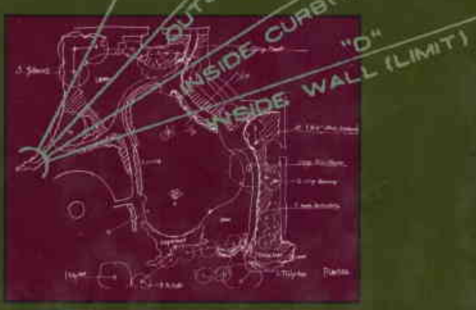
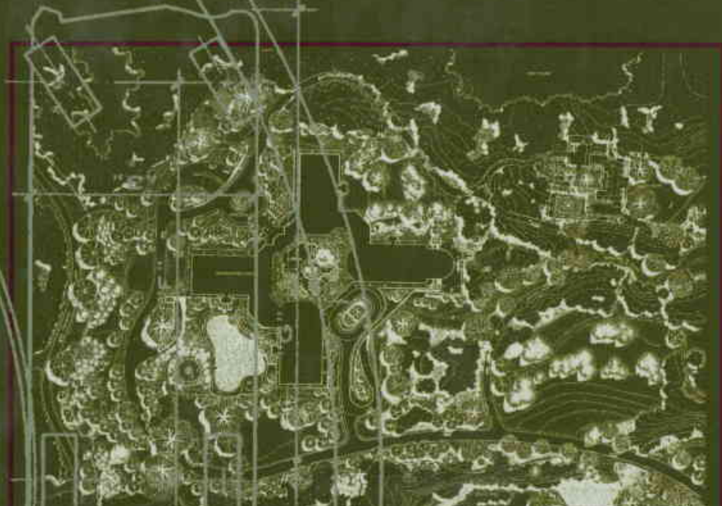
TIME-SAVER STANDARDS

FOR LANDSCAPE ARCHITECTURE

second edition





CHARLES W. HARRIS
NICHOLAS T. DINES

EXTENDED LENGTH VEHICLES

TIME-SAVER STANDARDS
FOR LANDSCAPE ARCHITECTURE:
DESIGN AND CONSTRUCTION DATA

Second Edition

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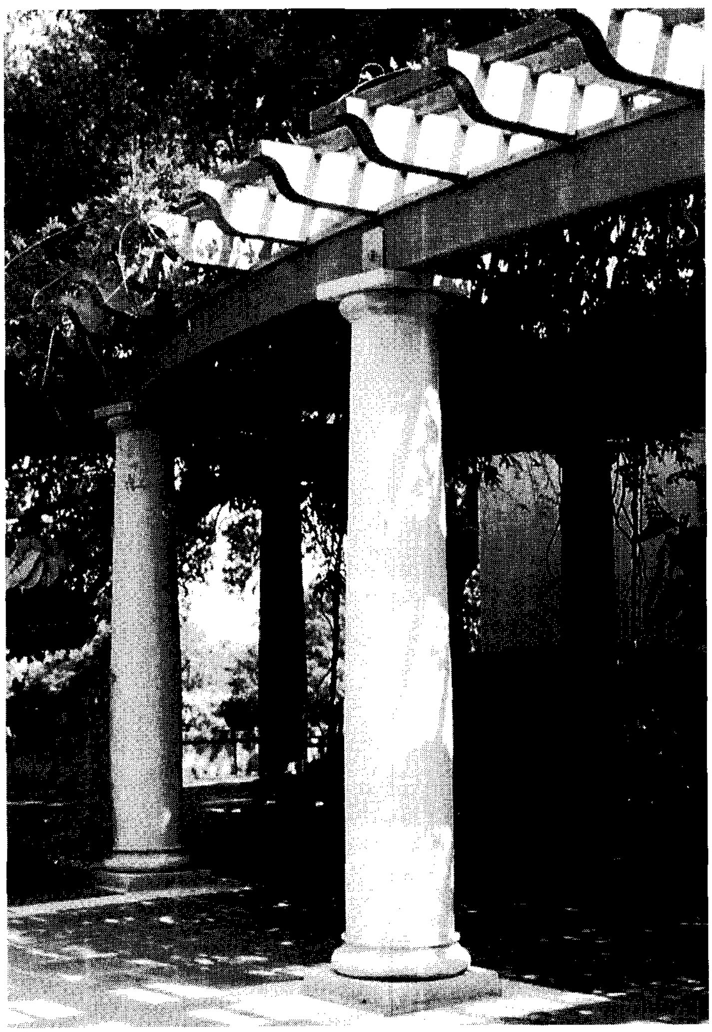
TIME-SAVER STANDARDS FOR LANDSCAPE ARCHITECTURE:

DESIGN AND CONSTRUCTION DATA

Second Edition



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Dedication

This second edition is dedicated to the memory of the late Dr. Albert Fein, who was instrumental in bringing the Editors and McGraw-Hill together to create the first edition. He was a champion of Landscape Architecture and possessed a broad view which encompassed both its social purpose and the technology required to give form to its vision. He was a historian, a mentor, a colleague, and a friend.

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Foreword

The publication of this handbook represents an historic event for the profession of landscape architecture. By scope and organization, it provides a broad practical definition of what landscape architecture is as an applied art and science. The data and standards it contains demonstrate how and where the profession interconnects with the efforts of many specialists from different sciences and technologies. In this way it is a book for the future as much as it is for the present; it recognizes the need for more interdependence between the various professions as specific tasks become larger and more complicated.

The initial idea for this handbook was conceived by Jeremy Robinson, formerly a senior editor at McGraw-Hill, who saw the growing national and international importance of landscape architecture and the need for such a handbook on design and construction data. It would be not only for landscape architects but also for architects, planners, engineers, conservationists, land developers,landscape contractors, and others who are concerned with our natural environment and how it is modified. The late Dr. Albert Fein, a consulting editor for landscape and landscape architecture at McGraw-Hill, brought the concept to Professor Charles Harris of the Harvard Graduate School of Design. Professor Harris has spent most of his career teaching landscape architecture with an early and continuing interest in land planning, design,and development. this book is a natural outgrowth of his longstanding interest in landscape construction, which was first influence by Professor Otto Schaeffer of the University of Illinois and later by Professor Walter L. Chambers of the Harvard Graduate School of Design. Harris enlisted the help of Professor Nicholas T. Dines of the Department of Landscape Architecture and Regional Planning, University of Massachusetts, in organizing, compiling, and editing material for the handbook.

Two basic abilities were needed for the successful completion of this handbook. They were the ability to persuade a large number of practitioners and academics to contribute and/or review material for the various sections and the ability to organize this massive amount of information into a useful overall format. The task took longer and much more personal effort and funds than the editors planned. Because both editors are teachers, they should be pleased that this handbook will provide a way to continue their "teaching" long after they have ended their present academic careers.

Hideo Sasaki
Lafayette, California
1987

Preface

This second edition of *Time-Saver Standards for Landscape Architecture: Design and Construction Data* has been expanded and re-designed to offer easier access to more information on landscape design and construction processes. The Editors have striven to create a common technical framework for the professions of landscape architecture, architecture, engineering, and planning, by expanding and emphasizing the core construction content of the profession. Site Construction Operations has been added to describe the procedures and equipment required to build on the land from the contractor's perspective; Spatial Standards has been revised to emphasize human-scale dimensions in the landscape, with provisions for small, medium, and large-scale cultural settings; A new section on Energy and Resource Conservation focuses on both site planning and design approaches which promote appropriate bioclimatic responses; Site Drainage has been folded into Stormwater Management with emphasis on best management practices and water quality; Plants and Planting now includes expanded coverage of xeriscape principles, native plant associations, and urban street tree detail advances; and lastly, Details and Devices has expanded coverage of new CAD details developed by the Editors for *Time-Saver Standards Landscape Construction Details* on CD. Promoting responsible resource conserving design and construction practices remains a prime objective of the second edition, continuing the original aim of the first edition. In many instances, minimum standards are accompanied by a recommended standard which may serve a broader objective.

Dimensions and quantities have been converted to metric values with US units in parentheses wherever possible. Soft conversion rules apply to manufactured products and proprietary clearances, and hard conversions apply to general planning guidelines rounded to the nearest 5 mm. Conversion rules set forth by the National Institute of Building Science have been added to the Appendix along with other data on metric practices in design and construction.

Specific figure references are cited at the end of the book, and general references are cited at the end of each section. All data shown is for preliminary planning and design only, and is not intended to serve as a substitute for informed professional judgment required of specific site circumstances. In all matters involving public health and safety, agency authorities or appropriate practicing professionals should be consulted.

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Preface to the first edition

Time-Saver Standards for Landscape Architecture: Design and Construction Data is a book about building on the land, a comprehensive process that involves several elements: (1) interaction with existing natural and cultural systems, (2) dependence upon both site-specitic and equipment-specific design and construction techniques, and (3) the use of a wide range of materials and devices.

The book covers some 50 topics, each comprising a separate sectino and grouped into nine divisions. They are linked together by a system of cross-references. For example, when the topic of a section requires showing a variety of alternatives for one detail, such as a curb, the reader is shown only a few generic types within the section. Additional examples are covered under the appropriate heading in Division 900: Details and Devices.

The topics represented within this handbook are but a small portion of the potential range of topics that deserve treatment. Several other topics have already been identified and some have received preliminary work, but for reasons of space, time, and other factors, they could not make it into this edition. Readers are invited to suggest topics and contributors for possible inclusion in later editions.

A dual system of measurements, U.S. standard and metric, has been included for many sections. The metric data, where shown, has been subordinated to the U.S. units.

Many of the standards shown in this book are considered to be minimal. The reader is urged to consider using more optimal standards for specific situations. Contributors were asked to include both "low-tech" and "high-tech" standards and data. It is expected that the reader will adapt the data as necessary for a specific application. References have been cited at the end of most sections from which more detailed data may be obtained. The reader is reminded that the data shown in this book cannot be considered a substitute for informed judgment based on careful consideration of all aspects of a specific problem. In all cases where public health and safety are involved, an authority on that problem should be consulted.

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Acknowledgments

The Editors wish to acknowledge with gratitude those who contributed new work, revised previous work, or who reviewed and corrected submitted drafts. Each contributor, section editor, technical writer, and reviewer is listed at the beginning of each section.

Assembling an anthology of methods, standards, and techniques requires research and a free exchange of ideas between many professional disciplines. The research office for the second edition was generously provided by the Department of Landscape Architecture and Regional Planning at the University of Massachusetts in Amherst. Special thanks go to Dr. Meir Gross, Department Head, for his enthusiastic support and to Dr. Robert Helgesen, Dean of the College of Food and Natural Resources, who through his support of the Department, indirectly helped the project reach its conclusion. Other departmental administrative assistance was ably provided by Dale Morrow.

The Editors continue to acknowledge the generous support offered by The Harvard Graduate School of Design which provided space and assistance for the first edition, and also to the many H.G.S.D. alumni and their firms for their support and assistance.

The Editors wish to specifically thank the following individuals groups, and organizations:

• Kyle D. Brown, Assistant Editor and Technical Writer, for his extraordinary organizational ability, his understanding of information technology, and for his invaluable critical perspective.

• Jeff Blankenship, for managing the project CAD work, for assisting in office management, and for his technical writing and editing contributions.

• Susan Gierman-Clark and Jeff Potter for outstanding assistance, cooperation, and leadership in the final book design and layout.

• Lori Kissinger, Julie Netzley, Sarah Gronquist, Megan Gardner, and Mark Fisher for early layout design, editing, and administrative contributions.

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• David Kvinge, Kat Hardesty, Kathy Crewe, Ginny Leonard, and Rob Malone for scanning, graphics, and editing final drafts.

The professional offices of Sasaki Associates, Inc. of Watertown, and The Berkshire Design Group of Northampton provided technical resources and professional consultation. Wallace, Roberts, and Todd, Inc. of Philadelphia, provided valuable assistance in securing CAD files for construction documents prepared by their office and shown in Section 110.

The Editors wish to further acknowledge the leadership and support extended to the project by the McGraw-Hill Publishing Company and especially the publisher, Sybil Parker, past editor, Joel Stein, and present editor Wendy Lochner for their vision, encouragement, and trust.

Lastly, we wish to thank our families who once again graciously made remarkable adjustments to allow this work to be carried to its conclusion.

Charles W. Harris and Nicholas T. Dines

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TIME-SAVER STANDARDS
FOR LANDSCAPE ARCHITECTURE:
DESIGN AND CONSTRUCTION DATA

Second Edition

DIVISION 100

Processes

SECTION 110

Construction Documents

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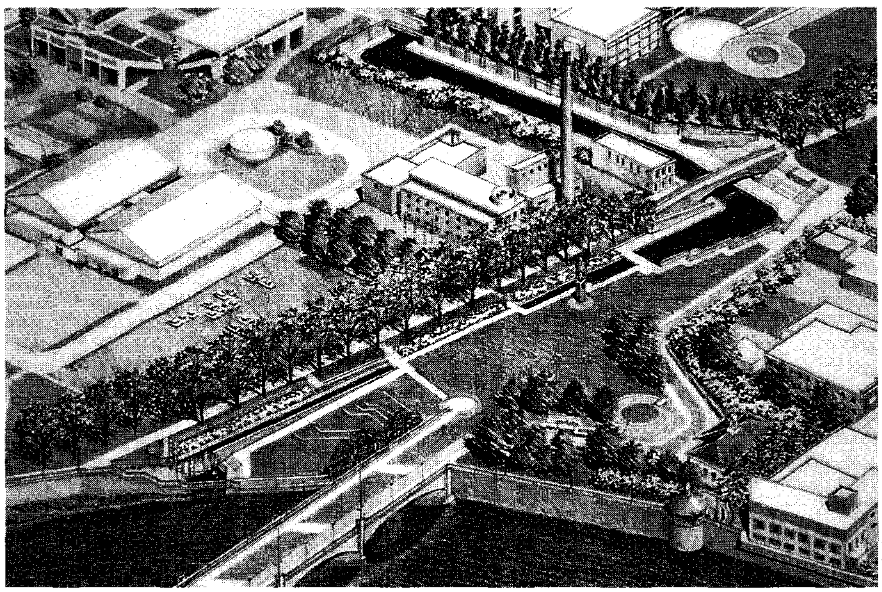
The illustrations for this section were supplied by Sasaki Associates, Inc., Watertown, Massachusetts and Wallace Roberts and Todd, Philadelphia, Pennsylvania.



Sasaki Associates

CONTENTS

1.0 INTRODUCTION

1.1 General

The production of landscape construction drawings (which, together with the specifications, constitute construction, or contract, documents) is the culmination of a systematic design process and begins the site development implementation or construction phase of project administration.

1.2 Example Project: Central Indianapolis Riverfront

The following construction drawings have been executed and furnished by Wallace Roberts and Todd of Philadelphia, Pennsylvania. These construction documents are based on the original master plan developed by Sasaki Associates, Inc., of Watertown, Massachusetts as shown in the aerial perspective at the front of this section. They represent the scope of work most generally associated with large waterfront planning projects. Although the figures pertain to a specific case study, they can serve as a general model for other similar projects (Figures 110-1 through 110-6).

The master plan for the nine-mile corridor of the White River that flows through the City of Indianapolis was designed to transform the urban reaches of the river into a unifying spatial system, forging new links between the downtown and the river and reconnecting the citizens of Indianapolis with a long-neglected resource. To protect the downtown from the river's periodic flooding, massive levees and flood walls had been constructed. These barriers, however, had the unwanted effect of dividing the city. To minimize this separation and create a public amenity, the master plan proposed the construction of continuous public access trails along both banks of the river. These riverfront promenades were designed to link downtown Indianapolis with existing recreational corridors to the north and south, taking their design cues from the varied urban contexts abutting the river. Major public open spaces at key locations along the riverfront promenades were included to enhance the connection between the river and the adjacent urban center.

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Signage and Graphics

2.0 CONSTRUCTION DOCUMENTS

2.1 Purpose

In essence, construction documents are graphic and verbal instructions to a contractor for the purpose of bidding and constructing a proposed design. Drawings are drafted to scale so that a contractor can readily assess the spatial relationships of proposed objects to each other and to existing known points in order to easily layout the design. Specifications include detailed descriptions of (1) general conditions, (2) special provisions, (3) materials, (4) quantities, and (5) information on installation. (Refer to 3.0 Specifications in this section for more information on specifications.)

Legal Responsibilities:

As formal legal contract documents, construction drawings must be accurate. Discrepancies (errors and omissions) between the proposed work and the existing conditions, or between the construction drawings and the specifications, should be kept to an absolute minimum.

Cost Estimates:

Construction drawings, together with the specifications, are used by contractors to estimate costs for bidding purposes. The specifications spell out in detail the type and quantity of materials to be used, the procedures for fabrication, and the application of products and materials. Construction drawings provide the contractor with information concerning linear and aerial dimensions, volumes, and the location of proposed elements (structures, trees, etc.). The drawings should be coordinated with the specifications so that the contractor has enough information to construct the project from the data shown.

2.2 Construction Operations Represented by Drawings

In actual practice, the information on each drawing is translated by the contractor into various operations, involving equipment and personnel. In effect, each drawing represents a class of operations in the field. The drawings are therefore organized by construction activity. Several different operations are normally carried out simultaneously during the construction of a project. Project construction is not a linear process; it more resembles a network of simultaneous activities.

The construction activities associated with site construction (as briefly discussed below) are:

1. Preliminary surveying
2. Tree protection, temporary conditions, erosion control, and transplanting
3. Clearing, grubbing, and demolition
4. Topsoil stripping and stockpiling
5. Rough grading
6. Finish grading
7. Installation of site improvements
8. Planting and seeding

Preliminary Surveying:

The contractor verifies the major dimensions, roadway geometry, property boundaries, construction limit line, stockpiling areas, and other horizontal measurements.

Tree Protection, Temporary Conditions, Erosion Control, and Transplanting:

All trees so designated on the drawings are wrapped or enclosed according to the specifications to protect them from root or bark damage. Some trees may be temporarily transplanted to avoid construction damage. Erosion control measures are employed to prevent silting of streams and drains and are usually regulated by Environmental Protection Agency specifications.

Clearing, Grubbing, and Demolition:

All trees, shrubs, rock outcrops, slabs, structures, and utility lines within the project area that are to be abandoned or moved are designated on the drawings for removal by the contractor.

Topsoil Stripping and Stockpiling:

The contractor removes all topsoil within the grading limits and stockpiles the soil in whatever areas will be convenient for future respreading at the completion of the project.

Rough Grading:

By blasting, trenching, backfilling, and cutting and filling to the proposed new subgrade, the contractor prepares all subgrade surfaces to receive foundation footings and subbase material for below- and on-grade structures. Trenching for utility lines also occurs at this stage. The top elevations of manholes and drains are set at their approximate grades without final brick course shims or rims.

At the completion of the rough grading, all exterior surfaces are cut or filled to specified rough-grade tolerances [± 150 to 300 mm (6 to 12 in)]. They are then ready for final grading prior to placing the topsoil and the wearing surfaces (concrete, asphalt, brick, etc.).

Finish Grading:

The project is staked out and resurveyed to establish the finished geometry and the elevations of walks, roads, and other edges. The paved areas are then graded to finer tolerances, and base material is installed. Topsoil is spread over the rough grades in the planted areas to within a tolerance of ± 25 to 75 mm (1 to 3 in).

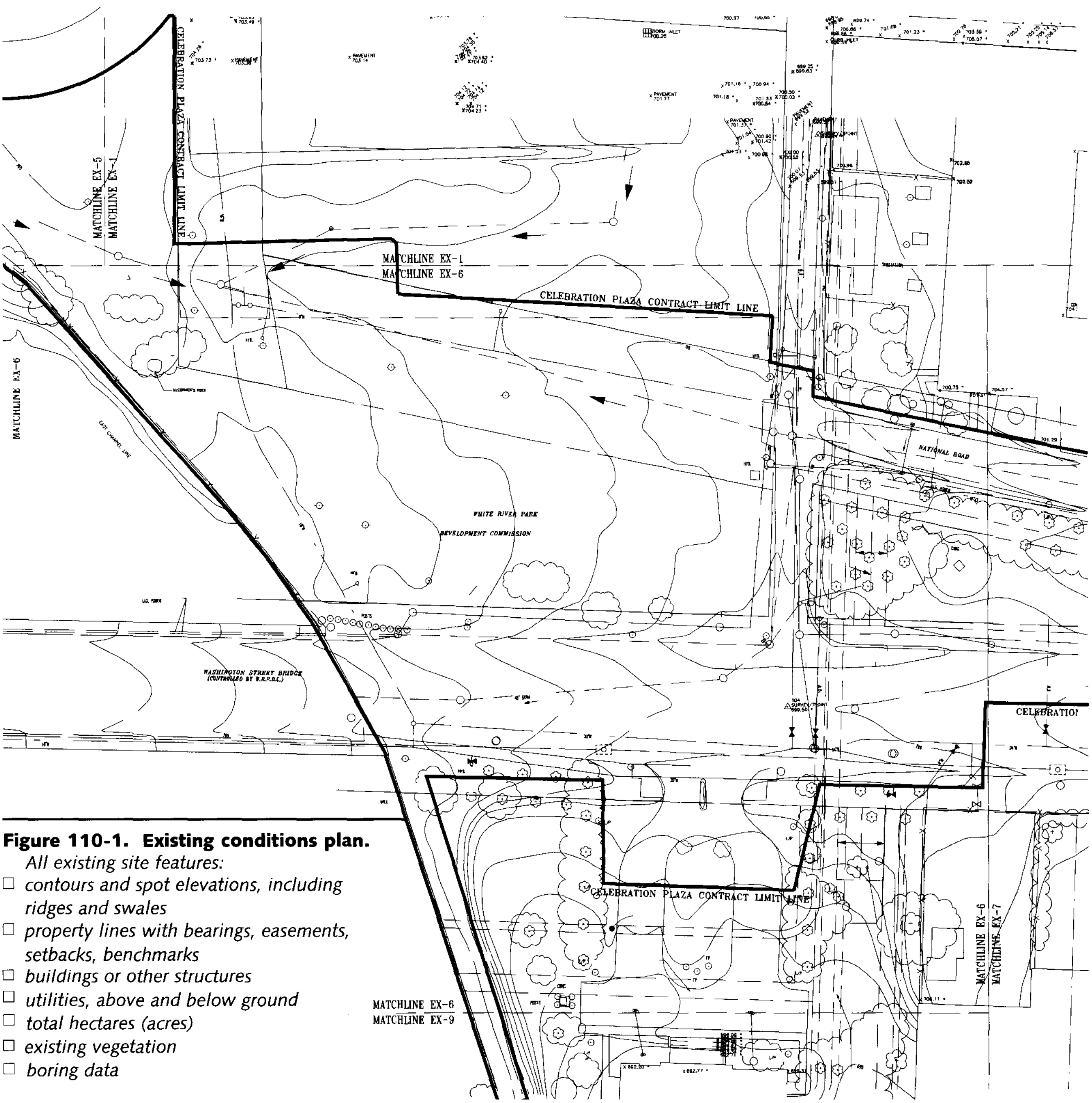


Figure 110-1. Existing conditions plan.
All existing site features:
- ☐ *contours and spot elevations, including ridges and swales*
- ☐ *property lines with bearings, easements, setbacks, benchmarks*
- ☐ *buildings or other structures*
- ☐ *utilities, above and below ground*
- ☐ *total hectares (acres)*
- ☐ *existing vegetation*
- ☐ *boring data*

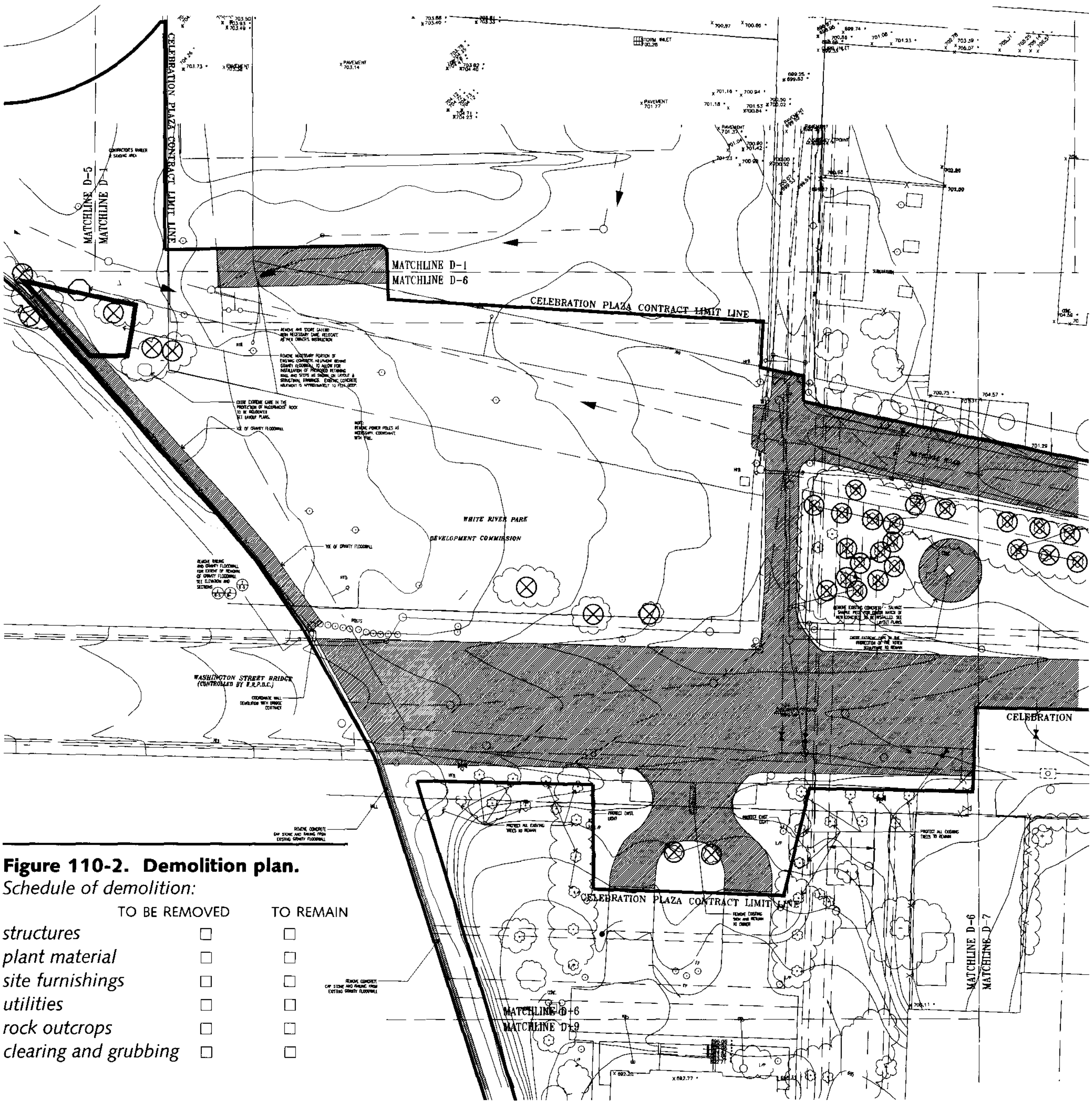


Figure 110-2. Demolition plan.

Schedule of demolition:

	TO BE REMOVED	TO REMAIN
structures	☐	☐
plant material	☐	☐
site furnishings	☐	☐
utilities	☐	☐
rock outcrops	☐	☐
clearing and grubbing	☐	☐

Installation of Site Improvements:

The contractor installs fixtures, benches, pavements, steps, trash receptacles, planters, equipment, and finish amenities.

Planting and Seeding:

The contractor plants trees, shrubs, and other plant materials; mulches and edges beds; and harrows, rakes, conditions, fertilizes, and seeds or sods lawn areas.

For a more detailed discussion of construction processes, refer to Section 130.

2.3 Drawing Organization

The contractor must fully understand the total package of information presented and its organization before any single operation can occur.

