1/4″	12′–6–1/8″	8′–0″
16′–0″	11′–1–7/8″	7′–9–1/4″	11′–8–1/4″	14′–2–7/8″	8′–0″

TYPICAL DOOR DETAILS
14.10



NOTE

14.8 * = Standard sizes

COMMERCIAL EQUIPMENT

MERCANTILE EQUIPMENT

VENDING EQUIPMENT

Illustrated in Figures 14.11 through 14.13 are the most common food and beverage vending machine styles, whose sizes vary with total capacity.

Service access of machines is generally from the front, although some cigarette machines require access from the top. Front clearance of 5 ft. is preferred for machines. If machines are located in dedicated rooms, a double door or a door larger than 3 ft. wide is preferred for vending machine transport and installation.

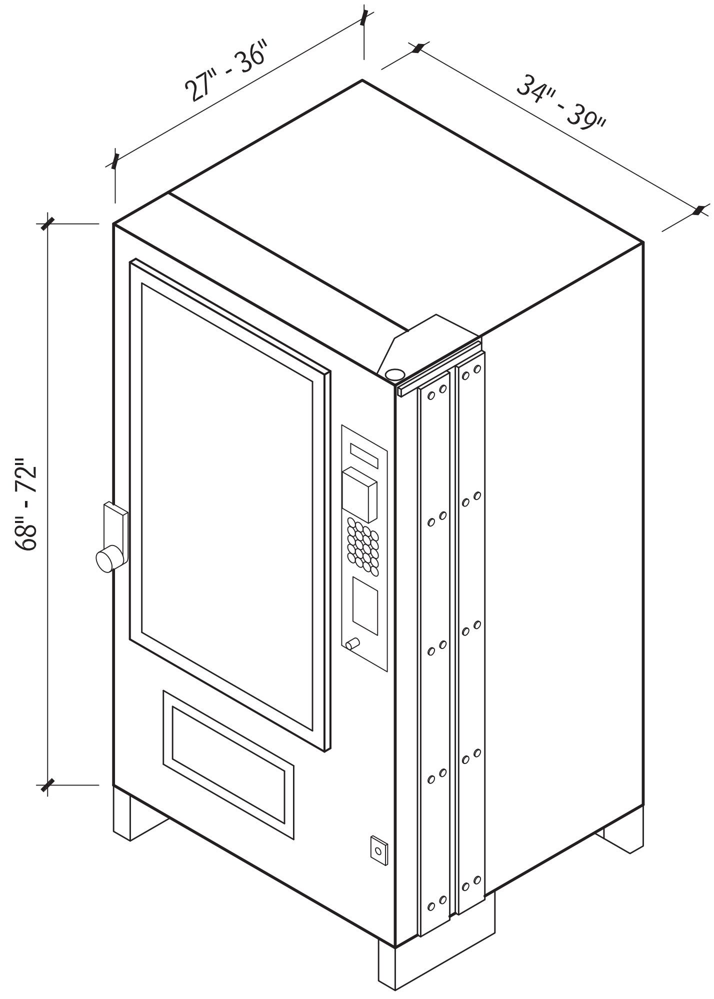
Hot water is not required, but some beverage units require a cold water supply with a shutoff valve. Typically, overflow waste collects into an internal tray. Refrigerated vending machines and microwave ovens require a rear wall clearance of up to 8 in., to permit cooling. Electric service is usually 120 volt and a separate circuit for each machine is preferred. Amperages vary widely from 2 to 20 A.

A wide range of vending equipment is available and generally custom-fabricated to meet specific requirements. Consult manufacturers of vending equipment for special applications; be sure to consult applicable codes, standards, and regulations for accessibility requirements.

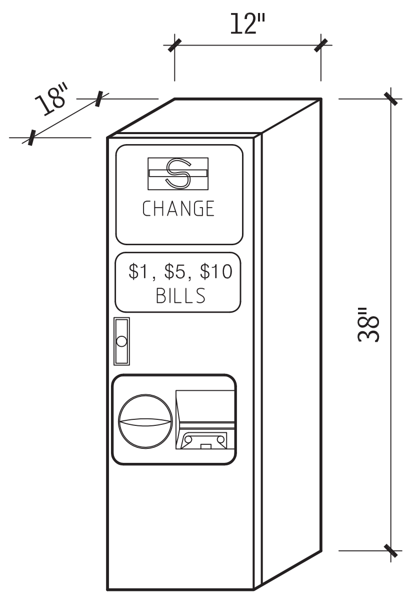
COMMON VENDING MACHINE TYPES
14.11

TYPE	CONTENTS	ELECTRICAL	WEIGHT, LB
Money changer	$1, $10, $20; 2,000 bills	115 V	180 net
Candy/snack	50 selections, 700 items	115 V, 3 A	500 net
Cold drinks	8 selections, 350 cans	115 V, 10 A	650 net
Hot drinks	50 selections, 900 cups	115 V, 20 A	600 net
Refrigerated food carousel	11 shelves, 150 products	115 V, 16 A	800 net
Microwave	8 cu ft.	115 V, 15 A	40 net

COMMON VENDING MACHINES
14.12



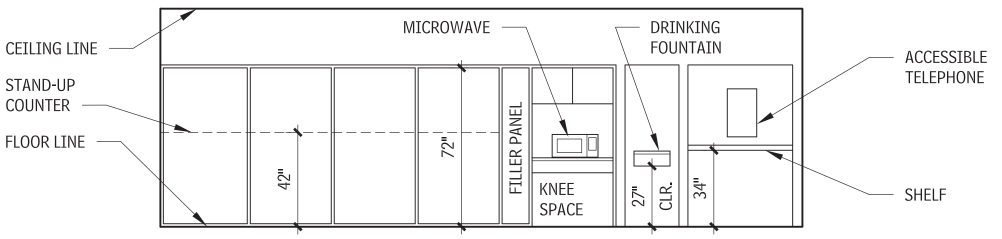
VENDING MACHINE (AXONOMETRIC)



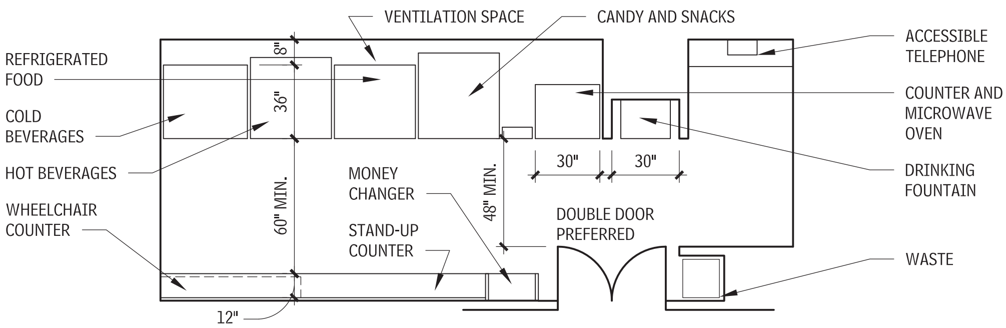
MONEY CHANGER

Contributor:
Jane Hansen, AIA, DeStefano + Partners, Chicago, Illinois.

VENDING MACHINE ROOM
14.13



ELEVATION



PLAN

CHECKROOM EQUIPMENT

DESIGN CONSIDERATIONS

Checkrooms should be adjacent to and have line-of-sight interaction with a lobby or circulation path between building entry and destination (auditorium, gallery, etc.). Provide ample space for orderly queuing out of the main circulation pathways. This is of particular importance in theaters, concert halls, and similar audience facilities where check-in and checkout of massive numbers of people occur in a very compressed period of time. In galleries, museums, and restaurants, traffic is more evenly dispersed, resulting in a diminished need for queuing space and a smaller staffing requirement for the checkroom itself.

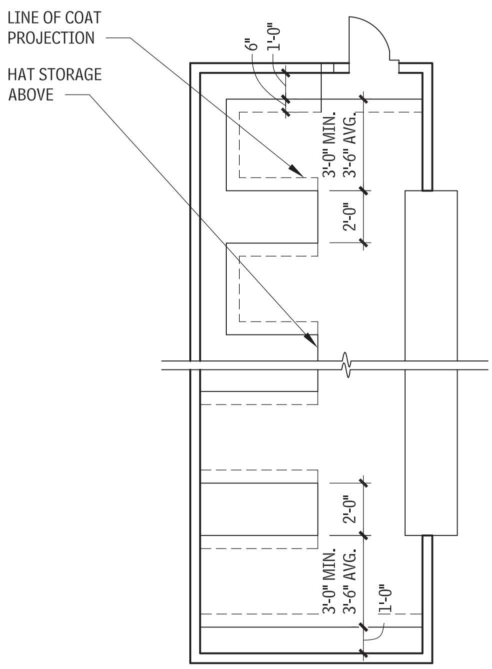
For general planning purposes, allow between 1–1/8 and 1–1/2 in. of rack space per garment, depending on climate. Allow for storage of hats, umbrellas, briefcases, and packages. Most conventional checkroom racks contain overhead shelves to permit accessories to be stored with the coat. For ease of access, shelves should not extend above 6 ft-8 in.

For small to medium-sized facilities, conventional checkrooms are adequate. In large facilities however, where hundreds of garments will be accommodated, consider the use of automated conveyor equipment. These systems conserve space and time by eliminating access aisles and the need to search for garments.

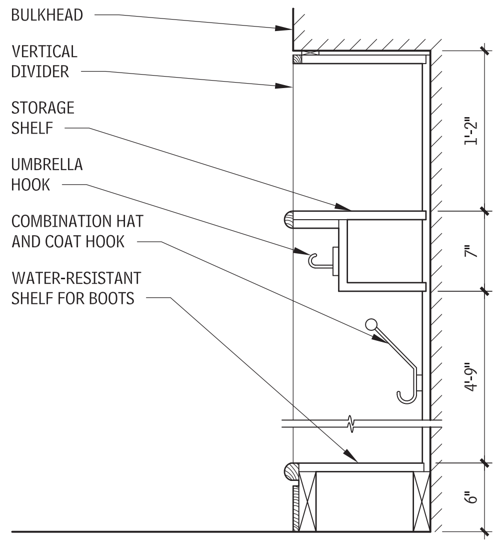
CHECKROOM AREA REQUIREMENTS
14.14

CAPACITY	AREA, CONVENTIONAL	AREA, AUTOMATED
100	75	N.A
200	140	100
300	200	130
400	240	150
500	310	180
1000	575	320
1500	760	460
2000	1025	600

CONVENTIONAL CHECKROOM
14.15



CHECKROOM RACK
14.16



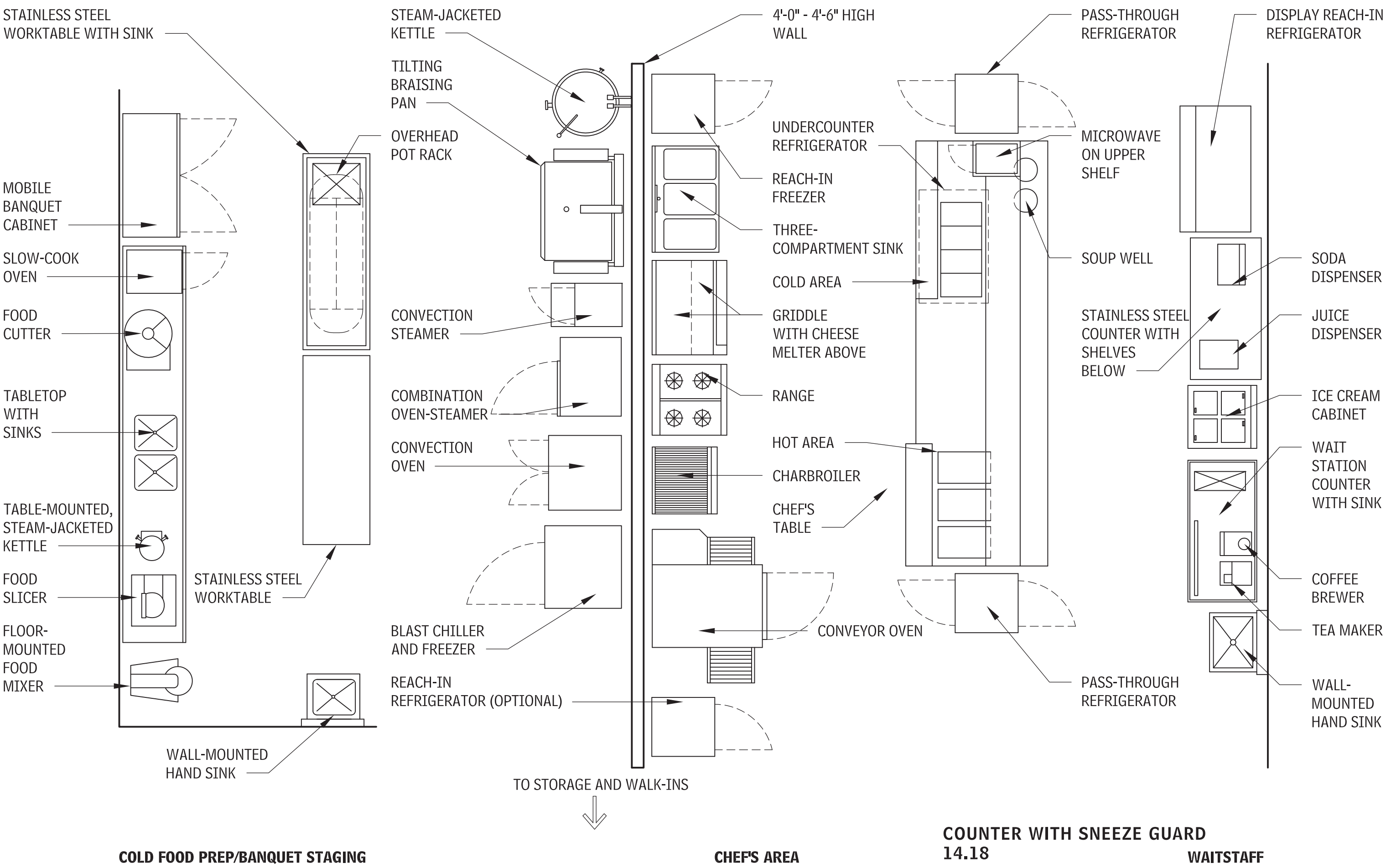
COMMERCIAL FOOD SERVICE EQUIPMENT

Food service equipment is typically specified by the food service consultant. All food service equipment must meet the sanitation and construction standards of the National Sanitation Foundation (NSF), an independent nonprofit organization dealing with public health issues. Most equipment is located in the "back of the house," however, some food-serving display units, such as salad bars, may be located in the public dining areas. Sneeze guards are required at open food displays, and refrigeration is required to store and serve perishable food.

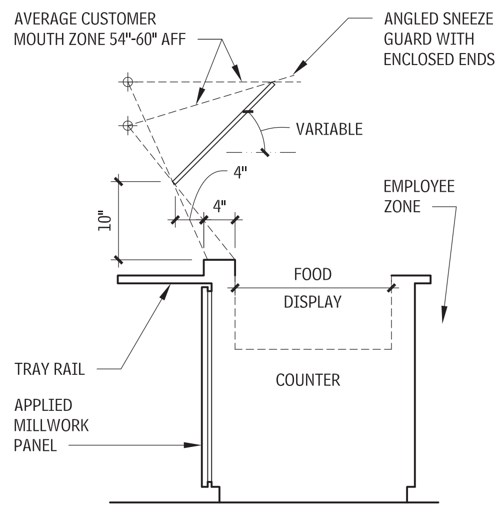
Exhaust hoods remove air, water and grease vapor, and food odors from the kitchen and dishwashing areas. Ovens and steam-jacketed kettles only require hoods that remove air, heat, and water vapor. If large amounts of grease from a broiler, char-broiler, fryer, or grill are present, the hood system must extract this pollutant before the air is drawn outside by fans. This is done with grease "cartridges" or with stainless steel extractors, both of which blow the exhausted air around violently. The grease particles are collected in a trough for easy removal or are run down a drain. If a water-wash hood is used, the drain must tie into a grease trap. Hood requirements are as follows:

- The length of the hood and the equipment types underneath determines CFM requirements for exhaust hoods. Typical requirements range from 150 to 450 CFM per linear foot of hood.
- Some codes may require a higher exhaust rate. To make up this air differential and to prevent more air from being drawn from surrounding areas, introduce air through a supply duct. The supplied air should make up 50 to 85 percent of the total exhaust.

COMMERCIAL KITCHEN PLAN
14.17

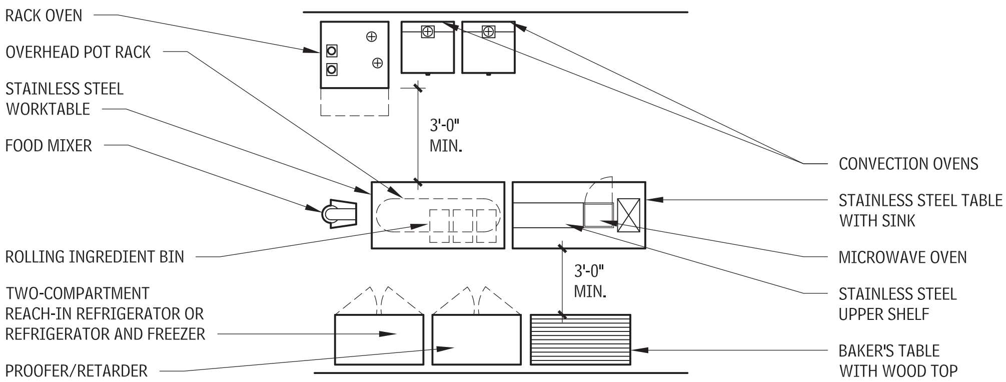


COUNTER WITH SNEEZE GUARD
14.18



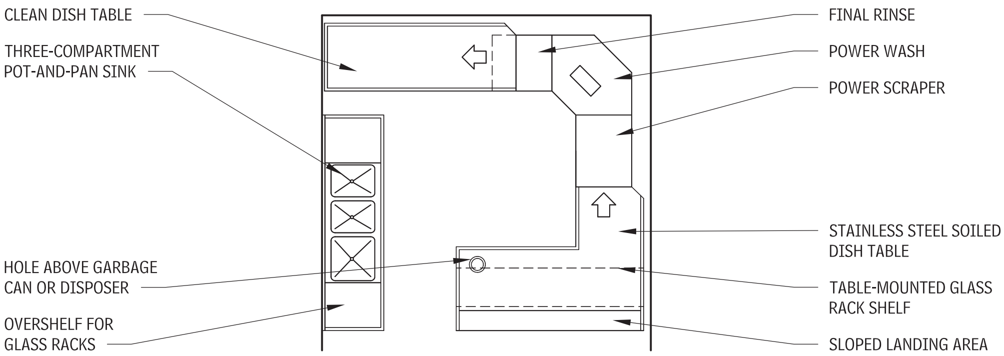
BAKERY EQUIPMENT

BAKERY AREA PLAN
14.19



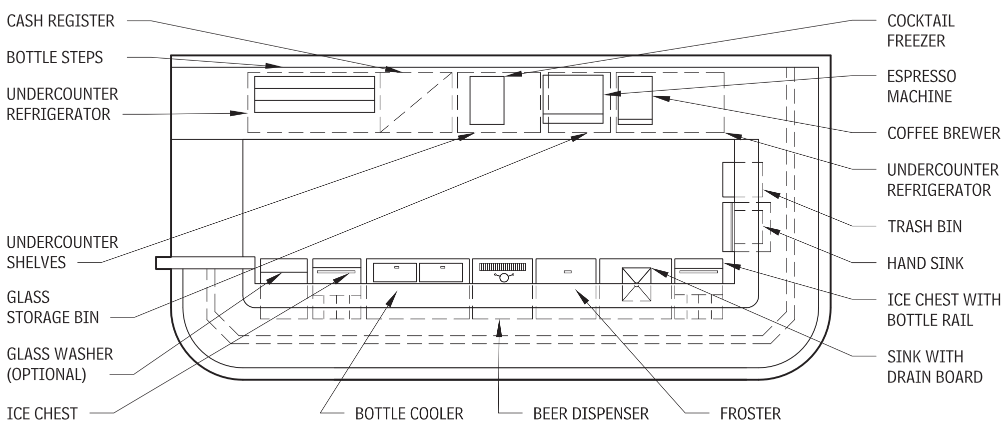
DISHWASHING EQUIPMENT

COMMERCIAL DISHWASHING AREA
14.20



COMMERCIAL BAR EQUIPMENT

BAR EQUIPMENT LAYOUT
14.21



Contributors:
Tim Shea, AIA, Richard Meier & Partners, Los Angeles, California; Ji-Seong Yun, Rhode Island School of Design, Providence, Rhode Island; Jim Johnson, Wrightson, Johnson, Haddon & Williams, Inc., Dallas, Texas; Janet B. Rankin, AIA, Rippeteau Architects, Washington, DC; Cini-Little International, Inc., Food Service Consultants, Washington, DC; Henry Grossbard & Cody Hicks, Post & Grossbard, Inc., Piermont, New York.

DETECTION EQUIPMENT

The security of the nation's public facilities, such as schools, airports, and courthouses, has taken on an increased importance. The National Institute of Justice (NIJ) has developed standards in the area of such detection devices, which outline requirements for system performance, including operator interface and/or controls, test objects, electromagnetic compatibility, and safety.

Consult the following reference:

- National Institute of Justice Standards, www.nlectc.org.

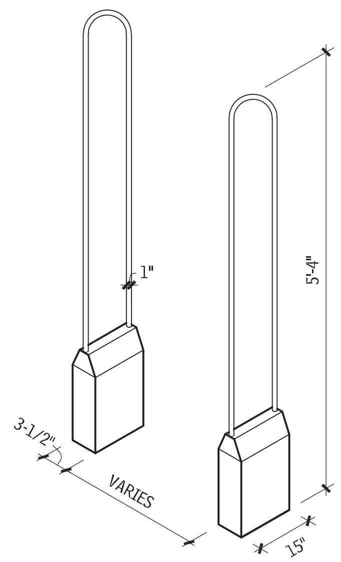
METAL DETECTORS

Among the most commonly used contraband-detection devices in public facilities is the walk-through metal detector. These detectors are available in a wide range of configurations and sizes, to meet a wide range of requirements. Refer to applicable codes, standards, and regulations for accessibility requirements.

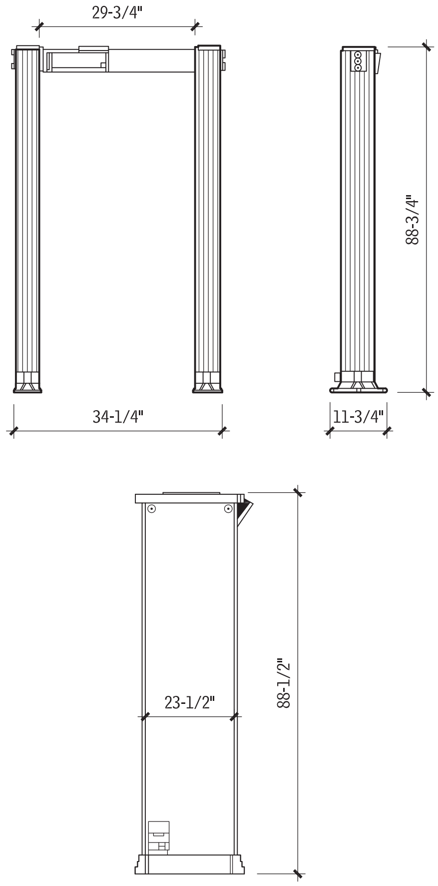
ELECTRONIC ARTICLE SURVEILLANCE DEVICES

Electronic article surveillance (EAS) devices are anti-shoplifting systems used to protect merchandise, libraries, and similar retail installations. Such systems include an antenna and tags and/or labels. Units are configured based on signal strength, and multiple units can be ganged to effectively protect any exit configuration. When purchases are registered, tags are either removed or passed over a deactivation pad. In some cases, deactivation is achieved by installation of a wire loop device beneath the counter.

OPEN-FRAME EAS SYSTEM
14.23



WALK-THROUGH METAL DETECTORS
14.22



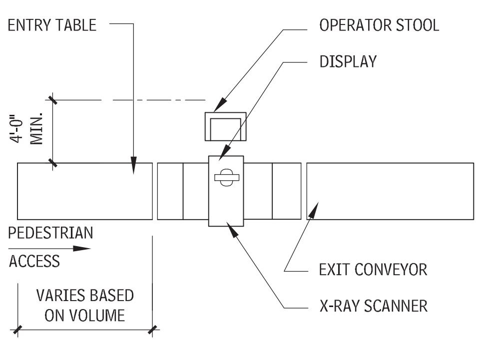
X-RAY SCANNING EQUIPMENT

X-ray machines and scanners are being installed increasingly more frequently in airports, government buildings, mailrooms, and security-sensitive areas, for scanning letters, small parcels, briefcases, and baggage. This equipment ranges from very compact, self-contained tabletop or floor-standing units to conveyorized screening equipment used in airports, cargo terminals, and the like. These units can weigh up to 2,000 lbs.

When considering larger equipment, carefully examine transport routes, to ensure adequate clearances for equipment delivery and staging. Refer to manufacturers' literature for electromechanical requirements.

X-RAY SCANNER CONFIGURATION
14.24

Configurations of entry tables, exit conveyors, and operator stool(s) are project- and volume-specific. Units are available with remote operator display capability.



PLAN

INSTITUTIONAL EQUIPMENT

MEDICAL EQUIPMENT

GENERAL ACUTE CARE

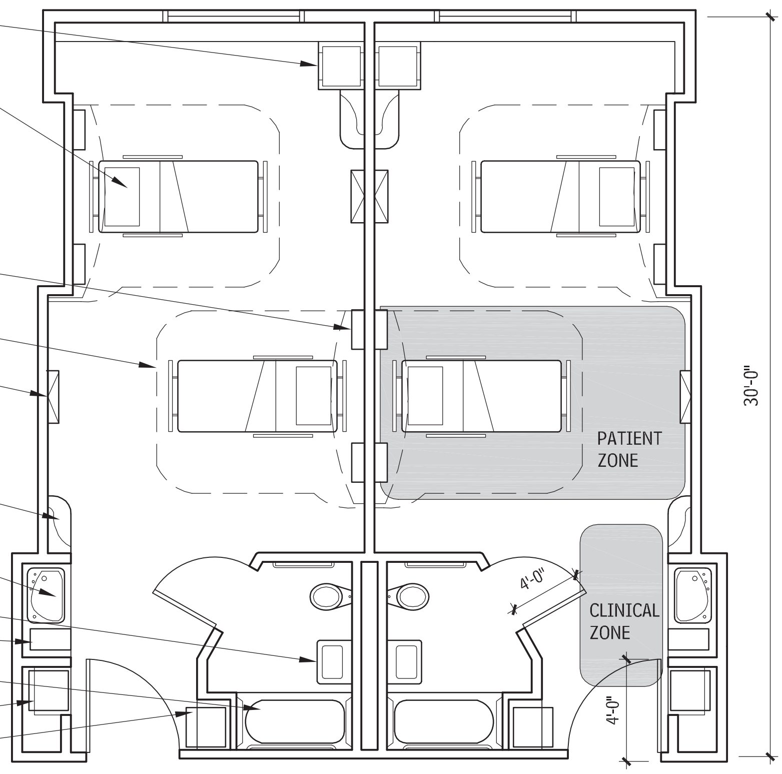
Patient rooms must be accessible, easy to maintain, and spacious enough to contain high-tech life-support and monitoring equipment. Entry doors should be a minimum of 48 in. wide. A clear area of 48 in. should be maintained at the foot of patient beds.

Equip patient rooms with basic amenities such as a patient chair, visitor chair, television set (VCR and computer with Internet access, optional), wardrobe for full-length garments and luggage, drawers for clothing and personal items, and countertop or open shelving for flowers and cards. Patient rooms include toilet facilities with direct access, although central bathing areas may be provided in lieu of individual showers.

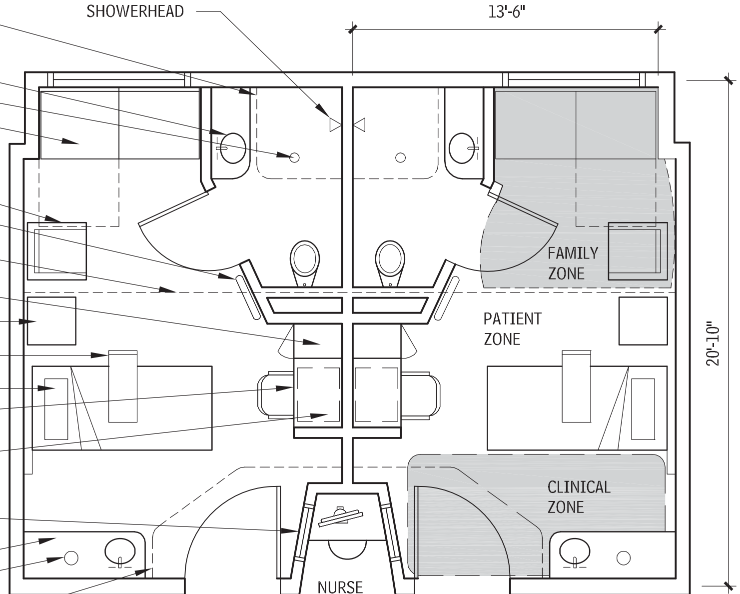
Doors to accessible toilet rooms must provide a clear opening of 32 in. minimum when opened 90°. If doors swing in, equip them with hardware that permits emergency access. Universal precautions require a lavatory in or near the entrance to each patient room for clinical use, and a place to store gloves, masks, and gowns. Space for electronic equipment, such as a patient data terminal and printer, may be required.

Semiprivate patient rooms should contain cubicle curtains for visual privacy.

SEMI-PRIVATE ROOM
14.26



PRIVATE PATIENT ROOM
14.25



INTENSIVE CARE

Patients in an intensive care unit (ICU) are under continuous observation; therefore each room should be visible from the nurse station or a staffed corridor workstation. Each unit must contain equipment for continuous monitoring and provide a nurse call at each bed for summoning assistance.

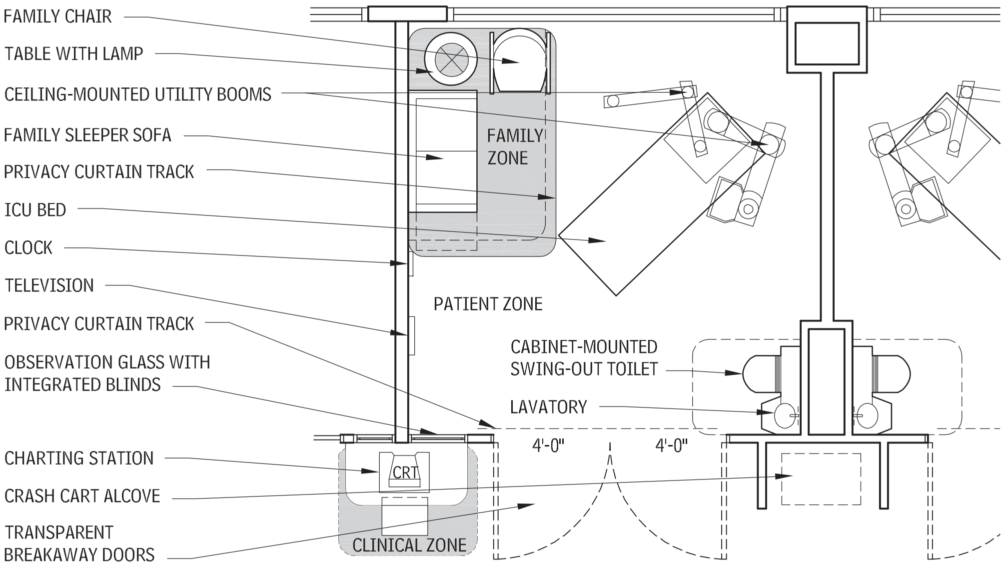
Beds should be within view of an exterior, preferably operable, window. If operable windows are provided, restrict degree of opening width to prevent escape or suicide attempts. Provide bedside space for visitors and a curtain for visual privacy.

Doors should be a minimum of 48 in. wide. Sliding doors may be used for access to rooms or cubicles within a suite.

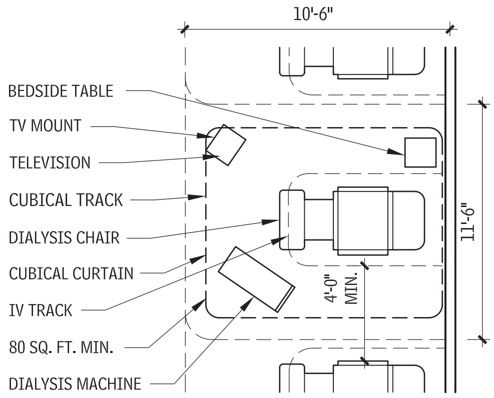
Provide at least one private room or cubicle in each ICU for patients requiring isolation and/or separation.

Toilet units can be provided in each bed area, along with a sink, a countertop for preparing medications, and universal precautions storage. IV tracks and exam lights are typically placed above each bed. Rolling life-support equipment often occupies space at the side and foot of the bed. Maintain a minimum of 48 in. on three sides of each bed. Utility columns containing power outlets and medical gas and communications devices allow 360° access around the patient.

INTENSIVE CARE ROOM
14.27



DIALYSIS MODULE
14.29



EXAMINATION ROOMS

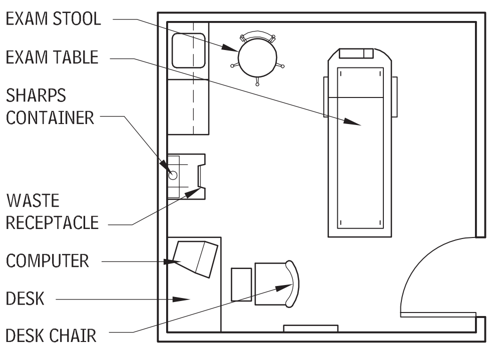
General-purpose examination rooms comprise the building blocks of outpatient facility design. Room configuration varies but the minimum room dimension is generally 8 ft. The size for examination rooms needs to be a minimum of 80 sq. ft., but 110 sq. ft. is recommended. Typically, medical providers work from the patient's right side (see Figure 14.28); therefore, rooms should be planned to permit this. In pediatric facilities, the exam table is often located with the patient's left against the wall, to increase safety. In women's health facilities, the table is positioned to face away from the room entrance door. Often, cubicle curtains are included to screen the patient from the corridor when the door is opened.

DIALYSIS MODULES

Outpatient dialysis facilities generally include open treatment positions. In Figure 14.29, a reclining chair is positioned against a service wall in an arrangement where privacy is achieved through a cubicle curtain arrangement. A minimum of 80 sq. ft. is required for each treatment station, and 145 sq. ft. is recommended with an aisle between stations.

Space requirements for chemotherapy/oncology patients are similar. Often, the cubicle curtain is replaced by a fixed screen or partition to increase privacy.

AMBULATORY CARE EXAMINATION ROOM
14.28



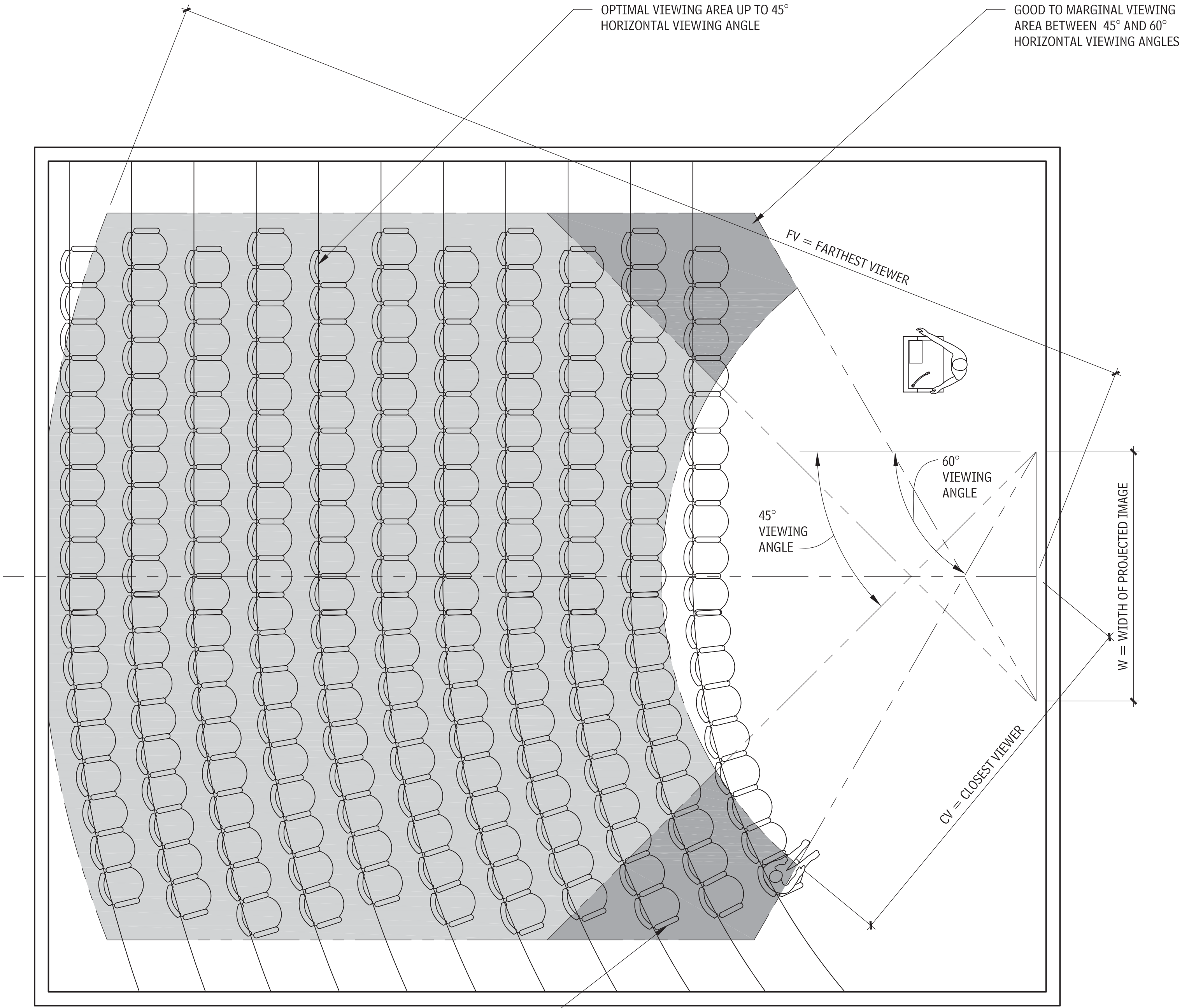
AUDIO-VISUAL EQUIPMENT

AUDIO-VISUAL DESIGN CONSIDERATIONS

VIDEO-CONFERENCING

Teleconferencing is voice or data communication between remote locations. *Videoconferencing* is teleconferencing with visual images added to voice and data communications. Generally, a videoconference space includes one or two video screens that enable conference participants to see and hear each other. When two displays are provided, one is generally used to show conference participants, and the other is used to show graphic images, information from a visual presenter or VCR. When there is only one display, the users can choose to view the conference or the graphic information on the larger part of the screen, and can view the other image in a "picture-in-picture" window.

DETERMINING OPTIMUM VIEWING AREAS
14.30



AUDIOVISUAL VIEWING AREA

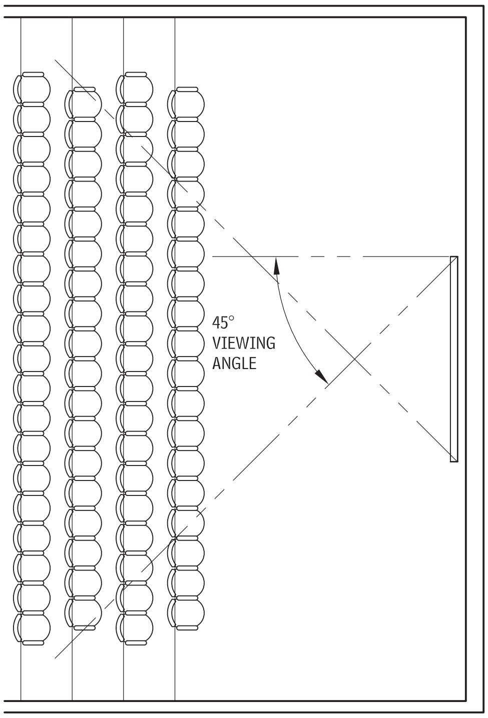
Screens that incorporate lenticular lens elements typically provide broad horizontal viewing areas, accompanied by restricted vertical viewing angles. This requires the viewers to be seated in the same plane.

Screens that incorporate both diffusion and Fresnel lens elements typically provide the most uniformly illuminated image—side to side, top to bottom, and corner to corner.

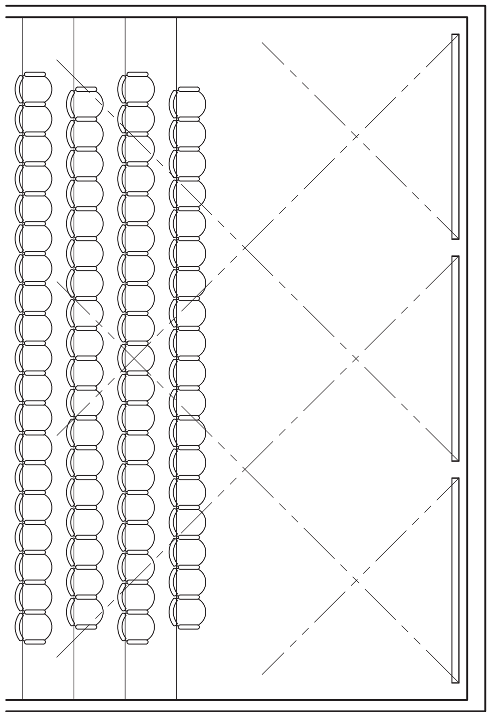
OPTIMUM VIEWING AREA
14.31

	COMPUTER VIDEO	HDTV	STANDARD (NTSC) VIDEO	35MM SLIDES	16MM MOTION PICTURE FILM	OVERHEAD TRANSPARENCIES
IMAGE ASPTECT RATIO (W-H)	4:3	16:9	4:3	2:3	4:3	1:1
H	0.75 X W	0.5626 X W	0.75 X W	1.5 X W	0.4255 X W	—
W	1.33 X H	1.78 X H	1.33 X H	.67 X H	2.35 X H	—
FV	≤ 4 X W	≤ 6 X H	≤ 8—10 X H	≤ 6 X H	≤ 4 X W	≤ 6 X H
CV	≥ 1.5 – 2 X W	≥ 1.5 – 2 X W	≥ 1.5 – 2 X W	≥ 1.5 – 2 X W	≥ 1.5 – 2 X W	≥ 1.5 – 2 X W

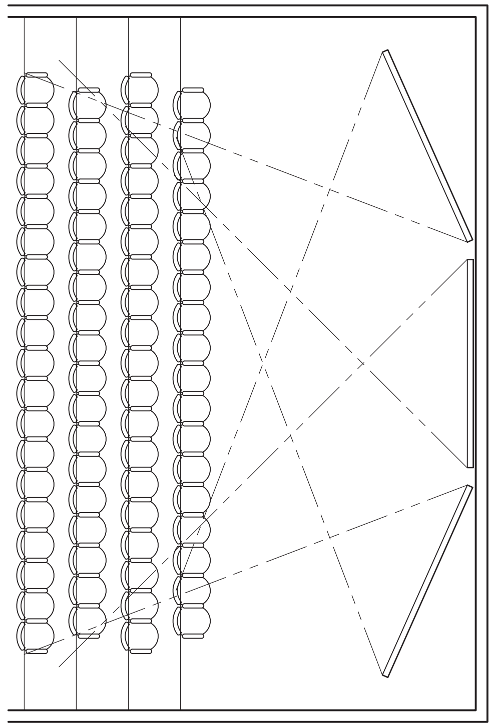
VIEWING ANGLES FOR A SINGLE FLAT SCREEN
14.32



VIEWING ANGLES FOR MULTIPLE SCREENS—PARALLEL ORIENTATION
14.33



VIEWING FOR MULTIPLE SCREENS—ROTATED ORIENTATION
14.34



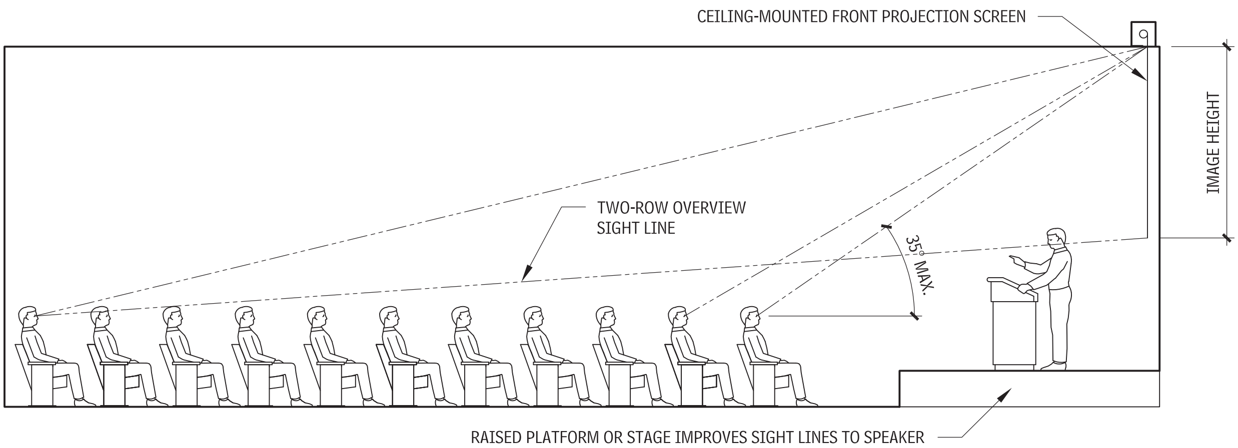
SIGHT LINES

The vertical viewing angle is the angle from the viewer's eyes to the top of the image. For the optimum sight line, it should not exceed 30° to 35° above the horizontal.

Vertical sight line studies provide information about how the image area relates to both the seating area and the projectors in projected image configurations. The typical concerns are that the screen should not be too high above any viewer, and that video projectors are not too far above or below the screen, which could require optical or electronic corrections for the image to display properly. Another concern is simply the avoidance of obstades between either the audience and the display or a projector and the screen.

Many video projectors are available with optional lenses that allow placement toward the front or at the center or rear of the room. The majority of video projectors are designed to be elevated so that the lens is approximately aligned with the top or bottom of the image. For rear projection, the lenses are often designed to allow the projector to be on the airis of the screen center.

SIGHT LINES WITH FLAT FLOOR
14.35

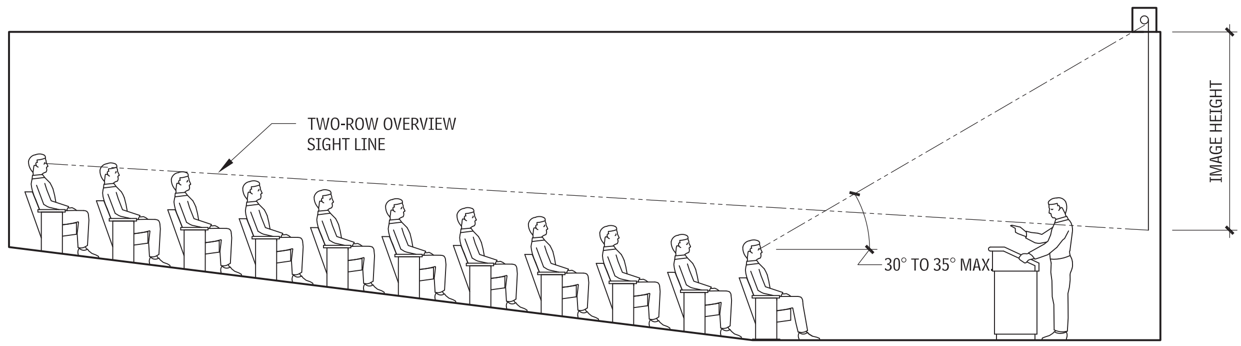


NOTES

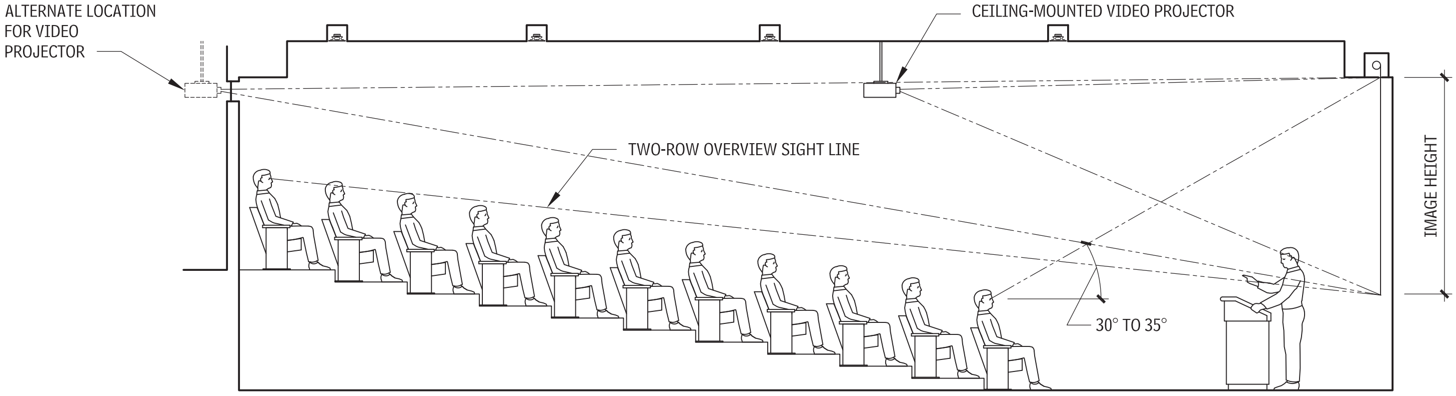
14.32 Single flat screen provides poor viewing for front corner seats.
14.33 All projection screens are mounted parallel to the front wall. This results in poor viewing for seats on the opposite side of the room from the screens.
14.34 Side projection screens are angled toward the audience. This results in improved viewing for people across the room from the screen.

Contributors:
Jeffery E. Bollinger and Jason Martinez, Acentech, Inc., Cambridge, Massachusetts and Cerami & Associates, Inc., New York, New York.

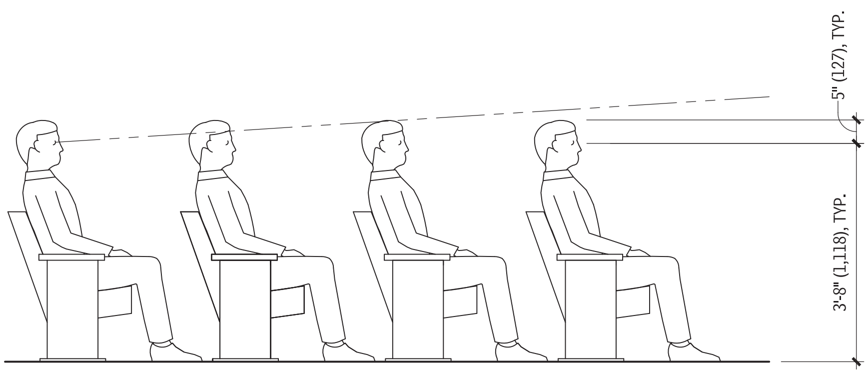
SIGHT LINES WITH SLOPED FLOOR
14.36



SIGHT LINES WITH STEPPED FLOOR
14.37



SIGHT LINES FOR TWO-ROW OVERVIEW
14.38



HUMAN FACTORS AND AUDIOVISUAL DESIGN

The design of an audiovisual facility within a finished interior space presents a specific set of multidisciplinary challenges that must be considered to ensure a successful system solution. Most AV systems have elements that affect the following trades and disciplines:

- Architecture and interior design
- Electrical
- Information technologies
- Telephony
- Heating, ventilating, and air conditioning
- Low-voltage cabling
- Lighting
- Acoustics
- Structural
- Ergonomics

In order to address the issues relating to the integration of audiovisual hardware into the architectural space, the starting point for any AV system should be in the domain of ergonomics and human factors, addressing the means and methods and dimensions to be used to deliver visual and audible information to people gathered in a room, whatever the dimension. Fundamental rules apply whether it is a small meeting room or a large auditorium. The design should initially be considered from the standpoint of an audience member who is receiving visual and audible information from a live presenter or through a display and sound system.

The two primary design goals are intelligibility and legibility. Intelligibility defines the degree to which an audience member can clearly understand the spoken word of a presenter or recorded material, as measured by the articulation loss of consonants. Legibility relates to how well each audience member can comfortably read displayed words, numbers, and graphic elements. The design parameters are first considered from the most distant viewer position, which is the worst seat in the house. If the person in the farthest seat can see and hear clearly, then all closer seats will naturally be within acceptable margins.

AUDIO INTELLIGIBILITY

Equally important in AV design to having clear line of sight and legibility for the displays is the intelligibility of the spoken word. The sound system should be designed and located to deliver crisp, clear audio, free from any howling feedback or artifacts that degrade the ability to understand. The target for the sound system is to deliver audio at 10 to 20 dB above the ambient background noise. This is achieved by using the proper types and directionality of speakers based on architectural surfaces, room shape, and seating areas.

Many architectural factors affect the clarity of the sound system, including:

- Cubic footage of space, which affects how long the reverberation or echo is from walls, floor, and ceiling
- Surface finishes, which provide a degree of sound absorption that reduces reverberation
- Dimensions of the ceiling, which affect the distance between a microphone and speakers, thus having an impact on the amount of loudness that can be achieved before howling feedback occurs
- Curved walls, which focus sound into hot spots and dead spots
- In large spaces, the width-to-length ratio of the room should not be a perfect multiple or harmonic, which may cause standing

NOTE

14.38 Minimum sight lines should be based on a two-row overview. This assumes that viewers can see between the heads of the people seated in the row directly in front of them.

Contributors:
Jeffrey E. Bollinger and Jason Martinez, Acentech, Inc., Cambridge, Massachusetts; Del Shuford, AIA, Gensler, Dallas, Texas, and Timothy W. Cape, CTS-D, Technitect, LLC, Decatur, Georgia.

waves bouncing between surfaces; these negatively affect intelligibility
- Noise caused by HVAC fans and ducts, which adds to the background noise

PRESENTATION ROOMS

There are a wide variety of spaces that may be considered presentation rooms: training rooms, lecture halls, classrooms, boardrooms, and auditoriums are common examples. These spaces typically share common AV requirements of image presentation along with audio media playback of program material and possibly speech reinforcement, depending on the size of the space. Within each of these categories, there are some common requirements.

Presentation furnishings include easels, lecterns, and portable sound systems. An audiovisual presentation system often includes the following equipment:

- Video display (video projector, flat-screen video display)
- Microphones, loudspeakers, and amplifiers
- Routing switcher (becoming less common)
- Remote control system
- A computer, for presentations or to browse the Internet
- Projector hookup for a portable notebook computer
- Document/object camera, for use with printed documents or small objects (becoming less common)
- Video equipment, including monitors, digital video disc (DVD) players, and camcorders

Typically, each of these components is provided by a different manufacturer. AV integrators combine these various components and ensure that they are properly installed.

For viewing images, the application and type of content should be determined. For example, legibility of displayed characters and symbols is of critical importance for instructional material in educational and other settings. In some spaces, more detailed image viewing may be required, such as in medical or military facilities. This will impact the image sizing requirements.

For the audio components, the need for audio program material must be considered in terms of numbers of channels of playback (e.g., monaural, stereo, or surround sound), and the need for reinforcement of speech must be determined (e.g., in a large house of worship or an auditorium).

AV SUPPORT SPACES

For a complete AV system, audio and video components mounted in the space with the user include equipment such as video displays, loudspeakers, microphones, cameras, connector plates, and control user interfaces. In addition, other devices will often be located outside the main user space. These may include AV control rooms, equipment rooms, and rear-projection rooms.

RESIDENTIAL EQUIPMENT

This section discusses equipment commonly used in residences, in particular, kitchens and laundry rooms.

KITCHENS

An ideal home kitchen design depends on a number of factors but in particular, the living habits and possessions of the kitchen users. A design that is considered excellent for one user may be unsuitable for another.

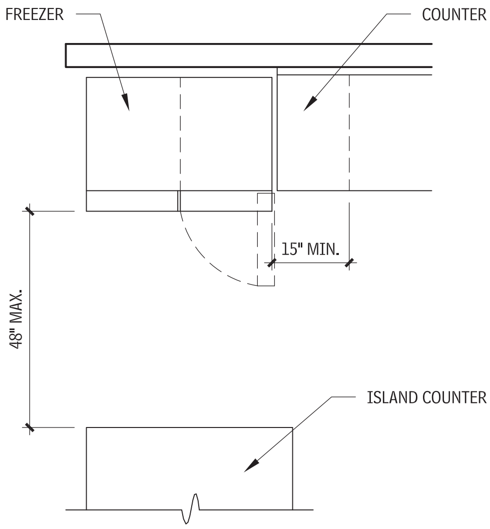
The major components of a well-planned kitchen are traffic and workflow; cabinets and storage; appliance placement and use/clearance space; counter surface and landing space; and room, appliance, and equipment controls.

KITCHEN DESIGN CONSIDERATIONS

Important design guidelines for working with residential kitchens include:

- No entry door, appliance door, or cabinet door should interfere with another door.
- All major appliances used for surface cooking should have a ventilation system, with a fan rated at 150 CFM minimum.
- No two primary work centers (the primary sink, refrigerator, preparation, or cooktop/range center) should be separated by a full-height, full-depth cabinet (measured from floor to top of wall cabinets).
- Work aisles (passages between vertical objects, both of which are work counters or appliances) should be at least 42 in. wide in one-cook kitchens, and at least 48 in. wide in multiple-cook kitchens.
- Open countertop corners should be clipped or radiused, and countertop edges should be eased to eliminate sharp edges.
- Controls, handles, and door/drawer pulls should be operable with one hand; require only a minimal amount of strength for operation; and not require tight grasping, pinching, or twisting of the wrist.

REFRIGERATOR WORK AREA
14.40

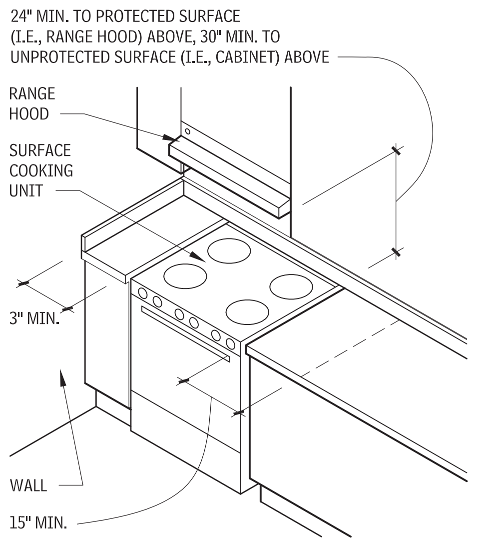


PLAN

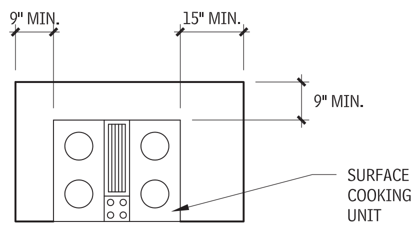
- Ground fault circuit interrupters should be specified on all receptacles in a kitchen.
- A fire extinguisher should be visibly located in the kitchen, away from cooking equipment and 15 to 48 in. above the floor; smoke alarms should be included near the kitchen.
- The window/skylight area should equal at least 10 percent of the total square footage of a separate kitchen or of a total living space that includes a kitchen.
- Every work surface in a kitchen should be well lit by appropriate task and/or general lighting.

SURFACE COOKING WORK AREA
14.41

In an enclosed configuration, allow a minimum at least a 3-in. clearance from the side wall, with flame-retardant surfacing material. The cooking surface and the adjacent counter area should be the same height.



SURFACE COOKING AT ENCLOSED CONFIGURATION



SURFACE COOKING AT OPEN (ISLAND) CONFIGURATION

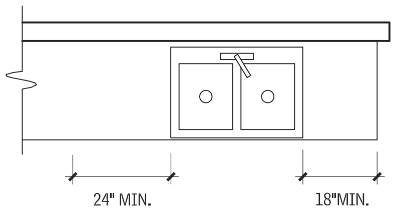
AVAILABLE TECHNOLOGY AND IMAGE SIZE REQUIREMENTS
14.39

TECHNOLOGY	DESCRIPTION	AVAILABLE SIZES	ADVANTAGES	DISADVANTAGES
Front projection	Reflective screen with projector on the same side of the screen as the audience.	Fixed: Almost any size. Retractable: Typically up to 25′ (7.6M) wide by 16′ (4.9M) high.	Larger image areas. Screens can be retractable.	Sensitive to ambient light. Retractable screens sensitive to air movement. Most projectors require ongoing filter and lamp replacements. Projectors can be noisy if in occupied space.
Rear projection	Transmissive screen with projector on the opposite side of the screen as the audience.	Fixed fabric: Almost any width by 16′ (4.9M) high. Fixed glass or acrylic: Up to approximately 12′ (3.7M) high by 16′ (4.9M) wide. Retractable: Typically up to 25′ (7.6M) wide by 16′ (4.9M) high.	Larger image areas. Less sensitive to ambient light than front projection.	Generally must be fixed, nonretractable screens. Additional space required for projection room. Most projectors require ongoing filter and lamp replacements.
Direct view	The image surface itself is luminous. Typical devices include flat-panel liquid crystal display (LCD), plasma, and older cathode-ray tube (CRT) technologies.	Typically 32 to 70″ (813 to 1,778) diagonal. Available up to 100″ (2,590) or more diagonal.	Least sensitive to ambient light.	Not available (and/or affordable) for larger image sizes.

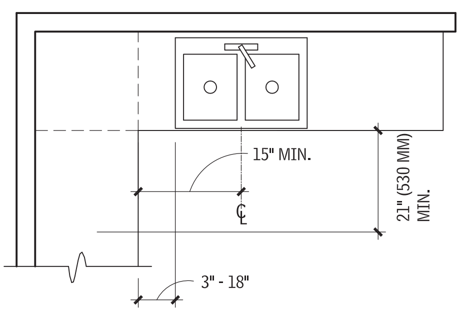
Contributors:
Del Shuford, AIA, Gensler, Dallas, Texas, and Timothy W. Cape, CTS-D, Technitect, LLC, Decatur, Georgia; Harry Spielberg, Cosentini Associates, New York, New York; Jane Clark, AIA, Zimmer Gunsul Frasca Partnership, Seattle, Washington; Jim Johnson, Wrightson, Johnson, Haddon & Williams, Inc., Dallas, Texas; Del Shuford, AIA, Gensler, Dallas, Texas, and Timothy W. Cape, CTS-D, Technitect, LLC, Decatur, Georgia.

SINK WORK AREA
14.42

A measurement of 24 in. minimum from the adjacent counter to the centerline of the sink makes possible a clear floor space of 30 by 48 in. centered on the sink. If the kitchen has only one sink, it should be located between or across from the cooking surface, preparation area, or refrigerator.

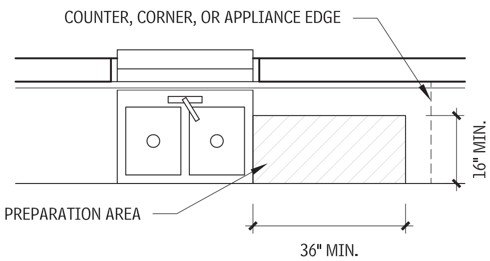


LINEAR COUNTER FRONTAGE

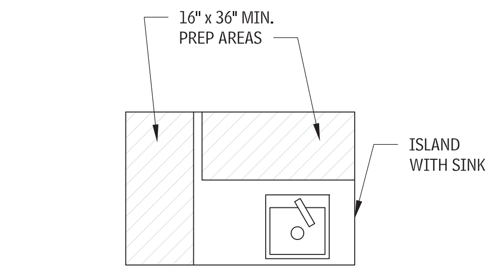


SINK ADJACENT TO CORNER

PREPARATION CENTER
14.43



PREPARATION AREA--ONE PERSON



PREPARATION AREA--TWO PERSONS

CENTERS OF ACTIVITY

Although the kitchen has evolved around three basic appliances—the sink, the range, and the refrigerator—a kitchen usually has many more centers of activity. Other considerations are primary or secondary cleanup sink center, preparation center, cooking center, microwave oven center, pantry center, a serving center, dining area, laundry area, home office center, or a media center.

- A primary cleanup sink center houses a recycling center, dishwasher, and food waste disposer.
- The secondary sink center may serve cleanup functions as well, but is generally associated with a food preparation center.
- A preparation center is a long, uninterrupted counter that may be placed between the sink and the cooking surface or the sink and the refrigerator. In a kitchen for multiple cooks, there will be more than one preparation area.
- A cooking center revolves around the cooking surface. A separate built-in oven need not be a part of this center unless it includes a microwave oven.
- A microwave oven should be located close to the major areas of activity because of frequency of use.
- A pantry center for storing foodstuffs, including storage cabinetry from floor to soffit or floor to ceiling, should be located near the preparation area.

KITCHEN LAYOUTS

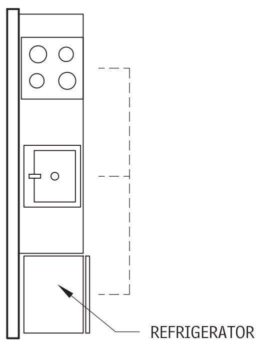
Kitchen layouts may be customized to suit the needs of each user, thus endless variations are possible.

- The U-shaped kitchen is usually considered the most efficient plan. In it, steps are saved because the cook is surrounded on three sides with a continuous countertop and storage system. Traffic is also naturally directed around the work area.
- The L-shaped kitchen with work centers on two adjacent walls forms a natural triangle that allows traffic to pass by the work area. The L shape gives the cook a generous amount of continuous counter space. If an L shape is combined with a freestanding central structure, all of the benefits of a U-shaped kitchen are available, with a more open, free-flowing plan. The island invites interaction between the cook and visitors and helpers because more than one person can work around this open counter.
- A corridor kitchen offers one cook the advantage of an efficient, close grouping of work centers on parallel walls. Disadvantages are that household traffic may cross back and forth through the area and that the shape is typically too small for two cooks. The single-wall kitchen type is only acceptable in small apartments or efficiency units.

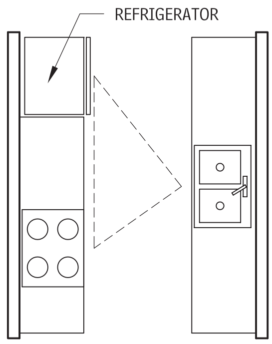
KITCHEN WORK TRIANGLE

The work triangle is the shortest walking distance between the refrigerator, primary food prep sink, and primary cooking surface, and is measured from the center front of each. Walkways and traffic patterns should not interfere with the primary work triangle, and cabinetry should not intersect any one triangle leg by more than 12 in. Each leg of a triangle length should be between 4 and 9 ft., and the total sum of the three legs should equal less than 26 ft.

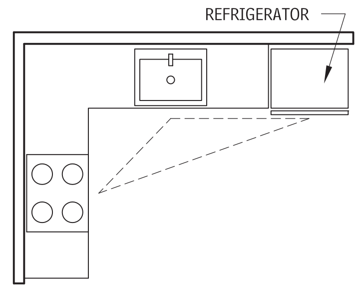
COMMON KITCHEN LAYOUTS
14.44



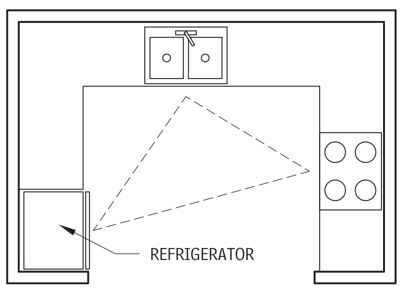
SINGLE-WALL



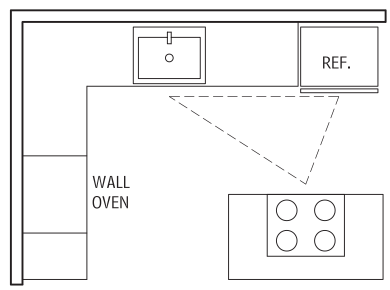
CORRIDOR/PARALLEL WALL



L-SHAPED



U-SHAPED



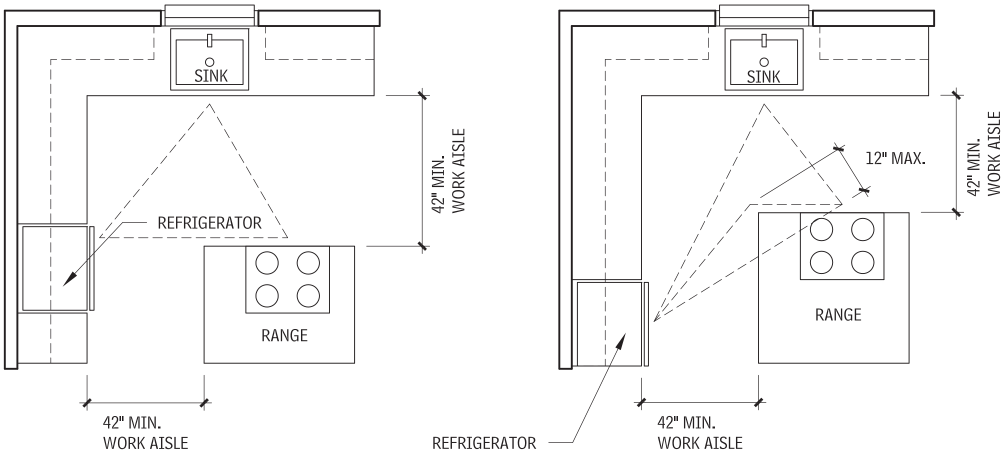
L-SHAPED WITH ISLAND

NOTE

14.43 The preparation area should be immediately adjacent to a sink.

Contributor:
National Kitchen and Bath Association, Hackettstown, New Jersey.

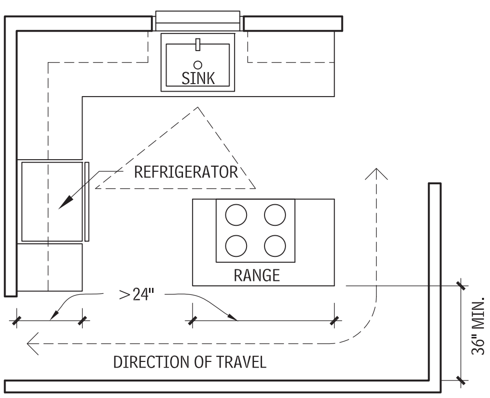
WORK TRIANGLE—ONE COOK
14.45



PLAN **PLAN**

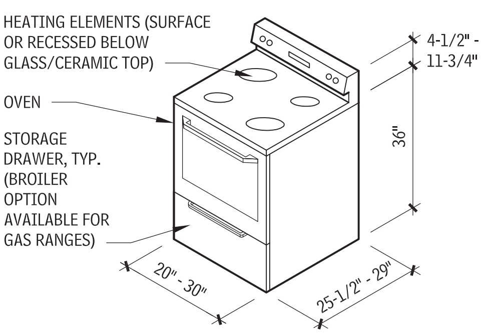
TRAFFIC FLOW ADJACENT TO WORK TRIANGLE
14.46

Walkways are passages between vertical objects that are greater than 24 in. deep in the direction of travel, of which not more than one is a work counter or appliance. Walkways should be at least 36 in. wide and should not cross through the work triangle.



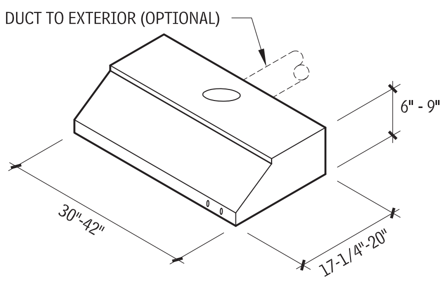
FREESTANDING RANGE/OVEN
14.47

Freestanding ranges/ovens may have front-mounted controls; if so, the backsplash area may be eliminated.

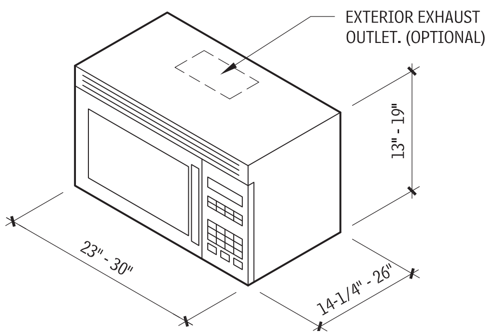


RANGE HOOD
14.48

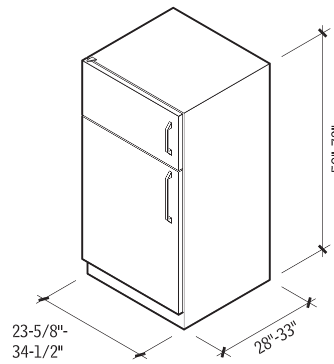
Range hoods vent through filters back into the room (self-venting), or through ducts and filters to the outdoors. Accessories such as fans, filters, and lights vary greatly in design configuration. Some ranges and cooktops are equipped with downdraft venting, which may eliminate the need for an overhead range hood. Fans typically vent from 50 to 350 CFM of air for standard residential cooktop use. For commercial ranges, consult a design professional for CFM requirements.



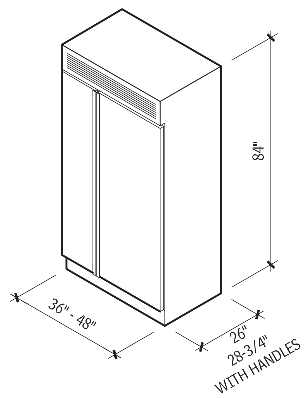
BUILT-IN MICROWAVE OVEN
14.49



REFRIGERATOR WITH TOP FREEZER
14.50

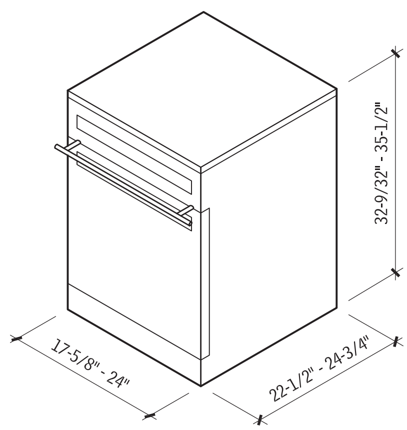


BUILT-IN SIDE-BY-SIDE REFRIGERATOR/FREEZER
14.51



BUILT-IN DISHWASHER
14.52

Do not place dishwasher farther than 10 ft. from sink, typically, for proper drainage.



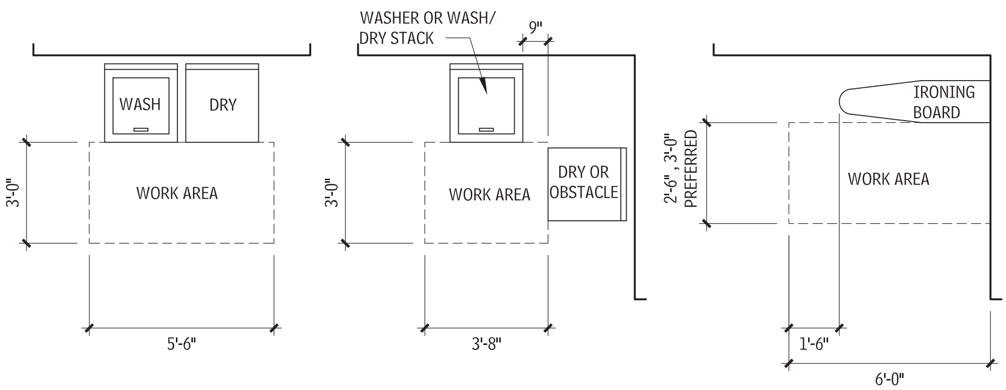
NOTE
14.49 Venting may be directed to the outside, or recirculated.

Contributor:
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland.

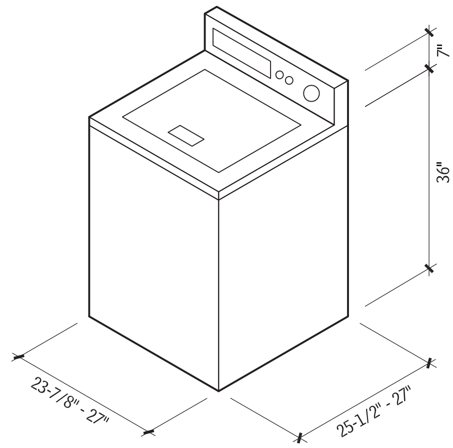
LAUNDRY ROOMS

Laundry equipment dimensions and features vary; consult manufacturers for specific details.

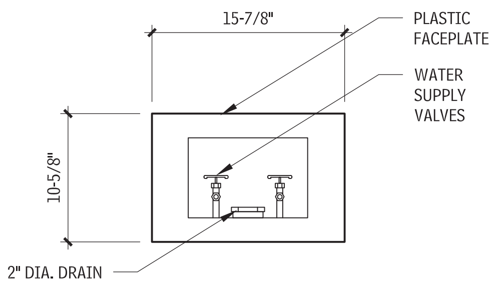
LAUNDRY EQUIPMENT CLEARANCES 14.53



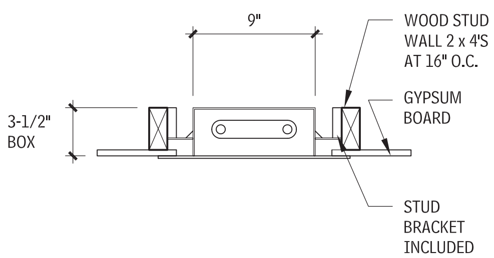
FREESTANDING TOP-LOADING WASHER 14.56



UTILITY CONNECTION BOX (RECESSED) 14.54

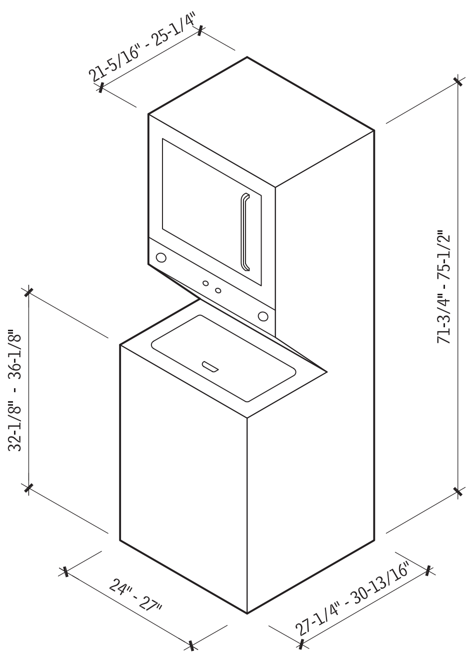


ELEVATION

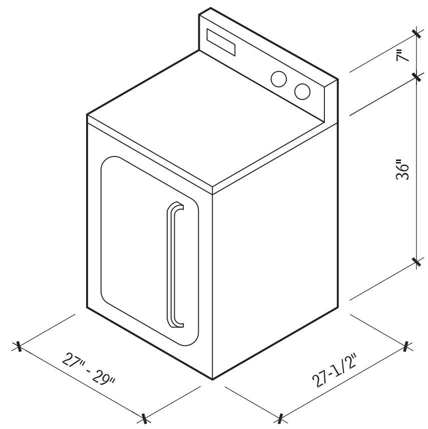


PLAN

STACKED WASHER-DRYER COMBINATION 14.55



FRONT-LOADING DRYERS 14.57



ENTERTAINMENT AND RECREATIONAL EQUIPMENT

THEATER AND STAGE EQUIPMENT

DESIGN CONSIDERATIONS: PERFORMANCE THEATERS

In performance halls used for concerts, the stage and audience seating area should be treated as one volume. In multiple-use halls, this is achieved with a hard orchestra shell, which must be demountable to allow for full use of the stage for scenery and stage sets. Acoustic requirements may dictate that reflective surfaces at the ceiling of the orchestra enclosure extend out above audience seating.

SEATING AREA DESIGN

The floor area efficiency in square feet per seat is a function of the row spacing, the average chair width, and the space allocation per seat for aisles, as shown in this equation:

Efficiency (F) = seat factor + aisle factor

$$F\,[\text{sq. ft./seat}] = (W_sT) \div (144) + (IT) \div (144)\,(1) \div (S_{avg})$$

where:

W_s = Average seat width in inches
T = Row-to-row spacing (tread) in inches
I = Average aisle width in inches (42-in. width, typical)
S_{avg} = Average number of seats in a row per single aisle: 8 or fewer—inefficient layout; 14 to 16—maximum efficiency (multiple-aisle seating); 18 to 50 and more—continental seating.

SEATING CAPACITY AND AUDIENCE AREA

The equation for determining seating capacity and audience area is:

$$\text{Audience area} = \text{capacity} \times \text{efficiency}$$

Minimum seat row spacing reduces maximum distance to stage.

EASE OF PASSAGE IN FRONT OF SEATED PERSONS

Guidelines for spacing seats to provide comfortable passage in front of seated patrons are as follows:

32 to 34 in.: Seated person must rise to allow passage.
36 to 38 in.: Some seated persons will rise.
40 in. and greater: Passage in front of seated persons possible.