Sheet Information:

The following information is often found on all sheets in the package:

1. Title block:
   - Sheet title
   - Client's name
   - Name of consulting firm(s), logo, address and phone number
   - Date
   - Drawn by:
   - Checked by:
   - Revision block
   - Job number
   - Sheet number
2. Border with appropriate space for binding sheets
3. North arrow
4. Written and graphic scale
5. Registration seal
6. Appropriate legend, notes and labels
7. References to copyright

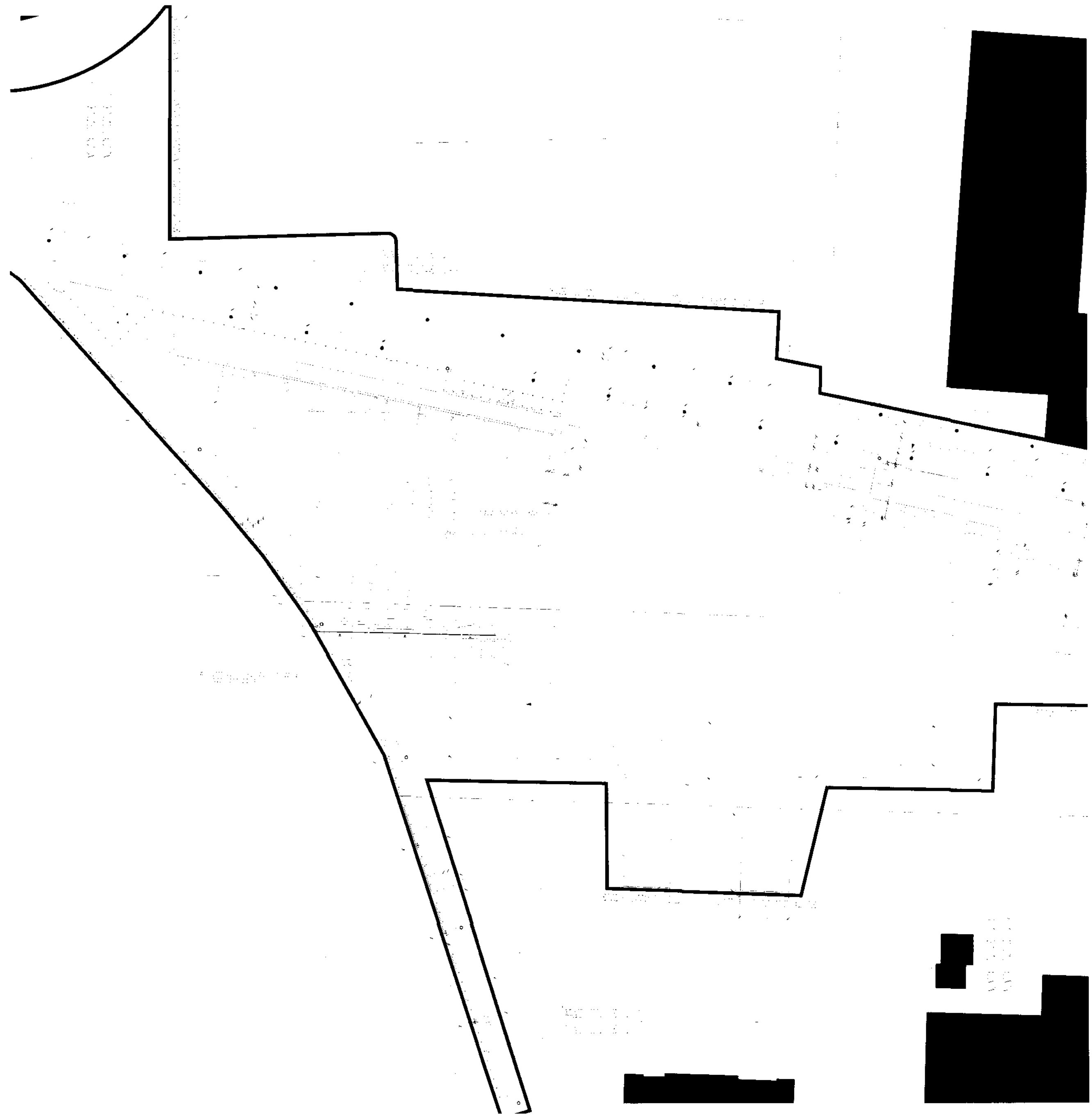


Figure 110-3. Layout and materials plan.

- ☐ *Existing site features, pavements, structures, major plant materials and topography*
- ☐ *Property lines with bearings and distances, easements, setbacks, match lines, limit of contract lines and benchmarks*
- ☐ *Boring locations with cross-reference to logs*
- ☐ *Roads, parking and service areas locating:*
  - *—centerline stations, bearings, distances, curve data, etc.*
  - *—intersection radii*
  - *—lot dimensions referenced to road centerline*
  - *—traffic marking locations, stalls*
  - *—required monument positions*
- ☐ *Buildings and other structures*
  - *—floor elevations noted*
  - *—located by dimensions from the column line or foundation to the site layout base line*
  - *—show overhanging floors and roof lines*
- ☐ *Outdoor lighting locations*
- ☐ *Other site features:*
  - *—walls, walks, steps*
  - *—benches and planters*

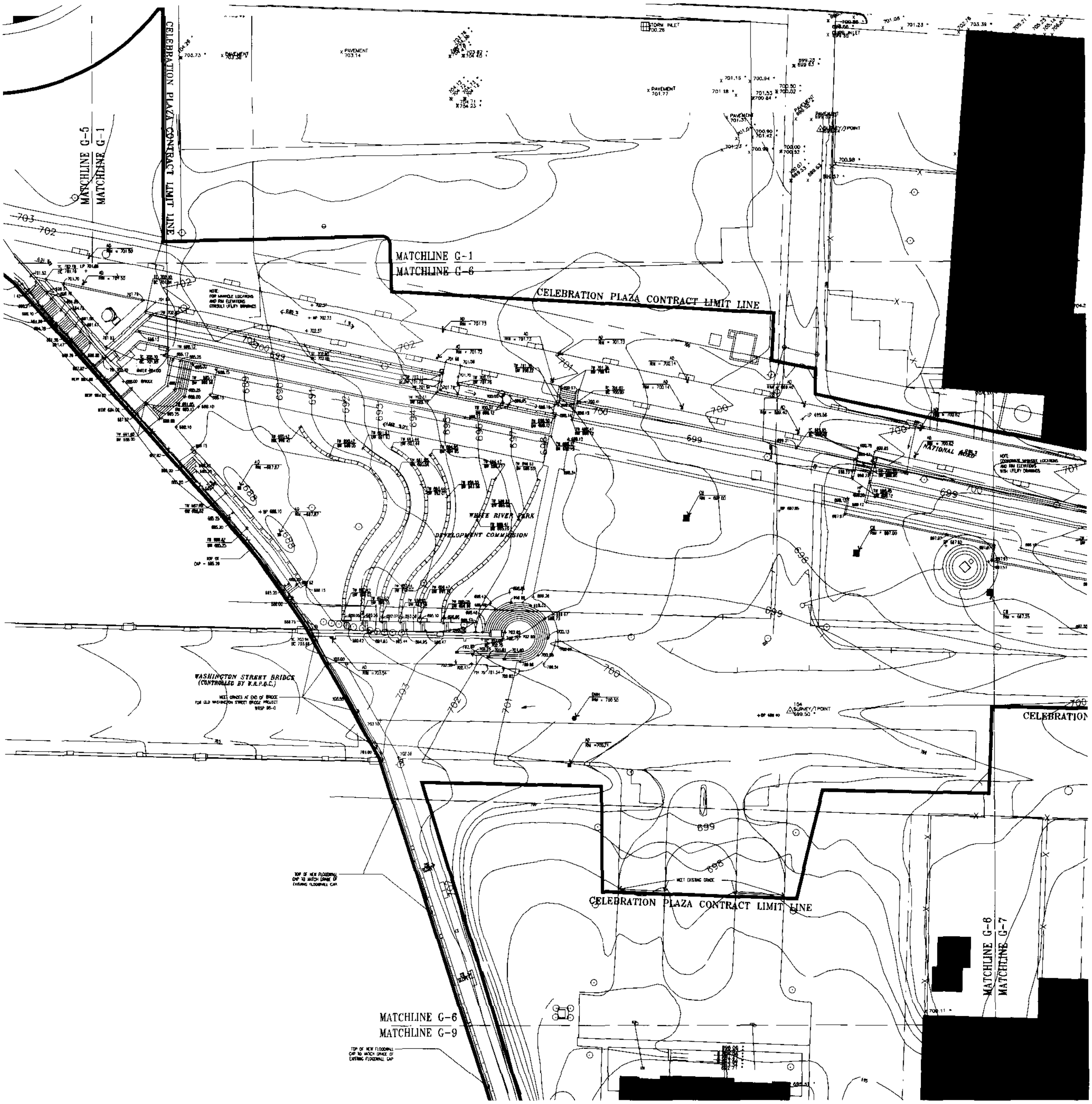
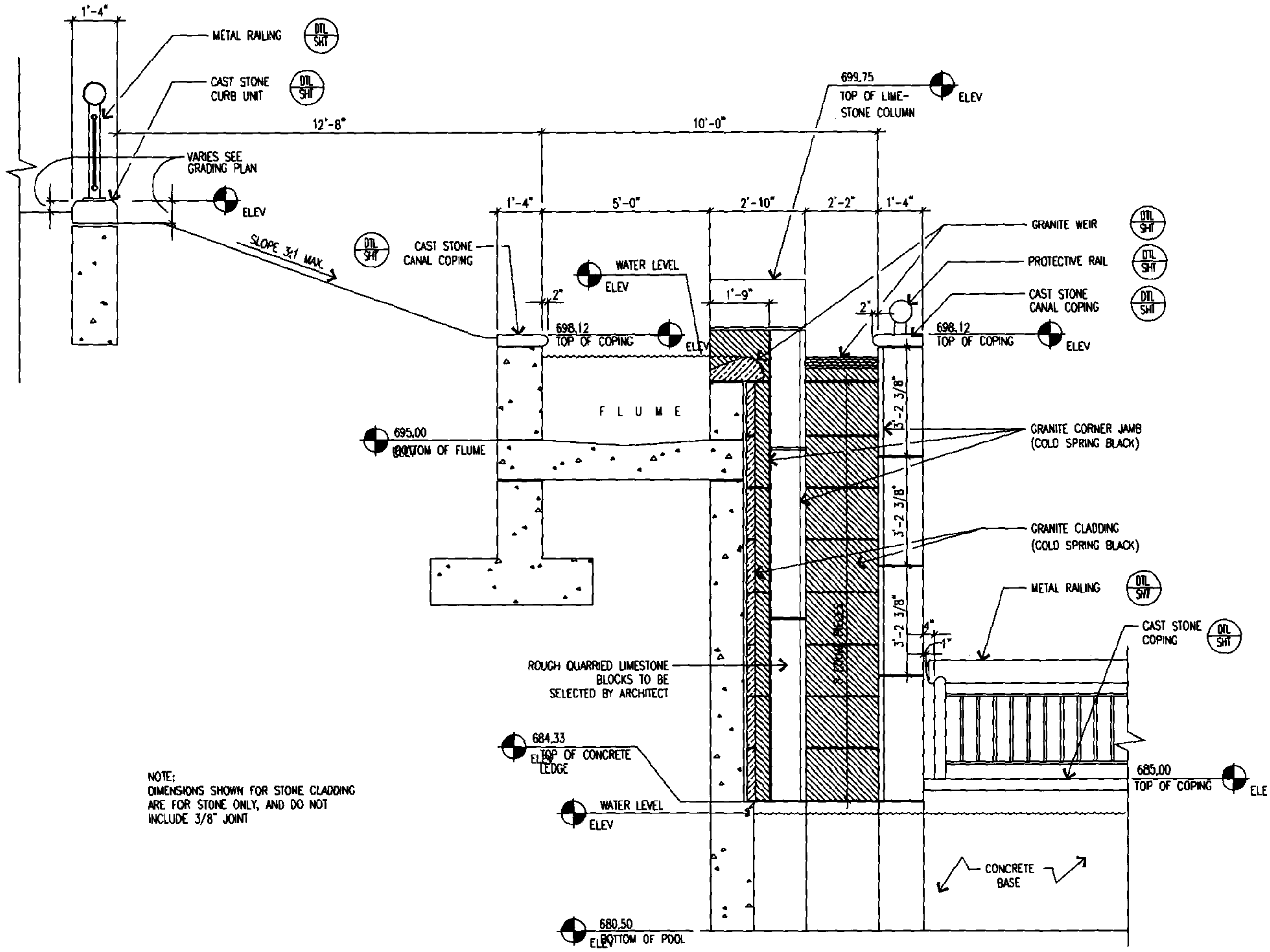


Figure 110-4. Grading and drainage plan.

- ☐ *Property lines, match lines, limit of contract and benchmark*
- ☐ *All site features including: roads, parking, walks, walls, steps, etc.*
- ☐ *Existing contours and spot grades*
- ☐ *Proposed grading including:*
  - *—high points, low points, ridge and swale centerlines and grades*
  - *—spot elevations at all changes of gradient, walk ends and inlets*
  - *—spot elevations at top and bottom of all walls, steps and ramps*
  - *—floor elevation for every access level of each structure*
- ☐ *Subsurface drainage network*
- ☐ *Existing building, auxiliary structures and trees to be retained*
- ☐ *Protection for trees that will be affected by grading*
- ☐ *Cut and fill calculations and/or profiles*



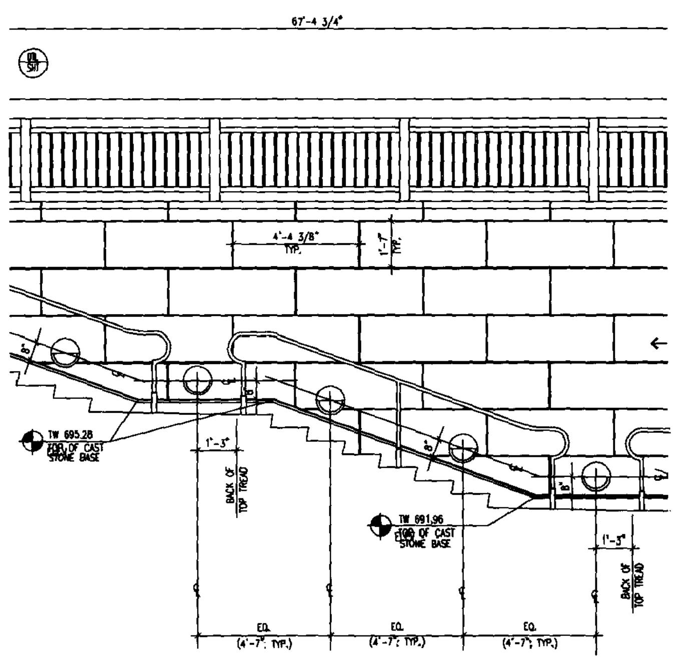


Figure 110-5. Site details and sections.

- ☐ *Earthwork sections*
- ☐ *Pavements, curbs and edgings*
- ☐ *Shelters, decks*
- ☐ *Screens, walls and steps*
- ☐ *Furnishings and features*
- ☐ *Utilities*
- ☐ *Plant installation*

For clarity, a set of construction documents is typically separated into the following drawing sets:

Primary drawings:

Primary drawings found in typical packages include:

1. Cover or index sheet
2. Existing conditions (Figure 110-1)
3. Demolition plan (Figure 110-2)
4. Site preparation plan
5. Layout (dimensioning) and materials plan(Figure 110-3)
6. Grading and drainage plan (Figure 110-4)
7. Planting plan and details
8. Utility plan
9. Site details and sections (Figure 110-5)

Additional drawings:

Additional drawings found in some packages include:

1. Plan enlargements (Figure 110-6)
2. Road profiles and sections
3. Shop drawings
4. Record (as built) drawings

Certain drawings may require multiple sheets for large, complicated projects, depending on the project area, drawing scale, and sheet size.

Cover or Index Sheet:

The cover sheet displays the project title, its sponsor, the consultants' names, an index to drawings by title and sheet number, a project location map, and sometimes a graphic key to the drawing symbols.

Existing Conditions Plan:

An existing conditions plan (Figure 110-1) is normally a reproduction of a registered survey plan for the site, drawn to or spliced into the standard sheet size of the working drawing set. It is this sheet that forms the basis for the horizontal controls presented in the layout plan and the vertical controls shown on the grading plan. This plan shows the property boundary line lengths and bearings, the total acres, the topographic configuration illustrated with contours and significant spot elevations, all existing structures, the vegetation (by type and size), utilities, easements, adjacent roads, a geodetic or DPW survey grid at 150 or 300 m (500 or 1000 ft) stations, a location map, and, in some cases, boring data.

The scale, date, and north arrow-which are required in all plan drawings-are of particular importance to the existing conditions plan. The date of the survey should be current enough to ensure that the survey is still valid. The north arrow should be labeled as true or magnetic north, since discrepancies between the two can vary by as much as 20 degrees or more, depending on geographic location.

Demolition Plan:

The information on a demolition plan is often overlaid the existing conditions plan and shows the items to be demolished, removed, relocated, or transplanted in order to prepare the site for new construction (Figure 110-2).

Site Preparation Plan:

This sheet illustrates the proposed development (in a line drawing only) and indicates the location of stockpiling areas, trees to be removed and thinned, limit of the work line, employee parking and construction road access, erosion control methods, concrete truck washout areas, staging areas, storage areas, stockpile areas, trees to be protected, and location of dewatering trenches or construction siltation ponds.

Layout and Materials Plan:

The layout plan (Figure 110-3) shows the proposed development superimposed on the existing conditions plan. The proposed design is located horizontally on the ground by using bearings and distances, station offsets, and coordinate points. Materials are identified, and keys to details and blowup plans are indicated. It is from this drawing that quantities of materials are calculated by the contractor.

Grading and Drainage Plan:

The grading plan (Figure 110-4) enables the contractor to establish vertical controls for the location of all site and building elements, based on their relationship to existing, identifiable elevations or bench marks. Elevational information is normally provided by both spot elevations and contour lines.

Surface drainage is an integral part of a grading plan. The locations and rim elevations of structures receiving storm runoff should be indicated on the grading plan even if complete subsurface utility information is provided on a separate site utility plan, since this information is basic to the site grading. If a separate site utility plan is not provided, the invert elevations and pipe sizes, types, and locations should also be included.

Care should be taken to coordinate the grading plan with building elevation drawings, finish floor elevations, and all utility drawings in order to avoid below-grade conflicts. The limit of grading is usually indicated by the no-cut/no-fill line.

Planting Plan and Details:

Planting plans must accurately show the locations of all proposed plant materials (differentiated graphically from existing plant materials to remain), their names, sizes, and any other characteristics that will assist the designer in specifying the precise type of specimen required. A plant list, or schedule, indicating the quantity, botanical name (including genus, species, and variety), common name, size (height, spread, caliper, etc.), spacing, and special requirements (multistem, first branch height, etc.) is normally included on the plan. (Refer to Section 550: Plants and Planting, for more information.)

Landscape contractors will use the plant list to determine the quantities for each variety unless directed to do otherwise. A note on the drawing or a clause in the specifications should state that the plan shall take precedence over the list in the event of a discrepancy.

Typical items on planting plans and details include:

1. Property lines, match lines, and limit of contract
2. Buildings and overhangs
3. Paved areas, terraces, and walls
4. Surface and sub-surface utilities
5. Location and size of existing plant material
6. Location, type, and size of proposed plant material
7. Areas to receive seed or sod
8. Planting list or schedule
9. Existing and proposed topography
10. Location of decorative lighting fixtures
11. Irrigation (if not part of the utilities plan)

Utility Plan:

Depending on the scale and complexity, the number of drawings under this general heading will vary with each project.

Typical items on utility plans and details include:

1. Stormwater drainage: surface and conduit system
2. Subdrainage: tile fields, footings, etc.
3. Sewerage: sanitary sewer and septic systems

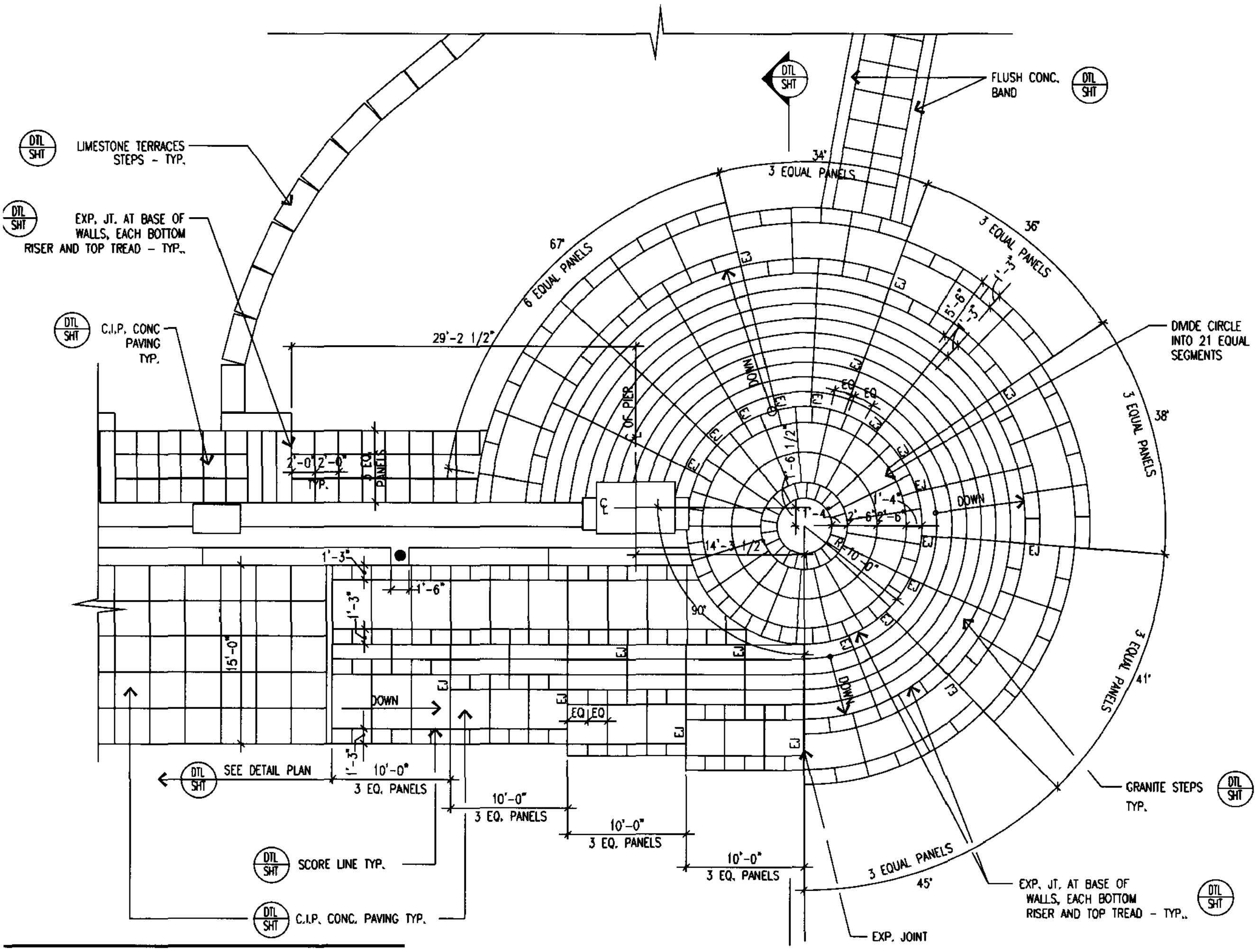


Figure 110-6. Plan enlargements.

☐ *Location of features*
☐ *Dimensions*
☐ *Grading*
☐ *Material pattern*
☐ *Planting*
☐ *Relation to overall plan*

4. Water distribution: drinking, irrigation, fountains, and fire control
5. Electrical layout: lighting and outlets
6. Buried cables: telephone, electrical, optic, cable TV, etc.
7. Special waste drains: chemical/acid, petroleum, etc.
8. Steam and heat lines: pipes, expansion joints, and heat cables
9. Fuel lines: natural gas and petroleum

In practice, utility plans are most often drawn on halftone grading plans so that existing conditions, horizontal layout, and vertical dimensions are shown. Utility plans must be coordinated with other drawings in order to avoid conflicts with major plantings or important hard-surfaced areas (future maintenance requirements), to avoid conflicts with other buried utilities, and to ensure sufficient cover.

Site Details and Sections:

The site details (Figure 110-5) convey specific methods of construction to the contractor. The manner in which this is achieved is often through sections, usually drawn to a scale of from 1:10 to 1:20 (1/2" = 1'-0" to 1 1/2" = 1'-0"). (See Table 110-1 Metric vs. Customary Scales and Ratios). Though not necessary, it is helpful to group details of like subjects together, such as pavements, walls, and stairs. Besides helping contractors to locate details, this shows the differences between similar sections more vividly. (Refer to Division 900: Details and Devices, for more information on construction details.)

As with the accompanying plans, the details work in concert with the specifications to provide complete data to the contractor. The information supplied by the specifications should not be included in the details.

Plan Enlargements:

Plan enlargements (Figure 110-6) are used as needed to show detail design layouts in courtyards or entrances, etc. They can show dimensions, grading, material pattern, planting, etc. For construction purposes, the scales of these blowups are typically 1:200 (1/16" = 1'-0" or 1" = 20'-0"), or 1:100 (1/8" = 1'-0" or 1" = 10'-0").

Road Profiles and Sections:

Road profiles show a profile section along the roadway centerline and designate finish and existing grades at 10 to 100 m (50 to 100 ft) stations along that line. The horizontal (H) scale is usually the same as that of the plan, and the vertical (V) scale is exaggerated at least 4:1 but more commonly 10:1 [1:500 (1" = 50')H and 1:50 (1" = 5')V]. The profile sheet shows the location and length of:

1. All vertical parabolic curves
2. Horizontal curves by symbol
3. Superelevation
4. High and low points

5. Top of curb
6. Bottom of gutter lines

Shop Drawings:

Shop drawings are provided by the contractor when required by the designer. In some cases a more efficient and economical solution may be arrived at if the contractor is given latitude in the design of special features requiring experienced craftsmanship. The landscape architect has final approval over shop drawings before the materials are ordered.

Record (As-Built) Drawings:

Often, in order to properly maintain a project after construction, a set of record drawings are created that show the design as it was actually built. The contractor is required to keep track of all changes and amendments to the original construction documents so the landscape architect can create an official record of the built project.

3.0 SPECIFICATIONS

The importance of well-written specifications for a design project cannot be overemphasized. The specifications present detailed information on the materials required, the fabrication procedures, and the application of products and materials. They establish the scope of the work and clearly spell out the criteria for altering the scope (change orders, deletions, etc.). The drawings establish the dimensions and identify the materials to be used, and the specifications establish the procedural and performance standards required to construct the design as shown on the drawings.

A major source of general construction specifications is the Construction Specifications Institute (CSI). Division 2 (Site-work) is reproduced in Table 110-2.

Table 110-1. METRIC VS. CUSTOMARY SCALES AND RATIOS

Metric Scales	Customary Ratio	Customary Scales
1:5	1:4	3"=1'-0"
1:10	1:18	1 1/2"=1'-0"
	1:12	1"=1'-0"
1:20	1:16	3/4"=1'-0"
	1:24	1/2"=1'-0"
1:50	1:48	1/4"=1'-0"
1:100	1:96	1/8"=1'-0"
1:200	1:92	1/16"=1'-0"
1:500	1:384	1/32"=1'-0"
	1:480	1"=40'-0"
	1:600	1"=50'-0"
1:1 000	1:960	1"=80'-0"
	1:1 200	1"=100'-0"
1:2 000	1:2 400	1"=200'-0"
1:5 000	1:4 800	1"=400'-0"
	1:6 000	1"=500'0"
1:10 000	1:10 560	6"=1 mile
	1:12 000	1"=1000'-0"
1:25 000	1:21 120	3"=1 mile
	1:24 000	1"=2000'-0"
1:50 000	1:63 360	1"=1 mile
1:100 000	1:126 720	1/2"=1 mile

Source: R.S. Means, *How to Estimate with Metric Units.*

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Table 110-2. CONSTRUCTION SPECIFICATION INSTITUTE: DIVISION 2 — SITEWORK

DIVISION 2: SITE CONSTRUCTION

02050	**BASIC SITE MATERIALS AND METHODS**
-055	**Soils**
-060	**Aggregate**
-065	**Cement and Concrete**
	Asphalt Cement
	Hydraulic Cement
	Plant-Mixed Bituminous Concrete
	Recycled Plant-Mixed Bituminous Concrete
-070	**Geosynthetics**
	Geocomposite Edge Drains
	Geocomposite In-Place Wall Drains
	Geogrids
	Geotextiles
-080	**Utility Materials**
	Hydrants
	Manholes
	Meters
	Utility Boxes
	Valves
-090	**Joint Material**
02100	SITE REMEDIATION
-105	**Chemical Sampling and Analysis**
-110	**Excavation, Removal, and Handling of Hazardous Materials**
-115	**Underground Storage Tank Removal**
-120	**Off-Site Transportation and Disposal**
-125	**Drum Handling**
-130	**Site Decontamination**
-140	**Landfill Construction and Storage**
-145	**Groundwater Treatment Systems**
-150	**Hazardous Waste Recovery Processes**
	Air and Steam Stripping
	Soil Vapor Extraction
	Soil Washing and Flushing
-160	**Physical Treatment**
	Coagulation and Flocculation
	Reverse Osmosis
	Solidification and Stabilization
-170	**Chemical Treatment**
	Chemical Precipitation
	Ion Exchange
	Neutralization
-180	**Thermal Processes**
	Incineration
	Thermal Desorption
	Vitrification
-190	**Biological Processes**
	Aerobic Processes
	Anaerobic Processes
	Bio-Remediation
-195	**Remediation Soil Stabilization**
02200	**SITE PREPARATION**
-210	**Subsurface Investigation**
	Boring and Exploratory Drilling
	Core Drilling
	Geophysical Investigations
	Groundwater Monitoring
	Seismic Investigation
	Standard Penetration Testing
	Test Pits
-220	**Site Demolition**
	Building Demolition
	Minor Site Demolition for Remodeling
	Selective Site Demolition
-230	**Site Clearing**
	Clearing and Grubbing
	Selective Clearing
	Selective Tree Removal and Trimming
	Sod Stripping
	Stripping and Stockpiling of Soil
	Tree Pruning
-240	**Dewatering**
-250	**Shoring and Underpinning**
	Foundation Grouting
	Grillages
	Needle Beams
	Sheetpiling
	Shoring
	Slabjacking
	Soil Stabilization
	Underpinning
	Vibroflotation and Densification
-260	**Excavation Support and Protection**
	Anchor Tiebacks
	Cofferdams
	Cribbing and Walers
	Ground Freezing
	Reinforced Earth
	Slurry Wall Construction

Soil and Rock Anchors

-280 Grade Adjustment and Abandonment of Existing Miscellaneous Structures

-285 Rebuilt Miscellaneous Structures

-290 Site Monitoring

02300 EARTHWORK

-310 Grading

Finish Grading

Rough Grading

-315 Excavation and Fill

Backfill

Borrow Excavation

Compaction Excavation

Fill

Trenching

-325 Dredging

-330 Embankment

Armoring

Earth Dams

Soil Embankment

-335 Subgrade and Roadbed

Pre-watering of Excavation Areas

Reconditioning

Subgrade Modification

-340 Soil Stabilization

Asphalt Soil Stabilization

Cement Soil Stabilization

Geotextile Soil Stabilization and Layer

Separation

Lime Slurry Soil Stabilization

Lime Soil Stabilization

Pressure Grouting Soil Stabilization

-360 Soil Treatment

Rodent Control

Termite Control

Vegetation Control

-370 Erosion and Sedimentation Control

Cement Concrete Paving for Stream Beds

Erosion Control Blankets and Mats

Gabions

Geogrids

Geotextile Sedimentation and Erosion Control

Mulch Control Netting

Paved Energy Dissipators

Riprap and Rock Lining

Rock Barriers

Rock Basins

Rock Energy Dissipators

Slope Paving

Synthetic Erosion Control and Revegetation

Mats

Turf Reinforcement Mats

Water Course and Slope Erosion Protection

-380 Scour Protection

-390 Shoreline Protection and Mooring Structures

Breakwaters

Groins

Jetties

Moles

Revetments

Seawalls

02400 TUNNELING, BORING, AND JACKING

-410 Tunnel Excavation

Compressed Air Tunneling

Muck Disposal

Rock Excavation - Drill and Blast

Rock Excavation - Tunnel Boring

Machine (TBM)

Soft Ground Shield-Driven Tunneling

-420 Initial Tunnel Support Systems

Prefabricated Steel Tunnel Linings

Rock Bolting

Steel Ribs and Lagging

-425 Tunnel Linings

Cast-in-Place Concrete Tunnel Linings

Precast Concrete Tunnel Lining

-430 Tunnel Grouting

Earth Stabilization Chemical Grouting

Rock Seam Pressure Grouting

Tunnel Liner Grouting

-440 Immersed and Sunken Tube Tunnels

-441 Microtunneling

-442 Cut and Cover Tunnels

-443 Tunnel Leak Repairs

-444 Shaft Construction

-445 Boring or Jacking Conduits

02450 FOUNDATION AND LOAD-BEARING ELEMENTS

-455 Driven Piles

Cast-in-Place Concrete Piles

Composite Piles

Concrete Displacement Piles

Concrete-Filled Steel Piles

Driven Pile Load Tests

Driven Pile Repairs

Precast Concrete Piles

Prestressed Concrete Pile
Sheet Piles
Steel H Piles
Timber Piles
Unfilled Tubular Steel Piles

-465 Bored Piles

Auger Cast Grout Piles
Bored and Augered Pile Load Tests
Bored and Augered Pile Repairs
Bored and Augered Test Piles
Bored and Belled Concrete Piles
Bored and Socketed Piles
Bored Friction Concrete Piles
Drilled Caissons
Drilled Concrete Piers and Shafts
Uncased Cast-in-Place Concrete Piles

-475 Caissons

Box Caissons
Excavated Caissons
Floating Caissons
Open Caissons
Pneumatic Caissons
Sheeted Caissons

-480 Foundation Walls

Anchored Walls
Concrete Cribbing
Manufactured Modular Walls
Mechanically Stabilized Earth Walls
Metal Cribbing
Permanently Anchored Soldier-Beam Walls
Slurry Diaphragm Foundation Walls
Soldier-Beam Walls

-490 Anchors

Rock Anchors

-495 Instrumentation and Monitoring

Foundation Peformance Instrumentation

02500 UTILITY SERVICES

-510 Water Distribution

Cisterns
Disinfection of Water Distribution
Fire Protection
Hydrants
Site Water
Valves
Water Supply

-520 Wells

Extraction Wells
Monitoring Wells
Recharge Wells
Test Wells
Water Supply Wells
Well Abandonment

-530 Sanitary Sewerage

Gauging Stations
Packaged Pumping Stations
Packaged Lift Stations
Sanitary Cleanouts
Sanitary Sewage Systems
Sanitary Sewer Manholes, Frames, and Covers
Sewage Collection Lines
Sewage Force Mains
Site Sanitary Sewage Lines

-540 Septic Tank Systems

Drainage Field
Grease Interceptor
Sand Filter
Septic Tank
Siphon Tank

-550 Piped Energy Distribution

Chilled Water Distribution
Hot Water Distribution
Liquid Petroleum Gas Distribution
Natural Gas Distribution
Oil Distribution
Steam Distribution

-570 Process Materials Distribution Structures

-580 Electrical and Communication Structures

Antenna Towers
Lighting Poles and Standards
Transmission Towers
Underground Ducts and Manholes
Utility Poles

-590 Site Grounding

02600 DRAINAGE AND CONTAINMENT

-610 Pipe Culverts

-620 Subdrainage

Foundation Drainage Piping
Geocomposite Drains
Geotextile Subsuface Drainage Filtration
Pipe Underdrain and Pavement Base Drain
Retaining Wall Drainage Piping
Subgrade Drains
Tunnel Drainage Piping
Underslab Drainage Piping

-630 **Storm Drainage Catch Basins, Grates, and Frames**
- Combination Storm Drain and Underdrain
- Inlets
- Storm Drainage Manholes, Frames, and Covers
- Storm Drainage Pipe and Fittings
- Water Detention Chambers

-640 **Culverts and Manufactured Construction**
- Concrete Arch Buried Bridge
- Metal Pipe - Arch Culverts
- Metal Plate Culverts
- Precast Reinforced Concrete Arch Culverts
- Precast Reinforced Concrete Box Culverts
- Precast Reinforced Concrete Rigid Frame
- Culverts

-660 **Ponds and Reservoirs**
- Cooling Water Ponds
- Distributions Reservoirs
- Fire Protection Reservoirs
- Leaching Pits
- Pond and Reservoir Covers
- Pond and Reservoir Liners
- Retention Basins
- Sewage Lagoons
- Stabilization Ponds

-670 **Constructed Wetlands**

02700 BASES, BALLASTS, PAVEMENTS, AND APPURTENANCES

-710 **Bound Base Courses**
- Aggregate-Bituminous Base Course
- Aggregate-Cement Base Course
- Asphalt-Treated Permeable Base Course
- Bituminous Concrete Base Course
- Cement Stabilized Open Graded Base Course
- Cement Treated Courses
- Cold-Recycled Bituminous Base Course
- Hydraulic Cement Concrete Base Course
- Lean Concrete Base Course
- Lime Treated Courses
- Lime-Fly-Ash Treated Courses
- Plain Cement Concrete Base Course

-720 **Unbound Base Courses and Ballasts**
- Aggregate Subbase
- Aggregate Base Course
- Cracked and Seated Portland Cement
- Concrete Base Course
- Rubberized Portland Cement Concrete
- Base Course
- Sub-Ballast
- Top Ballast

-730 **Aggregate Surfacing**
- Cinder Sufacing
- Crushed Stone Sufacing

-740 **Flexible Pavement**
- Asphalt-Rubber and Rubber Modified Bituminous Pavement
- Athletic Bituminous Pavement
- Bituminous Concrete Pavement
- Cold Mix Bituminous Pavement
- Fiber-Modified Bituminous Pavement
- Polymer-Modified Bituminous Pavement and Rubberized asphalt
- Road Mix Bituminous Pavement
- Stone and Split-Mastic Bituminous Pavement

750 **Rigid Pavement**
- Continuous Reinforced Cement Concrete Pavement
- Exposed Aggregate Pavement
- Plain Cement Concrete Pavement
- Power Compacted Concrete Pavement
- Prestressed Reinforced Cement Concrete Pavement
- Reinforced Cement Concrete Pavement
- Roller-Compacted Concrete Pavement

-755 **Cement Concrete Shoulders**

-760 **Paving Specialties**
- Cold Plastic Pavement Markings and Legends
- Curb Cut Ramps
- Painted Traffic Lines and Markings
- Pavement Joint Sealant
- Pavement Markings
- Raised Pavement Markers
- Snow Melting Cables and Mats
- Stamped Pattern Concrete Pavement
- Tactile Warning Sufaces

-770 **Curbs and Gutters**
- Bituminous Concrete Curbs
- Cement Concrete Curbs
- Cement Concrete Gutters and Curbs
- Gutters
- Stone Curbs
- Simulated Stone Curbs

-775 **Sidewalks**

-780 **Unit Pavers**
- Asphalt Block Pavers
- Brick Pavers
- Interlocking Precast Concrete Pavers
- Precast Concrete Pavers
- Pressed Pavers
- Stone Pavers

-785 Flexible Pavement Coating and Micro-Surfacing

Cape Seal

Chip Seal

Fog Seal

Latex-Modified Emulsion

Micro-Suffacing

Sand Seal

Sandwich Seal

Slurry Seal

Surface Treatment

-790 Athletic and Recreational Surfaces

Baseball Field Surfacing

Multi-Purpose Court Surfacing

Resilient Matting

Synthetic Grass Sufacing

Synthetic Running Track Surfacing

Tennis Court Sufacing

-795 Porous Pavement

02800 SITE IMPROVEMENTS AND AMENITIES

-810 Irrigation System

Agricultural Irrigation System

Drip Irrigation System

Lawn Sprinkler System

-815 Fountains

-820 Fences and Gates

Chain Link Fences and Gates

Ornamental Metal Fences and Gates

Plastic Fences and Gates

Wire Fences and Gates

Wood Fences and Gates

-830 Retaining Walls

Cast-in-Place Concrete Retaining Walls

Interlocking Block Retaining Walls

Masonry Retaining Walls

Precast Concrete Retaining Walls

Timber Retaining Walls

-840 Walk, Road, and Parking Appurtenances

Concrete Median Barrier

Crash Barriers

Delineators

Fenders

Guide Rail

Impact Attenuating Devices

Metal Median Barriers

Parking Bumpers

Traffic Barriers

-850 Prefabricated Bridges

-860 Screening Devices

Jet Blast Barriers

Screens and Louvers

Sound Barriers

-870 Site Furnishings

Bicycle Racks

Prefabricated Planters Seating

Tables

Trash and Litter Receptors

-875 Site and Street Shelters

Bus Stop Shelters

-880 Play Field Equipment and Structures

Athletic or Recreational Screening

Playground Equipment

Play Structures

Tennis Court Windbreakers

-890 Traffic Signs and Signals

Post-Mounted Signs

Structure-Mounted Signs

Traffic Signal Supports and Equipment

-895 Markers and Monuments

Boundary and Survey Markers

02900 PLANTING

-905 Plants, Planting, and Transplanting

-910 Plant Preparation

Blankets

Forms and Stabilizers

Hydro-Punching

Mats

Mulching

Netting

Soil Preparation

Stakes

Topsoil

-915 Shrub and Tree Transplanting

-920 Lawns and Grasses

Hydro-Mulching

Plugging

Seeding and Soil Supplements

Sodding

Sprigging

Stolonizing

-930 Exterior Plants

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Plants and Bulbs

Shrubs

Trees

-935 **Plant Maintenance**
- Fertilizing
- Liming
- Mowing
- Pruning
- Watering

-945 **Planting Accessories**
- Landscape Edging
- Landscape Timbers
- Planters
- Tree Grates
- Tree Grids

02950 SITE RESTORATION AND REHABILITATION

-955 **Restoration of Underground Piping**
- Grouting Underground Piping and Units
- Relining Underground Piping and Units
- Sealing Underground Piping and Units

-960 **Flexible Pavement Surfacing Recovery**
- Pavement Milling and Pavement Cold Planing

-965 **Flexible and Bituminous Pavement Recycling**
- Cement-Based Bituminous Pavement Base Courses
- Cold In-Place Recycled Bituminous Pavement Courses
- Full-Depth Reclaimed Bituminous Pavement Base Courses
- Hot In-Place Recycled Bituminous Pavement Courses
- Hot In-Place Recycled Surface Course Overlays
- Roadbed Modification

-975 **Flexible and Bituminous Pavement Reinforcement and Crack and Joint Sealants**
- Fabric Reinforcement for Bituminous Pavement
- Polymer Modified Asphalt Joint and Crack Sealing
- Stress-Absorbing Membrane
- Stress-Absorbing Membrane Interlayer

-980 **Rigid Pavement Rehabilitation**
- Cement Concrete Bonded Overlays
- Cement Concrete Direct Partially Bonded Overlays
- Cement Concrete Pavement Recycling
- Cement Concrete Unbonded Overlays
- Concrete Pavement Jacking and Slabjacking
- Concrete Pavement Patching
- Full Depth Patching
- Grinding of Concrete Pavement
- Grooving of Concrete Pavement
- Joint Cleaning and Resealing
- Joint Rehabilitation
- Partial Depth Patching
- Pavement-Shoulder Joint Resealing
- Slab Stabilization
- Subsealing and Stabilization

-990 **Structure Moving**

* *Source:* Construction Specification Institute.

Site Construction Operations

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CONTENTS

1.0 INTRODUCTION

1.1 General

Site construction may be viewed as an invasive procedure akin to biological surgery. It requires the designer and the contractor to have full knowledge of the site's vital systems, and to have access to a broad array of techniques, equipment, and mitigating strategies to effectively integrate the proposed changes with the site's existing infrastructure and its natural systems. This section addresses the procedures and equipment required to execute site work with special focus on the sequential steps commonly found in most light to medium duty site construction projects.

1.2 Operations Objectives

Site construction operations are sequenced to insure efficient and systematic use of equipment and labor with the aim of:

1. Protecting identified site resources as required by plans and regulatory authorities.
2. Coordinating various building trades and construction processes.
3. Maintaining safe working conditions to limit liability and prevent injury.
4. Eliminating delays and material waste so the project can be completed within time and budget constraints.
5. Delivering completed work as specified in accordance with contractual agreements.

1.3 Contractor's Perspective

The contractor's view of a proposed design is different from that of the designer's. Whereas the designer tends to view the project in terms of material finishes, and final outcomes, it is the responsibility of the contractor to reverse engineer the project (with the aid of details and profiles) to envision how the site must be prepared to receive the new design. Figure 130-1a. illustrates a designer's view of a typical design which emphasizes finished surface elevations and vertical and horizontal dimensions. Figure 130-1b. illustrates a contractor's analysis of the same design with emphasis on the subgrade elevations required for all roads, walks, plazas, piers, footings, tree pits, etc. The contractor's view envisions the subgrade as either the bottom of a cut operation, or the top of a fill operation. In either event, all such surfaces must be structurally prepared to create a uniform subgrade prior to major trenching and backfilling. The challenge to both designer and contractor is to accomplish this central task while limiting the area of disturbance. Figure 130-2 illustrates how a design is superimposed on an existing landscape to create contract work zones and protected areas. Special care is typically required at the junctions of site and structure and where the new landscape meets the existing conditions.

1.4 Common Work Sequence

Most site construction follows a common sequence starting with the contractor's bid submittal and ending with final inspection. The exact sequence will vary with climate zone, soil, and vegetative cover, and local laws and customs. However, aspects of each step occur in most instances. The following points briefly summarize the process:

1. Define the project scope and the degree of site intervention required (light, medium, or heavy).
2. Examine the existing site conditions to identify fragile zones or areas requiring extensive mitigation (wetlands, endangered species, mature specimen trees, poor soils, bed rock or boulders, hazardous wastes, etc.).
3. Prepare a detailed quantity take-off and develop a construction strategy (materials quantity list, equipment mobilization and labor crew requirements, final cost estimate, and time line chart).
4. Execute a preliminary layout survey to confirm alignment and dimensional accuracy with regard to existing site hazards to be avoided or assets to be protected. Adjust plan with client approval if required.
5. Prepare the site for new construction (site preparation).
6. Develop the site according to plans and specifications (execute work).
7. Receive final inspection and client approval (punch list).
8. Execute final contract items (final clean-up, mechanic's lien waivers, final inspections, final payment, and certificate of occupancy).

2.0 CONTRACTOR'S RESPONSIBILITIES

2.1 Bid Preparation

The contractor must first prepare a bid for the proposed work based upon a thorough review of the construction documents which are typically divided into four parts:

1. **Working Drawings–** Scaled graphic plans and sections representing the proposed site development, and containing limited written notes. Quantities are estimated from the indicated dimensions. Layout and grading data is sufficiently detailed to allow direct transfer of the plan geometry to the construction site. (Refer to Section 110: Construction Documents for more information).
2. **Specifications–** Written descriptions of the work to be accomplished. They provide quality standards established by regulatory agencies, independent testing agencies, and product manufacturers. Specifications may be written to describe specific construction methods, or they may describe desired outcomes or performance requirements, allowing a degree of latitude as to method of execution.
3. **General Conditions–** Requirements

KEY POINTS: Contractor's Responsibilities

The contractor's main responsibility is to execute the contract work in a safe, technically competent, and efficient manner.

1. All site construction work is governed by the Contract Documents which consist of: working drawings, specifications, general conditions, and the agreement form.
2. A bid price is estimated based upon the cost of implementing all of the provisionof the working drawings and specifications within the framework of the general conditions and the agreement.
3. Bid prices based on careful physical analysis of the site and related technical reports may result in ± 5% unit price accuracy. Poor site data can cause site preparation unit price swings of up to ± 20%.
4. Site access and fragility, magnitude of material quantities, and construction time period available determine the construction strategy required.
5. Before final payment may be made, a final inspection must be passed, and mechanics lien affidavits must be submitted.

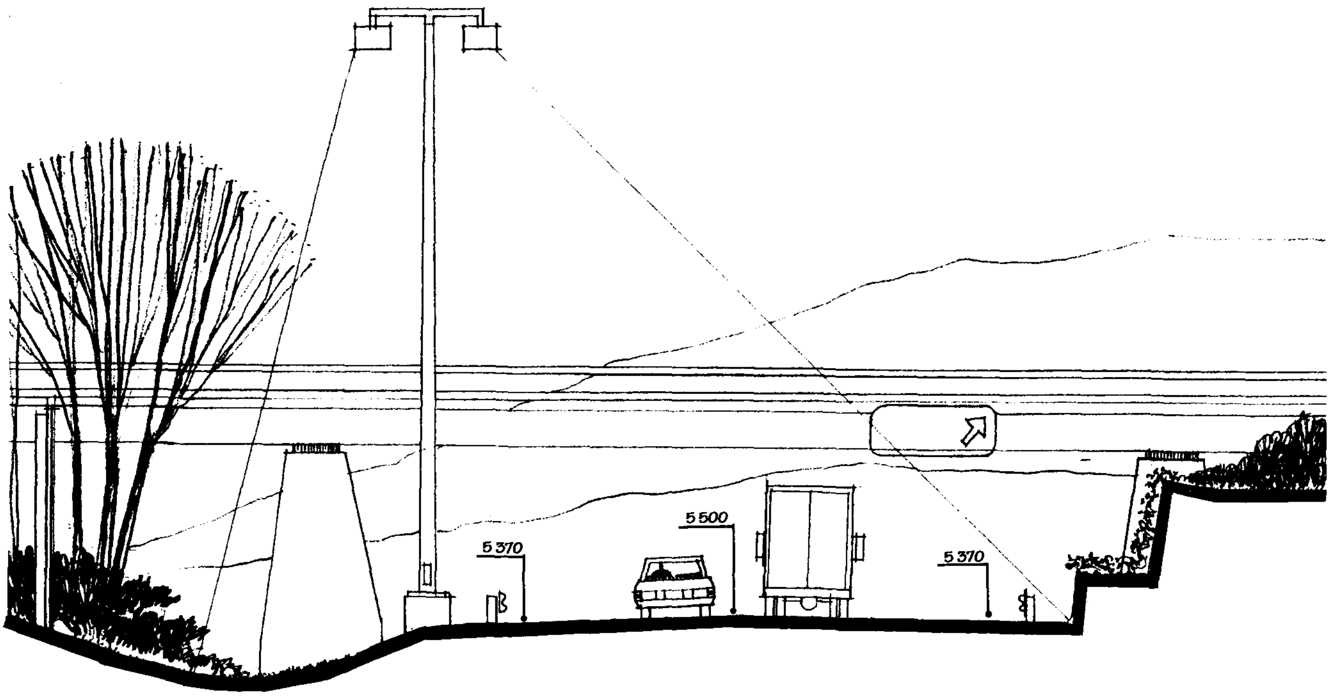


Figure 130-1 a. A typical design cross section emphasizing finished surface elevations.

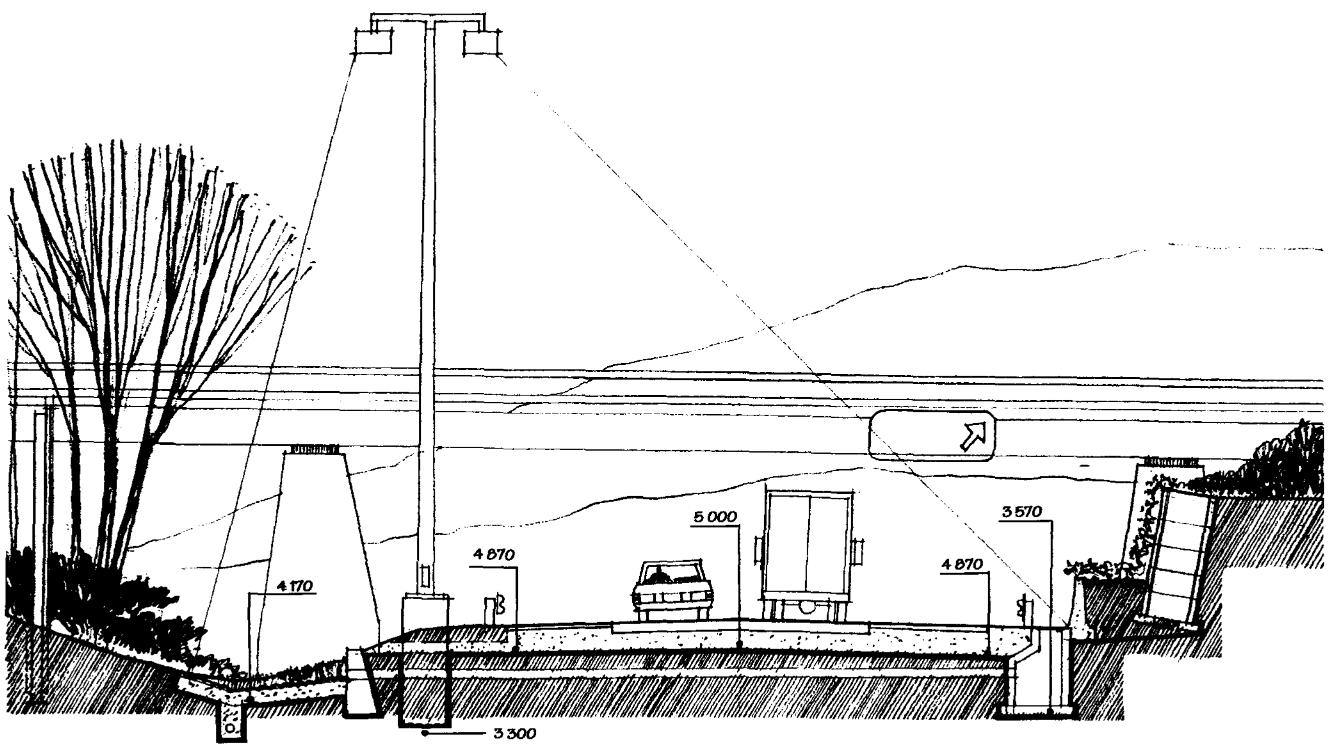


Figure 130-1 b. A contractor's analysis of the same design with emphasis on the subgrade elevations.

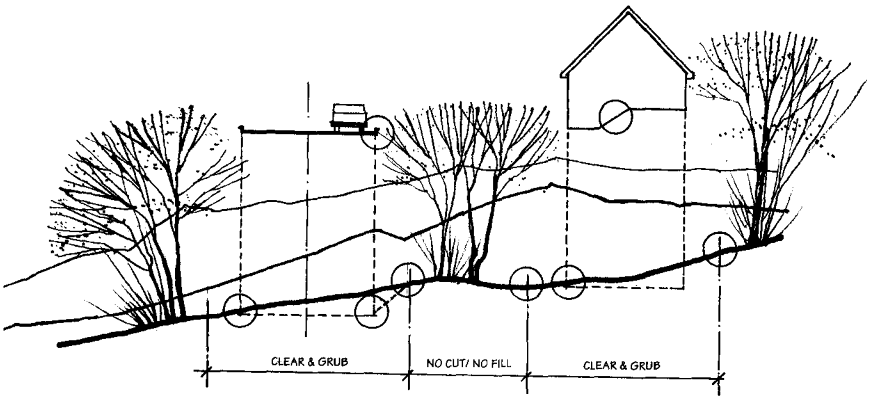


Figure 130-2. A design may be "surgically" installed within an existing landscape. *Circled junctions of new and old require special design attention.*

for executing the contract with regard to insurance coverage limits, bonds, field change orders, and all other similar administrative aspects.

4. **Agreement Form**–A legally binding document endorsed by the owner and the contractor which seals and initiates the contract. It contains a complete list of bid items, their respective quantities, and the unit pricing for each item with a price provision for adding or deleting a specific item after construction initiation.

A bid price is estimated based upon the cost of implementing all of the provisions of the working drawings and specifications within the framework of the general conditions and the agreement. The bid price represents the contractor's cost summary for:

1. Preparing the site to receive the design elements.
2. Furnishing and installing all materials as specified.
3. Providing the necessary equipment and labor crews for the required period of time.
4. Operation overhead expenses and profit.

2.2 Pricing

Site work has many variables which require site visits and careful study of site data (surveys, utilities, soil reports, boring data, etc.). Unit price estimates based on such scrutiny may result in a reasonably high accuracy of ± 5%. Most bid prices allow for unforeseen contingencies and can range in accuracy from ± 5 to 20%. There is often a correlation between unambiguous contract documents and accurate bid prices, due to greater contractor confidence in data accuracy.

2.3 Project Organization

Once the quantities and work scope are established, a time-line structure is designed to account for all site construction tasks which are required to complete the project. Using historical records and probability factors, an optimistic, pessimistic, and most probable time allotment is assigned to each task. The tasks are arrayed in a sequential diagram based upon the Program Evaluation Review Technique (PERT), or the more straight forward Critical Path Method (CPM) to account for the beginning and end of each task, and to indicate which tasks can occur simultaneously and which require linear sequencing.

Figure 130-3 illustrates a typical CPM diagram for the construction of a building. The initial site preparation tasks are executed in a linear fashion while other tasks begin and end at intermeshing intervals. The goal of such a time line is to discover the network of tasks upon which all other tasks depend. This is called the critical path and represents the sequence of events which ultimately determines the completion date.

Using PERT analysis on a daily basis, the network can be tracked and adjusted weekly so that the completion date can remain on target. Figure 130-4 represents a project bar based upon the PERT diagram. The critical path is identified by shaded bars. If the shaded tasks are not completed on-time, the project completion date will be missed. Project management can compensate when critical tasks are delayed through one or more of the following options:

1. Secure additional labor.
2. Shift existing labor from less critical tasks.
3. Add or divert equipment.
4. Work overtime.
5. Use multiple shifts.

Such actions will result in higher costs, which may need to be offset by striving to achieve optimistic completion time for less critical tasks.

2.4 Final Clean-up, Inspection, and Payment

The last operation on a construction project is the final clean-up. The contractor must remove all construction debris, temporary fencing, drainage fixtures, equipment, materials, and leave the site in "move-in" condition. Before final payment may be made, a final inspection must be passed, and mechanics lien affidavits must be submitted.

Punch List:

Final inspection requires the contractor to satisfy all of the requirements of the general conditions, including inspection of specific items on a punch list. The client's agent is required to verify compliance and to

KEY POINTS: Site Preparation

The contractor must prepare the site to receive the proposed design by using appropriate equipment for the project size while protecting natural resources.

1. Site clearing is the first step in preparing the site for new construction. It encompasses vegetation removal and structural demolition as specified on the construction drawings.
2. Before any earthwork grading may commence, all organic matter must be cleared and grubbed from the construction zone so that subgrades may be properly prepared.
3. Topsoil is typically stripped to a depth of 100-150 mm (4-6 in) and stockpiled for later use as a growing medium for plants and embankment stabilizing grasses.