ROW-TO-ROW SPACING CRITERIA

Consult local codes for required minimum row spacing. Codes typically stipulate a minimum clear plumb line distance measured between the unoccupied chair and the rear of the back of the chair in front, as follows:

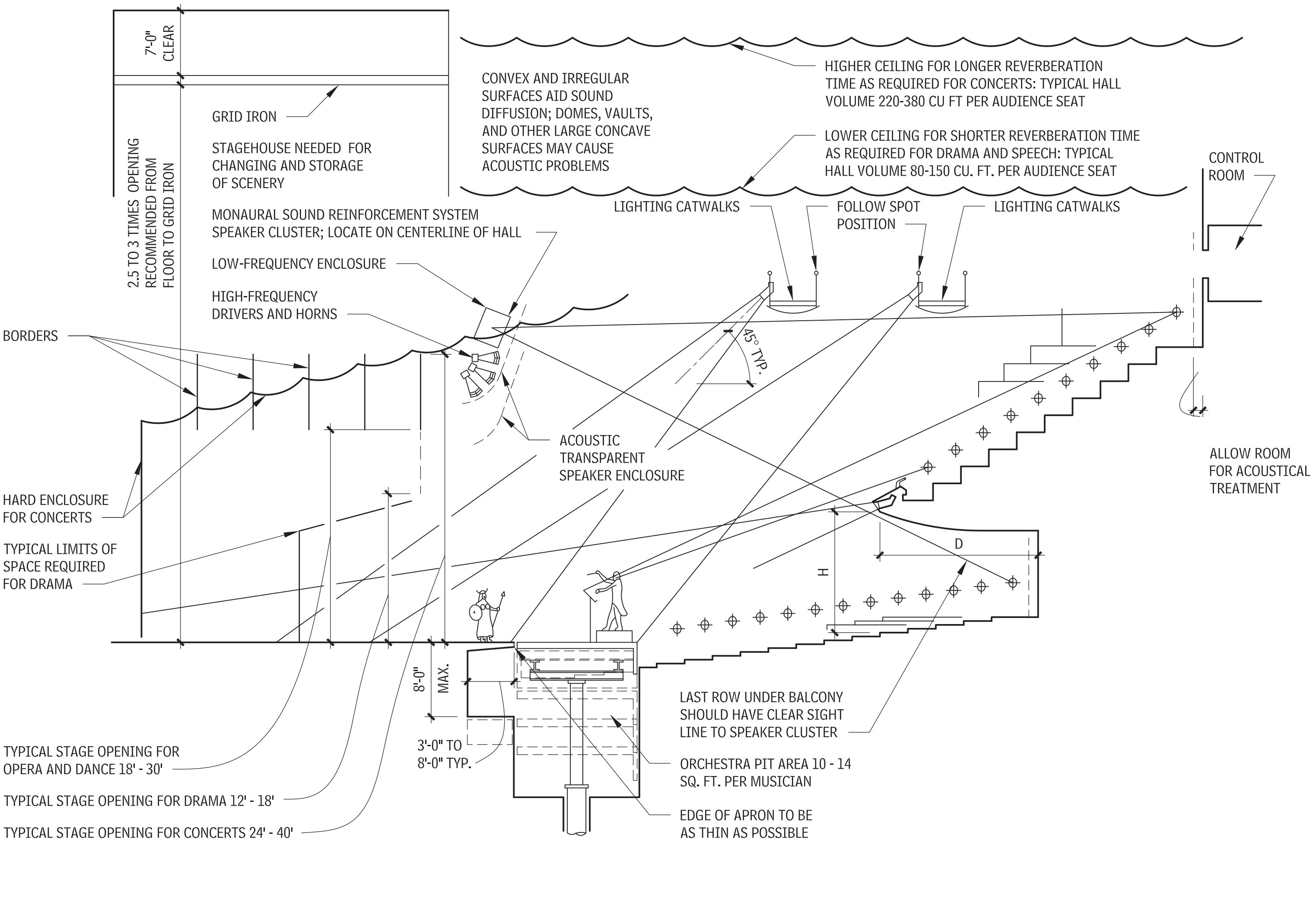
32 to 33 in.: Typical minimum for multiple-aisle seating.
34 to 37 in.: Typical minimum for modified continental seating.
38 to 42 in.: Typical minimum for continental seating.

COMFORT TO THE SEATED PERSON

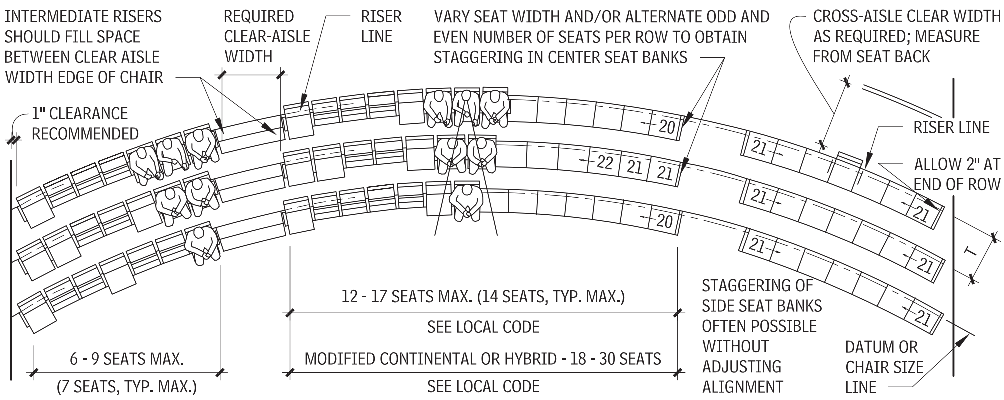
Guidelines for enough legroom to provide seated comfort are as follows:

32 in.: Knees will touch chair back—uncomfortable.
34 in.: Minimum spacing for comfort.
36 in.: Ideal spacing for maximum comfort.
38 in. and greater: Audience cohesiveness may suffer.

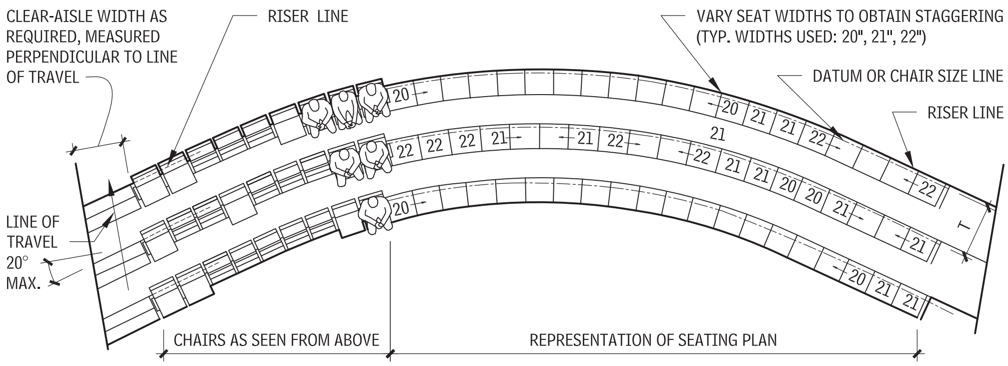
CONFIGURATION FOR LIVE PERFORMANCE
14.58



MULTIPLE-AISLE SEATING
14.59



CONTINENTAL SEATING
14.60

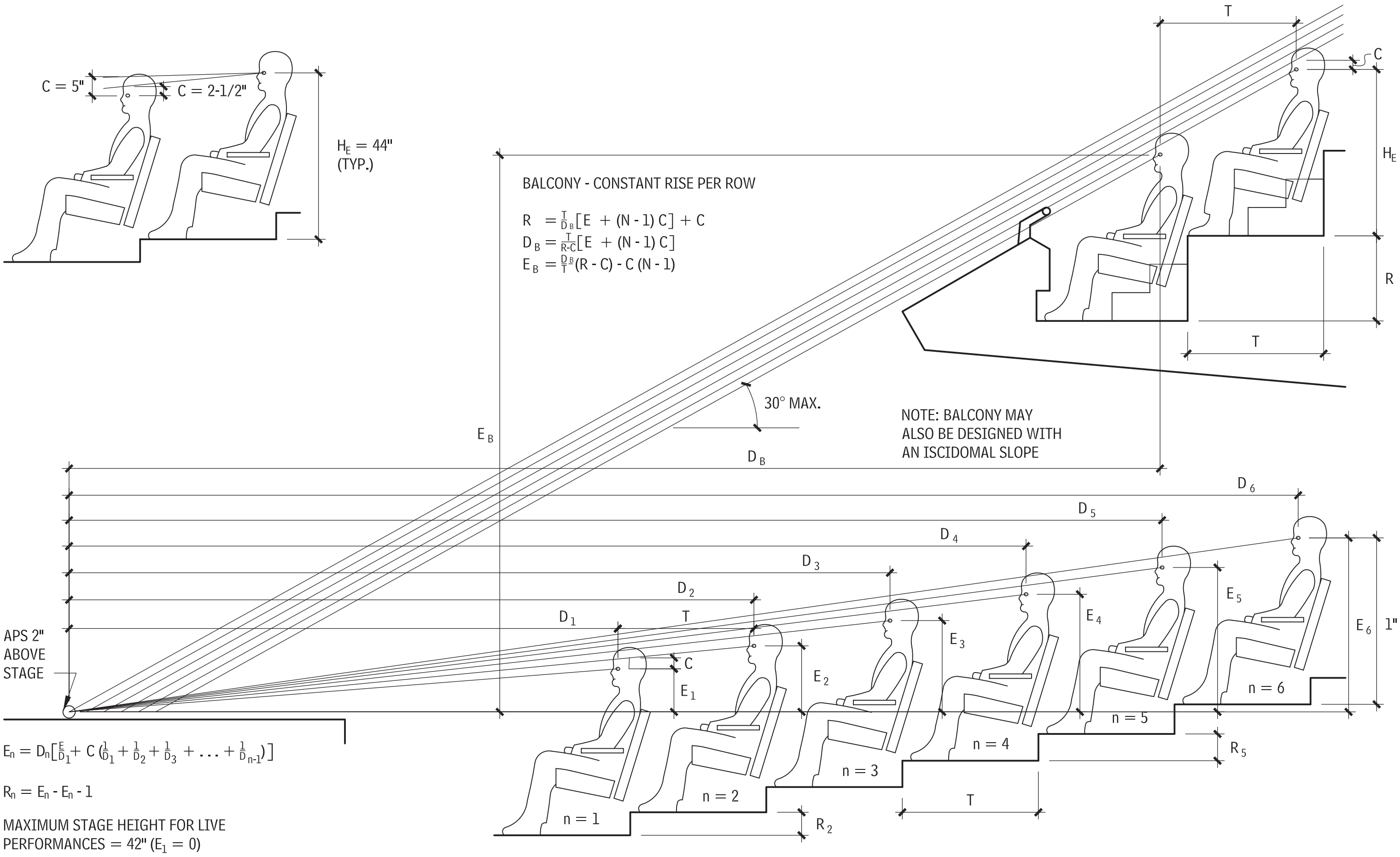


THEATER SAFETY

Excessive plumb line distance may entice exiting persons to squeeze ahead and cause a jam. Consult applicable codes for aisle and exit path widths.

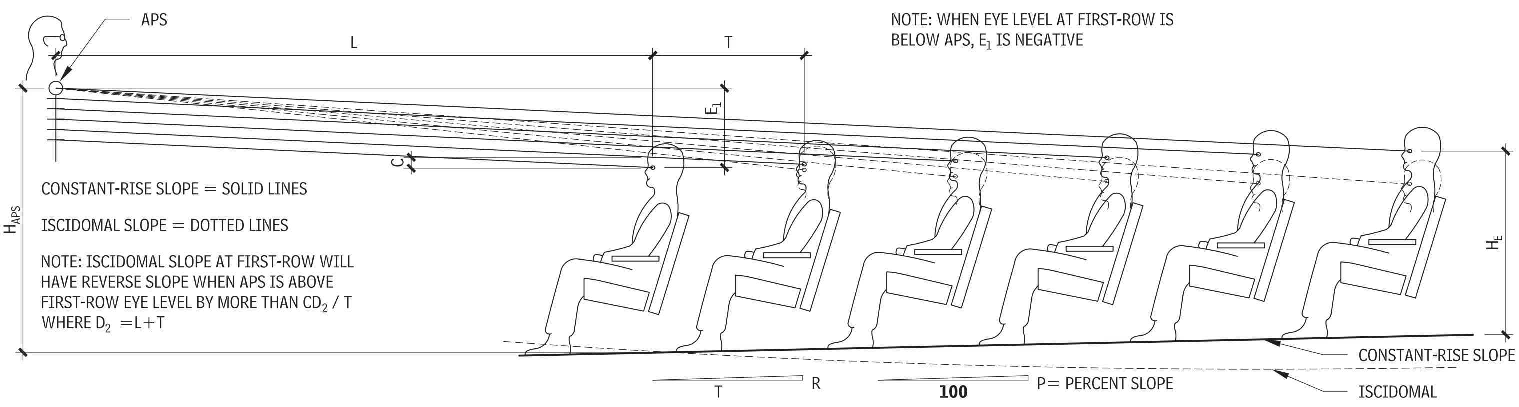
THEATER SIGHTLINES

SIGHT LINES FOR ISCIDOMAL (EQUAL-SEEING) FLOOR SLOPE
14.61



- APS = ARRIVAL OF POINT OF SIGHT (FOCAL POINT OR INTERSECTION OF HIGHEST SIGHT LINE WITH FOCAL PLANE)
- N = NUMBER OF ROWS IN SEAT BANK
- n = ROM NUMBER FOR WHICH COMPUTATIONS ARE BEING MADE
- D_1 = HORIZONTAL DISTANCE FROM APS TO FIRST-ROW EYE POSITION
- D_n = HORIZONTAL DISTANCE FROM APS TO EYE POSITION AT ROW N
- D_b = HORIZONTAL DISTANCE FROM APS TO EYE POSITION AT FRONT OF ROW OF BALCONY
- L = HORIZONTAL DISTANCE FROM FIRST-ROW EYE POSITION TO A VERTICAL FOCAL PLANE
- E_1 = ELEVATION OF EYE LEVEL AT FIRST ROW ABOVE APS
- E_n = ELEVATION OF EYE LEVEL AT ROW N ABOVE APS
- H_E = EYE HEIGHT OF SEATED PERSON (44 IN. TYPICAL; 1,117MM)
- H_{APS} = HEIGHT OF APS ABOVE FIRST-ROW FLOOR LEVEL
- C = SIGHT LINE HEAD CLEARANCE, 2 1/2 IN. (63MM) TO SEE OVER TWO ROWS IN FRONT; 5 IN. (127MM) TO SEE OVER ONE ROW IN FRONT
- T = ROW-TO-ROW SPACING (TREAD)
- R = RISER HEIGHT BETWEEN ROWS
- R_n = RISER HEIGHT AT FRONT OF ROW N
- P = PERCENT SLOPE

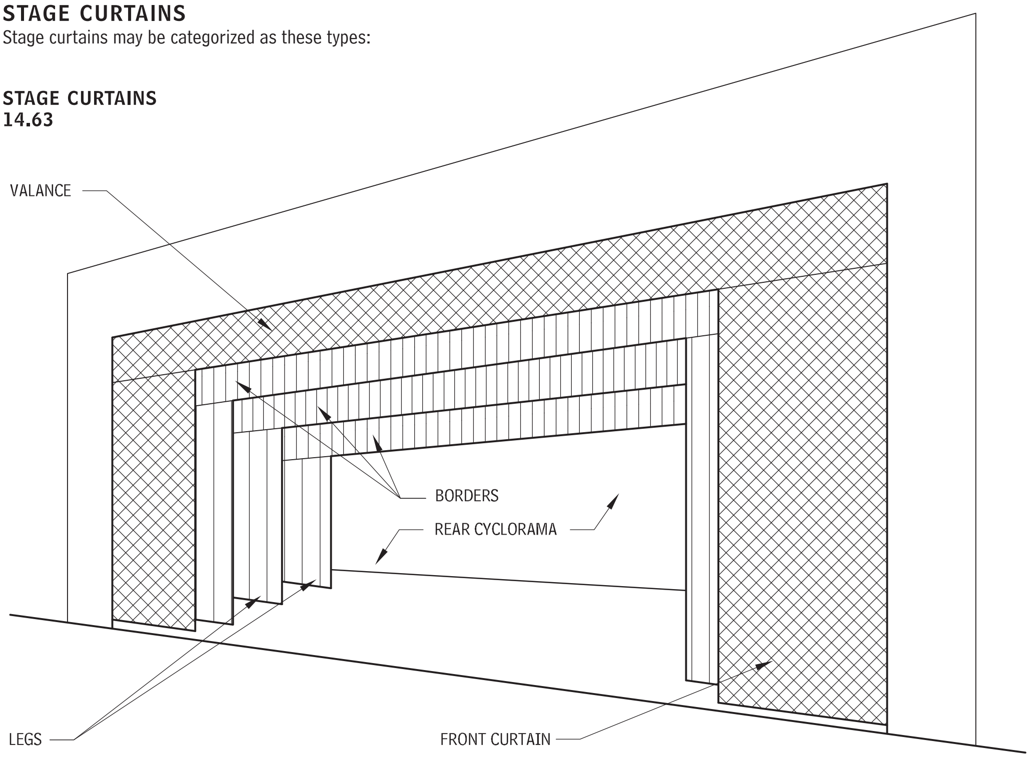
SIGHT LINES FOR SLIGHTLY SLOPED FLOOR—VERTICAL FOCAL PLANE
14.62



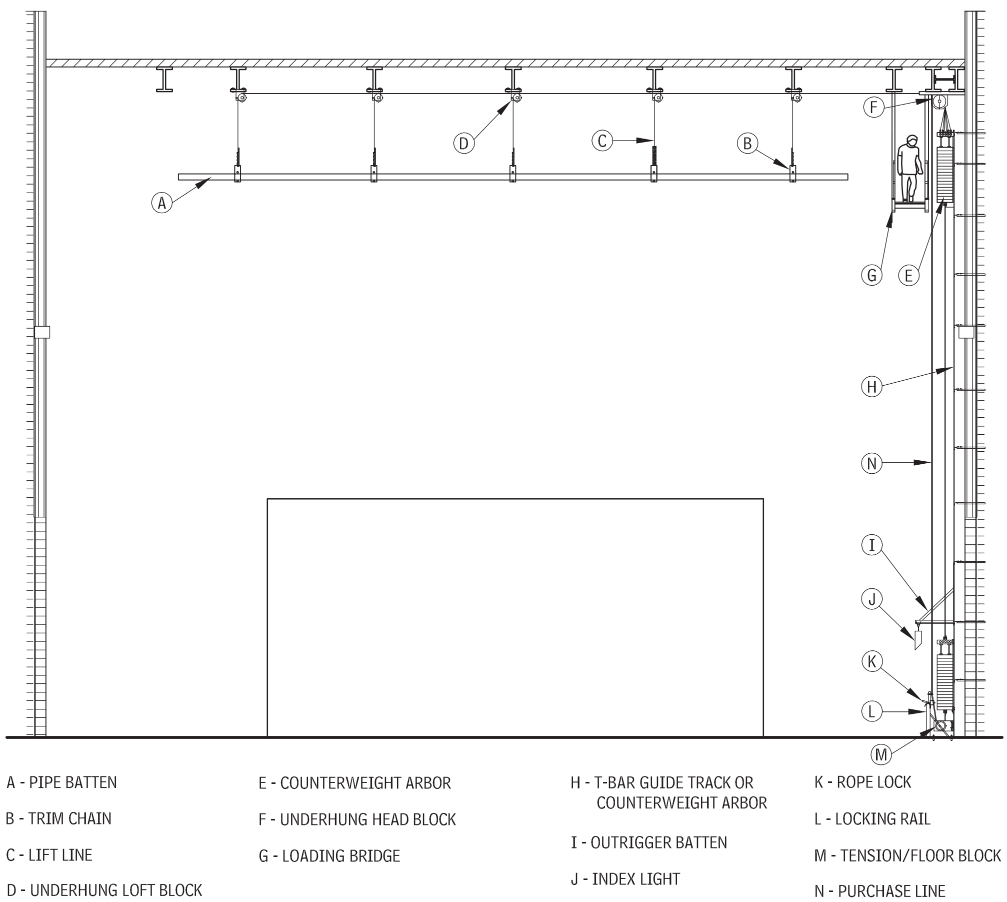
STAGE CURTAINS

Stage curtains may be categorized as these types:

STAGE CURTAINS
14.63



TYPICAL UNDERHUNG STAGE RIGGING SYSTEM
14.64



SINGLE-PURCHASE COUNTERWEIGHT

STAGE RIGGING SYSTEMS

Rigging systems control the movement of scenery and stage curtain elements in theaters. Counterweight and motorized rigging systems are available for a wide range of applications, from elementary schools to professional theaters. Rigging systems are designed based on the performance programming and the skill level of the people operating them.

PORTABLE STAGE EQUIPMENT

Modular, demountable stage platforms are available for multiple applications. Mobile stage equipment is generally manufactured in 4-ft by 8-ft sections in height, ranging from 8 to 32 in., with a wide variety of finish flooring. Folding mechanisms and transport arrangements (mobile systems self-transport) vary with manufacturer. Portable stage and riser systems are available on a 3-ft or 4-ft by 6-ft or 8-ft modules, for flat-floor or tiered arrangements. Stair units and guardrails, and dollies or caddies for transport are available as accessory components. Heights for tiered arrangements are generally based on 8-in. increments, and can extend to heights of 72 in. or more. Portable stage equipment should be adaptable to provide accessibility, as required.

NOTE

14.64 The underhung rigging system is only one of a variety of rigging system types, which vary according to theater design criteria. Consult manufacturers of rigging systems for particular system types.

ATHLETIC EQUIPMENT

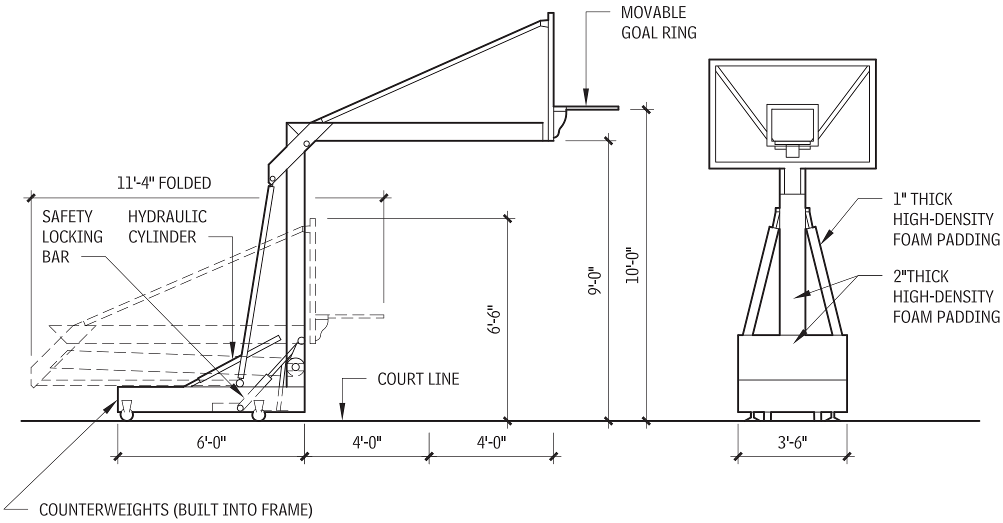
This section covers equipment related to a wide range of sports and athletic or fitness facilities, including:

BASKETBALL

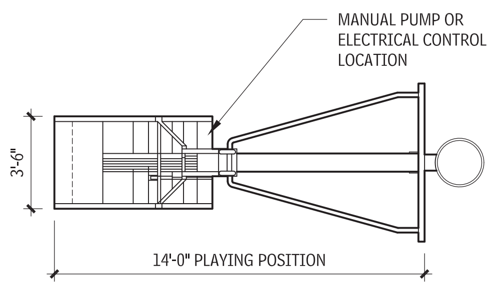
The equipment illustrated includes common forms of hydraulic goals and backboards.

Electronic scoreboard equipment is available in a wide range of sizes and configurations. For more information and the names of manufacturers, conduct an Internet keyword search on "athletic scoreboard equipment."

PORTABLE GOAL
14.65



ELEVATION

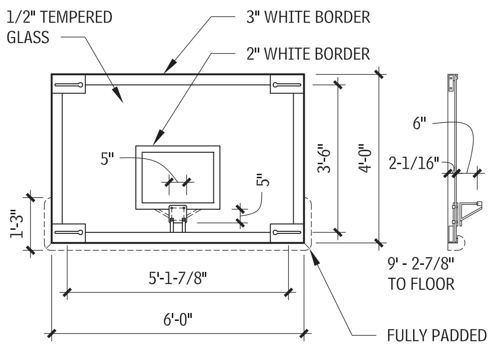


PLAN

BASKETBALL COURT DIMENSIONS
14.66

COURT	LENGTH (FT)	WIDTH (FT)	THREE-POINT LINE RADIUS (FT-IN.)
NBA	94	50	23–9
International	94	50	20–7
NCAA (men)	94	50	19–9
WNBA, NCAA (women)	94	50	19–9
High school (women)	84	50	19–9
High school (men)	84	50	19–9

BACKBOARD
14.67



ELEVATION **SECTION**

BILLIARDS, POCKET BILLIARDS, AND SNOOKER

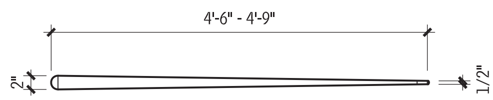
Design guidelines for these activities are as follows:

- Flooring must be permanently level and able to withstand point loads.
- Traditionally designed billiard tables weigh about 1.5 tons, spread over eight legs.
- Lighting must not produce harsh shadows, but some modeling of the ball is desirable. Avoid direct or reflected glare. True-color rendering is important in snooker. An overall bright light is needed for each table. Natural lighting is not essential, but fluorescent lamps are unacceptable.
- Some sound insulation is required to prevent distractions from outside the playing area.

TABLE DIMENSIONS
14.68

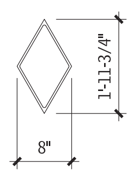
TYPE OF TABLE	PLAYING SURFACE WIDTH (FT-IN.)	PLAYING SURFACE LENGTH (FT-IN.)	TABLE SIZE WIDTH (FT-IN.)	TABLE SIZE LENGTH (FT-IN.)
English (Snooker)	7–2	14–4	8–2	15–4
Standard 9 ft.	4–2	8–4	5–2	9–4
Standard 8 ft. (2.4 m)	3–8	7–4	4–8	8–4
Standard 7 ft. (2.1 m)	3–2	6–4	4–2	7–4
Oversized 8 ft. (2.4 m)	3–10	7–8	4–10	8–8

GAME EQUIPMENT
14.69

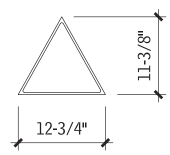


CUE

BRIDGE

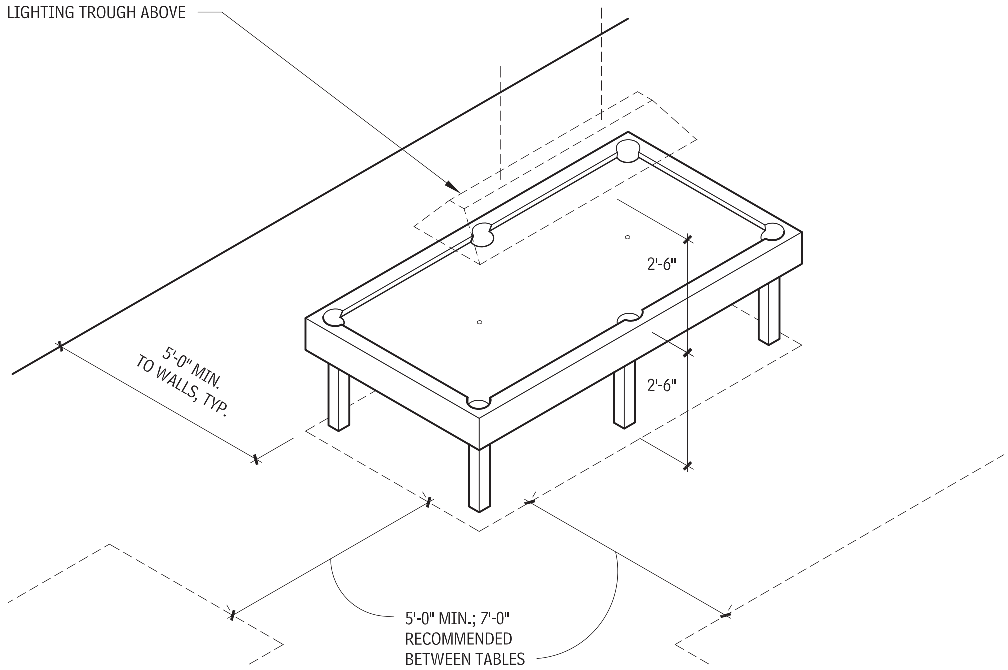


NINE-BALL RACK

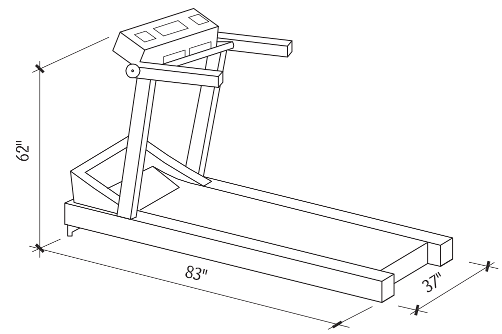


EIGHT-BALL RACK

BILLIARDS AND SNOOKER TABLE
14.70



TREADMILL
14.73



FITNESS EQUIPMENT

Exercise and fitness equipment varies widely by manufacturer and type. The dimensions shown here are for general reference only.

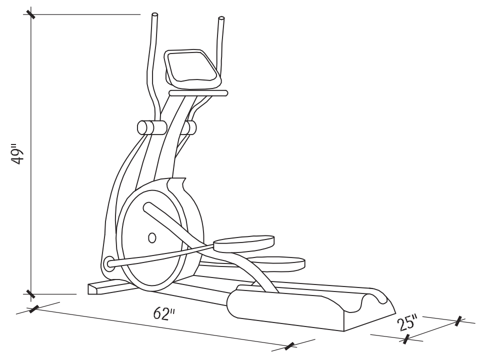
Cardio equipment includes elliptical trainers, bikes, stair climbers, and treadmills. These items are available in many styles and sizes. When planning gym spaces, provide at least as much circulation space/open space as that for equipment. Also, leave adequate space for mounting and dismounting of equipment.

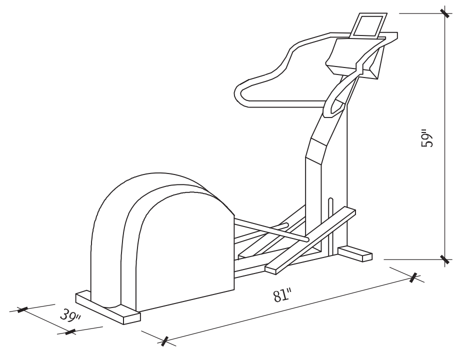
Strength-training equipment includes multi-station gyms, free weights, and a range of equipment designed to strengthen particular muscle groups. Consult manufacturers for planning data and dimensions of strength-training equipment.

SPACE PLANNING DATA FOR COMMON CARDIO EQUIPMENT
14.71

EQUIPMENT	AREA (SQ FT)
Treadmills	30
Bikes	10
Stair climbers	10–20
Rowing machines	20
Elliptical trainers	30

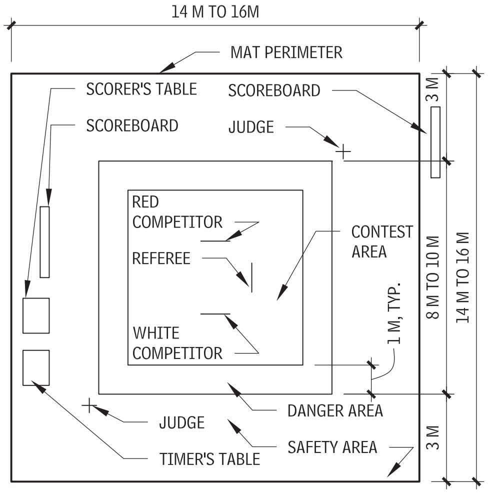
ELLIPTICAL TRAINERS
14.72





JUDO

JUDO MAT
14.74



KARATE

Ceilings should be a minimum of 10 ft. high to accommodate the swinging of swords and bows. Structural support is needed in the ceiling for the heavy bags used in karate. Eight 100-lb bags are located approximately 4 ft. o.c. Doors should not open into the mat area, and no mirrors or windows should be nearby.

KARATE MAT
14.75

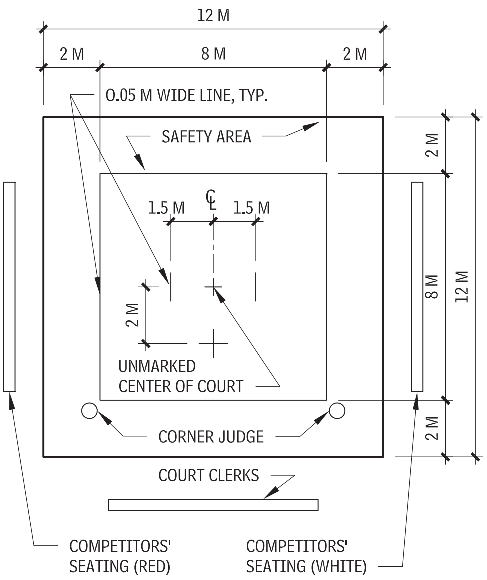


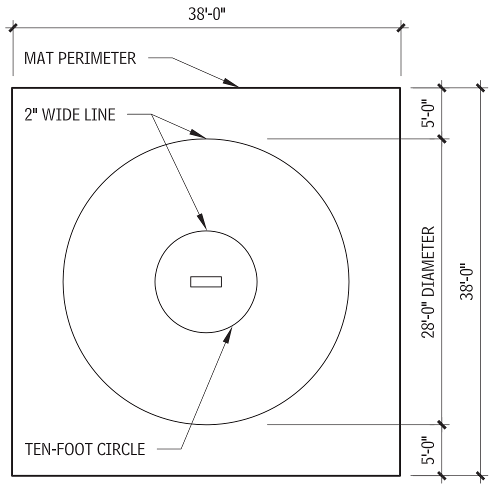
TABLE TENNIS

Design guidelines for table tennis are as follows:

- Flooring should be level and slightly resilient; nonskid material should not be used.
- Walls should provide a uniformly dark, matte background with enough contrast to help players follow the ball.
- Lighting often varies for different standards of play, but 15 to 50 fc (150 to 500 lux) at table height is the acceptable range. Do not use fluorescent or natural lighting; tungsten halogen lighting is preferable.
- Sectional tables should be stored upright when not in use.

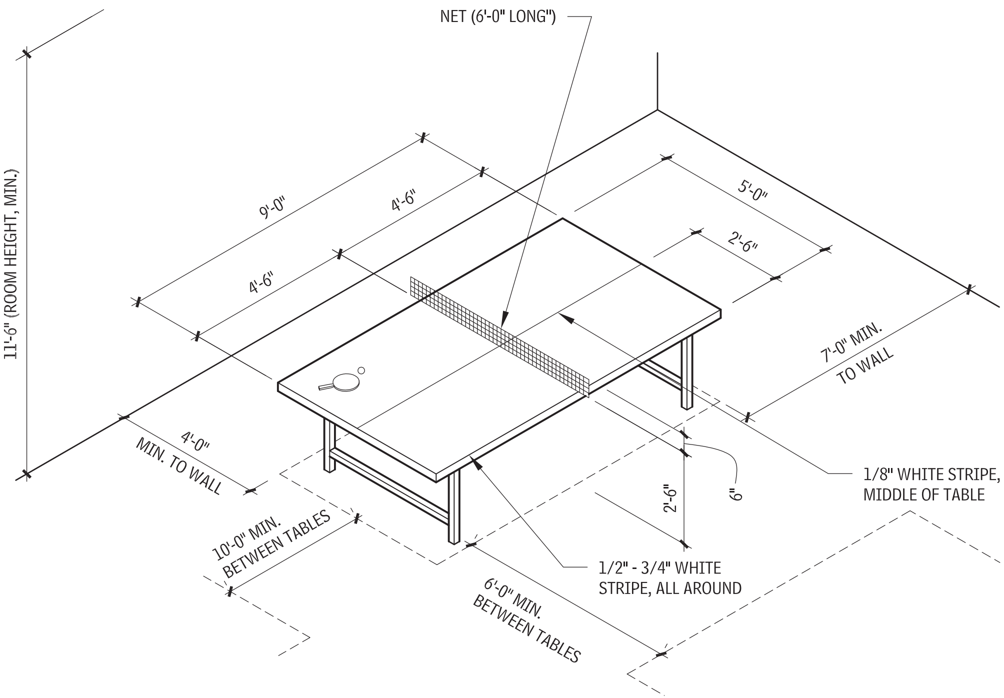
WRESTLING

TYPICAL MAT
14.76



TYPICAL MAT

TABLE DIMENSIONS
14.77



FURNISHINGS

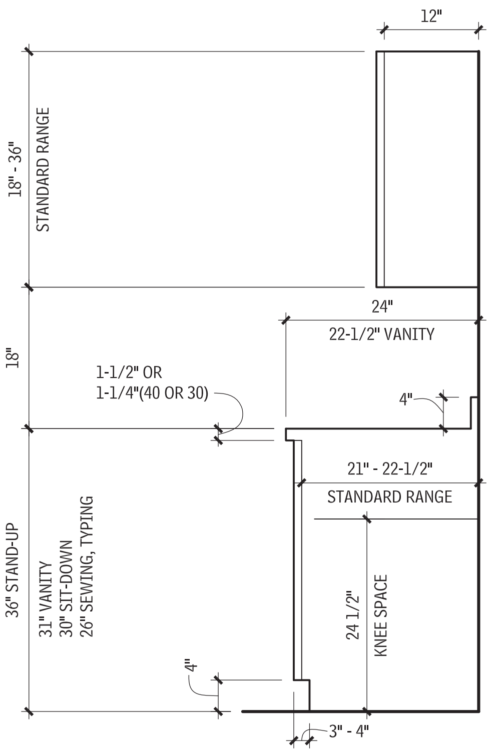
FIXED FURNISHINGS

FIXED CASEWORK

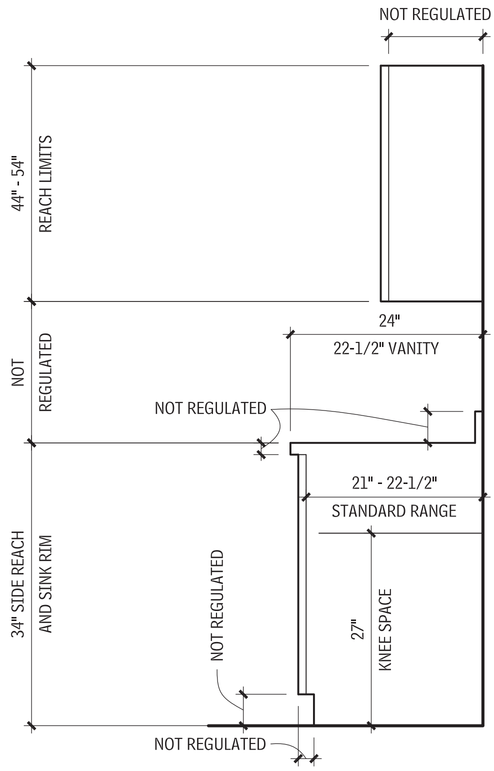
This section examines custom millwork standards and the details of cabinet construction. Reference Chapter 1 section on Accessibility for related information.

SHOP-FABRICATED CABINETS

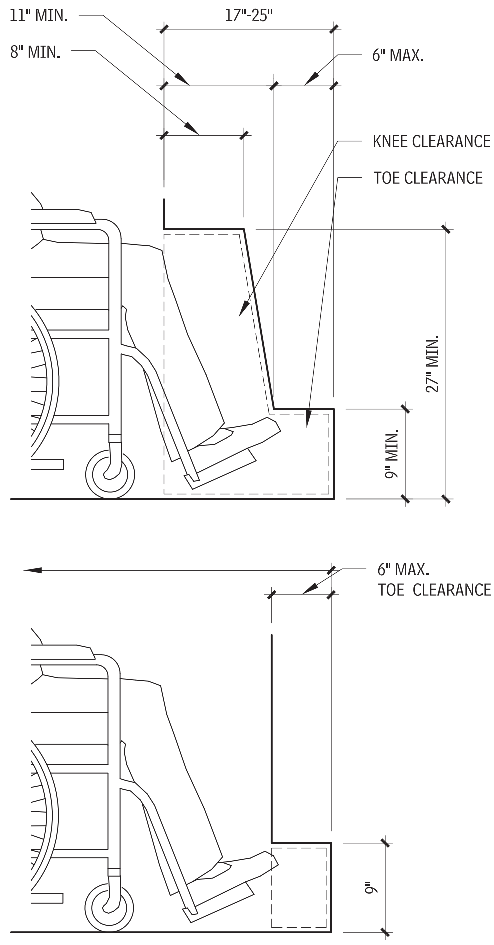
WALL-HUNG AND BASE CABINETS
14.78



ACCESSIBLE WALL-HUNG AND BASE CABINETS
14.79



KNEE AND TOE CLEARANCES
14.80

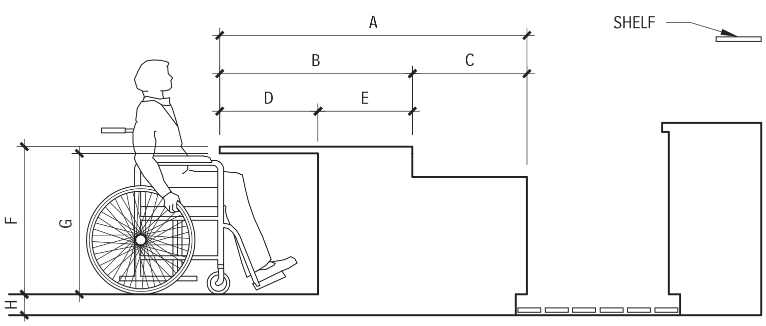


TOE CLEARANCE

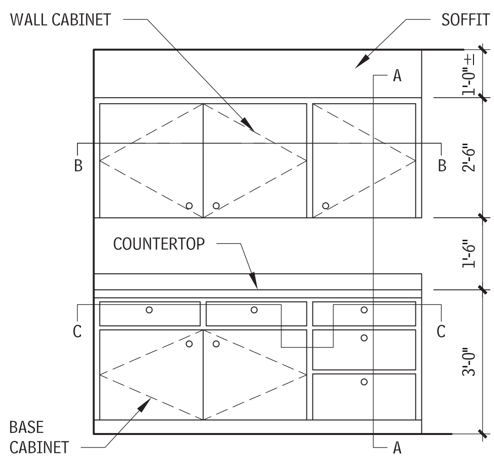
BARS AND COUNTERS
14.81

LOW COUNTER DIMENSIONS

A = 4'-11" TO 5'-6"
B = 3'-1" TO 3'-3"
C = 1'-10" TO 2'-0"
D = 17" TO 25"
E = 1'-6" TO 2'-0"
F = 2'-4" TO 2'-8"
G = 2'-3" MIN.
H = 4" - 8"



TYPICAL CABINET ELEVATION
14.82



ELEVATION

CABINET DETAILS

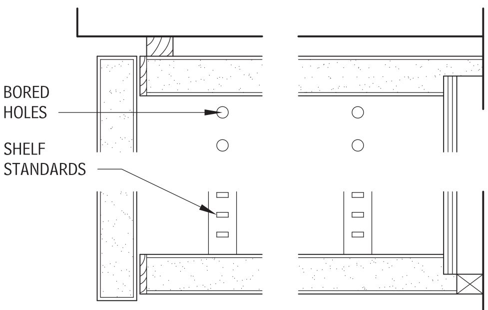
The Architectural Woodwork Institute (AWI) Quality Standards classify architectural cabinets in three categories: premium, custom, and economy. The materials, joinery, and finish quality are delineated for casework shops to follow.

- Premium is the highest grade, with close tolerances reserved for only the finest cabinets.
- Custom-grade cabinets, the most common, are made from very good materials with durable joinery.
- Economy-grade cabinets are used for utilitarian and inexpensive residential cabinets.

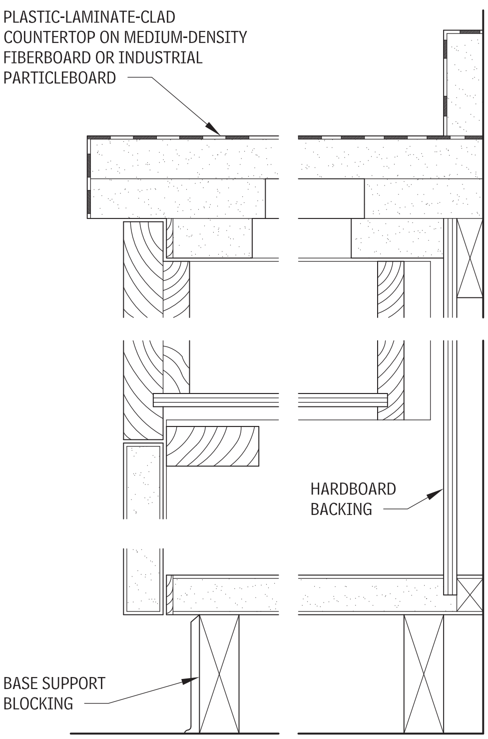
The AWI Quality Standards further classify cabinet parts as exposed, semi-exposed, and concealed, and specify a minimum grade for each. The finish to be used is specified as paint grade or stain grade, or whether plastic laminate or other material will be used.

To prevent movement caused by wood shrinkage, use only kiln-dried solid lumber or panel product for base supports.

FLUSH OVERLAY CONSTRUCTION—VERTICAL SECTION A-A
14.83

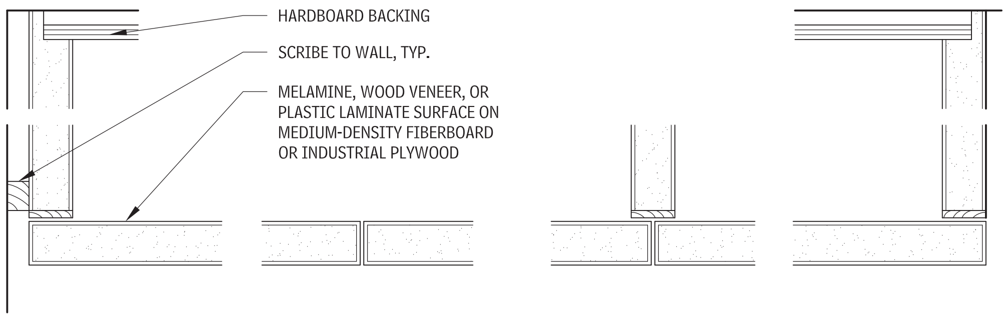


WALL CABINET

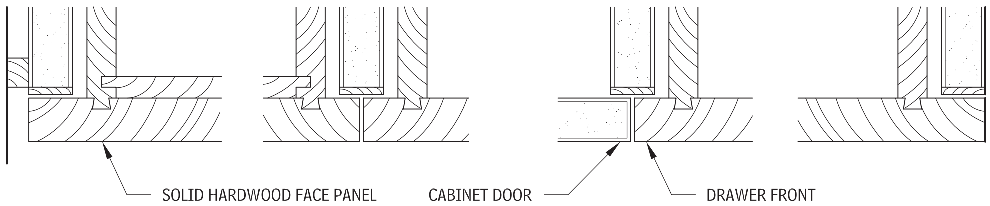


BASE CABINET

FLUSH OVERLAY CONSTRUCTION—HORIZONTAL SECTIONS
14.84



WALL CABINET - SECTION B-B



BASE CABINET - SECTION C-C

FLUSH OVERLAY CONSTRUCTION

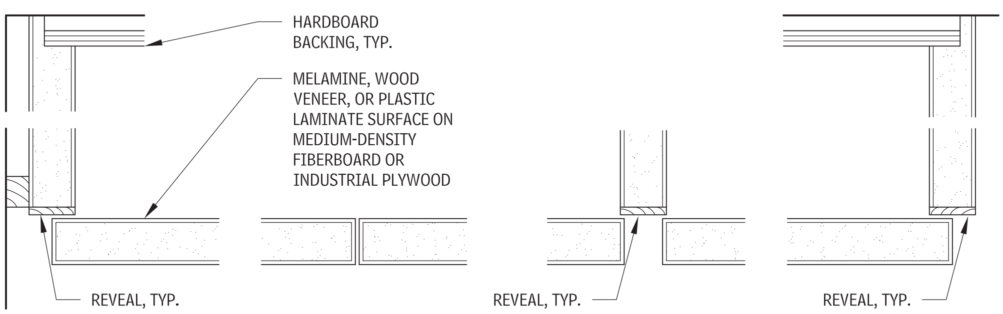
Flush overlay construction offers a clean, contemporary design because only the doors and drawer fronts are visible in elevation. The grain between doors and drawer fronts can be matched by cutting all pieces from the same panel. This cabinet style lends itself well to the use of plastic laminate for exposed surfaces. Conventional and concealed hinges are available for a variety of door thickness. Door and drawer joinery and materials may vary from the selection shown in the details.

REVEAL OVERLAY CONSTRUCTION

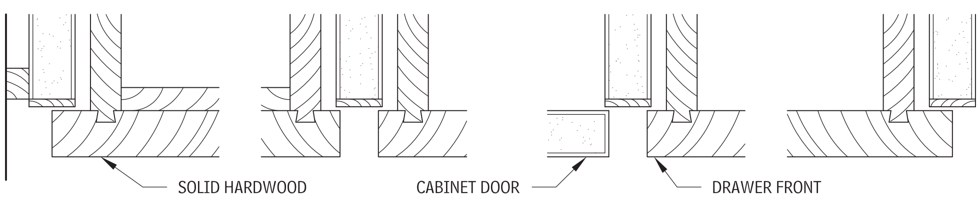
In this style of cabinet construction, the separation between doors and drawer fronts is accented by the reveal. The style is suited equally to either wood or plastic laminate construction. Figure 14.86 indicates a reveal at vertical and horizontal joints, but the designer may vary this arrangement.

A reveal wider than 1/2 in. requires the addition of a face frame, which would change the hinge requirements. With or without a face frame, this style allows the use of conventional or concealed

REVEAL OVERLAY CONSTRUCTION—HORIZONTAL SECTIONS
14.85



WALL CABINET SECTION B-B



BASE CABINET SECTION C-C

Contributor:
Greg Heuer, Architectural Woodwork Institute, Reston, Virginia.

hinges. Door/drawer joinery and materials may vary from selections shown Figure 14.86.

FLUSH INSET CONSTRUCTION WITHOUT FACE FRAME

In this style of construction, all door and drawer faces are flush with the face of the cabinet. This style allows the use of door and drawer fronts with different thicknesses.

Conventional as well as concealed hinges are available for a variety of door thicknesses. The material chosen for the case and doors and drawers influences the choice of hinges. In general, avoid conventional butt hinges when hinge screws would be attached to the edge grain of panel products.

Flush inset construction without any face frame is generally an expensive style, because increased care is necessary to fit and align the doors and drawers. The design features of this casework style are the same as for conventional flush construction with face frame, except that, here, the face frame has been eliminated.

This style does not lend itself to the economical use of plastic laminate covering finishes. Door/drawer joinery and materials may vary from those shown in Figure 14.87.

FLUSH INSET CONSTRUCTION WITH FACE FRAME

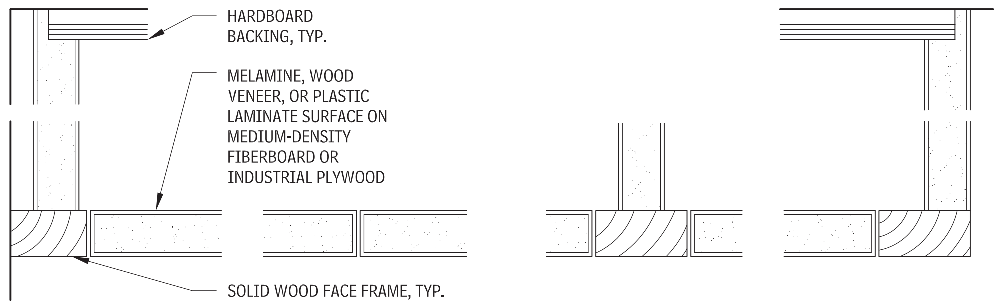
In this style of construction, all door and drawer faces are flush with the face of the cabinet. This style allows the use of different thicknesses for door and drawer fronts.

Conventional as well as concealed hinges are available for a variety of door thicknesses. The hinges chosen depend on the case and door/drawer material chosen. In general, avoid conventional butt hinges when hinge screws would be attached to the edge grain of panel products.

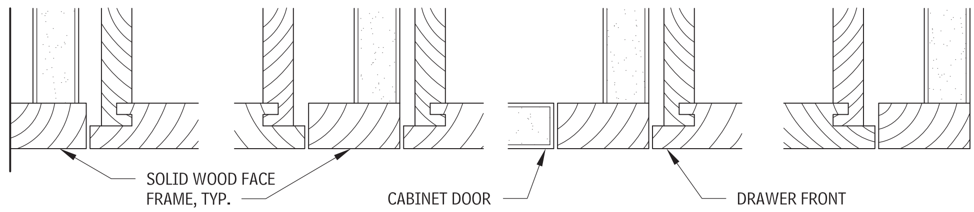
Flush inset construction with face frame is generally the most expensive cabinet door style because, in addition to the cost of providing the face frame, there is the cost of the increased care needed to fit and align the doors and drawers.

This style does not lend itself well to the economical use of plastic laminate surfaces. Door/drawer joinery and materials may vary from those shown in Figure 14.87.

FLUSH INSET CONSTRUCTION WITH FACE FRAME—HORIZONTAL SECTIONS
14.86



WALL CABINET SECTION B–B

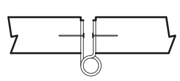
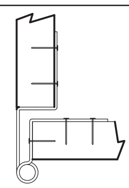
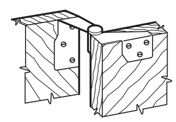
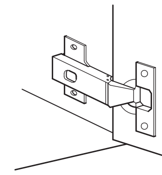
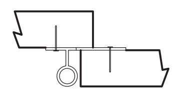
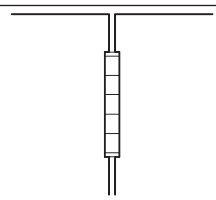
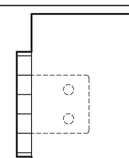
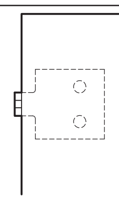
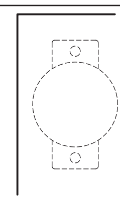
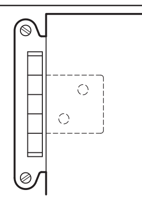
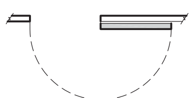
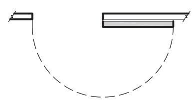
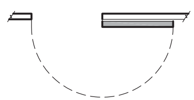
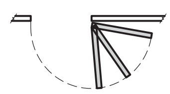
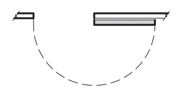


BASE CABINET SECTION C–C

CABINET HINGES AND CATCHES

Self-closing hinges spring-close the cabinet door when it is within 28° of being closed. When it is opened beyond 30°, the self-closer does not function, allowing the door to be left open. The self-closing feature eliminates the need for catches. Butt hinges are the only listed hinges not available with the self-closing feature.

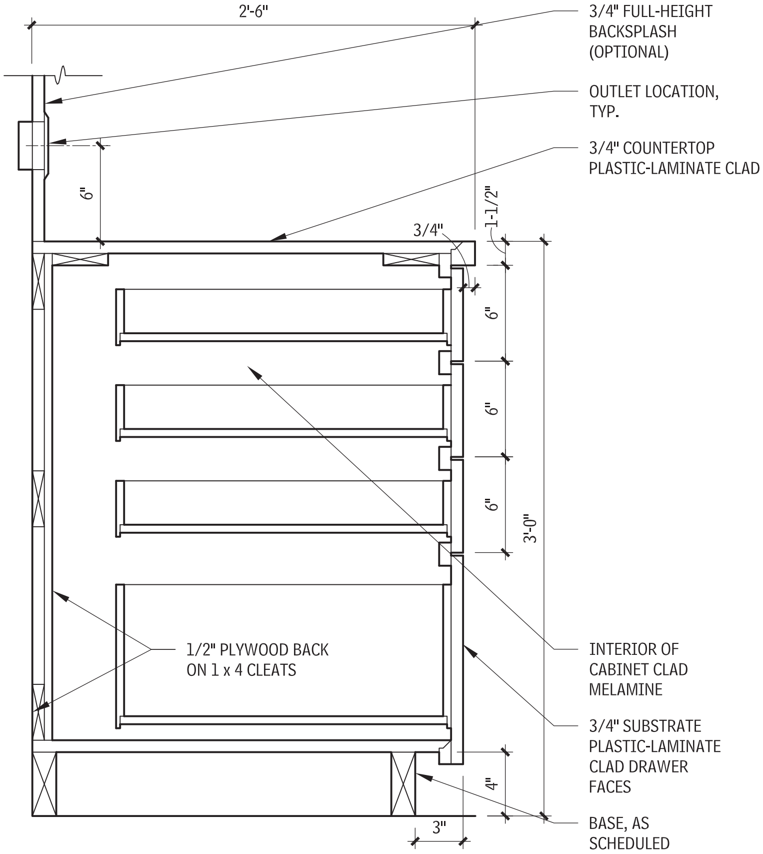
CABINET HINGES
14.87

	BUTT	WRAPAROUND	PIVOT (KNIFE)	EUROPEAN (CONCEALED)	FACE-MOUNT
Hinge type					
Elevation of cabinet face					
Door swing	180° 	180° 	180° 	95°, 125°, OR 170° 	180° 
Easily adjusted after installation?	No	No	No	Yes	Yes
Strength	High	Very high	Moderate	High to moderate	Moderate
Requires mortising?	Yes	Occasionally	Usually	Yes	No
Cost of hinge	Low	Moderate	Low	High	Low
Ease of installation	Moderate	Easy	Moderate	Very easy	Easy
Adjustability	No	One-way	Two-way	Three-way	No
Easily adjusted after installation?	No	No	No	Yes	No

Contributor:
Greg Heuer, Architectural Woodwork Institute, Reston, Virginia; Architectural Woodwork Institute, Reston, Virginia and Kelsey Kruse, AIA, George Vaeth Associates, Inc., Columbia, Maryland..

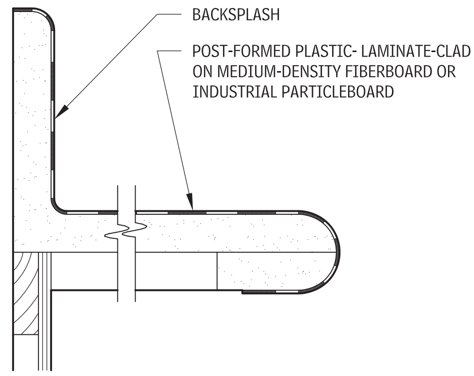
BASE CABINET CONSTRUCTION

BASE CABINET
14.88

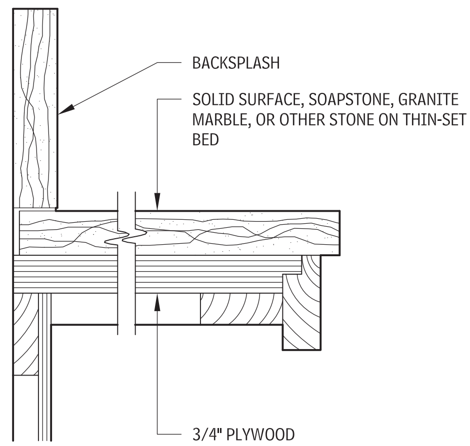


COUNTERTOPS

COUNTER AND BACKSPLASH DETAILS
14.89

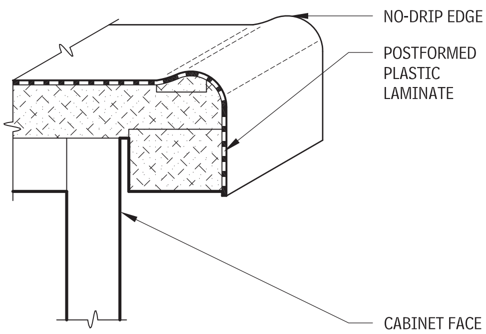


POST-FORMED PLASTIC-LAMINATE-CLAD COUNTERTOP

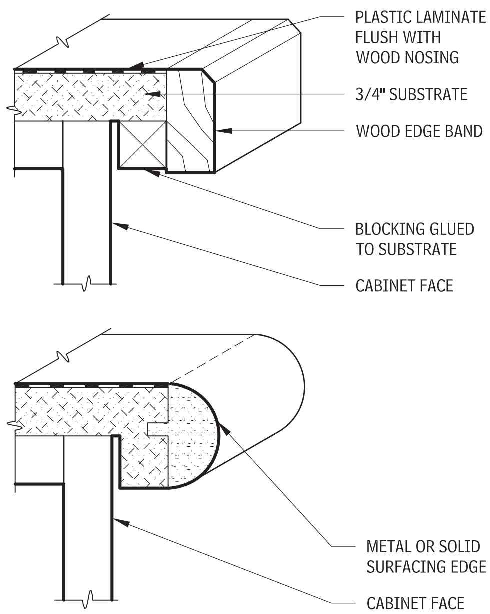


STONE COUNTERTOP

POSTFORMED EDGE
14.90



APPLIED EDGES
14.91

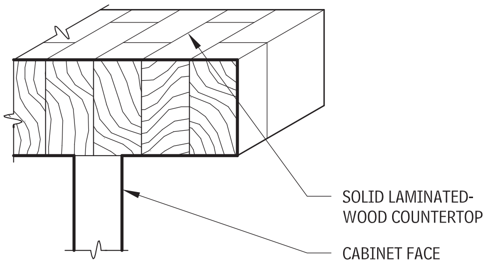


NOTES

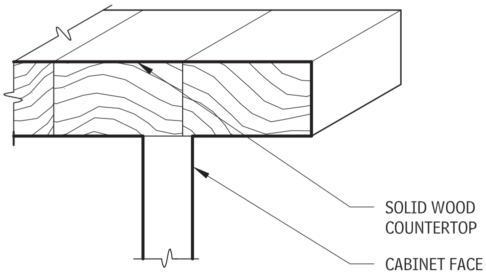
14.90 Postformed edge helps to contain spills.
14.91 Applied edges can be wood, metal, or solid-surfacing, and can be adhered to the countertop substrate. Depending on the edge detail, the applied edge can protect the plastic laminate surface from damage.

Contributor:
Architectural Woodwork Institute, Reston, Virginia.

SOLID-WOOD LAMINATED COUNTERTOPS
14.92

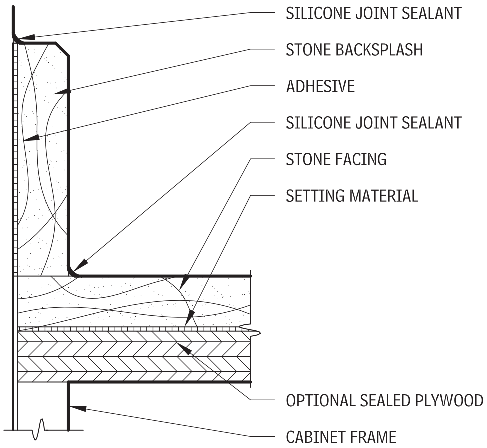


BUTCHER BLOCK

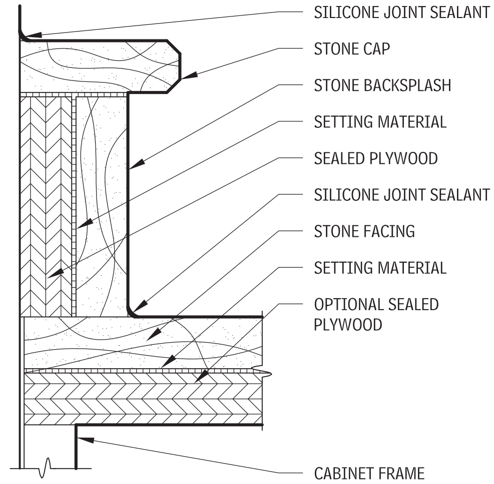


EDGE-GLUED BOARDS

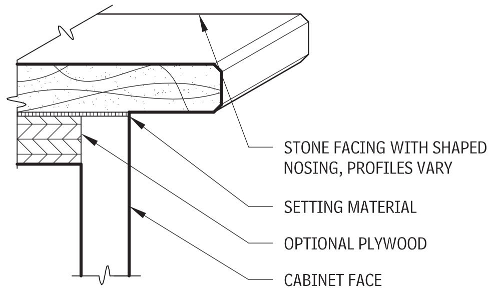
STONE COUNTERTOP DETAILS
14.94



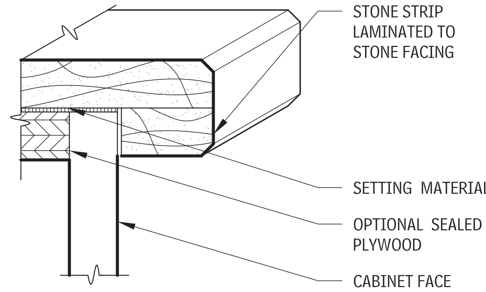
BACKSPLASH



BACKSPLASH WITH LEDGE CAP

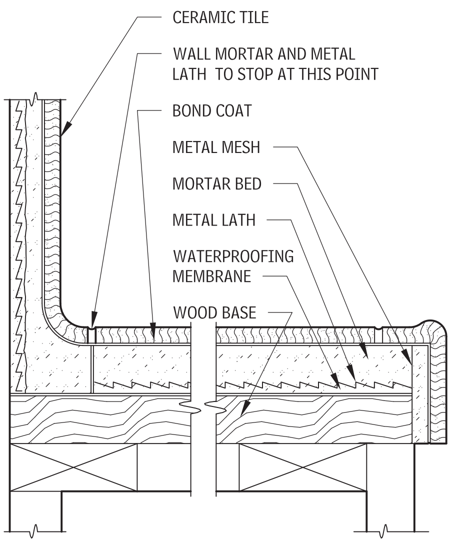


SLAB-EDGE

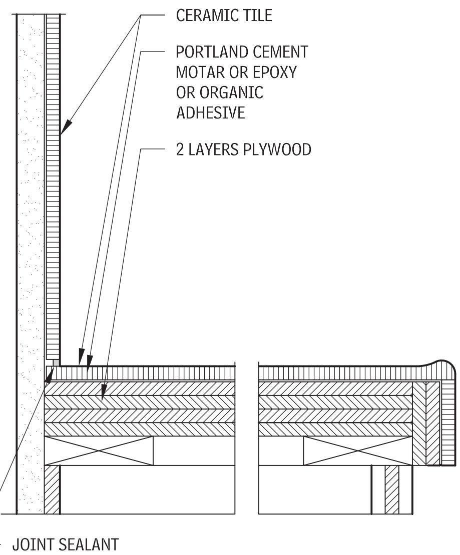


LAMINATED NOSING

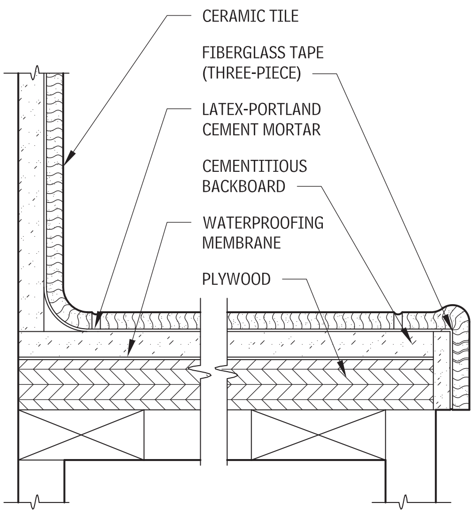
CERAMIC TILE COUNTERTOPS
14.93



MORTAR-BED SET



THIN-SET



CEMENTITIOUS BACKBOARD

FIXED SEATING

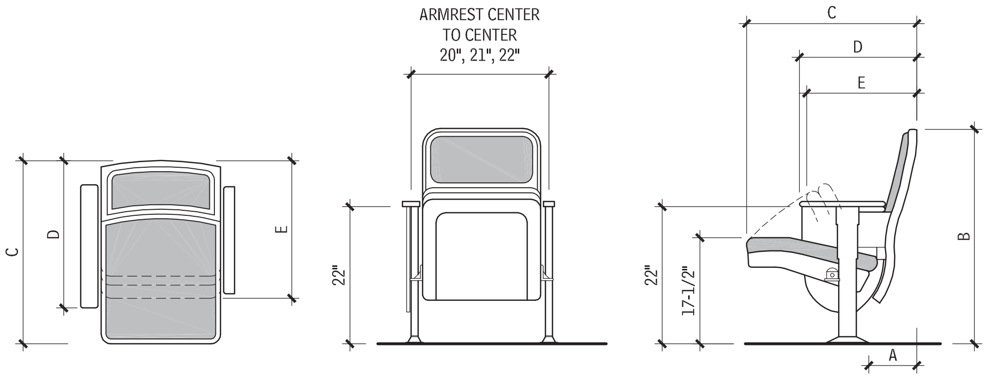
FIXED AUDIENCE SEATING

Fabricated fixed auditorium and theater seating is available in a wide range of styles, sizes, and configurations. Variables include the degree of back pitch and preferred seat width (center-to-center spacing). Removable and folding seating is available to meet accessibility requirements.

LECTURE HALL SEATING

Lecture hall seating often incorporates a writing surface, either through a foldaway option or by affixing a work surface onto the back of the chair in the previous row.

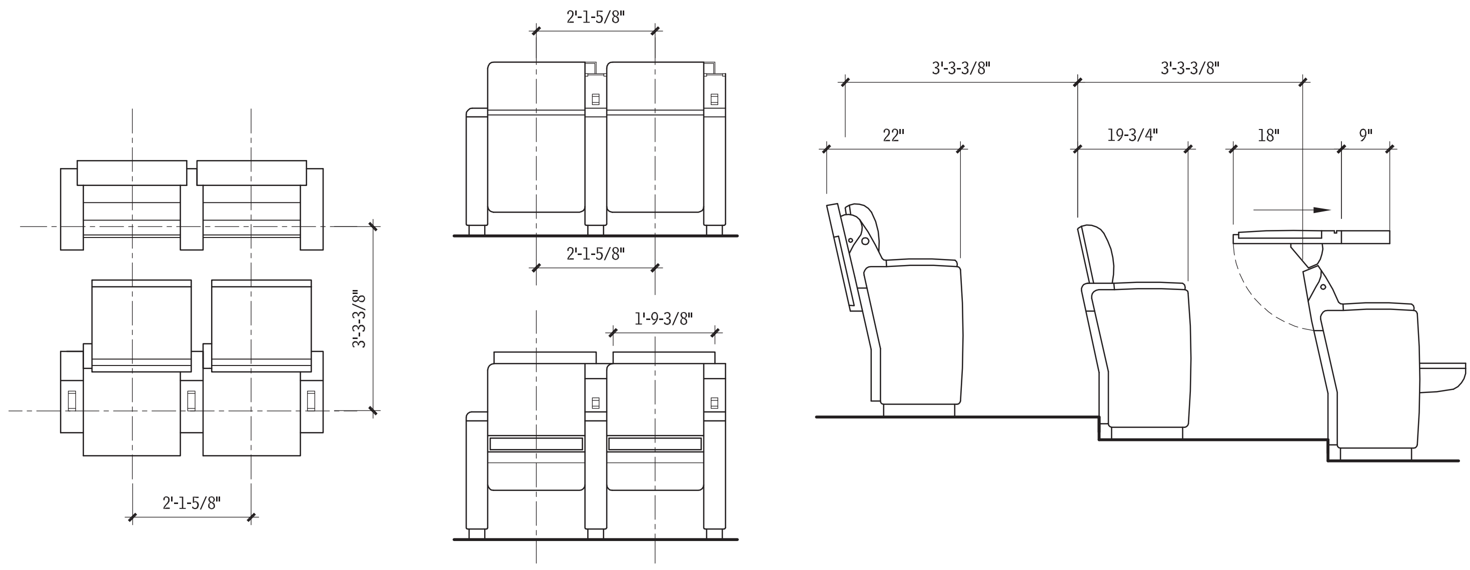
AUDITORIUM/THEATER SEATING
14.95



PLAN **ELEVATION** **SECTION**

DEGREE OF PITCH	18	22	26
A: Back pitch allowance (in.)	9–1/2	11	12
B: Overall height (in.)	35–1/2	35	34
C: Seat depth, down (in.)	27	28–1/4	29–1/2
D: Depth of back to end arm (in.)	21–1/2	23	24
E: Seat depth, up (in.)	19–1/2	20–3/4	22

LECTURE HALL SEATING
14.96



PLAN **ELEVATION** **SECTION**

NOTE

14.95 Consult manufacturers for actual dimensions.

RESTAURANT AND BAR SEATING

The dining rooms and bars in restaurants must be efficiently planned to optimize revenue. Upscale restaurants generally require more space between tables for privacy. The restaurant concept, menu, and operation style also influence space allocation. Depending on the type of restaurant and menu, kitchen areas range from 30 to 45 percent of the total restaurant area.

Building codes identify restaurants as assembly spaces. Comply with local code requirements for construction, including plumbing fixture counts.

The local department of health reviews restaurants for compliance with regulations for general sanitation in food handling and proper food storage.

Dimensions shown in Figure 14.100 are minimum clearances, and seating layouts indicate general configurations; they are not intended to depict any specific type of operation. Tables may be converted from square to round to enlarge seating capacity. Booth seating makes effective use of corner space. An accessible route, at least 36 in. wide, is required to connect the entrance, accessible fixed seating, and restrooms.

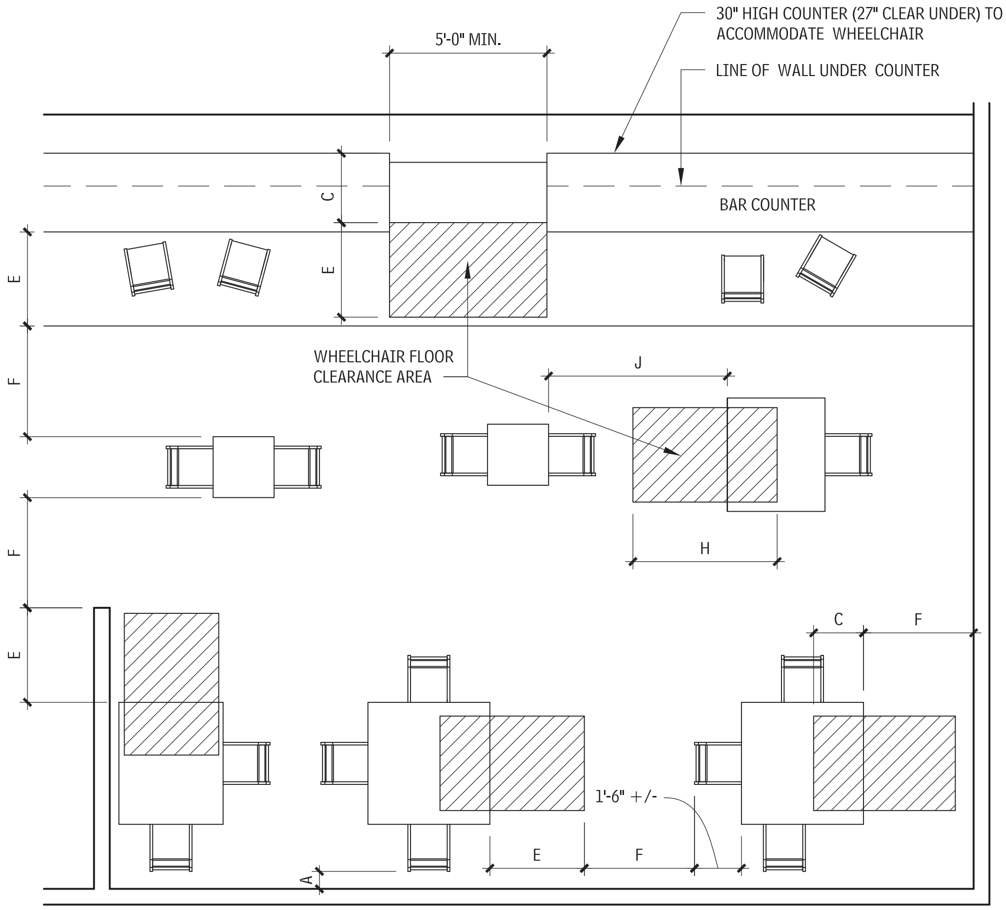
PRELIMINARY GUIDE FOR FRONT-OF-HOUSE AREAS
14.97

FOOD SERVICE VENUE	SUGGESTED AREA PER PATRON (SQ FT)
Banquet facility	10–11
Fast food	11–14
Full-service	15–18
Cafeteria	6–18
Upscale gourmet	17–22

DINING AND BAR AREA

Restaurant patrons typically form their first impression of a restaurant from the main dining room and bar areas. The restaurant concept may offer a variety of space types, including open or multilevel dining areas, secluded alcoves, private dining rooms, or features such as display cooking areas. A mix of seating and table types, adequate aisle and serving areas, and well-chosen materials and lighting combine to create a comfortable, inviting dining environment.

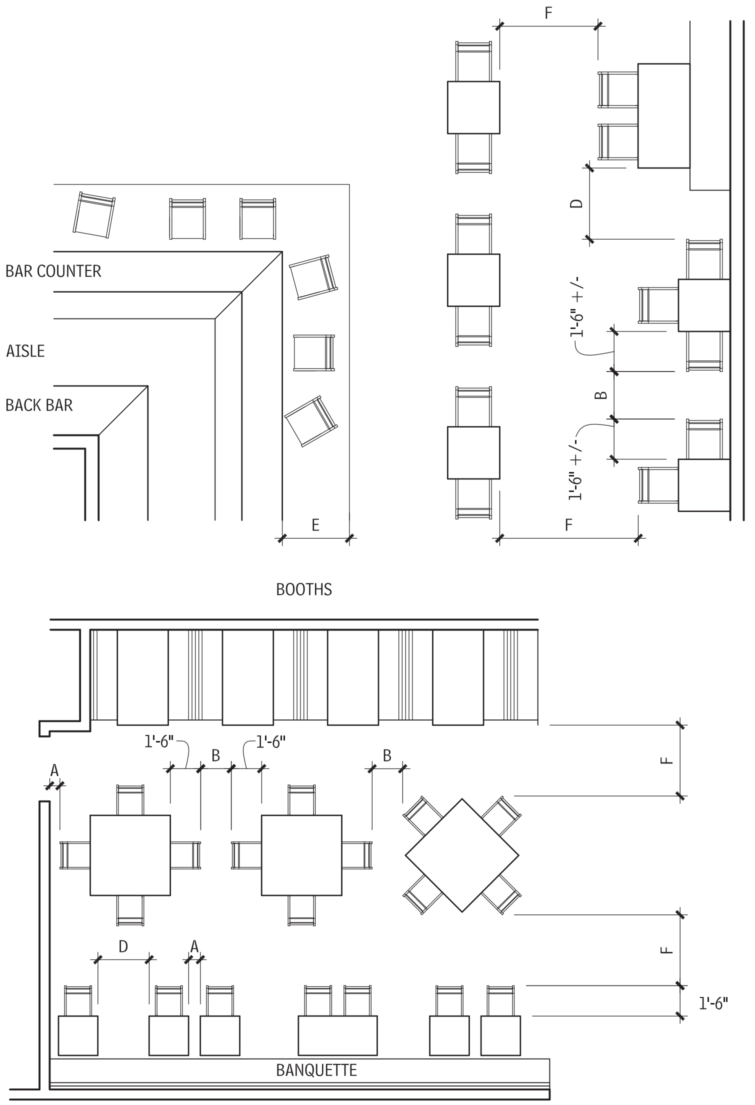
SEATING ARRANGEMENTS FOR PERSONS USING WHEELCHAIRS
14.98



NOTE

14.98 Refer to Figure 14.100 for clearances.

TYPICAL SEATING ARRANGEMENTS
14.99



Integrate 5 percent accessible seating allocation, distributed among various seating types, to accommodate both large and small groups. Consult codes, standards, and regulations for specific requirements for accessible seating and distribution. Tables, which should have rounded ends, are often 2 in. shorter than the booth seating.

Flexibility in dining spaces is an asset. Private dining and compartmentalization of the main dining areas provide a means of accommodating large or small groups of diners without disrupting the general dining area.

Bar areas may be open to the dining area or separate, possibly with a different design aesthetic from the main dining area. Hours of use, smoking areas (if allowed), and acoustics influence the location and adjacency of the bar to the dining area.

CLEARANCES
14.100

	DIMENSION (IN.)
A	6 minimum (NO PASSAGE)
B	18 (LIMITED PASSAGE)
C	19
D	30
E	30
F	42
G	48
H	54
I	72

WAITSTAFF SERVICE STATIONS

Waitstaff service stations are located between the front of the house and the back of the house. Service stations are typically furnished with equipment, supplies, and selected beverages. Many service stations include a point-of-service (POS) terminal to calculate patron bills and process credit card receipts, depending on the operations preference of the restaurant owner. The size and configuration of the space may determine the number of waitstaff stations/POS terminals.

FIXED BOOTHS AND BANQUETTES

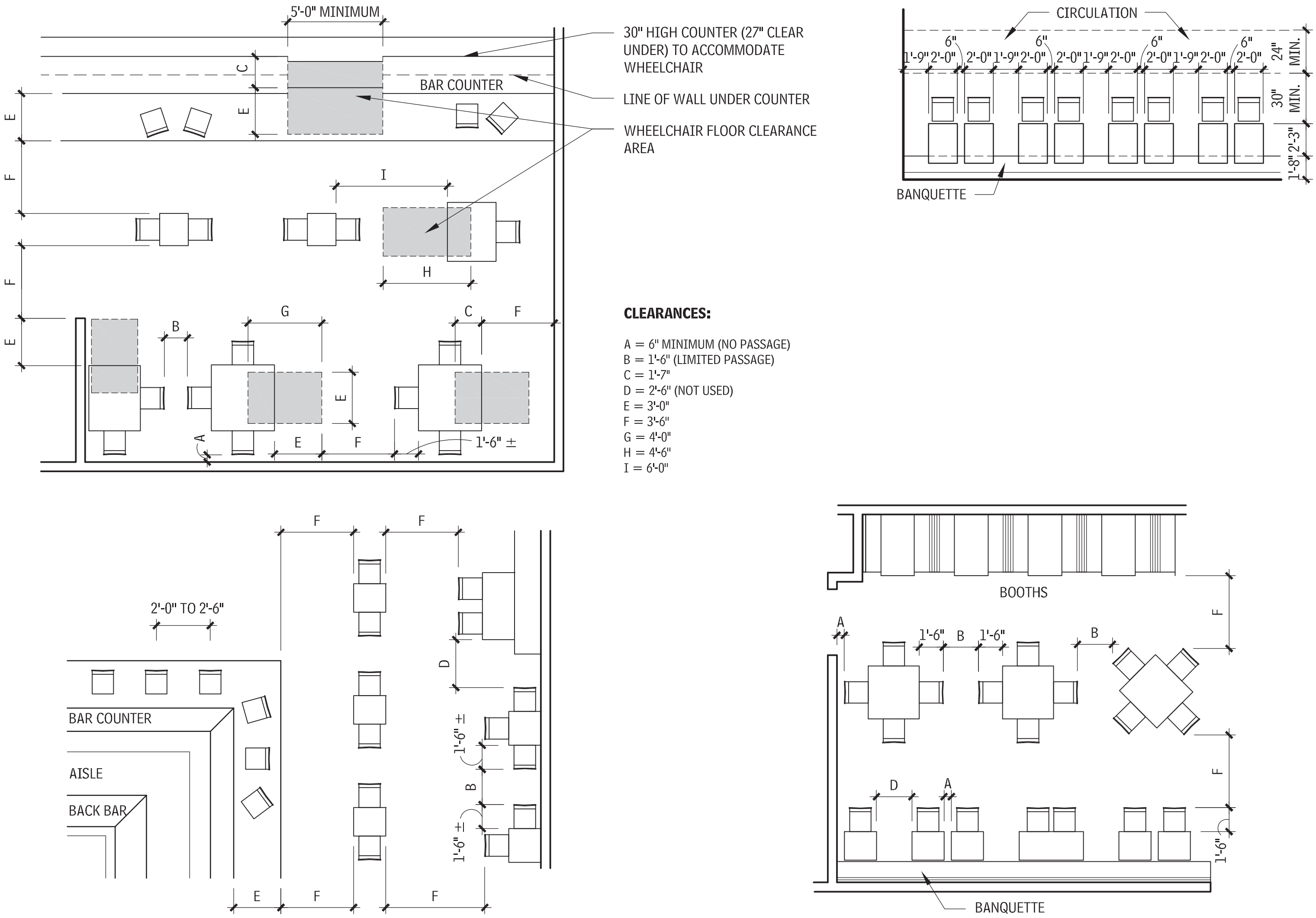
Banquettes can be used to provide comfortable, flexible seating arrangements and to serve as mid-height privacy screens. The table size mix can vary at banquette areas by locating tables next to one another or separately. Two tops, for example, can be combined to create a table for four or more diners. Booths are desirable for comfort, privacy, and intimacy.

Note that booth sizes may be determined by local building codes.

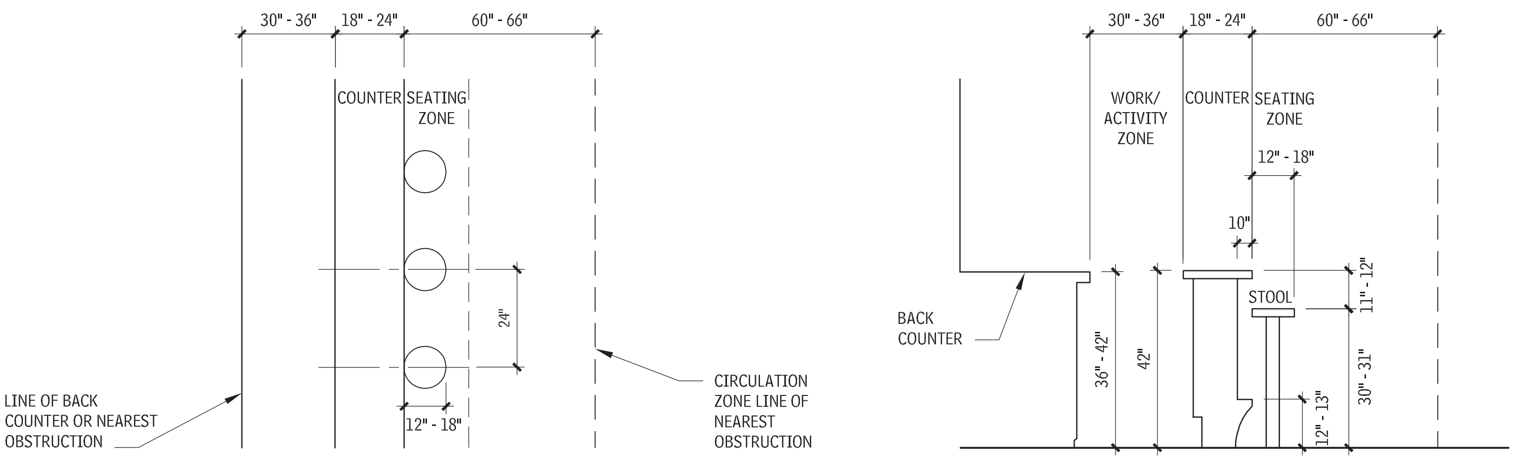
RESTAURANT FIXED COUNTERS AND STOOLS

The design of restaurant counter service areas must allow for adequate workspace clearance behind the counter. The clearance from the top of the seat to the underside of the countertop and the depth of the countertop overhang are critical. Often, footrests that are applied to the counter are located such that the patron's leg is not supported; it is more likely to be successful for seated patrons when the footrest is integral to the stool. Standing patrons will often use the counter-mounted footrest. Footrests prevent accessibility, and should not be included at accessible portions of counters.

BANQUETTE SEATING
14.101



COUNTER WITH FIXED SEATING
14.102



MOVABLE FURNISHINGS

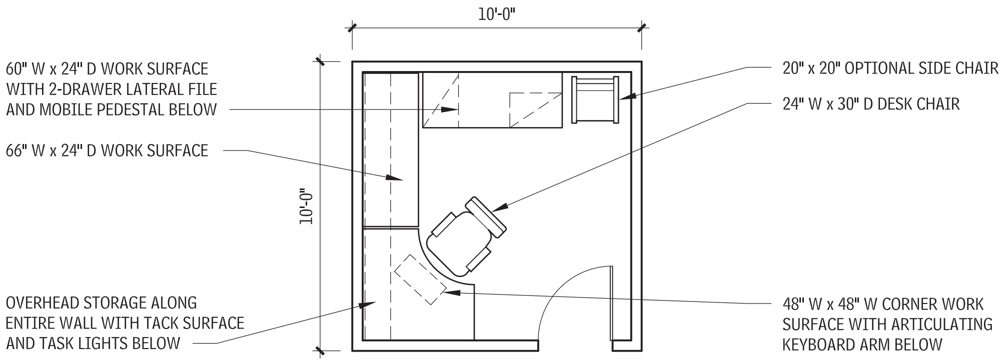
OFFICE FURNITURE

OFFICE FURNISHINGS DESIGN CONSIDERATION

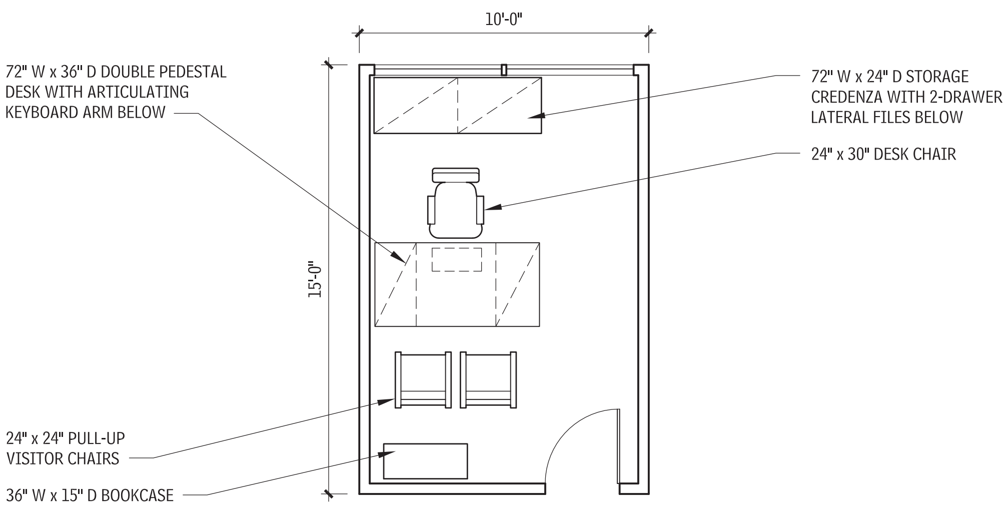
When planning the furnishing of office spaces, use these guidelines:

- The standard height for surfaces in an office is 28 to 30 in.
- The standard height for work surfaces that will accommodate a computer and/or a keyboard ranges from 25 to 30 in. Keyboards can be accommodated on a work surface either by lowering the work surface or installing an articulating keyboard arm under a standard-height work surface.
- Work surface depths typically range from 18 to 45 in., depending on the type and size of work being completed: 18 in. is used for storage, 30 in. is the standard desk depth, and 45 in. is used to accommodate conferencing.
- Occasionally, an office must accommodate stand-up work surfaces. The height of the work surfaces range from 36 to 52 in.
- Overhead storage above a work surface is standard, with 15- to 18-in. clearance.
- Knee space is integral to the use of desks, tables, and workstations. To serve wheelchair users, knee space with a clear height of approximately 2 ft-3 in. is sufficient.

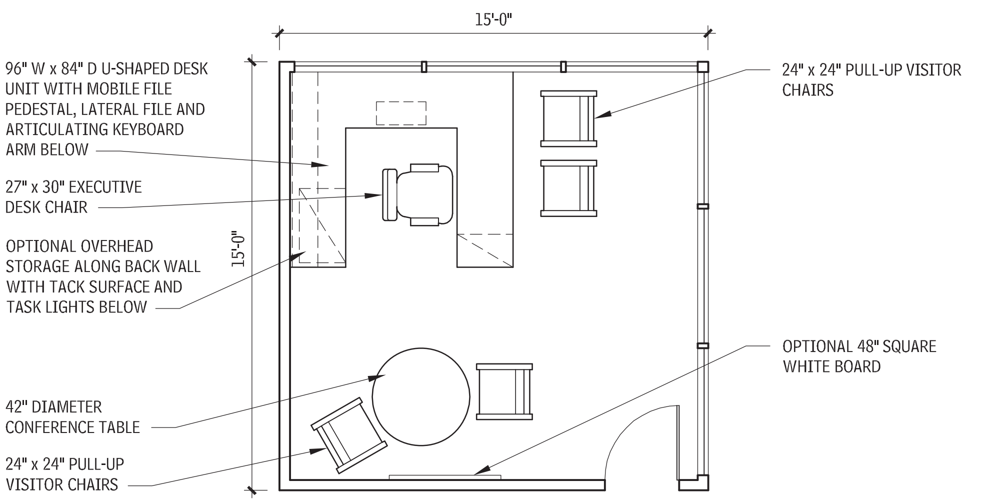
INTERIOR OFFICE—100 SQ FT
14.103



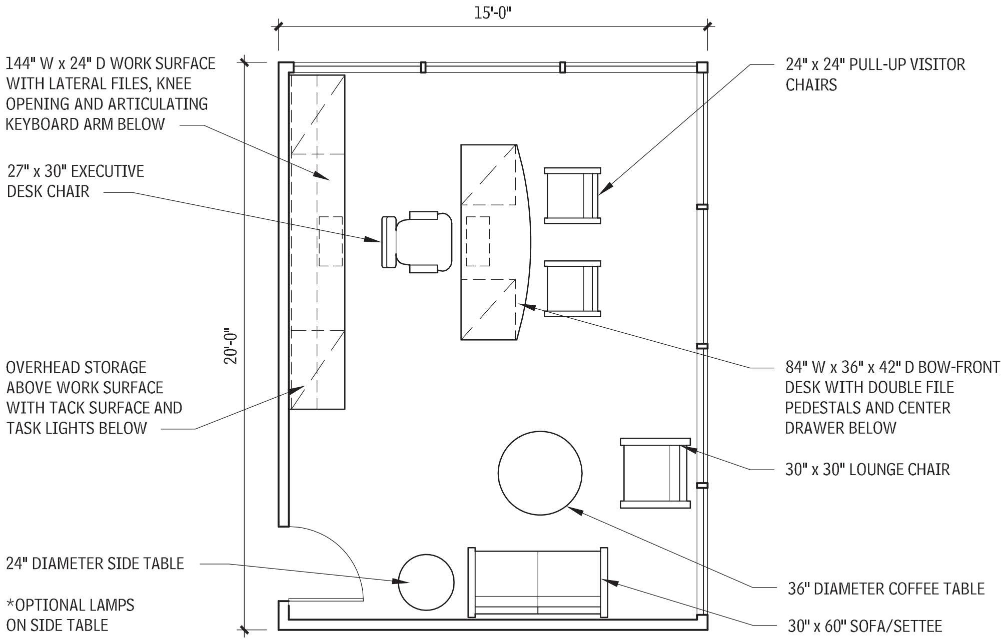
PERIMETER OFFICE, TRADITIONAL LAYOUT—150 SQ FT
14.104



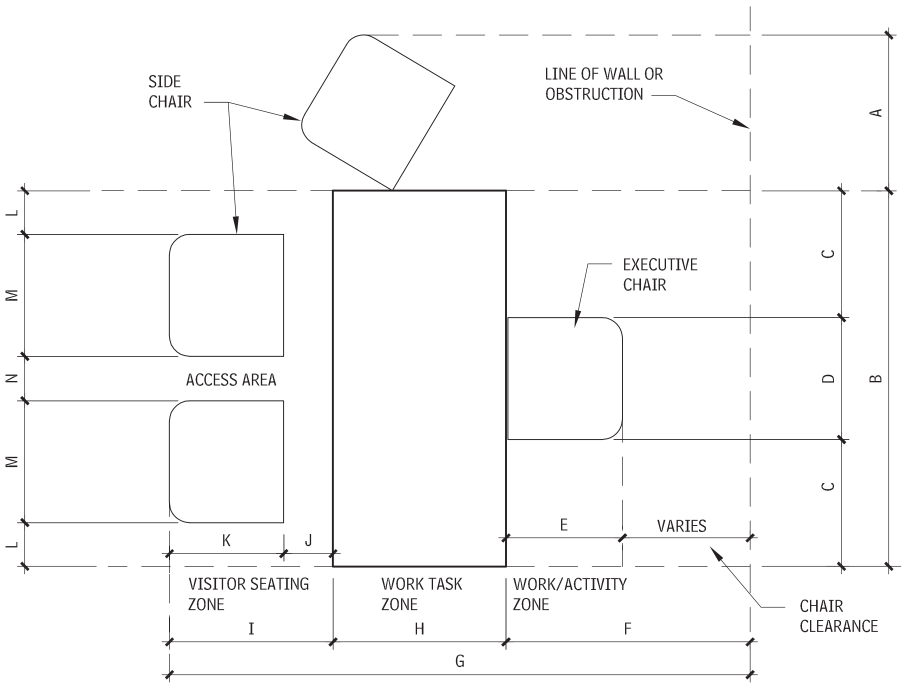
CORNER OFFICE, TRADITIONAL LAYOUT—225 SQ FT
14.105



CORNER OFFICE, WINDOW VIEW LAYOUT—300 SQ FT
14.106



OFFICE SPACE DIMENSIONS (IN.)
14.107



A	30–42
B	60–84
C	18–28
D	24–30
E	23–29
F	36 minimum
G	96–126
H	30–45
I	30–44
J	10–14
K	20–30
L	4–16
M	20–30
N	8–16

CONFERENCE ROOMS

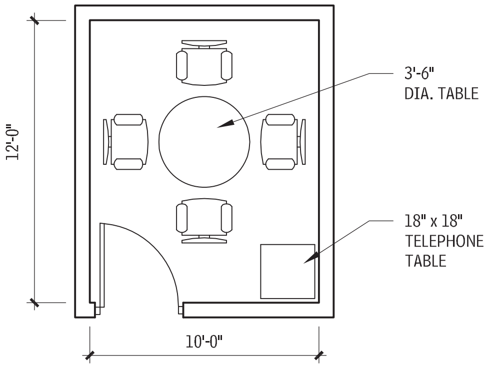
Conference rooms should be located in proximity to user groups. A conference room typically serves multiple groups or departments, therefore rooms in a high-rise office building may be organized near elevator banks on crossover floors for ease of access by many users. When a conference room functions as a flexible space, the location of entry/exit doors is positioned so that acoustic folding partitions or movable walls may be used to divide a larger space into smaller meeting areas.

CONFERENCE ROOM DESIGN RECOMMENDATIONS
14.108

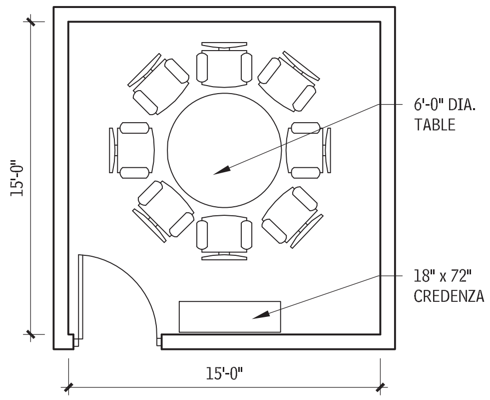
	OPTIMAL	MINIMUM
Chair spacing	3′–0″	2′–6″
Clearance around table	5′–0″	3′–6″
Clearance at head of table	7′–0″	5′–0″
Chair width (including arms)	26″	22″
Chair depth	25″	21″
Credenza depth	24″	18″
Table width (single seat at end)	60″	30″
Table width (double seat at end)	72″	60″
Round table seating capacity	(3.1425 × D) ÷ 36″	(3.1415 × D) ÷ 30″

Contributor:
Tammy Cavin and Tama Duffy Day, Perkins+Will, Washington, DC.

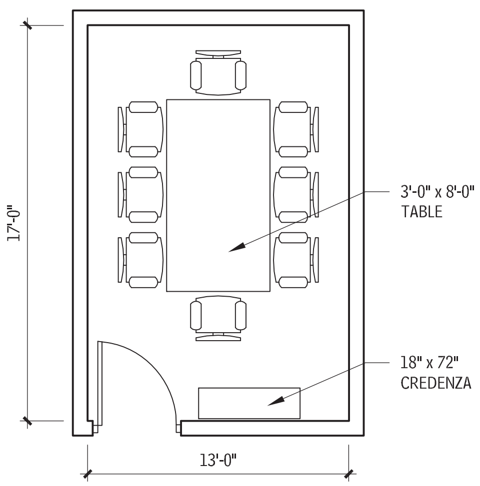
SMALL CONFERENCE ROOMS
14.109



TEAM ROOM: 120 SQ. FT.
TOTAL SEATS: 4

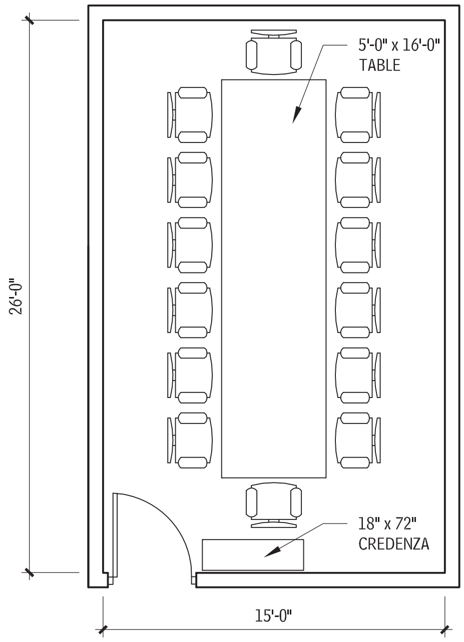


SMALL CONFERENCE ROOM: 225 SQ. FT.
TOTAL SEATS: 8

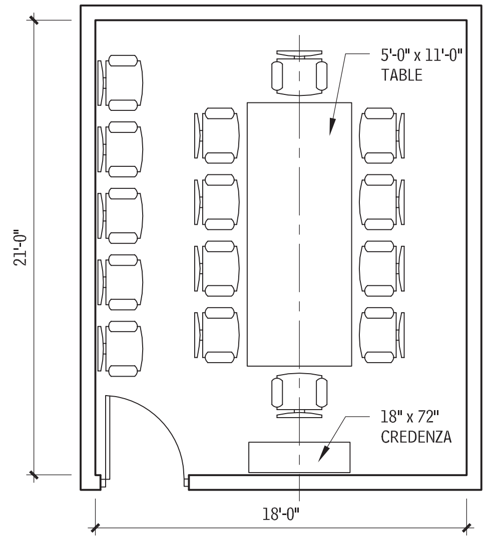


SMALL CONFERENCE ROOM: 225 SQ. FT.
TOTAL SEATS: 8

MEDIUM CONFERENCE ROOMS
14.110



MEDIUM CONFERENCE ROOM: 400 SQ. FT.
TOTAL SEATS: 12 - 14



MEDIUM CONFERENCE ROOM: 400 SQ. FT.
TOTAL SEATS: 10 - 15

CONFERENCE TABLES

Conference room table size and configuration influence the room size as well as the comfort of the occupants. A typical standard table size that can be used in most conference rooms improves efficiency in room layout, as well as in furniture storage and retrieval.

Tables in trapezoidal or other shapes permit flexibility in nonstandard table arrangements, which may be useful for situations such as videoconferencing. Modular tables provide greater flexibility in room layout than one large table. Consider room usage and quality level in determining table types and styles. Large tables should be broken into smaller modules for ease of installation.

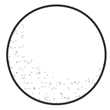
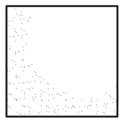
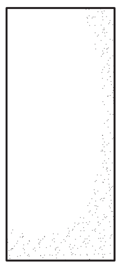
Table materials and finishes should reflect the function and quality level of the intended conference or training function. High-end quality rooms may be appropriate for custom tables of wood, stone, and glass. Midlevel conference room and training tables should be durable and comfortable, offer the appropriate features, and be cost-effective and easy to store.

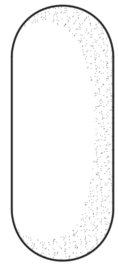
- Tabletop finishes can include plastic laminate, linoleum, wood veneer, and other materials.
- Edge materials, including wood, rubber, and leather, provide additional protection and/or comfort.
- Beveled and eased table edges provide greater comfort than squared edges, and are less subject to edge damage.
- Table edges that are beveled on the underside provide more room for chair arms.

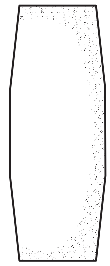
Follow these guidelines for designing conference and training tables:

- The optimum dimension for each occupant is 30 in., which allows for an average-size chair and space between occupants, without straddling table legs.
- A common table length for two persons is 60 in.
- The typical training table size is 30 in. wide, 60 in. long, and 29 in. high.
- Accessible heights should be 28 in. minimum to 34 in. maximum, with knee and toe clearance.
- Accessible tables may require special bases for clearance of a wheelchair.
- Table width should enable occupants to work comfortably and have reference space. A common minimum width is 24 in. A 30-in. or greater width can be used if space and function permits and if people are seated across from one another.
- Table bases should be stable, preferably with bearer bars.
- Folding or flip-top tables offer flexibility in room layout and usage.
- Tabletop or recessed power options include plug-in or hardwired capabilities with wire management for Local Area Network (LAN), power, and telephone.
- For computer usage, consider recessed computer monitors in special tables to improve sight lines.

SEATING CAPACITY GUIDELINES
14.111

		APPROXIMATE SEATING CAPACITY[a]	MINIMUM ROOM SIZE[b]	
ROUND TOPS				
DIAMETER (IN.)				
42		4	10′-6″ × 10′-6″	
48		5	11′-6″ × 11′-6″	
54		5	12′-6″ × 12′-6″	
60		6	13′-0″ × 13′-0″	
66		6	14′-0″ × 14′-0″	
72		7	14′-6″ × 14′-6″	
84		8	16′-0″ × 16′-0″	
96		10	18′-4″ × 18′-4″	
108		11	19′-0″ × 19′-0″	
120		12	20′-0″ × 20′-0″	
SQUARE TOPS				
DEPTH (IN.)	**WIDTH (IN.)**	**APPROXIMATE CAPACITY**	**MINIMUM ROOM SIZE[b]**	
30	30	4		
36	36	4		
42	42	4	10′-6″ × 10′-6″	
48	48	4	11′-6″ × 11′-6″	
54	54	4	12′-0″ × 12′-0″	
60	60	8	13′-0″ × 13′-0″	
RECTANGULAR TOPS				
DEPTH (IN.)	**WIDTH (IN.)**			
48	24	1		
60	24	4		
72	24	4		
84	24	3		
36	30	4	10′-0″ × 9′-0″	
48	30	4	11′-0″ × 9′-0″	
60	30	6	12′-0″ × 9′-0″	
72	30	6	13′-0″ × 9′-0″	
84	30	6	14′-0″ × 9′-0″	
96	30	8	15′-0″ × 9′-0″	
48	36	4	12′-0″ × 10′-0″	
60	36	6	12′-0″ × 10′-0″	
72	36	6	13′-0″ × 10′-0″	
84	36	6	14′-0″ × 10′-0″	
96	36	8	15′-0″ × 10′-0″	
72	42	6	13′-0″ × 11′-0″	
84	42	6	14′-0″ × 11′-0″	
96	42	8	15′-0″ × 11′-0″	
108	42	8	16′-0″ × 11′-0″	
120	42	10	17′-0″ × 11′-0″	
72	48	6	13′-0″ × 12′-0″	
84	48	8	14′-0″ × 12′-0″	
96	48	8	15′-0″ × 12′-0″	
108	48	10	16′-0″ × 12′-0″	
120	48	12	17′-0″ × 12′-0″	

		APPROXIMATE CAPACITY	MINIMUM ROOM SIZE[b]	
RACETRACK TOPS				
DEPTH (IN.)	**WIDTH (IN.)**			
72	36	6	13′-0″ × 10′-0″	
96	48	6	15′-0″ × 12′-0″	
120	48	8	17′-0″ × 12′-0″	
144	48	10	17′-0″ × 12′-0″	
120	60	10	17′-0″ × 15′-0″	
144	60	10	20′-0″ × 15′-0″	
180	60	12	21′-0″ × 15′-0″	
216	60	14	25′ 0″ × 15′-0″	
240	60	16	30′-0″ × 15′-0″	

BOAT TOPS					
DEPTH (IN.)	**WIDTH—CENTER**	**WIDTH—END**			
72	36	30	6	13′-0″ × 10′-0″	
84	38	31	6	14′-0″ × 10′-0″	
96	40	32	8	15′-0″ × 10′-0″	
120	44	33	10	17′-0″ × 12′-0″	
144	48	34	10	21′-0″ × 14′-0″	
168	52	35	12	23′-0″ × 15′-0″	
192	56	36	14	26′-0″ × 17′-0″	
216	60	37	16	29′-0″ × 18′-0″	
240	60	38	18	32′-0″ × 18′-0″	
264	60	39	20	35′-0″ × 18′-0″	
288	60	40	20	39′-0″ × 18′-0″	

NOTES

14.111 a. Approximate seating estimates are based on 30 in. per person. Chair widths are assumed to be 25 in., plus 5-in. space between chairs. Adjust these guidelines to accommodate the width of the chair.
b. These are minimum-sized rooms. When planning a conference room, provide an optimal clearance of 5 ft-0 in. around the table with 7 ft. -0 in. at the head of the table.

Contributor:
Vecta, Grand Prairie, Texas.

SEATINGS

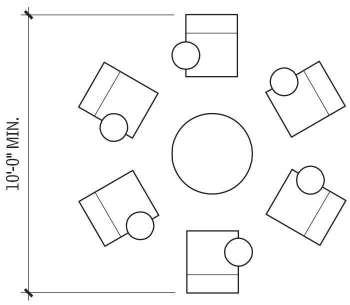
LOUNGE FURNITURE

Lounge seating is typically used in commercial interiors for waiting areas, lounges, and similar spaces. Sofas, love seats, lounge chairs, pull-up chairs, tables, and consoles comprise the typical furnishings. Each component is available in a wide variety of styles, shapes, and sizes, with a multitude of material and fabric options. This product differs from its residential counterpart in its increased durability and compliance with fire codes. Furniture arrangements, their related spatial requirements and individual furnishing dimensions indicated in Figures 14.112 through 14.119 are for preliminary design purposes; dimensions capture typical size ranges. Consult manufacturers for specific options and dimensions. The choice of lounge furniture will depend upon the space available (obviously, larger spaces allow for larger furniture); flooring materials (hard-surface materials that are maintained with wet mopping dictate furniture that does not have upholstery touching the floor); and the composition of the users. Specialty lounge furniture products are available to address the particular needs of special populations: elderly, obese (bariatric seating), and college (dormitory) are a few examples of such products.

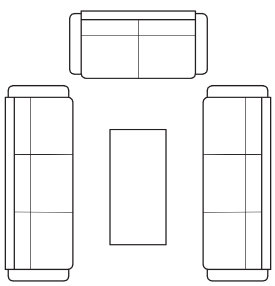
- For ambulatory people who have difficulty maintaining their balance, chairs should be stable, to provide support.
- Chairs equipped with armrests help ambulatory users to sit and rise, and are generally more comfortable.
- Wheelchair users who transfer diagonally can use chairs with armrests.
- People who transfer from a parallel position must have clear side access, which is offered by chairs without fixed armrests.
- Chair leg supports and cross-bracing should not obstruct kick space below the seat. Kick space allows chair occupants to position their feet partially beneath the body in order to rise.

SEATING ARRANGEMENTS

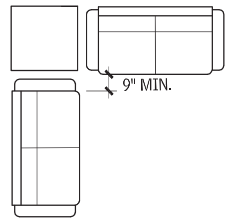
TABLET ARM LOUNGE CHAIRS
14.112



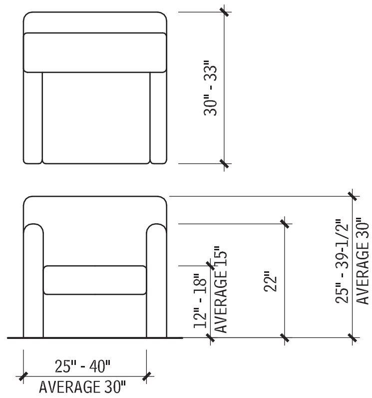
SOFAS AND LOVE SEAT
14.113



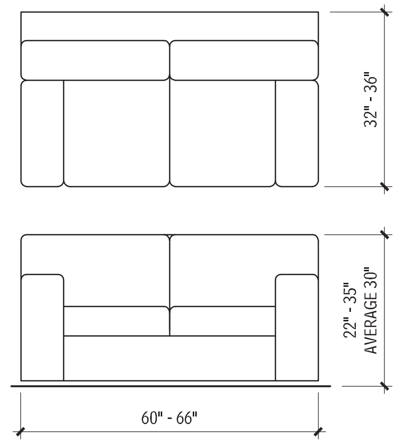
CORNER ARRANGEMENT
14.114



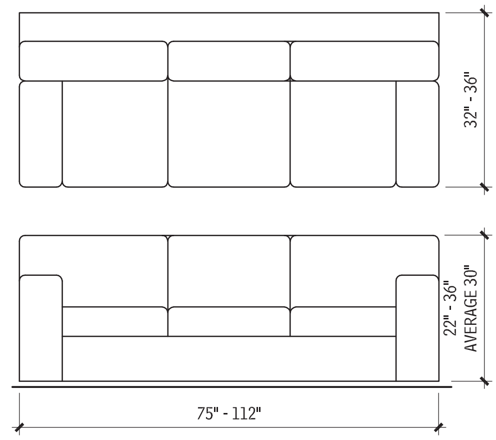
LOUNGE CHAIR
14.115



LOVE SEAT
14.116

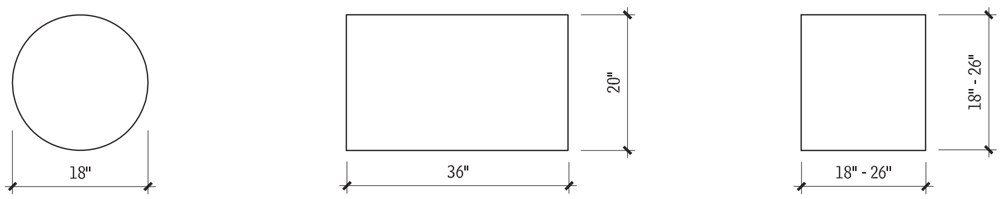


SOFA
14.117



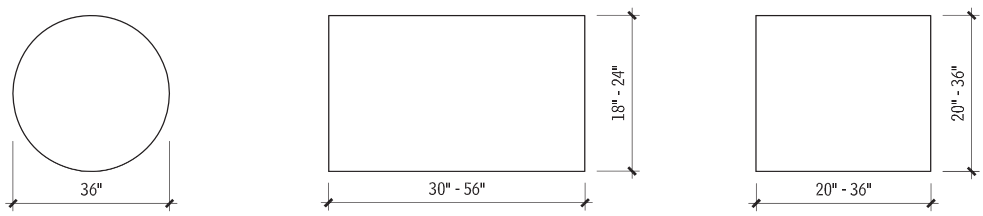
TABLES

SIDE TABLES
14.118



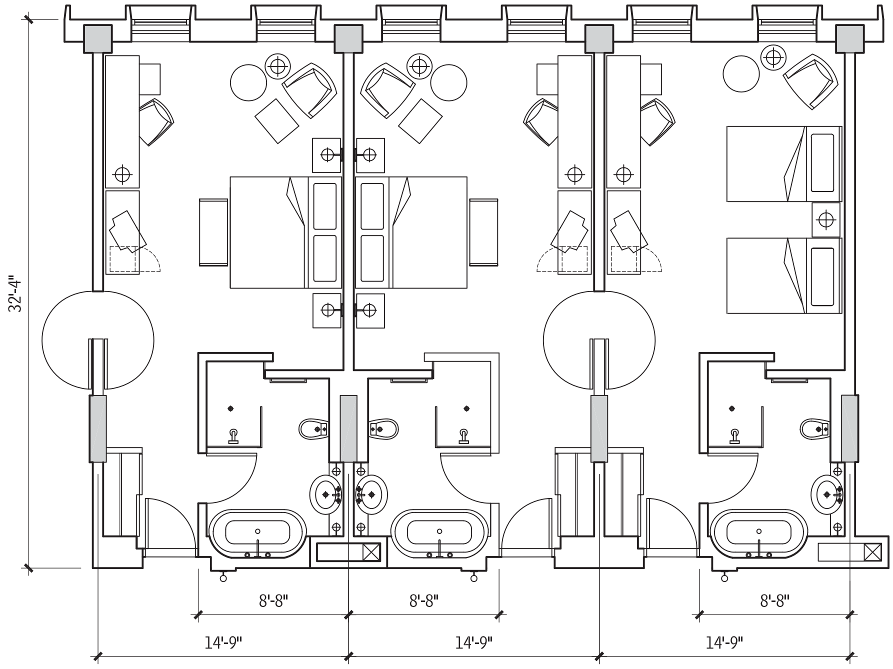
H = 18" H = 18" H = 18"

COFFEE TABLE
14.119



H = 18" H = 18" H = 18"

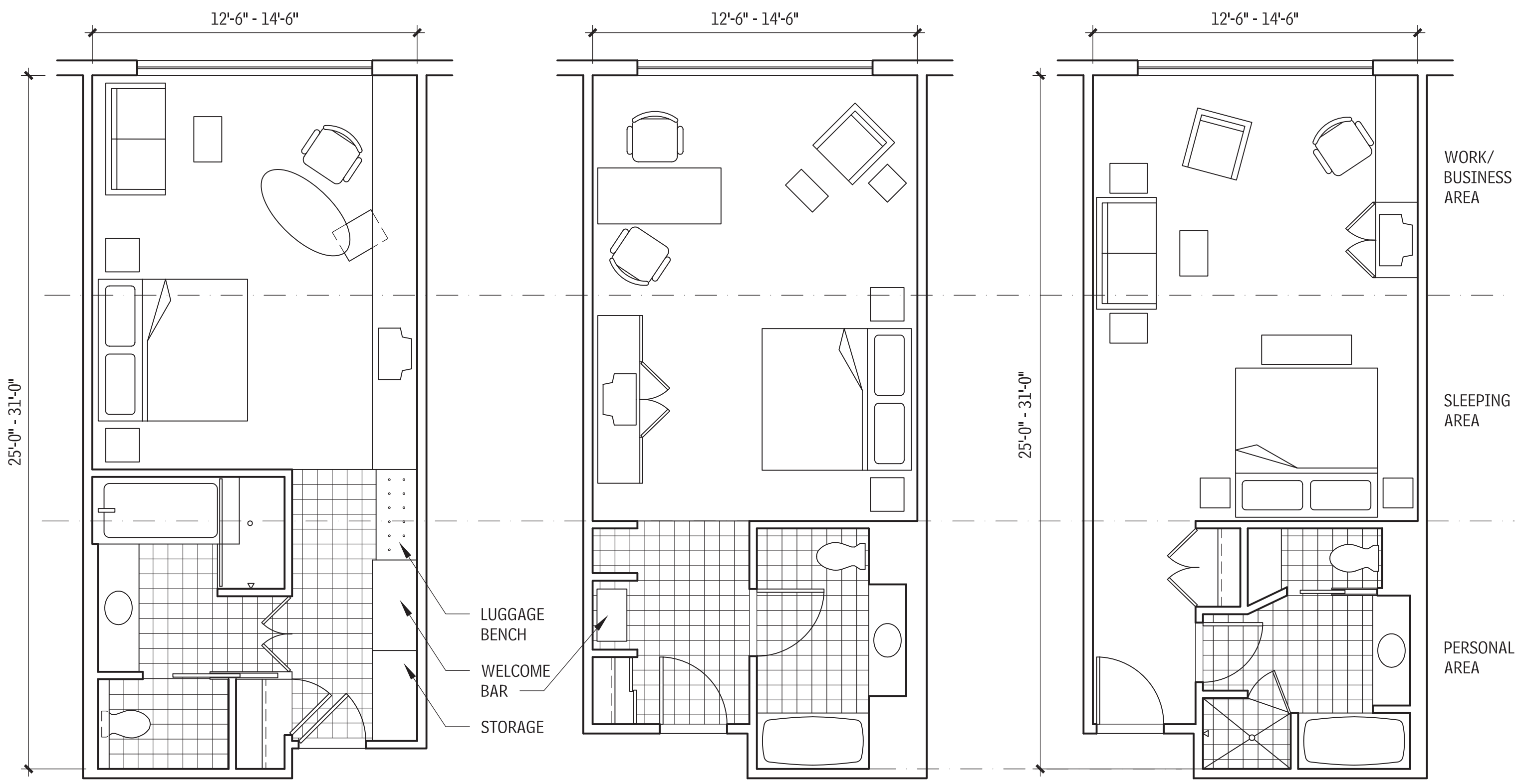
ROOM COMBINATIONS
14.120



HOSPITALITY FURNITURE

The dimensional requirements of the guest room modules and guest corridor are set by the owner. These dimensions establish the depth of the guest floor bay, which is approximately 60 ft. for double-loaded floors and 30 ft. for single-loaded floors. The double-loaded guest floor is the most efficient layout. However, because of the popularity of atrium environments, single-loaded corridor schemes are often utilized.

CONFIGURATIONS FOR GUEST ROOMS
14.121



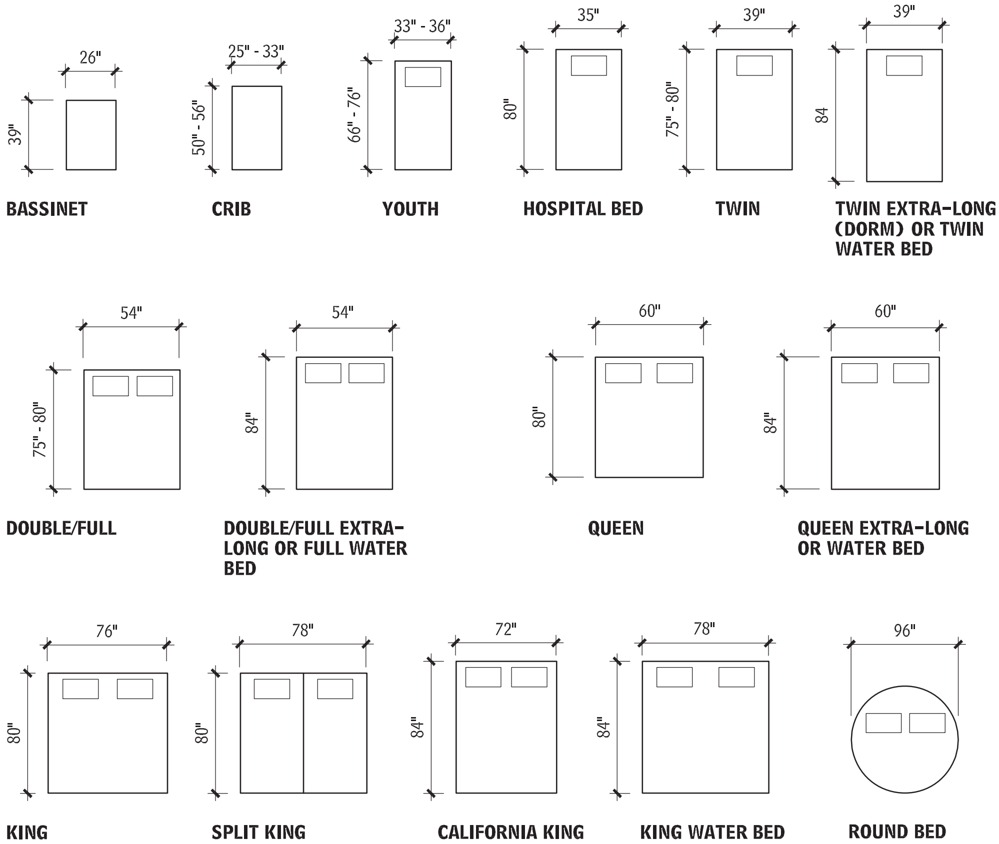
NOTES

Figures 14.120 and 14.121 Accessible rooms must be provided for each type of accommodation—singles, doubles, suites, views, smoking, nonsmoking, etc.

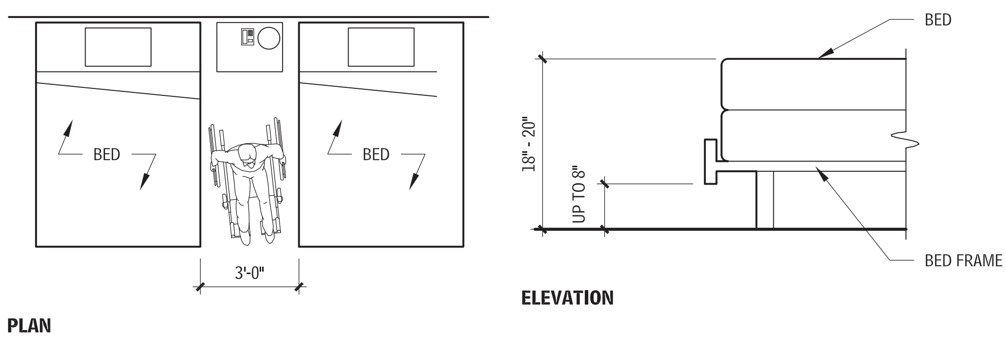
BEDS

For wheelchair users who can independently transfer themselves between bed and chair, bed heights should facilitate their movement back and forth in a sitting position. Transfer is easiest for these users if the mattress top approximately matches their wheelchair seat height (typically, 18 to 20 in.). Wheelchair users who cannot independently transfer themselves between bed and chair are assisted by attendants, who use a portable lift mounted on a metal stand. The lift base requires approximately 8 in. of clearance below the bed.

TYPICAL BED SIZES
14.122



BED ACCESSIBILITY
14.123



SCHOOL FURNITURE

GENERAL CLASSROOM

General classrooms (770 sq. ft. minimum, 900 sq. ft. recommended) are ever increasing in size because of the use of computers and the additional space required for technology equipment.

Many states have minimum standards for classroom size. Consult local requirements.

EARLY CHILDHOOD AND KINDERGARTEN CLASSROOMS

The design of schools for early childhood education has always been geared toward comfortable, supportive, and adaptive settings that are conducive to a learning process derived from familiar play and hands-on activities. Specific features associated with home as well as school are considered in developing an appropriate transitional setting. The type, size, scale, and variety of more public and private spaces underlie appropriate design and planning.

Among the general goals that all early childhood and kindergarten programs should strive to achieve are the following:

- Create a visually rich, fun, and surprising environment.
- Provide spaces and surfaces for display of children's work.
- Provide a variety of settings for work-in-progress.
- Introduce a variety of social settings for small and large groups.
- Make strong connections between the indoors and the outdoors; use daylighting as much as possible.
- Connect spaces to promote communication, orientation, and flexible programming and staffing.
- Build in flexibility of space to accommodate evolving teaching practices.
- Create a distinctive and pleasing entrance.

Pay special attention to the scale and height of typical elements such as windows, doors, doorknobs and pulls, sinks, toilets, counters, furnishings, mirrors, steps, shelving and storage, light switches, towel dispensers, and other accessories.

CHILDREN'S FURNISHINGS

Age-appropriate materials and equipment of sufficient quantity, variety, and durability should be readily accessible to children and be arranged on low, open shelves to promote independent use. Individual spaces for children to store their personal belongings should be provided.

PRESCHOOL DESIGN CONCEPTS

The space for children three years and older should be arranged to facilitate a variety of small group and individual activities, including block-building, sociodramatic play, art, music, science, math, and quiet reading and writing. Other activities such as sand play and woodworking are also often accommodated. Soft spaces as well as hard surfaces, such as wood floors and ample crawling and toddling areas, are typically provided for infants and young toddlers. Sturdy furniture is required to enable nonwalkers to pull themselves up or balance themselves while walking. School-age children should be provided separate space that is arranged to facilitate a variety of age-appropriate activities and permit sustained work on projects.

PRIVATE AREAS

Private areas should be made available indoors and outdoors so that children can have occasional solitude. Soft elements such as rugs, cushions, or rocking chairs should be provided for the comfort of the children, in addition to sound-absorbing materials to minimize noise.

STAFF WORK AREA

The work environment for staff should include a place for adults to take a break or work away from children, an adult-size bathroom, a secure place for staff to store their personal belongings, and an administrative area that is separated from the children's areas for planning or preparing materials.

ELEMENTARY AND MIDDLE SCHOOLS

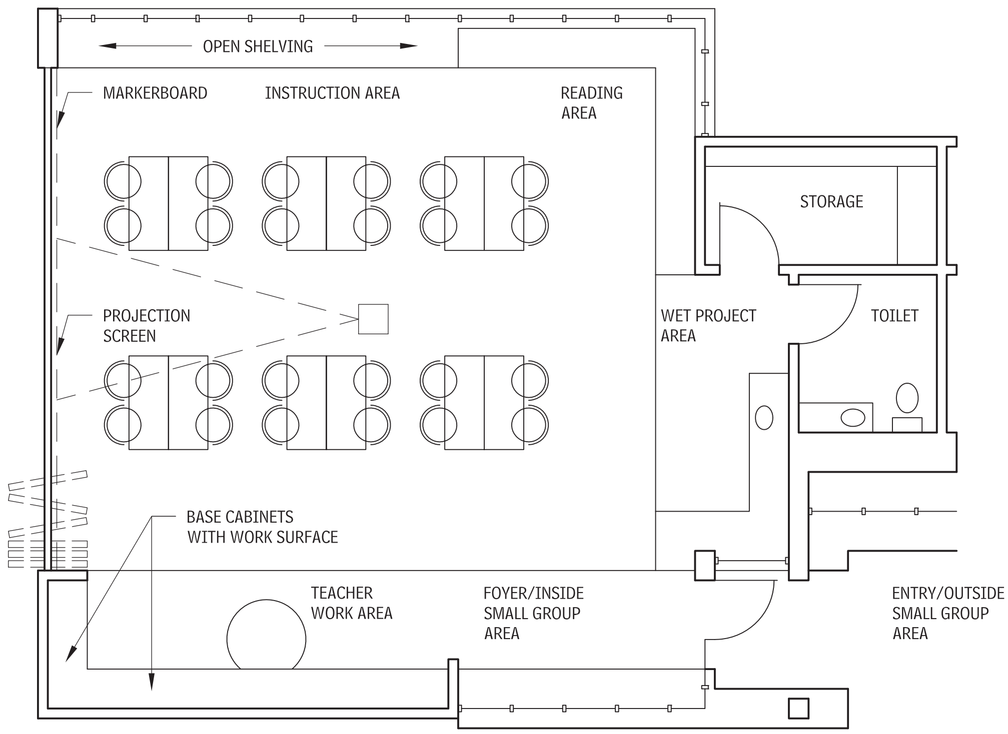
For general-purpose classrooms, it is common to size rooms for approximately 28 students though most schools attempt to keep the number of students per classroom lower, usually 22 to 24 students.

Classroom sizes typically range from 750 to 1,000 net sq. ft. Adequate space must be allowed for classroom materials and student storage. Storage should be sized for coats, briefcases, purses, backpacks, and other paraphernalia. Most elementary schools do not have lockers in corridors, so storage areas must be accommodated within the classroom.

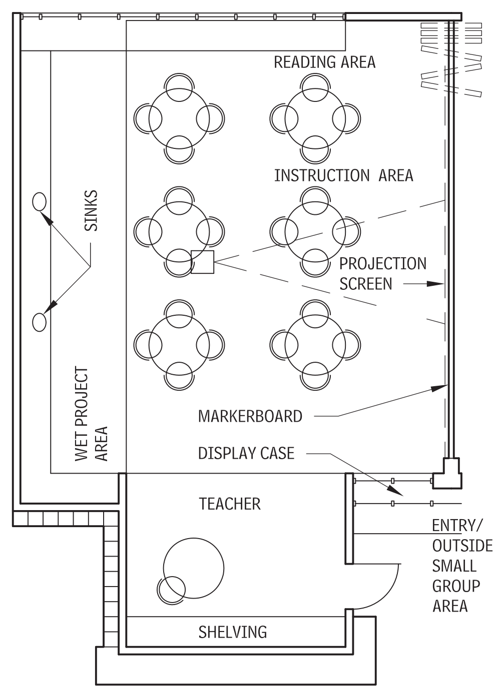
Many states have minimum standards for classroom size, so consult local requirements.

KINDERGARTEN AND GRADE 1 CLASSROOM
14.124

This classroom accommodates a variety of group and individual activities, with specific areas for instruction, group reading, wet projects, and small groups.



CLASSROOM FOR GRADES 2 THROUGH 5
14.125



MIDDLE SCHOOL AND JUNIOR HIGH SCHOOL

For most school districts in the United States, the middle school is still evolving, but typically it includes grades 6 through 8. Students are introduced to departmental teaching, interdisciplinary teaching, flexible scheduling, block scheduling, collaborative learning, and flexible groupings.

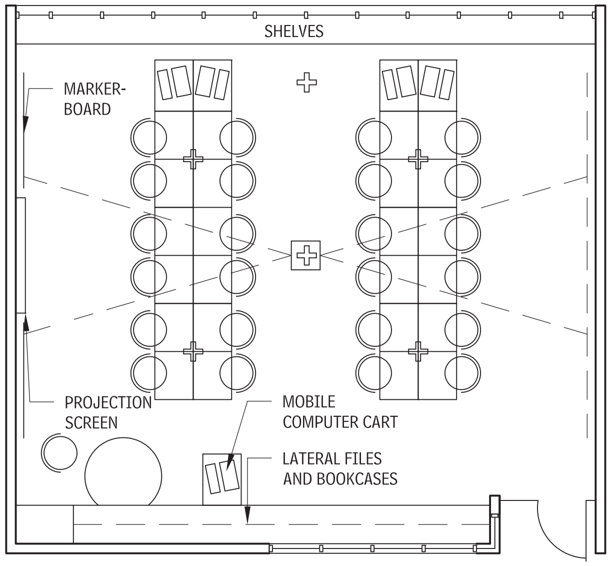
Typically, fundamental instruction spaces include general classrooms, library, and gymnasium spaces. Many school programs include large common areas that have been developed to offer flexible and multifunction opportunities within the same space. The gymnasium, auditorium, and cafeteria are combined in some fashion (sometimes for two of these functions only).

SPACE REQUIREMENTS FOR COMMON MIDDLE SCHOOL PROGRAM ELEMENTS
14.126

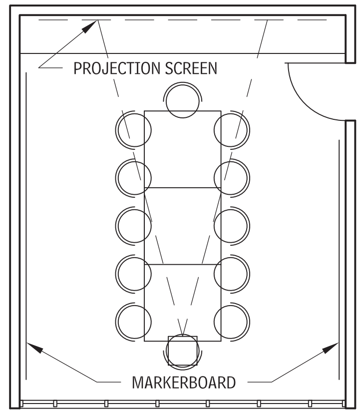
PROGRAM ELEMENT	TYPICALLY REQUIRED BY CODE	NET RANGE (SQ FT)
Computer center	No	850–1,200 (1 per 250 students)
Music instruction room	No	850–1,200 (1 per 250 students)
Laboratory spaces	No	1,000–1,200 (1 per 125 students)
Art instruction room	No	1,000–1,200 (1 per 250 students)
Gymnasium	Yes	3,500 (equals one station; 1 station per 250 students)
Cafeteria	Yes	School population x 50% x 10 (recommended) (provides two lunch periods, total)
Kitchen	No	Depends on food program and equipment; typically equal to one-third the size of dining area
Auditorium	No	School capacity x 50% x 7 (recommended) (based on seating one-half of the school population)
Library	Yes	10 per student (recommended)
Special-use rooms	No	500–750 per use
Media/video center	No	750–1,000
Exhibition/display areas	No	Standards developed on a school-by-school basis

STUDENT LEARNING SPACES
14.127

Classrooms are planned to have integrated technology available in a variety of configurations, to enable simulations research and streaming videos. Small group rooms are designed as breakout areas for the shared use of the middle school.

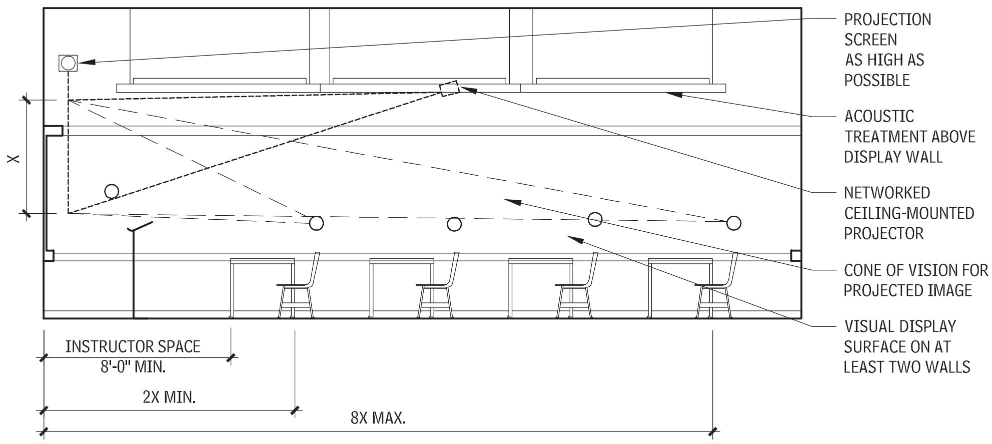


LARGE GROUP SPACES

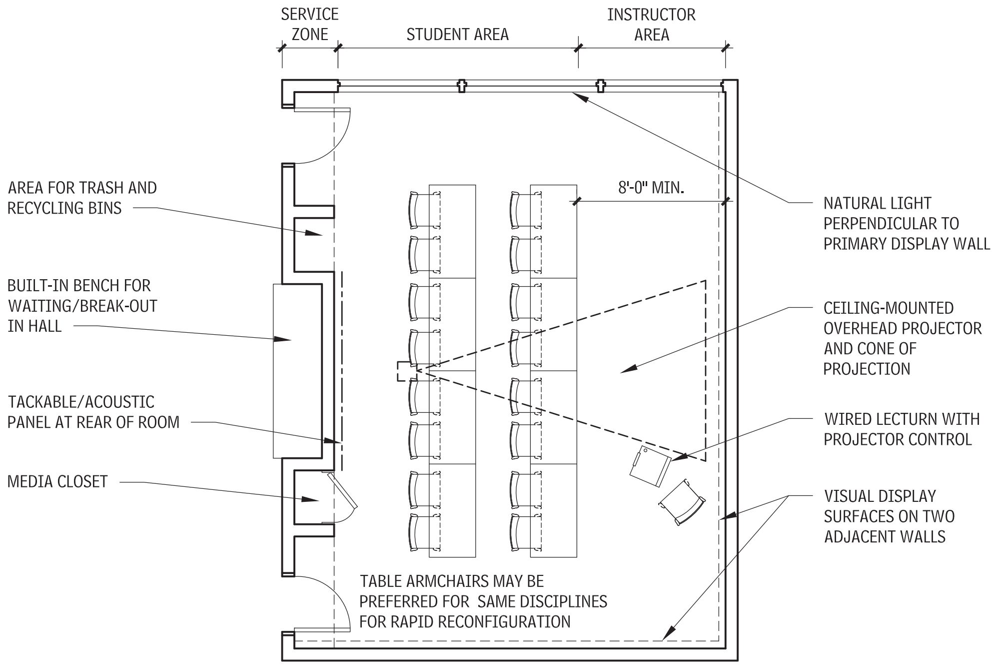


SMALL GROUP SPACES

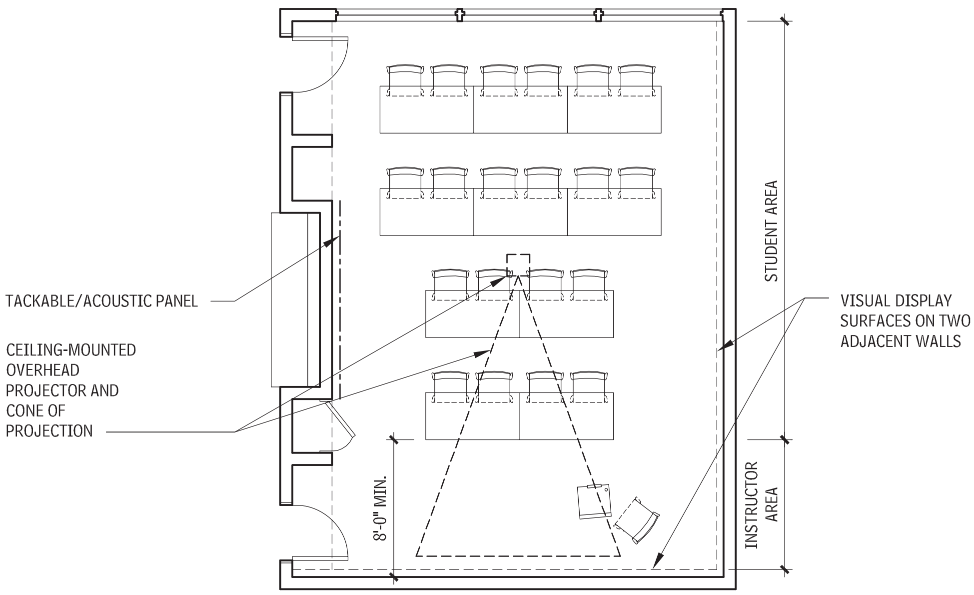
CLASSROOM SECTION
14.128



LANDSCAPE ARRANGEMENT, LECTURE STYLE—TABLE AND CHAIR
14.129



PORTRAIT ARRANGEMENT, LECTURE STYLE—TABLE AND CHAIR
14.130



HIGH SCHOOL

High schools are dedicated to the concept of group instruction with an emphasis on the importance of individual learning. Many campuses are considered "open," allowing students to move freely on and off campus and to have flexible scheduling of classes and independent studies. Many courses of study are offered, thus creating the need for more specialized rooms and, often, requiring larger, more flexible spaces.

DESIGN OF CLASSROOMS

The design objective for general-use classrooms should be to assist students to clearly see and hear any presentation. Therefore, special attention should be given to angles of view to the display wall or the projected image.

The integration of electronic media, especially overhead projectors and networked resources, has supplemented the traditional tools of the chalkboard and tablet-armchair, but has also presented new challenges for planning classrooms.

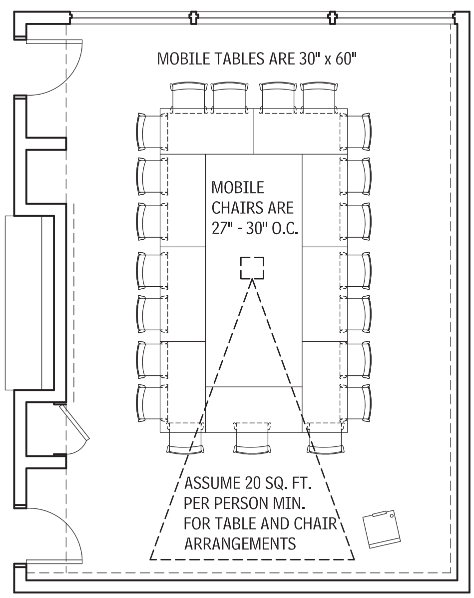
A heightened emphasis on teaching methodologies that stress discussion and interaction has created the need for furniture arrangements that are more flexible than traditional lecture-format row seating. Loose chairs and tables can be reconfigured for both discussion-style rooms and for lecture formats. Both table-and-chair and tablet-armchair arrangements are used. Similarly, the need to accommodate students' laptops and other mobile technologies has increased the need for individual student workspace areas in both situations.

Planning issues vary according to the size of the room. As the capacity increases, it becomes more reasonable to build fixed-furniture configurations. Smaller classrooms may be reconfigured more easily.

To plan a successful classroom, pay special attention to integrating various critical interrelated components, including:

Acoustics: The basic purpose of a classroom is clear communication; to that end, limit background noise, isolate sound between rooms, and accommodate appropriate reverberation time.
Audio/visual technology: Provision of a networked projector, along with the ability to control it from a wired lectern, is a basic level of media integration.
Display media writing and projection surfaces: These should cover as much of the teaching walls as is economically and spatially feasible.
Furniture: The ability to reconfigure loose furniture makes it possible to use the same room for different modes of learning—lectures, discussions, seminars, and small-group activities.

SEMINAR-STYLE TABLE AND CHAIR
14.131



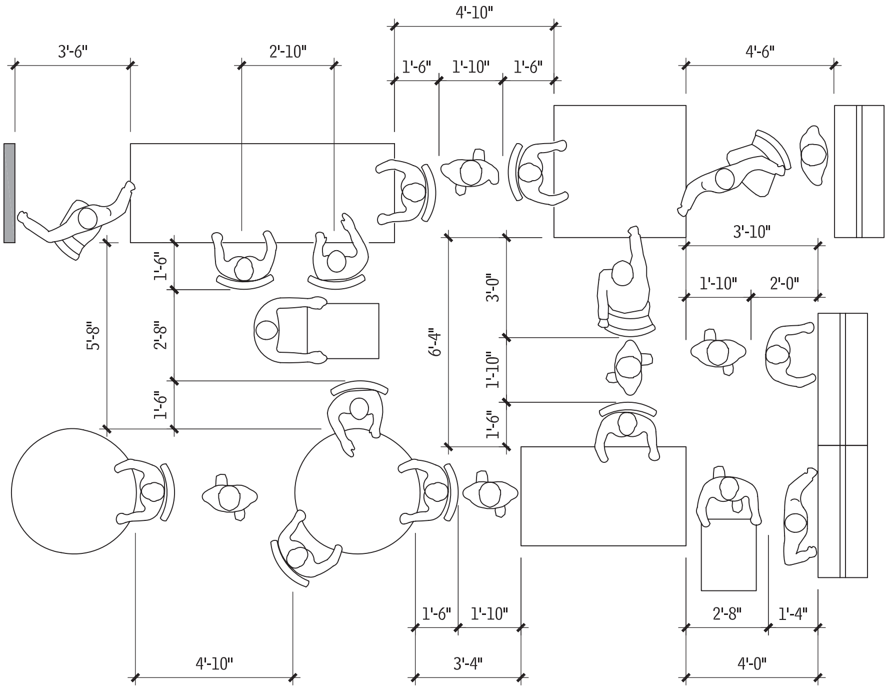
NOTES

Figures 14.129–14.131
a. Movable tables are shown as 30-in. by 60-in. rectangles and are available in various dimensions.
b. Modular shapes are recommended to enable reconfiguration of the same furniture into alternative configurations (e.g., double squares, trapezoids).
c. Landscape arrangements may be preferable to portrait because of proximity of students and instructors, but portrait arrangements offer better viewing angles to projected images.

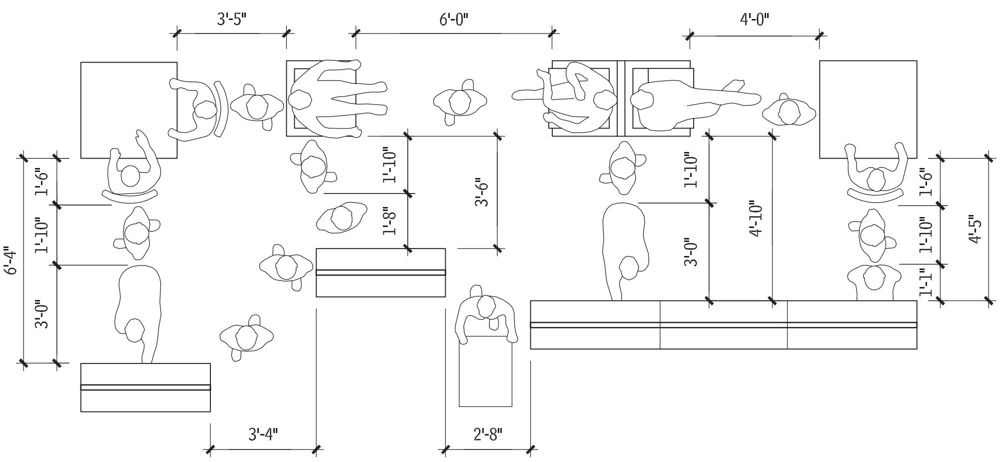
Contributors:
Peter Greenberg, GREENBERG DESIGN, Cambridge, Massachusetts, in association with Smith Maran Architects, Montclair, New Jersey.

LIBRARY READING ROOM TABLE LAYOUT
14.132

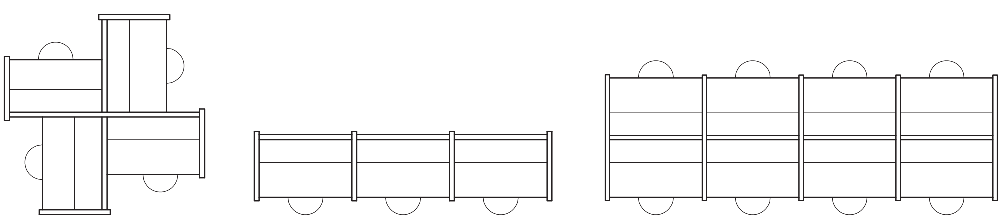
Round tables are not recommended for research purposes, but they may be desired in a staff room or in an area designed for light reading.



LOUNGE CHAIRS, TABLES, AND SHELVING LAYOUT
14.133



CARREL ARRANGEMENTS
14.134



PLAN PINWHEEL **PLAN SINGLE-FACED** **PLAN DOUBLE-FACED**

LIBRARY FURNITURE

Libraries now link digital information, paper information, resources, and print collections. Consequently, libraries are now places where people not only read and borrow books but also use computers to find information and access online services. Traditional library furnishings for accommodating printed volumes range from 13–1/2 to 19 books per square foot, with the average of 16 books per square foot of gross area. The average additional dead load is 25-lb/cu ft.

Consult the following references:

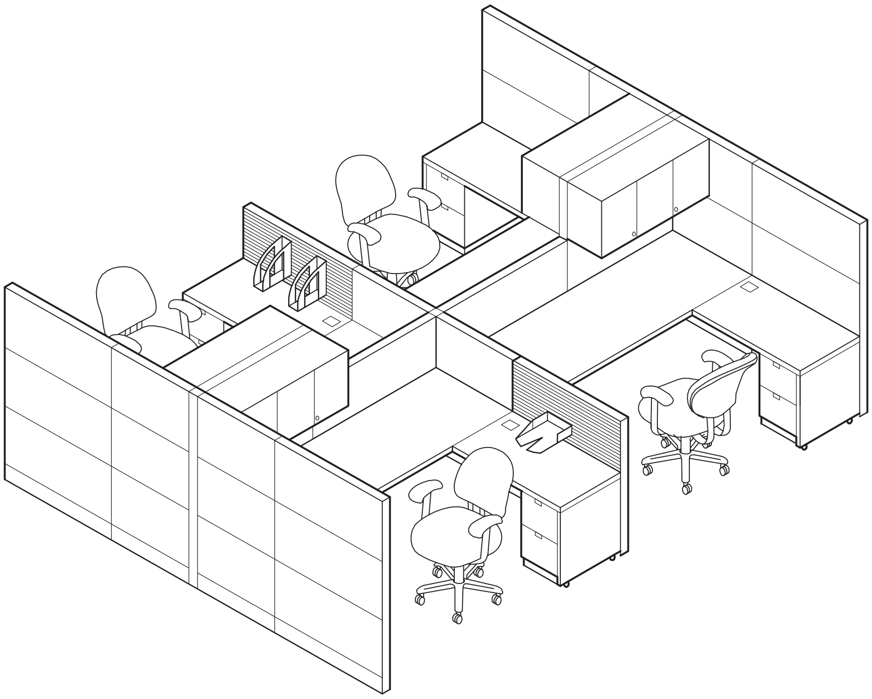
- American Library Association (ALA) www.ala.org
- Association of College and Research Libraries (ACRL) www.ala.org
- Library Administration and Management Association (LAMA) www.ala.org/lama
- International Federation of Library Associations and Institutions (IFLA) www.ifla.org

Specific furniture designed for library use, includes library tables, shelves, carrels, card catalogs, and so on. Specialized furniture may include dictionary stands, atlas cases, book trucks, display cases, and the like.

Design guidelines for workspaces include the following:

- About 5 percent of fixed tables and carrels should be accessible.
- Reading tables and study carrels often should incorporate power outlets and, possibly, Internet connections.
- Reading tables and study carrels should be sized large enough so that library patrons can spread out their materials, particularly in areas where oversized materials are viewed.
- The recommended height of study carrel partitions is at least 52 in. above the floor.
- Tables or podiums with slanted tops should be provided for more convenient reading of oversized materials or newspapers.
- Seating guidelines are as follows:
  - Comfortable seating, such as upholstered chairs and sofas, is generally best for informal reading or lounge areas.
  - Pull-up chairs with metal or wood arms are typically used at reading tables and carrels.
  - Mechanically adjustable chairs are rarely selected for libraries because they are subject to heavy use and frequent maintenance.

TRADITIONAL PANEL-SUPPORTED SYSTEM
14.135



SYSTEMS FURNITURE

There are two basic types of systems furniture: panel-supported and freestanding systems. Many manufacturers offer systems that combine freestanding components with traditional panel-supported units. These systems provide flexibility and function for workplace tasks. High-tech designs, as well as more conservative assemblies, are available.

Systems furniture is available that addresses the total workplace environment, using walls, panels, post-and-beam construction, work surfaces, filing, storage, raised-floor platforms for wiring and cabling, and other flexible elements. Often systems furniture products are compatible and may be interchangeable with other products from the same manufacturer, allowing greater flexibility.

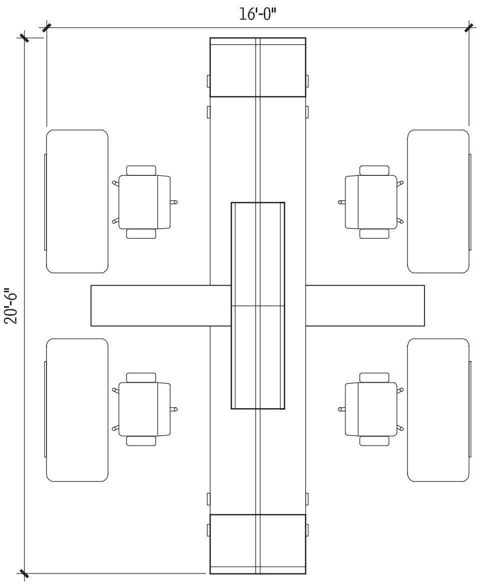
PANEL-SUPPORTED SYSTEMS

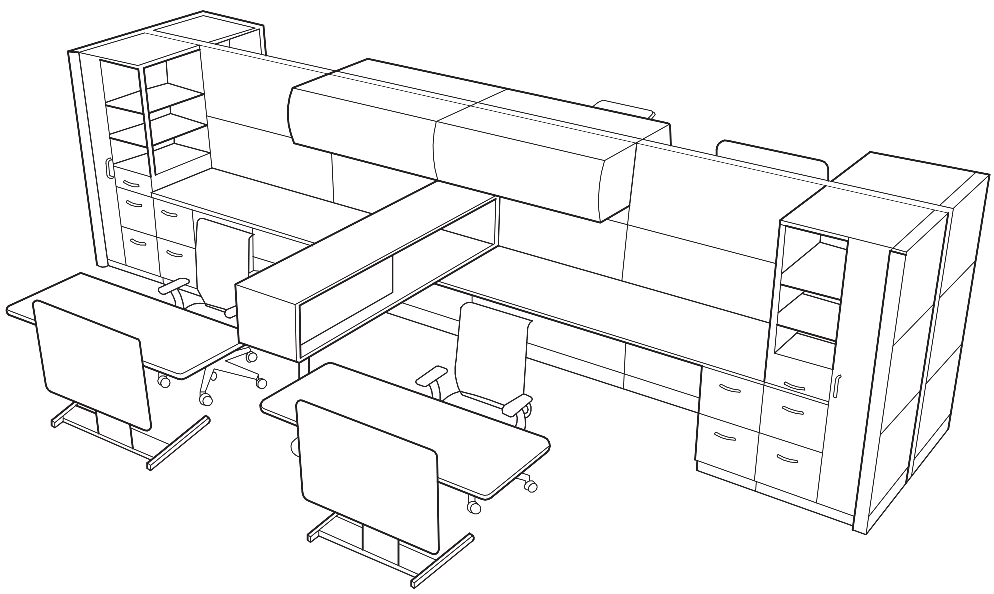
Panel-supported systems, the most popular type of systems furniture, support the work surfaces, accessories, and other furniture components from panels that form the boundaries of the workstation. Wall-mounted slotted standards are also available so that these systems can be hung on a traditional gypsum board wall. The Business and Institutional Furniture Manufacturer's Association (BIFMA) has authored a standard for panel-based systems furniture; and ANSI X5.6, "Standard for Office Furnishings Panel Systems," is used to test the safety of panels and panel-mounted components.

FREESTANDING SYSTEMS

Freestanding systems are independent of surrounding panels, and function like floor-supported desks. Furniture components can be attached to the work surface or may be freestanding mobile units. This type of systems furniture can be surrounded by panels, or installed in a space with gypsum board walls. New systems furniture types are being developed that integrate technology to the design of the furniture, such as post-and-beam products.

FREESTANDING SYSTEMS
14.136





NOTE

14.136 Source: Steelcase Inc., Grand Rapids, Michigan.

RESTAURANT SEATING

Different table sizes and shapes offer variety in seating arrangements. Table sizes are known as *tops* (two-top, four-top, etc.) and reflect the number of seats at that table type. The mix of table sizes is dependent on the target clientele, menu, and general operational goals. The opinions of designers and restaurateurs vary as to what are the ideal dimensions for restaurant chairs and tables. Factors including circulation, service, egress, and space dimensions should dictate optimal table and chair dimensions.

Table options include flip-up corners or edges, to increase table size or to change shape (e.g., square table to a round table).

Chair selections reflect the type of comfort level desired: a fast-food restaurant may provide hard-surface chairs and non-upholstered seats to discourage lingering, whereas a full-service restaurant may provide comfortable, upholstered dining chairs.

RESTAURANT SEATING DESIGN CRITERIA

Design criteria for restaurant seating fall into these five categories.

SERVICE AISLES

- For square seating, allow 72 in. minimum between tables (30-in. aisle, plus two chairs back to back).
- For diagonal seating, allow 36 in. minimum between corners of tables.
- For wall seating, allow 30 in. minimum between wall and seat back.
- Allow a minimum of 30 in. for bus cart and service cart access.

PATRON AISLES

- Refer to local codes for restrictions and requirements.
- Provide an accessible route to accessible seating, 36 to 44 in. wide.
- For wall seating, allow 30 in. minimum between walls and table.
- Provide clear floor space for table access. Such clear floor space cannot overlap knee space by more than 19 in.

TABLE PLACEMENT

- Consider restaurant type when designing table layouts; generally, upscale restaurants have more generous table spacing than casual, full-service restaurants.

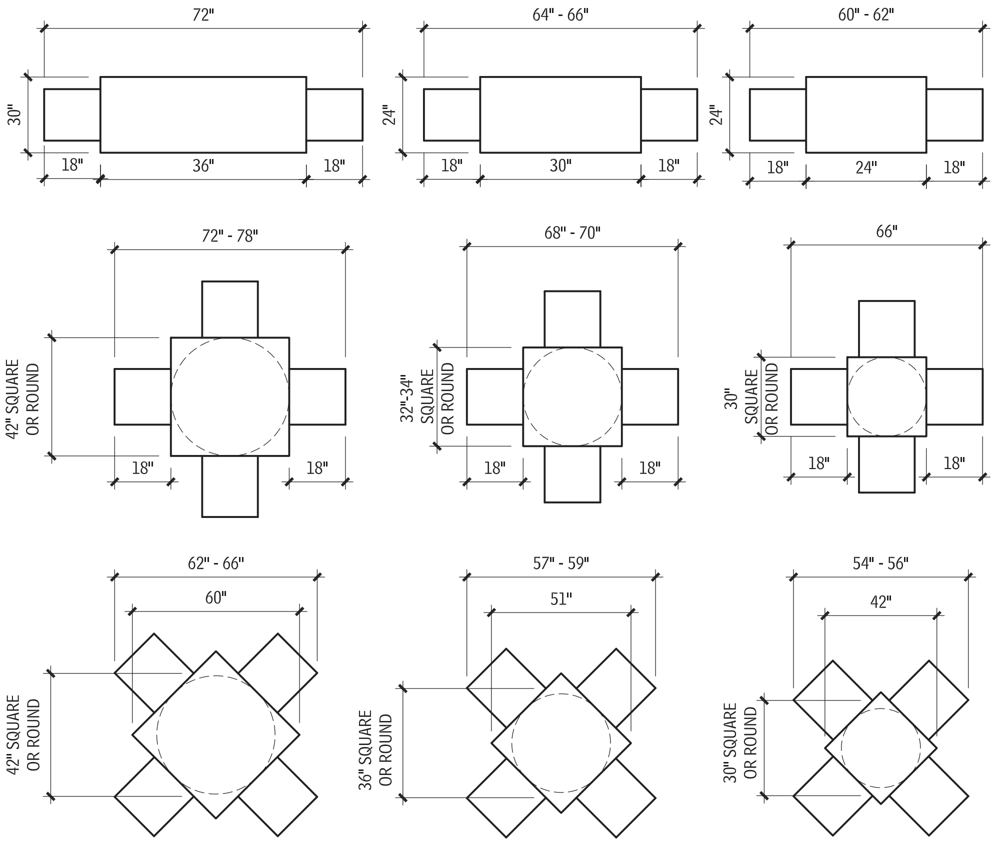
TABLE CRITERIA

- The tops of accessible tables should be 28 to 34 in. high. A portable raised leaf may be provided to adapt lower tables.
- If seating for people in wheelchairs is provided at tables, knee space at least 27 in. high, 30 in. wide, and 19 in. deep must be provided.

SEATING CRITERIA

- Accessible seating should be integrated within the dining area, and should accommodate both large and small groups.
- Chair seat height is usually 18 in. Seat heights should be slightly higher at accessible tables.
- Seats should be a minimum of 16 in. deep and 16 in. wide.
- Padding and cushions should be firm.
- Armrests aid diners in rising from the seat.
- Table or counter supports should not interfere with seat knee space so the feet can be positioned for rising.