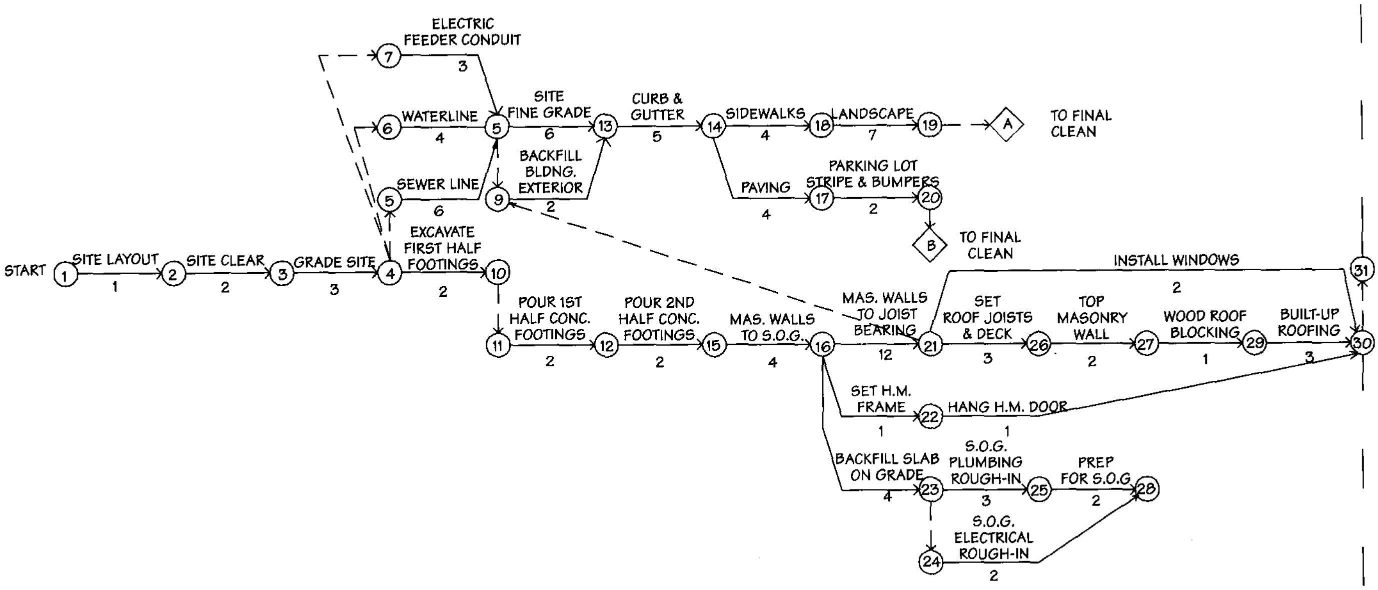


Figure 130-3. A typical CPM diagram for the construction of a building. *The initial site preparation tasks are executed in a linear fashion while other tasks are simultaneous.*

approve acceptance before final payment is issued.

Mechanics Liens:

All mechanics liens must be certified as being paid before the contractor receives final contract payments and is released from performance bond obligations. This protects the client from any future claim of non-payment for services due to funds held back by the contractor.

3.0 SITE PREPARATION

3.1 Preliminary Layout Survey and Staking:

Plan Discrepancies:

The proposed design is preliminarily staked out on the site to locate all key control points such as road traverse points-of-intersection (PI's), proposed building coordinates (corners or column centerlines), centerlines and edges of extensive parking lots, or other continuous planes (such as athletic fields, etc.). All discrepancies between plans and site location are recorded and reported to the designer for amendment and administrative change order if required.

Limit of Work Line:

Once amended, the following steps are commonly followed:

1. The limit of work line is staked to establish the disturbed area perimeter. This most often requires perimeter anti-siltation barriers and filters to be placed at low points to prevent construction site run-off from contaminating adjacent land and streams.
2. Specimen trees and vegetative masses designated for protection on the plans are staked out and secured as per specification to prevent damage from compaction, incision, or impact abrasion. Selected vegetation is often dug and moved to a temporary nursery for later planting (Refer to Section 550: Plants and Planting for further information).

3.2 Site Clearing

Site clearing is the first step in preparing the site for new construction. It encompasses vegetation removal and structural demolition as specified on the construction drawings.

General Demolition:

All designated structures such as existing buildings, pavements, curbs, walls, fences, ancillary site structures, buried utility basins, pipes and conduits, are typically removed from the new construction zone. If local regulations permit, selected foot-

Figure 130-4. A project bar diagram based upon a PERT diagram showing beginning and ending times of all tasks. *The critical path is shaded.*

ings, basements, and basins may be filled and buried as per specification. Rubbish handling and dump fees may be prohibitive for small scale projects. Re-cycling of older structures and materials may be a more economically sound alternative.

Selective Demolition:

Contaminated Structures: All chemically contaminated structures and materials must be removed from the site and disposed of in an approved facility according to regulatory specifications, to insure that the contamination is contained and mitigated. Removal of contaminated structures and soil can be very costly. Sites suspected of contamination must be thoroughly tested prior to design to determine the feasibility or appropriateness of development

Saw or Torch Cutting: Portions of existing pavements or site walls which are being extended or amended are typically sawn to provide a clean joint between new and old work. Metal structures may require torch cutting to prevent bending during general demolition activity.

Clearing and Grubbing:

Before any earthwork grading may commence, all organic matter must be removed from the construction zone so that subgrades may be properly prepared. Vegetation is first removed to prepare for topsoil stripping and stockpiling. The contractor typically visits the site to verify vegetative cover density, topography, accessibility, and soil hydrology to determine the best method for removing vegetation within the specified construction zone. All turf, weeds, shrubs, and trees, are cleared and stumps are grubbed out of the earth using specialized equipment for large sites, and hand labor for small sites. Table 130-1 correlates clearing method (equipment), vegetation type, and clearing area size for light, medium, and heavy vegetative cover. It is best to preserve as many large contiguous tree and shrub groups as possible to both enhance environmental quality, and to reduce site preparation cost. Heavy clearing [400 mm (16 in) diameter trees] is often more than twice the cost of light clearing [150 mm (6 in) diameter trees]

Selective Clearing: Selective clearing refers to the removal of individually marked trees or trees specified as having a particular diameter such as 75 mm (3 in) or less. This is commonly done to open an area for access, or to lessen competition for larger trees within a forest stand.

Tree and Stump Disposal: It is common practice to pass woody plant material, including grubbed stumps through a heavy wood chipper for use as on-site mulch later in the construction process. This creates a valuable organic resource and eliminates hauling fees.

3.3 Topsoil Stripping and Stockpiling

Topsoil is typically stripped to a depth of 100-150 mm (4-6 in) and stockpiled for later use as a growing medium for plants. All of the area within the limit-of-work line which is to be re-graded must be stripped. In areas previously compacted by vegetative clearing and demolition activities, the soil is scarified to loosen the imbedded topsoil before it is removed.

Equipment required for stripping is determined by the area size and the push or haul distances. There are three basic types of equipment and several variations of each type which are commonly employed:

Bulldozers: These are caterpillar track mounted tractors with broad front mounted blades which strip by pushing the soil forward at a controlled depth. Bulldozers come in a variety of sizes, but are generally not economical when the push distance is over 60 000 mm (200 ft). The cost per m^3 of earth moved for a haul distance of 90 000 mm (300 ft) may be 3 to 4 times greater than for a haul distance of 30 000 mm (100 ft) due to loss of efficiency. Bulldozers are used on most light to medium-sized construction sites, or may be used on larger sites with irregular or restricted operating distances. Figure 130-5 illustrates a typical steel track bulldozer commonly used for small scale stripping and excavation.

Scrapers: These come in a variety of types, but all are essentially motorized bins which scoop the soil via a cutting blade at the bottom of the bin. Soil is forced into the carrying bin from the bottom and requires high torque and low speed power. Most units are pushed by track bulldozers. Elevating scrapers are equipped with chain driven paddles which scoop the soil into the carrying bin, therefore requiring less power and no bulldozer assistance. Scrapers work

Table 130-1. AREA CLEARING EQUIPMENT SELECTION

Light Clearing, Vegetation up to 50 mm (2 in) Diameter

	Uprooting Vegetation	*Cutting Vegetation At or Above Ground Level*	*Knocking the Vegetation to the Ground*	*Incorporation of Vegetation into the Soil*
Small areas 4.0 hectares (10 acres)	Bulldozer blade, axes, grub hoes, and mattocks	Axes, machetes, brush hooks, grub hoes and mattocks, wheel-mounted circular saws	Bulldozer blade	Moldboard plows, disc plows, disc harrows
Medium areas 40 hectares (100 acres)	Bulldozer blade	Heavy-duty sickle mowers [up to 40 mm (1 1/2") dia.], tractor-mounted circular saws; suspended rotary mowers	Bulldozer blade, rotary mowers, flail-type rotary cutters, rolling brush cutters	Moldboard plows, disc plows, disc harrows
Large areas 400 hectares (1,000 acres)	Bulldozer blade, root rake, grubber, root plow, anchor chain drawn between two crawler trailers, rails		Rolling brush cutter, flail-type cutter, anchor chain drawn between two crawler tractors, rails	Undercutter with disc, moldboard plows, disk plows, disk harrows

Intermediate Clearing, Vegetation 75 to 200 mm (2-8 in)

	Uprooting Vegetation	*Cutting Vegetation At or Above Ground Level*	*Knocking the Vegetation to the Ground*	*Incorporation of Vegetation into the Soil*
Small areas 4.0 hectares (10 acres)	Bulldozer blade	Axes, crosscut saws, power chain saws, wheel-mounted circular saws	Bulldozer blades	Heavy-duty disc plow; disc harrow
Medium areas 40 hectares (100 acres)	Bulldozer blade	Power chain saws, tractor-mounted circular saws mower [up to 100 mm (4 in) diameter]	Bulldozer blade, rolling brush cutter [up to 125 mm (5 in) diameter], rotary	Heavy-duty disc plow, disc harrow
Large areas 400 hectares (1,000 acres)	Shearing blade, angling (tilted), bulldozer blade, rakes, anchor chain drawn between two crawler tractors, root plow	Shearing blade (angling or V-type)	Bulldozer blade, flail-type rotary cutter, anchor chain	Bulldozer blade with heavy-duty harrow

Heavy Clearing, Vegetation 200 mm (8 in) Diameter or Larger

	Uprooting Vegetation	*Cutting Vegetation At or Above Ground Level*	*Knocking the Vegetation to the Ground*
Small areas 4.0 hectares (10 acres)	Bulldozer blade	Axes, crosscut saws, power chain saws	Bulldozer blade
Medium areas 40 hectares (100 acres)	Shearing blade, angling (tilted) knockdown beam, rakes, tree stumper 350 mm (14 in) hardwood], shearingblade -power saw combination	Shearing blade (angling or V-type), tree shear [up to 650 mm (26 in) softwood;	Bulldozer blade
Large areas 400 hectares (1,000 acres)	Shearing blade, angling (tilted), knockdown beam, rakes, tree stumper, anchor chain with ball drawn between two crawler tractors	Shearing, blade (angling or V-type) shearing blade-power saw combination	Anchor chain with ball drawn between two crawler tractors

*This table suggests equipment requirements for Light, Intermediate, and Heavy Clearing. The productivity of the equipment will depend upon the density and the type of growth.

in continuous loop cycles skimming soil from the excavation zone and depositing it via a belly hopper in a linear stockpile formation. These machines require sufficient maneuvering room to be effective and economical. Figure 130-6 illustrates two common scraper types: a. bottom mounted scraper blade, b. elevating paddle mounted scraper blade. Figure 130-7 illustrates the methods of push loading scrapers.

Power Shovels: Also used for general excavation, these machines are often used to strip embankments or to reach areas too narrow for other machines. They must be used in combination with a truck hauler. Figure 130-8 illustrates a typical power shovel.

Table 130-2 shows soil compaction caused by different equipment.

4.0 SITE IMPROVEMENTS

4.1 Earthwork

After a site has been cleared and stripped of its organic soil horizon, it is prepared for general excavation. Typically, top and bottom of slope grade stakes are set to indicate to operators where embankment cuts begin and where embankment fills are to end. Earthwork operations are divided into cut, fill, trenching, and bulk excavation. Earth is moved to create platforms for new construction of all roads, buildings, parking, or open lawn areas. Subgrades are generally set before trench or bulk basement excavation occurs. Work is scheduled to avoid long hauls or excessive multiple handling. Figure 130-9 and Table 130-3 illustate the typical change in soil volume during earthmoving operations. Table 130-4 illustrates the ideal shovel output of bank units per hour. If soil is suitable, soil from cut areas is placed directly in adjacent fill areas using the largest piece of equipment possible. Figure 130-10 illustrates a typical cut and fill diagram showing the top-of-cut stake and bottom-of-fill stake laid out in a preliminary survey.

Cut Operations:

Cut operations lower the subgrade so that it may be prepared to receive pavement bases or topsoil for planted areas. Scrapers may be used for large areas and deep cuts, along with bulldozers to shape embankments. Although cut slopes may repose at 1:2 in most soils, a 1:3 or 1:4 slope is much more stable over time, and requires less expensive maintenance (mowing) operations (See Table 130-5 for typical angle of repose values of excavated soils). Long slopes may require bench terracing for sta-

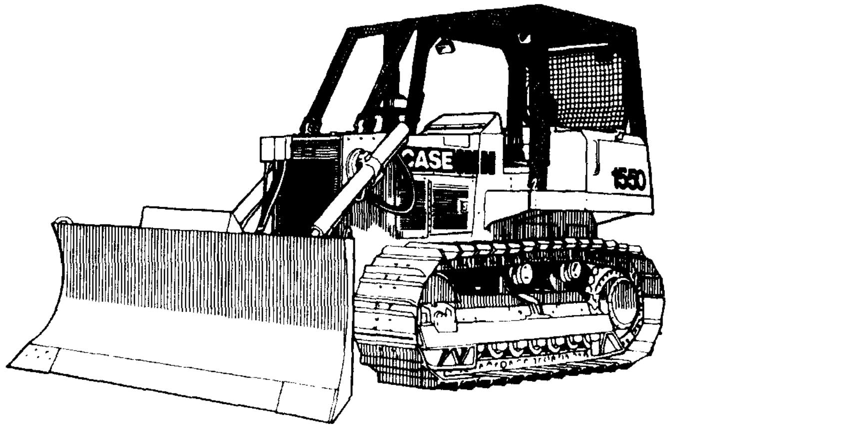
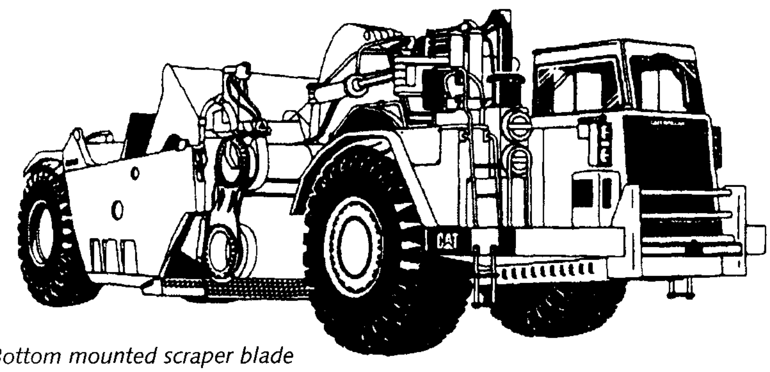
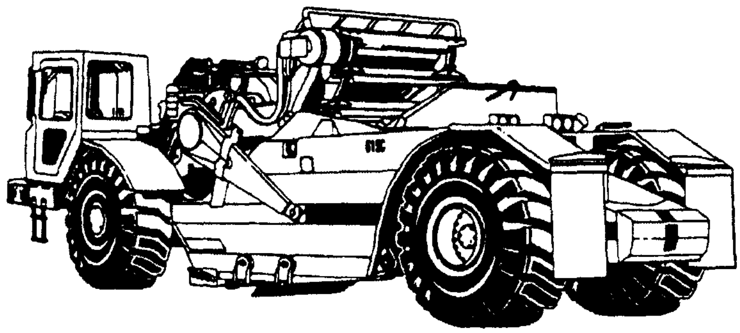


Figure 130-5. A typical steel track bulldozer commonly used for small to medium scale stripping and excavation.



a. Bottom mounted scraper blade



b. Elevating paddlemounted scraper blade

Figure 130-6. Common scraper types.

Table 130-2. SOIL COMPACTION GUIDE BY EQUIPMENT TYPE (UNIFIED SOIL CLASSIFICATION)

	Compaction Equipment*		Maximum Dry Density Modified Proctor	
Soil Type	Recommended	Suitable	g/cm³	lb/ft³
GW	VR, VP	PH, SW, SP, GR, CT	2.00-2.24	125-140
GP	VR, VP	PH, SW, SP, GR, CT	1.76-2.24	110-140
GM	VR, PH, SP	VP, SW, GR, CT	1.84-2.32	115-145
GC	PH, SP	SW, VR, VP, TF, GR, CT	2.08-2.32	130-145
sw	VR, VP	PH, SW, SP, GR, CT	1.76-2.08	110-130
SP	VR, VP	PH, SW, SP, GR, CT	1.68-2.16	105-135
sm	VR, PH, SP	VP, SW, GR, CT	1.60-2.16	100-135
sc	PH, SP	SW, VR, VP, TF, GR, CT	1.60-2.16	100-135
ML	PH, SP	TF, SW, VR, VP, GR, CT	1.44-2.08	90-130
CL	PH, SP	TF, SW, VR, GR, CT	1.44-2.08	90-130
OL	PH, SP	TF, SW, VR, GR, CT	1.44-1.68	90-105
MH	PH, SP	TF, SW, VR, GR, CT	1.28-1.68	80-105
CH	TF, PH, SP	VR, GR, SW	1.44-1.84	90-115
OH	TF, PH, SP	VR, GR, SW	1.28-1.76	80-110
Pt	Compaction not practical			

*Symbols:

CT = Crawler Tractor 9-27 metric tons (10-30 tons)

SW = Smooth Wheel 3-14 metric tons (3-15 tons)

GR = Grid Roller 5-14 metric tons (5-15 tons)

TF = Tamping Foot 5-27 metric tons (5-30 tons)

PH = Pneumatic Roller 9-45 metric tons (10-50 tons)

VP = Vibrating Plate <1 metric ton (<1 ton)

SP = Segmented Pad 5-27 metric tons (5-30 tons)

VR = Vibrating Roller 3-22 metric tons (3-25 tons)

Source: S. W. Nunnally, Construction Methods and Management

bility (Refer to Section 320: Grading Techniques for further information).

If a building is to be constructed in a cut zone, the area surrounding the proposed building site is graded to rough subgrade prior to footing excavation to minimize the cost of excessive trenching or bulk excavation. Well points or curtain drains may be required to lower the water table during construction. Test pits and borings during early exploration usually indicate the presence of ground water. Figure 130-11 shows new subgrades in general cut prior to building foundation excavation.

Pavements: The subgrade under pavements must be uniform, free of ruts or depressions, and sloped to drain. Specifications typically refer to acceptable sag tolerances in high quality construction. Large parking lots require care to insure that excavator tracks and blade striations run parallel to the slope to prevent infiltration or capillary water from accumulating in ruts under the finish pavement base.

Footings and Foundations: Excavation for footings and foundation walls require sufficient space for form work placement and removal. The base of the excavation should extend at least 600-900 mm (2-3 ft) beyond the foundation wall dimension. Excavation side slopes are usually set at 2:1, but in stable soils may be 1:1. The bulk of excavation is executed with power equipment, but hand digging is often employed for setting the footing to create a uniform and neat bearing surface. Bulldozers may be used for small structures, but power shovels are more common. (Refer to Table 130-2 for equipment capacities.)

Pipe and Pit Trenching: Trenching for utilities is usually accomplished by a backhoe, which has a normal reach of 1 800 mm (6 ft). Extensive or heavy duty trenching may employ a larger power hoe [2 400-3 000 mm (8-10 ft) reach], or a wheel or chain trencher. Chain trenchers have an excavation capacity of 38-380 m³ (50-500 yd³) per hour, depending on model type. Large trenches require slip-form bracing to prevent trench wall collapse and are backfilled immediately after each pipe segment is laid. Basin structure pits are usually dug during this operation. Figure 130-12 illustrates a backhoe showing trenching and loading capabilities. Table 130-6 illustrates standard cycles per hour for hydraulic backhoes.

Piers and posts: Architectural piers may be dug by backhoe if footings are required. If piers are columnar concrete and set in cylindrical fiber forms, holes may be dug by power auger up to 600 mm (24 in) in diameter. Electrical conduit trenches may be dug after fixture pier forms are set to avoid collapsing, using a chain bucket narrow trencher. Post holes for fences and light decking are typically dug by manual posthole diggers or hand operated power augers.

Rock Removal: Sound planning seeks to avoid rock removal due to cost and geological disturbance. The presence and density of rock is determined by seismic wave velocity readings. Readings above 2 500 m/sec (8,000 ft/sec) usually indicate removal by blasting. Readings below that threshold indicate removal by mechanical ripping. If blasting is required, regularly spaced holes are drilled to create a weak plane and explosive charges are set within them. Blasting areas are usually covered with heavy steel cable mesh fabrics interwoven with rubber tires to contain fragments during explosion. Ripping is accomplished with a hydraulic steel ripping knife mounted on the rear of a track bulldozer. Ripping is more economical and safer than blasting.

Fill Operations:

All areas designated to receive fill are typically scarified (surficially roughened) to create a mechanical bond between the subgrade and the new fill. Fill is systematically placed in specified layers or lifts [150-300 mm (6-12 in)] and compacted by appropriate machinery. Scrapers may place the soil in accurate lifts by setting discharge rate and bin blade height, and are the most economical method for executing large area fills. Trucks may deposit piles which require

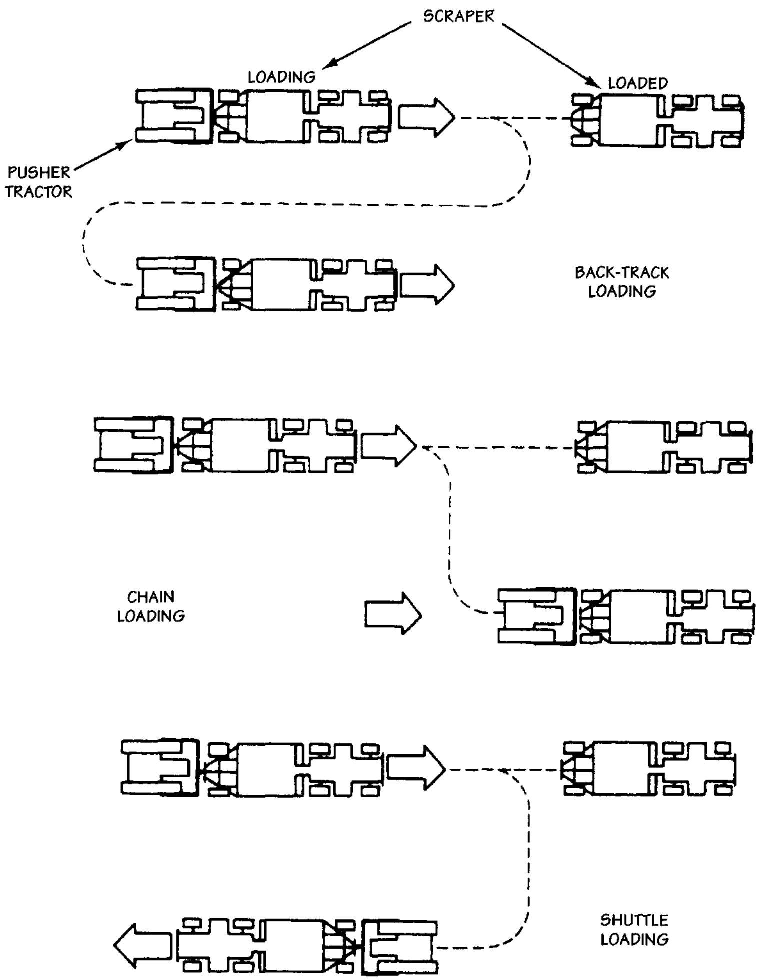


Figure 130-7. Methods of push loading scrapers.

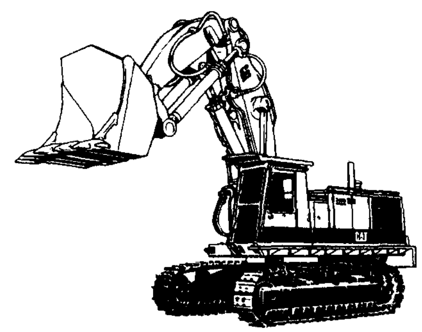


Figure 130-8. Power shovel.

spreading by bulldozer to the specified lift depth. This latter method is typical for light to medium construction. Each lift must be compacted to achieve the specified density of 95% so that the rate of infiltration and bearing capacity will resemble that of "undisturbed earth." This operation is also called "controlled fill placement" and is repeated until the new subgrade elevation is achieved. Soil types determine the method used for compaction.

Clay Soil Compaction: Cohesive soils such as clays and loams are commonly compacted using a tractor drawn sheepsfoot roller. High density compaction for these soils requires 8-12 passes. Figure 130-13 illustrates a sheepsfoot compactor.

Granular Soil Compaction: Granular soils must be rolled and vibrated using steel or rubber tire rollers, since sheepsfoot rollers are ineffectual on non-cohesive soils. Typically 4-6 passes are required to achieve the appropriate compaction density (Soil specifications will vary. Figure 130-14 illustrates an array of vibrating rollers.

Types of Fill:

General Fill: General fill is usually subsoil taken from on-site cut and must be structurally suitable to avoid differential settlement or excessive swelling. Good site design balances cut and fill and avoids sites with unsuitable construction soils (Refer to Section 320: Grading Techniques for information on balancing cut and fill).

Trench and Foundation Backfill: Backfilling of pipe and foundation trenches requires controlled lifts and careful compaction to avoid differential settlement and trench wall slump. Sands and aggregates are typically used as pipe and perforated drain bedding respectively. Backfill material should contain graduated particle sizes and not contain large stones, which could create air pockets.

Structural Fill: Structural fill typically is placed under building floor slabs and requires very stringent placement and compaction. It consists of graded aggregate base material placed in 150 mm (6 in) lifts, and vibrated and rolled to achieve 95% density. For reasons of cost and stability, such structural fills should not exceed 900 mm (3 ft) in common circumstances.

4.2 Drainage and Utilities

Placement of sanitary and storm sewer basins and pipes begin after cut and fill operations are completed so that outfalls may be connected to subsequent building drains, site curtain drains, and other temporary dewatering and construction runoff filtering systems. Care must be taken to insure that newly buried pipes have sufficient soil cover in those areas subject to heavy vehicular traffic. Most thin wall (steel and polymer) pipes require 750 mm (30 in) of soil cover to prevent crushing. At this stage in construction, subgrades may be 300-450 mm (12-18 in) below finish grades. All drain basins require controlled backfills to prevent lateral shifting in vehicular pavements. Most basin pits are dug with a power hoe (Refer to subsection 2.5: Pipe and Pit Trenching).

Structures:

Basins: Sanitary and stormwater basins require concrete footings, typically placed directly on excavated subgrade, unless soils require additional preparation. Depth of pit excavation must be carefully calculated

Table 130-3. TYPICAL SOIL WEIGHT AND VOLUME CHANGE CHARACTERISTICS*

	Unit Weight [kg/m³ (lb/cu yd)]						
	Loose	**Bank**	**Compacted**	**Swell (%)**	**Shrinkage (%)**	**Load Factor**	**Shrinkage Factor**
Clay	1 370 (2310)	1 780 (3000)	2 225 (3750)	30	20	0.77	0.80
Common earth	1 471 (2480)	1 839 (3100)	2 047 (3450)	25	10	0.80	0.90
Rock (blasted)	1 815 (3060)	2 729 (4600)	2 106 (3550)	50	–30**	0.67	1.30**
Sand and gravel	1 697 (2860)	1 899 (3200)	2 166 (3650)	12	12	0.89	0.88

*Exact values vary with grain size distribution, moisture, compaction, and other factors. Tests are required to determine exact values for a specific soil.

**Compacted rock is less dense than when in-place.

Source: S. W. Nunnally, *Construction Methods and Management, 1993.*

from finish grate rim elevation to account for:

1. Modular precast or masonry unit dimensions.
2. Invert elevation of the exit drain.
3. Sump depth if clean-out cavity is included.

Pipes: Well planned site design seeks to combine utility corridors to minimize site disruption and confine future repair activities to a manageable portion of the site. It is best to place pipes and conduits in ascending order of depth (deepest first and shallowest last) to avoid conflicts when utilities cross paths. On occasion, sewer lines may be laid with broad horizontal arcs to avoid disrupting tree stands. Care should be taken to maintain design slope and to provide for clean-out capability. It is common practice to lay pipe from the outfall back to the high point to prevent the pipe trench from filling with either rain water or infiltration water during construction operations. Perforated drain pipe trenches are frequently lined with a fabric separator to prevent fines from entering the stone drainage medium. The fabric is folded over the top of the pipe stone before the trench is backfilled to the surface (Refer to Section 880: Geotextiles for more information). Figure 130-15 illustrates a typical chain trencher for light conduits and small pipes.