TYPES AND SIZES OF TABLES
14.137



SPACIOUS SEATING
14 SQ. FT. /PERSON

AVERAGE SEATING
12 SQ. FT. /PERSON

COMPACT SEATING
10 SQ. FT. /PERSON

ROUND TABLES
14.138

NUMBER OF PERSONS	DIAMETER (IN.)
4 to 5	36–42
6 to 7	42–54
7 to 8	54–60
8 to 10	66

RECTANGULAR TABLES
14.139

NUMBER OF PERSONS	LENGTH (IN.)	WIDTH (IN.)
Two (on one side)	42–48	30
Six (three on each side)	70–84	30–36
Eight (four on each side)	90–108	36–42

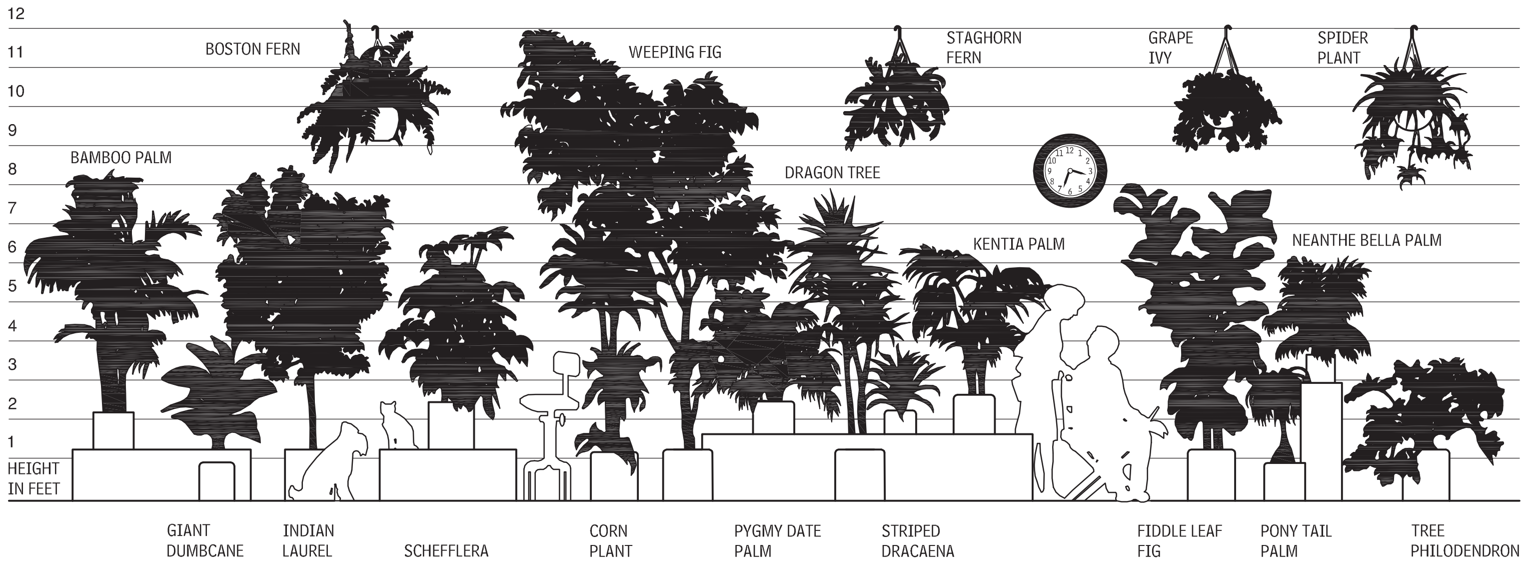
DINING CHAIR DIMENSIONS
14.140

	OVERALL DEPTH (IN.)	SEAT DEPTH (IN.)	WIDTH (IN.)
Large	22	18	18–20
Average	19–20	16	16
Compact	17–18	15	14

MOVABLE INTERIOR LANDSCAPING

Movable interior landscaping consists of plants, planters, and accessories that are not affixed to the building. The largest self-contained freestanding planter commercially available is approximately 6 ft. round or square, with a height of up to 4 ft. Movable plants are measured as overall height from the base of the growing container to the mean foliage top (not including isolated outstanding branches).

FORM, TEXTURE, AND SIZES OF SOME COMMONLY USED INTERIOR PLANTS. 14.141



Contributor:
Jon Pearson, ASLA, CSI CDT, EDAW, Inc., Alexandria, Virginia.

ELEMENT F: SPECIAL CONSTRUCTION

15

MANUFACTURED—FABRICATED ROOMS

SOUND-CONDITIONED ROOMS

SOUND-CONDITIONED (ISOLATED) ROOMS

Isolated rooms incorporate special construction to reduce intrusive noise and vibration from outside a room or to contain the sound and impact energy generated within a room. Typical applications include music practice rooms, sound studios, testing chambers, mechanical equipment rooms near sensitive areas, spaces exposed to low flying aircraft, and offices under gymnasiums. Construction of isolated rooms can be very expensive; it is, therefore, wise to locate high-noise sources away from acoustically critical areas early in space planning.

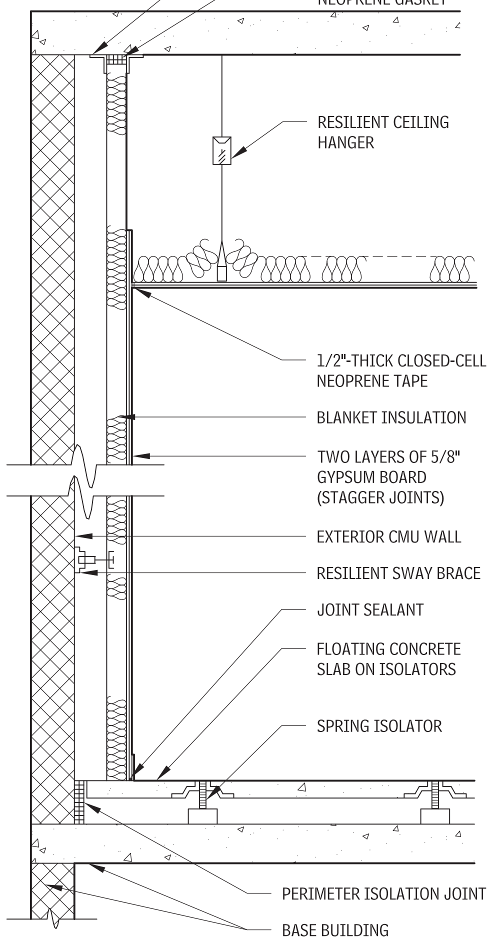
The correct design of an isolated room is a "box within a box." The inner box, which is the four walls, ceiling, and floor of the isolated room, should be an airtight enclosure constructed of dense, impervious materials; depending on the requirements it may be necessary to also isolate the box on resilient supports from the surrounding structure. The base structure that supports the isolated room must be as rigid and massive as possible.

The most effective floor construction is a floating concrete slab, which is separated from the building structure by steel springs, neoprene, or glass-fiber isolation mounts. This slab should also support the inner walls of the room. Any necessary structural bracing to the base building structure should be made with a resilient, nonrigid connection. The ceiling of the box can be suspended from resilient hangers, or supported from the walls of the inner box.

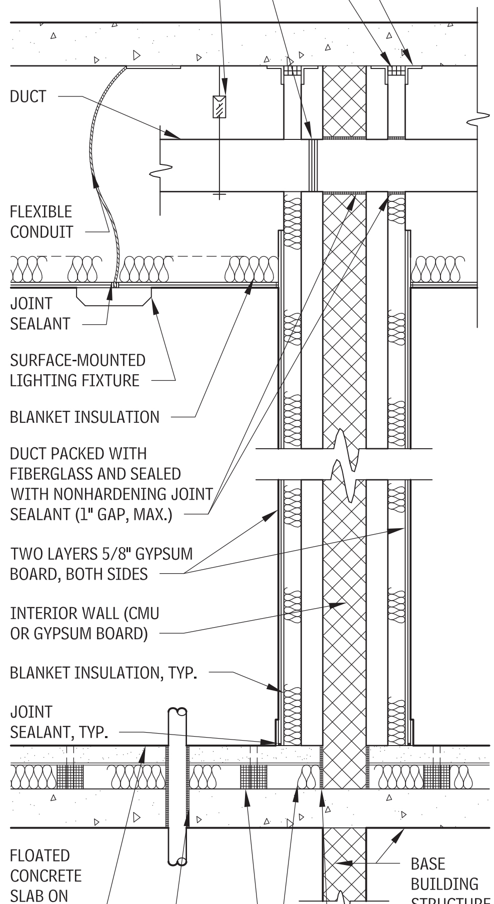
An isolation mat provides uniform deflection of the floating concrete floor under a wide range of design loads. It consists of 2-in.-thick, high-density, compressed molded fiberglass isolation pads, separated by low-density acoustic fiberglass.

Avoid flanking (continuous) paths between an isolated room and the base building structure. To ensure that wall penetrations and connections to facility services are also isolated, provide flexible connections in ducts and conduit between the inner and outer box, and resilient supports for all piping. Weatherstripped or sound-rated doors and multiple-glazed, acoustic windows should be part of the continuous, airtight enclosure that defines the inner box.

EXTERIOR WALL—SECTION
15.1

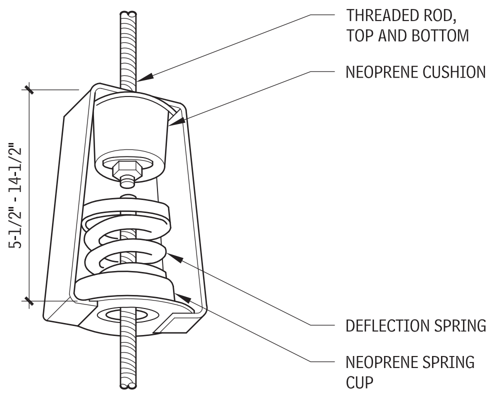


INTERIOR WALL—SECTION
15.2

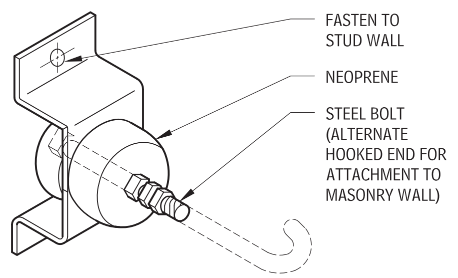


Contributors:
Cini-Little International, Inc., Food Service Consultants, Washington, DC; St. Onge, Ruff and Associates, Inc., York, Pennsylvania.

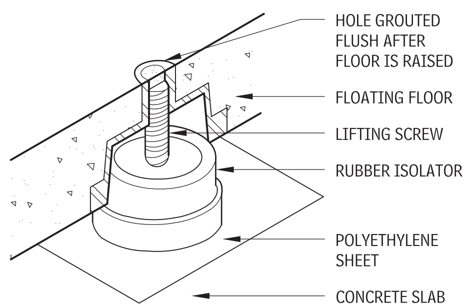
ISOLATOR DETAILS 15.3



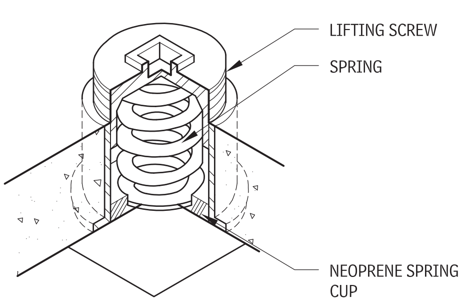
RESILIENT HANGER



SWAY BRACE



RESILIENT ISOLATOR



SPRING ISOLATOR

NOISE REDUCTION

- The degree of noise reduction that can be attained by an isolated room depends on the type of construction, its resiliency, the elimination of flanking paths, and the amount of dead air space surrounding the inner box. A well-built isolated room can achieve field performance ratings between STC 60 and STC 70 for airborne sound, and ratings of IIC 80 to 90 for impact noise. However, even minor flanking paths and acoustic short circuits through nonairtight joints can easily decrease these results by 10 points or more. The sound isolation between spaces will be only as great as the weakest sound path.
- Consult a qualified acoustic consultant for the planning and design of isolated rooms.

FABRICATED UNITS

In addition to the site-constructed sound-condition rooms, fabricated units are available. These rooms are sold as self-contained music practice rooms, audiometric booths, and control booths for manufacturing plants. Although the detailing of these structures is proprietary, the design approach is the same as with site constructed rooms. The degree of noise reduction that these manufactured rooms can attain depends on the same parameters used for site-constructed rooms.

SAUNAS AND STEAM BATHS

A sauna is a dry heat bath taken in a well-insulated room lined with untreated, kiln-dried softwood, and heated by igneous rocks. The purpose of the sauna is to induce perspiration, which cleanses the pores in the skin by removing impurities and lactic acid built up from physical exertion.

Because of the dryness of the air in a sauna (25 percent humidity, average), the body can accept the higher temperatures a sauna produces (180°F, average). It is usually better to lie down than to sit up in a sauna, for the temperature rises about 18°F for every foot above the floor level. If a bather is lying down, the heat is equally dispensed over the entire body. Saunas should be located near a shower for the cool-down portion of the sauna.

Saunas may be fabricated (precut pieces assembled on-site), modular (factory-built complete panels joined on-site), or custom built.

Steam bathing (discussed in further detail below) has effects similar to the sauna, but in a very different climate. Unlike the dry heat of a sauna, a steam bath (or Roman bath) is taken in a warm, moist atmosphere with temperatures up to 125°F and humidity near 100 percent. As with the sauna, the critical factor in steam bathing is the bather's interaction between heat and cold.

SAUNAS

The larger the sauna, the more heat is required; hence, the ceiling should be kept as low as possible within the limits imposed by the benches, which generally require 7 ft. clear height. Refer to local code requirements. A 24-in.-wide, 80-in.-high nonlockable door that opens outward is standard in a sauna. This door size maximizes bench space, minimizes heat loss, and provides safe entrance.

A 36-in.-wide door could make a design compatible with accessibility guidelines, but wheelchair access is discouraged, to protect the metal and plastic components of a wheelchair from excessive heat. Instead, an attendant can assist wheelchair-bound sauna users (liability and safety issues should be considered). Because of the weight of the door, a pair of 4-in. brass hinges with ball bearings is recommended. A heavy ball or roller catch keeps the door closed. Door handles are typically made of wood or other nonconductive material.

Indirect lighting is recommended in a sauna. The best position for the light is above and slightly behind the bather's normal field of view; the switch is always outside the room.

Softwoods such as western red cedar and redwood are used for wall finishes and bench construction in a sauna. Softwoods absorb humidity, keeping the atmosphere dry, and do not absorb heat as readily as hardwoods, keeping the surface comfortable to the touch. Wood should be kiln-dried to between 6 and 11 percent moisture content.

In private saunas, a water bucket and dipper for creating a burst of steam are common accessories. These are often not provided in public saunas, to prevent misuse by unknowledgeable bathers, as premature or excessive water application can damage heater parts.

SAUNA DESIGN

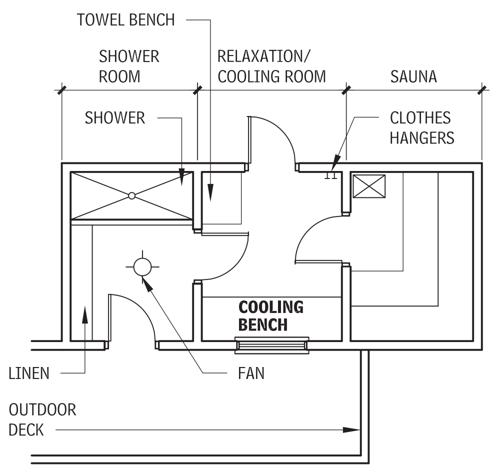
If the sauna framing does not extend to the ceiling of the room outside the sauna, an exterior finish that encloses the top of the sauna is recommended.

A 1-in. gap is recommended between the bottom of the door and the threshold for ventilation.

Wood-framed baseplates should be made of preservative-treated wood; all other framing may be standard wood framing. Metal framing is not recommended because of its high heat-conductance property.

SAUNA SUITE PLAN 15.4

A sauna suite offers a complete heating and cooling cycle with indoor and outdoor cooling areas.



SAUNA CONSTRUCTION

The tongue-and-groove boards used for interior finishes should be at least 5/8-in. thick but no wider than six times their thickness. Blind-nailing with galvanized, aluminum, or stainless steel nails is recommended.

Vapor retarders under paneling, whether attached to the insulation or separate, must be vapor proof and heat-resistant and act as a heat reflectant. Foil-backed, mineral-based insulation, R-11 minimum, is recommended.

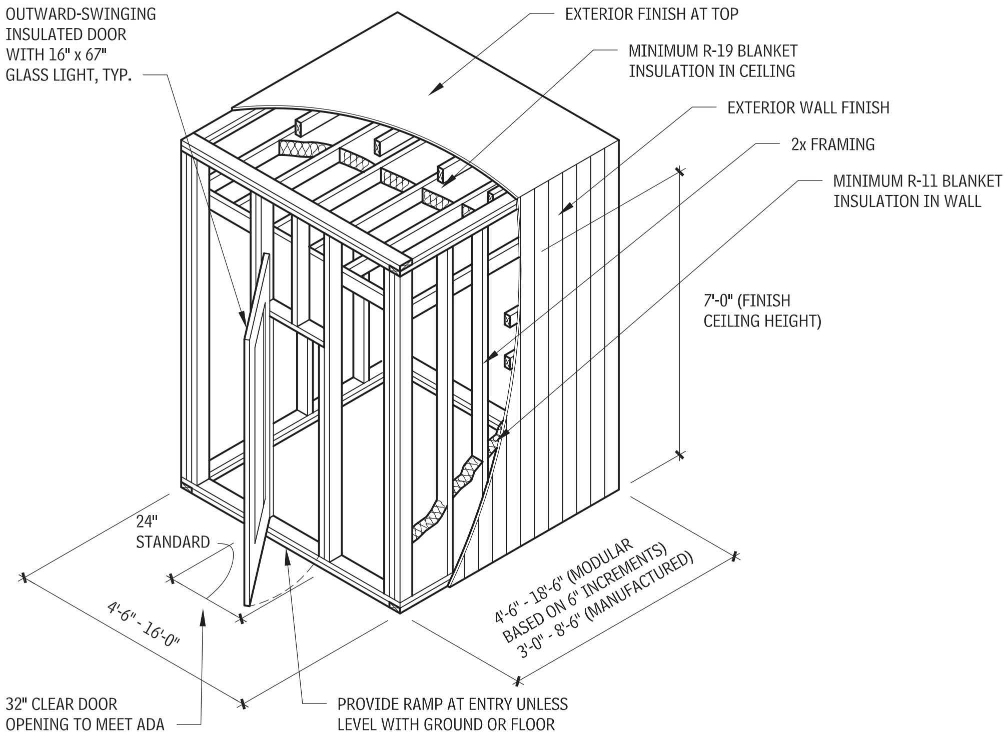
Air must be able to flow freely into and out of a sauna and should be changed four to six times per hour. Fresh air is provided through updraft action by combining an air inlet in the sauna wall directly below the heater, with an air outlet located at least 6 in. from the ceiling and 24 in. higher than the inlet. A vent space below the door may also be used.

NOTE

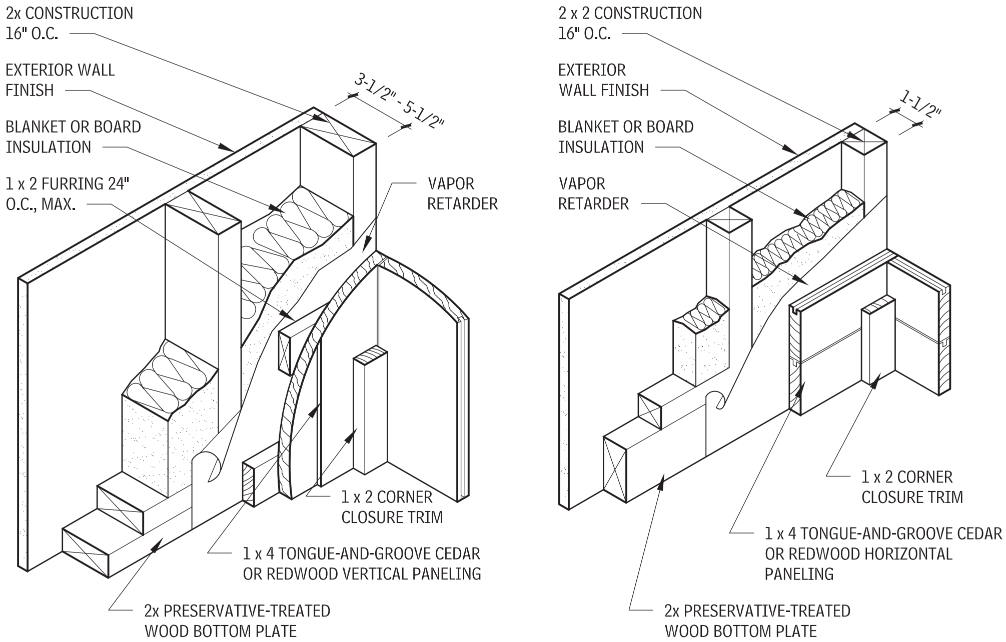
15.3 Resilient hangers typically are used to isolate duct vibration. Sway braces prevent buckling or overturning of tall or extremely long walls.

Contributor:
Cerami + Associates, New York, New York.

SAUNA CONSTRUCTION
15.5



SAUNA WALL CONSTRUCTION—DETAILS
15.6



CUSTOM **MANUFACTURED**

STEAM BATHS

Avoid the use of exposed, untreated materials that are subject to decay or corrosion.

Steam room ceilings should be sloped a minimum of 2 in./ft. to prevent condensation from collecting and dripping. Sloping from the middle to the edges reduces the height necessary to accomplish this. The ceiling should be no more than 8 ft. high.

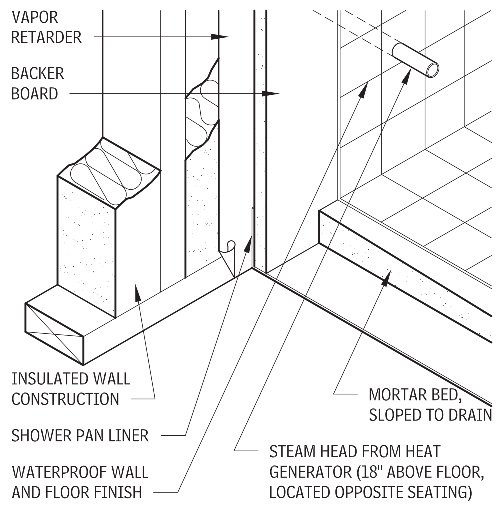
Use of vents inside the steam room is not recommended, but if they are installed, they must be positive closing with a vapor-tight seal and waterproof ducts.

Flooring should be skid-resistant, with a floor drain for condensation runoff and cleaning.

The steam generator must be compatible with the finish materials and the volume of the steam room. Residential steam generators can handle 50 to 500 cu ft., and larger models can service up to 1500 cu ft. Controls for the generator may be located inside or outside the room. The dimensions of the generator range from 13 to 17 in. high, 12 to 16 in. deep, and 7 to 8 in. wide.

STEAM ROOM WALL CONSTRUCTION
15.7

The walls, ceiling, floor, and benches in a steam room must be completely covered with a waterproof finish such as tile, marble, or acrylic. Exposed gypsum board or plaster is not recommended. All joints must be filled with waterproof sealant.



VAULTS

Precast concrete modular vault panels are considerably lighter and thinner than site-poured walls, and provide almost unlimited flexibility when sizing or locating a vault. Modular vaults can be expanded or relocated as required, reusing existing components.

Vault panels are typically fabricated from a high-density composite concrete mix with interlacing steel fibers and a welded grid of reinforcement bars. Although manufacturers provide standard vault sizes and configurations, a modular vault design can be custom-fabricated.

Clear spans of up to 19 ft., without the use of support beams, can be achieved by most modular vault systems, simplifying above-ground installations.

VAULT INSTALLATION

Engineered panels are site-assembled, typically by welding. Modular vault panels can be disassembled and moved to another location. Existing vaults can be increased or reduced in size by

Contributor:
Richard J. Vitullo, AIA, Oak Leaf Studio Architects, Crownsville, Maryland.

adding or removing panels. Typically, the interior and exterior finishes of the vault are the responsibility of the owner.

Conduit penetrations for alarm and other electrical connections are cast into the vault panels. Electrical and security wiring are typically included in a single panel that can be placed almost anywhere within the vault design. HVAC ports with built-in dampers can be specified to provide ductwork, to maintain a comfortable environment for vaults that are used as workspaces.

VAULT TYPES

Two types of vaults are used to protect valuables: burglary-resistant and fire-resistant.

BURGLARY-RESISTANT VAULTS

Underwriter's Laboratories (UL) and Insurance Services Offices (ISO) provide criteria by which the security performance of a vault can be evaluated.

UL performs attack tests on the modular vault systems to ensure that minimum requirements for burglary resistance are met. UL 608, "Standard for Burglary-Resistant Vault Doors and Modular Panels," classifies vault doors and modular panels by the approximate time it takes to break through the assembly. Test methods used to penetrate the door include expert burglary attack using cutting torches, fluxing rods, portable electric-powered tools, portable hydraulic tools, and common hand tools. The ratings are as follows:

- Class M: One-quarter hour
- Class 1: One-half hour
- Class 2: One hour
- Class 3: Two hours

ISO, an organization supported by insurance companies, provides a consistent basis for setting standards and rates used in calculating insurance costs. It has developed a system for rating security devices, including vaults. Although there are technical differences between the UL and the ISO standards, certain classifications can be considered comparable.

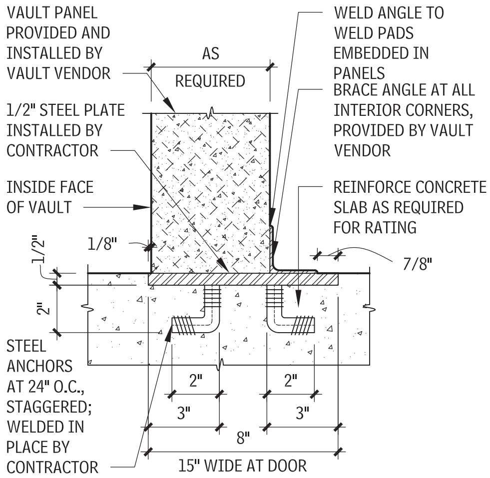
FIRE-RESISTANT VAULTS

Fire-resistant vaults are used primarily to protect vital records. NFPA 232, "Protection of Records," describes the relative humidity range and maximum temperature requirements for photographic materials, including silver-gelatin, vesicular, color film, and magnetic media. UL 155, "Standard for Tests for Fire Resistance of Vault and File Room Doors," classifies the fire resistance of vault walls and doors, as follows:

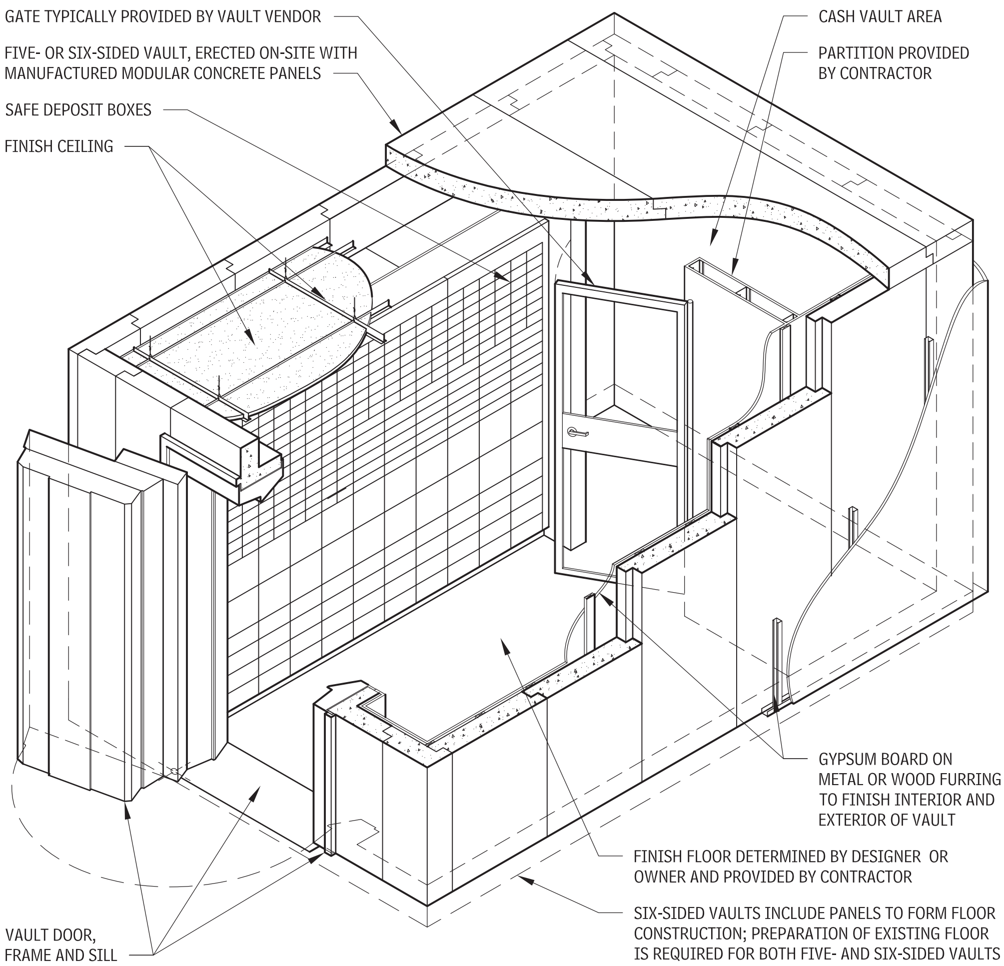
- Class B: Two hours
- Class A: Four hours
- Class AA: Six hours

The hour ratings approximate the time it takes for a fire to penetrate the modular vault system.

VAULT WALL SECTION
15.8



SIX-SIDED MODULAR CONCRETE PANEL VAULT
15.9



Contributor:
Kelsey A. Kruse, AIA, GVA Architecture-Interior Design, Columbia, Maryland.

SPECIAL STRUCTURES

FABRIC STRUCTURES

There are two types of nonpneumatic fabric structures. One supports the fabric membrane with a rigid frame, usually constructed of metal, the other is a self-supporting fabric membrane kept in tension with a supporting structure of steel or concrete. The rigid frame structures typically form pyramidal or long, continuous geometric shapes like sheds or barrel vaults. The self-supporting structures rely on opposing curves to distribute the necessary tension and typically form saddle, conical, or hyperboloid (anticlastic) shapes.

The structure that creates and maintains tension on the fabric can consist of cables and masts, a compression ring, trussed gridwork, or tied edges. These mechanisms create tension in the fabric sufficient to keep it taut. Any compressive loads imposed on the fabric will be balanced or, at most, reduced by the prestress created by the structure.

FABRIC STRUCTURE MATERIALS

The intended life span of the structure is an important factor in design decisions, fabrication details, and the cost of architectural fabric structures. The life span is most affected by the fabric material or membrane selected. Fabric is a directional material and does not have the same strength or elongation in all directions under a load. Materials with little creep are preferable for tensioned structures, as original prestress can be lost if the fabric stretches or deforms. Details allowing for retensioning must be incorporated if materials with moderate to high creep are used. Generally, the materials used in a membrane are composites consisting of a woven substrate protected with an applied coating.

The membrane is the principal structural component of a self-supporting or tensioned fabric structure. Two materials are generally used for membranes: polyvinyl chloride (PVC)-coated materials and fluorocarbon- (Teflon-) coated glass-fiber fabric.

PVC-coated polyester is a composite material composed of vinyl coating over both faces of a woven polyester fabric. The material is inexpensive, strong, translucent, and easy to fabricate, but has a limited life span and is only fire-resistant. For these reasons, it is used only in temporary or semipermanent structures.

Fluorocarbon-coated glass-fiber fabric is classified as a noncombustible material. Besides its advantages in fire safety, this fabric is extremely long-lasting, self-cleaning, and translucent, and is the accepted material for most permanent installations.

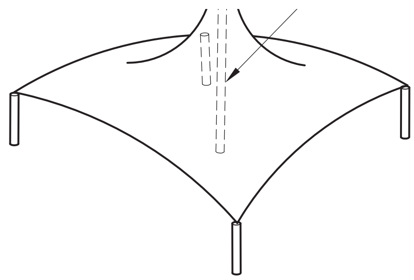
Development continues in fabric technology, and new products such as silicon-coated glass-fiber may offer an improvement in the range of material characteristics.

FABRIC STRUCTURE DESIGN

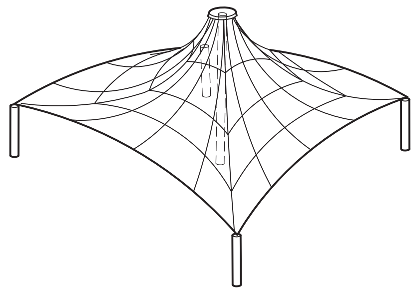
In recent years, the structural design of fabric structures has improved due to the increased use of the computer in the engineering process. The first step in the design process aided by computer modeling is the definition of an acceptable surface geometry, such as the hyperbolic paraboloid. A membrane mesh or network is then developed, representing the surface as a grid of lines. This graphic model is "prestressed," and the reactions are analyzed in an iterative, or repetition-based, process. Live loads such as wind, rain, or snow are applied to the model, and the stresses calculated in order to select the fabric and design the supporting structure or foundation.

The design, fabrication, and construction of fabric structures require close coordination among the architect, engineer, fabricator, and installer throughout the process, to ensure the strict quality control this technology requires. However, because most of the work is completed in the factory, minimizing on-site construction time, it is not unreasonable to maintain tight specifications.

FABRIC STRUCTURE DESIGNS
15.10

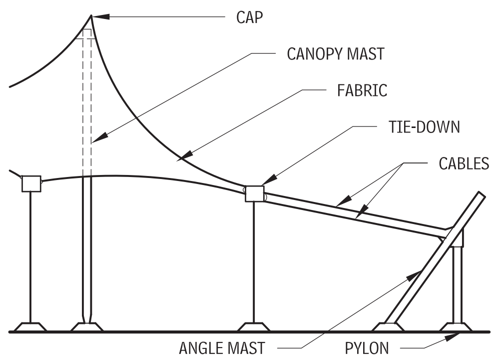


CONICAL-TYPE SURFACE GEOMETRY

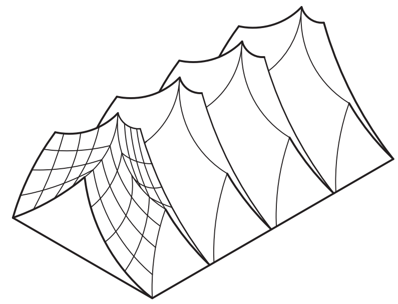


MEMBRANE MESH OVERLAY

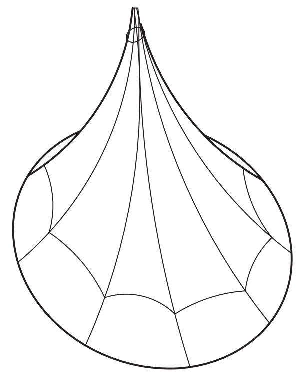
TYPICAL CONE-SHAPED TENSILE FABRIC STRUCTURE
15.11



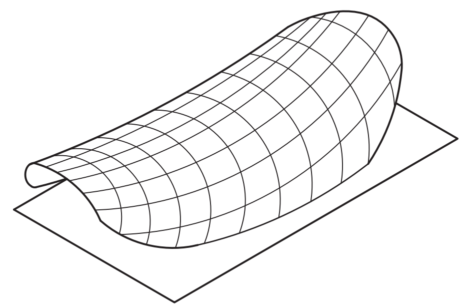
SELF-SUPPORTING MEMBRANE STRUCTURES
15.12



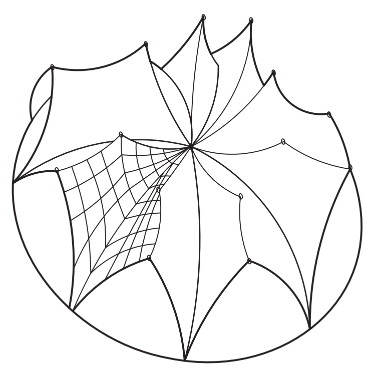
FOLDED-PLATE TENSILE



CONE-SHAPED TENSILE



HYPERBOLIC PARABOLOID



RADIAL FOLDED PLATE

RELATIVE FABRIC CHARACTERISTICS
15.13

FABRIC TYPE	STRENGTH	DIMENSIONAL STABILITY	FIRE RATING	DURABILITY	RESISTANCE TO SOILING	SOLAR TRANSMISSION	COST	TYPICAL USES	LIFE SPAN	REMARKS
PVC-coated polyester	5	3	3	3	3	2	$$	Temporary to semipermanent	3–15 years	Large selection of products; top coatings are required for durability; can enhance appearance and provide improved UV and fire resistance
PVC polyester scrim laminate	2	2	2	1	1	2	$	Temporary	1 year	Limited applications in architecture
PVC-coated fiberglass	4	4	4	3	3	2	$$$	Temporary to permanent	5–15 years	Limited availability; can be produced to order
PVC-coated Kevlar	5	3	3	3	2	2	$$$$	Semipermanent	5–10 years	Kevlar has strength and durability but is UV-sensitive; seams generally hand-sewn
PTFE-coated fiberglass	4	5	5	5	5	4	$$$$$	Permanent	25 years or more	Most durable material, now with a 25-year record of use
Silicon-coated fiberglass	3	5	5	4	2	5	$$$$	Semipermanent to permanent	20 years	Seam strength has been a weakness
PTFE fiberglass laminate	3	5	5	5	4	5	$$$$$	Semipermanent to permanent	20 years	Relatively new material

Source: Geiger Engineers, Suffern, New York.

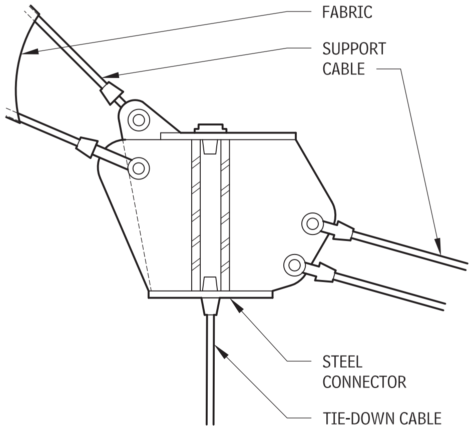
FABRIC STRUCTURE APPLICATIONS

Applications for fabric structures include the semipermanent and temporary fabric-and-frame structures applied to agricultural, greenhouse, and storage uses. Improved materials have allowed the use of these structures for waste treatment facilities, tennis courts, and pool facilities. More elaborate configurations, curved in plan and section, serve as outdoor concert halls, enclosed sports facilities, and atrium spaces for larger structures such as office buildings, medical facilities, shopping malls, and airports. Fabric structures are not substitutes for conventional construction, but their unique qualities enable them to perform certain building tasks very efficiently. In general, special performance requirements, such as the need for long spans or for natural lighting, encourage the use of fabric structures.

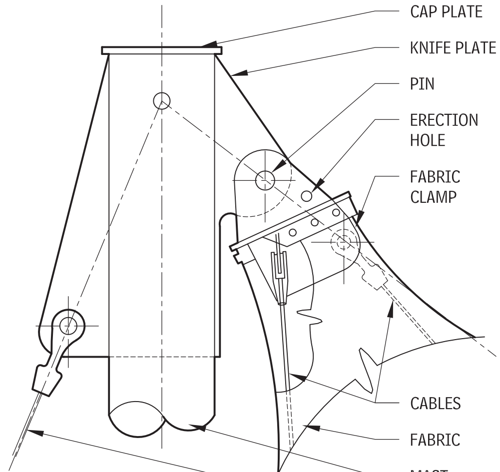
ENVIRONMENTAL CONSIDERATIONS

Under certain circumstances, a tensioned fabric structure can reduce energy consumption in a building. The natural light through the translucent surface reduces artificial lighting requirements; the reflectivity of the skin reduces heat gain; and the radiation of waste heat from the warm fabric surface to a cool sky results in an energy-efficient building in warm climates. In cold climates, a second skin or liner is normally used, often with glass-fiber insulation in the cavity to further reduce heat loss. These structures can be as energy-efficient as conventional buildings in many applications.

FABRIC STRUCTURE ANCHORAGE DETAILS
15.14

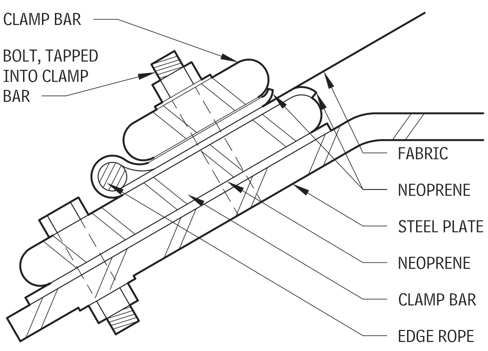


TIE-DOWN SECTION

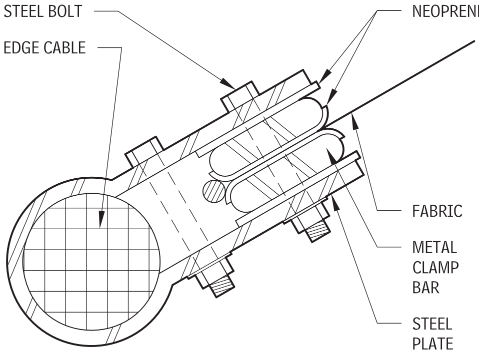


ALTERNATE EXTERIOR MAST TOP DETAIL

FABRIC EDGE CLAMP—ATTACHMENT DETAIL
15.15



EDGE OF CATENARY CABLE—ATTACHMENT DETAIL
15.16



NOTES

15.13 a. Values on chart are based on a scale of 0 to 5, with 0 a poor rating and 5 a very good one. The ratings are intended to provide a general comparison between the materials listed.
b. All materials listed are composites. Generally, the material strength is provided by a scrim or woven textile that has been sealed and protected with a coating or film.
c. Plastic, PVC, and polyester materials are subject to degradation from ultraviolet (UV) light, while glass fabrics and scrims are degraded by prolonged contact with moisture.

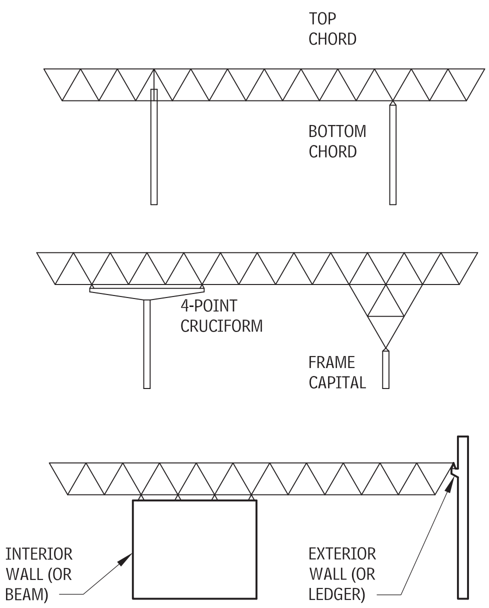
Contributors:
David Campbell, Geiger Engineers, Suffern, New York.
Industrial Fabrics Association, Roseville, Minnesota; adapted with permission from *Architectural Fabric Structures: The Use of Tension Fabric Structures by Federal Agencies* (Washington, DC: National Academy Press, 1985); Kathleen O'Meara, OM Architecture, Baltimore, Maryland.

The two primary ways of attaching fabric to anchorages are with edge catenary cables or clamps. Catenaries allow free-form design. When a tighter connection between fabric and building structure is required (e.g., on roofs, skylights, and air structures), a clamp system is used, in which the fabric is sandwiched between clamping bars or plates, which are bolted to the structure. Some membrane structures use both kinds of attachment. Air structures sometimes have sleeves and cables, plus a fabric closure panel that extends beyond the cable.

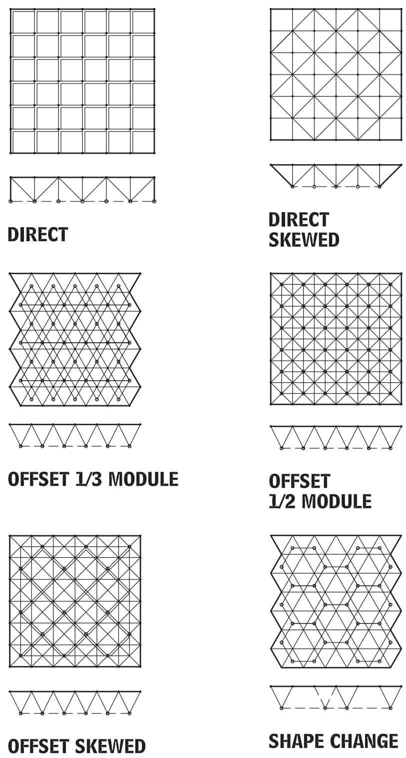
Tensile structures usually are custom-designed; anchoring and connection details also are customized. However, basics, such as clamping systems, have become more standardized. Some frame and connection materials have been adapted from other industries, such as space frames and marine rigging. To determine the appropriate design aesthetic for a project, consider the following aspects:

- Tensile structures are flexible, and the details must be designed to move under loads.
- Tensile structures weigh a fraction of the amount of other buildings, and many of the materials are translucent.
- Lateral forces play a much greater role in tensile structures than in conventional structures.
- It is essential that the physical resolution of each element's force vector (the angle of direction and magnitude) be accurate.
- Details, material specifications, and reaction forces affecting interfacing structures should be developed with an engineer or fabricator with the expertise in the design of fabric structures.

SUPPORT TYPES
15.17



COMMON PATTERNS
15.18



SPACE FRAMES

A space frame is a three-dimensional truss with linear members that form a series of triangulated polyhedrons. It can be seen as a plane of constant depth that can sustain fairly long spans and varied configurations of shape.

Prime attributes of space frames include:

- Light weight
- Inherent rigidity
- Wide variety of form, size, and span
- Compatible interaction with services, primarily HVAC

MODULE SELECTION AND CHARACTERISTICS
15.19

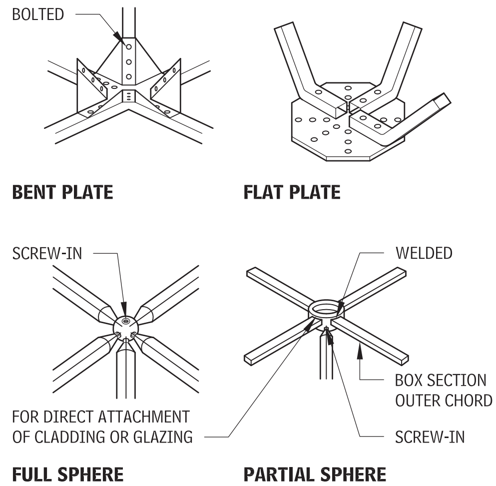
Select a space frame module that is compatible with the structural module in shape (e.g., a square module with orthogonal plan) and size (a multiple of the structural module), is consistent with the limitations of the interfacing systems (e.g., the maximum span of the roof deck or mullion spacing of the glazing system), and satisfies the spatial and aesthetic effects in scale and form.

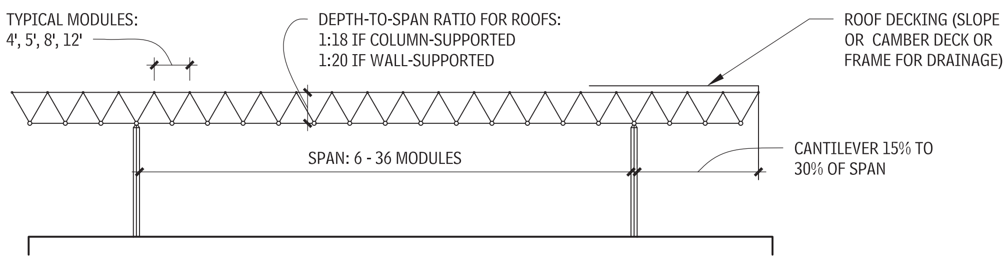
Most space frames are designed for specific applications, and a structural engineer with specific experience should be consulted. Manufacturers can provide the full range of capabilities (loading, spans, shapes, specific details) for their products. Standardized structural assemblies in 4- and 5-ft modules are available.

Metal space frames are classified as noncombustible construction, and can usually be exposed when 20 ft. above the floor. However, a fire suppression or a rated ceiling assembly may be required. Consult the appropriate codes.

Common finishes include paint, thermoset polyester, galvanized stainless steel, and metal plating.

NODE CONNECTIONS
15.20





NOTES

15.18 Many proprietary node systems are available for specific applications and budgets. Keep field connections to a minimum; welded connections often eliminate joint pieces.
15.20 Space frame supports are at joints only, not along members.

MANUFACTURED ENGINEERED STRUCTURES

METAL BUILDING SYSTEMS

Metal building systems are available in standard framing sizes and types from various manufacturers. Commonly used terms in the metal building industry include:

Bay: The dimension along a wall between the centerlines of wall columns and the dimension from the outside of an end-wall corner column to the centerline of the first adjacent wall column. Spacings range from 18 to 30 ft., with 20 to 25 ft. most common.

Width: Measured from the surface of the outside wall girts. Inside clearance varies.

Eave height: Measured from the bottom of a wall column to the top of an eave strut. Nominal 2-ft increments vary from 10 to 30 ft.

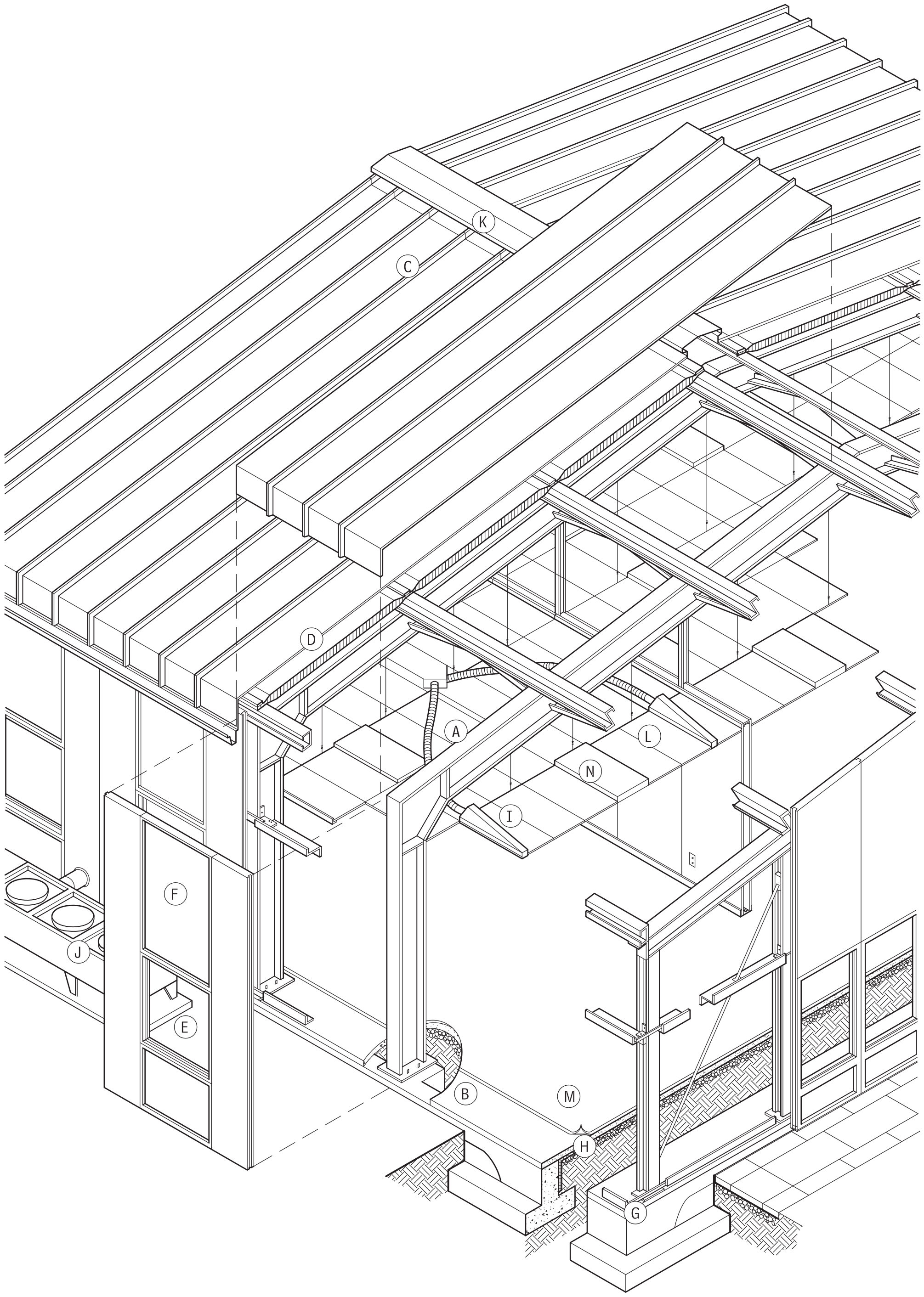
Diagonal bracing: Normally required in the plane of the columns and beams in one or more bays to prevent racking and to resist lateral loading perpendicular to the span of the frames.

Girts: Horizontal structural members that transmit lateral loads (pressure and suction) from the exterior walls to the columns. Sag rods may be needed to support the girts about the weak axis and to achieve design economy.

Anchor bolts: Necessary to resist reactions at column bases. Foundations must be designed for reactions transmitted by the column bases and anchor bolts.

Designers should verify that individual manufacturer's standard practice and any special design considerations meet or exceed established engineering principles, local practice, and applicable building codes.

METAL BUILDING SYSTEM
15.21



The letters enclosed in parentheses in the following list identify the respective components in Figure 15.43.

Structural Components

- Rigid steel frame (A)
- Cast-in-place concrete foundation and slab (B)

Envelope Components

- Roof: Standing seam metal roof (C); blanket insulation (D)
- Walls: Window assembly (E); insulated metal wall panels (F)
- Floor: Dampproofing (G) and vapor barrier (H)

Mechanical Components

- HVAC: Ducts and diffusers (I); heat pump (J); ridge vent (K)

Interior Components

- Ceilings: Suspended acoustic tile ceiling (L)
- Floors: Carpet (M)
- Lighting: Fluorescent light fixtures (N) and natural light

Metal building systems are predominantly used for single-story warehouse, agricultural, and light industrial facilities, though there is increasing demand for their use for office and retail facilities, and even expansion into the multistory market. This construction approach is particularly advantageous for applications requiring large interior clear spans, the support of heavy overhead cranes, or substantial expanses of roof. The metal building systems industry is able to respond to highly specialized needs, while still employing standardized structural components and factory fabrication.

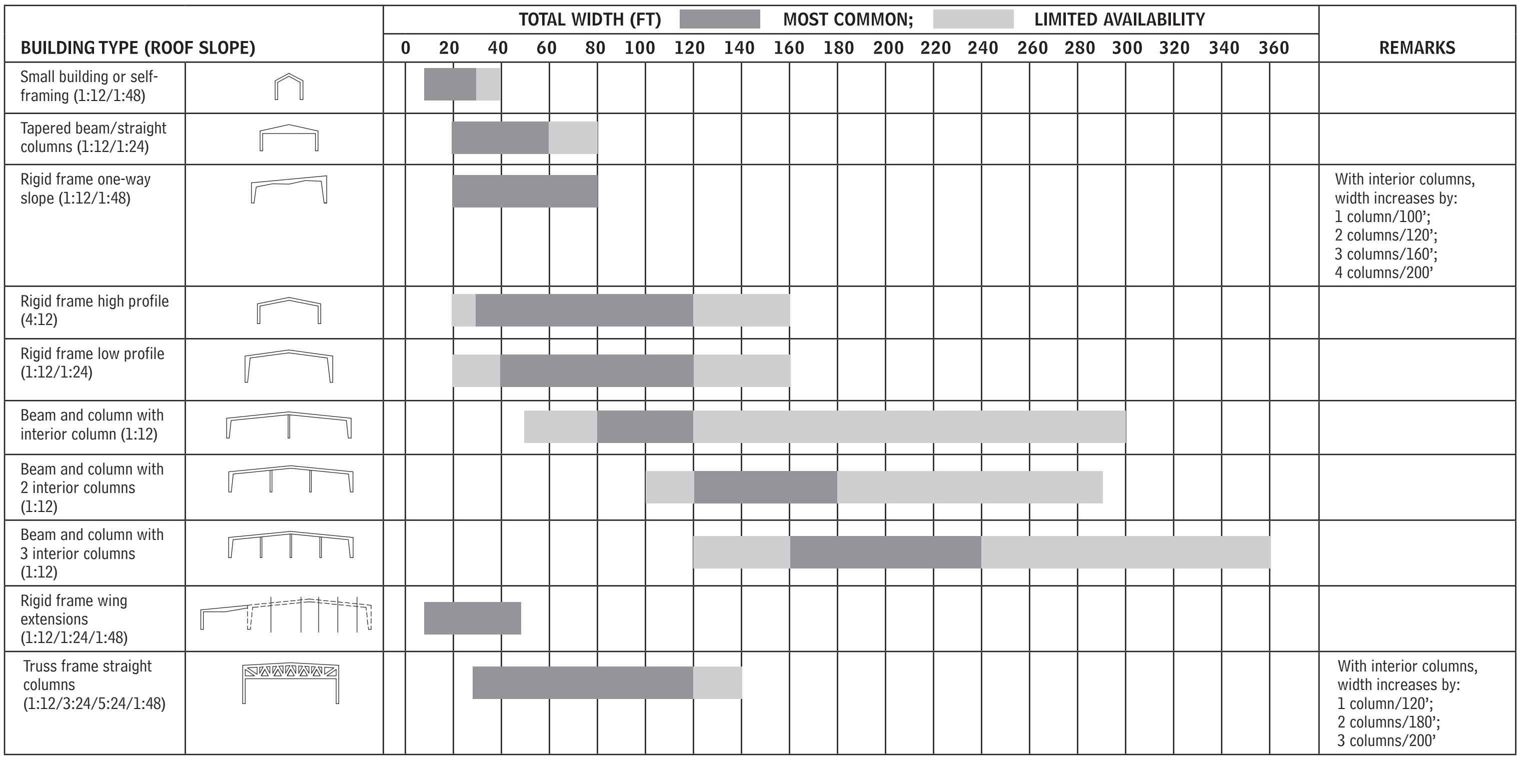
Metal building systems take advantage of factory assembly techniques and quality control. The structural integration of frame components with the building skin, for strength and rigidity, permits economy in the size and number of steel framing components. Primary and secondary framing members, fasteners, and panels interact to produce a light, stable building envelope. Framing and cladding components are designed, engineered, and fabricated in a plant, then shipped to the project site for erection. Often, the same company designs, engineers, and builds the system.

The metal building system integrates lightweight structural and envelope components, each of which add strength and rigidity to the overall form. The light weight of the envelope system, which is an asset for shipping, is, however, especially vulnerable to wind uplift, requiring care in design. Building corners and edges are particularly subject to wind-induced uplifting and suction. Additionally, the thin sheet steel wall panels may present acoustical issues when privacy or sound isolation are an issue.

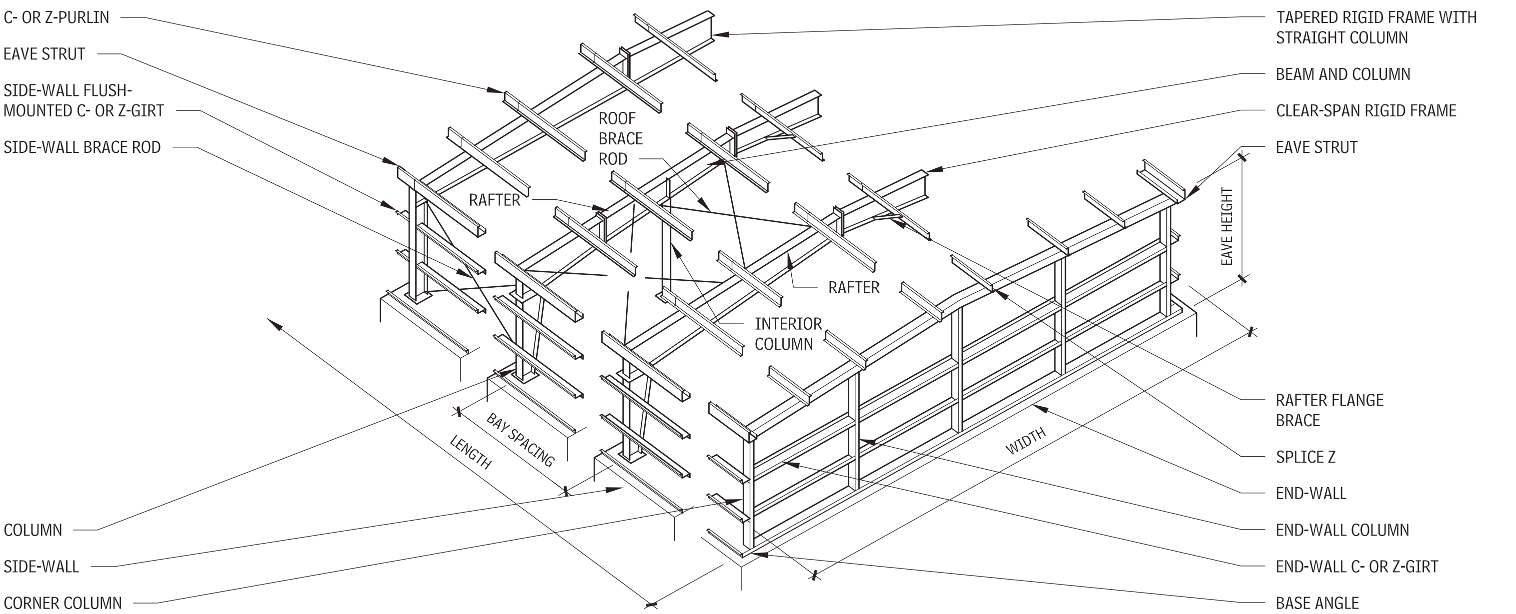
The standing seam metal roof system requires less maintenance than other alternatives, and its long-term performance record is excellent. Most standing seam metal roofs provide a free-floating monolithic membrane, connected by a series of slotted clips that allow movement. This method freely accommodates expansion/contraction cycles caused by thermal changes. In addition, a variety of details, colors, and finishes are available. The standing seam metal roof may present several areas of concern to architects: the modularity of roof panels and seams, important for locating plumbing stacks, skylights, and other roof equipment.

Although the structural and envelope systems of metal buildings are usually highly integrated, metal building system manufacturers rarely consider the mechanical and interior components in any detail.

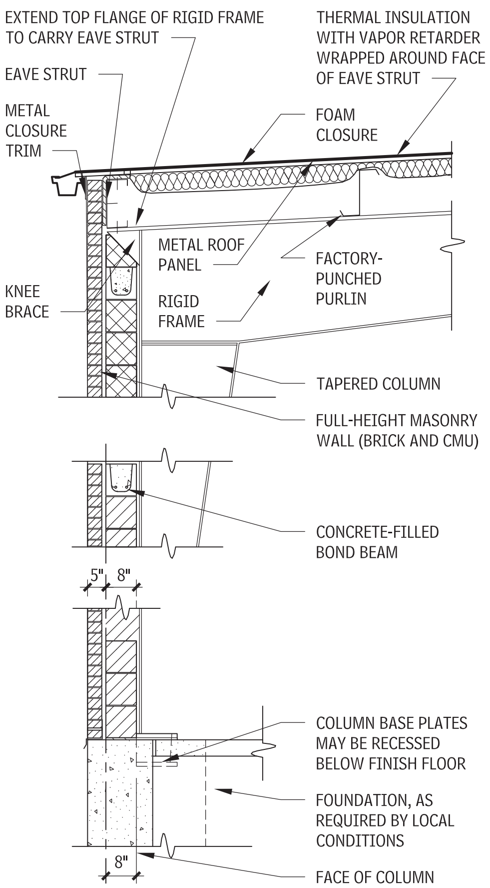
BUILDING TYPES AND WIDTHS
15.22



FRAMING SYSTEM COMPONENTS
15.23



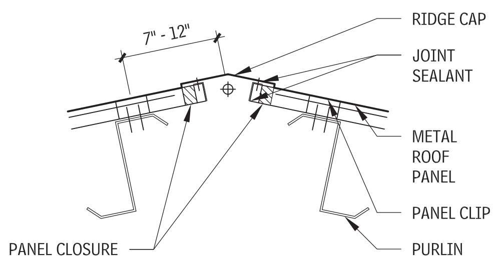
MASONRY AND BRICK VENEER WALL SECTION
15.24



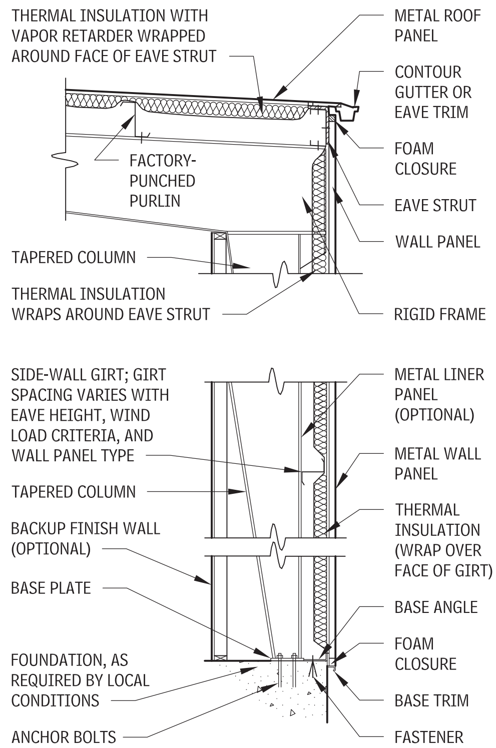
When using a metal building system a variety of exterior cladding alternatives are available, including lightweight corrugated metal, insulated sandwich panels that provide both interior and exterior finishes, masonry, and stucco. Metal building system manufacturers also offer door, window, and skylight components as integral parts of the envelope and interior. Designating responsibility for engineering, fabrication, and construction may allow better cost control. Architects working with metal building systems can rely on technical support from the manufacturer, including the preparation of fabrication and subsystem engineering documents.

The typical rectilinear nature of metal building systems frequently results in buildings that are more easily expanded. Mechanical and interior components are integrated in the ceilings or in the structure, but the mechanical equipment is normally kept on the exterior, sometimes presenting difficulty with visual integration.

RIDGE DETAIL
15.25



METAL WALL PANEL SECTION
15.26

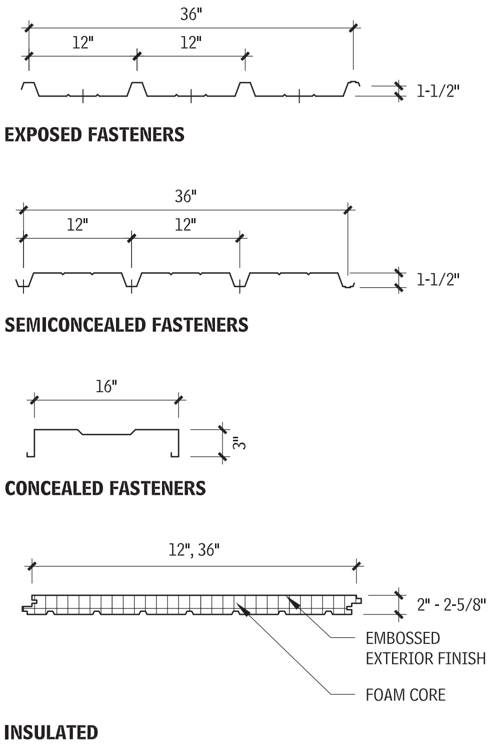


NOTE

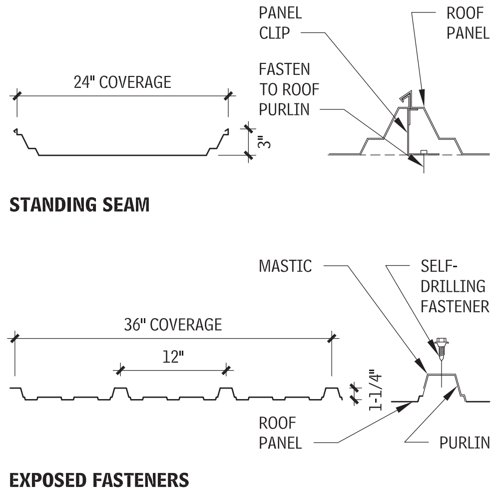
15.26 A sidewall girt may be inset between columns, attached by clip angles to the steel frame.

Contributors:
Based on Richard D. Rush, AIA, *The Building Systems Integration Handbook* (John Wiley & Sons, Inc., 1986); Robert P. Burns, AIA, Burns & Burns, Architects, Iowa City, Iowa.

COMMON WALL PANEL TYPES
15.27



ROOF PANEL TYPES
15.28



SPECIAL FUNCTION CONSTRUCTION

SOUND AND VIBRATION CONTROL

Many manufactured products are available to limit noise and vibration in buildings. Noise can transmit through the air and directly through building components or via vibration through the structure itself. The following discussion highlights a few common manufactured products that are available to address these concerns.

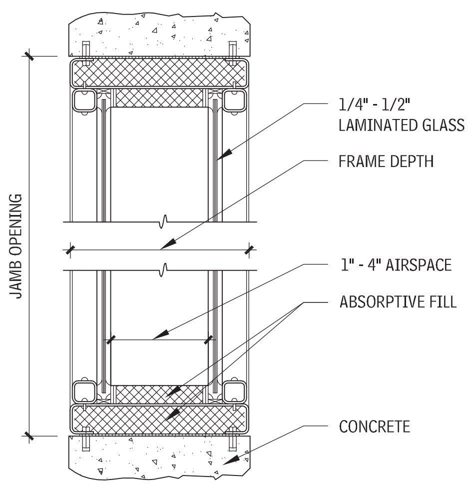
AIRBORNE SOUND ISOLATION

The products described here are used for airborne sound insulation.

ACOUSTIC WINDOW

Depending on the intended function, many spaces require a certain level of sound isolation from surrounding areas. Many common building components are available with specific acoustic ratings, but generally require specialized design and construction to achieve good performance. For example, where a high level of sound isolation is required between spaces that also need a visual connection, standard window assemblies may not be sufficient. Acoustic windows typically employ two panes of 1/4- to 1/2-in.-thick laminated glass separated by a 1- to 4-in. airspace and have been designed as an assembly to meet specific performance requirements up to Sound Transmission Class (STC) 55±.

ACOUSTIC WINDOW
15.29



ACOUSTIC DOOR

Where a partition is required to limit noise transmission, a door within that partition may be the weakest link, significantly downgrading the wall's overall acoustic performance. To address this, acoustic seals that fit tightly against the door when it is closed can be applied at the frame head and jambs. Similarly, automatic drop seals at the door bottom that activate when the door is closed should be provided. Door bottom seals should be adjustable to allow a precision fit after installation. Seals help to reduce noise penetration that occurs around the perimeter of the door, although sound isolation of a typical door, even with the addition of door seals, is generally limited to STC 35/40. Where increased acoustic performance is required, such as for recording studios or at machine rooms that abut occupied space, a unitary acoustic door and frame system should be utilized. These assemblies have been engineered to achieve acoustic ratings ranging from STC 45 to STC 60/65.

Most acoustically rated doors will use two or more sets of acoustic seals at the head and jamb and cam lift hinges to ensure that the door fits tightly against the frame/seals when closed.

STRUCTURE-BORNE SOUND ISOLATION

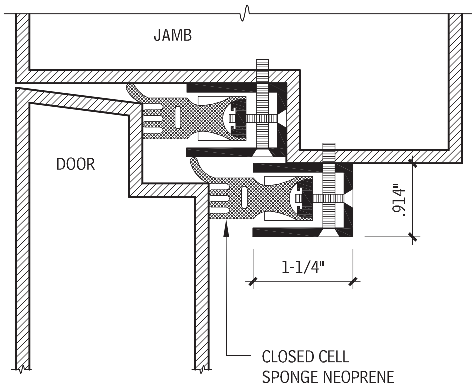
Structure-borne noise is that noise that is transmitted as vibration through the building structure and is radiated off room surfaces. Impact noise, such as that from hard-heeled shoes on hard flooring surfaces, can be transmitted through the structural components. To mitigate this, resilient underlayment materials should be

NOTE

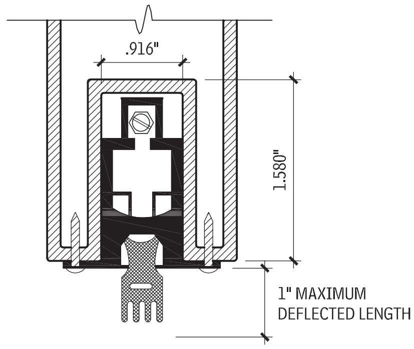
15.27 Wall panels are typically installed vertically, up to 40 ft. in length. Textured and smooth panels are typically factory finished, but may be field painted.

Contributor:
Robert P. Burns, AIA, Burns & Burns, Architects, Iowa City, Iowa.

ACOUSTIC DOOR SEALS
15.30



JAMB, HEAD, AND HINGE SEAL

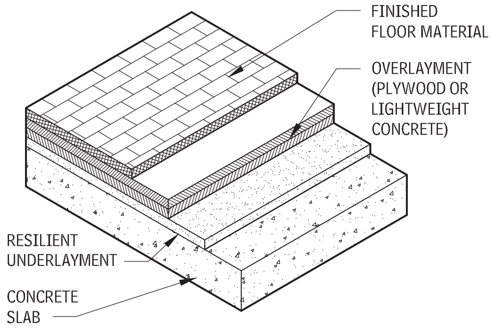


MORTISED AUTOMATIC DROP SEAL

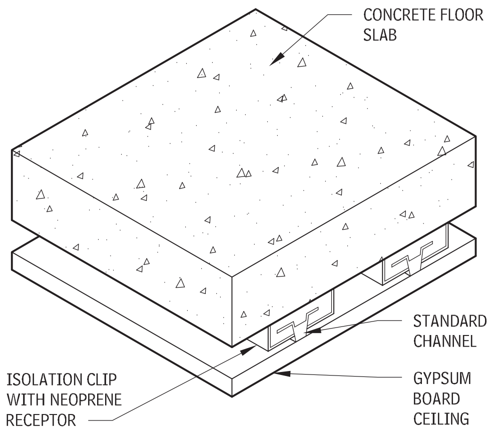
included as part of the floor assembly. Resilient underlayments are manufactured in a variety of thicknesses and materials, including meshed nylon wire, dense glass-fibers, rubber, and cork. An overlayment of lightweight concrete or plywood may be required to serve as a setting bed for the finished floor material.

Another product to help reduce structure-borne noise through floor and wall assemblies is the resilient isolation clip or brace. These clips provide a resilient connection between the structure and the finished wall or ceiling surface to mitigate structure-borne noise. Figure 15.32 shows standard furring channels held in place by the isolation clip, and a resilient receptor attached to the concrete floor slab.

RESILIENT UNDERLAYMENT
15.31



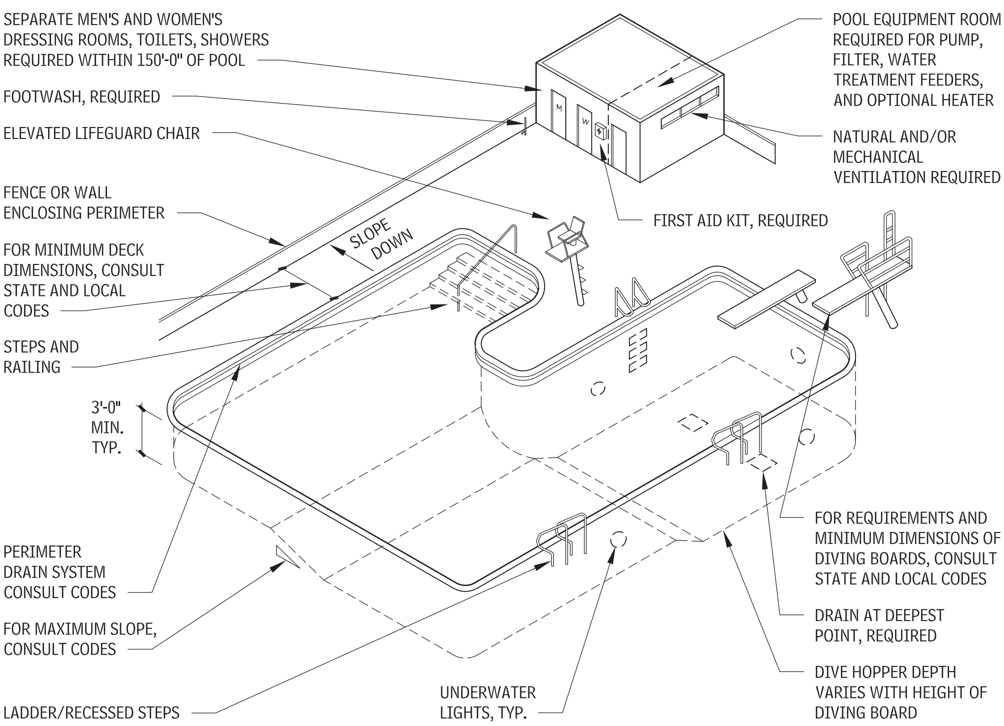
CLIP
15.32



SPECIAL FACILITIES COMPONENTS

AQUATIC FACILITIES

TYPICAL PUBLIC SWIMMING AND DIVING POOL REQUIREMENTS
15.33

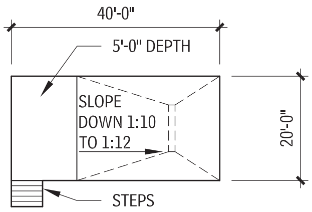


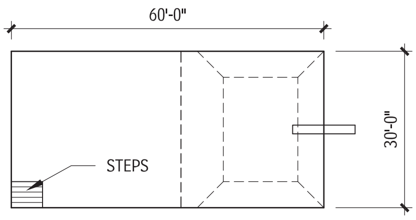
NOTES

1. All swimming pools must be equipped with a filtration system for clarifying the water; the system must be an integral part of the circulation system and consist of one or more filter units—either sand, diatomaceous earth, or cartridge type.
2. Every swimming pool must be equipped with a disinfectant feeder as required to keep the microbiological, chemical, and physical characteristics of the pool water within prescribed limits.
3. All swimming pools must have the water depth marked plainly at or above the waterline on the vertical wall where possible and on the edge of the deck next to the pool; depth markers must be 25 ft. or less on center.
4. When visitor or spectator areas are provided at swimming pools, there must be an absolute separation between those areas and the pool area. Provide separate toilets for visitors and spectators.
5. Every public pool must have a readily accessible room or area designated and equipped for emergency care.

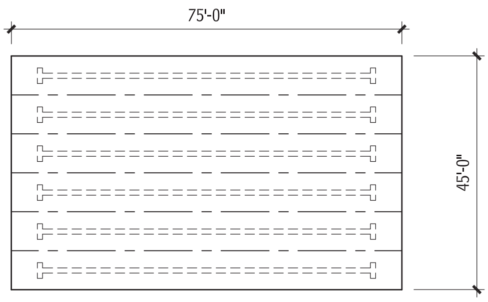
Contributors:
Jessica Powell, Rippeteau Architects, P.C., Washington, DC.
Robert D. Buckley, AIA, robert d. buckley * architect, Kalamazoo, Michigan; D. J. Hunsaker, Councilman/Hunsaker & Associates, St. Louis, Missouri; National Swimming Pool Foundation, Merrick, New York.