Headwalls and Endwalls: Both structures are essentially retaining walls requiring a footing to maintain constant pipe invert elevation in frost-thaw regions and shrink-swell soils. Headwalls typically require the swale invert to be flush with the pipe invert and may require a stone or concrete apron to prevent undermining due to

Table 130-4. IDEAL SHOVEL OUTPUT [Bm³/h (BCY/h)]*

	Shovel Dipper Size [m³ (yd³)]											
Type of Material	**0.57 (3/4)**	**0.75 (1)**	**0-94 (1 1/4)**	**1-13 (1 1/2)**	**1-32 (1 3/4)**	**1-53 (2)**	**1.87 (2 1/2)**	**2.29 (3)**	**2.62 (3 1/2)**	**3.06 (4)**	**3.51 (4 1/2)**	**3.82 (5)**
Moist loam or sandy clay	126 (165)	157 (205)	191 (250)	218 (285)	245 (320)	271 (355)	310 (405)	356 (465)	401 (525)	443 (580)	485 (635)	524 (685)
Sand and gravel	114 (155)	153 (200)	176 (230)	206 (270)	229 (300)	252 (330)	298 (390)	344 (450)	386 (505)	424 (555)	459 (600)	493 (645)
Common earth	103 (135)	134 (175)	161 (210)	183 (240)	206 (270)	229 (300)	271 (355)	310 (405)	348 (455)	390 (510)	428 (560)	463 (605)
Clay, tough, hard	84 (110)	111 (145)	138 (180)	161 (210)	180 (235)	203 (265)	237 (310)	275 (360)	310 (405)	344 (450)	375 (490)	405 (530)
Rock, well-blasted	73 (95)	96 (125)	119 (155)	138 (180)	157 (205)	176 (230)	210 (275)	245 (320)	279 (365)	313 (410)	348 (455)	382 (500)
Common excavation with rock	61 (80)	80 (105)	99 (130)	119 (155)	138 (180)	153 (200)	187 (245)	222 (290)	256 (335)	291 (380)	321 (420)	352 (460)
Clay, wet, and sticky	54 (70)	73 (95)	92 (120)	111 (145)	126 (165)	141 (185)	176 (230)	206 (270)	237 (310)	264 (345)	294 (385)	321 (420)
Rock, poorly blasted	38 (50)	57 (75)	73 (95)	88 (115)	107 (140)	122 (160)	149 (195)	180 (235)	206 (270)	233 (305)	260 (340)	287 (375)

*Based on 100% efficiency,90° swing, optimum depth of cut, material loaded into haul units at grade level. Based on PCSA data.
*Ideal Shovel output of bank units (B) per hour [Bm3/h (Byd3/h)] by bucket size.

Source: S.W. Nunnally, *Construction Methods and Management.*

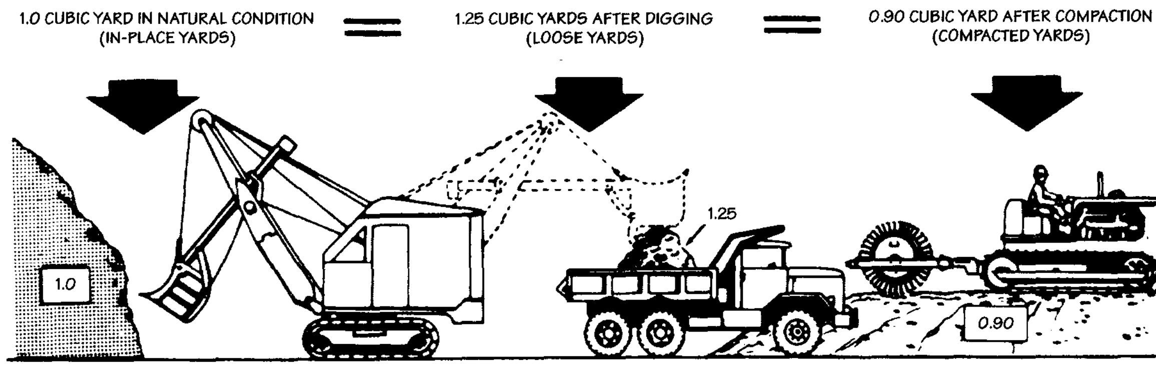


Figure 130-9. Typical soil volume change during earthmoving operations.

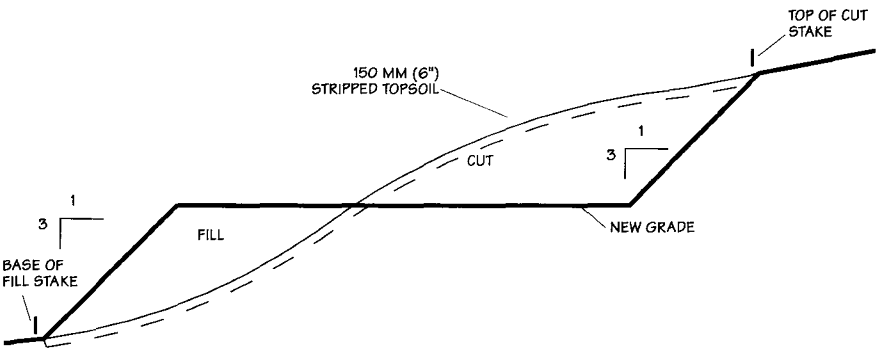


Figure 130-10. A typical cut and fill diagram showing the top-of-cut stake and bottom-of-fill stake.

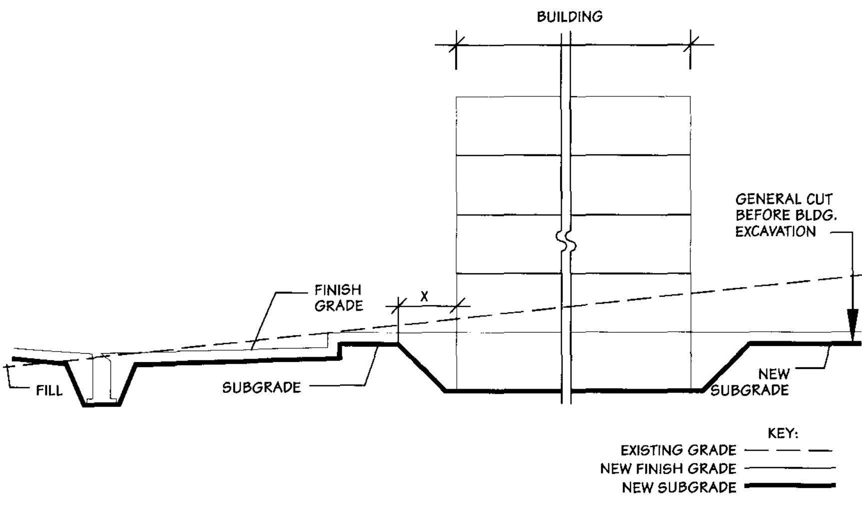


Figure 130-11. New subgrades in general cut prior to building foundation excavation.

turbulence. Endwall pipe inverts are typically held 150 mm (6 in) above the swale invert to allow free flow of water into the swale. The swale requires a stone or masonry apron to absorb discharge and prevent erosion.

Infiltration and Detention Ponds: These structures are often constructed using bulldozers, but in wet soils, may require draglines or hydraulic beam bucket excavation. Most regions require special permits when working near wetlands. Care should be taken to insure that siltation is kept to minimum during construction and that weir structures are securely fixed to earthen dams to prevent breaching during heavy loads (Refer to Section 420: Small Dams, for details of earth dams).

Electrical and Telecommunication Lines:

Local codes require specific depths for each type of utility. Typically, electrical lines must be buried to a depth of at least 600 mm (2 ft) and rigid conduit must be used under all paved areas (roads, drives, plazas). If pavement base is exceptionally deep, conduits are often placed after the aggregate pavement base is installed to prevent damage to the conduit due to the rough grading required to set finish subgrade. Telecommunication lines require separation from electrical lines to avoid magnetic field interference (Consult local codes).

Irrigation Systems:

Irrigation lines, having the shallowest depth [300-450 mm (12-18 in)], are often one of the last utilities installed. Some irrigation systems are set after sodding or seeding to insure precise placement of riser heads. Specialized narrow trenching equipment is used for minimal disturbance. Shrub bub-

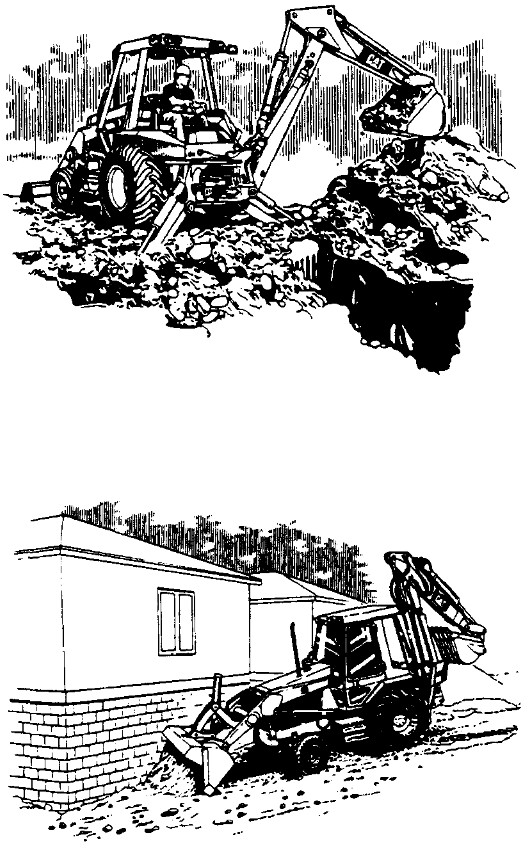


Figure 130-12. **A backhoe showing trenching and loading capabilities.**

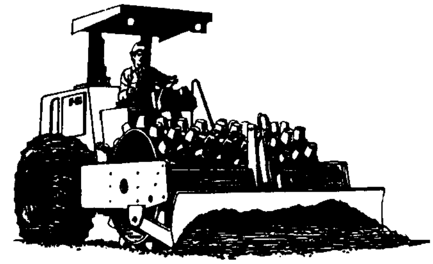


Figure 130-13. A sheepsfoot compactor used for colloidal soils.

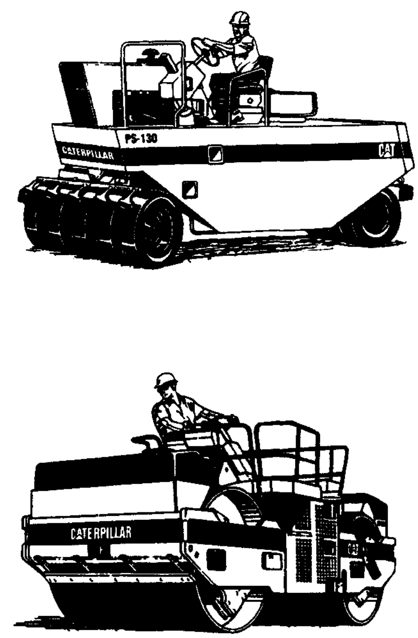


Figure 130-14. Typical vibrating rollers for granular soils.

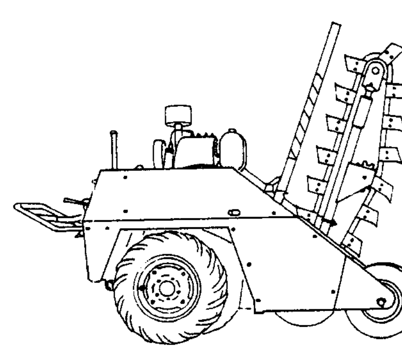


Figure 130-15. Typical chain trencher for light conduits and small pipes.

blers may be installed prior to planting. Internal soaker systems are installed after topsoil placement and finish grading, but before seeding or sodding. Valve boxes should be located on high ground to avoid moisture infiltration. Local practices are highly variable (Refer to Section 750: Irrigation for more information).

4.3 Grading

Grading operations prepare the site to receive pavements, plantings, and all other site improvements (Refer to Section 320: Site Grading for further information). The site is surveyed to set finish layout and grading stakes. Stakes are offset from road centerlines and pavement edges so as not to interfere with subsequent construction operations. Grade stakes are typically offset 300-600 mm (2-3 ft) from proposed pavement edges. Grading involves two phases; rough grading and finish grading.

Rough Grading:

Rough grading occurs after all cut and fill operations have established approximate elevations for proposed subgrades, according to drawing details, cross sections, and specifications. Typically, bulldozers, road graders, and hand labor is required to precisely set edges and to create uniform slopes. Grading under slabs and pavement structures requires precision within 15 mm (1/2 in). Table 130-7 indicates subgrade depth under various finish surfaces.

Finish Grading:

Finish grading refers to the final placement of topsoil between pavements and structure. Soil depths vary by planting type. Typically this is accomplished after major planting of trees and all other activities which require hauling have been completed.

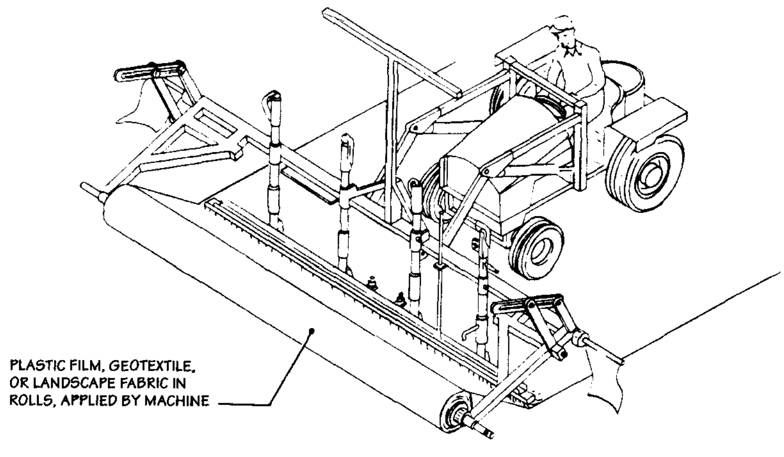


Figure 130-16. Geotextile fabric separator application equipment.

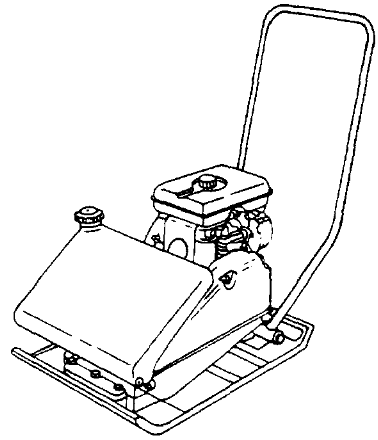


Figure 130-18. Hand operated vibrating plate power compactor.

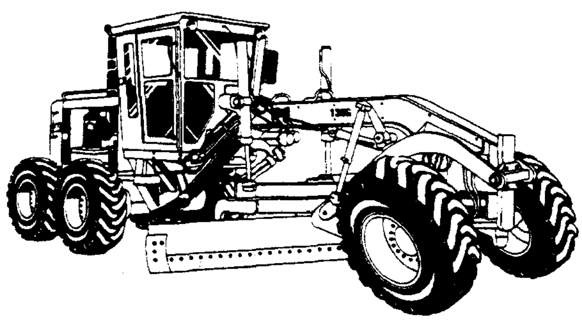


Figure 130-17. Typical motor grader used to smooth out compacted fill areas and subbase material.

Table 130-5. TYPICAL ANGLE OF REPOSE VALUES OF EXCAVATED SOIL.

Material	Angle of Repose(deg)
Clay	35
Common earth, dry	32
Common earth, moist	37
Gravel	35
Sand, dry	25
sand, moist	37

Source: S. W. Nunnally, *Construction Methods and Management,* 1993.

4.4 Paving and Surfacing

Pavement structures commonly consist of a base course and a wearing course. The base course is usually a prepared aggregate layer which extends beyond the finish pavement edge for drainage and support. The aggregate base may also serve as a base for various types of edging and curbing (Refer to Section 440: Surfacing and Paving for more information). All areas designated as hardscape on the plans receive layers of graded aggregate material as specified. The material may range from structural silica sands to crushed processed stone. In clay soils, a fabric separator may be placed on the subgrade to reinforce the base to guard against subgrade deformation and lateral subbase creep. A specially equipped tractor with a wide roll dispenser is used for large installations (Refer to Figure 130-16).

Aggregate Base Placement:

Roads and Parking Lots: Aggregate is placed on the prepared subgrade using the largest dump truck possible, and spread by bulldozer or road grader to achieve 150-200 mm (6-8 in) lifts. Vehicular pavements often require a subbase and base course to provide proper support for the finish pavement. Recycled pulverized pavements mixed with aggregates often provide an on-site resource from the demolition operation. Aggregate subbases are rolled and compacted using the method described for structural fill. Internal grade stakes may be set in large paved areas to clearly mark finish and subbase grades for equipment operators. Concrete or stone curbing may be set on the prepared subbase, in anticipation of the aggregate base course and the finish pavement course. Figure 130-17 illustrates a typical road grader. Base course aggregate is spread on the subbase course, rolled and compacted.

Walks and Plazas: Light pedestrian pavements commonly use a single course aggregate base which is usually spread by hand and vibrated with a flat plate vibrating power compactor after paving edges or forms are set. Unit pavers often require edging to be set on top of the aggregate base and attached with long metal spikes. Since bases are typically 100-150 mm (4-6 in) thick, the material is placed in a single lift and compacted with 3-5 passes. Plaza pavements subject to service vehicle loading may require an aggregate subbase course for greater strength. In such an event, a dense graded aggregate subbase is used to support a thinner sand or dense grade aggregate base course. Concrete forms are set and unit paver edging is installed in anticipation of the finish pave-

Table 130-6. STANDARD CYCLES PER HOUR FOR HYDRAULIC BACKHOES

		Machine Size		
Type of material	**Wheel Tractor**	**Small Excavator: [0.75 m3 (1 yd3)]**	**Medium Excavator: [0.94-1.72 m3 (1 1/4-2 1/4 yd3)]**	**Large Excavator: Over 1.72 m3 (2 1/2 yd3)**
Soft (sand, gravel,loam)	170	250	200	150
Average (common earth, soft clay)	135	200	160	120
Hard (tough clay, rock)	110	160	130	100

Source: S. W. Nunnally, *Construction Methods and Management,* 1993.

ment surfacing. Figure 130-18 illustrates a hand operated vibrating plate power compactor.

Wearing Surface Placement:

Pavement adjacent to major planting areas may require large trees and shrubs to be planted before final wearing surfaces are installed, to avoid damage from trucks or digging equipment. Certain other site improvements such as light poles, signs, or site sculpture, etc. may require installation prior to pavement placement to avoid unnecessary loading.

Asphalt: Roads composed of asphalt usually are installed in two courses. The base course is placed on a prepared aggregate base which often has been penetrated with a heated asphalt oil to insure proper adhesion of the asphalt base course to the aggregate (Refer to Section 820: Asphalt for specific information).

Concrete: Most concrete paving requires reinforcing steel mesh or bars to be placed between form edges. For maximum strength, the steel reinforcing should be lifted off of the aggregate base by means of metal chair clips, taking care that steel remains covered by at least 50 mm (2 in) of concrete. Sheets of welded wire mesh should lie straight and flat. Premolded or straight expansion joint filler should be placed in formwork to isolate slabs and walks every 7 500 mm (25 ft) (Refer to Section 830: Concrete for more information).

Unit Pavers and Stone: It is critical that unit pavers be placed on an adequately prepared aggregate base between secured edge restrainers to prevent lateral creep during loading over time. For commercial and driveway applications, it is common practice to use a dense grade aggregate subbase and a 25-50 mm (1-2 in) high silica content sand setting bed to serve as a proper support structure for unit pavers. The silica sand maintains its volume and particle size during prolonged periods of loading and vibration.

Special or Proprietary Surfaces: Porous pavements, or proprietary athletic facility surfaces often require specialized equipment and crews for installation. Actual sequence can vary from job to job. Allowances should be made for machinery access to avoid damage to finished portions.

4.5 Site Furnishings

Site furnishings is a general category that encompasses installation of most above ground fixtures and design elements such as light fixtures, fences and gates, signs, benches, drinking fountains, road and parking appurtenances, etc. It may involve connecting proprietary fixtures to previously wired concrete piers, attaching benches to slabs or piers, bolting guard rails onto previously set posts, or installing kiosks, clocks or information booths. The extent of this operation is determined by the scope and complexity of the design.

4.6 Planting Installation

As stated previously, the sequence of planting is highly dependent on site specific circumstances. Generally, large trees are planted after subgrades have been set and aggregate bases have been placed so that large equipment used to unload and move heavy tree balls will have solid bearing and will not destroy any finish work. On occasion, large specimen trees or previously dug and heeled-in existing trees will be planting within future building courtyards or other constricted access points. Contractors may use on-site cranes used for steel erection to move these larger specimen into position very early in the construction process. Trees planted so early in the project must receive special protection if adjacent to building erection activities (Refer to Section 550: Plants and Planting for more information).

Trees:

Trees planted early in the process must be placed with a grade stake to insure that the tree ball will align with the final topsoil or plaza finish grade, and that top soil or mulch be piled around the exposed tree ball to prevent drying before finish grading occurs. It is common practice to plant large trees directly on the tree pit bottom to prevent settlement. It is best to be 25-50 mm (1-2 in) higher than finish grade. Tree pits should be at least 600-900 mm (2-3 ft) wider than the tree ball. Most plants will grow more vigorously if given more root growing medium, especially pavement bound trees.

Shrubs:

Shrubs, unless very large, are usually planted just prior to finish grading and seeding so as

Table 130-7. SUBGRADE DEPTH UNDER VARIOUS FINISH SURFACES.

Finish Material	**Depth to Subgrade**
Topsoil (turf)	150 mm (6 in)
Planting Beds	200-450 mm (8-18 in)
Walks and Patios	200-300 mm (8-12 in)
Driveways and Parking	300-375 mm (12-15 in)
Roads and Service Drives	375-500 mm (15-20 in)

not to interfere with building painting, sign installation, light fixture attachments, etc.

Ground Covers and Herbaceous Plants:

Designated planting beds are usually edged and amended to receive groundcovers and herbaceous plants. Practices vary by region, but mulch is often placed on beds first to control weeds and to maintain moisture, then ground cover plantings are placed through the mulch. Herbaceous borders often do not specify mulch, and bulbs, and perennials are planted directly in the soil.

Seeding and Sodding:

Large Scale Sites: Sites with complex earth grading typically will require a final dressing of the subgrade to insure proper drainage and adhesion of the new topsoil after it is dumped and spread. Large projects may use a scraper to place the topsoil on the subgrade and tractor graders to smooth and rake the soil in preparation for seeding.

Small to Medium Scale Sites: After rough grading has been refined and scarified, topsoil is dumped and spread with a bulldozer to the desired depth, and fine raked to remove all stones, clumps, and large organic matter. The turf areas are seeded or sodded as specified. At this point, all edges and pavements have usually been installed and turf areas are carefully hand raked to achieve a consistent and neat junction with adjacent pavements and planting beds.

Special Conditions: In fine soils, swales are often lined with sod immediately after topsoil is placed to prevent erosion of bare soil. In heavy duty circumstances, jute matting is stapled over seeded embankments, especially those subject to periodic flooding adjacent to large swales or rivers banks. Steep banks may be hydro-seeded using saturated paper mulch, or blown-on straw mulch to hold seed and promote moisture retention. These special treatments may require a shift in normal procedure to accommodate equipment and access

KEY POINTS: Site Improvements

After a site has been prepared for new construction, the execution of the site design begins.

1. Earthwork operations are divided into cut, fill, trenching, and bulk excavation.
2. At the end of cut and fill operations subgrades may be 300-400 mm (12-18 in) below finish grades.
3. Placement of sanitary and storm sewer basins and pipes begin after cut and fill operations are completed so that outfalls may be connected to subsequent building drains, site curtain drains, and other temporary dewatering and construction runoff filtering systems.
4. Typically, electrical lines must be buried to a depth of at least 600 mm (2 ft) while irrigation lines are between 300 and 450 mm (12-18 in) deep.
5. Grading operations prepare the site to receive pavements, plantings, and all other site improvements (Refer to Section 320: Site Grading for more information).

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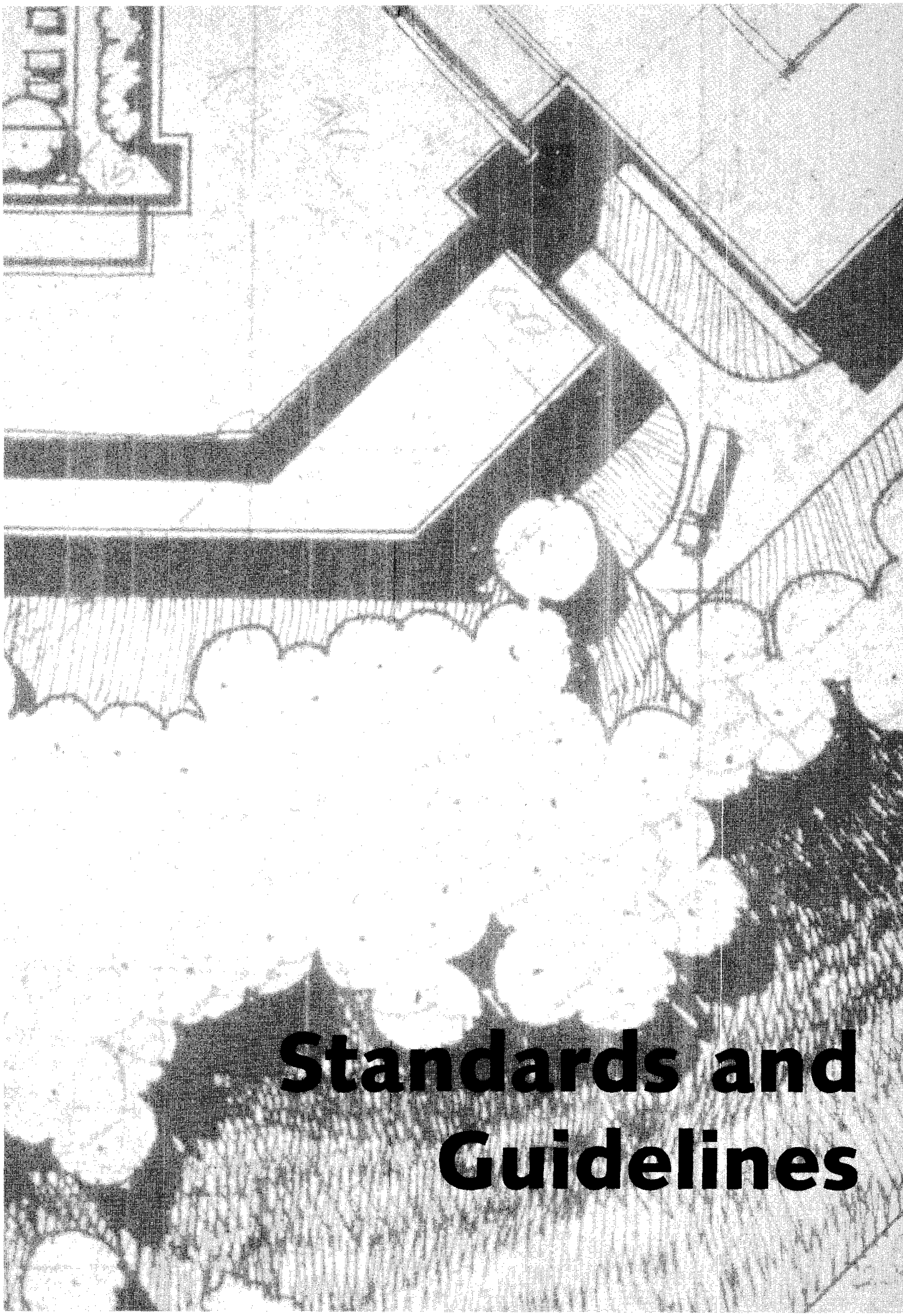
DIVISION 200



Standards and Guidelines

SECTION 210

Spatial Standards

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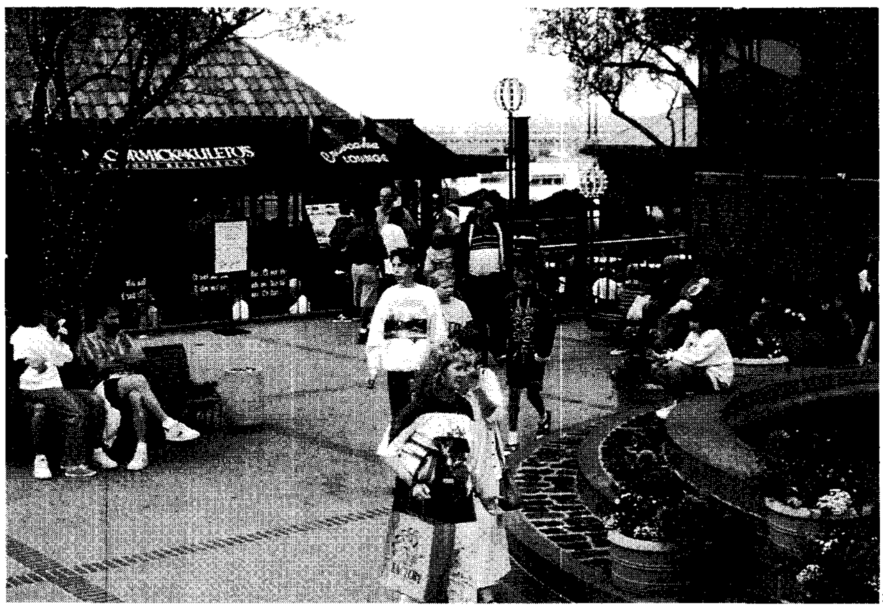


N. Dines

CONTENTS

1.0 INTRODUCTION

Human spatial standards are derived from ergonomic and cultural data and vary widely across cultures and land-use settings. Standards are often established to provide:

1. Minimal safety clearances (ergonomic/legal)
2. Perceived user comfort (psychological/perceptual)
3. Ceremonial protocol (cultural/ritual)
4. Aesthetic choice (personal/cultural)

Most "normative" standards require cultural adjustment before being applied to a particular design setting. Cultural standards are often referred to as the "hidden dimension," and at times may contradict strictly

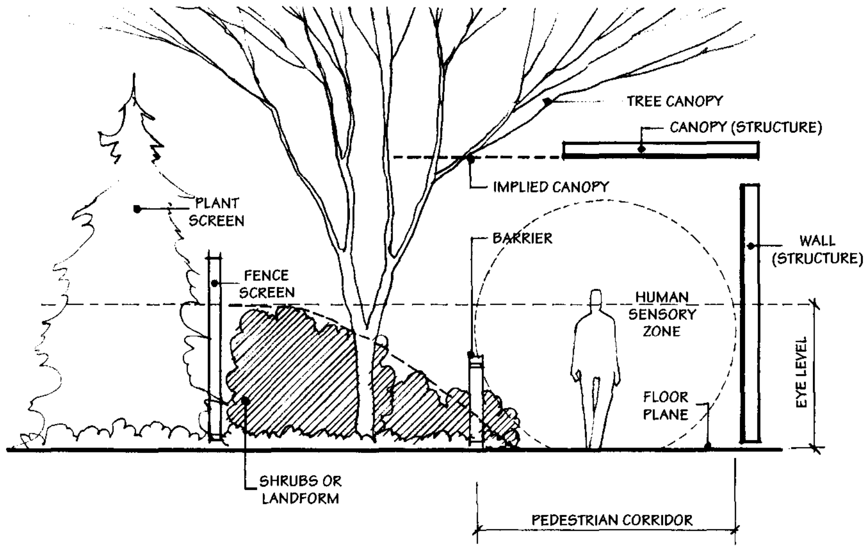


Figure 210-1. Elements of spatial enclosure: floor, wall, canopy, modified by time, light, climate, and intensity of activity.