TYPICAL PUBLIC POOLS
15.34



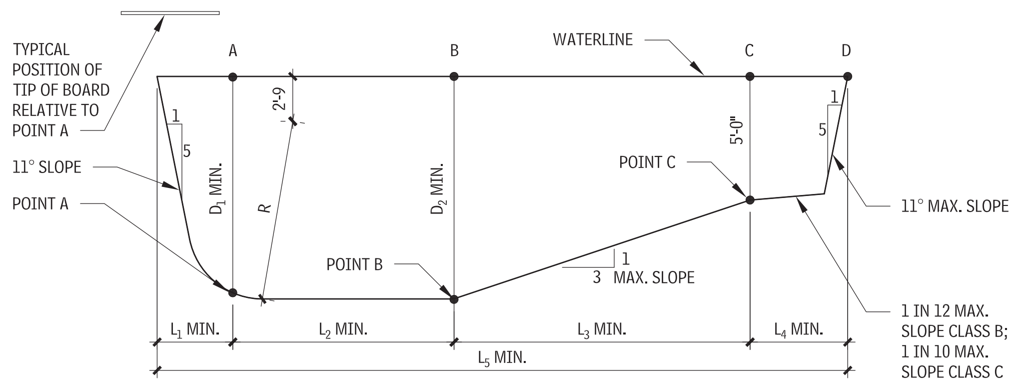


SWIMMING AND DIVING POOLS



6-LANE LAP POOL

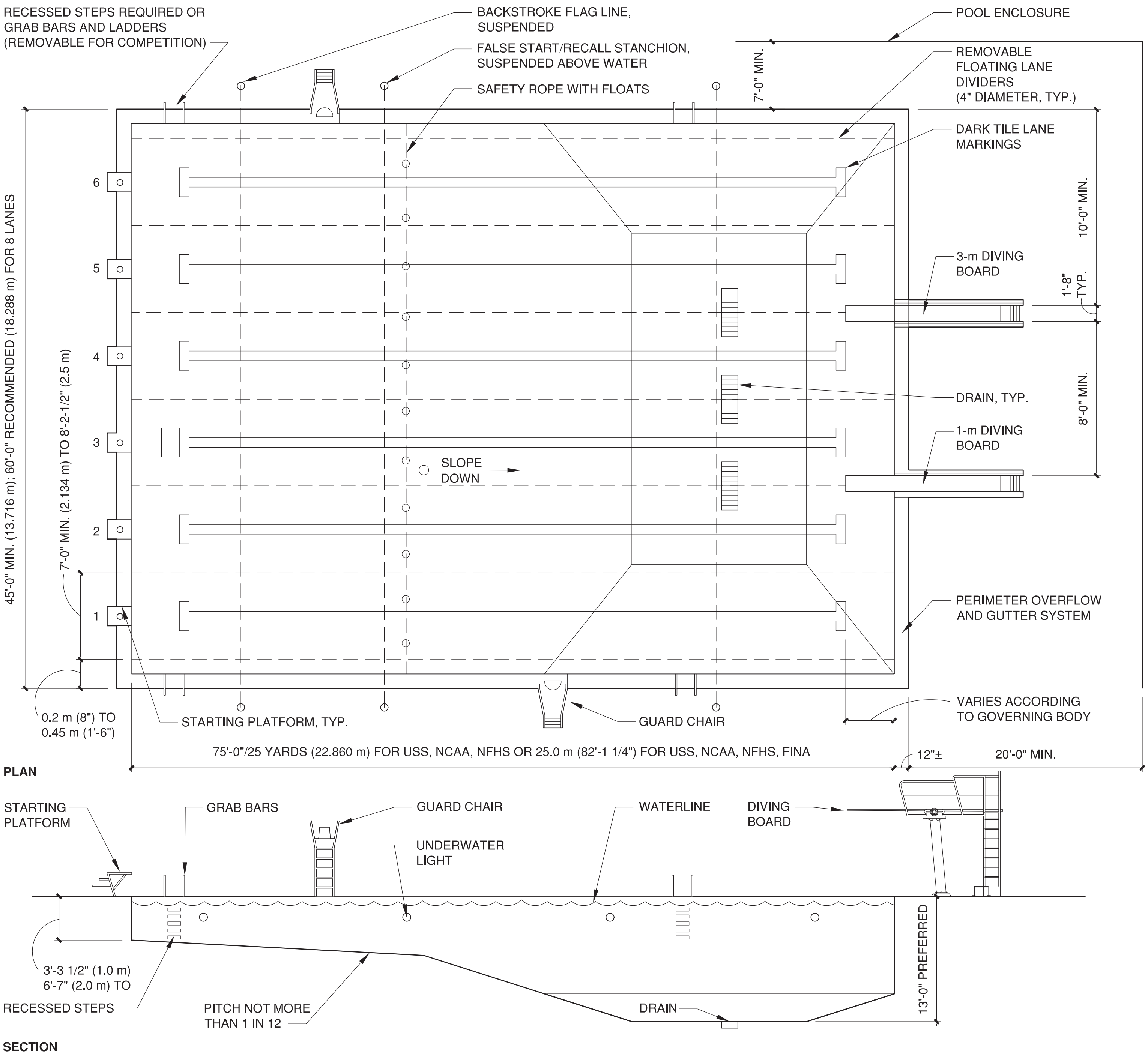
STANDARD DIMENSIONS KEY
15.36



STANDARD DIMENSIONS FOR PUBLIC SWIMMNG POOLS
15.35

POOL TYPE	DIVING EQUIPMENT: MAX BOARD LENGTH	DIVING EQUIPMENT: MAX HEIGHT OVER WATER	MIN DIMENSIONS[2]: D_1	D_2	R	L_1	L_2	L_3	L_4	L_5	MIN WIDTH OF POOL AT POINTS: A	B	C
VI	10–0	0–26	7–0	8–6	5–6	2–6	8–0	10–6	7–0	28–0	16–0	18–0	18–0
	—	(2/3)	(2.13)	(2.59)	(1.68)	(0.76)	(2.44)	(3.20)	(2.13)	(8.53)	(4.88)	(5.49)	(5.49)
VII	12–0	0–30	7–6	9–0	6–0	3–0	9–0	12–0	4–0	28–0	18–0	20–0	20–0
	—	(3/4)	(2.29)	(2.74)	(1.83)	(0.91)	(2.74)	(3.66)	(1.22)	(8.53)	(5.49)	(6.10)	(6.10)
VIII	16–0	—	8–6	10–0	7–0	4–0	10–0	15–0	2–0	31–0	20–0	22–0	22–0
	—	(1)	(2.59)	(3.05)	(2.13)	(1.22)	(3.05)	(4.57)	(0.61)	(9.45)	(6.10)	(6.71)	(6.71)
IX	16–0	—	11–0	12–0	8–6	6–0	10–6	21–0	—	37–6	22–0	24–0	24–0
	—	(3)	(3.35)	(3.66)	(2.59)	(1.83)	(3.20)	(6.40)	—	(11.43)	(6.71)	(7.32)	(7.32)

25-METER AND 25-YARD COMPETITION SWIMMING AND DIVING POOL
15.37



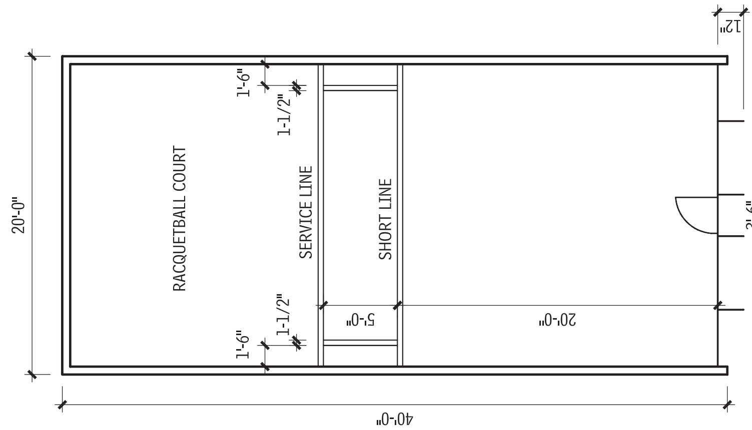
Contributors:
Robert D. Buckley, AIA, robert d. buckley * architect, Kalamazoo, Michigan; D. J. Hunsaker, Councilman/Hunsaker & Associates, St. Louis, Missouri; National Swimming Pool Foundation, Merrick, New York.

ATHLETIC AND RECREATION SPECIAL CONSTRUCTION

DIMENSIONS FOR STANDARD RACQUETBALL AND SQUASH COURTS
15.38

	FINISHED DIMENSIONS
RACQUETBALL COURTS	20'-0" × 40'-0" × 20'-0"
SQUASH COURTS	21'-0" × 32'-0" × 18'-6" (min.)

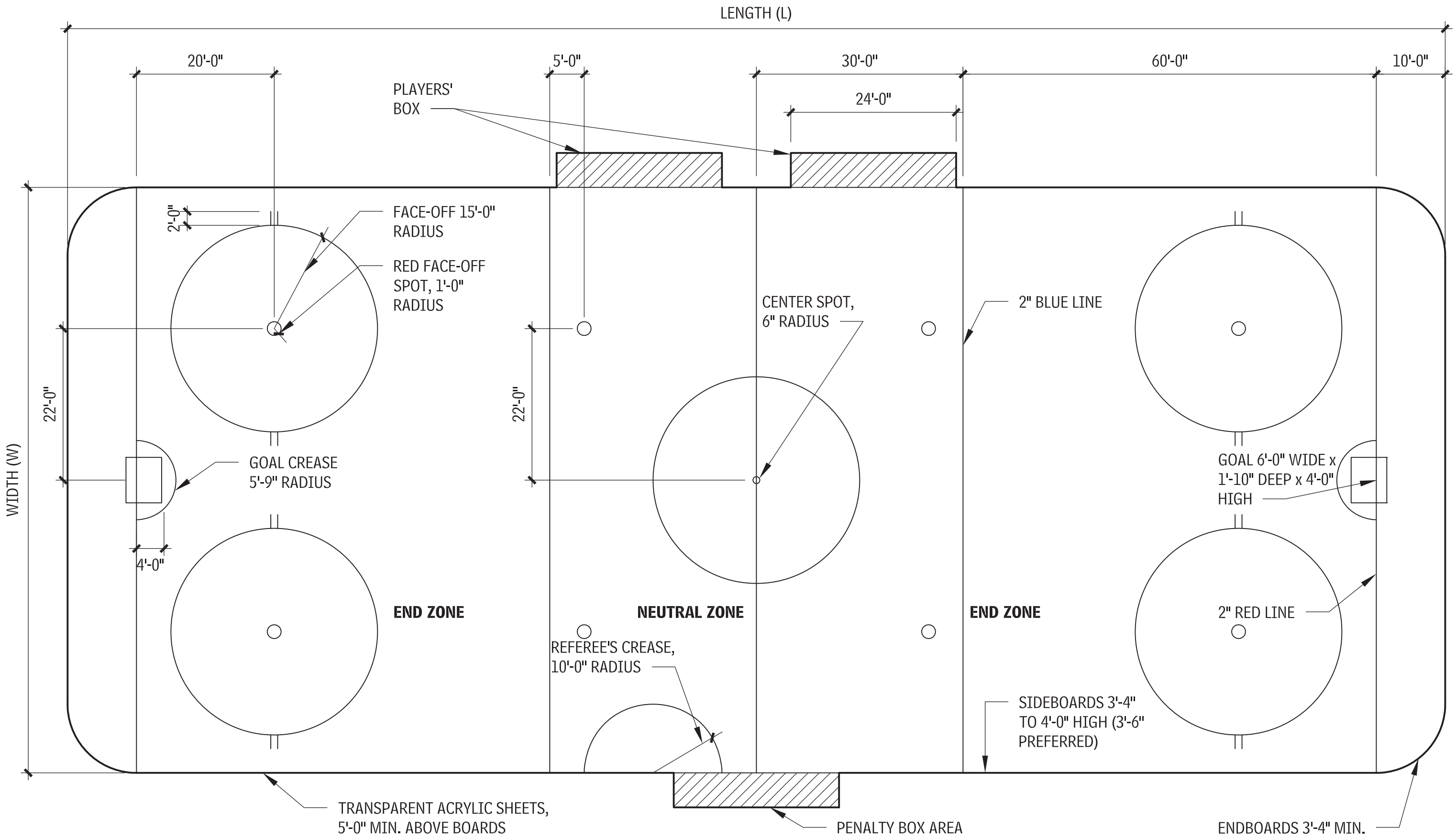
TYPICAL RACQUETBALL AND SQUASH COURT
15.39



ICE HOCKEY RINK SIZE
15.40

RINK TYPE	LENGTH (FT)	WIDTH (FT)
NHL	200	85
Olympic	200	100
NCAA	200	85
High school	200	85

ICE HOCKEY RINKS
15.41



PLAN

ELEMENT G: SITEWORK

16

SITE EARTHWORK

SLOPE PROTECTION AND EROSION CONTROL

Slope protection and erosion control is required when steep slopes are subject to erosion from stormwater runoff or flowing streams. Erosion can damage the site and pollute waterways with sediment.

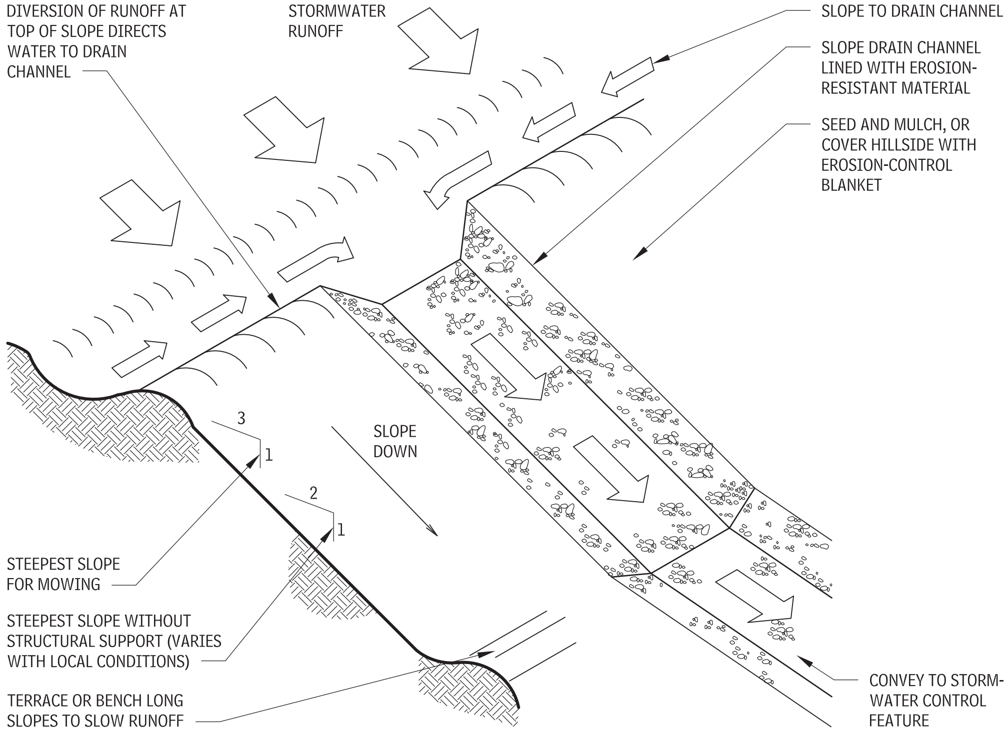
The need for mechanical stabilization can be reduced through careful site gradings that divert or slow the velocity of runoff and by avoiding disturbances to stable, natural streambanks. Check with regulatory agencies before planning to grade streambanks, wetlands, or floodplains.

Numerous proprietary products are available for streambank stabilization and erosion control, so consult manufacturers.

Follow these general design guidelines:

- Control erosion during construction with silt fences, straw bales, sediment ponds, and seeding and mulching. Adhere to local and state guidelines and regulations.
- Line channels with erosion-resistant material (sod, stone riprap, erosion-control blanket). Channel dimensions and lining should be designed for expected runoff.
- At the bottom of the slope drain channel, convey the flow to a storm sewer, detention pond, constructed wetland, or other control method that meets regulations.

GRADING AND EROSION CONTROL
16.1



WATER MANAGEMENT

DEWATERING

The construction of buildings, tunnels, utilities, and roadways often requires excavations that extend below the groundwater level, potentially resulting in detrimental effects. Soils above the groundwater level provide confinement to hydrostatic pressures. Once these overburden soils are removed, upward fluid pressures act on the remaining soil particles, loosening them and causing a marked reduction in strength. In the case of granular soils (including sands), excavation below the groundwater can cause soils to act like a viscous fluid and lose virtually all strength. For finer-grained soils (including materials containing silt and clay), hydrostatic pressures can cause a significant increase in moisture content, with a corresponding decrease in strength.

It is important to note that groundwater can cause adverse effects to overburden soils even when excavations do not extend below the static groundwater level. The use of vibratory equipment or heavy construction vehicles working in close proximity to the water table can cause water to migrate upward and cause a similar loss in strength.

To prevent loss of density and strength to soils that will support structural elements, it is critical that groundwater be properly assessed during the geotechnical investigation and that appropriate measures be taken to control water during the construction phase. The need for construction or permanent dewatering, and the means of dealing with it, should be addressed in the soils report for the project.

CONSTRUCTION DEWATERING

A number of methods can be used to control groundwater during the construction phase of a project. The selection of an appropriate method, or combination of methods, should be based on the nature of the subsurface materials through which the water flows and the depth to which the excavation must extend below the groundwater elevation. Acceptable means of water disposal should be determined prior to implementation. Following are descriptions of some of the more common types of dewatering methods.

DITCHING

When excavations are to extend only a short distance below the groundwater level, and subsurface soils contain a significant quantity of silts and clays, often groundwater may be controlled by ditching. In this technique, narrow trenches are excavated into the soil to a depth several feet below the groundwater level. The trenches are sloped such that the intercepted water drains to a low point, from which it is removed by gravity or pumped to a point off-site. Ditches are typically excavated along the upslope portion of the site or around the perimeter, to intercept water before it reaches the site. On larger sites, temporary ditches may also be required within the construction area. As this approach is typically only applicable to sites containing slow-draining, finer-grained soils, ditching must often be performed well in advance of construction.

WELLPOINTS

Wellpoints may be utilized for site dewatering where granular materials such as sands and gravels are present and where excavations are to extend to only a moderate depth below grade. Wellpoints consist of a series of slotted pipes inserted vertically into the ground and connected in series to a horizontal header pipe. The header pipe, in turn, is connected to a vacuum pump. The system essentially creates negative pressure in the wells to extract water from the soil through suction. With a normal atmospheric pressure of about 14 psi and normal pressure losses in the system, the maximum depth to which this technique is effective is typically about 15 ft.

DEEP WELLS

Where groundwater must be lowered to a significant depth, or where subsurface materials contain significant quantities of silt and/or clay, wellpoints may not be adequate to lower the groundwater to the desired level. In such instances, deep wells are often used. A deep well consists of one or more boreholes drilled well below the groundwater level and the depth of the proposed cut, then fitted with a filtered pipe and a positive displacement pump. The pump, which is situated in the base of the well, is not dependent on suction to extract water from the surrounding soil. Water passes into the bottom of the well by gravity, and the pump discharges the collected fluid to the surface. Unlike wellpoints, deep wells can lower the water table 100 ft or more, depending on the depth and spacing of the wells and the capacity of the pump.

CONSTRUCTION DEWATERING CONSIDERATIONS

When groundwater is pumped from the ground, the effective weight of the soil within the dewatered portion of the soil profile is increased roughly twofold. As a result, dewatering causes an increase in pressure on subsurface materials. For example, lowering of the groundwater level by 10 ft will cause an increase in stress of more than 600 psf to the materials below the new groundwater level. Such stress increases will result in some consolidation of the soils, which causes settlement of the ground surface both within the immediate project site and within a larger zone of influence extending some distance beyond the excavation limits. This factor is of particular concern when an excavation is to be made immediately adjacent to developed properties.

Dewatering can also change the direction of local groundwater flow. Should there be a contaminant plume in the vicinity of the site, it may be directed toward the dewatering system. Water collected under such conditions would need to be treated prior to discharge.

Alternatives to dewatering may include:

- Installation of sheet piles, or slurry walls into a low permeability layer below the depth of the proposed excavation, to significantly reduce groundwater inflow without affecting the level of the groundwater beyond the excavation limits.
- Freezing of the ground by employing injections of liquid nitrogen. This method causes the soil to act as an impermeable solid and allows the excavation to be made without removing water or affecting water beyond the zone of freezing.

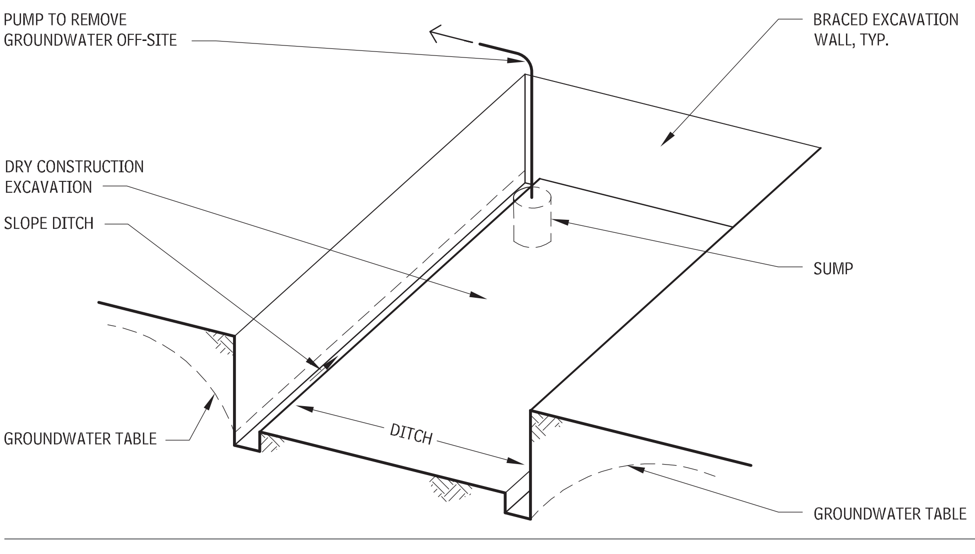
PERMANENT DEWATERING

In general, structures constructed or installed below the permanent groundwater table should be designed to be watertight, so that permanent dewatering is unnecessary. Where this is cost-prohibitive, and where a permanent lowering of the groundwater is desirable, several methods of permanent dewatering may be considered.

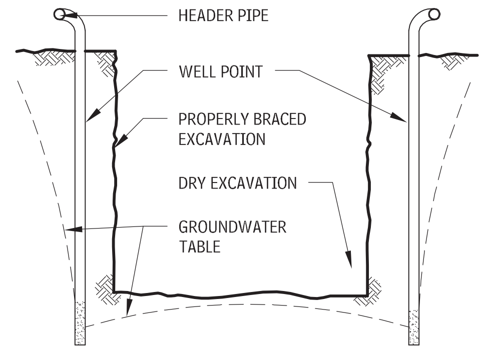
DEEP WELLS

As noted previously, deep wells consist of boreholes fitted with slotted pipe and a positive displacement pump. This type of system may be used as part of a permanent dewatering method, as well as for temporary construction applications. However, this type of method is not passive in nature, and requires periodic maintenance and upkeep, as well as a constant source of power, accessible cleanouts, and pressure-relief plugs.

DITCHING
16.2



WELLPOINTS
16.3



BASEMENT EXCAVATION

Nearly all new structures require some excavation to construct foundations or basements. The removal of soil by excavation results in changes of the soil stresses below and around the excavation. Nature reacts to a vacuum, and gravity will cause the ground—and sometimes the groundwater surrounding the excavation—to move toward the excavated area. The deeper the excavation and steeper the excavation slope, the greater the unbalanced forces.

Most soils have sufficient inherent strength to resist at least some of these unbalanced forces, at least for a short period of time. For shallow sloped excavations, the strength or resistance of most soils is sufficient to prevent excessive movements during the time required for construction. However, for deep excavations and/or areas that do not have sufficient room for a sloped cut, a temporary excavation support system is required to prevent the earth from caving in on the excavation. The Occupational Safety and Health Administration (OSHA) stipulate numerous regulations controlling soil excavations. These regulations should be consulted prior to excavation work, particularly if personnel will be working within the excavated area.

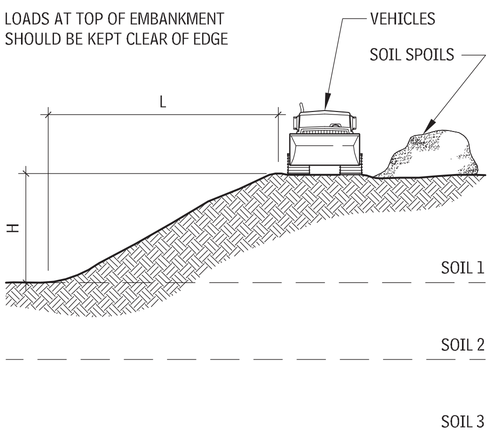
OPEN-CUT EXCAVATIONS

Open-cut excavations are generally excavations of large areas with gradual sloping sidewalls that do not require shoring. This method can be acceptable when the following conditions have been considered:

- Sufficient room for the slope on either side of the excavation
- Adequate room for placing the spoils away from the excavation
- No surface or groundwater issues with the excavation
- No loads near the top of the excavation, including: vehicles, existing buildings, soil loads, or construction equipment

Slope stability determines the slope of the sides of the excavation, which typically run at approximately 1.5 horizontal to 1.0 vertical for cohesionless soils under normal circumstances.

OPEN EXCAVATION
16.4



EMBANKMENT STABILITY FOR OPEN EXCAVATION
16.5

SOIL TYPES			L/H	REMARKS
1	2	3		
Fill	Rock		>1.5	Check sliding of Soil 1
Soft clay	Hard clay	Rock	>1.0	Check sliding of Soil 1
Sand	Soft clay	Hard clay	>1.5	Check lateral displacement of Soil 2
Sand	Sand	Hard clay	>1.5	
Hard clay	Soft clay	Sand	>1.0	Check lateral displacement of Soil 2

SHORED EXCAVATION

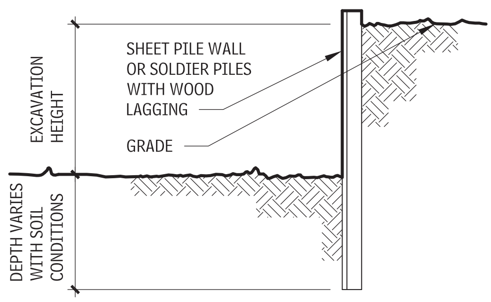
Most excavations that cannot be safely sloped back are supported with some type of temporary wall, called shoring, that can be constructed from the ground surface. Types of temporary walls include interlocking steel sheet piles or steel soldier piles with wood lagging, secant walls, slurry walls, cofferdams, and trenching.

SHEET PILES AND TIMBER SHORING

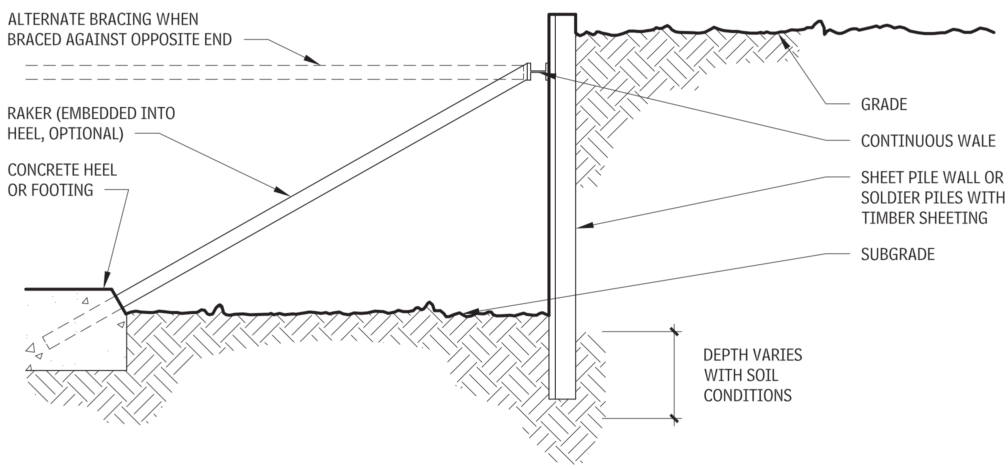
The most common types of shoring for earth support are interlocking steel sheet piling and timber shoring. Sheet piling is readily available in many shapes, sizes, and lengths, and is relatively watertight. Timber shoring uses less steel and is generally less expensive than sheet piling; however, it cannot be used as a barrier against groundwater flow, and could prove to be challenging where running sands are retained behind the walls.

Sheet piling is installed from the surface with a pile hammer, which will generate noise and vibration. Timber shoring can also be installed with a pile hammer, or by drilling and setting the soldier piles, thereby significantly reducing the noise and vibration from the pile-driving operation.

SHORING
16.6



INTERNALLY BRACED EXCAVATIONS
16.7



RAKER BRACE

LATERAL SUPPORT

Walls that extend to depths of 10 to 15 ft can generally be self-supported or cantilevered and do not require additional lateral support. This is accomplished by extending the shoring sufficient depth below the excavation. These "cantilevered" walls resist the lateral pressures from the soil and groundwater, although some deflection at the top of the wall should be expected. However, walls that extend deeper or have significant surcharge loads, or where deflection is a concern, will require some type of additional lateral support (known as "braced walls").

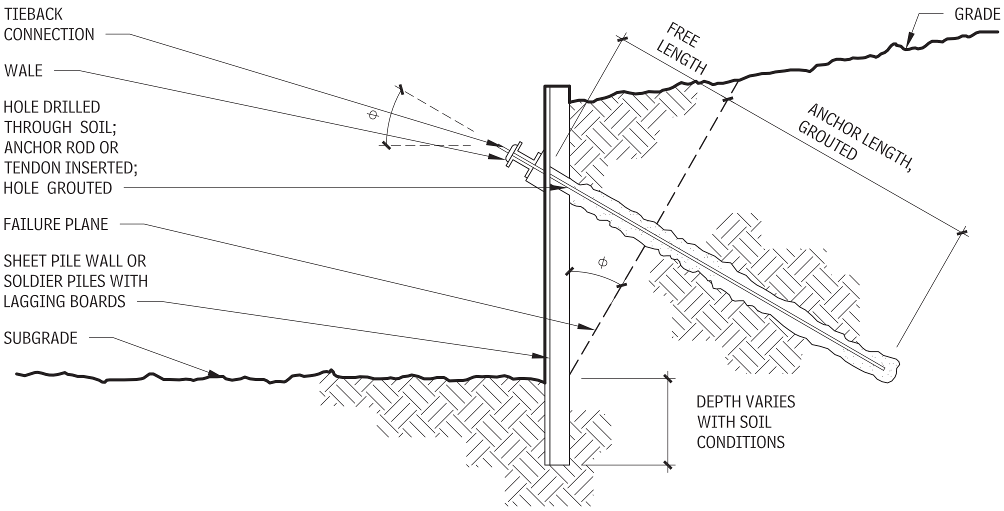
INTERNAL SUPPORT

The lateral support can be internal to the excavation, in the form of wales, struts, or rakers. Internal bracing is very effective, but interferes with the construction of the permanent structure.

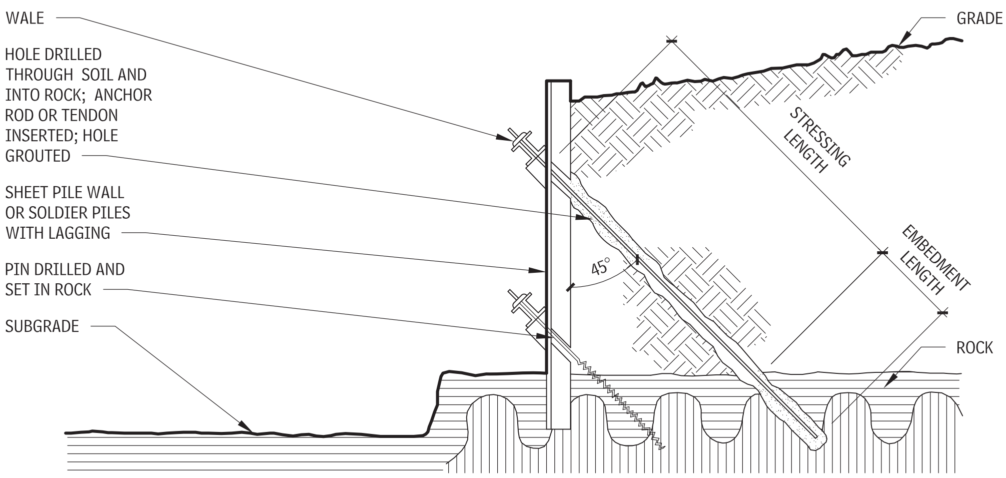
EXTERNAL SUPPORT

External bracing of the excavation is usually in the form of drilled tieback (ground) anchors. The use of tieback anchors to support the wall enables a clear and unencumbered excavation, but requires access to areas beyond the building, which may extend outside the property line. For this reason, tieback anchors are almost always the most desirable method of lateral support if the owner controls the property around the excavation, or if temporary easements can be obtained from private owners or public municipalities.

EXTERNALLY BRACED EXCAVATION DETAILS 16.8



EARTH ANCHOR BRACE



ROCK ANCHOR BRACE

BACKFILL AND COMPACTION

FILL AND BACKFILL

Fill is typically used to raise or level site grades. Backfill is used to fill in spaces around below-grade structural elements, such as around basement walls. The fill must have sufficient strength or resistance and low compressibility to support its own weight and any other overlying structures (pavements, floor slabs, foundations, etc.) without excessive settlement. When soils are excavated, they become loosened and disturbed. If they are suitable for reuse as structural fill or backfill, the soils must be placed in thin layers and compacted to achieve the required strength, resistance, and stability.

COMPACTION

Compaction is the process by which mechanical energy is applied to a soil to increase its density. The degree to which soil can be densified depends on the amount and type of compactive effort, type of soil, and moisture content. Soil is made up of solids and the void spaces between the solid particles. The void space almost always contains some water. If the water completely fills the void, the soil is considered to be totally saturated. During compaction, the total volume of the soil is decreased by reducing the volume of voids, while the volume of solids remains essentially unchanged. If the soil is saturated or nearly saturated during compaction, water must be expelled to decrease the void space.

MOISTURE-DENSITY RELATIONSHIP

Nearly all soil exhibits a defined moisture-density relationship for a specific level of compactive effort.

These relationships can be graphed in a nearly bell-shaped curve, with the maximum density at the apex, corresponding to the *optimum moisture content*.

Standard laboratory tests, such as the Standard Proctor (ASTM D-698) and Modified Proctor (ASTM D-1557), use a standard-size mold and a specific level of compactive energy to develop the moisture density curve for a specific soil. The maximum density from these curves defines the 100 percent level of compaction for a given soil. Compaction requirements for fill and backfill are generally specified as a percentage of the maximum density, typically between 90 to 95 percent, as determined using one of the standard laboratory tests mentioned above. The low and high moisture contents are usually represented as a horizontal line connecting opposite sides of the Proctor curve for a given density. This represents the range of moisture content within which the soil can be compacted most readily.

FIELD DENSITY TESTS

Field density tests are performed on compacted soil to verify that a specific level of compaction has been achieved. There are several methods for determining the in-place density of soil. Today, the most commonly used method involves the nuclear density gauge, a device that measures the reflection of atomic particles from a tiny radioactive source material to determine the soil density and moisture content. The test is performed at the surface without any excavation, and results can be obtained faster than with other test methods.

MOISTURE CONTROL

Moisture content of the fill and backfill should be near the optimum moisture content. Otherwise, the minimum required field density is very difficult (or impossible) to obtain, no matter how much energy is used for compaction. If the soil is too wet, the water in the pores cannot be expelled fast enough to allow for a sufficient decrease in volume. If the soil is too dry, the capillary forces around the soil particles are too large to be broken down by the compactive energy. Therefore, controlling the moisture of the fill and backfill to within specific limits near the optimum moisture content is necessary to achieve the required level of compaction.

SOIL TYPE AND COMPACTION EQUIPMENT

To be most effective, the compaction equipment must match the type of soil to be compacted. In general, compaction equipment can be divided into two basic groups: rollers or plates. Rollers come in large variations in size, but all use a weighted wheel or drum to impart energy to the soil. In addition, some rollers use an electric rotor to vibrate the drum, thereby increasing the energy to the soil. Other drums have protrusions called *sheepsfoots,* which impart a kneading action to the soils. Some plate compactors also use vibratory energy to compact the soils, while other plate compactors, called *tampers*, move up and down, imparting a vertical dynamic load to the soil.

In general, coarse-grained granular soils such as sands and gravels are more easily compacted than fine-grained soils such as clays and clayey silts. Vibratory energy is very effective in densifying sands and gravels, since the interparticle bonds are relatively weak. When the granular soils are vibrated at the correct frequency, the soil particles rearrange themselves into a denser state under their own weight and the weight of the compactor. Vibratory steel drum rollers and vibratory plate compacters are considered the most effective compaction equipment for granular soils.

Fine-grained soils hold more moisture and have higher internal interparticle forces. Vibratory energy is much less effective for these soils. Clayey soils require more mechanical energy to break down the internal forces during compaction. The kneading action of a sheepsfoot roller is very effective in this regard.

Fine-grained soils generally have a narrower range of moisture contents for optimum compaction. Often, the clayey soils are too wet to compact and the moisture content must be reduced. Reducing the moisture content in clay is typically done by allowing water to evaporate from the surface of the clay. The rate of evaporation is dependent on the ambient air temperature and wind conditions. However, the drying process can be enhanced by using a process called *aeration* in which steel discs are used to periodically turn the soil, thus exposing more of the soil to the atmosphere.

SITE GRADING

INTRODUCTION

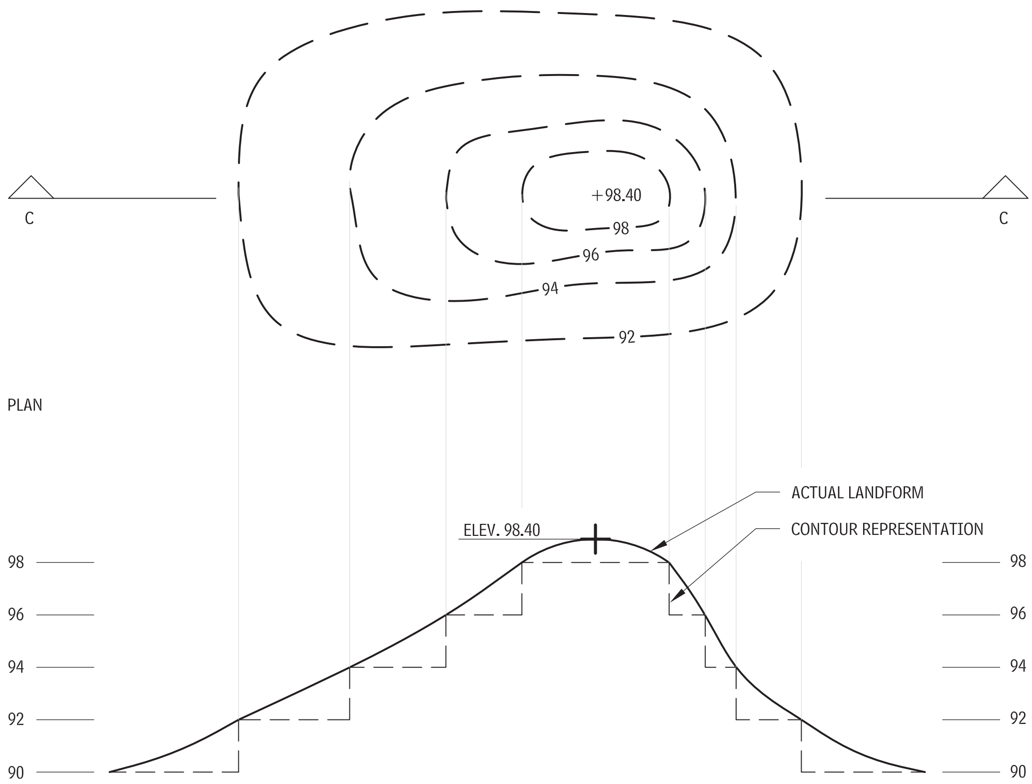
Through the process of grading and earthwork, the designer adapts a building program from a two-dimensional drawing board to the dynamics of an actual site. Through skillful grading, the designer directs drainage away from buildings and controls runoff from leaving the site and adversely affecting the environment. He or she creates level areas for intensive use, such as parking lots and playing fields. In addition to accommodating the functional requirements of the program, the designer may add to the experience of visiting the site by screening out undesirable views and capitalizing on dramatic vistas. He or she may also manipulate the landforms to protect users from adverse elements such as wind and noise.

CONTOURS

Topographic changes in the landscape are represented on two-dimensional maps using the convention of contours. A contour is a horizontal plane slicing through the earth at a constant elevation above sea level or some other known reference elevation. A contour line, as illustrated on a topographic map, represents the edge of the contour plane as it meets the surface of the landform. The shoreline of a pond best represents the image of how a contour's edge meets the surface. If the surface of the water represents the contour plane, and water seeks a constant elevation, then the water's edge on a still pond could be illustrated as a contour line. If after a few dry days in summer the water elevation drops, then the surface represents a new contour elevation, and the still-moist shoreline retains evidence of the higher elevation.

The contour interval, or the vertical distance between two contours, is always the same throughout an entire drawing. Intervals of 1, 2, 5, 10, 20, 50, 100, 500, and 1,000 are common. The smaller the interval, the greater the degree of accuracy on a map and the greater the number of contours represented. Selection of the interval is a function of the scale of the drawing, the steepness of the terrain, and the use intended for the property. A section drawn through several contours appears to represent a stacked configuration, but in reality, the change between contours represents a gradual transition, like the fluid landforms of the earth.

SECTION REPRESENTATION OF PLAN
16.9



SECTION C–C

Contributors:
Donald Neubauer, PE, Neubauer Consulting Engineers, Potomac, Maryland; Mueser Rutledge Consulting Engineers, New York, New York; James W. Niehoff, PE, Chief Engineer, PSI, Wheat Ridge, Colorado and Timothy H. Bedenis, PE,.e. Chief Geotechnical Engineer, Soil and Materials Engineers, Inc., Plymouth, Michigan.

SLOPES, GRADES, AND SPOT ELEVATIONS

Gradient refers to the changing elevation along the Earth's surface. The slope of a gradient, or the difference in elevation between two points over a given distance, is also defined as:

Slope = Rise/Run

(See Figure 16.10.)

Another frequently used helpful designation is:

Gradient = Vertical Distance/Horizontal Distance (G=V/H)

Memorizing the following inversions of this equation is also useful:

$$V = G \times H$$

$$H = V/G$$

Gradients may be expressed as percentages, decimals, ratios, or angles. Percent slope is based on the rise or fall over a distance of 100 ft. The decimal equivalent for a 25 percent slope is 0.25. In a ratio, the horizontal dimension is traditionally given first, as in 4:1 (four to one). Ratios are often used when describing steeper slopes.

SLOPE FORMULA 16.10

$$\text{SLOPE} = \frac{\text{RISE}}{\text{RUN}}$$

ALSO EXPRESSED AS: $G = \frac{V}{H}$

WHERE:

$$\text{GRADE} = \frac{\text{VERTICAL DISTANCE}}{\text{HORIZONTAL DISTANCE}}$$

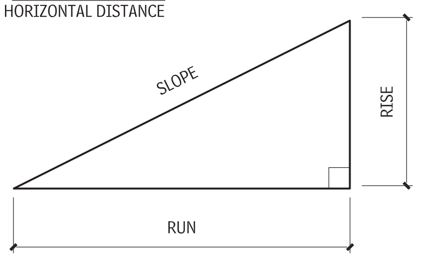


ILLUSTRATION 14

GRADIENTS 16.11

PERCENT SLOPES	DECIMALS	RATIOS	ANGLES
5	0.05	20:1	2.86
10	0.10	10:1	5.71
20	0.20	5:1	11.31
25	0.25	4:1	14.04
33.33	0.3333	3:1	18.43
45	0.45	2.22:1	24.25
50	0.50	2:1	26.57
100	1.00	1:1	45

In small-scale construction, such as when laying out a brick patio, contractors often refer to slopes in terms of inches per foot. A 2 percent slope is equivalent to 1/4 in. per ft; a 1 percent slope is equivalent to 1/8 in. per ft. This allows for a greater degree of accuracy within subtle grade changes.

Grades on consistently sloping surfaces are identified on grading plans with small arrows, pointing downhill. Maximum and minimum ratios are identified on gradients of gradual or ever-changing slopes. Spot elevations represent exact elevations at key points, usually accurate to the hundredths' place. The highest and lowest elevations on a landform are usually designated with spot elevations.

Rougher surfaces require greater slope for positive drainage than smooth surfaces because the friction encountered can slow the speed of water and potentially result in surface ponding. Ponding on walkways can create a slipping hazard for pedestrians on a wet surface, which can be exacerbated with winter icing.

Surface texture can also affect the perception of slope. Coarser textures are less noticeable than smooth. As a general rule, slopes of 2 percent and above are clearly perceptible to the eye. Lesser slopes may be more visible if a contrasting horizontal line is adjacent.

GRADING STANDARDS 16.12

SURFACE	MAXIMUM (%)	MINIMUM (%)
Lawns and grass areas	33 (3:1)	2
Unmowed slopes	50 (2:1)	2
Athletic fields	2	0.5
Planted slopes	10	0.5
Berms	20	5
Plaza/patios (concrete)	2.5	0.75
Plaza/patios (brick, flagstone)	2.5	1.5
Side slopes of walks (concrete)	4	1
Longitudinal slope on walks (not ADA)	10	0.75
Longitudinal slope on streets	20	1
Longitudinal slope on driveways	20	1
Longitudinal slope on parking areas	5	1
Slope of road shoulders	15	1
Crown of streets	3	1
Side slopes of swales	10	1
Longitudinal slope of swales (grassed)	5	1
Side slope of ditches	Angle of repose	Angle of Repose
Longitudinal slope of ditches (no riprap)	5	1

TYPICAL GRADING PLAN LEGEND 16.13

TYPICAL LEGEND

— — 53 —	EXISTING CONTOUR
53	PROPOSED CONTOUR
→ 3 % →	SWALE CENTERLINE
+ 59.32	EXISTING SPOT ELEVATION
+ 59.68	PROPOSED SPOT ELEVATION
+ TC 64.28	TOP OF CURB
+ BC 63.78	BOTTOM OF CURB
+ TW 94.35	TOP OF WALL
+ BW 90.35	BOTTOM OF WALL
+ TS 72.14	TOP OF STEP
+ BS 68.64	BOTTOM OF STEP
+ HP 89.68	HIGH POINT
+ LP 52.15	LOW POINT
— PL — - - —	PROPERTY LINE
ROW	RIGHT-OF-WAY
→ SD →	STORM DRAIN
DI	DROP INLET
RE 72.14 OR RIM 72.14 CB	RIM ELEVATION
IE 29.90 OR INV 29.90 CB	INVERT ELEVATION
(M) MH	MANHOLE
CB RIM 28.60 INV IN 24.50 INV OUT 24.25	CATCH BASIN WITH RIM ELEVATION, INVERT IN AND INVERT OUT

NOTE

16.12 Always check code requirements for local standards.

Contributors:
Carrie Fischer, "Design for Wetlands Preservation," topic II.A.1 in *Environmental Resource Guide* (Washington, DC: American Institute of Architects, 1992) and Thomas Schueler, Metropolitan Washington Council of Governments, Washington, DC.

SITE IMPROVEMENTS

PLANNING CONSIDERATIONS

THOROUGHFARE NOMENCLATURE

Thoroughfares are endowed with two attributes: capacity and character. Capacity refers to the number of vehicles that can move safely through a segment within a given time. It is physically manifested by the number of lanes and their width and by the centerline radius, the curb radius, and the super elevation of the pavement. Character refers to a thoroughfare's suitability for pedestrian activities and a variety of building types. Character is physically manifested by the thoroughfare's associated building, frontage, and landscape types and sidewalk width. Many communities currently incorporate bicycle lanes into their urban planning as alternate means of transportation.

Conventional traffic engineering practice uses terms such as "collector" and "arterial," which denote only capacity. This is too simplistic and tends to create an environment inhospitable for pedestrians. The following nomenclature more adequately describes the combination of capacity and character necessary to create true urbanism.

THOROUGHFARE TYPES

Capacity and character are combined and adjusted to achieve a complete series of useful thoroughfare types. The series is best regarded in pairs: keeping the right-of way width (R.O.W) constant, each pair illustrates one type suitable in two ways, one for a relatively rural condition and another suitable for a more urban condition.

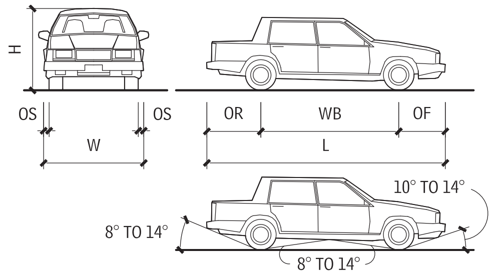
VEHICLE DIMENSIONS

In setting design parameters, the designer assumes that all vehicles present are "design vehicles." Design vehicles are selected to represent approximately the 85th percentile vehicle in a range from smallest to largest. In the recent past, small or compact car stalls were often separated from large or standard stalls in parking designs. However, a decline in smaller car sales and the increasing use of light trucks, vans, and utility vehicles (LTVUs) for personal transportation have made small-car-only stalls ineffective as a design tool. Therefore, while small car and large car design vehicles—as well as a composite encompassing both small and large—have been given here for reference, parking design must be based on a composite passenger vehicle that includes not only cars but light trucks, vans, and sport/utility vehicles.

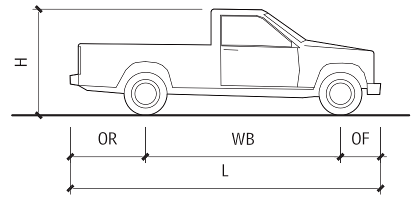
THOROUGHFARE TYPES
16.14

WIDE THOROUGHFARES		
BOULEVARD		**HIGHWAY**
25–50 mph	Design speed	35–55 mph
90 ft	Min. centerline radius	165–800 ft
15 ft	Curb return radius	35 ft
30 sec	Pedestrian cross time	N/A
Always	On-street parking	Never
Closed	Drainage	Open
PRIMARY THOROUGHFARES		
MAIN STREET		**AVENUE**
20–25 mph	Design speed	25–35 mph
90 ft	Min. centerline radius	165 ft
15 ft	Curb return radius	25 ft
12 sec	Pedestrian cross time	15 sec
Always	On-street parking	Always*
Closed	Drainage	Open/Closed
STANDARD THOROUGHFARES		
STREET		**ROAD**
20–25 mph	Design speed	25–35 mph
90 ft	Min. centerline radius	165 ft
15 ft	Curb return radius	25 ft
12 sec	Pedestrian cross time	8.5 sec
Always	On-street parking	Usually*
Closed	Drainage	Open/Closed
SECONDARY THOROUGHFARES		
MINOR STREET		**RURAL ROAD**
20–25 mph	Design speed	25–35 mph
90 ft	Min. centerline radius	165 ft
15 ft	Curb return radius	20 ft
8.5 sec	Pedestrian cross time	13 sec
Always*	On-street parking	Never
Closed	Drainage	Open
LOCAL PASSAGEWAYS		
ALLEY		**LANE**
N/A	Design speed	N/A
N/A	Min. centerline radius	N/A
5 ft	Curb return radius	20 ft
6.5 sec	Pedestrian cross time	3.5 sec
Usually*	On-street parking	Usually
Closed	Drainage	Open
PATHWAYS		
PASSAGE		**PATH**
N/A	Design speed	N/A
N/A	Min. centerline radius	40 ft
N/A	Curb return radius	5 ft
4.5 sec	Pedestrian cross time	4.5 sec
Never	On-street parking	Never
Closed	Drainage	Open

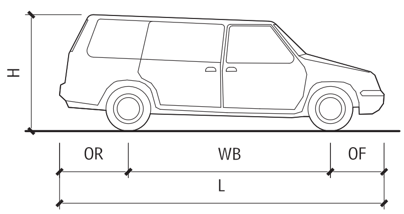
PASSENGER CAR
16.15



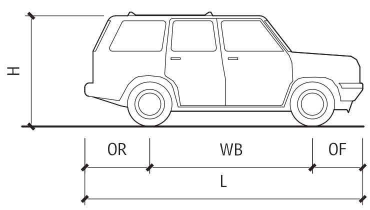
LIGHT TRUCK
16.16



VAN
16.17



SPORT/UTILITY
16.18



NOTE

16.14 *Not striped.

DESIGN VEHICLE DIMENSIONS (CARS)
16.19

	LENGTH	WIDTH	HEIGHT	WHEELBASE	OVERHANG FRONT	OVERHANG REAR	GROSS WEIGHT
VEHICLE	(L)	(W)	(H)	(WB)	(OF)	(OR)	(LB)
Small car[1]	15'-0"	5'-7"	4'-8"	8'-6"	2'-0"	4'-6"	2850
Composite passenger vehicle[2]	16'-9"	6'-4"	6'-10"	9'-5"	3'-0"	4'-4"	6000
Light truck	17'-9"	6'-6"	6'-0"	11'-0"	2'-9"	4'-0"	8600
Van	16'-9"	6'-3"	6'-10"	10'-0"	2'-9"	4'-0"	4600
Sport/utility vehicle	16'-0"	6'-4"	6'-2"	9'-4"	3'-0"	3'-8"	6000
Wheelchair lift van (personal use)	17'-8"	6'-8"	8'-0"	11'-6"	2'-6"	3'-8"	6000
Boat trailer	20'-0"	8'-0"	6'-0"	See figure 16.43	3'-0"	8'-0"	4000
RV—conventional trailer	27'-0"	7'-0"	9'-0"	See figure 16.44	3'-0"	12'-0"	5000
RV—fifth wheel (pickup-based)	34'-0"	8'-6"	12'-0"	8'-0"	22'-0"	12'-2"	3500
RV—folding trailer	16'-0"	7'-6"	5'-0"	—	8'-6"	7'-6"	1500
Slide-in pickup camper	18'-11"	10'-0"	7'-3"	—	—	—	2900
Stretch limousine	24'-6"	6'-0"	5'-0"	15'-6"	4'-0"	5'-0"	9000
Shuttle van (11 passengers)	20'-0"	6'-6"	6'-10"	11'-6"	3'-0"	5'-6"	11,000

TRUCK AND TRAILER SIZES

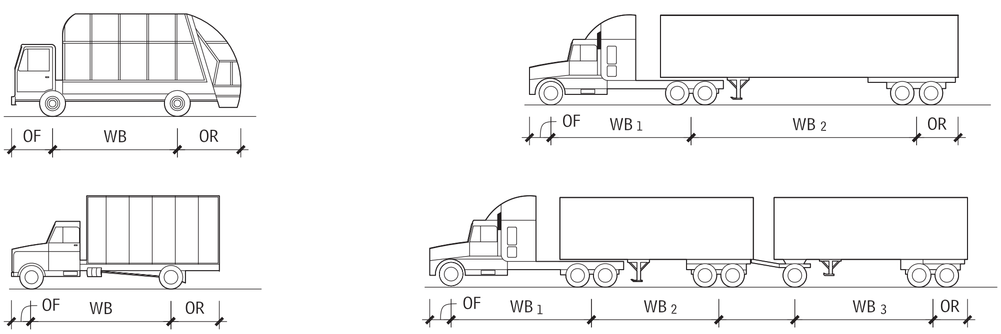
DESIGN VEHICLE DIMENSIONS (TRUCKS)
16.20

VEHICLE TYPE	LENGTH (L)	WIDTH (W)	HEIGHT (H)	WHEELBASE (WB)	OVERHANG FRONT (OF)	OVERHANG REAR (OR)	GROSS WEIGHT (LB)
Trash truck	25'-5"	7'-11"	10'-0"	13'-2"	4'-8"	7'-7"	20,000
Single unit truck*	30'-0"	8'-6"	See Figure 16.47	20'	4'-0"	6'-0"	20,000
WB-40 truck*	50"-0"	8'-6"	See Figure 16.47	13'/23'/4'	4'-0"	6'-0"	80,000
WB-50 truck*	60'-0"	8'-6"	See Figure 16.47	16'/4'/26'/4'	3'-0"	2'-0"	80,000
WB-60 truck*	65'-0"	8'-6"	See Figure 16.47	10'/20'/10'/18'	2'-0"	5'-0"	80,000

MAXIMUM ALLOWABLE HEIGHT AND WIDTH
16.21

VEHICLE HEIGHT		VEHICLE WIDTH*	
TOTAL HEIGHT	STATE	TOTAL WIDTH	STATE
13'-6"	In all states except those listed below	8'-6"	In all states except those listed below
13'-0"	CO		
14'-0"	AK, CA, HI, ID, KS, MT, NM, NV, ND, OR, UT, WA, WY	8'-0"	DC, GA, IL, KY, LA, MI, MD, MO, NC, PA, WV
14'-6"	NB	9'-0"	HI

TRUCK TYPES
16.22

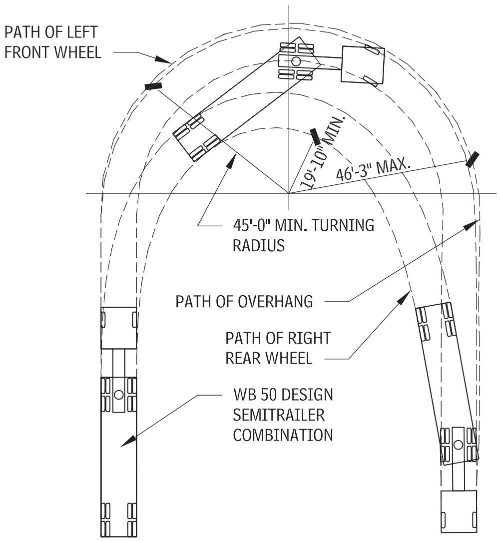


NOTES

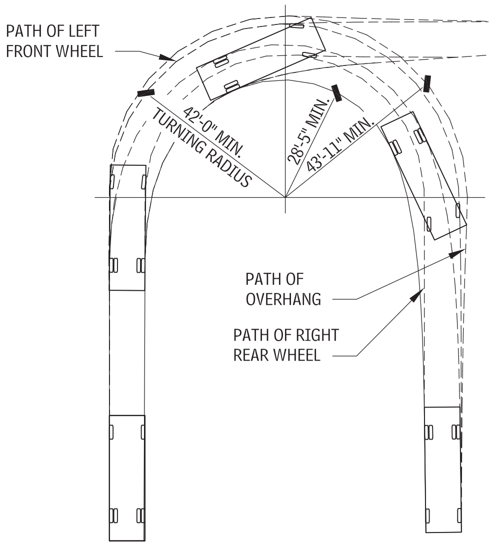
16.19 [1] Small car classes 5 through 7 per Parking Consultants Council (PCC).
[2] A composite passenger vehicle is a design vehicle that encompasses passenger cars, light trucks, vans, and sport/utility vehicles. It is the vehicle for which a parking facility should be designed.
16.20 *Generally in conformance with AASHTO, A Policy on Geometric Design of Highways and Streets (1990).

16.21 *Width is 8 ft-0 in. or 8 ft-6 in. according to state regulations. Length and area restrictions vary by state and locale. Verify exact dimensions and restrictions.

TURNING RADIUS
16.23



WB–50 SEMITRAILER DESIGN VEHICLE



SINGLE–UNIT TRUCK DESIGN VEHICLE

MAXIMUM ALLOWABLE LENGTH (SEMITRAILER AND TRACTOR)
16.24

UNIT	EACH TRAILER	STATE
55'-0"	48'-0"	DC
60'-0"	45'-0"	HI
60'-0"	53'-0"	DE, GA
60'-0"	—	MO, NC, OR, WV
65'-0"	48'-0"	ME, NY, VT, WI
65'-0"	53'-0"	IL, KY
65'-0"	—	CA, LA, NM, VA
70'-0"	57'-4"	CO
75'-0"	48'-0"	ID
75'-0"	53'-0"	AK, MN, ND
92'-0"	53'-0"	UT
—	48'-0"	CT, FL, MA, NV
—	48'-6"	RI
—	50'-0"	MI, MS, TN
—	53'-0"	MD, MS, MT, NB, NH,
		NJ, IN, IA, OH, OK, PA,
		SC, SD, WA
—	53'-6"	AR
—	57'-6"	AZ
—	59'-0"	TX
—	59'-6"	KS
—	60'-0"	WY

MAXIMUM ALLOWABLE LENGTH (DOUBLE SEMITRAILER AND TRACTOR)
16.25

UNIT	EACH TRAILER	STATE
59'-0"	28'-6"	MI
60'-0"	29'-0"	DE
61'-0"	—	UT, WA
65'-0"	28'-0"	MD, MO
65'-0"	28'-6"	AR, IL
65'-0"	—	NB, NM, NY
70'-0"	28'-0"	OK
70'-0"	28'-6"	CO
75'-0"	28'-0"	ND, ID
75'-0"	28'-6"	CA, MN
75'-0"	—	AK, OR
80'-0"	28'-6"	SD
—	28'-0"	CT, DC, FL, GA, MA, NH, NJ
—	28'-6"	AZ, IN, IA, KS, MT, NV, OH, RI
—	30'-0"	MS
—	—	WY

MAXIMUM ALLOWABLE LENGTH (STRAIGHT BODY TRUCKS)
16.26

UNIT		STATE
40'-0"		In all states, except those listed below
35'-0"		NC*, SC*
42'-0"		IL
42'-6"		KS
45'-0"		CT, HI, ID, KY, OK, ME, SD, TX, UT
50'-0"		ND
55'-0"		MT
60'-0"		GA, WY
65'-0"		VT

NOTE

16.26 *Two axles—35 ft; three axles—40 ft.

PARKING LOTS

DESIGN CONSIDERATIONS FOR PARKING LOTS

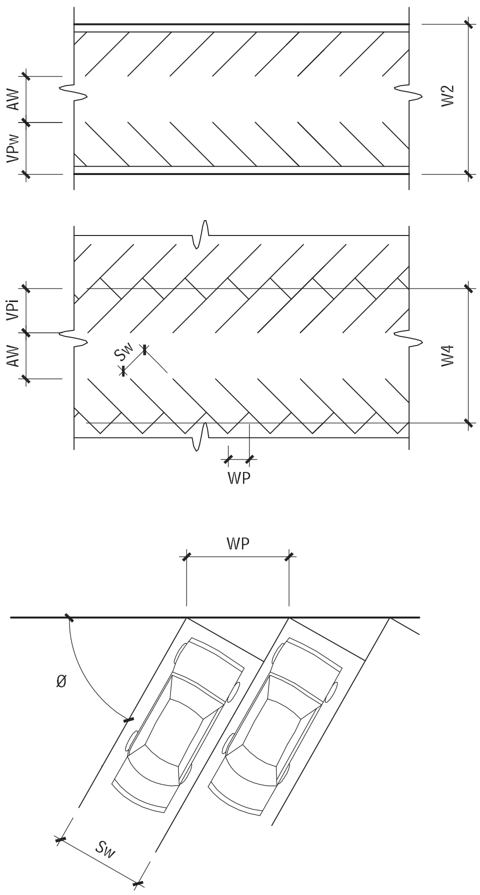
Creating vital places is the job of those of who design, build, finance, and plan the built environment. Unfortunately, too often, as acres of asphalt attest, engineering standards are applied cavalierly; they are not used properly to help design the place. Even "just a parking lot" can be made into a place of delight.

Some strategies to employ that go beyond bare-bones engineering are:

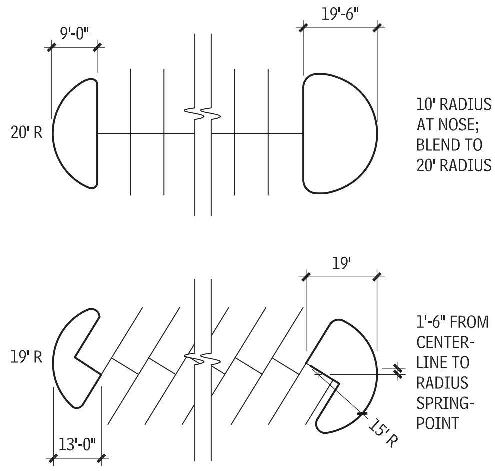
- *Parking courts*: Like the forecourt of a grand English manor, a parking place can serve as the introduction to a building. It may be a formal garden, an entrance hall, or a place to display art.
- *Multiple uses*: For many of the hours in a year, even a busy parking lot stands empty or underused. Find and design for other activities such as youth basketball, or the summer yard of a garden store.
- *Design for pedestrians*: Make the pedestrian activities the highest priority in the placement, size, location, and other details of the site design. Virtually everyone who drives to a parking lot walks out of it.
- *Reduce parking*: Find a means for multiple uses to share a lot over the course of the day or week. Design so that people can park once and go to multiple destinations. Design so that the parking does not impede other modes of transport such as walking, bicycles, or buses.

The tables and diagrams in this section provide the basic guidelines for the size and layout of stalls, grades in parking lots, the geometry of end islands, and the number of accessible stalls. For more detailed information on the design of access driveways, circulation patterns, calculating parking demand, safety, sustainability, and other aspects, refer to *Parking Spaces: A Design, Implementation, and Use Manual for Architects, Planners, and Engineers,* by Mark C. Childs (New York: McGraw-Hill, 1999).

SPACE LAYOUTS
16.27



END ISLANDS
16.28



STALL AND MODULE DIMENSIONS
16.29

			STALL WIDTH		STALL DEPTH PARALLEL TO AISLE		AISLE WIDTH	MINIMUM MODULES	
	CAR TYPES		PARALLEL TO CAR	PARALLEL TO AISLE	TO WALL	TO INTERLOCK	MINIMUM	WALL TO WALL	INTERLOCK
ANGLE		TURNOVER	(SW) (FT)	(WP) (FT)	(VP^{W}) (FT)	(VP^{i}) (FT.)	(AW) (FT)	(W2) (FT)	(W4) (FT)
90	Mix	A	9.00	9.0	18.4	18.4	24.0	60.8	60.8
		B	8.75	8.8	18.4	18.4	24.0	60.8	60.8
		C	8.50	8.5	18.4	18.4	24.0	60.8	60.8
		D	8.25	8.3	18.4	18.4	24.0	60.8	60.8
	Small	A	8.00	8.0	15.1	15.1	22.3	52.4	52.4
		B	7.75	7.8	15.1	15.1	22.3	52.4	52.4
		C	7.50	7.5	15.1	15.1	22.3	52.4	52.4
		D	7.25	7.3	15.1	15.1	22.3	52.4	52.4
75	Mix	A	9.00	9.3	19.4	18.6	21.0	59.9	58.2
		B	8.75	9.1	19.4	18.6	21.0	59.9	58.2
		C	8.50	8.8	19.4	18.6	21.0	59.9	58.2
		D	8.25	8.5	19.4	18.6	21.0	59.9	58.2
	Small	A	8.00	8.3	16.2	15.4	20.0	52.5	50.8
		B	7.75	8.0	16.2	15.4	20.0	52.5	50.8
		C	7.50	7.8	16.2	15.4	20.0	52.5	50.8
		D	7.25	7.5	16.2	15.4	20.0	52.5	50.8
70	Mix	A	9.00	9.6	19.5	18.4	18.6	57.5	55.3
		B	8.75	9.3	19.5	18.4	18.6	57.5	55.3
		C	8.50	9.0	19.5	18.4	18.6	57.5	55.3
		D	8.25	8.8	19.5	18.4	18.6	57.5	55.3
	Small	A	8.00	8.5	16.4	15.3	17.9	50.6	48.4
		B	7.75	8.2	16.4	15.3	17.9	50.6	48.4
		C	7.50	8.0	16.4	15.3	17.9	50.6	48.4
		D	7.25	7.7	16.4	15.3	17.9	50.6	48.4
65	Mix	A	9.00	9.9	19.4	18.0	16.1	54.9	52.2
		B	8.75	9.7	19.4	18.0	16.1	54.9	52.2
		C	8.50	9.4	19.4	18.0	16.1	54.9	52.2
		D	8.25	9.1	19.4	18.0	16.1	54.9	52.2
	Small	A	8.00	8.8	16.4	15.0	15.7	48.5	45.8
		B	7.75	8.6	16.4	15.0	15.7	48.5	45.8
		C	7.50	8.3	16.4	15.0	15.7	48.5	45.8
		D	7.25	8.0	16.4	15.0	15.7	48.5	45.8
60	Mix	A	9.00	10.4	19.1	17.5	13.7	51.9	48.7
		B	8.75	10.1	19.1	17.5	13.7	51.9	48.7
		C	8.50	9.8	19.1	17.5	13.7	51.9	48.7
		D	8.25	9.5	19.1	17.5	13.7	51.9	48.7
	Small	A	8.00	9.2	16.3	14.7	13.6	46.1	42.9
		B	7.75	8.9	16.3	14.7	13.6	46.1	42.9
		C	7.50	8.7	16.3	14.7	13.6	46.1	42.9
		D	7.25	8.4	16.3	14.7	13.6	46.1	42.9
55	Mix	A	9.00	11.0	18.7	16.9	11.2	48.7	45.1
		B	8.75	10.7	18.7	16.9	11.2	48.7	45.1
		C	8.50	10.4	18.7	16.9	11.2	48.7	45.1
		D	8.25	10.1	18.7	16.9	11.2	48.7	45.1
	Small	A	8.00	9.8	16.0	14.2	11.5	43.5	39.8
		B	7.75	9.5	16.0	14.2	11.5	43.5	39.8
		C	7.50	9.2	16.0	14.2	11.5	43.5	39.8
		D	7.25	8.9	16.0	14.2	11.5	43.5	39.8

NOTES

16.29 a. Turnover categories: A = very high turnover, such as at a post office or convenience store; B = high turnover, such as at a general retail store; C = medium turnover, such as at airports or hospitals; D = low turnover, such as at an employee parking lot.
b. Figure 16.63 defines the dimensions used in this table.
c. Stalls at angles between 90° and 60° are confusing as to whether the aisle is one-way or two-way. Do not use angles between 90° and 75°. Stalls at a 75° angle with two-way aisles are advocated by some because the right-hand side parking maneuver is easier into an angled stall; however, making a left-hand turn to park in a 75° stall is difficult. A minimum of 22 ft is necessary for two-way aisles, and 24 to 25 ft allows ample walking space and occasional left-hand parking. Stalls at angles between 45° and 0° (parallel parking) are not generally advisable because they are space-inefficient and confusing.
d. Stall stripes are often painted 6 to 10 in. shorter than the stall depth to encourage drivers to pull fully into the stall.
e. The table uses a minimum aisle width of 11 ft. This dimension is minimally sufficient to allow passage of cars and pedestrians. In high turnover or special situations such as lots primarily serving the elderly or children, a pedestrian walkway and/or a wider aisle should be provided.

STALL AND MODULE DIMENSIONS (Continued)
16.29

			STALL WIDTH		STALL DEPTH PARALLEL TO AISLE		AISLE WIDTH	MINIMUM MODULES	
			PARALLEL TO CAR	PARALLEL TO AISLE	TO WALL	TO INTERLOCK	MINIMUM	WALL TO WALL	INTERLOCK
ANGLE	CAR TYPES	TURNOVER	(SW) (FT)	(WP) (FT)	(VP^W) (FT)	(VP^i) (FT.)	(AW) (FT)	(W2) (FT)	(W4) (FT)
50	Mix	A	9.00	11.7	18.2	16.2	11.0	47.4	43.3
		B	8.75	11.4	18.2	16.2	11.0	47.4	43.3
		C	8.50	11.1	18.2	16.2	11.0	47.4	43.3
		D	8.25	10.8	18.2	16.2	11.0	47.4	43.3
	Small	A	8.00	10.4	15.7	13.6	11.0	42.4	38.2
		B	7.75	10.1	15.7	13.6	11.0	42.4	38.2
		C	7.50	9.8	15.7	13.6	11.0	42.4	38.2
		D	7.25	9.5	15.7	13.6	11.0	42.4	38.2
45	Mix	A	9.00	12.7	17.5	15.3	11.0	46.1	41.5
		B	8.75	12.4	17.5	15.3	11.0	46.1	41.5
		C	8.50	12.0	17.5	15.3	11.0	46.1	41.5
		D	8.25	11.7	17.5	15.3	11.0	46.1	41.5
	Small	A	8.00	11.3	15.2	12.9	11.0	41.4	36.9
		B	7.75	11.0	15.2	12.9	11.0	41.4	36.9
		C	7.50	10.6	15.2	12.9	11.0	41.4	36.9
		D	7.25	10.3	15.2	12.9	11.0	41.4	36.9

Sources: Adapted and recalculated from *Parking*, Robert D. Weant and Herberts Levinson, 1990, Eno Foundation; *Parking Structures: Planning, Design, Construction, Maintenance and Repair*, Anthony P. Chrest, Mary S. Smith, Sam Bhuyan, Chapman & Hall, 1996; Ricker, 1957.

STALL DIMENSIONS FOR SPECIAL CONDITIONS
16.30

	WIDTH (FT)	LENGTH (FT)	CLEAR HEIGHT (FT)
Designated large vehicle	9	18.5 to 20	
Passenger truck[a]	9	18.5	
Accessible car[b]	8 + 5 for aisle	17.5	
Accessible van[b]	8 + 8 for aisle	17.5	8.16
Universal[c] (accessible car or van)	11 + 5 for aisle	8.16	
Valet[d]	7.5	17	
Europe typical[e]	7.83 to 8.16	15.58 to 16.42	
Bicycle[f]	2.5	6	
Motorcycle[f]	3.33	7	

CURB PARKING
16.31

	STALL		SOURCE	
	LENGTH	OTHER		
Accessible loading[a]	22' minimum	Platform 5' wide, 20' long, 9.5' clear height	ADAAG 4.6.5 and 4.6.6	
Truck loading	30–60'	Add truck length per additional truck	Weant & Levinson	
Drop-offs/taxi	50'	Add 25' per additional vehicle	Weant & Levinson	
Paired (length per pair)	44–50'	20' stalls	Hunnicutt, p. 666	
Compact	19'		Hunnicutt, p. 666	
End stall	20'		Hunnicutt, p. 666	
Interior stall	22'–24'		Hunnicutt, p. 666	
CURBSIDE BUS LOADING				
		WHEEL POSITION FROM CURB		
	6"	1'	One 40' bus	Additional per bus
Upstream of intersection	L[b] + 85'+	L + 65'+	105–125'	L + 5'+
Downstream of intersection				
Street width >39'	L + 55'+	L + 40'+	80–95'	L
Street width 32–39'	L + 70'+	L + 55'+	95–110'	L
Midblock				
Street width >39'	L + 135'+	L + 100'+	140–175'	L
Street width 32–39'	L + 150'+	L + 115'+	155–190'	L

GRADES IN PARKING LOTS
16.32

GRADE	CONDITION
6% maximum	Continuous slope in parking lot
12% maximum, 30′ long	Nonparking automobile ramps with pedestrians allowed
15% maximum	Nonparking automobile ramps with signs banning pedestrians
> 6% change	A vertical curve transition is required.
1% minimum/2% rec.	Slope to drain asphalt
.5% minimum/2% rec.	Slope to drain concrete
2% (1:50) maximum	Slope within accessible stalls in any direction
5%	Accessible route running slope (2% cross slope)

NOTES

16.30 a. From Charles E. Dare, "Consideration of Special Purpose Vehicles in Parking Lot Design. ITE Journal, May 1985.
b. Per ADAAG, "Americans with Disabilities Act Accessibilities Guidelines for Building and Facilities," 1991.
c. (ATBCB) Architectural and Transportation Barriers Compliance Board, Bulletin #6: Parking, 1994.
d. From Robert H. Burrage and Edward G. Morgen, Parking (Eno Foundation for Highway Traffic Control, 1957), p. 242.
e. From James Hunnicutt, "Parking, Loading, and Terminal Facilities" in Transportation and Traffic Engineering Handbook (Prentice Hall, 1982), p. 50.
f. From Robert Weant and Herbert Levinson, Parking (Eno Foundation for Highway Traffic Control, 1990), p.167.
16.31 a. Bus-loading statistics adapted from Homburger and Quinby, "Urban Transit," in *Transportation and Traffic Engineering Handbook*, 2d ed. (Prentice Hall, 1982).
b. L = length of bus.

16.32 Adapted from Chrest, Smith & Bhuyan, 1996; ITE, 1982; and Untermann, 1984.

REQUIRED NUMBER OF ACCESSIBLE STALLS
16.33

GENERAL CASE	
TOTAL IN PARKING LOT	REQUIRED MINIMUM NUMBER OF ACCESSIBLE SPACES
1–25	1
26–50	2
51–75	3
76–100	4
101–150	5
151–200	6
201–300	7
301–400	8
401–500	9
501–1,000	2% of total
1,001 and over	20 + 1 per 100 over 1,000
Number of accessible spaces	Required minimum number of van-accessible spaces
1–8	1
33 and over	1 additional van-accessible per 8 accessible spaces
SPECIAL CASES	
PLACE	REQUIREMENT
Medical outpatient units	10% of total stalls in lots serving visitors and patients
Medical units that specialize in persons with mobility impairments	20% of total stalls in lots serving visitors and patients
Valet parking	No stalls required; however, an accessible loading zone is required, and it is strongly recommended that self-park stalls be provided.
Residential	1 for each accessible dwelling unit and 2% for all additional units. Guest, employee, and nonresident parking must comply with table.

Note: These are general guidelines. Designer needs to refer to local Zoning Ordinance for actual requirements.

LOTS ACCESSIBLE TO THE MOBILITY IMPAIRED

Parking is a critical element of accessibility. In fact, the first federal court case that resulted in a civil penalty under Title III of the Americans with Disabilities Act (ADA) was for failure to make parking accessible.

The ADA is a civil rights law, meaning that the Department of Justice is charged with enforcing the law. People who believe they have been discriminated against may sue the property owner. The ADA Accessibility Guidelines for Buildings and Facilities (ADAAG) issued by the government are not building codes subject to state or local approval or variances.

The information in this section was compiled from publications of the United States Architectural and Transportation Barriers Compliance Board (United States Access Board) and other sources, as noted. Note, however, that the law and best practices continue to evolve, so designers are cautioned to review materials and conditions specific to the project at hand. Note that lots owned by government agencies generally follow Title II rules, which are usually more stringent than the Title III rules for privately owned lots discussed in this section.

REQUIRED NUMBER OF ACCESSIBLE STALLS

Whenever parking is supplied, no matter how the total amount is determined, a portion of the stalls must be accessible to people with mobility impairment (hereafter called *accessible stalls*). Local codes may exceed the federal requirement for required number of accessible stalls listed in Figure 16.33; the more stringent rule governs. When a facility has more than one parking lot, the required number of stalls is determined lot by lot. In employee or contract lots, accessible stalls must be provided, but "accessible spaces may be used by persons without disabilities when they are not needed by (persons) with disabilities" (Bulletin #6: Parking, Architectural and Transportation Barriers Compliance Board, 1994). When the use of a facility—for example, a senior center—indicates that more accessible stalls are needed than are required according to Figure 16.33, a study should be conducted to determine an adequate supply of accessible stalls.

LOCATION OF ACCESSIBLE STALLS

The location of accessible stalls must give mobility-impaired persons preferential treatment in terms of access, and must not discriminate against them in terms of amenities (e.g., if the general stalls have hail protection canopies, the accessible stalls must also). The shorthand rule is that accessible stalls should be located with the shortest possible route to the entrance(s). Relevant U.S. regulations include the following:

> "Accessible parking spaces serving a particular building shall be located on the shortest route of travel from adjacent parking to an accessible entrance. In parking facilities that do not serve a particular building, accessible parking shall be located on the shortest accessible route of travel to an accessible pedestrian entrance of the parking facility. In buildings with multiple accessible entrances with adjacent parking, accessible parking shall be dispersed and located closest to the accessible entrances..."

> "Accessible spaces can be provided in other lots or locations, or in the case of parking garages, on one level only when equal or greater access is provided in terms of proximity to an accessible entrance, cost and convenience. The minimum number of spaces must still be determined separately for each lot..."

VAN-ACCESSIBLE STALLS

Van-accessible stalls must be marked as such, but this does not restrict the stall to use by vans ((ATBCB) Architectural and Transportation Barriers Compliance Board, Bulletin #6: Parking, 1994).

ACCESSIBLE STALL LAYOUT GUIDELINES

Design guidelines for the layout of parking stalls are as follows:

- Two accessible stalls may share an access aisle. However, this should be done only when the stalls are at 90° and allow both front-in and back-in parking.
- Curb ramps or other obstructions may not be within the stall's access aisle, but may begin at the curb face when vehicles overhang a curb (Chrest, Smith & Bhuyan, 1996, p. 212).
- Car overhang may not obstruct the clear width of a sidewalk access route. Wheel stops and/or a reinforced signpost may help limit car overhang.

ACCESSIBLE SIGNAGE

Parking spaces that are to be accessible should be designated by signage indicating the spaces are reserved. Van-accessible spaces should have the words "van-accessible" printed below the universal symbol of accessibility. The ADAAG requires that the sign not be obscured by a car or parked van. Centering the sign on the access aisle may improve its visibility.

ACCESSIBLE EQUIPMENT

Equipment such as parking meters, automated teller machines, pay stations, and ticket dispensers must have accessible controls. Most such equipment is now designed with operating mechanisms that are considered accessible, so the designer's major role is to place the controls at a proper level and to provide clear access to them.

Specifically, parking meters for accessible stalls should be placed at or near the head or foot of the parking space, to ensure that no obstruction occurs for the operation of a side lift or a passenger-side transfer. The meter should be placed a maximum of 42 in. above the public sidewalk. The accessible stall should be a minimum of 30 in. by 48 in.

PASSENGER LOADING ZONES

There must be at least one passenger loading zone for the mobility impaired whenever designated loading zones are provided. There must also be an access aisle at least 5 ft wide and 20 ft long adjacent and parallel to the vehicle pull-up space. A clear height of 9 ft-6 in. is required at the loading zone and along the vehicle route, to, from, and within the zone. The vehicle space and the access aisle must be level with surface slopes not exceeding 1:50 (2 percent) in all directions. Neither curb ramps nor street furniture may occupy the access aisle space.

POROUS PAVEMENTS

Porous pavements reduce or eliminate urban stormwater problems at the source by changing the way urban structures are built and the way they operate hydrologically. They restore the landscape's natural water-retaining function by bringing water back into contact with the underlying soil, or emulate it by filtering and storing water in the pavement structure. By combining pavement stormwater control functions into a single structure, they reduce costs, compared with dense pavements that require downstream stormwater control facilities.

Properly applied porous pavements can also enlarge urban tree rooting space, reduce the urban heat island effect, reduce traffic noise, increase driving safety, and improve appearance. Therefore, their selection and implementation are integral parts of the multifaceted concerns of urban design, and all of their effects are considered together in evaluations of benefits and costs. As porous paving materials become increasingly used, their potential cumulative effect is great, because pavements are the most ubiquitous man-made structures—they occupy two-thirds of the constructed surfaces in urban watersheds.

This section briefly reviews the types of porous paving materials that are available and some provisions necessary in their installation. Considerably more scope and detail on this subject are covered in the book *Porous Pavements*, by Bruce K. Ferguson (Boca Raton, FL: CRC Press, 2005).

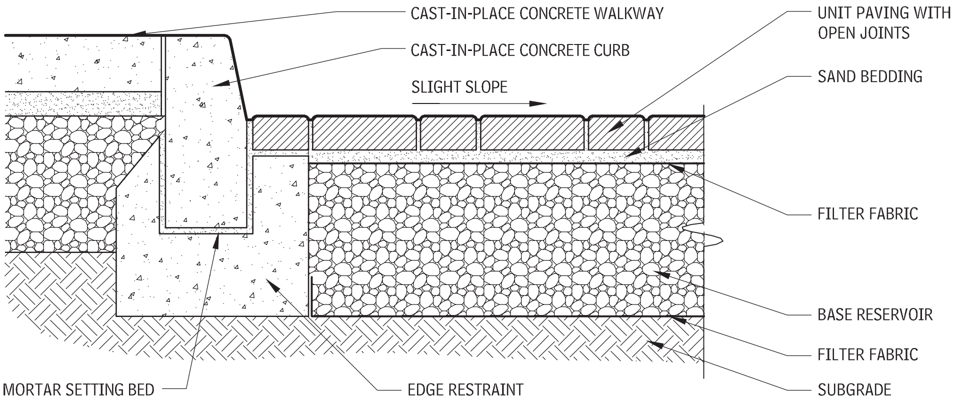
POROUS PAVEMENT CONSTRUCTION

To make a successful porous pavement, it must be selected right, designed right, installed right, and maintained right. Failures—clogging and structural degradation—result from neglecting one or more of these steps. Construction of porous pavements is not more difficult than that of dense pavements, but it is different, and its different specifications and procedures must be strictly adhered to.

The dominant component in most porous paving materials is aggregate, such as crushed stone. It is crucial that this aggregate be

Contributor:
Mark Childs, University of New Mexico, Albuquerque, New Mexico, from *Parking Spaces: A Design, Implementation, and Use Manual for Architects, Planners, and Engineers* (New York: McGraw-Hill, 1999).

POROUS PAVEMENT CONSTRUCTION WITH RAISED CURB
16.34



"open-graded"—that is, have a narrow range of particle sizes. The void space between single-sized particles typically amounts to 30 to 40 percent of the aggregate's volume; the aggregate's permeability is commonly over 1,000 in. per hour. As long as the particles are angular, open-graded aggregate obtains structural stability from particle-to-particle interlock.