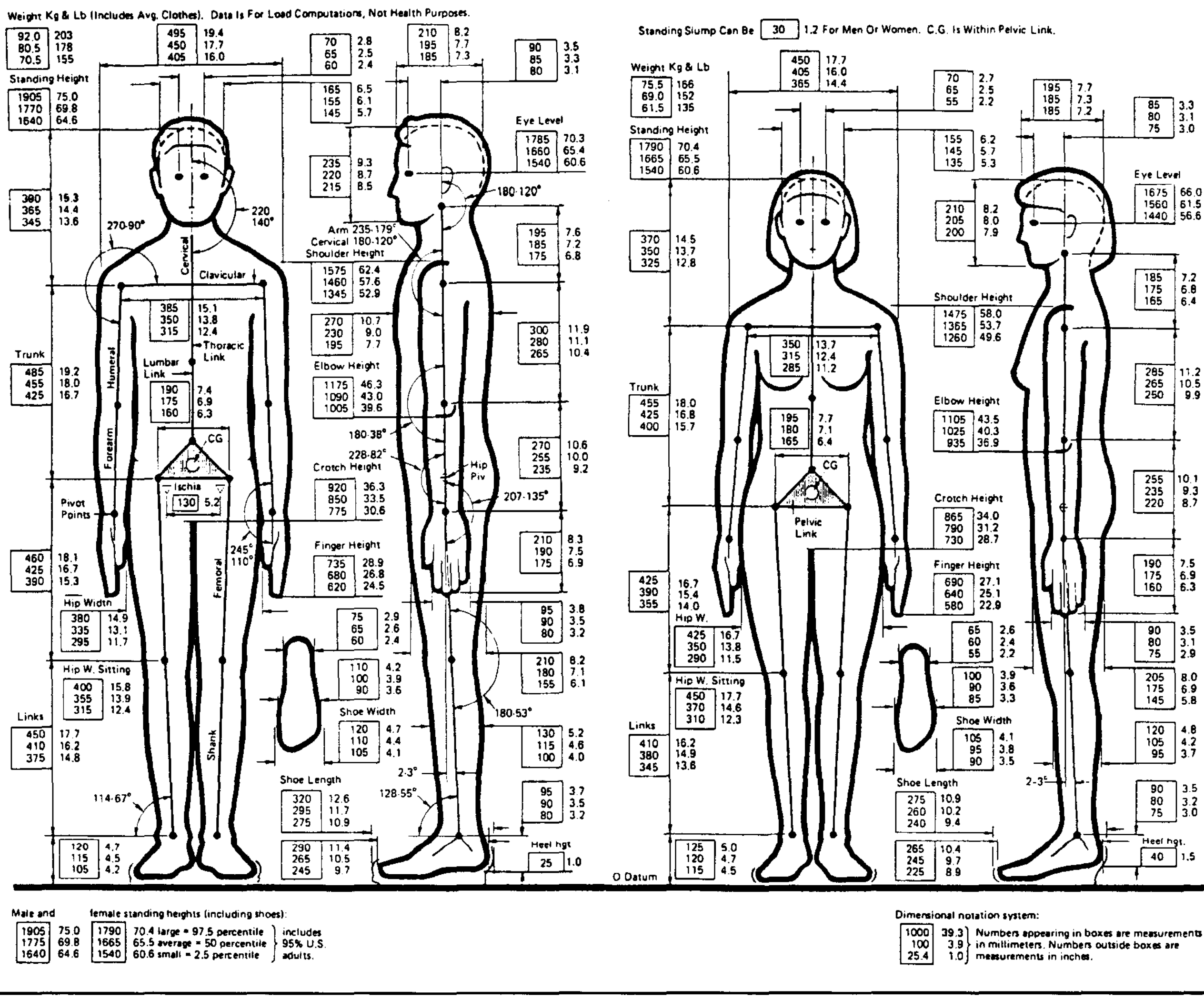


Figure 210-2. Standing adult male and female dimensions. *(Anthropometric data provided by Henry Dreyfuss Associates).*

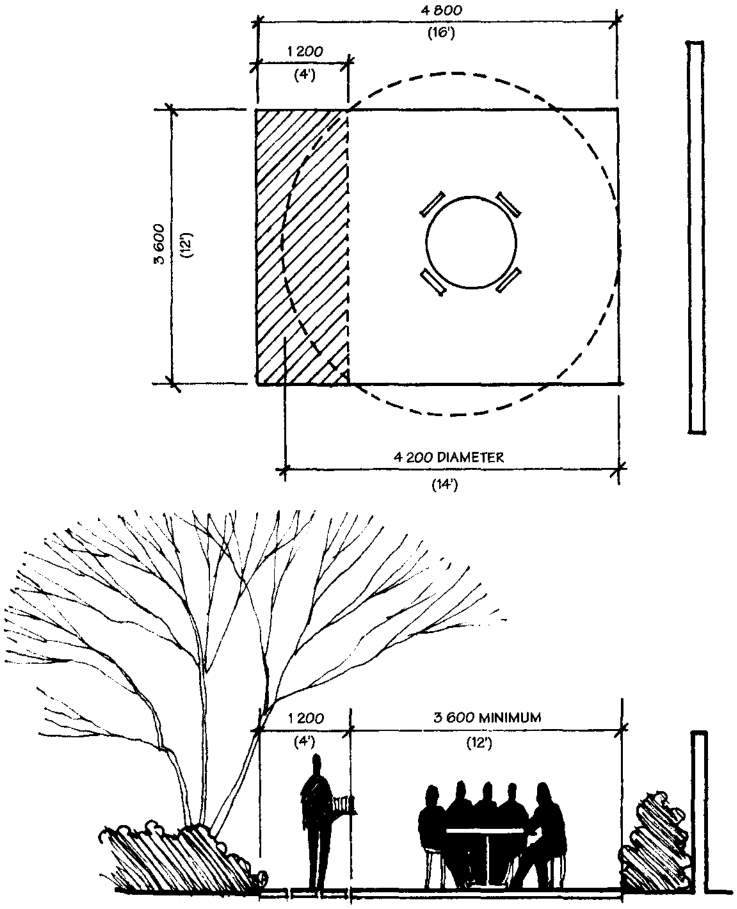
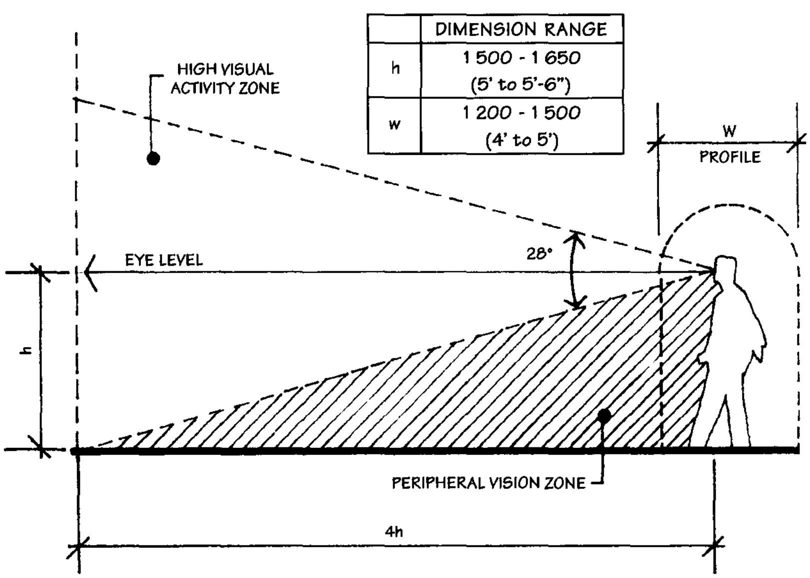


Figure 210-3. Patio dining requirements. *Circulation space should be factored into spatial design.*



	DIMENSION RANGE
h	1 500 - 1 650 (5' to 5'-6")
w	1 200 - 1 500 (4' to 5')

Figure 210-4. Pedestrian peripheral vision zone. *The vertical cone of vision results in a peripheral floor distance of 6 000-6 600 mm (20-22 ft).*

physical or ergonomic requirements. Dimensions indicated in this section are primarily North American and may not apply in all circumstances.

2.0 APPLICATIONS

2.1 Human Spatial Settings

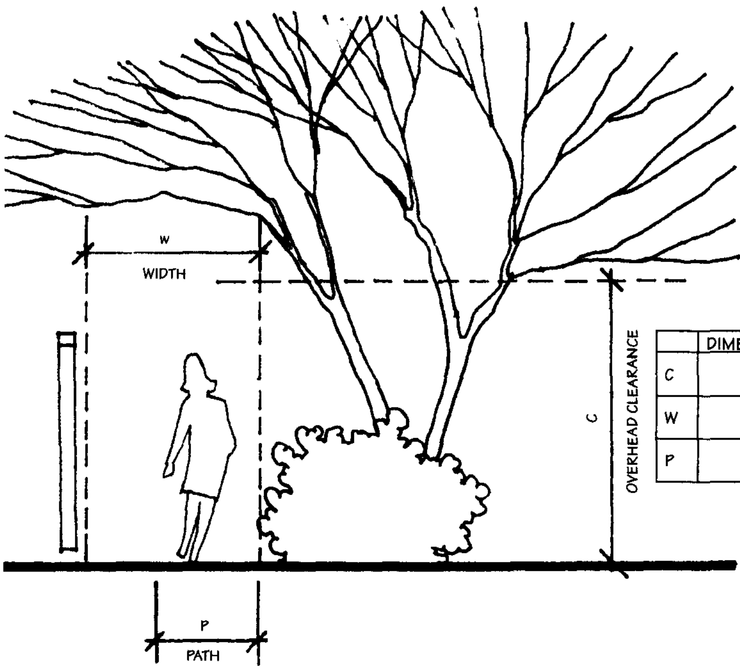
Human spatial and dimensional requirements, derived from land-use intensity and cultural setting, may be conceptualized as "space-time environments." Such environments are structured by enclosing floor, wall, and canopy elements, and are modified by time, light, climate, and intensity of activity. Figure 210-1 illustrates the elements of spatial enclosure in the outdoor environment as they relate to human perception (Refer to Section 340: Pedestrian Circulation for more detailed coverage of perceptual factors).

Ergonomic Measurements:

Typically ergonomic data accounts for age, sex, and size as indicated by percentile ranking. Figure 210-2, derived from data provided by Henry Dreyfuss Associates, indicates critical male and female standing position dimensions required for the design of human environments and artifacts. Minimum dimensions developed for architectural interior environments require modification when applied to exterior space. Generally, more exterior space is needed to accommodate most human activities commonly associated with interior applications, such as dining, walking in a hallway, and sitting in a group, because behavior and scale perception are altered by the context of sky and vista. Minimum patio or deck space required for exterior dining may be 40 to 60% greater than that which is minimally required for interior dining. As illustrated in Figure 210-3, a 3 000 x 3 000 mm (10 x 10 ft) dining room when placed on a patio setting typically requires a 3 600 x 3 600 mm or 3 600 x 4 500 mm (12 x 12 ft or 12 x 15 ft) exterior floor area to avoid feeling "cramped" by the lesser dimensions while in the openness of the outdoors.

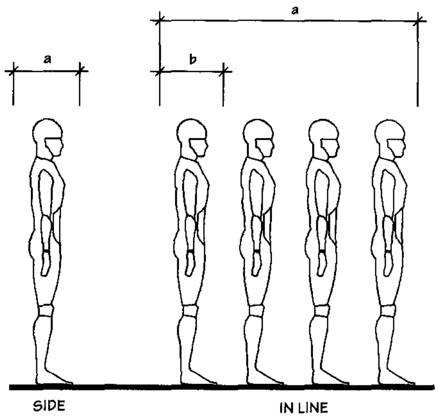
Peripheral Vision:

Figure 210-4 illustrates the typical relationship between the human eye level height and the perceived floor plane. Commonly, the floor plane is below the vertical cone-of-vision (28°) for a distance of 4 times the average eye level height of 1 500-1 650 mm (5 to 5 ft-6 in). In other words, a floor plane distance of 6 000-6 600 mm (20-22 ft) is typically within a pedestrian's peripheral vision zone. The vertical cone-of-vision



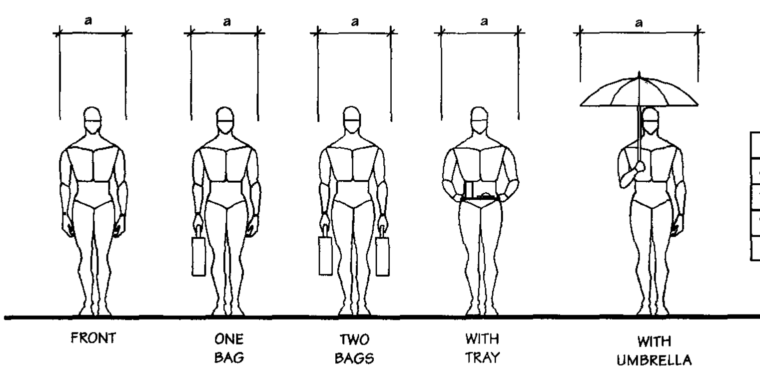
	DIMENSION RANGE
C	2 100–2 400 (7' to 8')
W	1 500 (5')
P	600--900 (2' to 3')

Figure 210-5. Typical vertical and horizontal garden clearances. *Branches and hanging vines are usually pruned to allow about 2 100 mm (7 ft) vertical clearance and about 1 500 mm (5 ft) horizontal clearance on a 600-900 mm (2-3 ft) wide path.*



	a	b
SINGLE SIDE	330 (13")	PER PERSON
PACKED NORMAL	1 880 (74")	470 (18")
WAITING LINE (WITH GEAR)	3 050 (120")	763 (30")
NORMAL LINE	2 135 (84")	534 (21")
CHOIR	2 030 (80")	508 (20")
WALKING	2 540 (100")	635 (25")
STRIDING	3 505 (138")	876 (35")

Figure 210-6. Minimum queuing distances.



FRONT	535 (21")
ONE BAG	800 (32")
TWO BAGS	1 015 (40")
WITH TRAY	965 (38")
WITH UMBRELLA	1 120 (44")

Figure 210-7. Width requirements for selected pedestrian activities.

narrows considerably as velocity increases (Refer to Section 342: Vehicular Circulation and Section 340: Pedestrian Circulation for additional information).

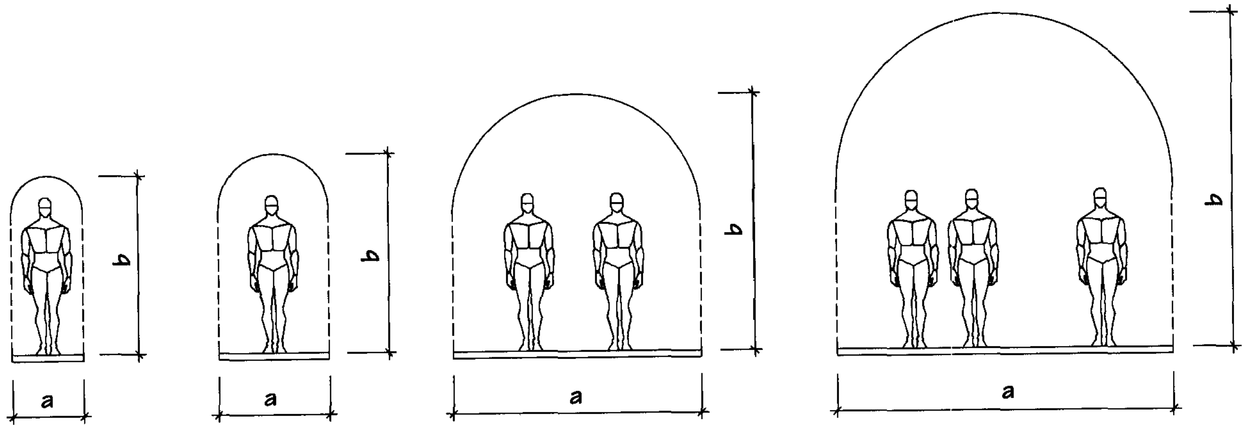
Intimate Garden Scale:

Figure 210-5 illustrates typical vertical and horizontal clearances found in small garden settings. Although these dimensions vary widely due to local practices and personal taste, the table shows general clearances required for mobility, safety, and maintenance considerations (Refer to Section 240: Outdoor Accessibility for more specific data on universal design considerations).

Figures 210-6 through 210-11 illustrate spatial dimensions required for various common human activities.

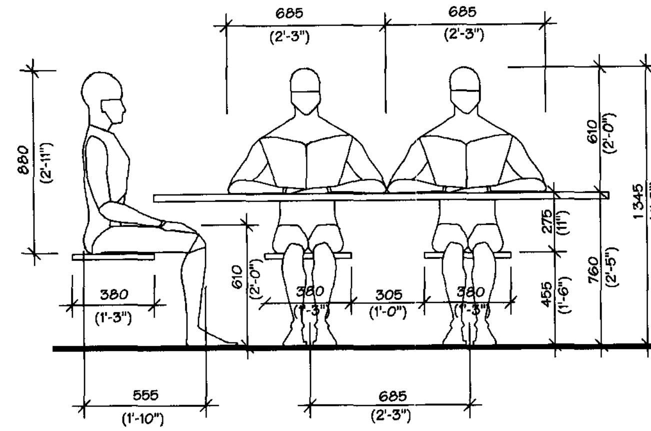
2.2 Vehicular Dimensions and Spatial Requirements

Vehicular spatial and dimensional requirements vary by vehicle type, land-use setting, and movement pattern (Refer to Section 342: Vehicular Circulation for information on road width and right of way). These spatial standards rely more heavily on physical data, but also include allowances for cultural settings and psychological expectations. Figure 210-12 illustrates the contextual elements that give scale to the pedestrian and vehicular landscape. Spatial standards must accommodate the intermingling of both large vehicles and pedestrians. Safe setbacks and clearances must be provided to protect pedestrians, plantings, structures, lights and other elements of the designed environment, while providing adequate maneuvering room for various types of vehicles.



TYPE	a WIDTH	b CLEARANCE
PATH		
SMALL GARDEN	450 (1'-6")	1 998 (6'-8")
TYPICAL	900 (3')	2 100 (7')
PREFERRED	1 200 (4')	2 100 (7')
WALK		
SINGLE	900 - 1 200 (3' to 4')	2 100 (7')
COUPLE MINIMUM	1 500 (5')	2 100 (7')
PREFERRED	1 800 (6')	2 100 (7')
FOUR ABREAST MINIMUM	2 400 (8')	2 100 (7')
PREFERRED	2 700 (9')	2 400 (8')
PUBLIC WAY		
MINIMUM	2 400 (8')	2 400 (8')
PREFERRED	3 000 (10')	3 000 (10')
METROPOLITAN/INSTITUTIONAL		
PEDESTRIAN WAY MINIMUM	3 000 (10')	3 000 (10')
MEDIUM	4 500 (15')	3 600 (12')
LARGE	6 000 (20')	4 500 (15')

Figure 210-8. Pedestrian walkway width and height requirements.



Circle		Square		Rectangular		
Persons	a	Persons	a&b	Persons	a	b
2	600 - 900 (2 - 3')	2	600 - 900 (2 - 3')	---	---	---
4	900 - 1 200 (3 - 4')	4	900 - 1 200 (3 - 4')	4	750 (2'-6")	1 500 (5')
6	1 200 - 1 500 (4 - 5')	6	1 200 - 1 500 (4 - 5')	6-8	900 (3')	2 100 (7')
8	1 500 - 1 800 (5 - 6')	8	1 500 - 1 800 (5 - 6')	8-10	1 050 (3'-6")	2 400 (8')
10	1 800 - 2 100 (6 - 7')	10	1 800 - 2 100 (6 - 7')	10-12	1 200 (4')	3 000 (10')

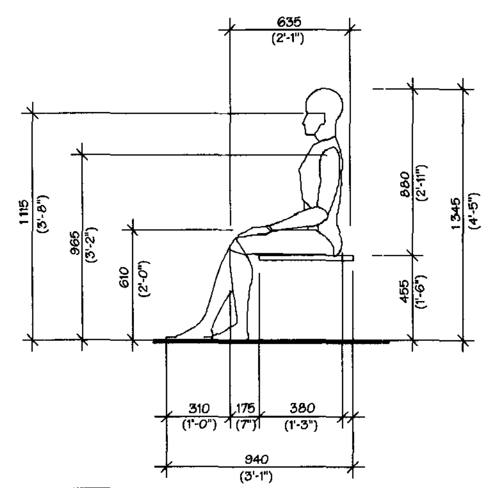


Figure 210-9. Seated figures.

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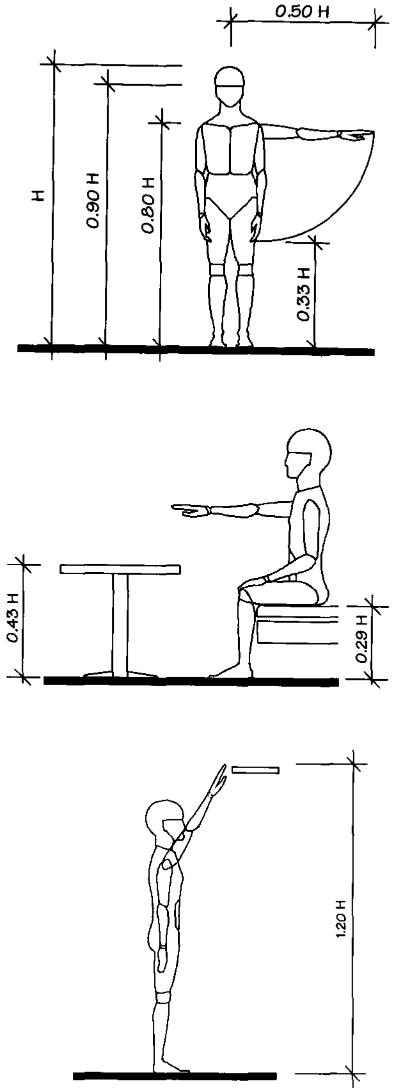
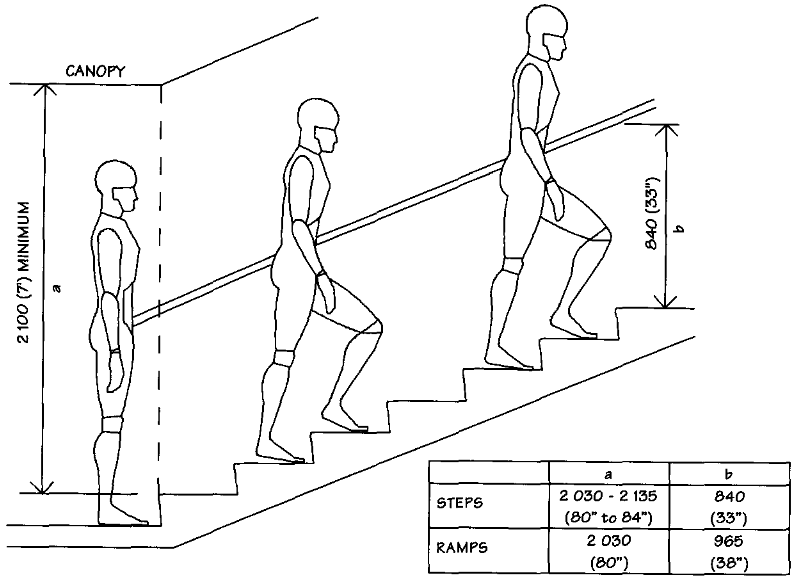


AGE	H
9	1 320 (52")
7	1 220 (48")
5	1 090 (43")

Figure 210-10. Child's dimensional proportions for ages 5, 7, and 9.



	a	b
STEPS	2 030 - 2 135 (80" to 84")	840 (33")
RAMPS	2 030 (80")	965 (38")

Figure 210-11. Covered stairway and ramp vertical clearances.

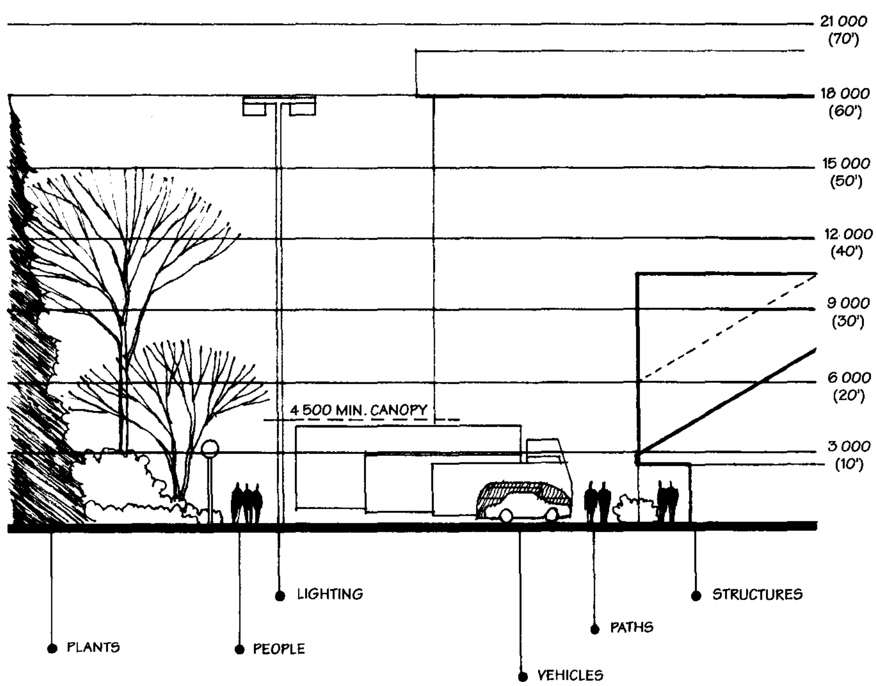


Figure 210-12. Elements of the pedestrian and vehicular landscape. *Scale variation in this landscape type is extreme. Tall commercial buildings, large trees, large trucks and transit vehicles, lights, and signs must co-exist with human scaled walks and corridors.*

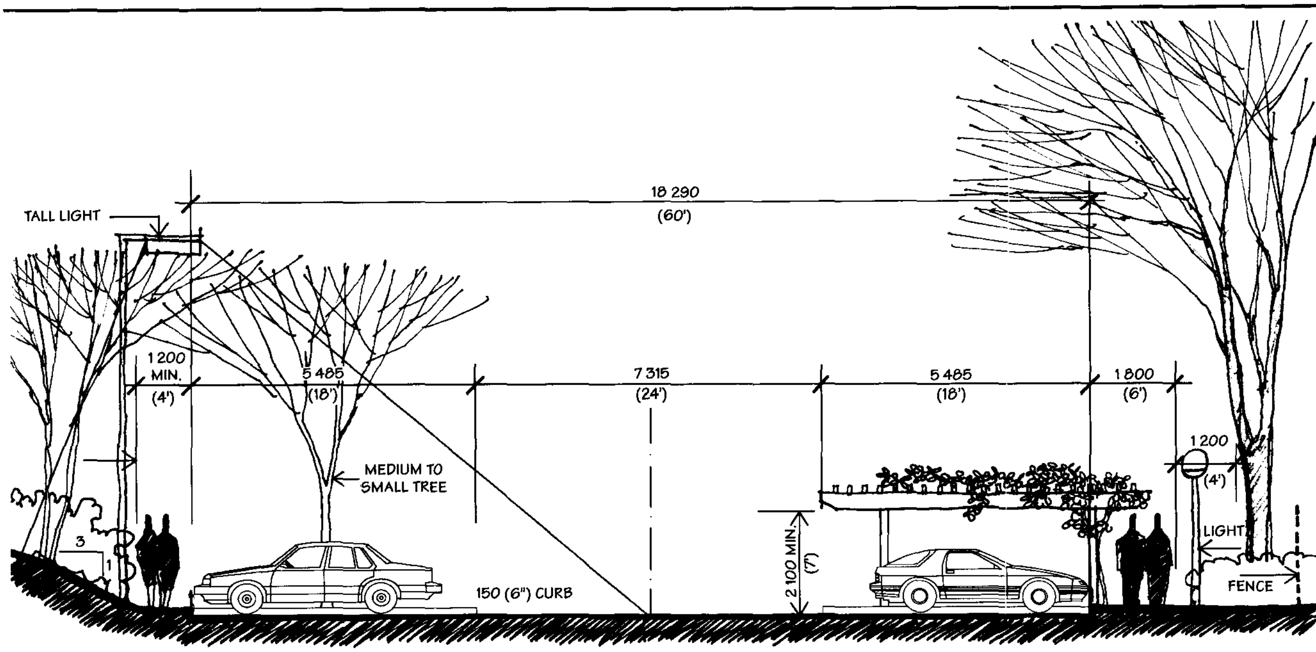


Figure 210-13. Auto parking elements and typical spatial dimensions. *Typically plantings, land form, screens, and structures are used to create a more hospitable transition from auto to pedestrian path.*

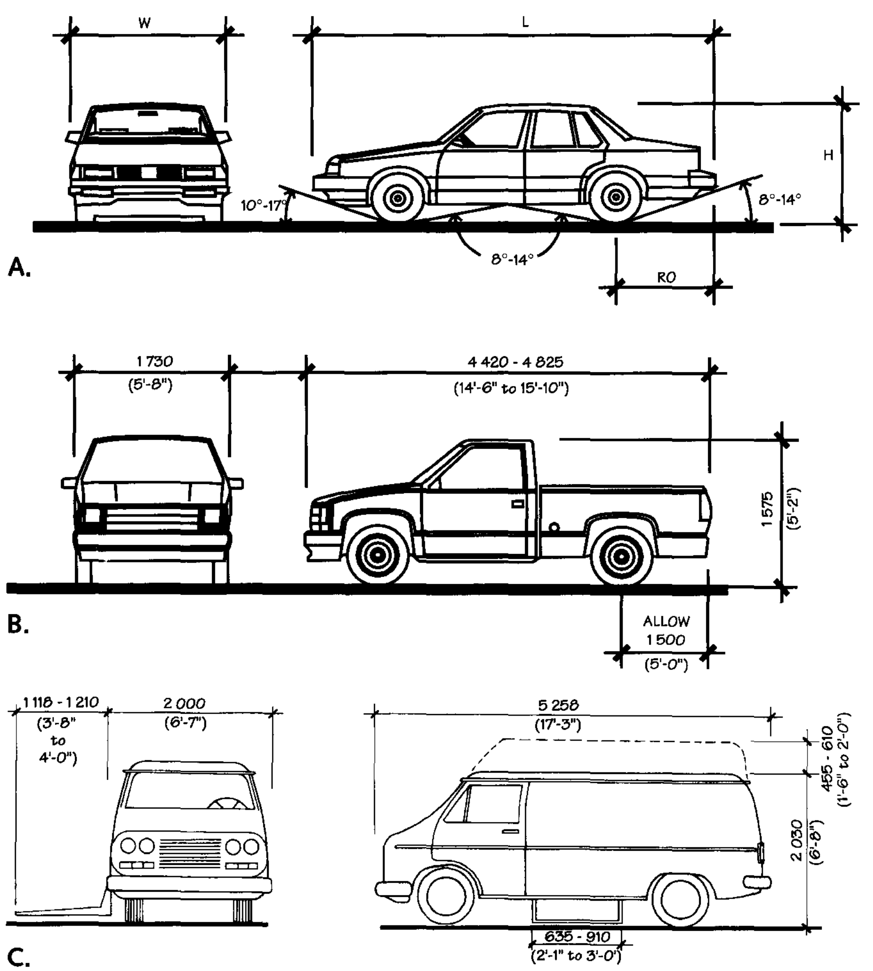


Figure 210-14. Vehicular dimensions by type. *a. Typical automobile, b. Small pick-up truck, c. Large van. (Refer to tables on vehicular dimensions.)*

Pedestrians move from vehicles to pathways within parking lot settings. Figure 210-13 illustrates the typical design elements and spatial standards which may be employed in parking area design. The data indicates minimum tolerances based on vehicle size and mechanics, and also points to recommended dimensions and configurations. Generally, parking pavement should be minimized, allowing storm water runoff to be interrupted by vegetative growth in order to slow velocities and allow cleansing and infiltration (Refer to Section 330: Stormwater Management for more detailed information). Drainage objectives may support visual objectives by breaking up the mass of hard surface area through the use of landform and planting.

Automobiles:

Figure 210-14 and the accompanying chart indicates key dimensional data by vehicle type. Rear overhang and bottom clearance angles are especially noted because they affect minimum distances of structures and plantings to parking lot curbs, and to maximum ramp differentials respectively. Figures 210-15 and 210-16 illustrate overhang and degree of slope relationships. Rear overhang is generally larger than front overhang, and for design purposes, rear overhang provides the more conservative dimension to determine minimum setbacks. It is common practice to allow for a 1 500 mm (5 ft) overhang. Parking lots designed to accommodate special vehicles such as larger trucks, recreational vehicles, and

Vehicular Dimensions

Type	Length L	Width W	Height H	Rear Overhang RO	Outer Radius R	Inner Radius R1
Subcompacts	3 530 to 4 470 (11'-7" to 14'-8")	1 550 to 1 725 (5'-1"to 5'-8")	1 270 to 1 395 (4'-2" to 4'-7")	1 140 (3'-9")	6 045 (19'-10")	3 275 (10'-9")
Compacts	4 215 to 4 670 (13'-10" to 15'-4")	1 675 to 1 725 (5'-6" to 5'-8")	1 320 to 1 420 (4'-4" to 4'-8")	1 295 (4'-3")	6 550 (21'-6")	3 610 (11'-10")
Midsize	4 570 to 5 080 (15'-0" to 16'-8")	1 700 to 1 830 (5'-7" to 6'-0")	1 270 to 1 450 (4'-2" to 4'-9")	1 320 (4'-4")	6 830 (22'-5")	6 835 (12'-7")
Large Cars	4 620 to 5 610 (15'-2" to 18'-5")	1 725 to 2 030 (5'-8" to 6'-8")	1 395 to 1 520 (4'-7" to 5'-0")	1 345 (4'-5")	7 010 (23'-0")	3 835 (12'-7")
Large Pick-up	4 820 to 6 150 (15'-10" to 20'-2")	1 955 to 2 060 (6'-5" to 6'-9")	1 750 to 1 930 (5'-9" to 6'-4")	1 320 (4'-4")	7 620 (25'-0")	4 265 (14'-0")

boat trailer assemblies, should be designed accordingly to prevent damage to plantings or other structural elements.

Interior and exterior radii of the design vehicle are essential for the design of turn-a-round and arrival loops to insure sufficient pavement widths and front, side, and rear overhang clearances. Figure 210-17 illustrates the location of the R1 (interior) and the R (exterior) turning radius and refers to the table in Figure 210-14. The door swing typically requires 1 115 mm (3 ft-8 in).

Parking and Maneuvering Patterns:

Figures 210-18 through 210-23 indicate dimensional requirements of common parking and service access maneuvers for a range of vehicle types and sizes. Each site requires careful analysis to design the most appropriate pattern for a particular circumstance. These examples are meant to serve as points of departure for design. The figures also indicate critical setbacks required to allow for overhang clearances and snow removal in cold climates. An overhang minimum of 1 500 mm (5 ft) should be allowed at all back-up spaces to allow for a variety of vehicle types, including occasional service or delivery vans.

Parking Dimensions:

Figure 210-24 illustrates basic parking lot dimensions required of perpendicular and angled parking. Cars parked perpendicular to the travel aisle yields the most efficient number of cars per ha (acre) since it requires less space. The least efficient parking results from 30° angle layouts, which are typically used only when their is insufficient lateral dimension for other options. The accompanying table indicates the dimensional relationship between stall width and back-up aisle width. As the stall width narrows, the aisle width must widen to compensate. Typical stall dimensions for standard 90° parking are 2 740 x 5 485 mm (9 x 18 ft) and are commonly used in a minimum 18 290 mm (60') curb to curb parking module.

Figure 210-25 a illustrates a typical double loaded single aisle pull-through parking lot commonly found in recreation pull-off parking areas. Such lots are a safer alternative to road shoulder parking, and afford an opportunity to screen the parking with land form and plantings. As indicated in the drawing, plants and signs must be set-back 15 000 mm (50 ft) at entrances and exits to avoid obscuring driver vision. A 9 000 mm (30 ft) buffer between the road and parking lot edge is desirable, but should be at least 4 800 mm (16 ft) wide to provide room for screen planting or fencing. Parking lot length should be determined by stall width plus handicap parking allowances. Additional parking may be added to outer edges as shown, but will result in fewer planting options. Figures 210-25 b, and c illustrate other variations of single aisle parking, but example "c" is the least desirable due to poor circulation

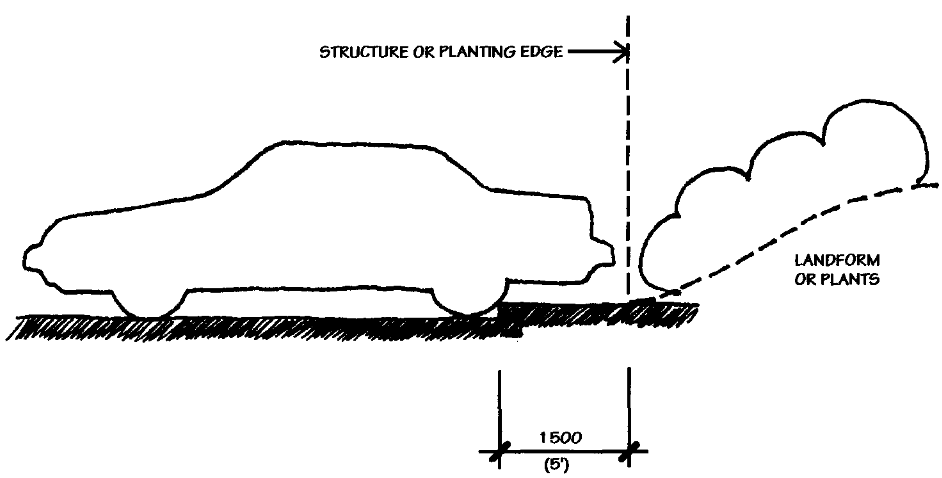


Figure 210-15. Recommended overhang clearance for vehicular parking lots. *A generous standard of 1 500 mm (5 ft) will accommodate back-in maneuvers and will protect trees, and structures. Cold climates may require more space to accommodate snow removal.*

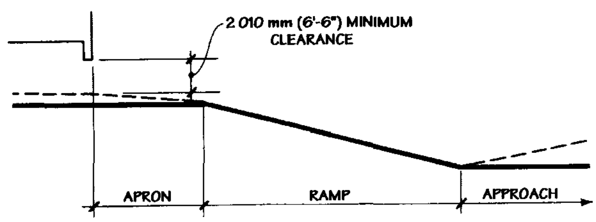


Figure 210-16. Common slope and vehicular ramp clearance data.

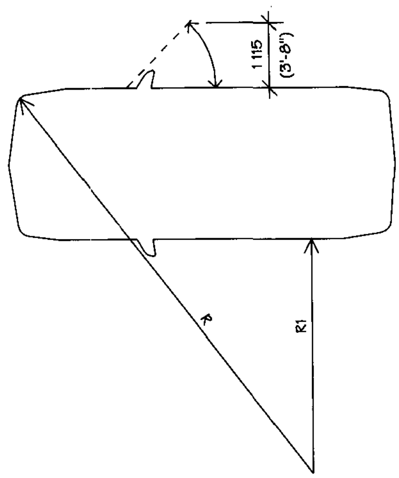
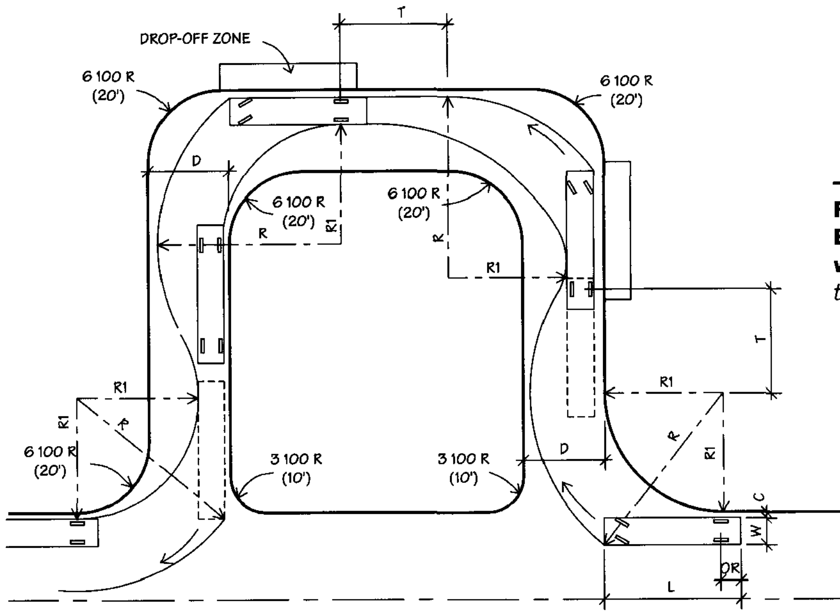


Figure 210-17. Interior (R1) and Exterior (R) turning radius location, with typical door swing values *(Refer to table in Figure 210-14).*

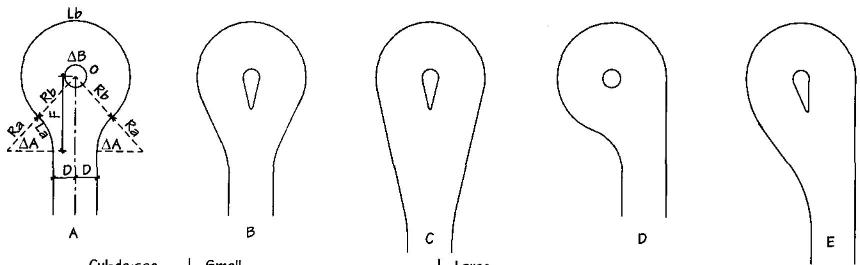


"U" Drive and Vehicle Turning Dimensions

Vehicle	R	R1	T	D	C
Small Car	6 045 (19'-10")	3 275 (10'-9")	3 660 (12'0")	3 050 (10'-0")	150 (6")
Compact Car	6 555 (21'-6")	3 605 (11'-10")	4 570 (15'-0")	3 300 (10'-10")	180 (7")
Standard Car	6 835 (22'-5")	3 835 (12'-7")	4 570 (15'-0")	3 405 (11'-2")	230 (9")
Large Car	7 010 (23'-0")	3 835 (12'-7")	4 570 (15'-0")	3 660 (12'-0")	255 (1'-0")
Intercity Bus*	16 765 (55'-0")	10 060 (33'-0")	9 145 (30'-0")	6 860 (22'-6")	255 (1'-0")
City Bus	16 305 (53'-6")	10 060 (33'-0")	9 145 (30'-0")	6 860 (22'-6")	255 (1'-0")
School Bus	13 260 (43'-6")	7 925 (26'-0")	9 145 (30'-0")	5 920 (19'-5")	255 (1'-0")
Ambulance	9 145 (30'-0")	5 715 (18'-9")	7 620 (25'-0")	4 040 (13'-3")	255 (1'-0")
Paramedic Van	7 620 (25'-0")	4 265 (14'-0")	7 620 (25'-0")	3 960 (13'-0")	255 (1'-0")
Hearse	9 145 (30'-0")	5 715 (18'-9")	6 095 (20'-0")	4 040 (13'-3")	255 (1'-0")
Airport Limousine	8 610 (28'-3")	4 610 (15'-1.5")	6 095 (20'-0")	4 610 (15'-1.5")	255 (1'-0")
Trash Truck†	9 755 (32'-0")	5 485 (18'-0")	6 095 (20'-0")	4 875 (16'-0")	255 (1'-0")
U.P.S. Truck	8 535 (28'-0")	4 875 (16'-0")	6 095 (20'-0")	4 265 (14'-0")	255 (1'-0")
Fire Truck	14 630 (48'-0")	10 465 (34'-4")	9 145 (30'-0")	4 775 (15'-8")	255 (1'-0")

* Headroom = 4 265 (14"-0")
† Headroom = 4 570 (15'-0")

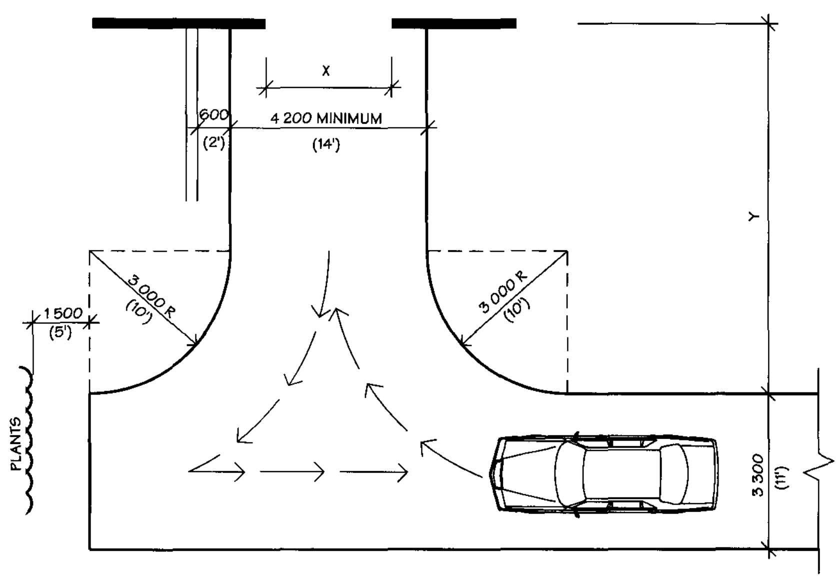
Figure 210-18. Dimensions and turning radii for arrival and drop-off facility.



Cul-de-sac	Small	Large
O	4 875 mm (16'-0")	6 700 mm (22'-0")
F	15 520 mm (50'-11")	26 590 mm (87'-3")
A	46.71°	35.58°
B	273.42°	251.15°
R_a	9 750 mm (32'-0")	30 480 mm (100'-0")
R_b	11 580 mm (38'-0")	15 240 mm (50'-0")
L_a	7 950 mm (26'-1")	18 795 mm (61'-8")
L_b	55 270 mm (181'-4")	66 800mm (219'-2")
D	3 000 mm (10'-0")	3 600 mm (12'-0")

Note: Vehicle R values should not exceed R_b

Figure 210-19. Cul-de-sac dimensions and forms.



X	2 700 mm (9')	3 050 mm (10')	3 350 mm (11')	3 660 mm (12')
Y	7 500 mm (25')	7 200 mm (24')	6 900 mm (23')	6 600 mm (22')

Figure 210-20. Turnaround at garage with parallel approach to door and adequate space to maneuver.

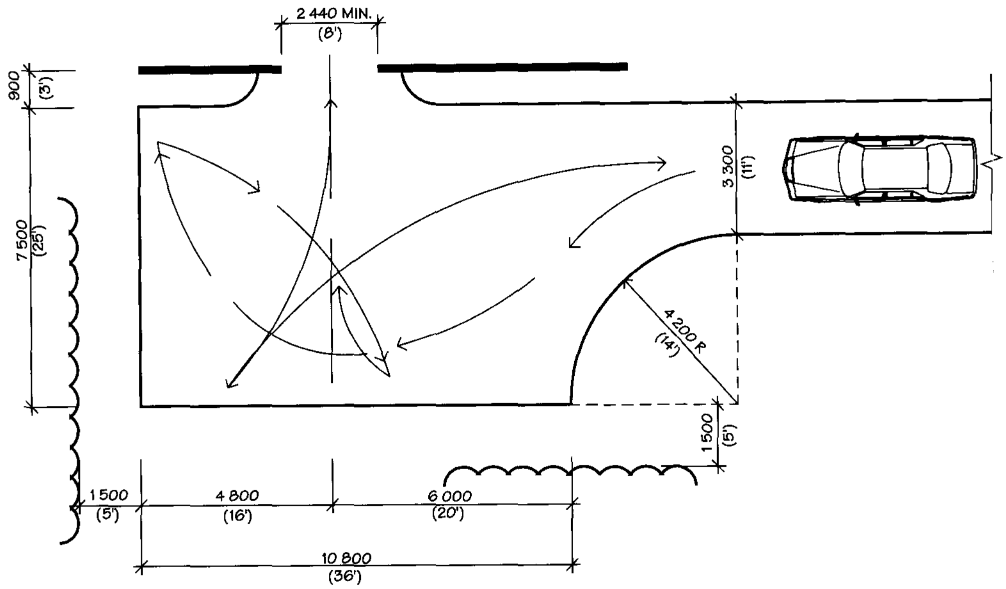
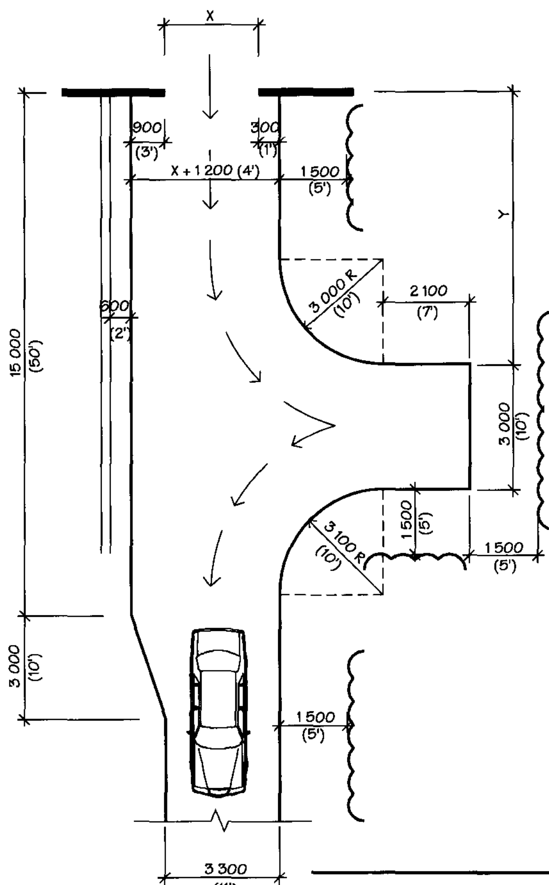


Figure 210-21. Turnaround at garage door requiring multiple maneuvers due to inadequate space.



X	2 700 mm (9')	3 050 mm (10')	3 660 mm (12')	4 875 mm (16')
Y	7 925 mm (26')	7 600 mm (25')	7 200 mm (24')	7 200 mm (24')

Figure 210-22. Straight-in garage entrance with minimum radius back-out apron.

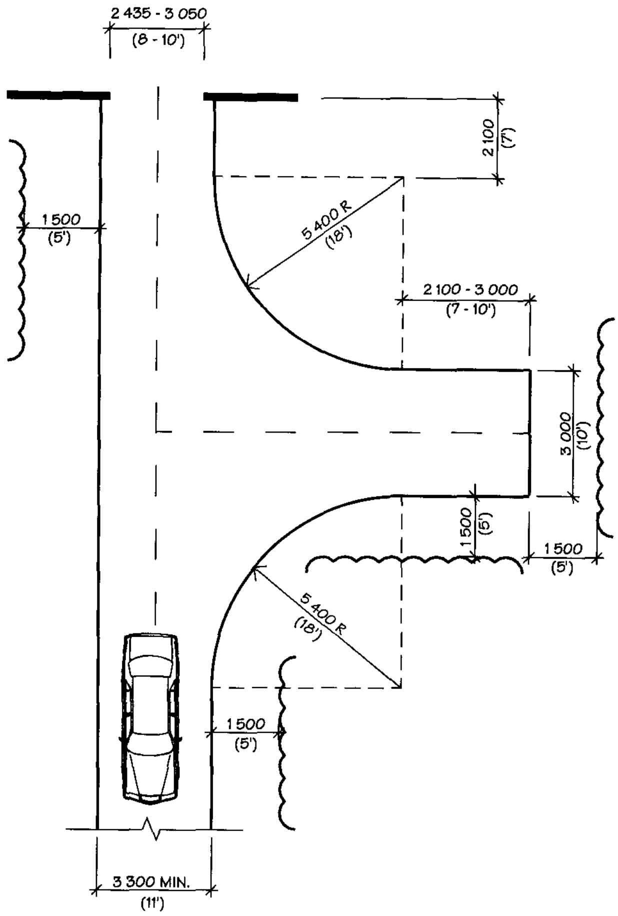
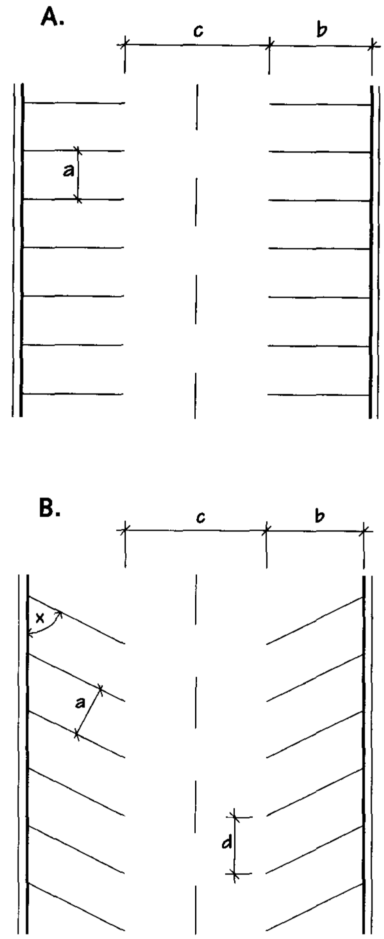


Figure 210-23. Straight-in garage entrance with large radius back-out apron to serve as guest parking space.



x°	Stall Width a	Stall Depth b	Aisle Width c	Skew Width d
90°	2 440 (8'-0") 2 590 (8'-6") 2 740 (9'-0")	5 485 (18'-0") 5 485 (18'-0") 5 485 (18'-0")	8 530 - 9 750 (28' to 32') 7 620 - 8 840 (25' to 29') 7 010 - 8 230 (23'to 27')	
60°	2 440 (8'-0") 2 590 (8'-6") 2 740 (9'-0")	5 970 (19'-7") 5 485 (18'-0") 5 180 (17'-0")	5 790 (19'-0") 5 485 (18'-0") 5 180 (17'-0")	2 820 (9'-3") 2 995 (9'-10") 3 175 (10'-5")
45°	2 440 (8'-0") 2 590 (8'-6") 2 740 (9'-0")	5 610 (18'-5") 5 690 (18'-8") 5 815 (19'-1")	3 660 (12'-0") 3 350 (11'-0") 3 350 (11'-0")	3 450 (11'-4") 3 660 (12'-0") 3 885 (12'-9")
30°	2 440 (8'-0") 2 590 (8'-6") 2 740 (9'-0")	4 850 (15'-11") 5 000 (16'-5") 5 130 (16'-10")	3 350 (11'-0") 3 040 (10'-0") 2 740 (9'-0")	4 875 (16'-0") 5 180 (17'-0") 5 485 (18'-0")
0°	2 440 (8'-0") 2 590 (8'-6") 2 740 (9'-0")	6 700 (22'-0") 6 700 (22'-0") 7 010 (23'-0")	3 350 (11'-0") 3 505 (11'-6") 3 660 (12'-0")	

Figure 210-24. Parking lot dimensions for various stall widths and angles. *(Adaptation courtesy of Vollmer Associates).*

Table 210-1. AREA SPACE STANDARDS AND PARKING RATIOS FOR OUTDOOR SPORT FACILITIES

AREA SPACE STANDARDS (based upon population)

Sport	Facilities per 1,000 population	Notes
Multicourt	Minimum 1 + 1/2,000-light 25-50%	1.5 mile maximum radius
Handball "	Minimum 1 + 1/5,000-10,,000 1/10,,000	
Volleyball	1/2,000 to 1/3-4,000	communities 10,,000+
Shuffleboard	Minimum 1-2 + 1/2,000-light 25%	communities over 500
Basketball " "	1 goal/500 1 goal/l ,000 + one full court 1 acre/5,000 persons	communities under 3,000 communities over 3,000
Croquet	1/2,000-light 25%	
Horsehoe	Minimum 2 + 1/2,000-light 25-50%	community over 500
Softball	Minimum 1 + 1/3,000-light 50%	community over 1,000
Little league	1/10,,000 Minimum 1 + 1/4,000-light 25%	
Baseball " " "	1/3,000 Minimum 1 + 1/6,000-light 50% 1/30,,000 1/6,000	community over 1500 community 1 mile maximum radius
Football soccer " " "	Minimum 1 + 1/5-15,000 Minimum 1 + 1/8,000 for football 2 acres/1000 1/80,000	
Tennis " " " "	Minimum 1 + 1/2,000-light 50-76% 1/1,0000 1/2,000 1500 S.F./player 1 acre/5,000	community 0.67 miles radius
Athletic field	Approximate 20 acres 1/5,0000-lighted accommodate 200 people/acre	1-2 miles or 20 minutes

Table 210-1a. PARKING RATIOS FOR OUTDOOR SPORTS FACILITIES

Sport	Suggested Minimum parking for normal use
Archery	1 /target
Badminton	2/court
Baseball	15+/diamond-player
Baseball	20/diamond-spectator
Bowling, lawn	2/green lane
Croquet	2/court
Golf	8/green
Golf	1 /practice tee
Football, touch	10/field
Horseshoes	1 /court
Trap shooting	2/range
Shuffleboard	2/court
Softball	15/diamond
Tennis, deck	2/court
Tennis, lawn	2/court
Volleyball	6/court

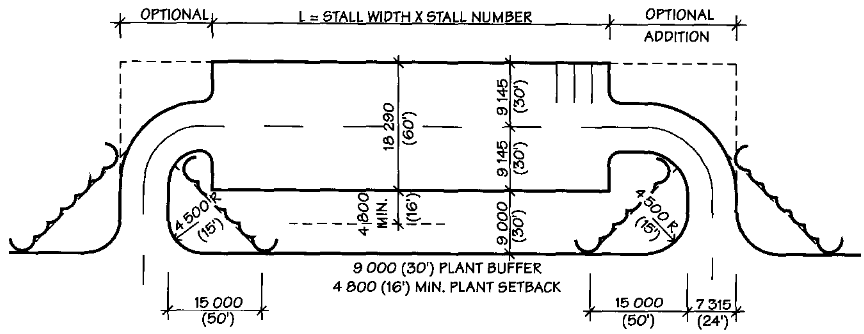


Figure 210-25 a. Double loaded single aisle pull-through parking lot.