To protect a pavement's surface from sedimentary clogging, surface drainage should be away from the pavement edge in every possible direction, so that sediment is prevented from washing on and, conversely, being allowed to wash off. On the downhill side, large, numerous curb cuts should be added, if necessary. On the uphill side, a swale should be added, if necessary, to divert potentially sediment-laden runoff. These provisions limit most porous pavements to infiltrating the stormwater that falls directly upon the pavement, not runoff from surrounding earthen slopes.

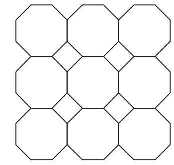
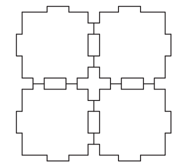
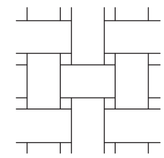
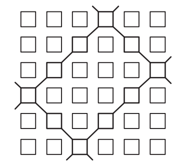
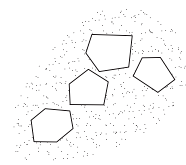
Each porous paving material has its own advantages and disadvantages for specific applications, and its own requirements for design, construction, and maintenance. A development site should be analyzed in detail to distinguish pavement settings where different, optimally suited materials can be placed. In all pavements, areas can be distinguished with different needs for hydrology, appearance, subsurface tree rooting, and cost.

ALTERNATIVE POROUS PAVING MATERIALS

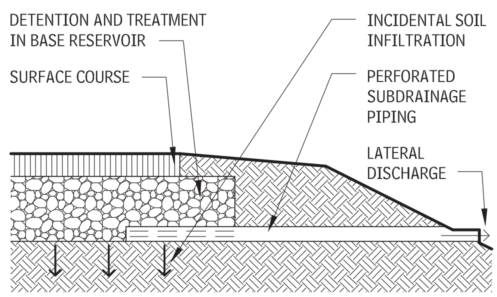
There are a number of alternative porous paving materials, among them:

- *Porous aggregate* is unbound gravel, crushed stone, crushed recycled brick, or decomposed granite. In most regions, unbound aggregate is both the least expensive of all firm surfacing materials and the most permeable. It is suitable for very light traffic such as that in residential driveways, lightly used portions of parking lots, and lightly used walkways. Annual maintenance for weeding or to replace lost material may be necessary.
- *Porous turf* makes a "green" open space where transpiration actively cools urban heat islands. It is suitable for bearing very light traffic, such as that in parking spaces used once per week or during seasonal peak shopping periods. The rooting-zone soil should be sandy, to resist compaction. Porous turf must be regularly mowed, fertilized, and irrigated; and because maintenance must be scheduled, it should be used only where traffic can be controlled or predictably scheduled.
- *Plastic geocells* are latticelike products that hold aggregate or topsoil in their cells, inhibiting displacement and compaction. The surface permeability, temperature, and visual appearance are essentially that of the grass or aggregate fill.
- *Open-jointed blocks and open-celled grids* are units of concrete, brick, or stone, with open joints or cells. Porous aggregate or turf in the openings gives the pavement its porosity and permeability. Many block products can bear remarkably heavy traffic, but absorb water intended for turf and hold heat in warm climates.
- *Porous concrete* is portland cement concrete made with single-sized aggregate. A qualified installer is required. The durability of porous concrete in cold climates can be enhanced by air entrainment and polymer fiber reinforcing. Properly installed porous concrete can bear heavy traffic loads, and the surface is universally accessible by most measures.
- *Porous asphalt* is bituminous concrete made with single-sized aggregate. Polymer fibers and liquid polymer additive can reduce drainage of the binder down through the pores—without them, the binder would leave surface aggregate particles unbound while accumulating into a clogging layer inside the structure. Properly installed porous asphalt can bear heavy traffic loads, and the surface is universally accessible by most measures.
- *"Soft" paving materials* include granular organic or recycled materials such as bark mulch, crushed shells, and rubber granules. They are suitable for very light traffic such as that in pedestrian walkways, residential driveways, equestrian ways, and very lightly used parking stalls. Materials with durable single-sized particles have the highest infiltration rates and are the least susceptible to displacement, crushing, and compaction.
- *Decks* are surrogates for pavements. They are completely permeable to air and water as long as their decking components are perforated or spaced apart from each other. Their footings leave the soil below almost entirely free for infiltration and tree rooting. Decks are uniquely suited to sites with steep slopes or where native tree roots or ecosystem dynamics are to be very conscientiously protected. They are made from a variety of natural, manufactured, and recycled materials; hence, their durability varies with the material and its preservative treatment.

POROUS UNIT PAVING
16.35

TYPE	TYPICAL SURFACE PATTERN
Unit pavers with indentations (e.g., Uni Eco-Stone)	
Unit pavers with spacers (e.g., SF-Rima)	
Unit pavers laid in open-jointed pattern (e.g., brick)	
Open-celled grids (e.g., Turfstone)	
Widely spaced unit pavers (e.g., fieldstone)	

DRAINAGE OUTLET AT BOTTOM OF BASE RESERVOIR
16.36



UNIT PAVING

Unit paving assemblies are used principally for applications such as shopping plazas, building entrances, walkways, patios, residential driveways, and residential parking areas. But they may also be used for streets with heavy vehicular traffic and for industrial floors or other special conditions.

There are several types of unit pavers:

- Precast concrete unit pavers
- Brick unit pavers
- Wood pavers
- Recycled-rubber pavers
- Stone pavers
- Porous unit pavers

PEDESTRIAN AND LIGHT-TRAFFIC BRICK PAVERS

Because of its more vulnerable exposure to weathering, and the constant stress of traffic, even light-traffic brick pavers must maintain higher compressive strength and lower porosity than face brick. ASTM C 902, "Standard Specification for Pedestrian and Light Traffic Paving Brick," establishes the criteria for pedestrian and light-traffic brick pavers. *Light-traffic* refers to frequency, or pavements that receive limited vehicular traffic at low speeds, such as driveways and arrival courts (*light* does not refer to the weight of a vehicle). An arrival court may normally receive automobile traffic, but the occasional moving van will not damage an ASTM C 902 paver. The classification of light-traffic brick pavers is dependent on its intended application and use. There are three weathering classes of pavers and three types of pavers, based on anticipated traffic and the required levels of resistance to abrasion by traffic.

CLASSES

- *Class SX* (severe exposure) should be specified where pavements may encounter freezing while saturated with water. In contrast to face brick, Class SX pavers must have a minimum average compressive strength of 8,000 psi. An individual unit may not have strength below 7,000 psi.
- *Class MX* (moderate exposure) may be called for in southern climates where freezing is not expected.
- *Class NX* (negligible exposure) is for interior use only.

TYPES

- *Type I* bricks are recommended where highly abrasive traffic is anticipated, such as in driveways or heavily concentrated pedestrian zones.
- *Type II* bricks are best suited for typical pedestrian environments such as public walkways.
- *Type III* bricks offer the least resistance to abrasion and should be used in low-traffic residential applications.

HEAVY VEHICULAR PAVING BRICK

Where vehicular traffic is greater in speed, volume, and weight, a stronger brick is naturally required. Brick in heavy-traffic situations not only must tolerate the added structural load, but is also subjected to greater abrasion and the tendency for both horizontal and twisting forces. ASTM C1272, "Standard Specification for Heavy Vehicular Paving Brick," establishes the standard. ASTM lists two types and three application classifications for heavy vehicular paving brick.

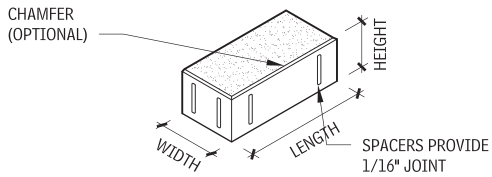
TYPES

- *Type R* is intended for situations where a rigid or semirigid setting bed and base are provided (such as concrete or asphalt). With Type R pavers, the minimum average compressive strength is set at 8,000 psi, with the rigid setting bed and base contributing to the overall compressive strength of the cross section. Type R pavers carry a minimum thickness dimension of 2-1/4 in.
- *Type F* brick is stronger and better suited for use with a flexible base (such as compacted aggregate), along with an adequately compacted subgrade. Type F pavers are required to have a higher overall compressive strength than Type R pavers, with a minimum average of 10,000 psi. Type F pavers must have a thickness of no less than 2-5/8 in.

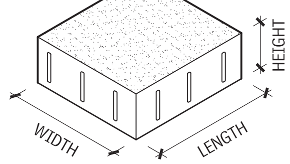
APPLICATIONS

- *Application PS* refers to heavy paving brick for general, all-purpose use. Where there is a greater concern for overall uniformity, including precision in dimension, degree of warping, and chipping, *Application PX* should be specified.
- *Application PA* deals with paving bricks with specific visual characteristics, such as size and color.
- Consult with a landscape architect or engineer for appropriate design guidelines.

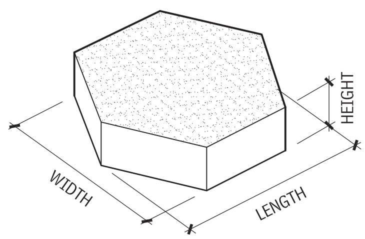
TYPICAL PAVER SHAPES
16.37



RECTANGULAR



SQUARE



HEXAGONAL

TYPICAL PAVER SIZES (IN.)[b]
16.38

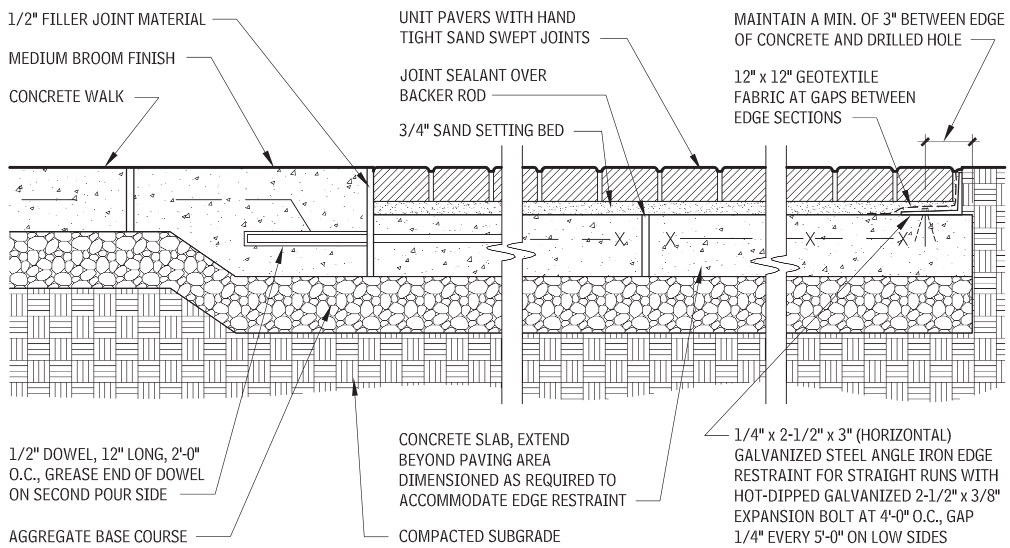
RECTANGULAR[b]		SQUARE	HEXAGONAL	
WIDTH (IN.)	LENGTH (IN.)	WIDTH AND LENGTH (IN.)	WIDTH (IN.)	LENGTH (IN.)
4	8	4	6	6
3-5/8	7-5/8	6	8	8
3-1/2	7-1/2	8	12	12
7-5/8	7-5/8	12		
8	8	16		

PAVER SELECTION

Paver units are selected according to color, texture, abrasion resistance, and resistance to weathering. The texture of the unit affects slip resistance (the coarser the texture, the better the slip resistance). *Abrasion resistance* refers to the wear and tear an assembly is subjected to under normal use. According to ASTM C 902 (brick pavers) and ASTM C 936 (concrete pavers), an abrasion index classification determines the type of unit required for an intended exposure. A dense, hard-burned extruded brick with 8,000 psi compressive strength that conforms to ASTM C 902, Class SX, Type I (water absorption of less than 5 percent, meets/exceeds C 67 freeze/thaw) resists both abrasion and weathering and is adequate for most heavy-traffic exterior applications. Molded brick with 4,000 psi compressive strength conforms to ASTM C 902, Class SX, Type II, and may be adequate for most exterior pedestrian applications only. Some manufacturers recommend 8,000 psi pavers for both vehicular and pedestrian applications. Consult the manufacturer to learn which products are suitable for use as pavers in a particular application.

For all light or heavy vehicular traffic applications, 3-1/8-in. paver thickness is recommended; 2-3/8-in. thickness is recommended for pedestrian applications. Assess potential traffic loads when planning unit paving installations. Heavy vehicular loads require a rigid or semirigid continuous base, whereas a flexible base and flexible paving are suitable for light vehicular loads (residential type). Use either base type for pedestrian traffic. Appropriate base courses for heavy traffic would include asphalt over roadbase (Class 6), concrete over Class 6 roadbase, and just Class 6 roadbase. When using only roadbase under heavy loads, it should be at least twice as thick as the recommended 6-in. roadbase for pedestrian traffic. (Roadbase refers to compacted aggregate stone base course and the Classes are referencing DOT (Division of Transportation) standards).

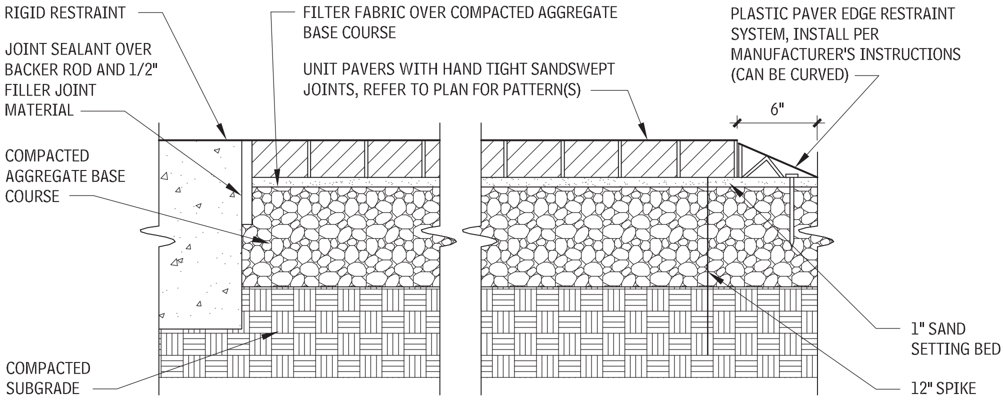
UNIT PAVERS ON SAND WITH CONCRETE BASE
16.39



NOTES

16.38 a. The height of pavers varies with the manufacturer and application, but is usually 1-1/4, 2-1/4, 2-5/8, or 2-3/4 in.
b. Check with manufacturers for availability of chamfers.
16.39 a. For curved conditions, use a manufactured angle-edge restraint with same-size expansion bolts at preset openings. No anchor may be greater than 6 in. from the gap or end of run. Spacing of gaps may increase depending on design of restraint. Recommended spacing of gaps should not exceed 5 ft o.c.
b. If the landscape edging is aluminum, paint the area that comes in contact with the concrete slab with bituminous paint. Also, provide an insulating fiber washer.
c. Meet flush with adjacent hardscape finish grades.
d. Refer to drainage detail if unit pavers slope to restraint.

UNIT PAVERS ON AGGREGATE BASE
16.40



Choose a bond pattern based on expected traffic patterns—traffic should travel perpendicular to the long dimension of the paving unit. For vehicular areas, use a gravel subbase (minimum 6 in. of crushed gravel) compacted to 95 percent, and paver sizes 8 in. square or smaller. Consult a civil engineer to accurately define paver sizes, shapes, gravel depth, concrete base depth, and concrete reinforcement requirements.

PAVER PREPARATION

Proper subgrade preparation of areas to be paved is important. Here are relevant guidelines:

- Remove all vegetation and organic material, and consider the location of existing or proposed underground utilities and storm drainage, as well as user convenience.
- Plan for surface and subsurface drainage. Slope paving away from buildings, retaining walls, and so on, at 1/8 to 1/4 in. per foot. Rigid paving always requires adequate surface drainage, with the long dimension of the mortar joints running parallel to the direction of runoff. Flexible paving requires both surface and subsurface drainage.
- Prevent horizontal movement of all types of mortarless unit paver assemblies—this is imperative. If the pavers are on an aggregate base, provide a rigid plastic edge restraint using spikes driven into the stone base designed for this purpose. A flush concrete curb works as well. If the paving system is over a concrete base, regardless of the setting bed (sand or bituminous), the pavers along the edge can be mortared to the base, but take care to ensure this method does not trap water which will seep into the setting bed. Another method is to secure an angle iron to the concrete base with anchor bolts, allowing for gaps on a regular basis to permit seepage. Cover vertical gaps with a small, perforated metal sheet for bituminous setting beds, or filter fabric for sand beds, to prevent erosion.

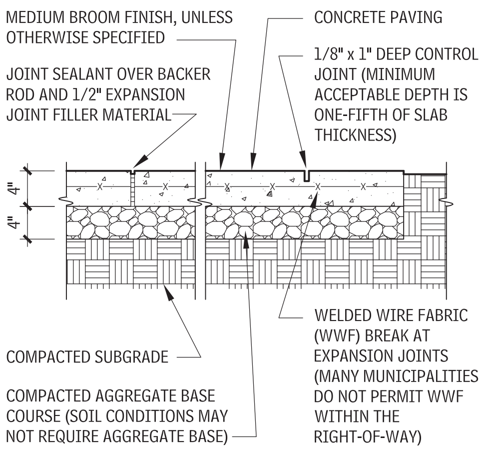
In addition, be aware that chamfers on both clay and concrete pavers are required for heavy driving applications (e.g., public streets and parking lots). Chamfered edges avoid the splintering of edges that can occur.

There are three major types of unit paver joint material:

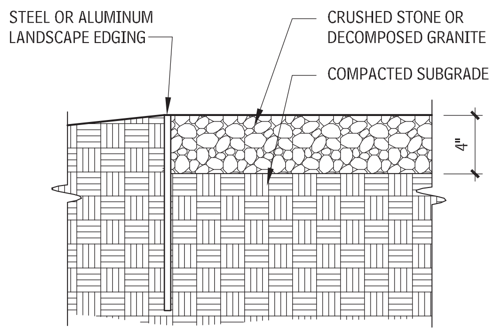
- Mortar
- Grout (portland cement and sand without hydrated lime)
- Dry mixture of grout

PEDESTRIAN PAVING

PEDESTRIAN CONCRETE WALK-ON GRADE
16.41



CRUSHED STONE PAVING
16.42



DESIGN CONSIDERATIONS

Additional design guidelines for working with unit paving systems include the following:

- Drainpipes may be omitted at well-drained areas.
- Provide positive outflow for drainpipes.
- Do not use unsatisfactory soil (expanding organic). Satisfactory soil must be compacted to 95 percent.
- Hand-tight paving joints are preferred over mortar joints. However, when mortar joints are required, and freezing and thawing are frequent, use latex-modified mortar.
- Install concrete footing for edging 10 to 14 in. wide and 6 to 8 in. deep. It is preferable to place the bottom of the footing at freezing depth. If the freezing depth is deeper than the bottom of the footing, provide 4 in. of gravel below the footing.
- Interlocking pavers are available in concrete, hydraulically pressed concrete, asphalt, and brick in different weight classifications, compressive strengths, surface textures, finishes, and colors. Consult local suppliers for availability.
- Subject to the manufacturer's recommendations and local code requirements, use interlocking concrete pavers in areas subject to heavy vehicle loads at speeds of 30 to 40 mph.
- Be aware that concrete interlocking unit paver sizes may be based on metric dimensions. When paver shape permits, use the herringbone pattern for paving that is subject to vehicular traffic.
- Continuous curb or other edge restraint is required to anchor pavers in applications subject to vehicular traffic.

PAVING SYSTEM CONSTRUCTION

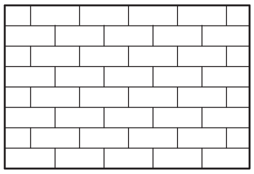
When working with unit pavers, keep in mind the following facts and guidelines:

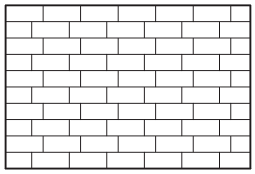
- Unit paving assemblies are also classified according to the type of base supporting the paver, either rigid, semirigid continuous or flexible. Base types are a reinforced or unreinforced concrete slab-on-grade that accepts either rigid or flexible pavers (*rigid*); asphalt or bituminous concrete that accepts flexible pavers only (*semirigid continuous*); a compacted gravel, sand, or sand-cement mixture that accepts flexible pavers only (*flexible*); and suspended diaphragm or structural floor and roof assemblies, which vary by design and accept either rigid or flexible pavers.
- Setting bed (cushion) material, placed between the base and paving surface, functions as a leveling layer to help refine the finished grade and compensate for irregularities in the base and paver unit surfaces. Setting bed material should be a 1- to 1-1/2-in. layer of bedding sand (ASTM C 33). Pavement can be subject to sinking when sand bedding layer is thicker than this. Cement or lime products are not recommended for jointing material. A flexible pavement (no mortar) with ASTM C 144 sand for jointing is preferable, regardless of use; however, there are products on the market that can be added to the joint sand to stabilize it. It is a particularly good idea to use such products with irregular sand molded brick pavers where there is a greater opportunity for wider joints, which may wash out. Doing so also reduces the chance of unwanted vegetation growing in the joints in less-traveled areas.
- Use mortar setting or leveling beds only in conjunction with concrete and asphalt bases; the thickness of the bed may vary from 1/2 to 2 in.

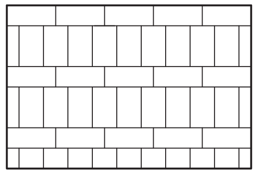
NOTES

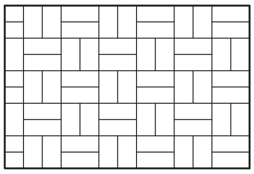
16.40 a. The thickness of the aggregate base varies depending on soil conditions and loading.
b. Pedestrian areas are approximately 6 to 8 in.; vehicular areas are approximately 8 to 12 in.
16.41 a. Install expansion joints with joint sealant when paving is adjacent to vertical faces, curbs, steps, any fixed object, or other rigid paving material, and at maximum 20 ft o.c., unless otherwise noted on plans.
b. Meet flush with adjacent hardscape finish grades.

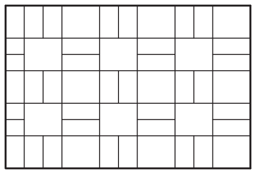
UNIT PAVER PATTERNS
16.43

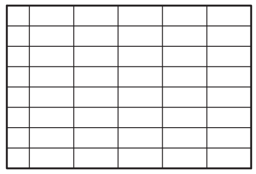

RUNNING BOND

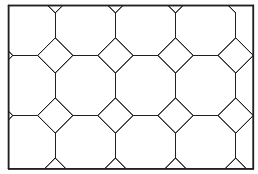

OFFSET BOND

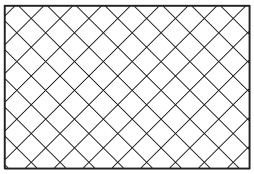

MIXED RUNNING AND STACK BOND

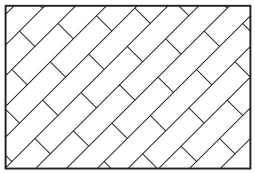

BASKET WEAVE

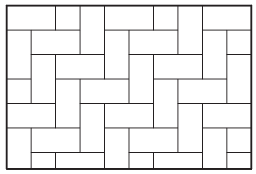

BASKET WEAVE

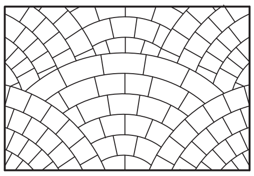

STACK BOND

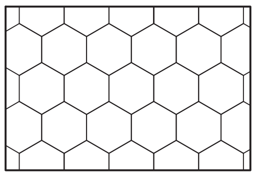

OCTAGON AND DOT

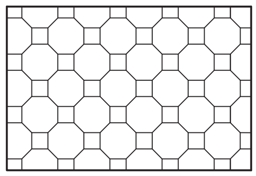

DIAGONAL STACK


DIAGONAL BOND

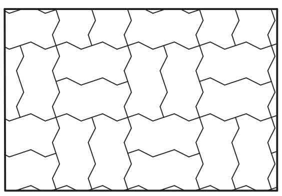

HERRINGBONE

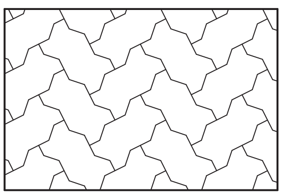

ROMAN COBBLE

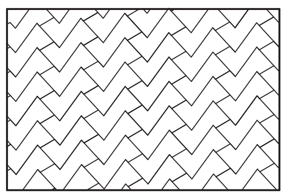

HEXAGON

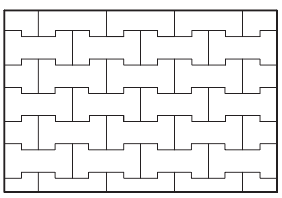

BASKET WEAVE OR PARQUET

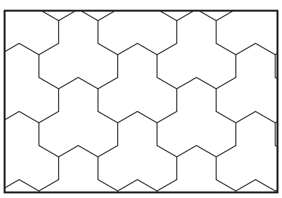
INTERLOCKING UNIT PAVER PATTERNS
16.87


BASKET WEAVE


HERRINGBONE

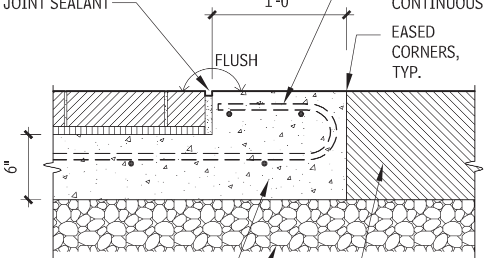

DIAGONAL RUNNING BOND


RUNNING BOND

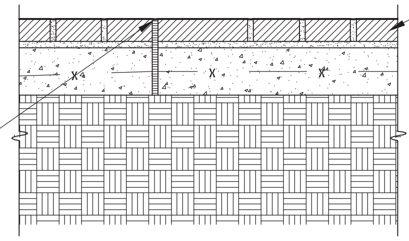

COMBINED HEXAGON

- Membranes are installed in unit paving assemblies for several purposes: to control the passage of moisture, reduce weed growth, prevent the sand course from filtering into lower courses, and as a bond break. Consider using bond breaks between rigid paving and rigid bases to accommodate differential movement. Membranes are of sheet or liquid material that can resist moisture, rot, and decay. Sheet materials include asphalt roofing felt, polyethylene film, vinyl, neoprene, and rubber. Liquid types are asphalt, modified urethane, or polyurethane bitumen; these are preferred for irregular surfaces.
- Use base materials, including gravel, concrete, and asphalt, for support, drainage, and/or groundswell protection. For maximum drainage efficiency and to prevent upward capillary action, specify clean, washed gravel.
- Expansion joints can alleviate thermal and moisture movement, especially in rigid or mortared assemblies. Expansion joints are generally located parallel or adjacent to curbs and edgings, at right angle turns, around interruptions (e.g., manhole cover assemblies), at set distances in long runs of masonry, and where dissimilar materials meet.
- Expansion joints are required to be full depth up to finish grade for unit pavers mortared to a concrete slab. Full-depth expansion joints are optional when the setting bed is sand or bituminous over a concrete slab. However, in regions where the seasonal fluctuation in temperature is 50° or greater, during the cold season, pavers flanking an expansion joint below may show slight separation, which closes up in the warm season. This is only evident with the bituminous setting bed because each paver is adhered to the setting bed with a neoprene tack coat. A gap does not usually show up with a sand setting bed because the pavers have the flexibility to move.

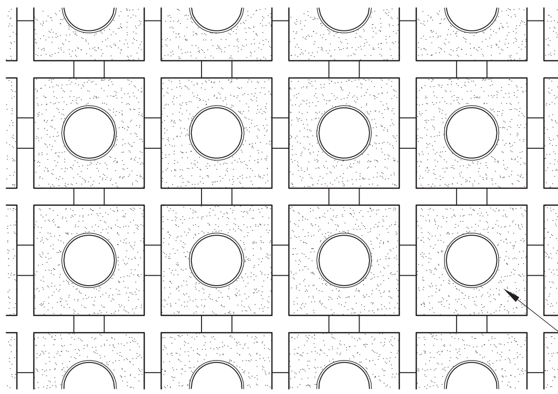
INTEGRAL FLUSH CONCRETE CURB WITH UNIT PAVERS
16.44



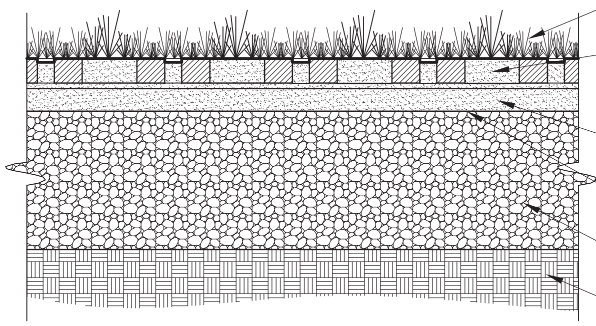
STONE PAVERS
16.45



GRASS PAVING SYSTEM
16.46



PLAN



SECTION

NOTES

16.46 a. Voids may be filled with grass, ground cover, or gravel.
b. Grass pavers may be used to control erosion.
c. Preformed lattice unit grids are used for storm runoff control, pathways, parking areas, and soil conservation.

Contributors:
Dennis Carmichael, FASLA, EDAW, Inc., Alexandria, Virginia; Jon Pearson, EDAW, Inc., Alexandria, Virginia; and John Rowe, Pavestone Company, Dallas, Texas.

EXTERIOR STAIRS AND RAMPS

Throughout the centuries, stairs and ramps have been used to address elevation changes in the landscape. They can be heroic or modest, nuanced or straightforward, detailed or plain. They represent for designers opportunities to create delight, variety, viewpoints, and accents in the movement of people across a landscape. They are also zones for heightened access and safety consideration. This section leaves for the designer's imagination the full potential of stairs and ramps as artistic design elements, and concentrates instead on access and safety design issues.

REGULATIONS

Stairs and ramps as components of the pedestrian walkway system are regulated for minimum design standards at federal, state, and local levels. With the Americans for Disabilities Act (ADA), the role of stairs and ramps in creating accessibility for all became a specific design focus. For designers, the first requirement is to thoroughly review the relevant jurisdiction's accessibility and safety codes related to stairs and ramps. Any discrepancies between the information presented in this discussion and any regulation should always be resolved in the favor of the regulation.

There are differences in the design requirements between local, state, and federal accessibility and safety regulations. Identifying and determining the relevant regulations for a project requires research and discussion with the project client. Private and local government projects usually must adhere to local, state, and federal requirements. State and federal projects usually exempt themselves from application of regulations enacted by lower jurisdictional levels.

A review meeting early in the design process with the relevant building code enforcement group is advisable. Determining the applicable regulations with the client is a professional liability responsibility of the design professional.

EXTERIOR VERSUS INTERIOR DESIGN STANDARDS

Exterior stairs and ramps must deal with climatic issues that interior situations do not—obvious examples being rain and snow. In addition, the design and spatial variety of exterior landscape spaces make the location of stairs and ramps less predictable for pedestrians. Thus, in exterior design factors such as tread depth and slope, traction, and detectable warning zones become important issues to consider. Directly applying interior stair and ramp standards to exterior locations is generally not a good practice.

EXTERIOR STAIR DETAILS

A rule of thumb for tread depths and riser heights for exterior stairs can be translated to this equation:

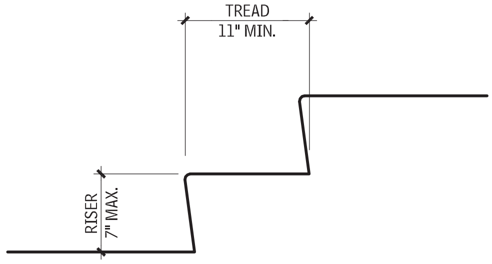
Height of two risers + depth of one tread = 26 inches

For exterior locations, a recommended range for risers is between 4 and 7 in., with recommended tread depth of 12 to 18 in.

Stairs in exterior locations require a slope on the tread to shed rain and snow melt. A generally recommended slope is a 2 percent slope from front to back of tread, or a 1/4-in. on a 12-in.-wide tread.

The leading edge of a step is called the *step nose*. Stair nose details vary depending on the material used. Detailing of the stair nose is an important safety consideration. The current accessibility standard is that step noses should have a radius of 1/2 in., with no overhang deeper than 1/2 in. on the step. The goal is to reduce the potential points where a person's shoe could become trapped or tripped, such as a toe under a step overhang or a heel at a sharp nose edge.

RISER AND TREAD PROPORTIONAL DETAIL
16.47



RISER HEIGHT (IN.)	TREAD DEPTH (IN.)
4	18
4-1/2	17
5	16
5-1/5	15
6	14
6 -/2	13
7	12

The leading 2 inches of the tread shall have visual contrast of dark-on-light or light-on-dark from the remainder of the tread (per ANSI A117.1).

CONSTRUCTION OF EXTERIOR STAIRS

A construction concern for concrete stairs is the placement of reinforcing bars. Reinforcing steel should be placed a minimum of 3 in. back from any exposed surface of the step. Maintaining a minimum 3-in. clearance reduces the potential for breakup of the step due to differential freeze/thaw expansion between the reinforcing steel and the concrete. This is especially important in the stair nose zone. Adding slip dowels and keyed joints at the top of concrete stairs to adjacent concrete paving or subsurface layers is a good construction detail, to avoid differential settlement and tripping hazards. The bottom step footing on concrete stairs or concrete subsurface for stairs should extend down, at a minimum, to the local freeze depth.

EXTERIOR STAIR RUNS, WIDTHS, AND LANDINGS

Single steps should be avoided, as they create a tripping hazard because of their lack of visibility. Stairs and steps in general should be distinguished from surround paving by a difference in material, color, or pattern, to highlight and make them more prominent. In most jurisdictions, when there are more than three steps, handrails must be provided.

As a general rule, exterior stair landings should, at a minimum, match the width of the stairs and be a minimum of 3 ft deep. Exterior stairs when located at main entries or emergency exits of buildings should, at a minimum, be the width of the exiting doorways. This helps to maintain a safe emergency egress zone. Providing a landing at doorways and gates that are served by stairs makes using doorways safer and more convenient. The swing of the door should be accounted for in scaling the depth of a landing, to avoid having to be on a step to open or close a door or gate.

Installing intermediate stair landings where an elevation change of between 2-1/2 and 5 ft has been reached on a run of stairs creates a comfortable resting place for users. When longer runs of stairs are used, consideration for larger landings with opportunities for sitting should be given. Landings should be built with a minimum 2 percent slope toward the downhill edge.

RAMPS

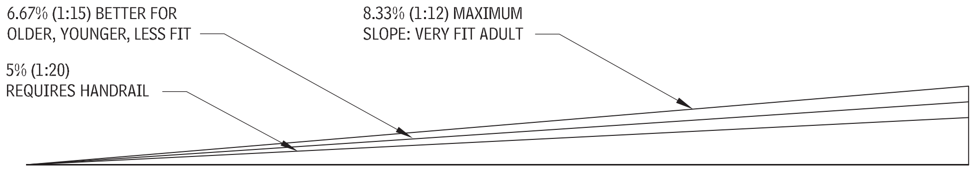
Accessible ramp slope standards initially were based on research using disabled adult males as the test population. This means that, perhaps, it is not the best standard for the elderly, children, or the frail. Thus, for the greatest universal access of a project, designers should target for the lowest ramp slope rate practical. Research based on the elderly and children is beginning to show that a better slope rate for those populations is 1:16 or lower. The 1:12 or 8.333 percent slope rate should be considered the maximum rate, not the goal.

As a practical cost consideration, any ramp that is flatter than 1:20 does not require handrails and, thus, can avoid that cost.

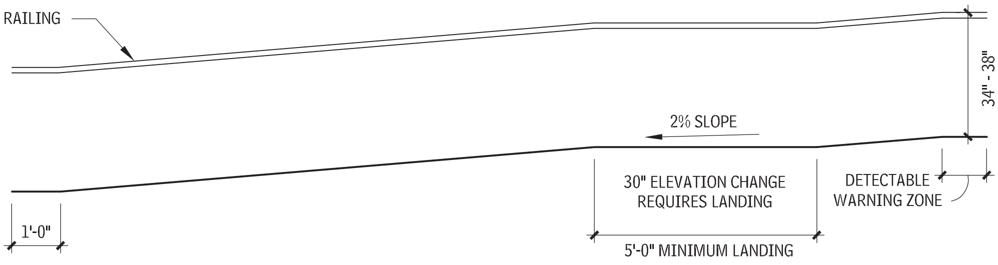
STREET RAMPS

There are two common locations for exterior ramps: at street corners and crossings, and where grade changes occur. The design of street ramps is highly regulated by local, state, and federal ordinances. This discussion does not provide street ramp stan-

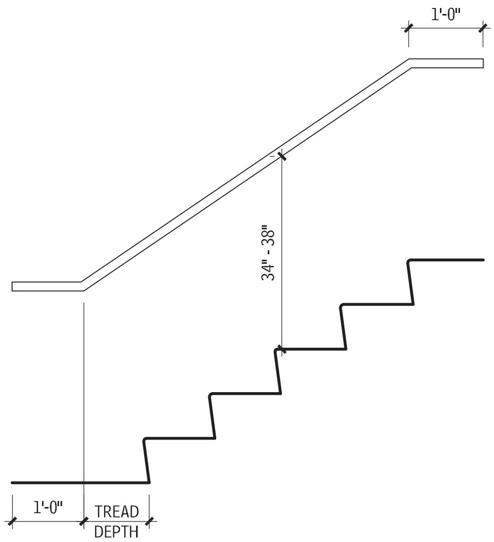
RAMP SLOPE RATIOS
16.48



RAMP SECTION
16.49



STAIR RAIL DETAIL
16.50



dards because the design requirements are diverse and undergo frequent review and modification. Thus, for street ramp standards, the design professional is referred directly to the relevant ordinance determined by discussion with the relevant code enforcement agency and the client.

EXTERIOR RAMP DETAILS

The most important design feature of an exterior ramp is the surface of the ramp. Ensuring that it is not slick in wet weather is critical for safety. Follow these guidelines:

- On concrete ramps, the surface should be, at minimum, a medium broom finish, with the broom strokes being perpendicular to the flow of traffic.
- Stone clad ramp designs should consider honed or scored surfaces, and avoid any smooth, flat finish.
- Metal ramp designs should consider structural grille/grate panels or embossed or patterned metal, and avoid any smooth finish.
- Installing slip dowels or keyed joints at the tops and bottoms of ramps to adjacent paving helps to avoid differential movement that causes tripping hazards at the entries to the ramp.

RAMP WIDTHS AND LANDINGS

Design guidelines for ramp widths and landings are as follows:

- An accessible ramp should have a clearance between ramp handrails of at least 36 in., to allow a person in a wheelchair room for his or her hands to turn the wheels.
- A ramp landing should occur at a maximum of 30 ft of run of a ramp. The ramp landing must be a minimum of 60 in. clear depth.
- If ramps change direction at landings, the minimum landing size must be 60 by 60 in.
- If an exterior doorway is located at a ramp landing, the landing must comply with safety and access requirements for the door.

STAIR AND RAMP HANDRAILS

As part of the accessible system, stair and ramp handrails are covered under access and safety regulations. Their placement, height, length, strength, and safety details fall under the design guidance of these regulations. Thus, familiarity with the relevant codes is paramount.

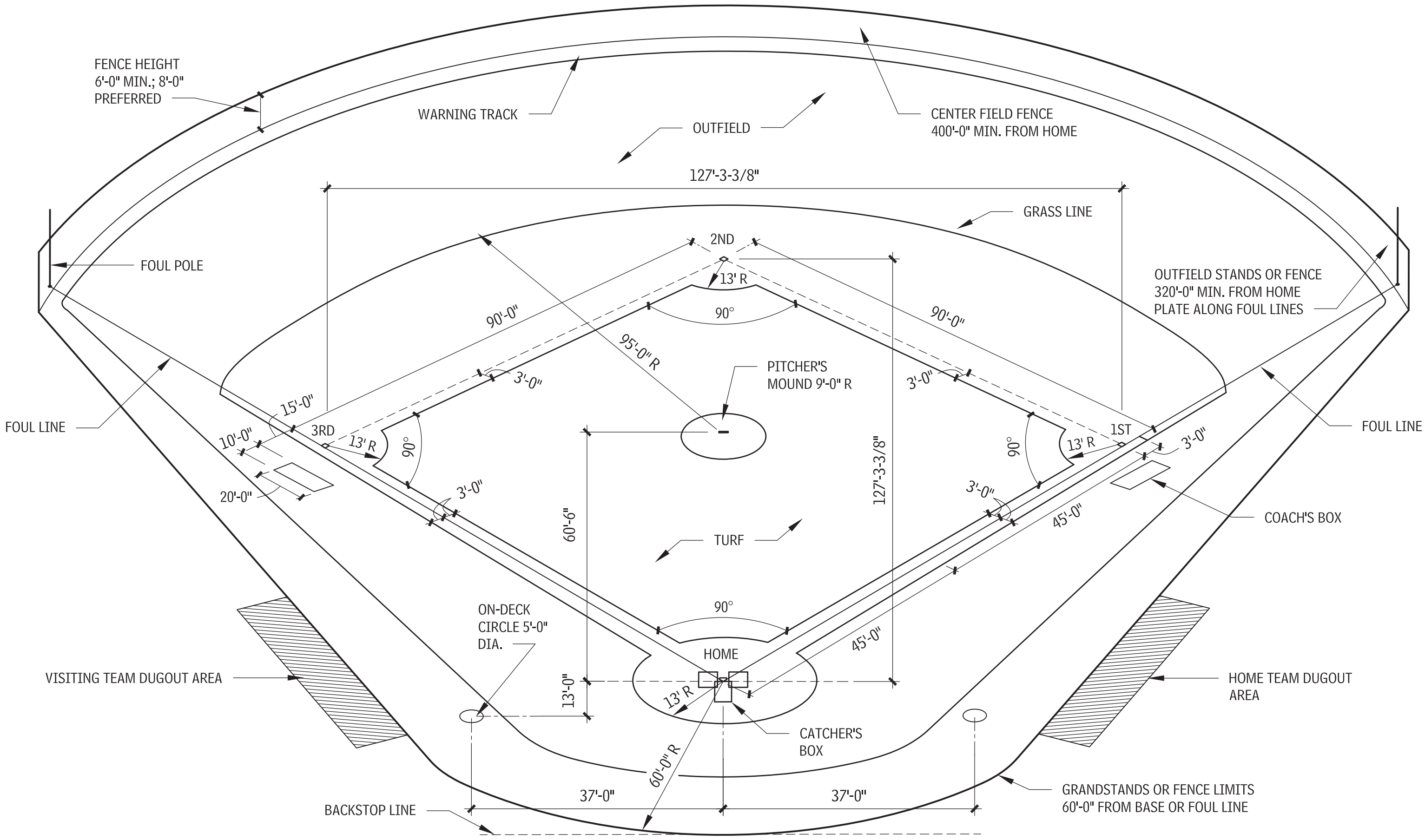
General requirements for all handrails are:

- The top of the handrail to stair nose or ramp surface distance should be constant—a height between 34 to 38 in.
- The diameter or width of the handrail must be 1-1/4 to 1-1/2 in.
- Structurally, the handrail must be able to withstand 250 lbs of downward pressure per inch.
- The ends of handrails should not be sharp.
- General standards for stair handrails are:
  - At the top of the stair run, the rail must be level for 12 in. before the first step nose.
  - At the bottom of stair run, the rail must extend for one tread length at the same slope as over the majority of the stairs, then remain level for an additional 12 in.
- General standards for ramp handrails are:
  - At the top of the ramp, the rail must be level for 12 in. before the top of the ramp.
  - At the bottom of the ramp, the rail must remain level for 12 in. beyond the end of the ramp.

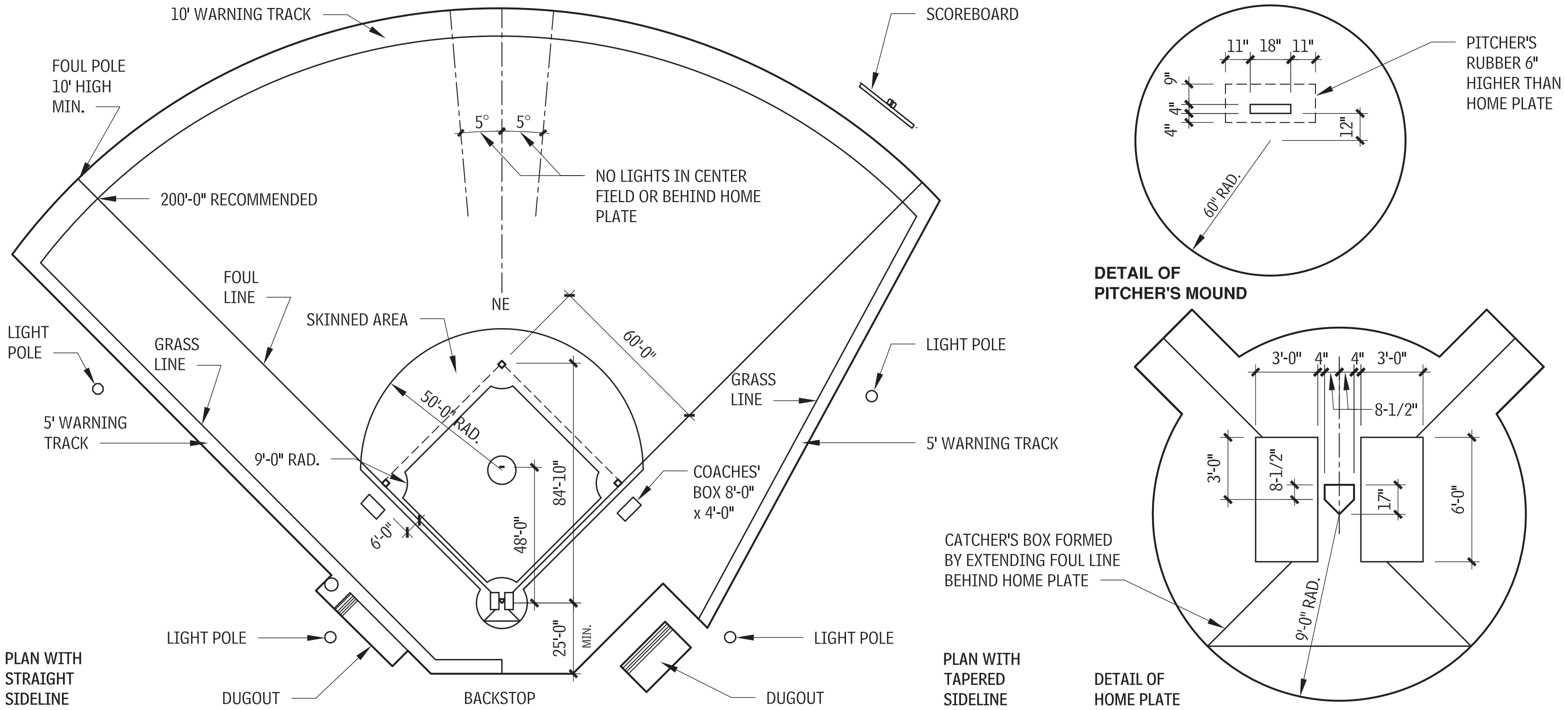
Contributor:
Faith Okuma, Design Workshop, Santa Fe, New Mexico.

ATHLETIC AND RECREATIONAL AREAS

MAJOR LEAGUE BASEBALL FIELD
16.51



PLAN OF LITTLE LEAGUE BASEBALL FIELD
16.52



PLAN OF SOFTBALL FIELD
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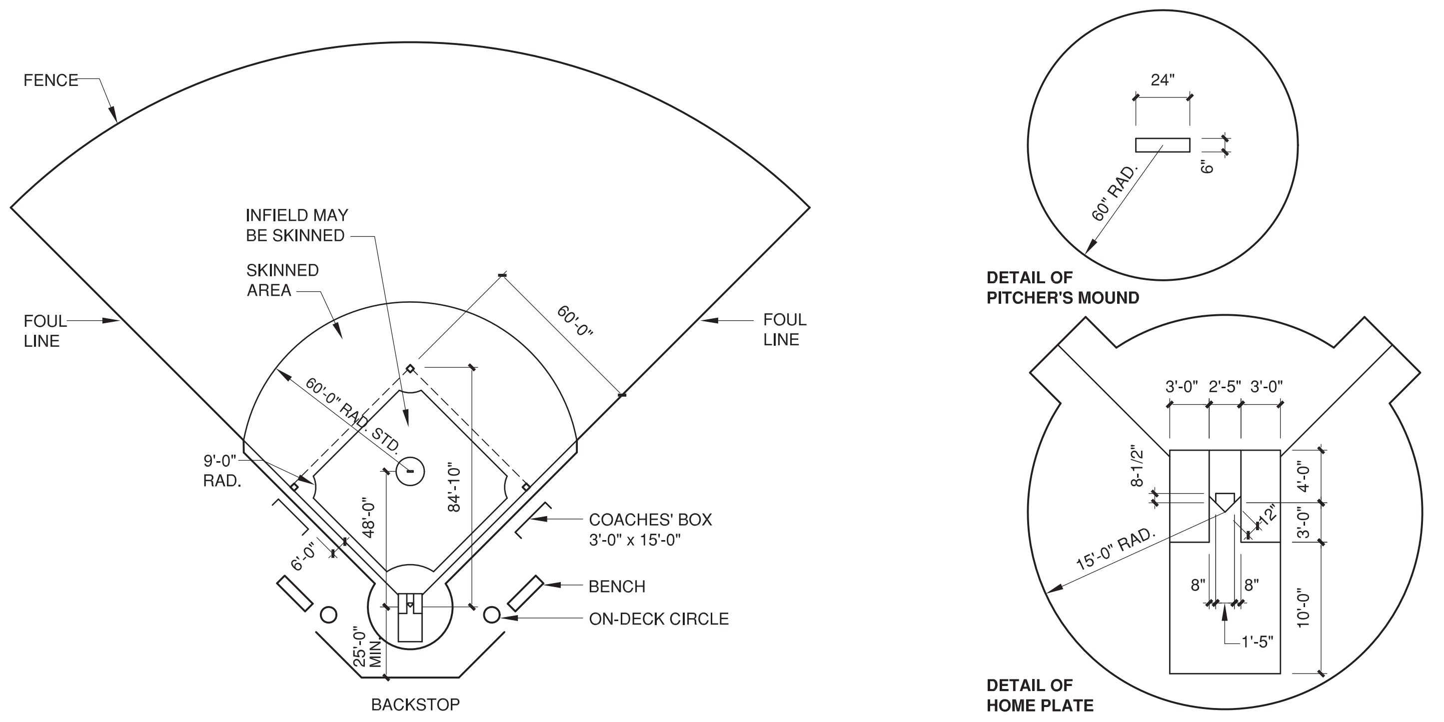
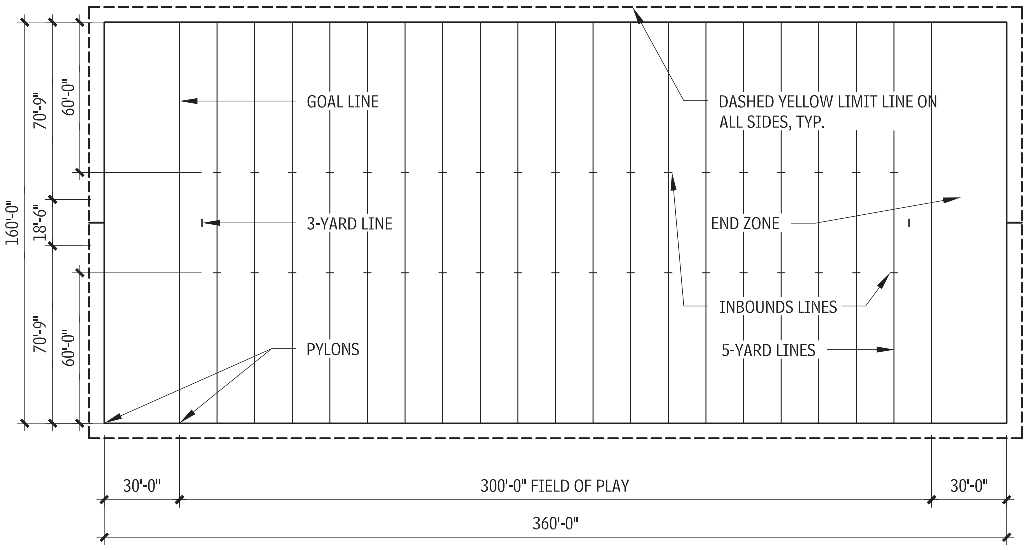


NATIONAL COLLEGIATE ATHLETIC ASSOCIATION FIELD
16.54



HIGH SCHOOL FOOTBALL FIELD
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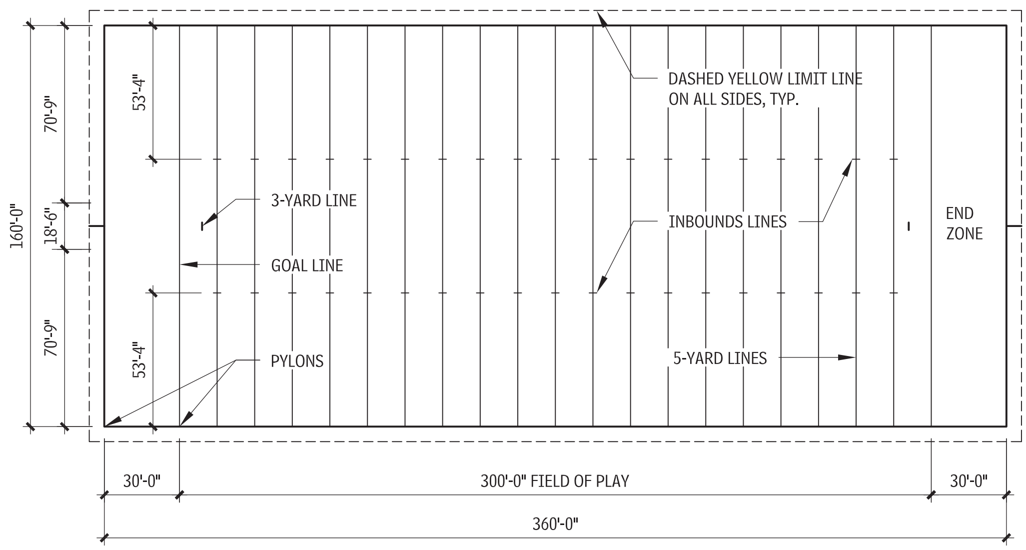
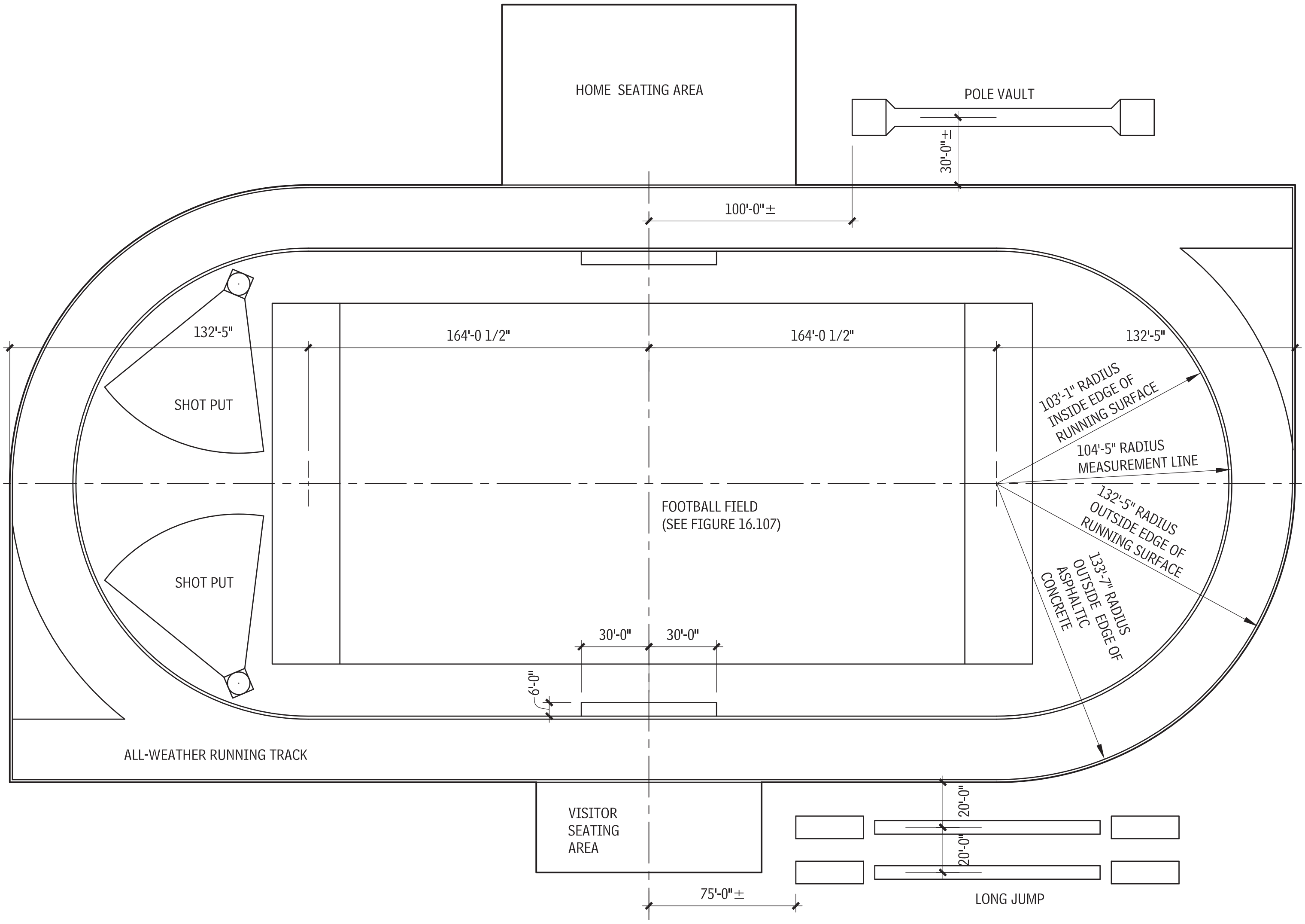


MULTIPURPOSE HIGH SCHOOL STADIUM
16.56



NCAA SOCCER
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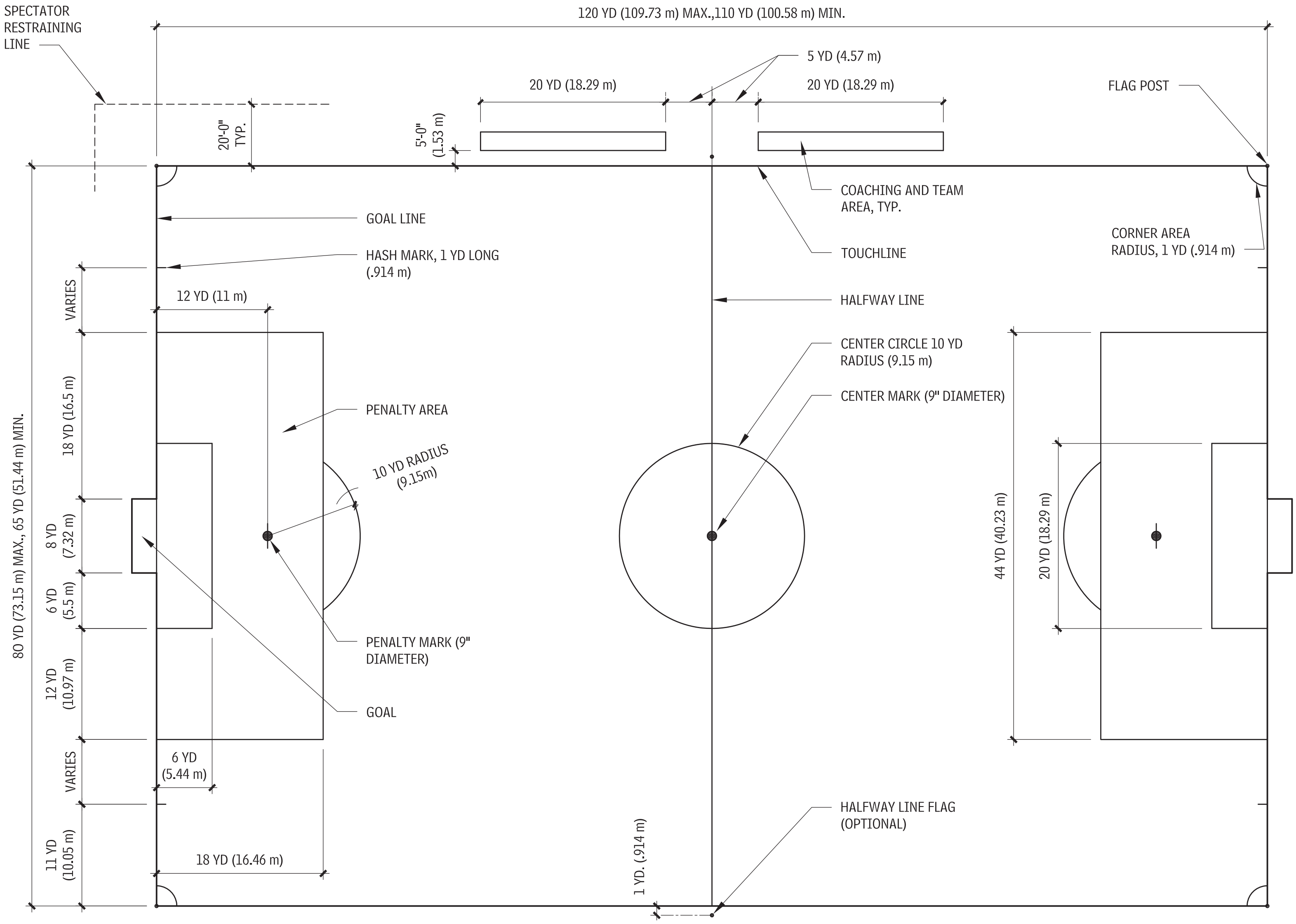
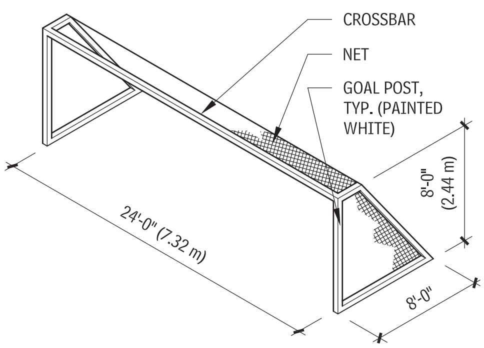
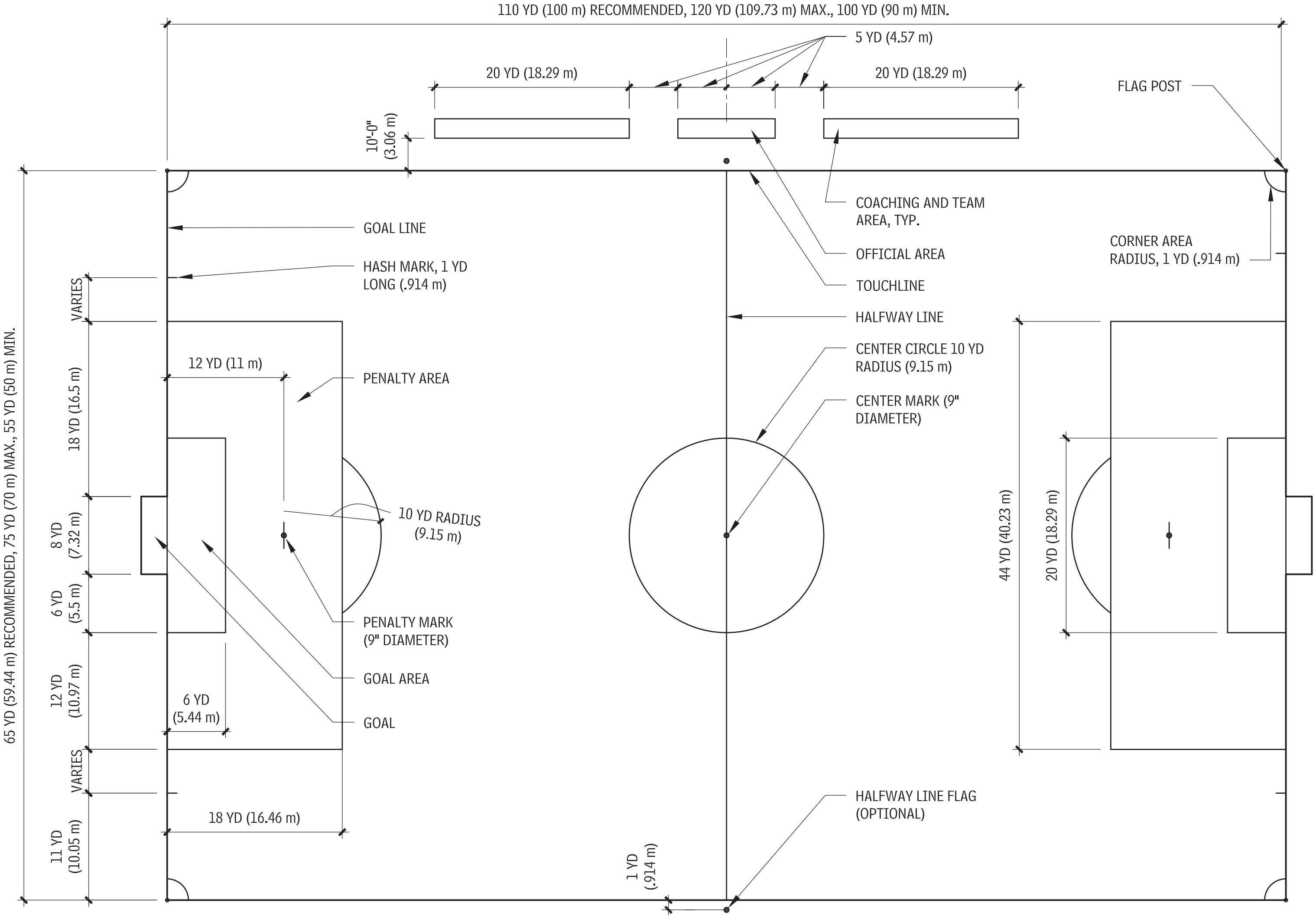


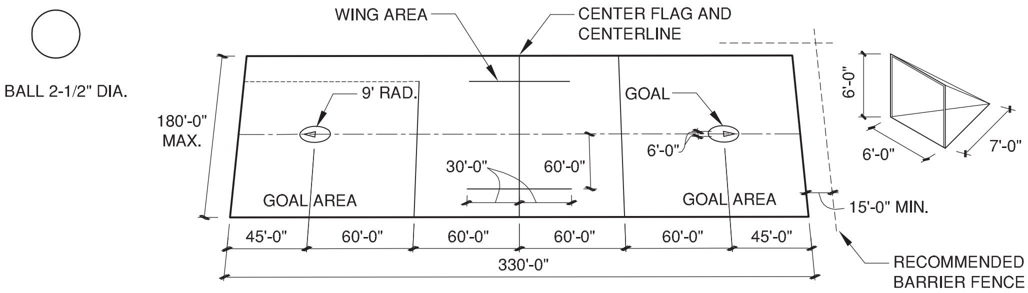
SOCCER GOAL
16.58



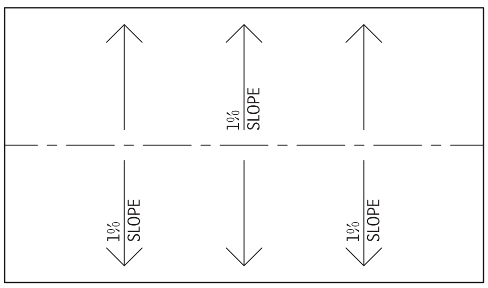
HIGH SCHOOL SOCCER
16.59



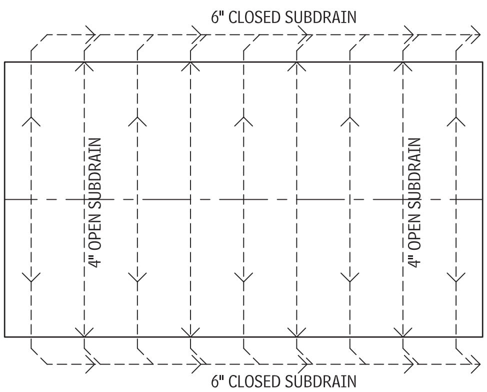
LACROSSE
16.60



RECTANGULAR SPORTS FIELDS
16.61

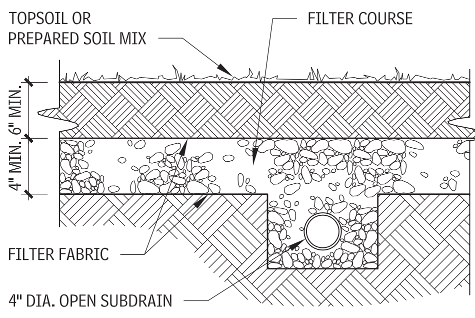


PREFERRED GRADING

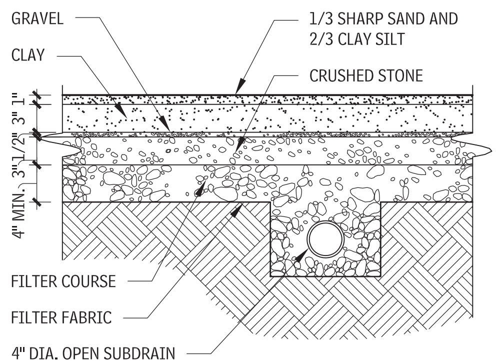


SUBSOIL DRAINAGE

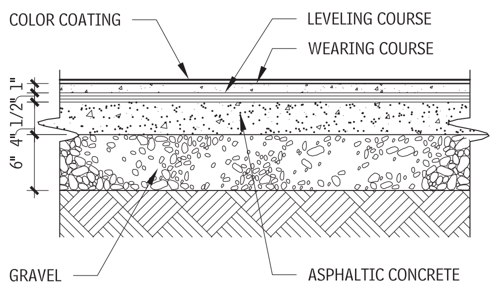
PLAYING SURFACES
16.62



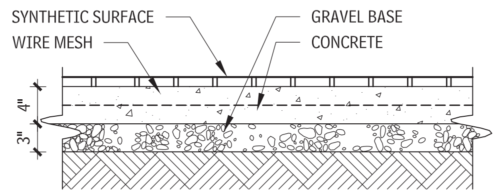
NATURAL TURF



SAND CLAY



BITUMINOUS CONCRETE



SYNTHETIC SURFACE

SITE DEVELOPMENT

FOUNTAINS AND DECORATIVE POOLS

Materials used in fountain and pool design should be durable—that is, capable of resisting damage caused by water, cracks, weather, stains, and freeze/thaw cycles. Suitable materials include stone, concrete, brick, tile, and metals such as copper, bronze, cast iron, and steel. Fiberglass, acrylic, and waterproof membranes such as PVC, EPDM, and butyl are commonly used.

OVERVIEW

The metamorphosis of fountains has been geometric in the last 20 years. Technology and innovation have teamed to allow design professionals greater flexibility in creating stunning displays. Education is likely the most important responsibility of the design professional, as the complexities of water features require the efforts of many disciplines. The architectural support team should be composed of not only fountain consultants but plumbing, electrical, and structural engineers. In some situations, it is necessary to enlist chemical engineers, waterproofing consultants, and specifiers.

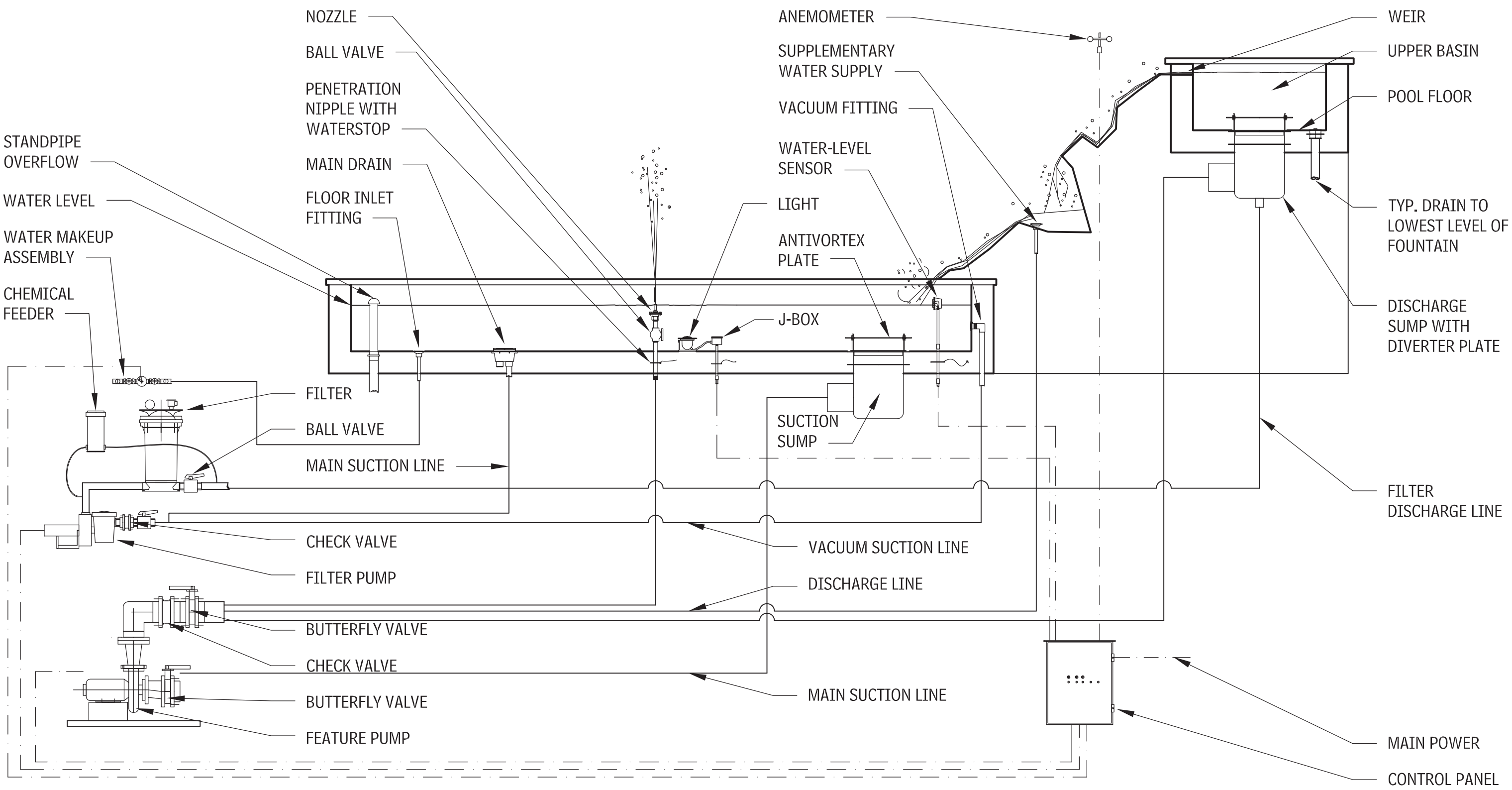
Generally speaking, the design/build concept of fountains may not be in the best interest of architects or owners, due to the involved nature of competent systems.

PLAYGROUNDS

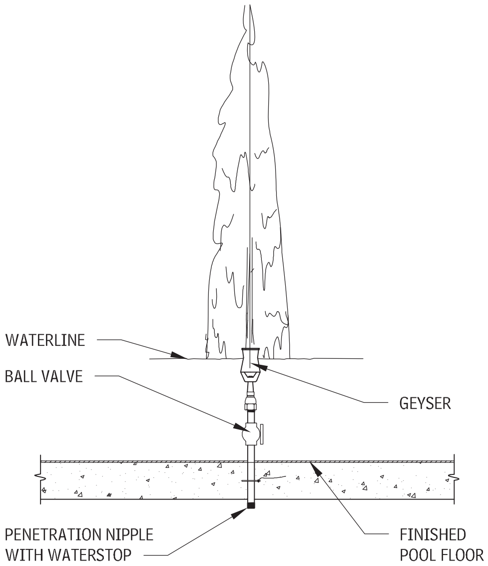
Play is vital to the physical, emotional, and social growth of children. To encourage healthy growth, the play environment must challenge children at their level of development, yet reassure them as they investigate their physical limits. Each stage of development prompts different types and levels of interaction and activity. The outdoor play environment becomes increasingly important as the boundaries of the child's world stretch beyond the home and primary care. Play equipment should be selected and designed to attract, fascinate, and sustain the interest of the age groups who will use it, while promoting agility, strength, and balance.

Playing may consist of imitation, role-play, and fantasy play, as well as more active pursuits. Space and equipment must be provided to encourage jumping, climbing, swinging, sliding, crawling, hanging, running, building, sitting, and meeting. Designs should provide opportunities for children to be imaginative and to interact socially. Ideally, the equipment should be a flexible, three-dimensional system that allows children to move in every direction and challenges them with a consistently changing space.

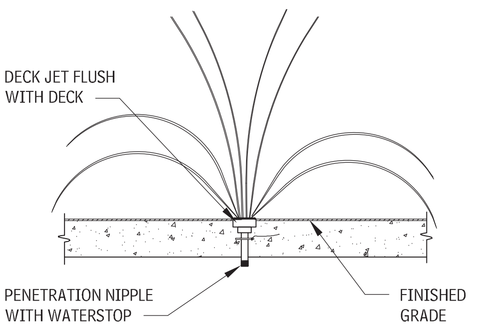
SCHEMATIC FOUNTAIN LAYOUT
16.63



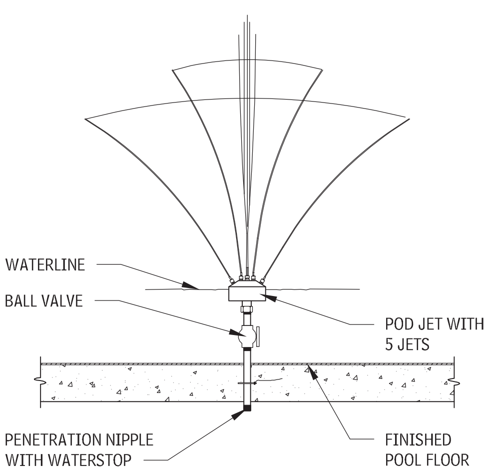
GEYSER NOZZLE
16.64



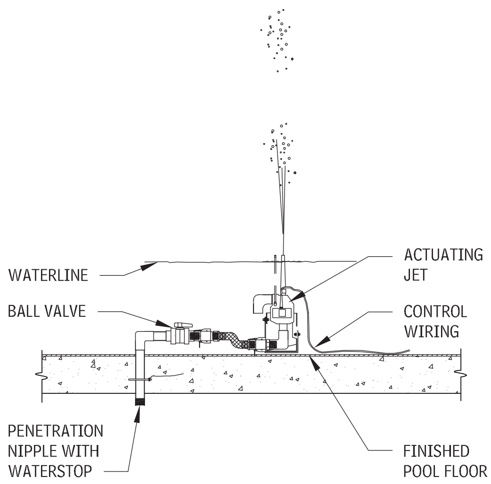
DECK NOZZLE
16.65



BRONZE POD NOZZLE
16.66



ACTUATING JET
16.67



Three age groups must be considered in designing playgrounds. Toddlers (3 to 5 years) should be separated from older children by a fence they can see through. This makes it easier for caregivers to supervise the younger children yet allows the toddlers to feel a part of things. Early elementary (6 to 9 years) and late elementary (9 to 12 years) children have traditionally been separated, but an option is to design equipment that has several levels of difficulty, allowing use by both groups.

Most traditional play equipment is designed to stand alone as single units, although these may be linked together. Where space or other conditions limit the scope of development, such equipment is useful. However, because a child's play activity tends to proceed in a continuous flow, integrated play areas have proved more successful than arrangements of individual items. Combining several materials, colors, and textures also makes the play space more inviting. A variety of options are available to the designer in both custom and manufactured products.

It is important to note that playgrounds are required to be accessible. For more information on these requirements, refer to the ADA Accessibility Guidelines (ADAAG) for Play Areas, which may be found at *www.ada.gov*.

PLAYGROUND DESIGN CONSIDERATIONS

The design of a playground should meet the needs and sustain the interest of the children who will use the site. For example:

- Using nonrepetitive elements and semitransparent features creates mystery and surprise.
- Dynamic, movable components allow more creative opportunities for children, and a variety of textures stimulates the sense of touch.
- Children never tire of playing with sand and water. Manufacturers offer a wide variety of water features for the playground, including wading pools and fountains. Water elements also encourage adult interaction.
- Space for congregating can be provided as semienclosed refuge or open area.
- Bridges add interest to equipment and can provide connections between structures; they also create more climbing and refuge space. In addition to traditional plank bridges, there are arched, rope, suspension, or tire bridges.

If a theme such as a ship, castle, or fort is incorporated in the playground, the playground equipment will automatically encourage the child's imagination. However, don't replicate these themes too closely; leave most of the creation to the child.

Adults should not be separated from the play area. Ample seating should be provided for them, and the playground equipment should be interesting to adults, too, as their presence enables security, instruction, and approval.

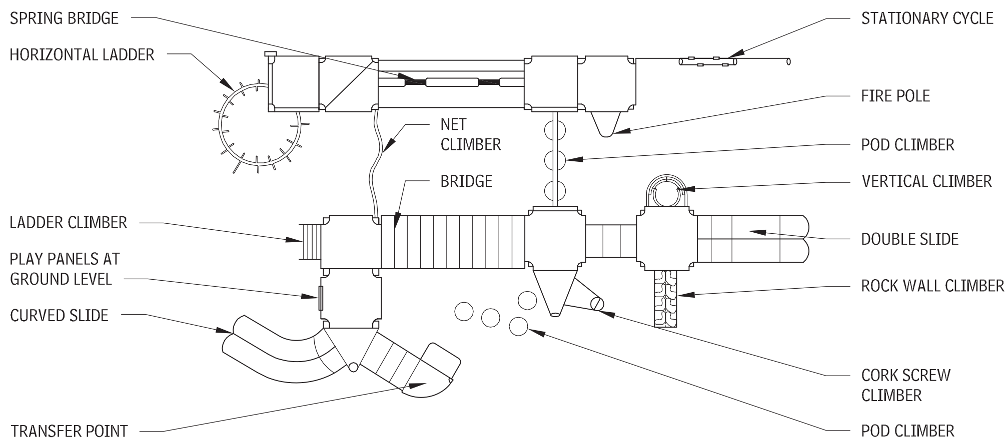
Practical questions to answer when designing a playground are:

- How does the equipment appear from the surrounding area?
- What are the views from the site?
- How much noise will travel to and from the playground?

The design should consider the time of day the equipment will be used and be suitable for use all year.

As with any site development, good drainage is critical. If loose fill materials are used as protective surfacing, drainage must not be allowed to pass through the loose fill material, otherwise compaction and or erosion of the protective surfacing can occur. Shade is desirable in hot climates, especially for playgrounds designed for 2- to 5-year-olds. Metal slides should not be used unless the slide is shaded.

TYPICAL PLAY STRUCTURES
16.68



Contributor:
Michael Barnicle, Delta Fountains, Jacksonville, Florida.

PLAYGROUND SAFETY AND MATERIALS

No playground is completely safe. The potential for accidents is inherent in the element of risk involved in most play. Nonetheless, playground equipment should provide challenging activities in the safest way possible.

Round, square, and rectangular timber should be pine or fir (oak warps; redwood splinters). Color should be in the form of stain, not paint, and all edges should be beveled or rounded. Steel pipe, sheets, chain, and drums can be vinyl-coated. Chain, rope, and tires are available in plastic. Use of concrete and stone should be kept to a minimum. Hardware should be galvanized or stainless steel, and joints and connections covered or recessed.

For guidance, designers should consult the U.S. Consumer Product Safety Commission's *Handbook for Public Playground Safety,* and ASTM International's ASTM F 1487.01, "Standard Consumer Safety Performance Specification for Playground Equipment for Public Use." Playground designs should adhere to the guidelines established in both publications. In addition, the National Recreation and Park Association certifies playground auditors. Prior to use by the public, playgrounds should be audited for safety by a certified playground auditor.

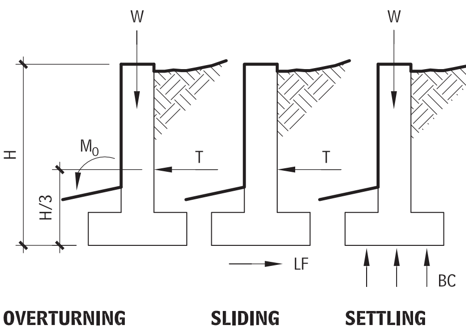
RETAINING WALLS

Retaining walls are designed and constructed to resist the thrust of the soil, which can cause the wall to fail by overturning, sliding, or settling. In stone walls, resistance to soil thrust can be helped by battering the stonework (i.e., recessing or sloping the masonry back in successive courses).

Garden-type retaining walls, usually no higher than 4 ft, are generally made from small building units of stone, masonry, or wood. For higher walls, reinforced concrete is more commonly used. Terracing may be built with walls of wood, stone, brick, or concrete.

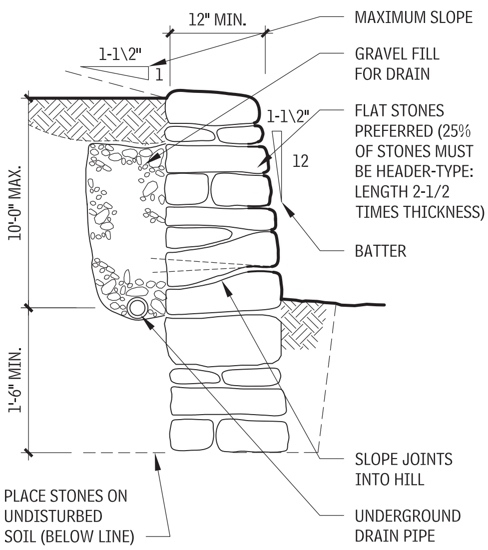
Walls less than 2 ft high do not require drains or weepholes. Preservative-treated wood is recommended for any design in which wood comes in contact with the ground. Redwood may be substituted if desired.

FORCES RESISTED BY RETAINING WALLS
16.69

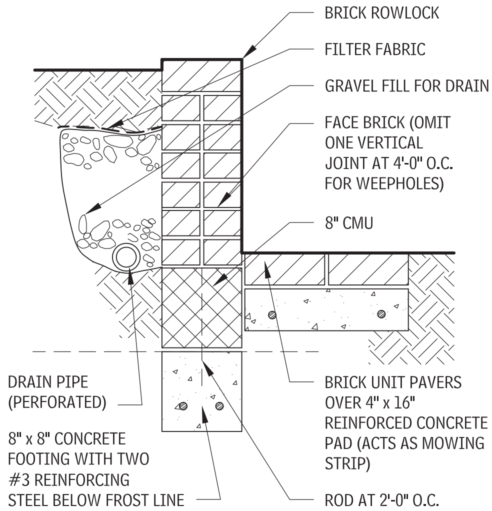


DRY-PLACED STONE RETAINING WALL
16.70

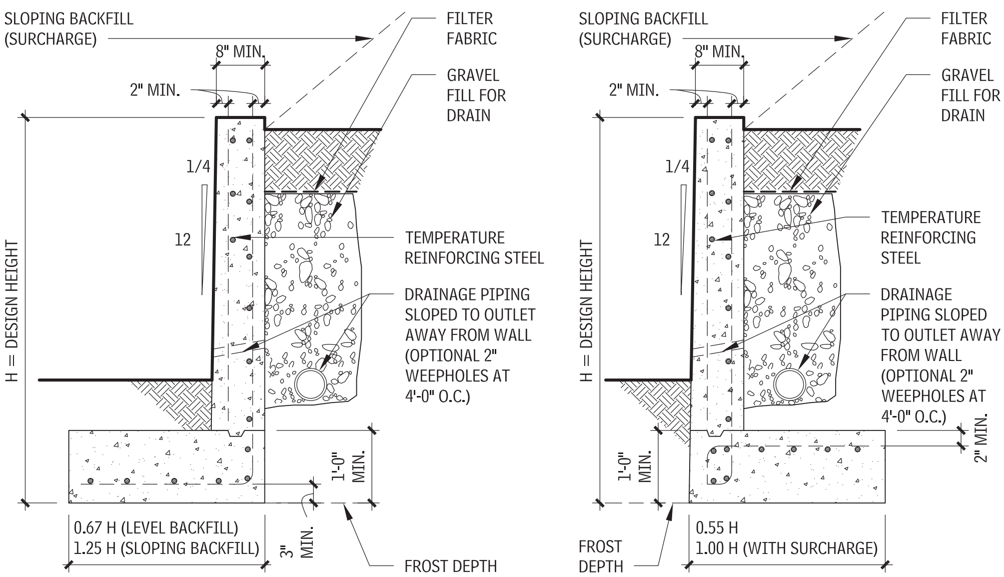
Stagger vertical joints from course to course 6 in. minimum horizontally. The thickness of the wall at any point should not be less than half the distance from that point to the top of the wall.



BRICK UNIT MASONRY RETAINING WALL
16.71



L-TYPE RETAINING WALLS
16.72



NOTES

16.69 a. H = height of wall, A = area of footing, W = composite weight of wall, T= lateral thrust of soil on wall, d = width of base of wall; M_0 = overturning moment of a retaining wall; MR = resisting moment; LF = lateral force on wall in psf; BC = bearing capacity of soil.

b. The overturning moment of a retaining wall (equal to $T \times H/3$) is resisted by the resisting moment of the wall. For symmetrical sections, the resisting moment equals $W \times d/2$. Using a safety factor of 2, $MR \geq 2 \times M_0$ (assume 33° angle of repose of soil).

c. The lateral (sliding) thrust of soil on a wall must be resisted. The resisting force is the weight of the wall multiplied by the coefficient of soil friction. Using a safety factor of 1.5, $LF \geq 1.5T$, where $T = (w \times H2)/2$.

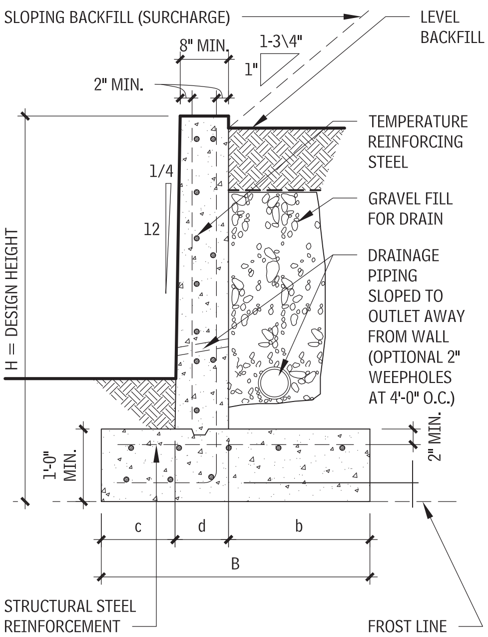
d. The bearing capacity of the soil must resist vertical forces (settling)—the weight of the wall plus any soil bearing on the base plus any vertical component of the soil thrust for a wall with any surcharge. Using a safety factor of 1.5, $BC \geq 1.5\ W/A$.

CAST-IN-PLACE CONCRETE RETAINING WALLS

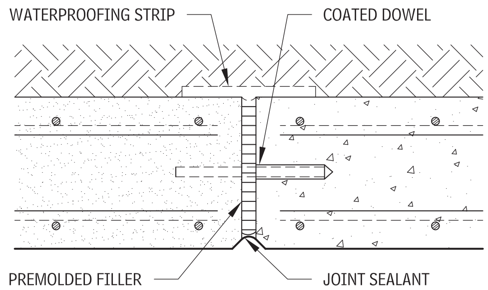
When designing cast-in-place concrete retaining walls, keep these guidelines in mind:

- Provide control and/or construction joints in concrete retaining walls approximately every 25 ft. Every fourth control and/or construction joint should be an expansion joint. Coated dowels should be used if average wall height on either side of a joint is different.
- Consult with a structural engineer for final design of all concrete retaining walls.
- Concrete keys may be required below retaining wall footing to prevent sliding in high walls and those built on moist clay.

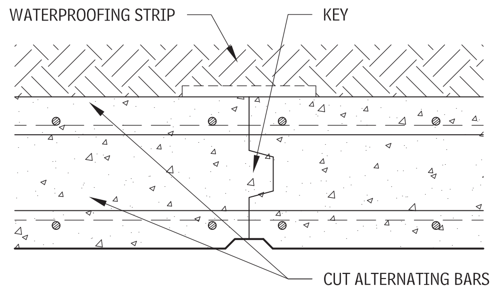
T-TYPE RETAINING WALL
16.73



RETAINING WALL JOINTS
16.74



VERTICAL EXPANSION JOINT



VERTICAL CONTROL JOINT

PRELIMINARY DIMENSIONS FOR CAST-IN-PLACE CONCRETE RETAINING WALLS
16.75

APPROXIMATE CONCRETE DIMENSIONS (FT-IN.)									
BACKFILL SLOPING DIAMETER = 29" 45' (13/4:1)					BACKFILL LEVEL—NO SURCHARGE				
HEIGHT OF WALL (H)	WIDTH OF FOOTING (B)	WIDTH OF WALL (D)	HEEL (B)	TOE (C)	HEIGHT OF WALL (H)	WIDTH OF BASE (B)	WIDTH OF WALL (A)	HEEL (B)	TOE (C)
3-0	2-8	0-9	1-5	0-6	3-0	2-1	0-8	1-0	0-5
4-0	3-5	0-9	2-0	0-8	4-0	2-8	0-8	1-7	0-5
5-0	4-6	0-10	2-6	1-2	5-0	3-3	0-8	2-2	0-5
6-0	5-4	0-10	2-11	1-7	6-0	3-9	0-8	2-5	0-8
7-0	6-3	0-10	3-5	2-0	7-0	4-2	0-8	2-6	1-0
8-0	7-0	1-0	3-8	2-4	8-0	4-8	1-0	2-8	1-0
9-0	7-6	1-0	4-2	2-4	9-0	5-2	1-0	3-2	1-0
10-0	8-6	1-0	4-9	2-9	10-0	5-9	1-0	3-7	1-2
11-0	11-0	1-1	7-2	2-9	11-0	6-7	1-1	4-1	1-5
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15-0	15-0	1-6	9-9	3-9	15-0	9-0	1-4	5-9	1-11
16-0	16-0	1-7	10-5	4-0	16-0	9-7	1-5	6-2	2-0
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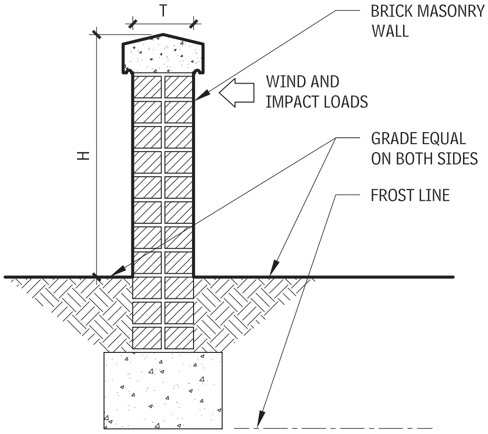
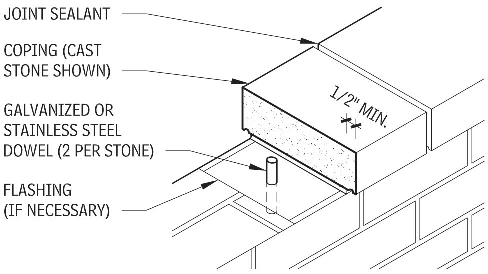
22-0	22-0	2-4	14-4	5-4	22-0	13-3	1-11	8-7	2-9

STRAIGHT GARDEN WALLS
16.76

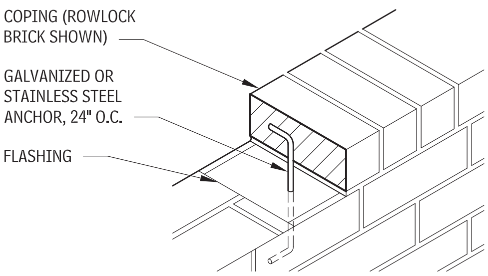


COPING DETAILS
16.77

In general, through-wall flashing should be used immediately under the coping of garden walls. However, this decision depends on several factors, including the type of coping used, the number of joints used, and the climatic conditions of the area (whether there is high or low precipitation and the number of freeze/thaw cycles).



STONE



BRICK (NO DRIP SHOWN)

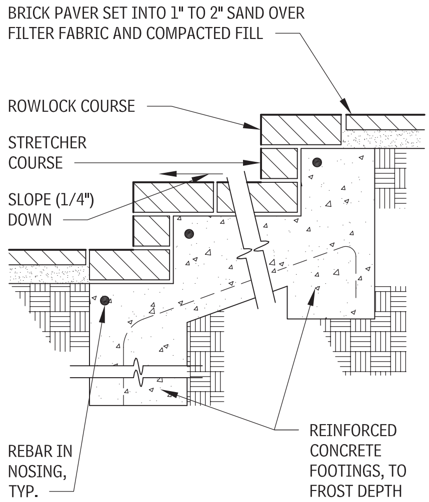
REQUIRED EMBEDMENT FOR PIER FOUNDATION*
16.78

WALL SPAN (FT)	WIND LOAD (10 PSF)			WIND LOAD (15 PSF)			WIND LOAD (20 PSF)		
	WALL HEIGHT (FT)								
	4	6	8	4	6	8	4	6	8
8	2′-0″	2′-3″	2′-9″	2′-3″	2′-6″	3′-0″	2′-3″	2′-9″	3′-0″
10	2′-0″	2′-6″	2′-9″	2′-3″	2′-9″	3′-3″	2′-6″	3′-0″	3′-3″
12	2′-3″	2′-6″	3′-0″	2′-3″	3′-0″	3′-3″	2′-6″	3′-3″	3′-6″
14	2′-3″	2′-9″	3′-0″	2′-6″	3′-0″	3′-3″	2′-9″	3′-3″	3′-9″
16	2′-3″	2′-9″	3′-0″	2′-6″	3′-3″	3′-6″	2′-9″	3′-3″	4′-0″

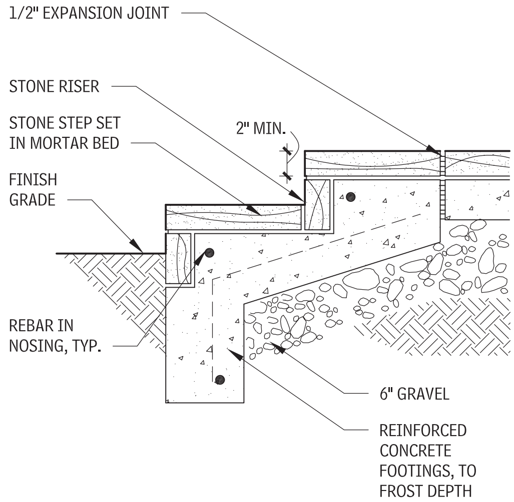
NOTES

16.76 a. Design straight garden walls (without piers) with sufficient thickness to provide lateral stability.
b. To resist 10 psf wind pressure, the height above grade (H) and thickness (T) should relate as follows: $H \leq .75T^2$ (H and T are in inches).
16.78 *For wall sizes shown within shading, a 24-in. diameter foundation is required. All other values have been obtained using an 18-in. diameter foundation. To figure the vertical spacing and size of reinforcing steel required for panel walls, consider the probable wind load and the wall span between piers. Consult a structural engineer for assistance.

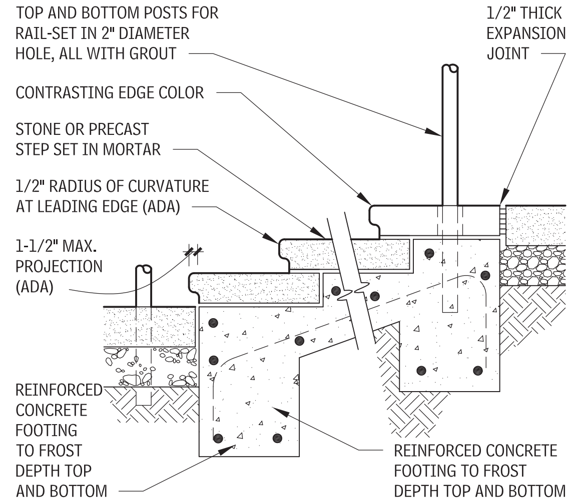
MASONRY SITE STEPS
16.79



BRICK

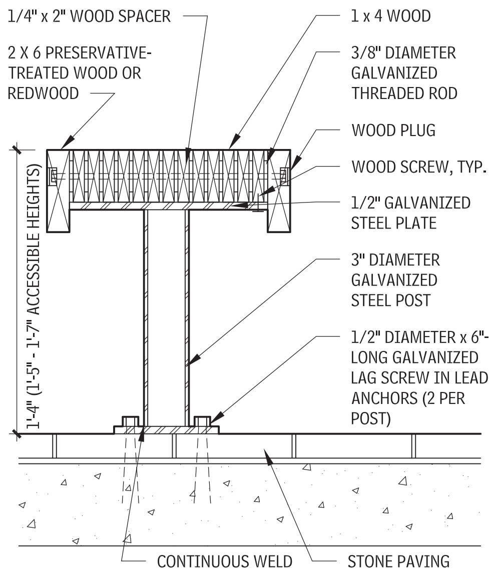


STONE

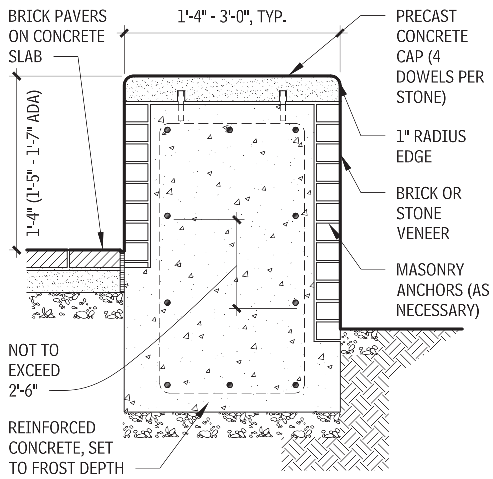


CAST STONE

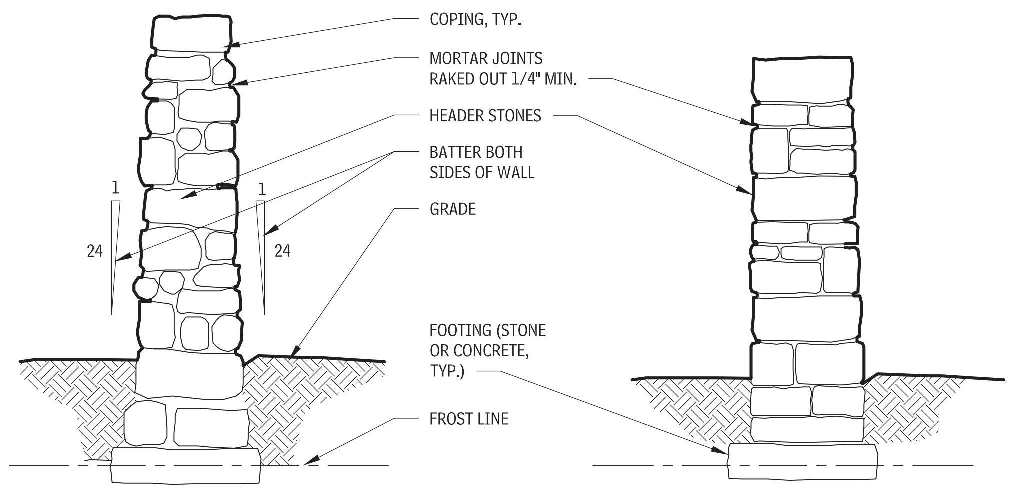
SITE SEATING
16.80



BRICK VENEER SEAT WALL
16.81



MORTARED STONE WALLS
16.82



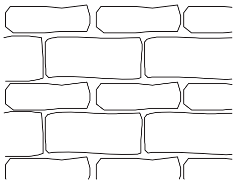
NATURAL FIELDSTONE (UNCOURSED) **ASHLAR (COURSED)**

NOTES

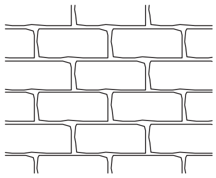
16.81 a. Provide handrails on both sides of all stairs along accessible routes.
b. Slope step surfaces so water will not accumulate on the walking surface.
c. These details are for reference only. Consult the applicable codes and accessibility requirements.

Contributor:
Dennis Carmichael, FASLA, EDAW, Inc., Alexandria, Virginia.

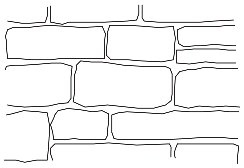
ASHLAR STONE WALL PATTERNS
16.83



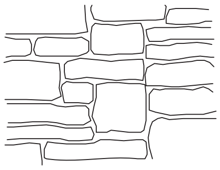
COURSED WITH
IRREGULAR COURSES



COURSED WITH
REGULAR COURSES

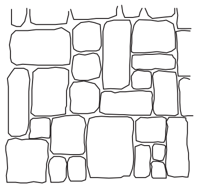


COURSED WITH
BROKEN COURSES

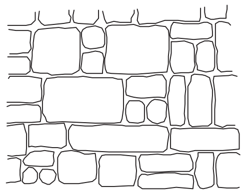


RANDOM–COURSED
RANDOM BOND

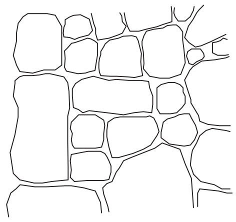
RANDOM RUBBLESTONE WALL PATTERNS
16.84



UNCOURSED WITH
ROUGHLY SQUARED
RUBBLE



COURSED WITH ROUGHLY
SQUARED RUBBLE



UNCOURSED WITH
ROUGH RUBBLE

LANDSCAPING

URBAN TREE ROOTING

As a rule of thumb, a tree's rooting zone must be at least 24 in. deep and at least as large in area as the tree's canopy at maturity. In densely built-up urban areas, porous pavements with base courses of "structural soil" make long-lived trees viable. The porous surface course admits air and water. The rooting zone is the pavement's base course, made of single-sized aggregate that bears the pavement's load. Into the aggregate's void space is mixed no more than 15 to 20 percent, by volume, of nutrient- and water-holding soil; the remaining unfilled void space provides aeration, drainage, and rooting space. A hydrogel can be used to hold the soil onto the aggregate particles during mixing. Aggregate made of expanded shale, clay, or slate (ESCS) provides additional water-holding capacity; some ESCS aggregates also provide nutrient-holding capacity. Drainage at the base of the rooting layer is mandatory.

IRRIGATION

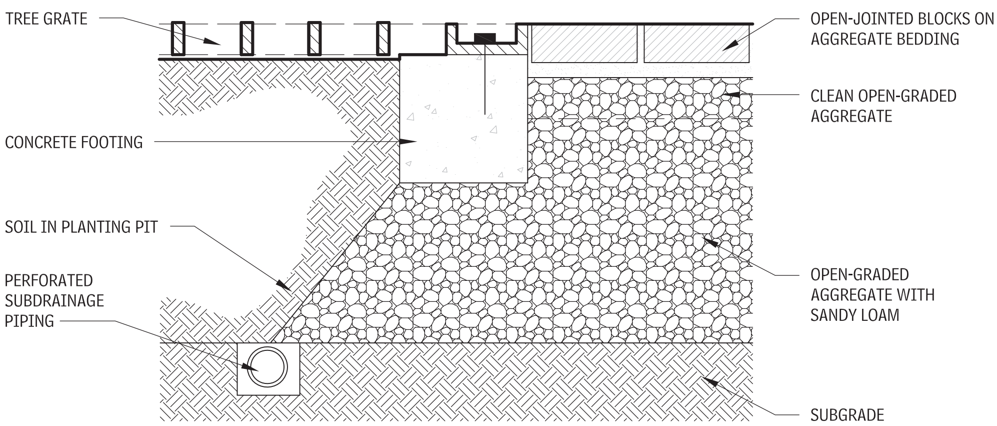
Irrigation system design considerations include the water supply, site conditions, climate, and plant material selection. The available volume of the water supply is measured in gallons per minute (gpm). The available pressure of the water supply is measured in pounds per square inch (psi). Water supply can be from a public or private utility system, or can be pumped from a well or pond. Selection of irrigation equipment and sizing of distribution piping is based on available volume and pressure of the water supply.

Site conditions that must be considered are topography, drainage, soil type, and solar exposure. Important climatic conditions include predominant wind direction, annual rainfall, and temperature variations. When irrigation systems are subject to freezing temperatures, precaution against damage to the system components from freezing must be built into the design.

Planting materials have different requirements for water. In fact, variations of turf grass may have vastly different watering needs. Plant water requirements include water lost by evaporation into the atmosphere from the soil and soil surface, and by transpiration, which is the water actually used by the plan. The combination of these is called *evapotranspiration* (E.T.).

Because turf grass has the highest rate of E.T. of any planting materials in the landscape, and because the E.T. of turf varies depending on the seasons, irrigation systems are designed to replace water lost at the highest level of E.T. for the turf grass in the landscape.

STRUCTURAL-SOIL BASE COURSE FOR TREE ROOTING
16.85



Contributor:
Bruce K. Ferguson, FASLA, University of Georgia, Athens, Georgia.

IRRIGATION SYSTEM COMPONENTS

There are a number of common irrigation system components, among them:

- *Backflow preventer*: Prevents water from the irrigation system from backflowing into the potable water supply.
- *Controller*: Acts as a timer that maintains status of the day of the week and time of the day in order to activate electric control valves at a specific day, time of day, and duration.
- *Main line*: The primary pipe supply line that distributes water from the point of connection of the source of supply to the electric control valves. Main line piping of sizes 2-1/2 in. in diameter and larger are typically class 200 PVC. Piping of sizes 2 in. and smaller are typically schedule 40 PVC.
- *Electric control valve*: Low-voltage solenoid-actuated valves that control the flow of water from the main line into the lateral line piping. Electric control valves are activated by the controller. Signals are sent from the controller to the valves through direct burial wires.
- *Lateral line piping*: The pipe supply line that distributes water from an electric control valve to a sprinkler head or a drip emitter. Depending on the application, lateral line piping can be schedule 40 PVC, class 200 PVC, or class 160 PVC. Lateral line piping for drip irrigation is typically polyethylene tube.
- *Sprinkler head*: A water distribution device attached to the lateral line piping. Rotary and impact sprinkler heads are used to irrigate large areas and can be spaced from 20 to 80 ft o.c. Pop-up spray sprinkler heads are used to irrigate smaller areas and can be spaced from 5 to 20 ft o.c. Sprinkler heads are used to irrigate turf grass or broad areas of low-growing shrubs or ground covers. For optimum efficiency, sprinkler heads are spaced to provide overlapping head-to-head coverage.
- *Bubbler head*: A water-distribution device used to irrigate shrubs and ground covers by placing water immediately adjacent to the plant, or by flooding a planting bed.
- *Drip emitter*: A water distribution device that distributes water very slowly, in increments measured in gallons per hour. Drip emitters are used to water individual plants.

WATER CONSERVATION

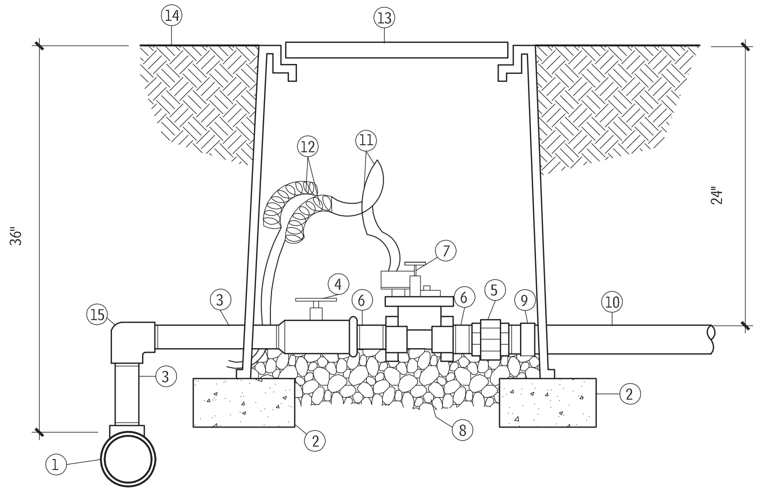
The following water conservation efforts can earn LEED credits:

LEED WE Credit 1.1: Use water-efficient landscaping and reduce potable water use by 50 percent. This credit can be achieved by using native plant materials requiring less water and by properly designing an efficient irrigation system. Using alternative turf species and reducing the amount of turf in the landscape will help to reduce irrigation demand. Alternative water sources such as treated sewage effluent will reduce the demand for potable water.

LEED WE Credit 1.2: Use water-efficient landscaping and eliminate potable water use. Use water captured on-site, graywater for irrigation, or treated effluent, or eliminate the installation of an irrigation system completely. Innovative technologies should be employed for a more efficient irrigation system. Technologies include:

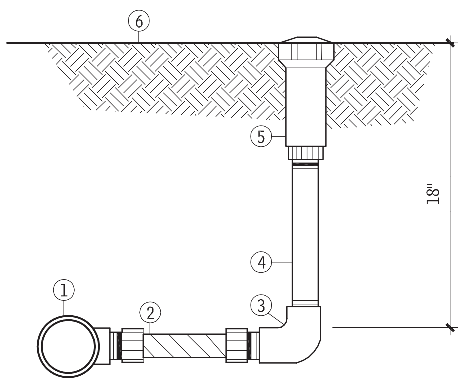
- Drip irrigation
- Evapotranspiration (E.T.)-based controllers
- Rain and wind shutoff devices
- Soil moisture sensors that shut off the irrigation system when the soil moisture is adequate for the landscape
- Centralized irrigation system control
- Weather stations used to estimate evapotranspiration on a daily or short-term basis

AUTOMATIC VALVE ASSEMBLY
16.86



1. MAINLINE SERVICE TEE
2. SOLID CMU BLOCK (FOUR)
3. SCH 80 PVC NIPPLE, LENGTH AS REQUIRED
4. SCH 80 PVC BALL VALVE WITH UNIONS
5. SCH 80 PVC UNION
6. SCH 80 PVC NIPPLE, 3" LENGTH
7. AUTOMATIC VALVE
8. 1" ROUND GRAVEL, 3 CU FT
9. SCH. 40 PVC BALL ADAPTER
10. LATERAL PIPING
11. WATERPROOF WIRE CONNECTOR
12. 36" WIRE EXPANSION LOOPS
13. BODY VALVE BOX WITH BOLT-DOWN COVER AND 8" EXTENSIONS, AS REQUIRED
14. FINISH GRADE
15. SCH 80 PVC THREADED ELL

POP-UP SPRAY ASSEMBLY
16.87



1. PVC LATERAL PIPE FITTING
2. 1/2" x 6" FLEX NIPPLE
3. 1/2" SCH 40 PVC THREADED ELBOW
4. 1/2" SCH 80 PVC THREADED NIPPLE, LENGTH AS REQUIRED
5. POP-UP SPRINKLER
6. TOP OF MULCH OR TOP OF SOD BED

Irrigation system management is also critical to reducing water waste. Proper system design is essential, including designing for correct pressure, elevation changes, varying plant material and microclimates. The design should employ appropriate equipment. Proper system maintenance includes fixing broken sprinklers and drip laterals and adjusting sprinklers to minimize overspray on to hard surfaces. Maintenance also includes adjusting the controller for the season and the weather conditions. This can be accomplished using an on-site weather station or with the use of public local weather station data or E.T. information. Features on the controllers include water budget capabilities; E.T. controllers based on historic patterns, including temperature and rain; and E.T. controllers based on real-time data.

To minimize water waste, the manager must adjust the controller to fine-tune station operating times to match conditions for each irrigation lateral; employ repeat cycles, depending on soil conditions; adjust lateral operating pressures; make changes to the irrigation system as plant material matures; and irrigate at night when evaporation is lowest.

TREES, PLANTS, AND GROUND COVERS

The physical environment of the site, the design needs of the project, and the design character of the trees are all factors that must be considered in selecting trees and preparing a landscape plan for a building.

Soil conditions (acidity, porosity) at the site, the amount and intensity of sunlight and precipitation, and the seasonal temperature range in the area create the physical environment in which trees must be able to survive. In addition, it is essential to consider how the location and topography of the site will direct the wind, resulting in cold winds and cooling breezes that can affect the health of trees.

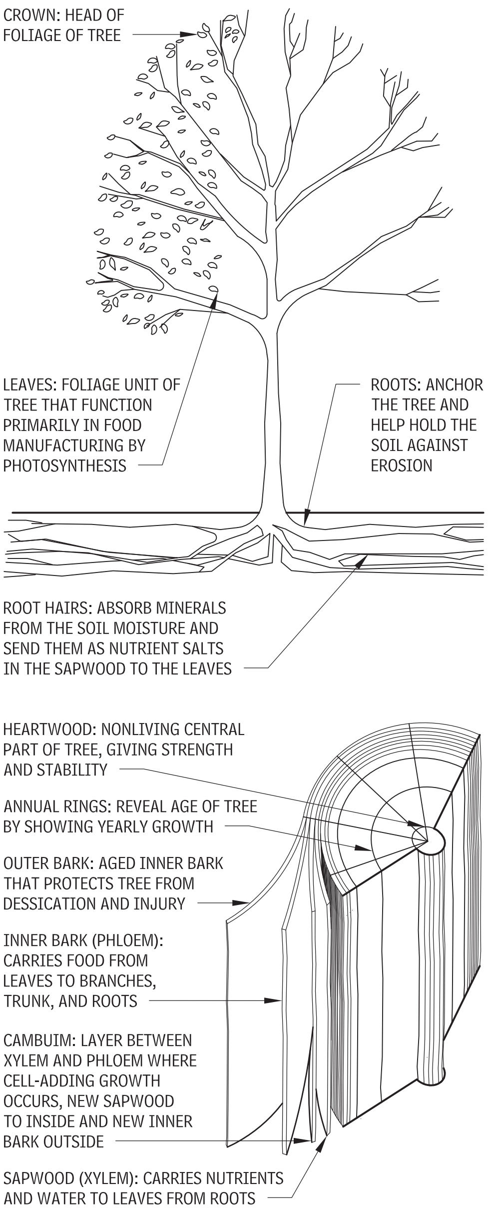
NOTE

16.86 The contractor must install one automatic valve assembly per valve box.

Trees can be used to address the design needs of a project by directing pedestrian or vehicle movement, framing vistas, screening objectionable views, and defining and shaping exterior space. Trees can also be used to modify the microclimate of a site and to help conserve building energy use from heating, cooling, and lighting systems.

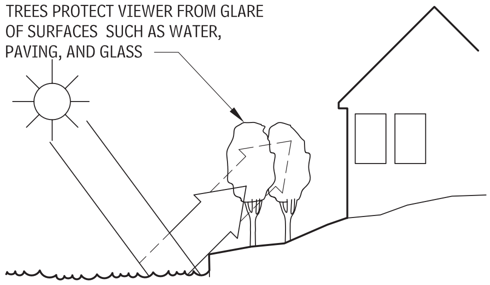
The design character of the trees themselves plays a part in which species are best suited for a particular application. The shape of a tree can be columnar, conical, spherical, or spreading, and the resulting height and mass will change over time as the tree matures. Some trees grow quickly, and others more slowly, and their color and texture varies from coarse to medium to fine, affecting their character. The appearance of deciduous trees changes with the seasons, while the effect of an evergreen remains relatively constant.

PHYSICAL CHARACTERISTICS OF TREES
16.88



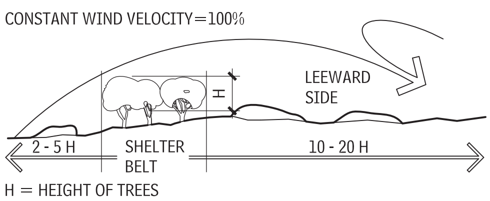
GLARE PROTECTION
16.89

The vertical angle of the sun changes seasonally; therefore, the area of a building subject to the glare of reflected sunlight varies. Plants of various heights can screen sun (and artificial light) glare from adjacent surfaces.



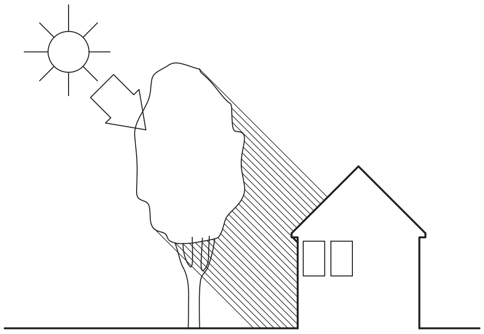
WIND PROTECTION
16.90

Shelter belt wind protection reduces evaporation at ground level, increases relative humidity, lowers the temperature in summer and reduces heat loss in winter, and reduces blowing dust and drifting snow. The amount of protection afforded is directly related to the height and density of the shelter belt.



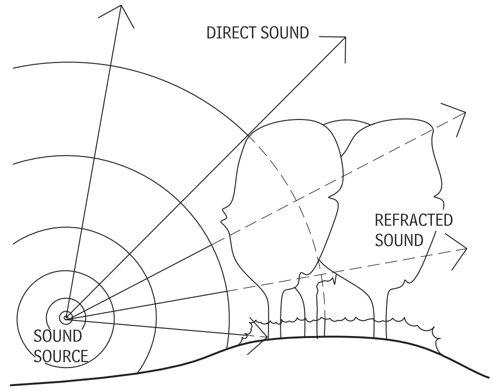
SHADE PROVISION
16.91

In summer, trees obstruct or filter the strong radiation from the sun, cooling and protecting the area beneath them. In winter, evergreen trees still have this effect, whereas deciduous trees, having lost their leaves, do not.



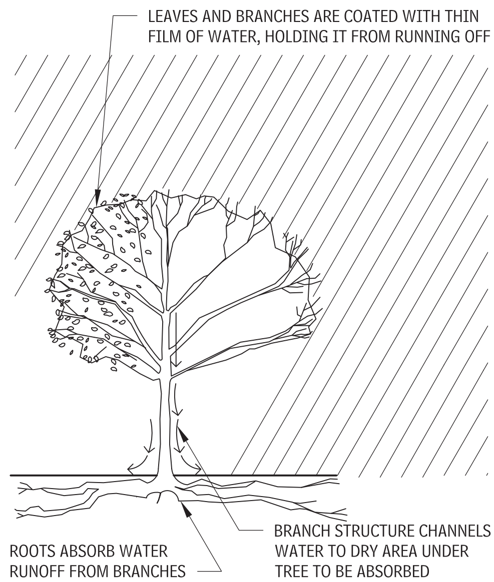
SOUND ATTENUATION
16.92

A combination of deciduous and evergreen trees and shrubs reduces sound more effectively than deciduous plants alone. Planting trees and shrubs on earth mounds increases the attenuating effects of a buffer belt.



RUNOFF REDUCTION
16.93

Mature trees absorb or delay runoff from stormwater at a rate four to five times that of bare ground.



Contributor:
James Urban, ASLA, James Urban Landscape Architecture, Annapolis, Maryland.

PLANTING DETAILS

Planting details for trees and shrubs, tips on soil improvement, and general design considerations are the topics addressed in this section.

TREE PLANTING DETAILS

These three guidelines will aid in the successful planting of trees:

- For container-grown trees, use fingers or small hand tools to pull the roots out of the outer layer of potting soil; then cut or pull apart any roots circling the perimeter of the container. Incorporate commercially prepared mycorrhiza spores in the soil immediately around the root ball at rates specified by the manufacturer.
- During the design phase, confirm that water drains out of the soil; design alternative drainage systems as required.
- Thoroughly soak the tree root ball and adjacent prepared soil several times during the first month after planting, and regularly throughout the following two summers.

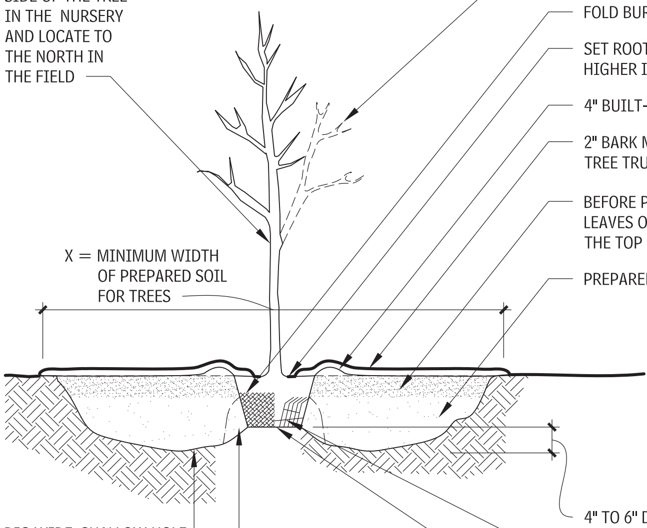
Note that the planting process is similar for deciduous and evergreen trees.

SHRUB PLANTING DETAILS

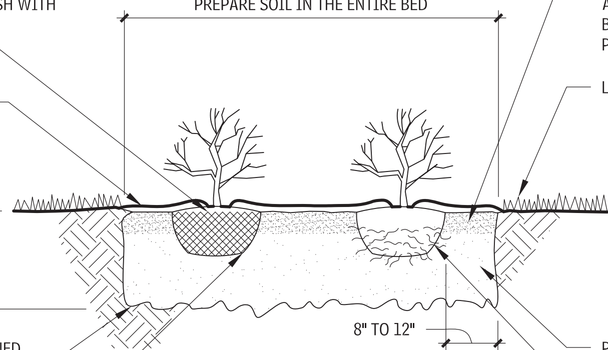
For successful shrub planting, follow these guidelines:

- For container-grown shrubs, use fingers or small hand tools to pull the roots out of the outer layer of potting soil; then cut or pull apart any roots that circle the perimeter of the container. Incorporate commercially prepared mycorrhiza spores in the soil immediately around the root ball at rates specified by the manufacturer.
- Confirm that water drains out of the soil during the design phase; design alternative drainage systems as required.

TREE PLANTING DETAIL (BALLED AND BURLAPPED PLANTS)
16.94



SHRUB PLANTING DETAILS
16.95



GENERAL RANGE OF SOIL MODIFICATIONS AND VOLUMES FOR VARIOUS SOIL CONDITIONS
16.96

POSTCONSTRUCTION SOIL CONDITION	MINIMUM WIDTH PREPARED SOIL FOR TREES (X)	TYPE OF PREPARATION
Good soil (not previously graded or compacted; topsoil layer intact)	6′ or twice the width of the root ball, whichever is greater	Loosen the existing soils to the widths and depths shown in Figures 16.94 and 16.95.
Compacted soil (not previously graded; topsoil layer disturbed but not eliminated)	15′	Loosen the existing soils to the widths and depths shown in Figures 16.94 and 16.95; add composted organic matter to bring the organic content up to 5% dry weight.
Graded subsoils and clean fills with clay content between 5% and 35%	20′	Minimum treatment: Loosen existing soil to widths and depths shown in Figures 16.94 and 16.95; add composted organic matter to bring organic content up to 5% dry weight.
		Optimum treatment: remove top 8–10" or the existing material, loosen existing soils to the widths and depths shown in Figures 16.94 and 16.95; add 8"–10" of loam topsoil.
Poor-quality fills, heavy clay soils, soils contaminated with rubble or toxic material	20′	Remove existing soils to the widths and depths shown in Figures 16.94 and 16.95; replace with loam topsoil.

SOIL IMPROVEMENT

The quality of soil available for planting varies widely from site to site, especially after construction activity has occurred. The nature of construction results in compaction, filling, contamination, and grading of the original soil on a site, rapidly making it useless for planting. Previous human activity at a site can also affect the ability of the soil to support plants.

During the design phase, assumptions must be made regarding the probable condition of the soil after construction is complete. The health of existing or remaining soil determines what types of soil preparation will be required and the volume of soil to be prepared. Conditions will vary from location to location within a project, and details must be condition-specific. For large projects or extreme conditions, it is useful to consult an expert experienced in modifying planting soils at urban sites.

To ensure good soil health at a project site, follow these guidelines:

- Whenever possible, connect the soil improvement area from tree to tree.
- Always test soil for pH and nutrient levels, and adjust these as required.
- Loosen soil with a backhoe or other large coarse-tilling equipment, when possible. Tilling that produces large, coarse chunks of soil is preferable to tilling that results in fine grains uniform in texture.
- Make sure that the bottom of planting soil excavations is rough, to avoid matting of soil layers as new soil is added. It is preferable to till the first lift (2 to 3 in.) of planting soil into the subsoil.

STANDARD ROOT BALL SIZES FOR NURSERY-GROWN SHADE TREES
16.97

CALIPER[a] (IN.)	HEIGHT RANGE (FT-IN.)	MAXIMUM HEIGHT (FT)	MINIMUM BALL DIAMETER (IN.)	MINIMUM BALL DEPTH (IN.)
1/2	5–6	8	12	9
3/4	6–8	10	14	10-1/2
1	8–10	11	16	12
1-1/4	8–10	12	18	13-1/2
1-1/2	10–12	14	20	13-1/2
1-3/4	10–12	14	22	14-1/2
2	12–14	16	24	16
2-1/2	12–14	16	28	18-1/2
3	14–16	18	32	19-1/2
3-1/2	14–16	18	38	23
4	16–18	22	42	25
5	18–20	26	54	32-1/2

TREE PLANTING IN URBAN AREAS

Traditional urban designs in which trees are regularly spaced in small openings within paved areas generally result in poor tree performance because such designs generally do not provide adequate soil for root growth, and ignore the fact that trees must significantly increase trunk size every year. Moreover, competition for space, both at ground level and below, is intense in urban areas.

Although it is possible to design uncompacted soil volumes for trees under pavement, this is very expensive and the soil is never as efficient as that in open planting beds. Increasing trunk size can only be accommodated by using flexible materials that can change configuration over time. Urban designs that have flexible relationships between trees, paving, and planting beds and large areas of open planting soil offer the best opportunity for long-term tree health and lower maintenance costs.

Areas of dense urban development leave little room for tree roots to develop. Large areas of pavement, competition with foundations and utilities for space belowground, and extensive soil compaction and disruption limit the amount of soil available for trees. When the area of ground around the tree is open to the rain and sun is less than 400 to 500 sq ft per tree, the following design guidelines should be followed to encourage the growth of large healthy trees.

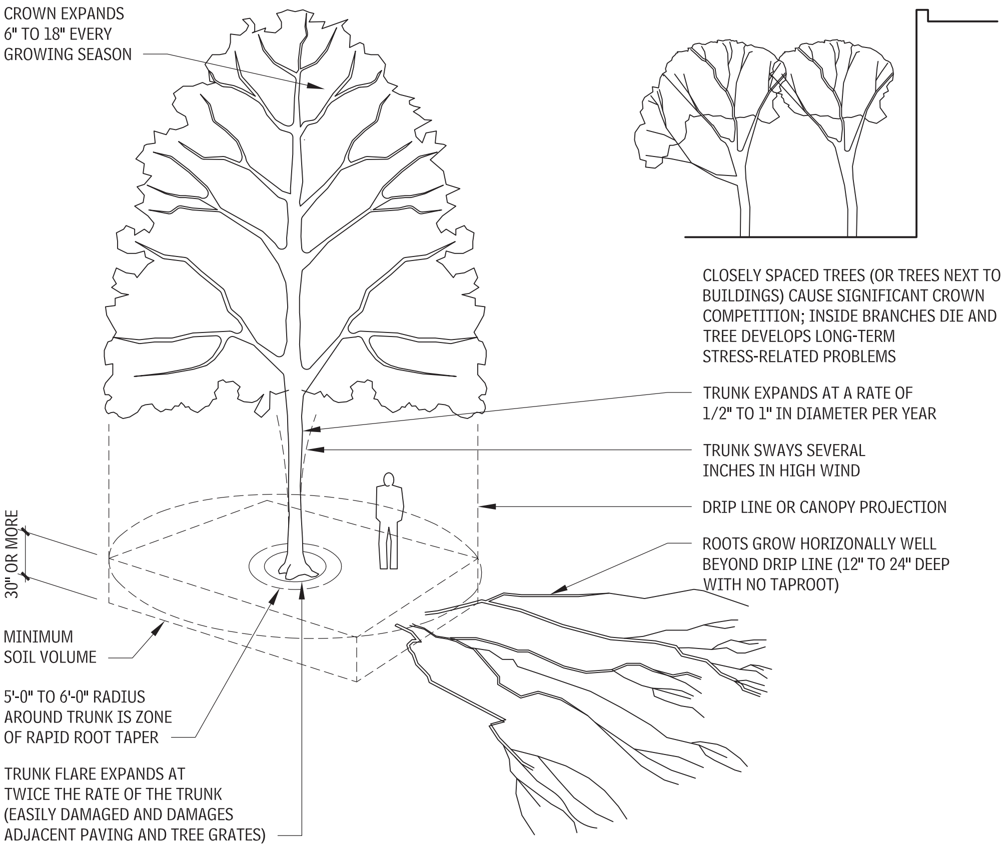
Five major parts of the tree structure must be accommodated in the design process:

- *Crown growth*: The tree crown expands every growing season at a rate of 6 to 18 in. per year. Once the crown reaches a competing object such as a building or another tree canopy, the canopy growth in that area slows and then stops. Eventually the branches on that side of the tree die. As the canopy expansion potential is reduced, the overall growth rate and tree health are also reduced.
- *Trunk growth*: The tree trunk expands about 1/2 to 1 in. per year. As the tree increases in size, the lower branches die and the trunk lengthens. Tree trunks move considerably in the wind, especially during the early years of development, and are damaged by close objects.
- *Trunk flare*: At the point at which the trunk leaves the ground, most tree species develop a pronounced swelling or flare as the tree matures. This flare grows at more than twice the rate of the main trunk diameter and helps the tree remain structurally stable. Any hard object placed in this area, such as a tree grate or confining pavement, will either damage the tree or be moved by the tremendous force of this growth.
- *Zone of rapid root taper*: Tree roots begin to form in the trunk flare and divide several times in the immediate area around the trunk. In this area, about 5 to 6 ft away from the trunk, the roots rapidly taper from about 6 in. in diameter to about 2 in. Most damage to adjacent paving occurs in this area immediately around the tree. Keeping the zone of rapid taper free of obstructions is important to long-term tree health. Once a tree is established, the zone of rapid taper is generally less susceptible to compaction damage than the rest of the root zone.
- *Root zone*: Tree roots grow radially and horizontally from the trunk and occupy only the upper layers (12 to 24 in.) of the soil. Trees in all but the most well-drained soils do not have taproots. A relationship exists between the amount of tree canopy and the volume of root-supporting soil required (see Figure 16.98). This relationship is the most critical factor in determining long-term tree health. Root-supporting soil is generally defined as soil with adequate drainage, low compaction, and sufficient organic and nutrient components to support the tree. The root zone must be protected from compaction both during and after construction. Root zones that are connected from tree to tree generally produce healthier trees than isolated root zones.

NOTE

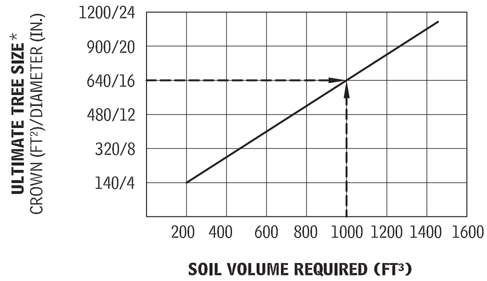
16.97 [a]Up to and including the 4-in. caliper size, the caliper measurement indicates the diameter of the trunk 6 in. above ground level. For larger sizes, the caliper measurement is taken 12 in. above ground level.

TREE STRUCTURE—PARTS AND GROWING CHARACTERISTICS
16.98



SOIL VOLUME FOR TREES
16.99

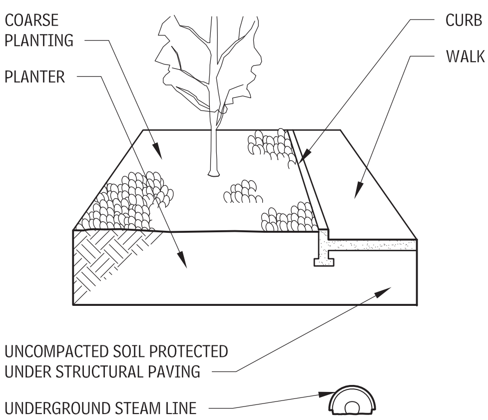
The ultimate tree size is defined by the projected size of the crown and the diameter of the tree at breast height. For example, a 16-in. diameter tree requires 1000 cu ft of soil.



*THE ULTIMATE TREE SIZE IS DEFINED BY THE PROJECTED SIZE OF THE CROWN AND THE DIAMETER OF THE TREE AT BREAST HEIGHT

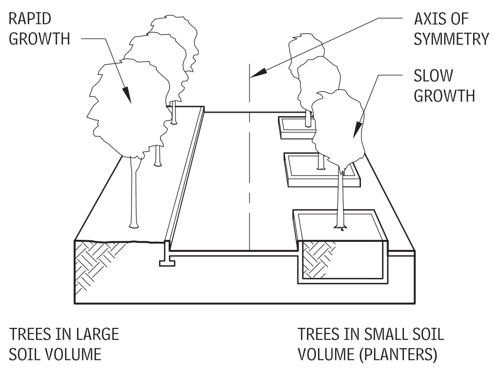
SOIL PROTECTION FROM COMPACTION AND DEGRADATION
16.100

Coarse plantings keep pedestrians out of planters. Curbs protect planters from pedestrians and deicing salts. Underground steam lines must be insulated or vented to protect planter soil.



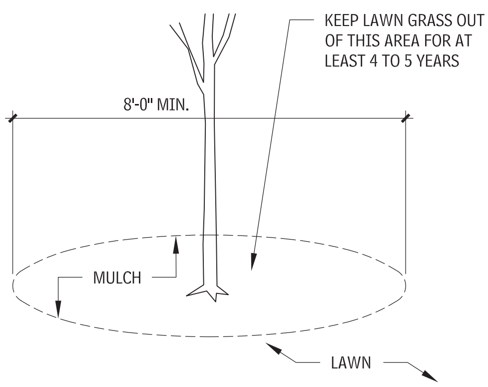
VISUALLY SYMMETRICAL TREES
16.101

If visually symmetrical tree planting is required, symmetrical soil volumes are also required to produce trees of similar crown size.



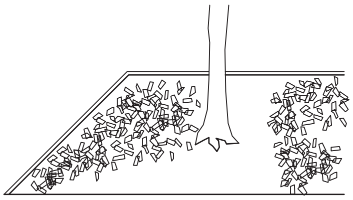
TREES PLANTED IN LAWNS
16.102

Young trees planted in lawn areas face substantial competition from the roots of grasses.

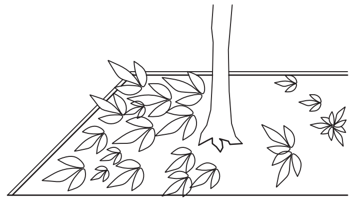


TREE BASE PROTECTION
16.103

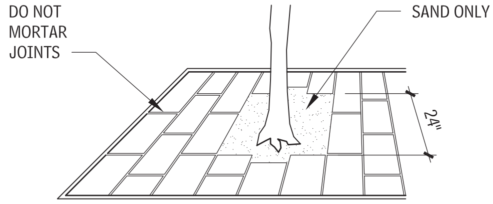
Alternatives to tree grates (and guards) include softer, organic coverings that suit the purpose better, are less expensive, and require less maintenance over the life of the tree.



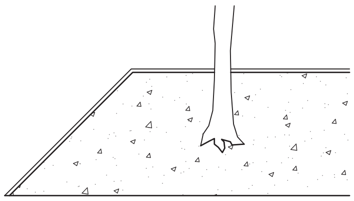
BARK MULCH



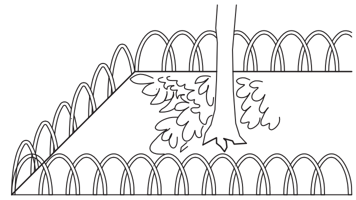
GROUND COVER PLANTS



SAND-SET PAVERS



STONE DUST OR GRAVEL



LOW FENCE AND GROUND COVER

SELECTING PLANTS FOR ROOFTOP PLANTING

When choosing plants for a rooftop setting, consider the factors outlined here:

- *Wind tolerance*: Higher elevations and exposure to wind can cause defoliation and increase the transpiration rate of plants. High parapet walls with louvers can reduce wind velocity and provide shelter for plants.
- *High evaporation rate*: The drying effects of wind and sun on the soil in a planter reduce soil moisture rapidly. Irrigation, mulches, and moisture-holding soil additives (diatomaceous earth or organic matter) help reduce this moisture loss.
- *Rapid soil temperature fluctuation*: The variation in conduction capacity of planter materials results in a broad range of soil temperatures in planters of different materials. Cold or heat can cause severe root damage in certain plant species. Proper drainage helps alleviate this condition.
- *Topsoil*: Improve topsoil in planters to provide optimum growing conditions for the plants selected. A general formula calls for adding fertilizer (determined by soil testing) and one part peat moss to five parts sandy loam topsoil. More specific requirements for certain varieties of plants or grasses should be considered.
- *Root capacity*: Choose plant species carefully, considering their adaptation to the size of the plant bed. If species with shallow, fibrous roots are used instead of species with a coarse root system, consult with a nursery advisor. Consider the ultimate maturity of the plant species when sizing a planter.

ROOFTOP PLANTING DETAILS

There are five factors when designing rooftop plantings:

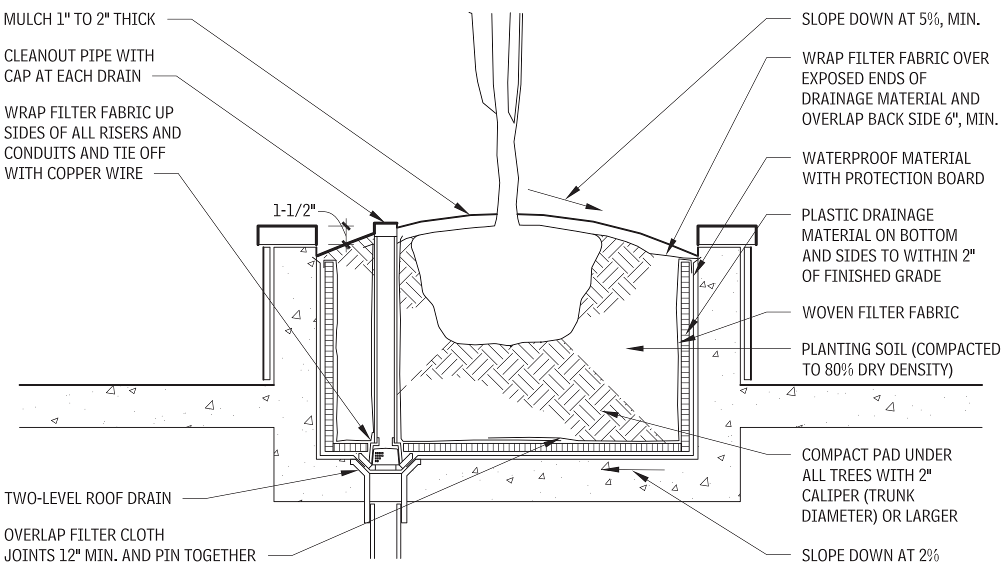
- *Soil depth*: Minimum soil depth in a planter varies with the plant type: for large trees, the soil should be 36 in. deep or 6 in. deeper than the root ball; for small trees, 30 in. deep; for shrubs, 24 in. deep; and for lawns, 12 in. deep (10 in. if irrigated).
- *Soil volume*: To determine sufficient soil volume, refer to the chart included in Figure 16.99, "Soil Volume for Trees."
- *Soil weight*: The saturated weight of normal soil mix ranges from 100 to 120 pcf, depending on soil type and compaction rate. Soils can be made lighter by adding expanded shale or perlite. Soils lighter than 80 pcf cannot provide structure adequate to support trees.
- *Drainage fabric*: Plastic drainage material should be a minimum of 1/2 in. thick. Most drainage material comes with a filter fabric attached, but the overlap joints provided are not wide enough for the unconsolidated soils found in planters. A second layer of woven filter fabric, delivered in rolls greater than 10 ft in width, should be installed. Tuck the fabric over the exposed top of the drainage material to keep soil out of the drainage layer.
- *Insulation*: Most planters do not require insulation; however, in colder climates planters with small soil volumes located over heated structures may require insulation. Consult local sources for a list of cold-hardy plants.

GRAYWATER WASTEWATER MANAGEMENT

GRAYWATER HARVEST AND TREATMENT

Structures individually or in aggregate, involving human presence and use, are watersheds. They take in water and release water. They differ from natural watersheds in that human structures take in potable water and release wastewater. With rising cost and scarcity of potable water, the sewer solution is really no solution. The cleansing of the sewer water to an acceptable standard for further disposition in waterways and oceans has become prohibitively expensive, if done properly, and an ecological disaster, if not. The subject here then is wastewater management—graywater harvest and treatment.

ROOFTOP PLANTER
16.104



Contributor:
James Urban, ASLA, James Urban Landscape Architecture, Annapolis, Maryland.

What is graywater? It is what we create from potable water when we wash ourselves, our clothing, our dishes, and our foods. The sources of graywater in an urban watershed are kitchen sinks, dishwashers, washing machines, baths, showers, and bathroom sinks. There are caveats in the use of this graywater: The kitchen sinks may need grease traps. The washing machines may need filters. The soaps and detergents used in our watershed should be truly biodegradable. The garbage disposals may need to be abandoned. In an urban household practicing water conservation and using water-conserving appliances, three-fourths of the water produced on a daily basis is graywater. In a 200-hundred-gallon-a-day household, 150 gallons of graywater awaits reuse.

The water must be collected and treated to a level consistent with its intended use. If at that point the graywater is disinfected, it can be used on-site for all purposes, except drinking and irrigating edible plants. Air conditioning and flushing toilets, as well as irrigation, are appropriate uses. Further polishing of the graywater through multiple disinfectants, such as U/V, ozone, and/or an R/O system produces potable water. If the issue is merely to dispose of the graywater, absent a specific purpose, such as watering a vegetable garden, disinfection is unnecessary.

The standard use of graywater that is not disinfected is the irrigation of plants and trees. Irrigation is accomplished by subsurface distribution of the water. How the subsurface distribution is accomplished is dependant on soil conditions, ranging from impermeable soil requiring a zero discharge system to permeable soil that will safely accept discharge without threatening groundwater or sensitive wetlands. An impermeable membrane may be required to protect groundwater. The simplest systems, where appropriate, discharge graywater directly to fruit trees and shrubs. In the zero-discharge system, the graywater may be disposed of in a designed planter growing bamboo or some other thirsty plant.

A new field of endeavor exists for the landscape architect: the design of an interior wash water garden or a private arboretum, redolent with tropical plants. How about a shower in a personal rain forest recycling shower water for a second shower?

THE VALUE OF GRAYWATER

Graywater is essentially wash water. It consists of all household wastewater, aside from toilet water (also known as blackwater). The same contents that make graywater a pollutant in some areas (streams, rivers, and groundwater) also make graywater a resource in others. Because graywater often contains nitrogen, phosphorus, and potassium (all important nutrients for plants), it is quite useful when applied to vegetation.

TREATMENT SYSTEM

A pipe system is needed to transport the graywater from its source. These pipes can be thinner than regular wastewater pipes because they do not have to transport toilet water and solid waste. To avoid grease clogs, these pipes should be installed straight, avoiding any necks and depressions, and should be held to at least a 0.5 percent gradient.

For small systems in which the graywater is to be put to use immediately, treatment is not as crucial. The graywater can be directed to a mulch bed and used for plants. However, in larger systems, where the graywater is not to be used immediately and must be stored, pretreatment is needed. Clogs and odor can result from solid matter suspended in the graywater. Additionally, graywater can contain pollutants, pathogens, heavy metals, and microorganisms. If these contents are not treated, they can break down, resulting in undesirable anaerobic conditions.

How can these materials be removed? They can be removed by gravity (similar to a septic tank), by premade filter, or by gravel filter. The method of treatment will depend on the size of the system and destination of the graywater supply.

CONTROLLED IRRIGATION

The soil ecosystem of the destination plant bed is used to convert the graywater. The amount of water released into the soil should be configured to meet the evapotranspiration rate of the plants it feeds. This rate is usually between 1 to 4 gallons per square yard per day. If too much water is applied, saturation occurs. If too little water is applied, plant growth will be inhibited by lack of resources. In either case, the plant life suffers.

SOIL FILTER SYSTEMS

Soil layers are used to filter the graywater before it reaches its destination. A soil with medium particle size should be selected. Soils too fine or too coarse will not allow the water to filter through properly. Saturation should be avoided. Some pores should be free for gas exchange.

It is also important to provide for even water distribution across the filter. If water distribution is uneven, clogs will result and the filtering process will not be as effective. A well-designed soil filter system will have high pollutant removal efficiencies (see Figure 16.105).

SOIL FILTER REMOVAL EFFICIENCIES
16.105

MATERIAL	REMOVAL EFFICIENCY %
Suspended solids and organic compounds	90–99
Pathogens	95–99.9
Phosphorus	30–95 (depends on soil properties and water load)
Nitrogen	30

TRICKLING FILTERS

Trickling filters consist of layers of porous materials with a lot of surface area. Water is dispersed over the top of the filter and percolates downward as a thin layer, treated aerobically as it passes over the surfaces of the filter materials. Via an underdrainage system, the water is then collected and solids are allowed to settle before the water is transported to its destination site. The advantage to this system is that it is reliable and can recover from wastewater excesses. Trickling filters are not as efficient as soil filters, however, and they create a sludge that must be removed.

GRAYWATER END USE

The end use of graywater can be directed to the following:

- *Discharged to surface waters*: Graywater is discharged to surface water quite easily. After treatment, the water can be released into open trenches and allowed to wash away with rainwater.
- *Groundwater*: If it is intended to be released to groundwater, graywater must be well treated with a very reliable system. After treatment, the water should seep through an unsaturated soil depth of 3 ft or more before joining groundwater. In addition, safety zones should be set around water extraction sites to avoid complications.
- *Irrigation*: When graywater is used in irrigation, it is best to apply in the ground, as opposed to being sprayed. Graywater is best suited in irrigation of cropland that supports plants whose leaves or stems are not eaten directly. Fruit and berry plants are appropriate. When using graywater in irrigation of crops that are consumed raw, it is advisable to wait at least a month after irrigation to harvest.

GRAYWATER MANAGEMENT GOALS

The preventive goals of graywater treatment are to leave nearby areas undamaged, avoid odor and stagnant water, prevent anaerobic conditions in the water, and to keep groundwater and reservoirs uncontaminated. When all these goals are met, graywater treatment yields tremendously positive results. It can be used for landscaping, plant growth, and renewed groundwater. Perhaps most importantly, water that is treated and reused allows freshwater in natural ecosystems to remain untouched.

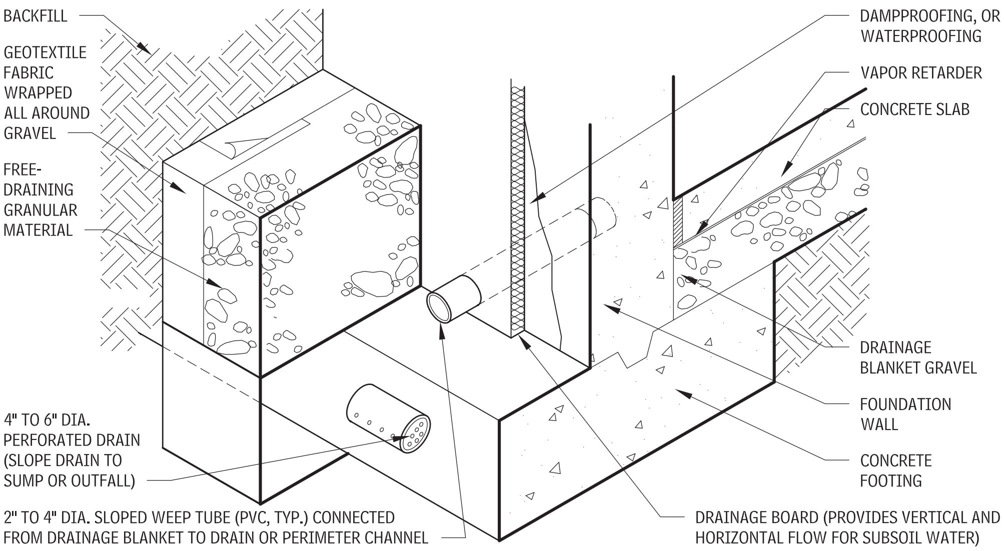
There are many laws in place regulating how graywater can be treated and what it can be reused for. These laws vary from state to state and must be reviewed and checked closely before a plan for graywater use is proposed and implemented. Despite legal barriers, many developers and scientists believe that with further testing and studies, graywater treatment systems will become more prevalent. In fact, a few companies now offer installation of contained (includes a lining), ornamental graywater gardens.

SITE CIVIL UTILITIES

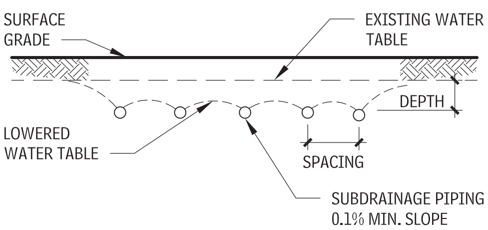
SUBSURFACE DRAINAGE SYSTEMS

Subsurface drainage systems are very different engineering designs from surface drainage systems. Surface drainage systems intercept and collect stormwater runoff and convey it away from a building and site with the use of large inlets and storm drains. Subsurface drainage systems typically are smaller in size and capacity and are designed to intercept the slower underground flows of a natural groundwater table, underground stream, or infiltration of soils from surface sources. Surface and subsurface systems typically require discharge either through a pumping station or by gravity drainage to an adequate outfall.

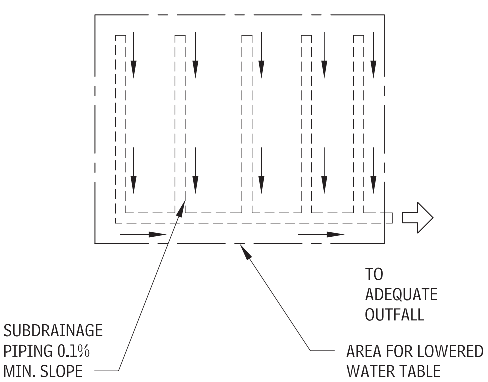
FOUNDATION DRAINAGE PIPING
16.106



SUBDRAINAGE PIPING
16.107

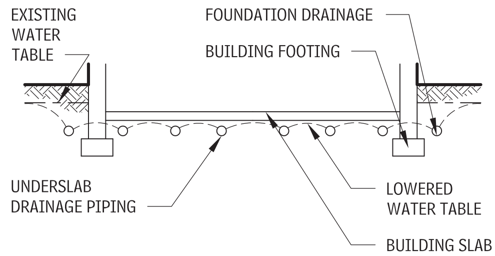


SECTION



PLAN

UNDERSLAB DRAINAGE
16.108



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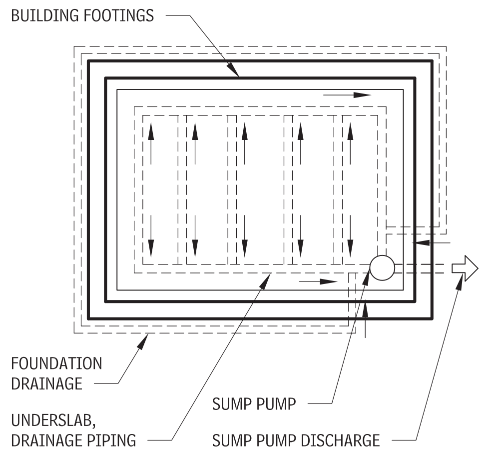
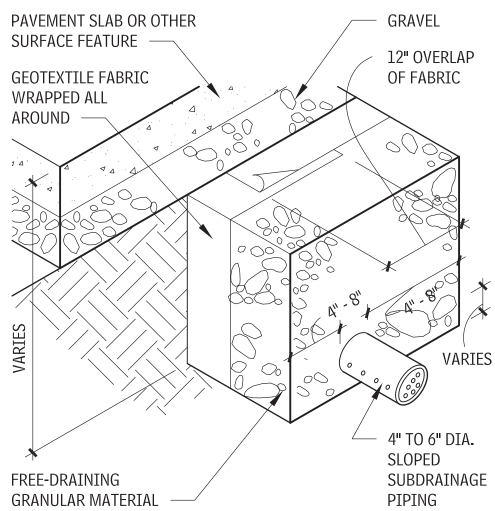


PLAN

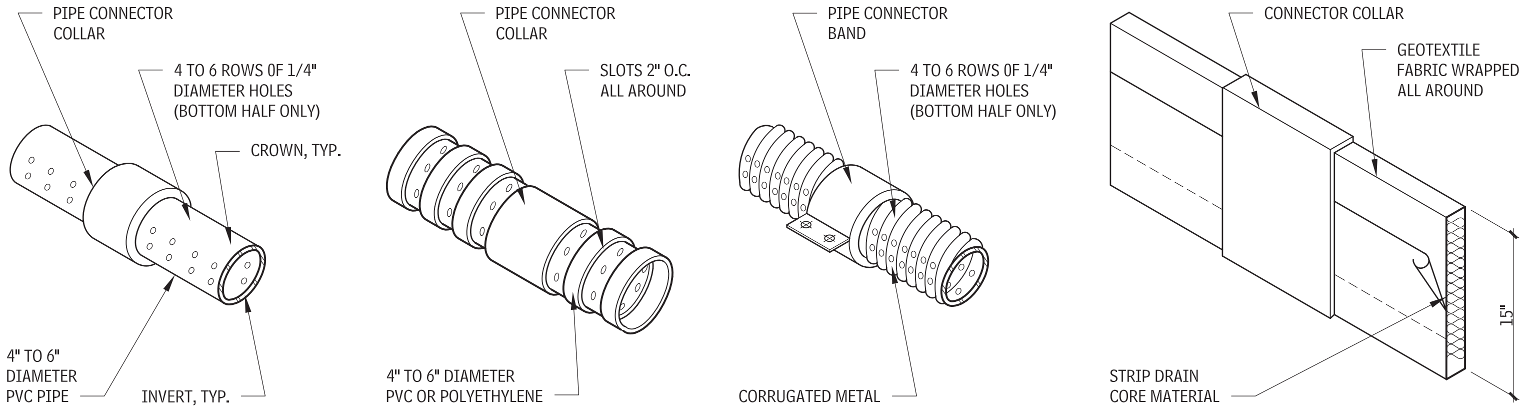
TYPICAL SUBDRAINAGE DETAIL
16.109



NOTES

16.107 a. Subdrainage is laid out to meet the needs of a site. A grid, parallel line, or random pattern at low points in the topography is used to collect subsurface water.
b. Depth and spacing of subsoil drainage pipes depend on soil conditions. Geotechnical design may be required to ensure effective operation of a subsoil drainage system.
16.109. The depth of subdrainage piping determines by how much subsurface water levels will be reduced.
b. When a perforated drainpipe is used, install it with the holes facing down.
c. When used to intercept hillside seepage, the bottom of a trench should be cut a minimum of 6 in. into underlying impervious material.

TYPICAL SUBDRAINAGE PIPING
16.110



TYPE A **TYPE B** **TYPE C** **TYPE D**

STORM DRAINAGE UTILITES

Storm drainage utilities are designed to collect and dispose of rainfall runoff to prevent the flow of water from damaging building structures (through foundation leakage), site structures, and the surface grade (through erosion). The two basic types of surface drainage are the open system and the closed system.

- The open system, which utilizes a ditch/swale and culvert, is used in less densely populated, more open areas where the flow of water above grade can be accommodated fairly easily.
- The closed system, which utilizes pipes, an inlet/catch basin, and manholes, is used in more urban, populated areas, where land must be used efficiently and water brought below the surface quickly to avoid interference with human activity.

The two systems are commonly combined where terrain, human density, and land uses dictate.

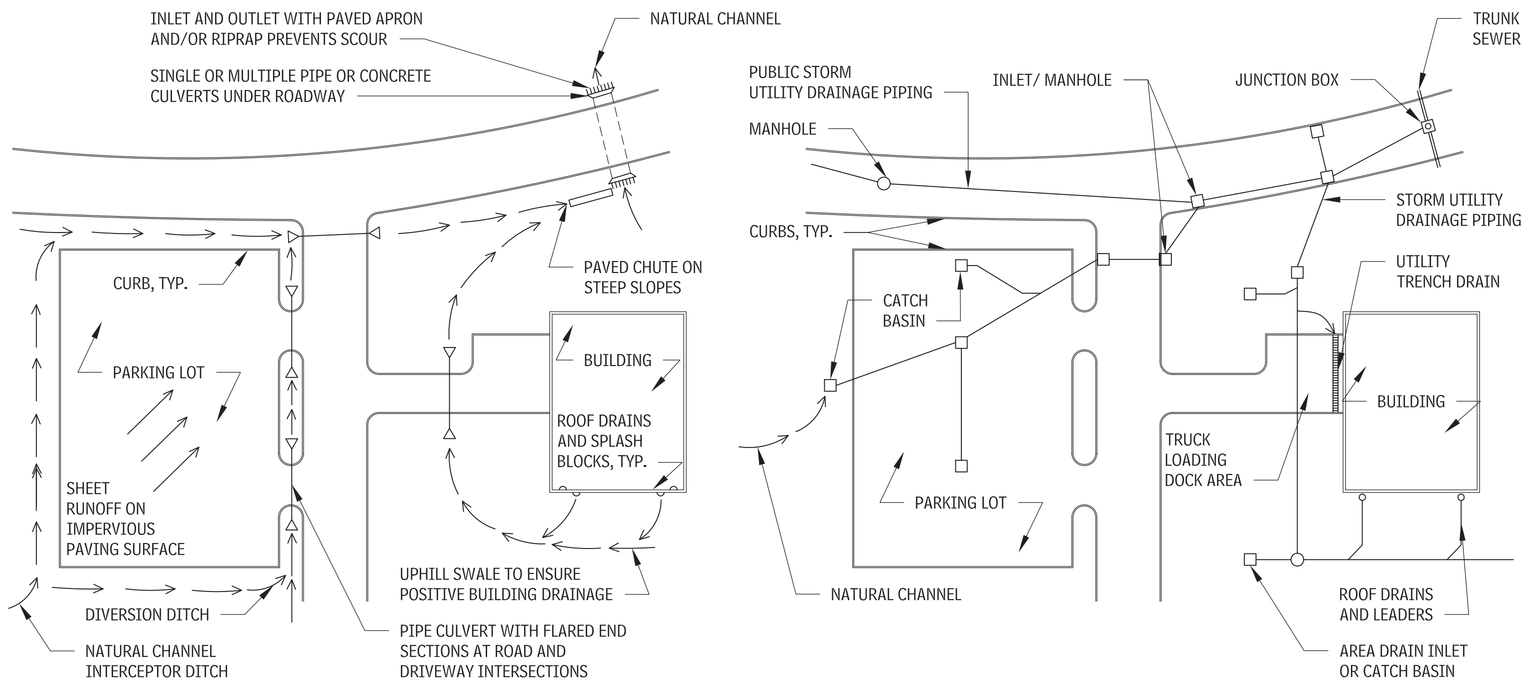
A pervious or porous paving is often used for parking and other hard site surfaces. This drainage system allows water to percolate through the paved surface into the soil, similar to the way the land would naturally absorb water.

DESIGN CONSIDERATIONS FOR SURFACE DRAINAGE SYSTEMS

When designing surface drainage systems, follow these guidelines:

- Lay out all slopes, grates, swales, and other drainage features according to the ADA, without restricting accessible routes for persons with disabilities. Refer to applicable codes, standards, and regulations for accessibility requirements.
- Lay out grades so runoff can safely flow away from buildings. If drains become blocked, do not allow backed-up water to accumulate around the foundation.
- Keep in mind that an open system, or one in which water is kept on top of the surface as long as possible, is generally more economical than a closed system.
- Consider the effect of ice forming on the surface when determining slopes for vehicles and pedestrians.
- Consult local codes on such criteria as intensity and duration of rainstorms and allowable runoff for the locality.

STORM DRAINAGE UTILITIES (IMPERVIOUS PAVING)
16.111



OPEN SYSTEM **CLOSED SYSTEM**

POROUS PAVING SYSTEMS

Porous paving materials, methods for sizing channels, and design considerations for porous paving systems are the topics of this section.

POROUS PAVING MATERIALS

The two principal types of porous paving are monolithic surfacing material and unit pavers.

- *Monolithic porous paving* is stone aggregate bound with asphalt or portland cement. The aggregate must be sorted to exclude the "fines" or sand-sized particles that normally fill the voids between larger pieces. Without the fines, water is able to run through the paving material. Generally, porous asphalt and concrete are both strong enough for parking and roadway surfaces and pedestrian uses.
- *Precast concrete unit pavers*, with shapes that allow water to flow through them, can also give surface stability for parking or driveways. Paver types are available for exposed placement, or for burial just below the surface. In the latter case, the soil-pea gravel or vegetation in the pavers is exposed and can help percolate precipitation into the ground.

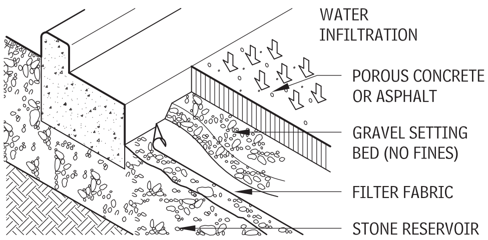
To reduce runoff and increase water absorption, porous paving must be underlaid with a bed of unbound aggregate. The unbound aggregate acts as a structural support and forms a reservoir to hold precipitation until it can percolate into the soil. Use of porous paving may permit use of a significantly smaller and simpler storm drainage system.

DESIGN CONSIDERATIONS FOR POROUS PAVING SYSTEMS

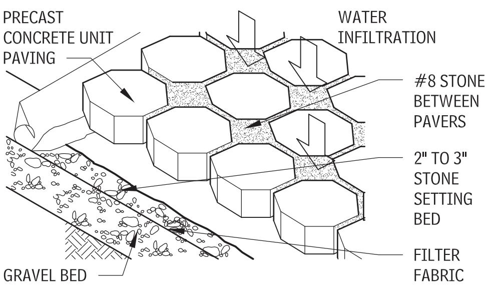
Design considerations for working with porous paving systems include the following:

- Soils around porous paving installations must have a minimum percolation rate of about 1/2 in./hr, and should not be more than about 30 percent clay. On sites where the slope is greater than 3 percent, terracing the paved areas allows the bottom of each reservoir to remain level.
- Proper specification and supervision are important in the installation of porous paving materials. Soil under the reservoir must not be unduly compacted during construction.
- Porous concrete can withstand heavier loads than porous asphalt. Because it does not soften in hot weather and may be more susceptible to freeze/thaw damage, it is better suited to warmer climates. Additives may be introduced to improve cold climate performance.
- Porous asphalt has good freeze/thaw resistance, but is best suited for areas in which traffic is limited, such as employee parking.
- While clogging of monolithic porous paving is generally not a problem, recommended maintenance may include use of a hydrovac once or twice a year, as well as the prompt removal of leaves and windblown sand.
- The reservoir below porous paving has no fixed depth but is designed according to the slope of the site, the soil percolation rate, and the size of the design storm. Consult a civil engineer or landscape architect.

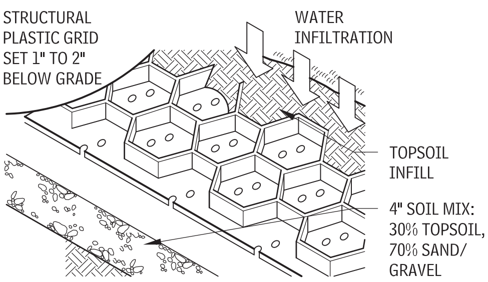
POROUS PAVING TYPES
16.112



MONOLITHIC SURFACE



OPEN PAVERS AT GRADE

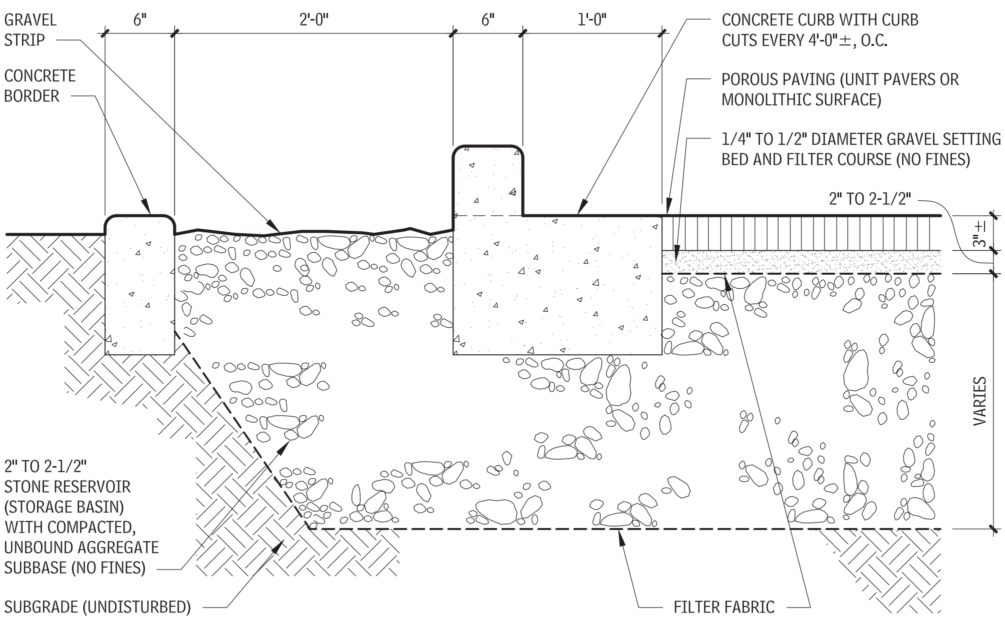


STRUCTURAL GRID/PAVERS BELOW GRADE

SLOPES
16.113

DESCRIPTION	MINIMUM %	MAXIMUM %	RECOMMENDED %
Grass—mowed	1	25	1.5 –10
Grass—athletic field	0.5	2	1
Walks—long	0.5	12*	1.5
Walks—transverse	1	4	1–2
Streets—long	0.5	20	1–10
Parking	1	5	2–3
Channels—grass swale	1	8	1.5–2
Channels—paved swale	0.5	12	4–6

POROUS PAVING AND STONE RESERVOIR DETAIL
16.114



NOTE

16.113 *For accessibility, 8.3 percent maximum.

Contributor:
Pearse O'Doherty, ASLA, Graham Landscape Architecture, Annapolis, Maryland.

SITE ELECTRICAL UTILITIES

SITE LIGHTING

DESIGN CONSIDERATIONS

Creating good design for site lighting is not just about picking the latest technology or the best fixture. It is about using lighting to convey the overall story of a project. The story may be one of safety in a casino parking lot or it may be one of excitement in an outdoor mall where visitors can gather with their families for an evening to have dinner and see a movie.

Site lighting design requirements vary from project to project, and so need to be defined with the individual project team prior to preparing a design. Site lighting requirements typically include lighting pedestrian pathways, landscaping, landscape features, water features, and architectural features such as statuary and adjacent public roadways, parking areas, and nearby facades.

Site lighting design, at its core, is about lighting the environment in a manner that responds to the desired function of the guests within the space. There may be multiple functions such as wayfinding, creating gathering spaces, interacting with the organic and built environments, and meeting security requirements, which all must be taken into account. The overall design intent of the space must allow for these functions to coexist seamlessly, or the guest experience will be negative.

As a part of the design preparation, designers will want to familiarize themselves with the landscape design and current foliage specifications on the project. Lighting fixtures can be used to highlight trees, accent shrubbery, and be mounted in trees to light the path below. It is important to know which trees are deciduous and which trees retain their canopies when making these determinations. It is also highly recommended that lighting designers work closely with the landscape architect to understand which trees will allow the attachment of lighting hardware and mounting straps.

Once the site lighting tasks and requirements have been determined, the designer can begin selecting fixtures, determining lamp types, and preparing the layout.

REGULATIONS AND CODES

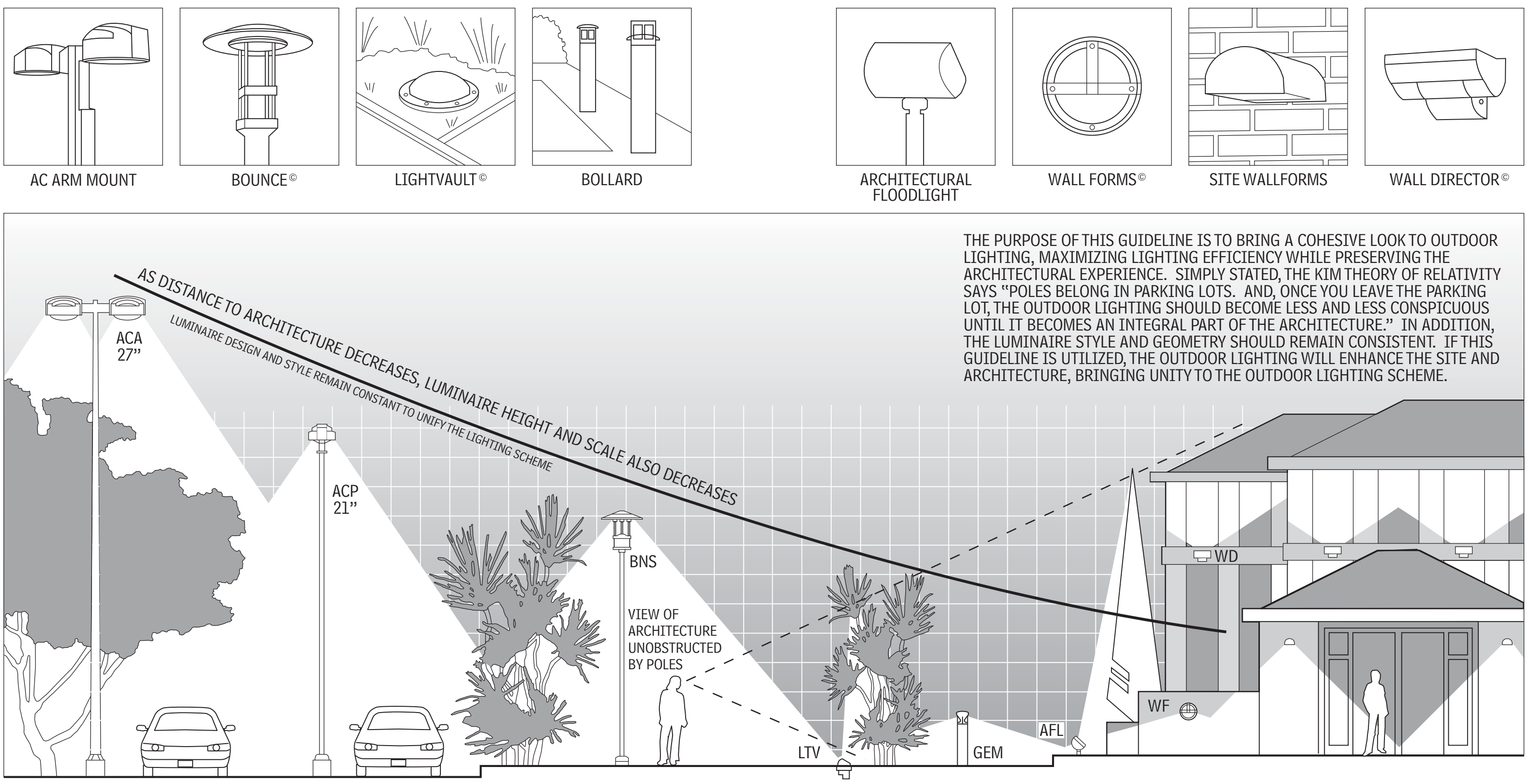
Other factors to consider when designing site lighting are local and national energy codes, any locality-specific dark-sky ordinances, and the current lighting levels in the surrounding and adjacent areas. The International Dark-Sky Association (IDA) is a nonprofit group whose mission is "to preserve and protect the nighttime environment and our heritage of dark skies through quality outdoor lighting." This association (*www.darksky.org*) has been an active voice in the creation of many of the local dark-sky ordinances.

Several calculation programs are available to help verify the illuminance levels are being met in the site lighting design. AGI32 (*www.agi32.com*) is commonly used for site lighting studies, as is LumenMicro by Lighting Technologies (*www.lighting-technologies.com*).

The most difficult part of creating a good lighting design is to meet all of the functional and code requirements of a site while mixing in the desired aesthetics of the project. Providing the right nighttime identity for a site is key to making any project a success.

CPTED recommendations state that lighting has two purposes: illumination of human activity and security. All pedestrian walkways and access routes should be illuminated a minimum of 4 Footcandles to meet IES minimum standards.

RELATIONSHIP OF OUTDOOR LIGHTING TO SITE AND ARCHITECTURE
16.115



SITE/ROADWAY ZONE
PARKING LOTS AND ROADWAYS REQUIRE LUMINAIRES ON 20' - 40' POLES TO EFFICIENTLY LIGHT THESE LARGE AREAS. THEREFORE, THIS LIGHTING BECOMES DOMINANT, AND SETS THE DESIGN AND STYLE FOR ALL OTHER LIGHTING AS YOU PROGRESS TOWARDS THE BUILDING.

PEDESTRIAN ZONE
AS YOU LEAVE THE PARKING LOT AND TRANSITION TO PEDESTRIAN AREAS, POLES SHOULD DECREASE IN HEIGHT TO 10' - 16'. IN ADDITION, LUMINAIRES SHOULD DECREASE IN SCALE, AND CAN HAVE MORE DECORATIVE FEATURES TO BE APPRECIATED AT THE PEDESTRIAN LEVEL.

LANDSCAPE/PATH ZONE
NEAR THE BUILDING, LUMINAIRES SHOULD BEGIN TO DISAPPEAR, BLENDING INTO THE LANDSCAPE AND HARDSCAPE ELEMENTS.

BUILDING/PERIMETER ZONE
NO POLE MOUNTED LUMINARIES SHOULD EVER BE USED NEAR THE BUILDING, AS THEY WILL DOMINATE THE ARCHITECTURE. THE ONLY EXCEPTION WOULD BE THE USE OF DECORATIVE LUMINARIES TO DELINEATE ENTRANCES TO THE STRUCTURE. BUILDING MOUNTED, ARCHITECTURALLY COMPATIBLE FIXTURES SHOULD BE ALMOST INVISIBLE.

APPENDICES

CLASSICAL ARCHITECTURAL ELEMENTS

A

INTRODUCTION

CLASSICAL ARCHITECTURAL ELEMENTS: THE "ORDERS"

The elements of classical architecture, which we inherited from the ancient Greeks, have been in constant use and continual evolution for over 2000 years. They consist of the various columns, along with their bases and capitals, beams, and decorative moldings. These elements are used in harmony with one another and their use is governed by rules of proportion and specifics of ornamental detail. These are referred to as "the classical orders of architecture." It is generally accepted that there are five such orders that have been classified since the Renaissance: Tuscan, Doric, Ionic, Corinthian, and Composite (a combination of Corinthian and Ionic).

CLASSICAL ORDERS AND GRAPHIC STANDARDS

Through most of the life of *Architectural Graphic Standards* since its first edition in 1932, there had been no specific section of details of the orders until 1988, when the eighth edition of *Graphic Standards* published a two-page spread. This was then expanded in the ninth edition (1994) to six pages and so it remained in the tenth edition. Given the underlying technical-, detail-oriented focus of *Architectural Graphic Standards* it may not have been seen as part of its mission to incorporate information of such a fundamentally design-oriented aspect, since this information was readily available elsewhere in greater detail. With the twelfth edition we are again incorporating the essential graphic information about the orders and how to compose and delineate them and have added information about the history, meaning, and uses of the orders in the past, present, and future.

ORDERS ARE A "LIVING" EVOLVING ORGANISM

In using and understanding the orders it is important to accept that they are not a static unchanging formula to be memorized and applied exactly by rote. Like a language, or any other means of sophisticated expression, it is not so much the specifics of the "words" that the orders represent, but rather that they provide a highly sophisticated grammatical language which can be used in many different modes of expression. Over time they have had a rich variety of sources and inspirations and have evolved in many different ways as well. First, they owe their initial existence and form through reference to actual buildings of the ancient world. Second, it is through codification and propagation throughout history that they have endured. Third, at key moments, individual architects have adapted and "swerved" from the accepted norms, and this has enabled the orders to grow and evolve in important ways.

BECOMING CANONICAL

The orders themselves, of which there were four identified in Roman times, were first described as such by Pollio Vitruvius, the architect and theoretician who wrote an architectural treatise in Augustan Roman times in 30–20 B.C. It was not until the Renaissance that interest in the accurate interpretation and use of the classical forms was revived in the treatises of Leon Battista Alberti (1450) and Sebastiano Serlio (1537). The work of both was a revival of Vitruvius, but also significantly went back to the actual Roman sources. The physical remains of Roman buildings were then being rapidly plundered and recycled in Renaissance buildings, so the appropriation of design elements was completely in keeping. It was Serlio who first codified five orders of classical architecture: Tuscan, Doric, Ionic, Corinthian, and Composite. Again in Summerson's words:

HARMONY AND PROPORTION

The orders present a sophisticated compositional system which is precisely governed by principles of proportion and harmony between parts. Each of the five orders has its own particular rules of proportion and characteristics controlling which parts and elements are used with each order. The key aspects of this are the proportion of each element (column diameter to height, base to column, column to entablature, for example) as well as how the repetitive elements are placed (intercolumniation). These principals are not arbitrary, but are based both on historical precedent and aesthetic principals of beauty and composition. Historically, the Doric order with its stout columns and narrow spaces between columns represented the prevailing conservatism of structural design, which by the time of the Ionic order, had evolved permitting more structurally daring use of more slender columns and longer spans.

The design principals of proportion and composition that underlie the orders are important in all aspects of design concerned with the appearance and perception of a structure. These principals remain important to us as designers even if we are not intent on creating a building which can be strictly defined as "classical." Classicism has been employed on a widely varying spectrum of literalness as to the use of its form, and particularly during the first half of the twentieth century practitioners like Auguste Perret in France and Marcello Piacentini in Italy showed that a relatively stripped form of classicism could still express monumentality, permanence, and stability. Summerson argues that the mere presence of columns, capitals, moldings, and the other typical elements of classicism do not always represent classicism if specific forms are absent:

"There is, however, one point about this rather abstract conception of what is classical and it may be put as a question. Is it possible, you may ask, for a building to display absolutely none of the trappings associated with classical architecture and still, by virtue of proportion alone, to qualify as a 'classical' building? The answer must, I think, be 'no'. You can say, in describing such a building, that its proportions are classical, but it is simply confusing and an abuse of terminology to say that it *is* classical. The porches of Chartres Cathedral are, in distribution and proportion, just about as classical as you can get, but nobody is ever going to call them anything but Gothic.

The fact is that the essentials of architecture—as expounded by the Renaissance—are to be found expressed, consciously or unconsciously, throughout the architectures of the world. And while we must incorporate these essentials in our idea of what is classical we must also accept the fact that classical architecture is only recognizable as such when it contains some allusion, however slight, however vestigial, to the antique 'orders'. Such an allusion may be no more than some groove or projection which suggests the idea of a cornice or even a disposition of windows which suggests the ratio of pedestal to column, column to entablature. Some modern buildings—notably those of the late August Perret and his imitators—are classical in this way: that is to say, they are thought out in modern materials but in a classical spirit and sealed as classical only by the tiniest allusive gestures."[11]

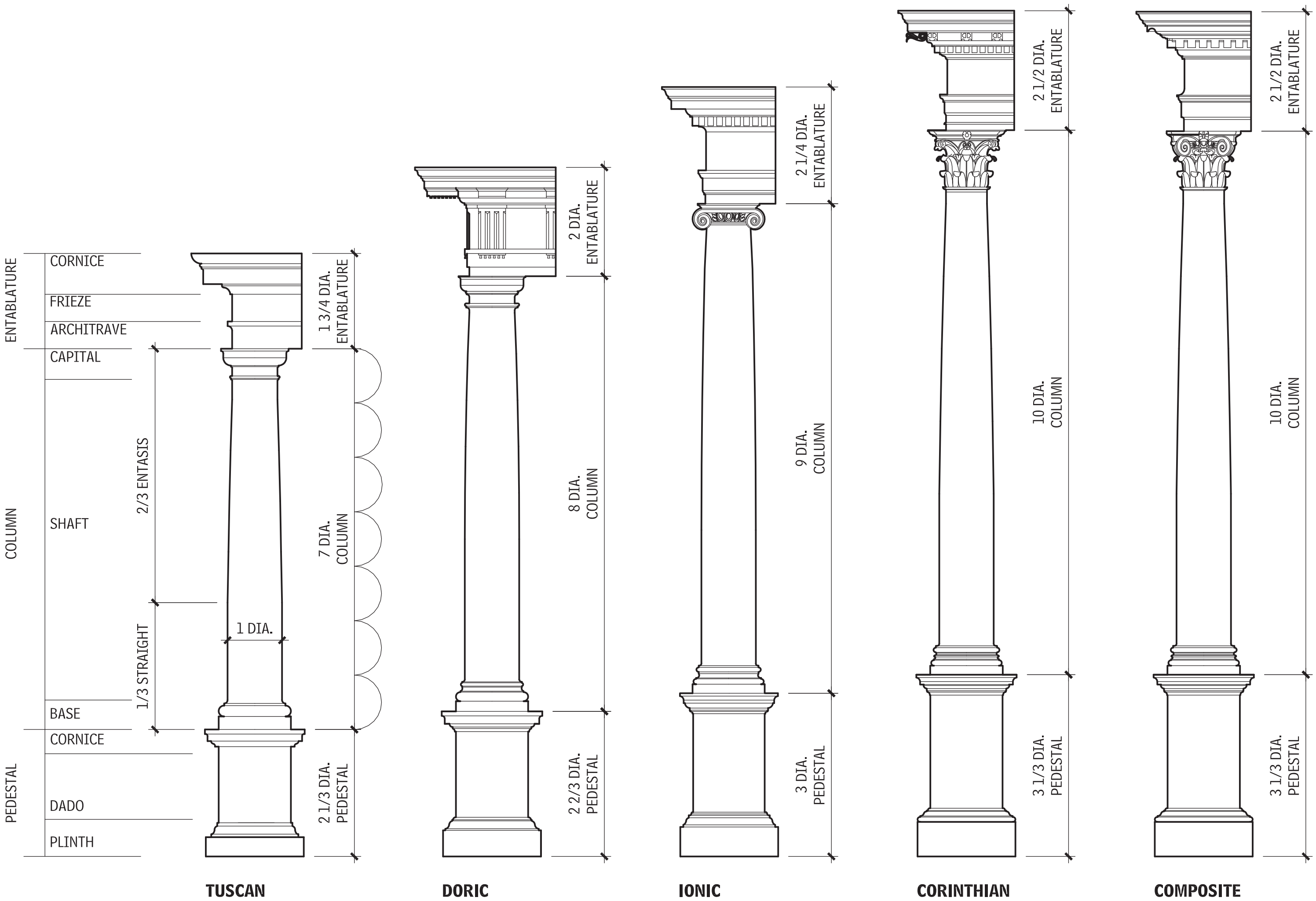
THE ORDERS IN CONTEMPORARY PRACTICE

It is in two contexts and with two objectives that this revised presentation of the orders is offered: First, in the spirit of all other solutions and details provided in *Architectural Graphic Standards,* these orders are intended for use by those who practice classical architecture—a group always growing in number. Second, the ideas and sensibilities which the orders represent have a relevance that goes far beyond the practices of classical architecture and in fact applies to all practitioners who wish to touch upon human perception and empathic response to habitation.

CLASSICAL ORDERS

Classical architecture is based on five distinct and formalized systems of columns and horizontal supports, called the orders. A proportional system in which the parts and divisions of each order, measured in multiples or divisions of the diameter of the lowest part of the relevant tapered column shaft, distinguishes each unique order.

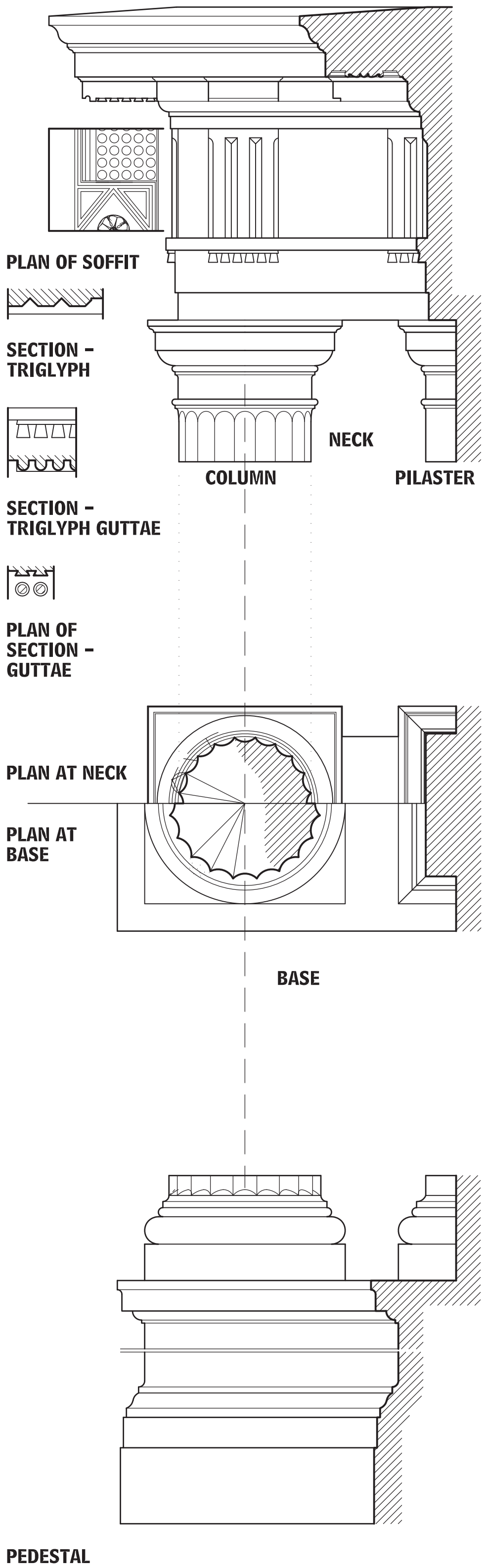
THE FIVE CLASSICAL ORDERS—RENAISSANCE PROPORTIONS
A.1



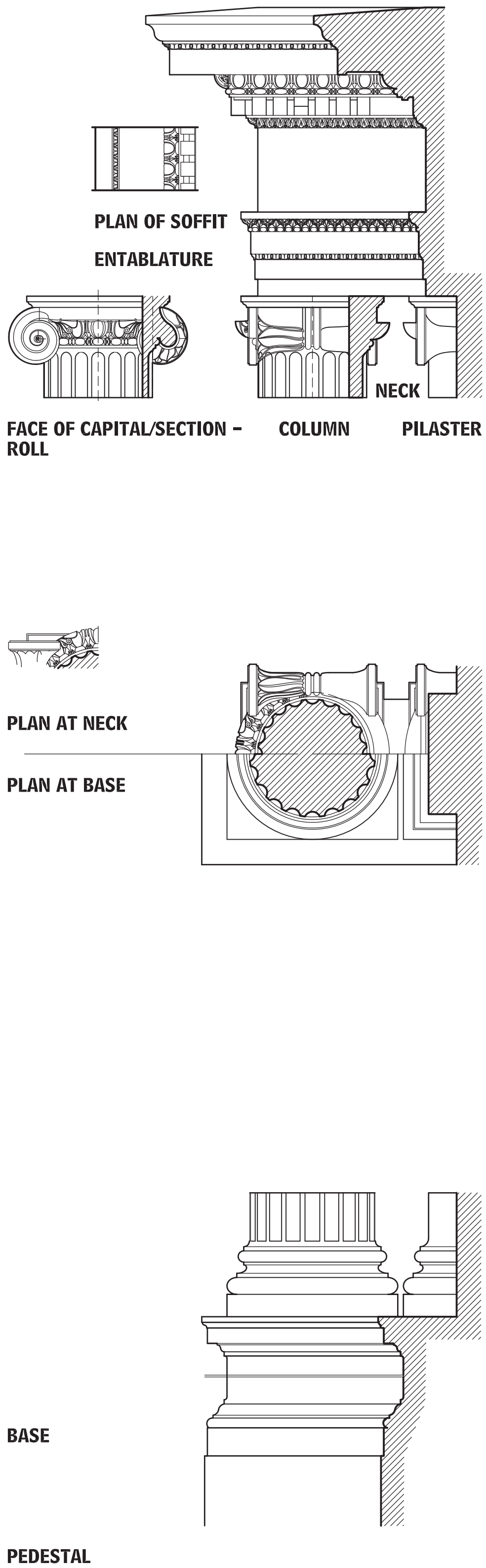
Contributor:
Stephen Harby, Santa Barbara, California.

CLASSICAL ORDERS AND DETAILS

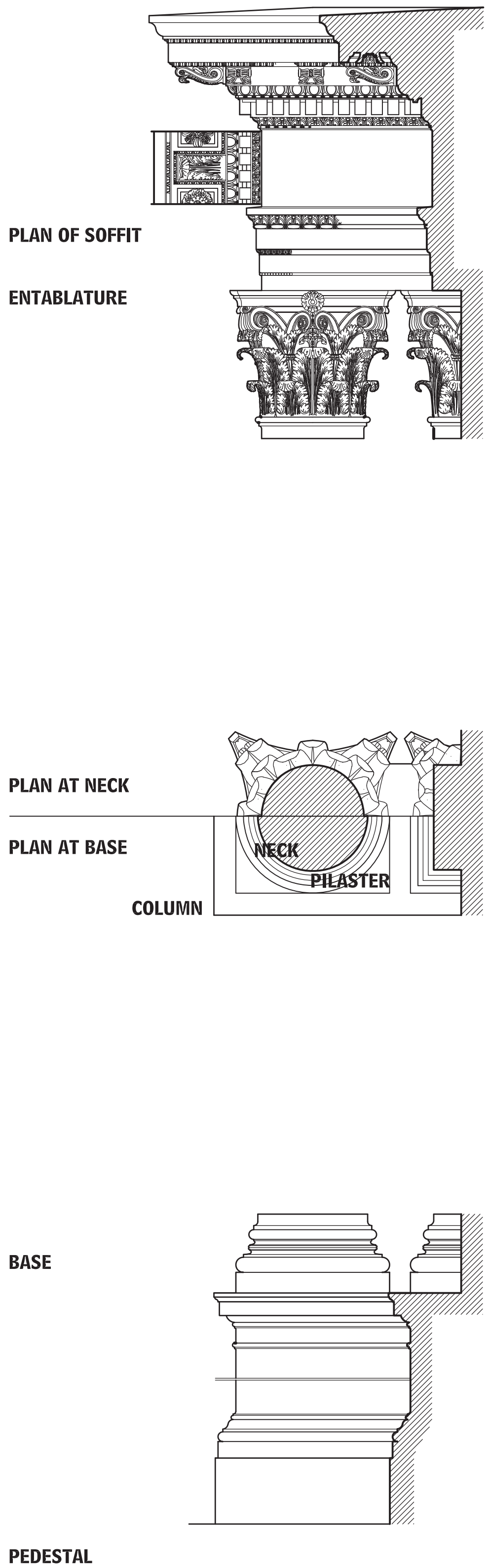
DORIC ORDER (MUTULAR)
A.2



IONIC ORDER
A.3



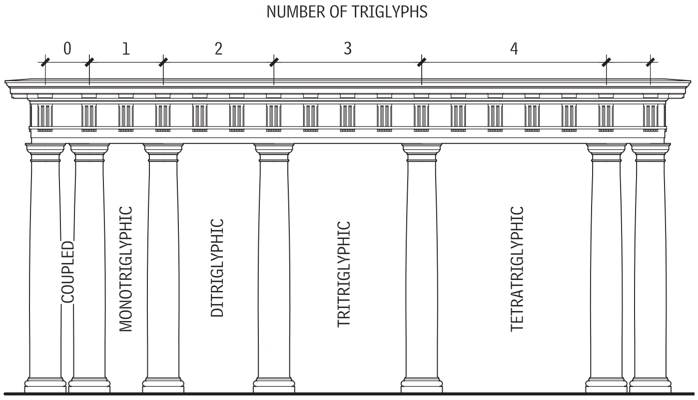
CORINTHIAN ORDER
A.4



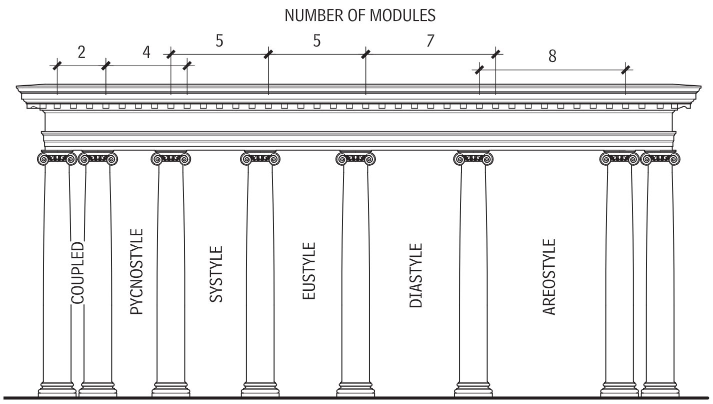
Contributor:
Scot C. McBroom, AIA, Alexandria, Virginia.

INTERCOLUMNIATION AND ARCHES

INTERCOLUMNIATION A.5

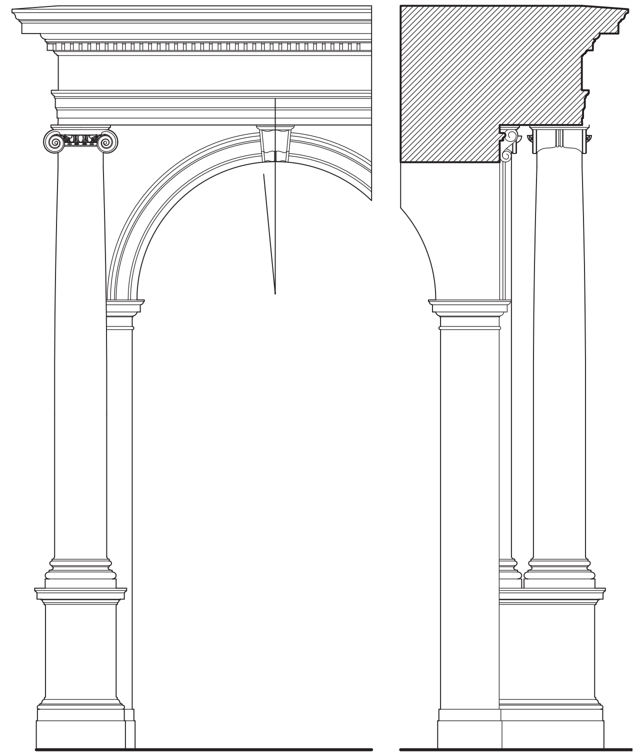


ROMAN DORIC INTERCOLUMNIATION

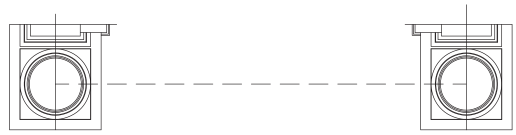


ROMAN IONIC INTERCOLUMNIATION

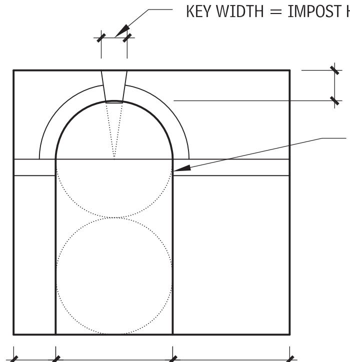
ARCHED DOORWAY A.6



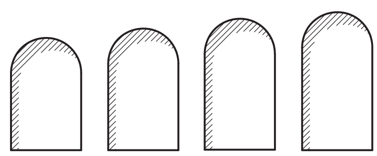
ELEVATION **SECTION**



PLAN



CHAMBERS' GUIDELINES FOR SETTING OUT ARCHES



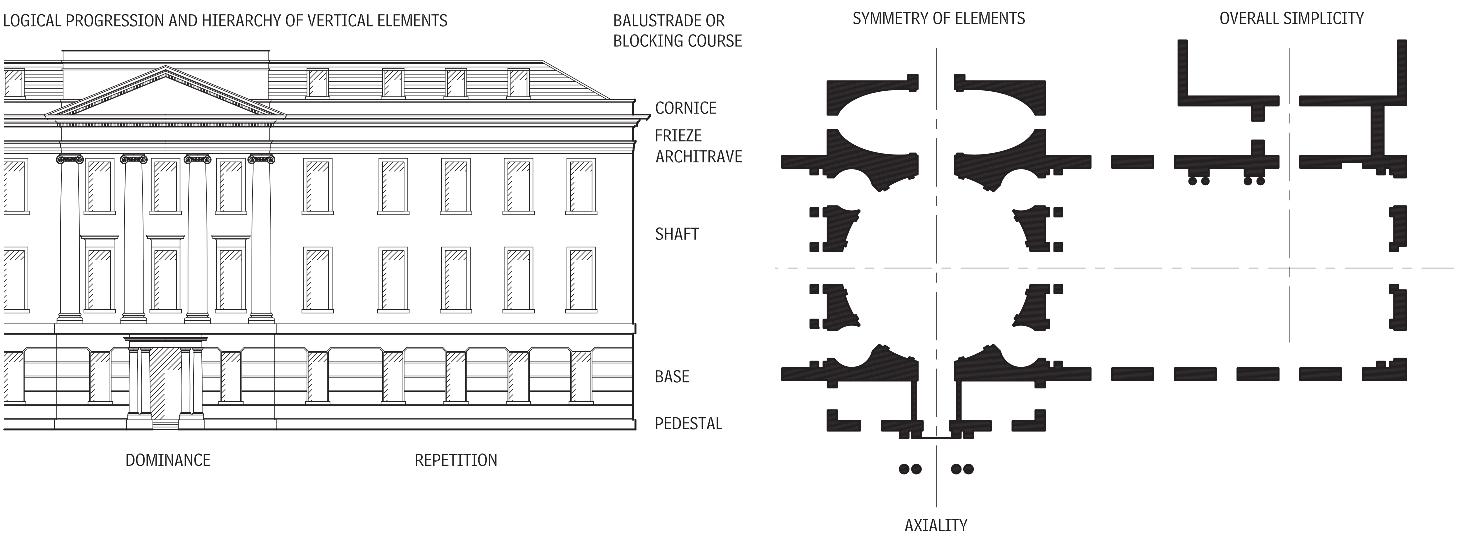
PROPORTIONS OF OPENINGS

WINDOWS

WINDOWS
A.7

USE OF CLASSICAL ELEMENTS AND HIDDEN ORDERS

CHARACTERISTICS OF CLASSICISM
A.8



MATHEMATICAL DATA

B

DECIMAL EQUIVALENTS

DECIMAL EQUIVALENTS
B.1

FRACTION	DECIMAL OF AN IN.	DECIMAL OF A FT
1/64	0.015625	
1/32	0.3125	
3/64	0.046875	
1/16	0.0625	0.0052
5/64	0.078125	
3/32	0.09375	
7/64	0.109375	
1/8	0.125	0.0104
9/64	0.140625	
5/32	0.15625	
11/64	0.171875	
3/16	0.1875	0.0156
13/64	0.203125	
7/32	0.21875	
15/64	0.234375	
1/4	0.250	0.0208
17/64	0.265625	
9/32	0.28125	
19/64	0.296875	
5/16	0.3125	0.0260
21/64	0.328125	
11/32	0.34375	
23/64	0.359375	
3/8	0.375	0.0313
25/64	0.390625	
13/32	0.40625	
27/64	0.421875	
7/16	0.4375	0.0365
29/64	0.453125	
15/32	0.46875	
31/64	0.484375	
1/2	0.500	0.0417
33/64	0.515625	
17/32	0.53125	
35/64	0.546875	
9/16	0.5625	0.0469
37/64	0.578125	
19/32	0.59375	

FRACTION	DECIMAL OF AN IN.	DECIMAL OF A FT
39/64	0.609375	
5/8	0.625	0.0521
41/64	0.640625	
21/32	0.65625	
43/64	0.671875	
11/16	0.6875	0.0573
45/64	0.703125	
23/32	0.71875	
47/64	0.734375	
3/4	0.750	0.0625
49/64	0.765625	
25/32	0.78125	
51/64	0.796875	
13/16	0.8125	0.0677
53/64	0.828125	
27/32	0.84375	
55/64	0.859375	
7/8	0.875	0.0729
57/64	0.890625	
29/32	0.90625	
59/64	0.921875	
15/16	0.9375	0.0781
61/64	0.953125	
31/32	0.96875	
63/64	0.984375	
1	1.00	0.0833
2	2.00	0.1667
3	3.00	0.2500
4	4.00	0.3333
5	5.00	0.4167
6	6.00	0.5000
7	7.00	0.5833
8	8.00	0.6667
9	9.00	0.7500
10	10.00	0.8333
11	11.00	0.9167
12	12.00	1.0000

METRIC UNITS COMMONLY USED IN CONSTRUCTION

METRIC UNITS COMMONLY USED IN CONSTRUCTION
B.2

QUANTITY	UNIT	SYMBOL
Length	meter, millimeter	m, mm
Area	square meter	m^2
Volume	liter, cubic meter	L, m^3
Mass (weight)	kilogram, megagram, metric ton (tonne)	kg, Mg, t
Slope	percent height/width ratio	% mm:m, mm:mm, m:m
Time	second (no change)	s
Pressure	pascal, kilopascal, megapascal	Pa, kPa, MPa
Force	newton, meganewton	N, MN
Electric current	ampere (no change)	A
Electrical potential	volt (no change)	V
Power	watt, kilowatt, megawatt (no change)	W, kW, MW
Energy, work, unit of heat	joule, megajoule	J, MJ
Temperature	degrees celsius	°C
Frequency	hertz, megahertz	Hz, MHz

NOTE

B.2 Unit prefixes: milli (m) = 1/1000; kilo (k) = 1000; mega (M) = 1 000 000

CONVERSION FACTORS
B.3

QUANTITY	FROM INCH-POUND UNITS	TO METRIC UNITS	MULTIPLY BY
Length	mile	km	1.609 344*
	yard	m	0.914 4*
	foot	m	0.304 8*
	foot	mm	304.8*
	inch	mm	25.4*
Area	square mile	km^2	2.590 00
	acre	m^2	4 046.87
		ha (10 000 m^2)	0.404 687
	square yard	m^2	0.836 127 36*
	square foot	m^2	0.092 903 04*
	square inch	mm^2	645.16*
Volume	acre foot	M^3	1 233.49
	cubic yard	M^3	0.764 555
	cubic foot	M^3	0.028 316 8
		cm^3	28 316.85
		L (1000 cm^3)	28.316 85
	100 board feet	m^3	0.235 974
	gallon	L (1000 cm^3)	3.785 41
	cubic inch	cm^3	16.387 064*
		mm^3	16 387.064*
Mass	lb	kg	0.453 592
	Kip (1000 lb)	metric ton (1000 kg)	0.453 592
Mass/unit length	plf	kg/m	1.488 16
Mass/unit area	psf	kg/m^2	4.882 43
Mass density	pcf	kg/m^3	16.018 5
Force	lb	N	4.448 22
Force/unit length	plf	N/m	14.593 9
Pressure, stress, modulus of elasticity	psf	Pa	47.880 3
	psi	kPa	6.894 76
Bending moment, torque, moment of force	ft·lb	N·m	1.355 82
Moment of mass	lb·ft	kg·m	0.138 255
Moment of inertia	$lb·ft^2$	$kg·m^2$	0.042 140 1
Second moment of area	in4	mm^4	416 231
Section modulus	in^3	mm^3	16 387.064*
Mass/area (density)	lb/ft^2	kg/m^2	4.882 428
Temperature	°F	°C	5/9(∞F-32)
Energy, work, quantity of heat	kWh	MJ	3.6*
	Btu	J	1055.056
	ft·lb	J	1.355 82
Power	ton (refrig)	kW	3.517
	Btu/s	kW	1.055 056
	hp (electric)	W	745.700
	Btu/h	W	0.293 071
Heat flux	$Btu/f^2·h$	W/m	3.152 481
Rate of heat flow	Btu/s	kW	1.055 056
	Btu/h	W	0.293 071 1

NOTE

B.3 *Denotes an exact conversion.

CONVERSION FACTORS (continued)
B.3

QUANTITY	FROM INCH-POUND UNITS	TO METRIC UNITS	MULTIPLY BY
Thermal conductivity (k value)	Btu/ft·h·°F	W/m·K	1.730 73
Thermal conductance (U value)	Btu/ft^2·h·°F	W/m^2·K	5.678 263
Thermal resistance (R value)	ft^2·h·°F/Btu	m^2·K/W	0.176 110
Heat capacity, entrophy	Btu/°F	kJ/K	1.899 1
Specific heat capacity, specific entropy	Btu/lb·°F	kJ/kg·K	4.186 8*
Specific energy, latent heat	Btu/lb	kJ/kg	2.326*
Vapor permeance	perm (23 °C)	ng/(Pa·s·m^2)	57.452 5
Vapor permeability	perm/in	ng/(Pa·s·m)	1.459 29
Volume rate of flow	ft^3/s	m^3/s	0.028 316 8
	cfm	m^3/s	0.000 471 947 4
	cfm	L/s	0.471 947 4
Velocity, speed	ft./s	m/s	0.3048*
Acceleration	ft./s^2	m/s^2	0.3048*
Momentum	lb·ft/s	kg·m/s	0.138 255 0
Angular momentum	lb·ft^2/s	kg·m^2/s	0.042 140 11
Plane angle	degree	rad	0.017 453 3
Power, radiant flux	W	W	1 (same unit)
Radiant intensity	W/sr	W/sr	1 (same unit)
Radiance	W/(sr·m^2)	W/(sr·m^2)	1 (same unit)
Irradiance	W/m^2	W/m^2	1 (same unit)
Frequency	Hz	Hz	1 (same unit)
Electric current	A	A	1 (same unit)
Electric charge	A·hr	C	3600*
Electric potential	V	V	1 (same unit)
Capacitance	F	F	1 (same unit)
Inductance	H	H	1 (same unit)
Resistance	W	W	1 (same unit)
Conductance	mho	S	100*
Magnetic flux	maxwell	Wb	10-8*
Magnetic flux density	gamma	T	10-9*
Luminous intensity	cd	cd	1 (same unit)
Luminance	lambert	kcd/m^2	3.183 01
	cd/ft^2	cd/m^2	10.763 9
	footlambert	cd/m^2	3.426 26
Luminous flux	lm	lm	1 (same unit)
Illuminance	footcandle	lx	10.763 9

SELECTED EQUATIONS AND CONSTANTS

SCIENTIFIC NOTATION

Scientific notation is used to abbreviate large numerical values in order to simplify calculations.

$4.2 \times 10^4 = 4.2 \times (10 \times 10 \times 10 \times 10) = 42{,}000$

$1.0 \times 10^1 = 1 \times 10 = 10$

$6.0 \times 10^{-4} = 6.0 \times (1 / 10 \times 10 \times 10 \times 10) = 0.0006$

MULTIPLYING AND DIVIDING POWERS

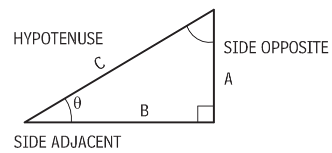
$$x^n x^m = x^{nm} \qquad (x^n)^m = x^{nm}$$

$$\frac{x^n}{x^m} = x^{n-m} \qquad \frac{1}{x^n} = \sqrt[n]{x}$$

PYTHAGOREAN THEOREM

$$c^2 = a^2 + b^2$$

PYTHAGOREAN THEOREM
B.4



BASIC TRIGONOMETRY FUNCTIONS

$$\sin\theta \frac{\text{opposite}}{\text{hypotenuse}} = \frac{a}{c}$$

$$\cos\theta \frac{\text{adjacent}}{\text{hypotenuse}} = \frac{b}{c}$$

$$\tan\theta \frac{\text{opposite}}{\text{adjacent}} = \frac{a}{b}$$

$$\cot\theta \frac{\text{adjacent}}{\text{opposite}} = \frac{b}{a}$$

RADIANS AND DEGREES

A radian is a way of measuring angles in addition to degrees. Radians are the primary unit of angular measurement used in calculations.

$$1\text{ rad} = \frac{180°}{\pi} = 57.3 \quad \text{(approx)}$$

$$1° = \frac{\pi}{180°} = 0.01745\ \text{rad} \quad \text{(approx)}$$

LINEAR DISTANCE

The distance *s*, which a point *p* on the rim of a rotating wheel covers, is called linear distance. The angle θ, the intercepting angle, is measured in radians.

$$s = r\theta$$

LINEAR SPEED

The linear speed *v*, of the point *p* around the rim of a rotating wheel, is the time taken *t* for a point to travel the distance *s*.

$$v = \frac{s}{t}$$

NOTE

B.3 *Denotes an exact conversion.

ANGULAR SPEED

The angular speed ω, of the point *p* around the rim of a rotating wheel is the time taken, *t*, for the point to travel the angular distance, θ. The angular distance can be measured in degrees, revolutions, or radians. The resulting units of angular speed depend on the units used for angular distance and time.

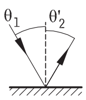
$$\omega = \frac{\theta}{t}$$

LAW OF REFLECTION

A light ray reflects from a surface such that the angle of reflection equals the angle of incidence.

$$\theta' = \theta_2$$

LAW OF REFLECTION
B.5

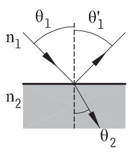


LAW OF REFRACTION

When a light ray traveling through a transparent medium strikes another transparent medium, part of the ray is reflected and part is refracted, entering the second medium. The angle of the refracted ray depends on the angle of incidence and the index of refraction of both mediums.

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

LAW OF REFRACTION
B.6



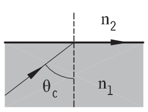
TOTAL INTERNAL REFLECTION

When light attempts to move from a medium with a high index of refraction to a medium with a low index of refraction, there is a particular angle of incidence large enough that the angle of refraction reaches 90°. The transmitted light ray moves parallel to the surface of the first medium and no more light is transmitted.

This angle of incidence is called the critical angle and depends on the indexes of refraction of the two mediums. Any angle of incidence larger than the critical angle is reflected back into the first medium.

$$\sin\theta_c = \frac{n_2}{n_1}$$

TOTAL INTERNAL REFLECTION
B.7



SPEED OF LIGHT IN MEDIUM

$$c_{medium} = \frac{c_{vac}}{n_{medium}}$$

THERMAL EXPANSION OF LENGTH

An object of initial length L_o at some temperature. With a change in temperature of ΔT, the length increases ΔL. The constant a α is called the average coefficient of linear expansion for the given material.

$$\Delta L = \alpha L_o \Delta T$$

THERMAL EXPANSION OF AREA

An object of initial area A_o at some temperature. With a change in temperature of ΔT, the area increases ΔA. The constant γ is the average coefficient of area expansion for the given material.

$$\Delta A = \gamma A_o \Delta T \qquad \gamma = 2\alpha$$

THERMAL EXPANSION OF VOLUME

A mass of initial volume V_o at some temperature. With a change in temperature ΔT, the volume increases ΔV. The constant β is called the average coefficient of volume expansion for a given material.

$$\Delta V = \beta V_o \Delta T \qquad \beta = 3\alpha$$

USEFUL CONSTANTS

INDEXES OF REFRACTION (N)
B.8

Air at 20°C, 1 atmosphere			1.000
SOLIDS AND LIQUIDS AT 20°C			
Water	1.333	Polystyrene	1.49
Ice (H_2O)	1.309	Glass, crown	1.52
Fused quartz	1.458	Glass, flint	1.66

LINEAR EXPANSION COEFFICENTS (A)
B.9

Aluminum	24×10^{-6}	Concrete	12×10^{-6}
Brass and bronze	19×10^{-6}	Lead	29×10^{-6}
Copper	17×10^{-6}	Steel	11×10^{-6}
Glass, ordinary	9×10^{-6}		

VOLUME EXPANSION COEFFICENTS (β) ($\beta = 3\alpha$)
B.10

Air	3.67×10^{-3}

NATURAL CONSTANTS
B.11

Speed of light in a vacuum	$C = 3.0 \times 10^8$ m/s
Standard gravity	$g = 9.80$ m/s^2

WEIGHT OF MATERIALS

WEIGHT OF MATERIALS
B.12

To establish uniform practice among designers, it is desirable to present a list of materials generally used in building construction, together with their proper weights. Many building codes prescribe the minimum weights of only a few building materials. It should be noted that there is a difference of more than 25 percent in some cases.

BRICK AND BLOCK MASONRY		PSF
4" brickwork		40
4" concrete block, stone or gravel		34
4" concrete block, lightweight		22
4" concrete brick, stone or gravel		46
4" concrete brick, lightweight		33
6" concrete block, stone or gravel		50
6" concrete block, lightweight		31
8" concrete block, stone or gravel		55
8" concrete block, lightweight		35
12" concrete block, stone or gravel		85
12" concrete block, lightweight		55
CONCRETE		**PCF**
Plain	Cinder	108
	Expanded slag aggregate	100
	Expanded clay	90
	Slag	132
	Stone and cast stone	144
Reinforced	Cinder	111
	Slag	138
	Stone	150
FINISH MATERIALS		**PSF**
Acoustic tile unsupported per 1/2"		0.8
Building board, 1/2"		0.8
Cement finish, 1"		12
Fiberboard, 1/2"		0.75
Gypsum board, 1/2"		2
Marble and setting bed		25–30
Plaster, 1/2"		4.5
Plaster on wood lath		8
Plaster suspended with lath		10
Plywood, 1/2"		1.5
Tile, glazed wall, 3/8"		3
Tile, ceramic mosaic, 1/4"		2.5
Quarry tile, 1/2"		5.8
Quarry tile, 3/4"		8.6
Terrazzo 1", 2" in stone concrete		25
Vinyl tile, 1/8"		1.33
Hardwood flooring, 25/32"		4
Wood block flooring, 3" on mastic		15
FLOOR AND ROOF (CONCRETE)		**PSF**
Flexicore, 6" precast lightweight concrete		30
Flexicore, 6" precast stone concrete		40
Plank, cinder concrete, 2"		15
Plank, gypsum, 2"		12
Concrete, reinforced, 1"	Stone	12.5
	Slag	11.5
	Lightweight	6–10
Concrete, plain, 1"	Stone	12
	Slag	11
	Lightweight	3–9

WEIGHT OF MATERIALS (continued)
B.12

FUELS AND LIQUIDS	PCF
Coal, piled anthracite	47–58
Coal, piled bituminous	40–54
Ice	57.2
Gasoline	75
Snow	8
Water, fresh	62.4
Water, sea	64
GLASS	**PSF**
Polished plate, 1/4"	3.28
Polished plate, 1/2"	6.56
Double strength, 1/8"	26 oz
Sheet A, B, 1/32"	45 oz
Sheet A, B, 1/4"	52 oz
Insulated glazing, 5/8" plate with airspace	3.25
Wire glass, 1/4"	3.5
Glass block	18
INSULATION AND WATERPROOFING	**PSF**
Blanket per 1" thickness	0.1-0.4
Corkboard per 1" thickness	0.58
Foamed board insulation per 1" thickness	2.6 oz
Five-ply membrane	5
Board insulation	0.75
LIGHTWEIGHT CONCRETE	**PSF**
Concrete, aerocrete	50–80
Concrete, cinder fill	60
Concrete, expanded clay	85–100
Concrete, expanded shale-sand	105-120
Concrete, perlite	35–50
Concrete, pumice	60–90
METALS	**PCF**
Aluminum, cast	165
Brass, cast, rolled	534
Bronze, commercial	552
Bronze, statuary	509
Copper, cast or rolled	556
Gold, cast, solid	1205
Gold coin in bags	509
Iron, cast gray, pig	450
Iron, wrought	480
Lead	710
Nickel	565
Silver, cast, solid	656
Silver, coin in bags	590
Tin	459
Stainless steel, rolled	492–510
Steel, rolled, cold drawn	490
Zinc, rolled, cast or sheet	449
MORTAR AND PLASTER	**PCF**
Mortar, masonry	116
Plaster, gypsum, sand	104–120
PARTITIONS	**PSF**
2 × 4 wood stud, gypsum board, two sides	8
4" metal stud, gypsum board, two sides	6
4" concrete block, lightweight, gypsum board	26
6" concrete block, lightweight, gypsum board	35
2" solid plaster	20
4" solid plaster	32

ROOFING MATERIALS	PSF
Built up	6.5
Concrete roof tile	9.5
Copper	1.5–2.5
Corrugated iron	2
Deck, steel without roofing or insulation	2.2–3.6
Fiberglass panels (2-1/2" corrugated)	5–8 oz
Galvanized iron	1.2–1.7
Lead, 1/8"	6.8
Plastic sandwich panel, 2-1/2" thick	2.6
Shingles, asphalt	1.7–2.8
Shingles, wood	2–3
Slate, 3/16" to 1/4"	7–9.5
Slate, 3/8" to 1/2"	14–18
Stainless steel	2.5
Tile, cement flat	13
Tile, cement ribbed	16
Tile, clay shingle type	8–16
Tile, clay flat with setting bed	15–20
Wood sheathing per inch	3
SOIL, SAND, AND GRAVEL	**PCF**
Ashes or cinder	40–50
Clay, damp and plastic	110
Clay, dry	63
Clay and gravel, dry	100
Earth, dry and loose	76
Earth, dry and packed	95
Earth, moist and loose	78
Earth, moist and packed	96
Earth, mud, packed	115
Sand or gravel, dry and loose	90–105
Sand or gravel, dry and packed	100–120
Sand or gravel, dry and wet	118–120
Silt, moist, loose	78
Silt, moist, packed	98
STONE (ASHLAR)	**PCF**
Granite, limestone, crystalline	165
Limestone, oolitic	136
Marble	173
Sandstone, bluestone	144
Slate	172
STONE VENEER	**PSF**
2" granite, 1/2" parging	30
4" granite, 1/2" parging	59
6" limestone facing, 1/2" parging	55
4" sandstone or bluestone, 1/2" parging	49
1" marble	13
1" slate	14
STRUCTURAL CLAY TILE	**PSF**
4" hollow	23
6" hollow	38
8" hollow	45
STRUCTURAL FACING TILE	**PSF**
2" facing tile	14
4" facing tile	24
6" facing tile	34
8" facing tile	44

SUSPENDED CEILINGS	PSF
Mineral fiber tile 3/4", 12" × 12"	1.2–1.57
Mineral fiberboard 5/8", 24" × 24"	1.4
Acoustic plaster on gypsum lath base	10–11
WOOD	**PCF**
Ash, commercial white	40.5
Birch, red oak, sweet and yellow	44
Cedar, northern white	22.2
Cedar, western red	24.2
Cypress, southern	33.5
Douglas fir (coast region)	32.7
Fir, commercial white, Idaho white pine	27
Hemlock	28–29
Maple, hard (blacks and sugar)	44.6
Oak, white and red	47.3
Pine, northern white sugar	25
Pine, southern yellow	37.3
Pine, ponderosa, spruce: eastern and sitka	28.6
Poplar, yellow	29.4
Redwood	26
Walnut, black	38

AREA AND VOLUME CALCULATION

ARCHITECTURAL AREA OF BUILDINGS

The architectural area of a building is the sum of the areas of the floors, measured horizontally in plan to the exterior faces of perimeter walls or to the centerline of walls separating buildings. Included are areas occupied by partitions, columns, stairwells, elevator shafts, duck shafts, elevator rooms, pipe spaces, mechanical penthouses, and similar spaces having headroom of 6 ft. and over. Areas of sloping surfaces, such as staircases, bleachers, and tiered terraces, should be measured horizontally in plan. Auditoriums, swimming pools, gymnasiums, foyers, and similar spaces extending through two or more floors should be measured once only, taking the largest area in plan at any level.

Mechanical penthouse rooms, pipe spaces, bulkheads, and similar spaces having a headroom less than 6 ft. and balconies projecting beyond exterior walls, covered terraces and walkways, porches, and similar spaces shall have the architectural area multiplied by 0.50 in calculating the building gross area.

Exterior staircases and fire escapes, exterior steps, patios, terraces, open courtyards and light wells, roof overhangs, cornices and chimneys, unfinished roof and attic areas, pipe trenches, and similar spaces are excluded from the architectural area calculations. Interstitial space in healthcare facilities is also excluded.

ARCHITECTURAL VOLUME OF BUILDINGS

The architectural volume of a building is the sum of the products of the areas defined in the architectural area times the height from the underside of the lowest floor construction to the average height of the surface of the finished roof above, for the various parts of the building. Included in the architectural volume is the actual space enclosed within the outer surfaces of the exterior of outer walls and contained between the outside of the roof and the bottom of the lowest floor, taken in full: bays, oriels, dormers; penthouses, chimneys; walk tunnels; enclosed porches and balconies, including screened areas.

The following volumes are multiplied by 0.50 in calculating the architectural volume of a building; nonenclosed porches, if recessed into the building and without enclosing sash or screens; nonenclosed porches built as an extension to the building and without sash or screen; areaways and pipe tunnels; and patio areas that have building walls extended on two sides, roof over, and paved surfacing.

Excluded from the architectural volume are outside steps, terraces, courts, garden walls; light shafts, parapets, cornices, roof overhangs; footings, deep foundation, pilling caissons, special foundations, and similar features.

NET ASSIGNABLE AREA

The net assignable area is that portion of the area that is available for assignment to an occupant, including every type of space usable by the occupant.

The net assignable area should be measured from the predominant inside finish of enclosing walls in the categories defined below. Areas occupied by exterior walls, partitions, internal structural, or party walls are to be excluded from the groups and are to be included under "construction area."

1. *Net assignable area*: Total area of all enclosed spaces fulfilling the main functional requirements of the building for occupant use, including custodial and service areas such as guard rooms, workshops, locker rooms, janitors' closets, storerooms, and the total area of all toilet and washroom facilities.
2. *Circulation area*: Total area of all enclosed spaces which is required for physical access to subdivision of space such as corridors, elevator shafts, escalators, fire towers or stairs, stairwells, elevator entrances, public lobbies, and public vestibules.
3. *Mechanical area*: Total area of all enclosed spaces designed to house mechanical and electrical equipment and utility services such as mechanical and electrical equipment rooms, duct shafts, boiler rooms, fuel rooms, and mechanical service shafts.
4. *Construction area*: The area occupied by exterior walls, partitions, and structure.
5. *Gross floor or architectural area*: The sum of areas 1, 2, 3, and 4 plus the area of all factored non- and semi-enclosed areas equal the gross floor area or architectural area of a building.

In commercial buildings constructed for leasing, net areas are to be measured in accordance with the "Standard Method of Floor Measurement," as set by the Building Owners and Managers Association (BOMA).

The net rentable area for offices is to be measured from the inside finish of permanent outer building walls, to the office or occupancy side of corridors and/or other permanent partitions, and to the center of partitions that separate the premises from adjoining rentable areas. No deductions are to be made for columns and projections necessitated by the building.

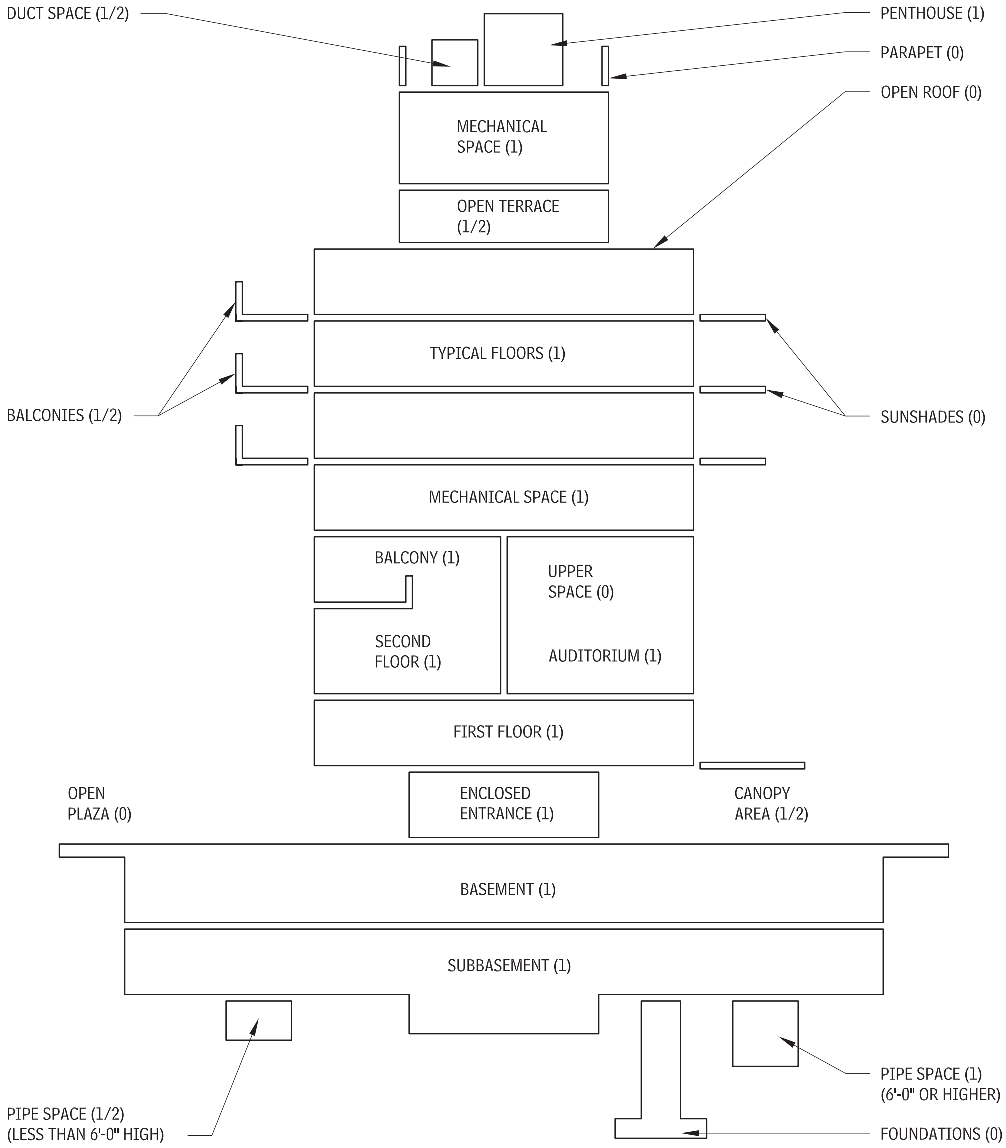
The net rentable area for stores is to be measured from the building line in case of street frontages and from the inside finish of other outer building walls, corridor, and permanent partitions and to the center of partitions that separate the premises from adjoining rentable areas. No deductions are to be made for vestibules inside the building line or for columns that are projections necessary to the building. No addition is to be made for projecting bay windows.

If a single occupant is to occupy the total floor in either the office or store categories, the net rentable area would include the accessory area for that floor of corridors, elevator lobbies, toilets, janitors' closets, electrical and telephone closets, air-conditioning rooms and fan rooms, and similar spaces.

The net rentable area for apartments is to be measured from the inside face of exterior walls, and all enclosing walls of the unit.

Various government agencies have their own methods of calculating the net assignable area of buildings. They should be investigated if federal authority of funding applies to a project. Also, various building codes provide their own definitions of net and gross areas of buildings for use in quantifying requirements.

ARCHITECTURAL AREA DIAGRAM
B.13



Contributor:
T. Edward Thomas, AIA, Hansen Lind Meyer, Inc., Orlando, Florida.

STRUCTURAL CALCULATIONS

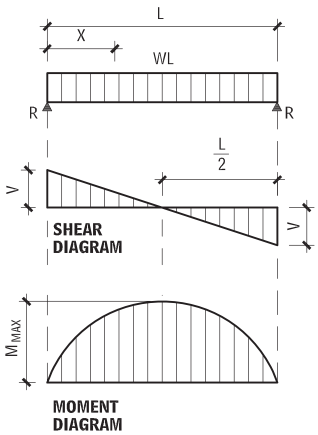
C

FORMULAS NOMENCLATURE
C.1

NOMENCLATURE	MEANING
E	Modulus of elasticity of steel at 29,000 ksi
I	Moment of inertia of beam (in.^{4})
M_{max}	Maximum moment (kip in.)
M_1	Maximum moment in left section of beam (kip in.)
M_2	Maximum moment in right section of beam (kip in.)
M_3	Maximum positive moment in beam with combined end moment conditions (kip in.)
M_x	Moment at distance x from end of beam (kip in.)
P	Concentrated load (kips)
P_1	Concentrated load nearest left reaction (kips)
P_2	Concentrated load nearest right reaction, and of different magnitude than P_1 (kips)
R	End beam reaction for any condition of symmetrical loading (kips)
R_1	Left end beam reaction (kips)
R_2	Right end or intermediate beam reaction (kips)
R_3	Right end beam reaction (kips)
V	Maximum vertical shear for any condition of symmetrical loading (kips)
V_1	Maximum vertical shear in left section of beam (kips)
V_2	Vertical shear at right reaction point, or to left of intermediate reaction point of beam (kips)
V_3	Vertical shear at right reaction point, or to right of intermediate reaction point of beam (kips)
V_x	Vertical shear at distance x from end of beam (kips)
W	Total load on beam (kips)
A	Measured distance along beam (in.)
B	Measured distance along beam which may be greater or less than "A" (in.)
L	Total length of beam between reaction points (in.)
W	Uniformly distributed load per unit of length (kips per in.)
W_1	Uniformly distributed load per unit of length nearest left reaction (kips per in.)
W_2	Uniformly distributed load per unit of length nearest right reaction, and of different magnitude than W_1 (kips per in.)
X	Any distance measured along beam from left reaction (in.)
X_1	Any distance measured along overhang section of beam from nearest reaction point (in.)
Δ_{max}	Maximum deflection (in.)
Δ_a	Deflection at point of load (in.)
Δ_x	Deflection at any point x distance from left reaction (in.)
Δ_{x1}	Deflection of overhang section of beam at any distance from nearest reaction point (in.)

STATIC LOADS FOR SIMPLE BEAMS

SIMPLE BEAM—UNIFORMLY DISTRIBUTED LOAD
C.2



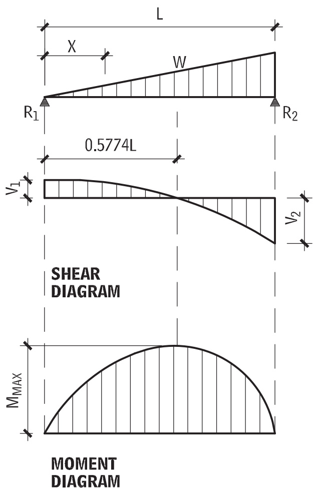
$\frac{WL}{2} = V = R$

$W\left(\frac{L}{2} - X\right) = V_X$

$\frac{WL^2}{8} = M_{MAX}$

$\frac{5WL^4}{384EI} = \Delta_{MAX}$

SIMPLE BEAM—LOAD INCREASING UNIFORMLY TO ONE END
C.3



$\frac{W}{3} = V_1 = R_1$

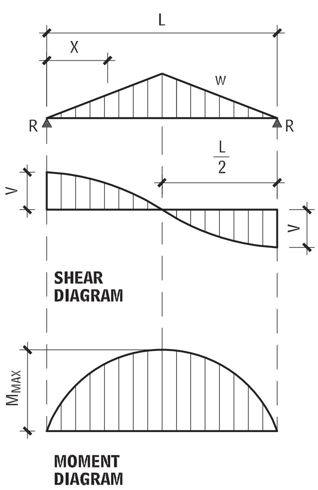
$\frac{2W}{3} = V_{2MAX} = R_2$

$\frac{W}{3} - \frac{WX^2}{L^2} = V_X$

$\frac{2WI}{9\sqrt{3}} = M_{MAX}$

$0.01304\ \frac{WL^3}{EI} = \Delta_{MAX}$

SIMPLE BEAM—LOAD INCREASING UNIFORMLY TO CENTER
C.4



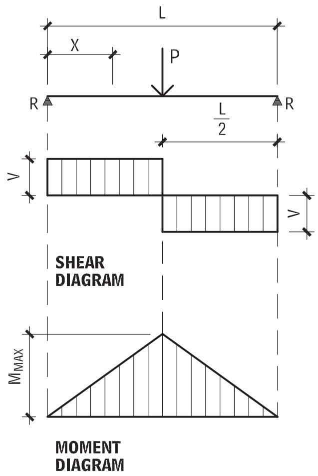
$\frac{w}{2} = V = R$

$\frac{W}{2L^2}(L^2 - 4X^2) = V_X$

$\frac{WL}{6} = M_{MAX}$

$\frac{WL^3}{60EI} = \Delta_{MAX}$

SIMPLE BEAM—CONCENTRATED LOAD AT CENTER
C.5

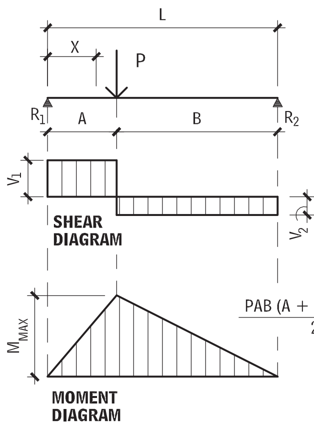


$\frac{P}{2} = V = R$

$\frac{PL}{4} = M_{MAX}$

$\frac{PL^3}{48EI} = \Delta_{MAX}$

SIMPLE BEAM—CONCENTRATED LOAD AT ANY POINT
C.6



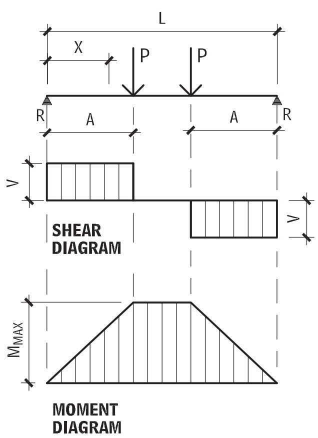
$\frac{PB}{L} = V_1 = R_1$

$\frac{PA}{L} = V_2 = R_2$

$\frac{PAB}{L} = M_{MAX}$

$\frac{PAB\,(A + 2B)\sqrt{3a(a + 2B)}}{27EIL} = \Delta_{MAX}$

SIMPLE BEAM—TWO EQUAL CONCENTRATED LOADS SYMMETRICALLY PLACED
C.7

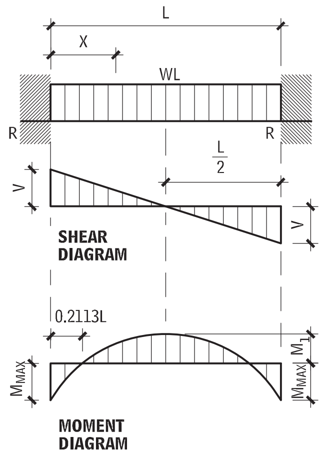


$P = V = R$

$PA = M_{MAX}$

$\frac{PA}{24EI}(3L^2 - 4A^2) = \Delta_{MAX}$

FIXED BEAM—UNIFORMLY DISTRIBUTED LOAD
C.8



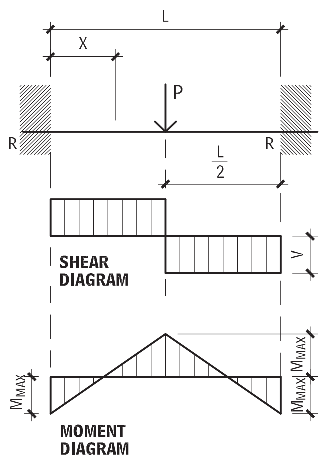
$\frac{WL}{2} = V = R$

$\frac{WL^2}{12} = M_{MAX}$

$\frac{W}{12}(6LX - L^2 - 6X^2) = M_X$

$\frac{WL^4}{384EI} = \Delta_{MAX}$

FIXED BEAM—CONCENTRATED LOAD AT CENTER
C.9



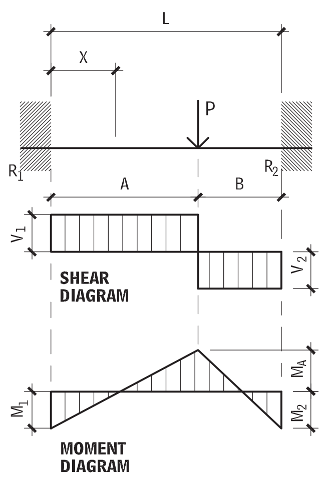
$\frac{P}{2} = V = R$

$\frac{PL}{8} = M_{MAX}$

$\frac{P}{8}(4X - L) = M_X$

$\frac{PL^3}{192EI} = \Delta_{MAX}$

FIXED
C.10



$\frac{PB^2}{L^3}(3A + B) = V_1 = R_1$

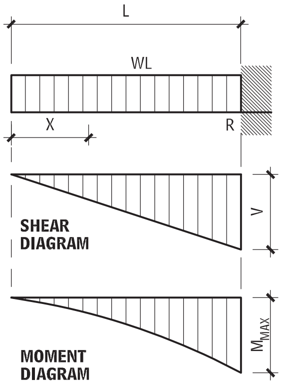
$\frac{PA^2}{L^3}(A + 3B) = V_2 = R_2$

$XR_1 - \frac{PAB^2}{L^2} = M_X$

$\frac{2PA^3B^2}{3EI(3A + B)^2} = \Delta_{MAX}$

STATIC LOADS FOR CANTILEVER BEAMS AND OVERHANGS

CANTILEVER BEAM—UNIFORMLY DISTRIBUTED LOAD
C.11



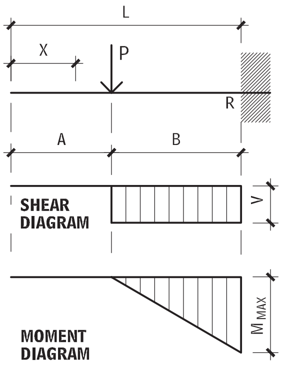
$WL = V = R$

$WX = V_X$

$\frac{WL^2}{2} = M_{MAX}$

$\frac{WL^4}{8EI} = \Delta_{MAX}$

CANTILEVER BEAM—CONCENTRATED LOAD AT ANY POINT
C.12

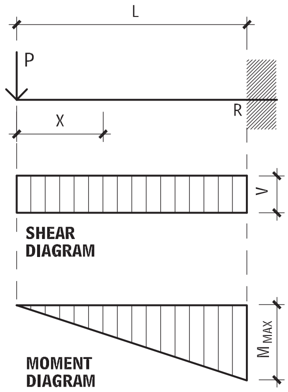


$P = V = R$

$PB = M_{MAX}$

$\frac{PB^2}{6EI}(3L - B) = \Delta_{MAX}$

CANTILEVER BEAM—CONCENTRATED LOAD AT FREE END
C.13

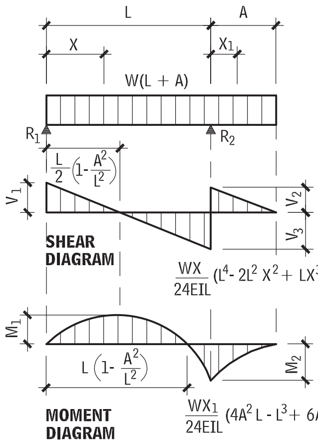


$P = V = R$

$PL = M_{MAX}$

$\frac{PL^3}{3EI} = \Delta_{MAX}$

BEAM OVERHANGING ONE SUPPORT—UNIFORMLY DISTRIBUTED LOAD
C.14



$\frac{W}{2L}(L^2 - A^2) - V_1 = R_1$

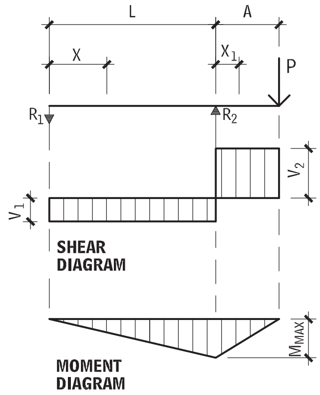
$\frac{WX}{2L}(L^2 - A^2 - XL) = M_X$

$\frac{W}{2}(A - X_1)^2 = M_{X1}$

$\frac{WX}{24EIL}(L^4 - 2L^2X^2 + LX^3 - 2A^2L^2 + 2A^2X^2) = \Delta_X$

$\frac{WX_1}{24EIL}(4A^2L - L^3 + 6A^2X_1 - 4AX_1^2 + X_1^3) = \Delta_{X1}$

BEAM OVERHANGING ONE SUPPORT—CONCENTRATED LOAD AT END OF OVERHANG
C.15



$\frac{PA}{L} = V_1 = R_1$

$PA = M_{MAX}$

$\frac{PAL^2}{9\sqrt{3EI}} = \Delta_{MAX}$

$\frac{PA^2}{3EI}(L + A) = \Delta_{MAX1}$

INDEX

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