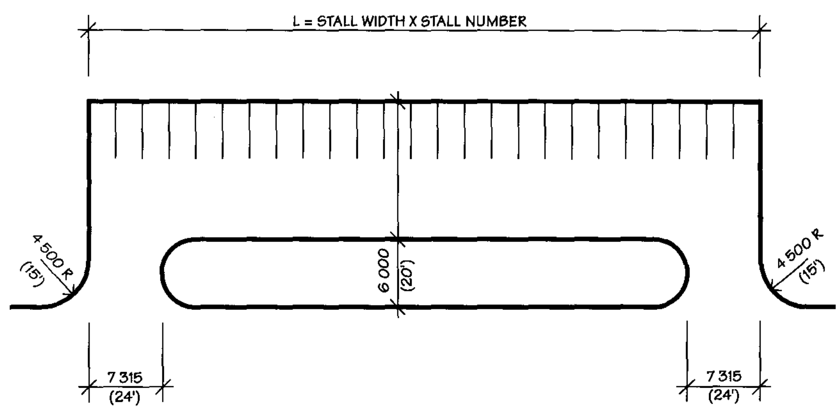


Figure 210-25 b. Single loaded aisle pull-through parking lot with small plant buffer.

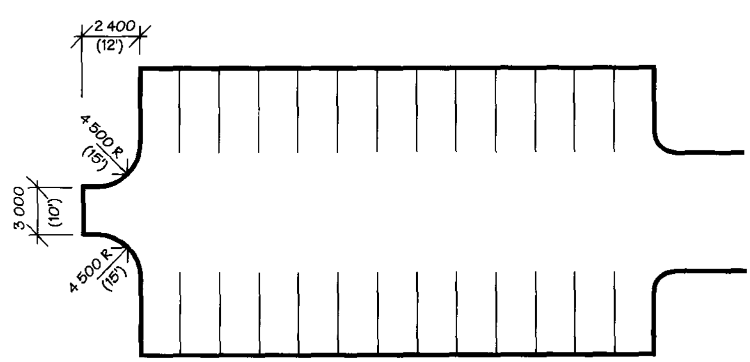


Figure 210-25 c. Double loaded single aisle dead-end parking lot. Not recommended for high turnover lots. Use only in utilitarian applications.

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when full and should be used only for utilitarian parking. Street entrance radius is typically 4 500-6 000 mm (15-20 ft). Small curb radius at parking stalls is typically 1 000-1 500 mm (3-5 ft).

Figures 210-26 a, b, c, d, and e, illustrate various adaptations of 90° parking patterns and show the advantages of adding plantings, drop-off zones, and screening. Figure 210-26 a. yields a parking rate of 62 cars/ha (152 cars/ac) but results in a barren unwelcoming environment lacking in pedestrian amenities. Figure 210-26 b. adds planting islands at parking row ends, providing greater turning clearances and planting opportunities. Figure 210-26 c. yields 45 cars/ha (112 cars/ac) and is commonly used as a method for organizing drainage, pedestrian circulation, lighting, and planting in large lots. Planting islands should be as wide as possible [6 000-9 000 mm (20-30 ft)] to allow for maximum tree root space and for winter snow clearing where required. Figure 210-26 d. is often used in informal settings to capture existing plants or earth features such as rock outcrops or landforms, and also to emphasize smaller parking units (The inset shows an alternative configuration). Figure 210-26 e. yields 59 cars/ha (145 cars/ac), has a high potential for "capturing" existing trees in random patterns throughout a large parking lot, and may facilitate snow clearing by allowing more lateral plowing movements than linear curbing systems.

Trucks and Transport:

Site design requiring access and loading of freight and mass transit vehicles must provide safe and efficient operating space, using the least amount of paving surface allowable to diminish runoff volumes. Accurate data regarding vehicle sizes, turning radii, and maneuvering patterns is essential to accomplish these two objectives.

Figures 210-27 through 29 illustrate dimensional requirements for open and closed freight loading docks with emphasis on vehicle sizes and turning radii. Maximum heights, widths, and lengths vary by local and state authority. Conventional semitrailers average 16 760 mm (55 ft) in length, 4 115 mm (13 ft 6 in) in height, and 2 435 mm (8 ft) in width. Maximum height is 4 420 mm (14 ft 6 in). This data is important for the design of bridge and service access ramp clearances. The average loading floor height at the loading dock is 1 270 mm (4 ft 2 in).

Table 210-2. AREA REQUIREMENTS FOR PLAYGROUNDS AND SPORTS AREAS

Type of equipment or area	Area per unit m2 (f2)	Capacity in numbers of users	Suggested number to be included
Apparatus			
Slide	42 (450)	6	1**
Horizontal bars	17 (180)	4	3**
Horizontal ladders	35 (375)	8	2**
Traveling rings	58 (625)	6	1
Giant stride	114 (1,225)	6	1
Small junglegym	17 (180)	10	1
Low swing	14 (150)	1	4*
High swing	23 (250)	1	6*
Balance beam	9 (100)	4	1
See-saw	9 (100)	2	4
Medium junglegym	46 (500)	20	1
Miscellaneous equipment and areas			
Open space for games (ages 6-10)	929 (10,000)	80	1*
Wading pool	279 (3,000)	40	1*
Handcraft, quiet games	149 (1,600)	30	1*
Outdoor theater	186 (2,000)	30	1
Sand box	28 (300)	15	2
Shelter house	232 (2,500)	30	1†
Special sports areas			
Soccer field	3344 (36,000)	22	1
Playground baseball	1858 (20,000)	20	2
Volleyball court	260 (2,800)	20	1
Basketball court	348 (3,750)	16	1
Jumping pits	111 (1,200)	12	1
Paddle tennis courts	167 (1,800)	4	2‡
Handball courts	98 (1,050)	4	2
Tether tennis courts	37 (400)	2	2‡
Horseshoe courts	56 (600)	4	2
Tennis courts	669 (7,200)	4	2‡
Straightaway track	669 (7,200)	10	1‡
Landscaping	557 (6,000)		
Paths, circulation, etc.	650 (7,000)		

* Minimum desirable.

** One or all of these units may be omitted if playground is not used in conjunction with a school.

† May be omitted it sanitary facilities are supplied elsewhere.

‡ May be omitted if space if limited.

Source: From *Architectural Systems Community Planning.*

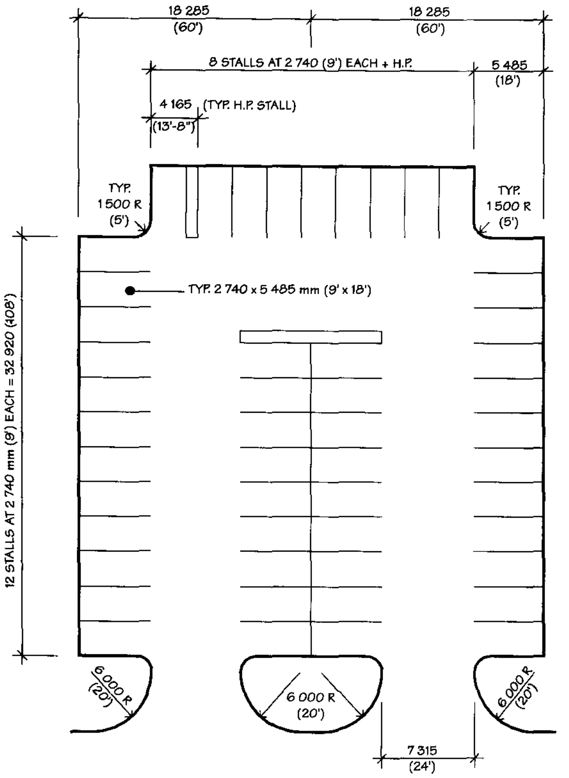


Figure 210-26 a. Double loaded multiple aisle parking. Using all perimeters for parking, this scheme yields the highest number of stalls per ha (ac), but results in a harsh environment.

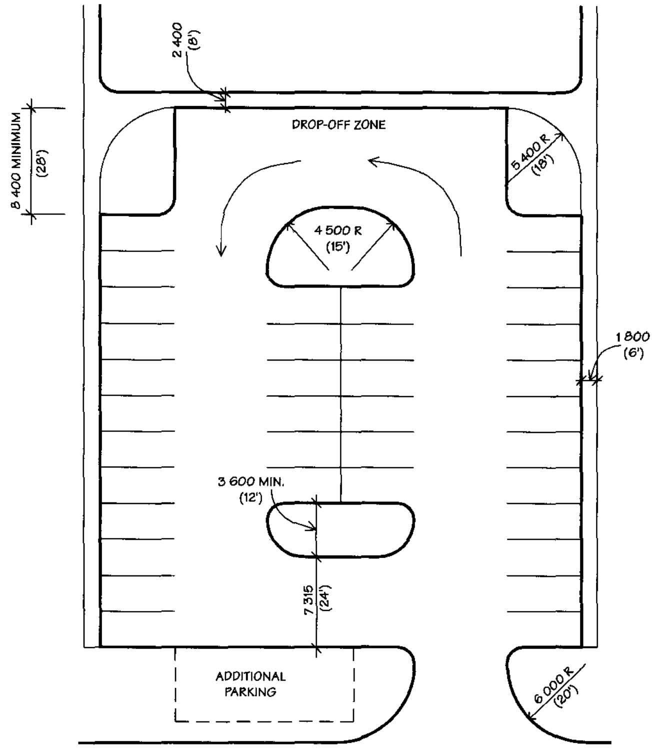


Figure 210-26 b. Variation of (a.) adding drop-off and end planting islands.

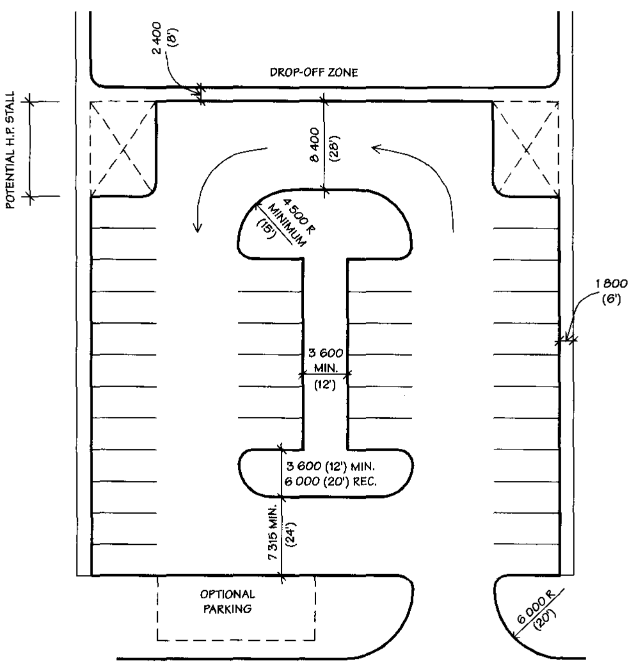


Figure 210-26 c. Separation of parking bays by planting strips. *Planting strip widths must allow for root growth and snow in cold zones.*

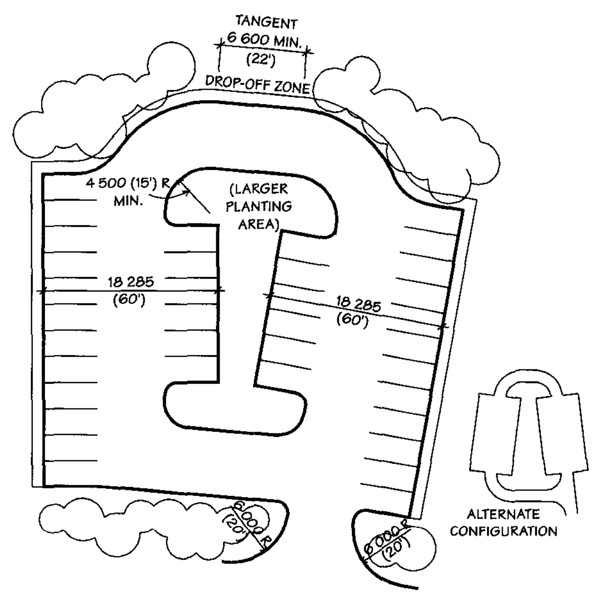


Figure 210-26 d. Skewed bays allows existing plants to be captured through proper grading and adds to reduction of contiguous pavement expanses.

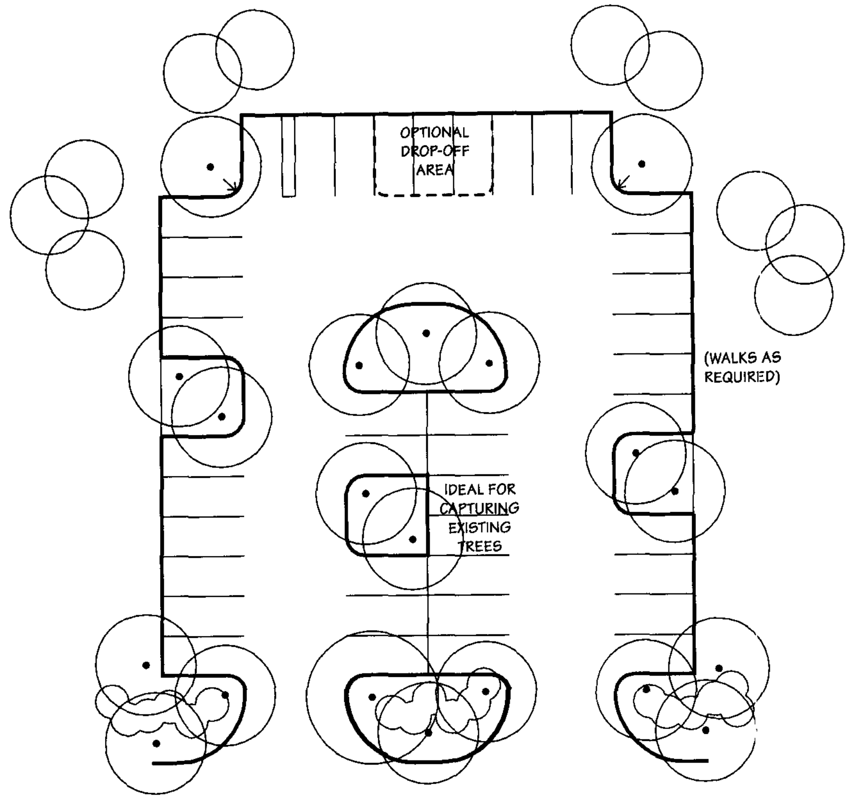


Figure 210-26 e. Random planting beds allow for broader areas of planting medium for trees and greater snow clearing freedom in cold zones.

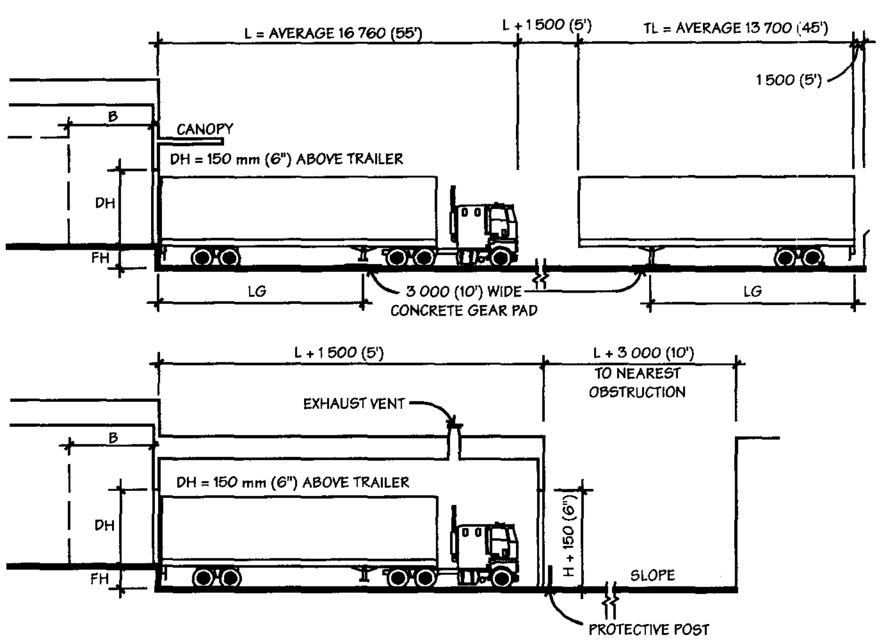


Figure 210-27. Closed and open freight loading dock dimensions.

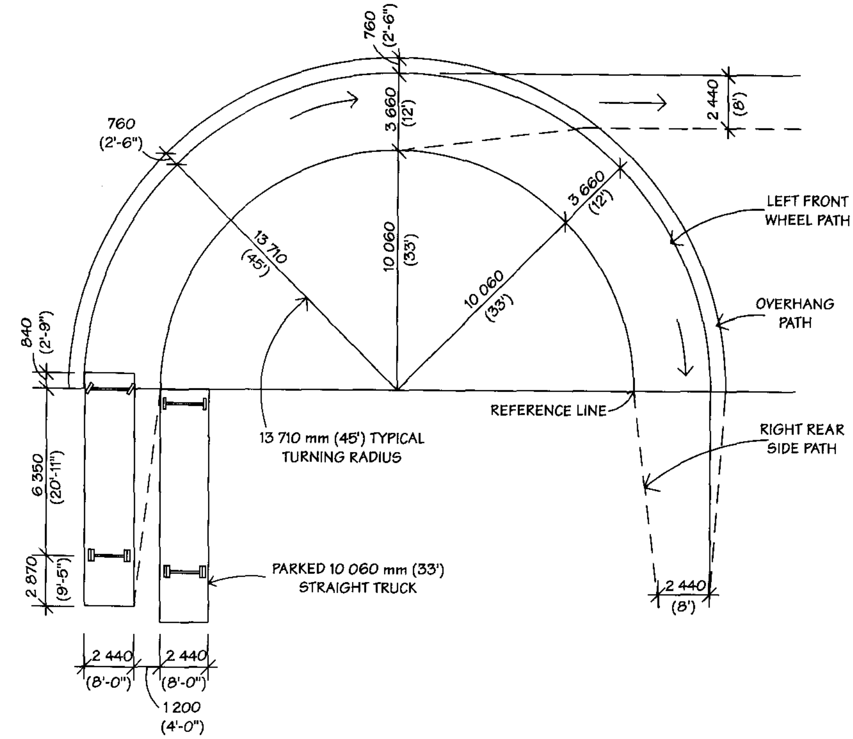


Figure 210-28. Space requirements and dimensions of tractor trailers and selected large vehicles.

Vehicle Height	
Maximum Allowable	
Total Height	**State**
4 115 mm (13'-6")	In all states except those listed below
3 960 mm (13'-0")	FL
4 265 mm (14'-0")	CA, ID, ME, NV, ND, OR, UT, WA, WY
4 420 mm (14'-6")	CO, NB

Average SemiTrailer Dimensions				
	Length (L)			
	8 230 mm (27'-0")	12 190 mm (40'-0")	13 715 mm (45'-0")	Refrigerator 12 190 mm (40'-0")
Floor Height (FH)	1 270 mm (4'-2")	1 270 mm (4'-2")	1 270 mm (4'-2")	1 450 mm (4'-9")
Rear Axle (RA)	915 mm (3'-0")	1 575 mm (5'-2")	1 780 mm (5'-10")	1 345 mm (4'-5")
Landing Gear (LG)	5 790 mm (19'-0")	9 145 mm (30'-0")	10 515 mm (34'-6")	8 965 mm (29'-5")

Average Dimensions of Vehicles			
	Type of Vehicles		
	Double Semitrailer	Conventional Semitrailer	Straight Body Truck
Length (L)	21 335 mm (70'-0")	16 765 mm (55'-0")	5 180 mm to 12 190 mm (17'-0" to 40'-0")
Width (W)	2 440 mm (8'-0")	2 440 mm (8'-0")	2 440 mm (8'-0")
Height (H)	4 115 mm (13'-6")	4 115 mm (13'-6")	4 115 mm (13'-6")
Floor Height (FH)	1 220 mm to 1 370 mm (4'-0" to 4'-6")	1 220 mm to 1 320 mm (4'-0" to 4'-4")	915 mm to 1 220 mm (3'-0" to 4'-0")
Track (T)	1 980 mm (6'-6")	1 980 mm (6'-6")	1 780 mm (5'-10")
Rear Axle (RA)	915 mm to 1 220 mm (3'-0" to 4'-0")	1 220 mm to 3 660 mm (4'-0" to 12'-0")	685 mm to 3 660 mm (2'-3" to 12'-0")

Large Vehicle Dimensions

Vehicle	(L) Length	(W) Width	(H) Height	(OR) Overhang Rear
Intercity Bus	13 715 (45'-0")	2 745 (9'-0")	2 745 (9'-0")	3 075 (10'-1")
City Bus	12 190 (40'-0")	2 590 (8'-6")	2 590 (8'-6")	2 440 (8'-0")
School Bus	12 040 (39'-6")	2 440 (8'-0")	2 590 (8'-6")	3 860 (12'-8")
Ambulance	6 355 (20'-10.25")	2 110 (6'-11")	3 050 (10'-0")	1 625 (5'-4")
Paramedic Van	6 555 (21'-6")	2 440 (8'-0")	1 980 (6'-6")	1 220 (4'-0")
Hearse	5 995 (19'-8")	2 030 (6'-8")	2 820 (9'-3")	1 625 (5'-4")
Airport Limousine	6 850 (22'-5.75")	1 930 (6'-4")	1 525 (5'-0")	1 195 (3'-11")
Trash Truck	8 585 (28'-2")	2 440 (8'-0")	3 355 (11'-0")	1 830 (6'-0")
Delivery Truck	8 000 (26'-3")	2 415 (7'-11")	3 250 (10'-8")	2 565 (8'-5")
Fire Truck	9 755 (32'-0")	2 440 (8'-0")	2 945 (9'-8")	3 050 (10'-0")

* Exact sizes of large vehicles may vary

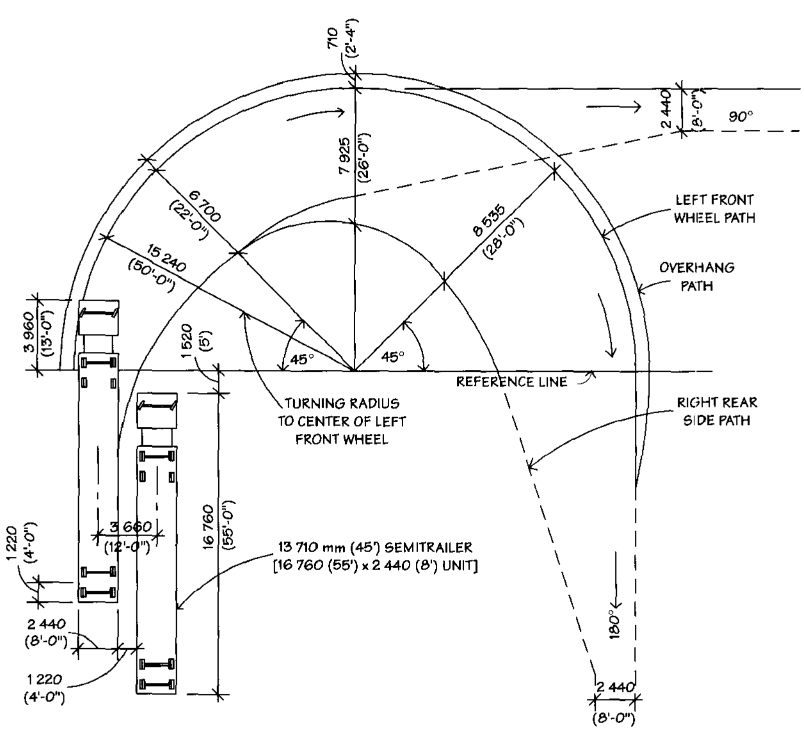
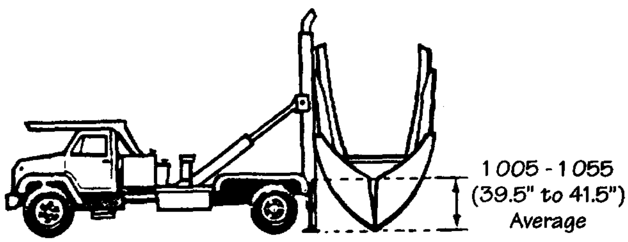


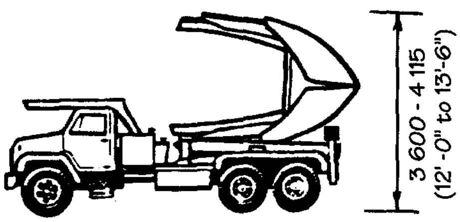
Figure 210-29. Turning radii for buses and semitrailers.

Miscellaneous Trucks

	Item	Maximum Length	Maximum Width	Maximum Height	Maximum Turning Radius
	Collection Truck	7 950 (26'-1")	2 590 (8'-6")	3 225 (10'-7")	10 365 (34'-0")
	Bulk Collection Truck	8 435 (27'-8")	2 590 (8'-6")	2 745 (9'-0")	10 365 (34'-0")
	Detachable Container and Hauling Unit	9 095 (29'-10")	2 440 (8'-0")	3 990 (13'-1")	8 840 (29'-0")
	Concrete Mixer	9 145 (30'-0")	2 590 (8'-6")	3 200 (10'-6")	10 365 (34'-0")

Figure 210-30. Maintenance and specialized vehicle dimensions.





Tree Spade Table

Specification	Model 55	Model 65	Model 80	Model 90
*Nominal tree trunk diameter	125-150 (5" to 6")	150-180 (6" to 7")	205-255 (8"to 10")	255-305 (10' to 12")
Wieght of Transplant	18 740 (8,500 lbs.)	22 045 (10,000 lbs.)	28 660 (13,000 lbs.)	34 835 (15,800 lbs.)
**Height closed for transporting (approx.) (A)	3 605 (11'-10")	3 710 (12'-2")	4 075 (13'-4.5")	4 115 (13'-6")
Width closed for transporting	2 430 (7'-11.75")	2 430 (7'-11.75")	2 585 (8'-5.75")	2 585 (8'-5.75")
Root ball width (approx.) (hydraulically adjustable)	1 395 (55")	1 650 (65")	2 030 (80")	2 285 (90")
Root ball depth (hydraulically adjustable)	1 220 (48")	1 345 (53")	1 370 (54")	1 525 (60")
Root ball weight (approx.)	7 715 (3500 lbs.)	10 470 4,750 lbs.	18 740 (8,500 lbs.)	24 250 (11,000 lbs.)

** Dependent upon truck chassis frame height.

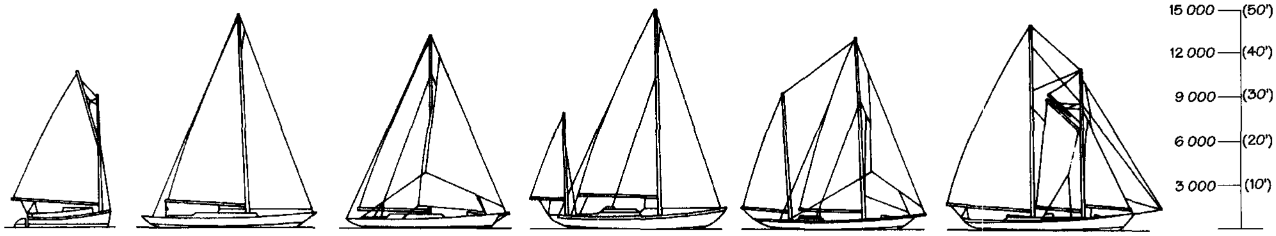


Figure 210-31. Range of sailboat types typically encountered in coastal and large lake regions.

Figure 210-30 illustrates various maintenance and other specialized vehicle sizes and spatial requirements. This data is important to anticipate space needs of maintenance and site construction operations.

Boats and Docks:

Marina development and dock facilities may accommodate boats from 4 265 mm (14 ft) to 24 380 mm (80 ft). Figure 210-31 illustrates the range of sailboat types typically encountered in coastal and large lake settings. Figure 210-32 illustrates the components and dimensions of slips and catwalks as indicated by the data table. Figure 210-33 illustrates a typical boat launching ramp and indicates basic design criteria.

3.0 COMMUNITY PLANNING DATA

The area standards shown in Tables 210-1 through 210-4 are derived from selected existing communities in North America. They providide "general standards" which may serve as a basis of comparison for planning purposes. For very active communities and user groups, these standards may need to be increased by 25 to 50% to reflect local conditions. Such standards are subject to great regional variation.

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Panero, Julius and Martin Zelnik, Human Dimensions and Interior Space. *Whitney Library of Design, New York, 1979.*

Ramsey/Sleeper, John Ray Hoke, Jr. (ed.) . Architectural Graphic Standards, 8th ed., *Wiley, New York, 1994.*

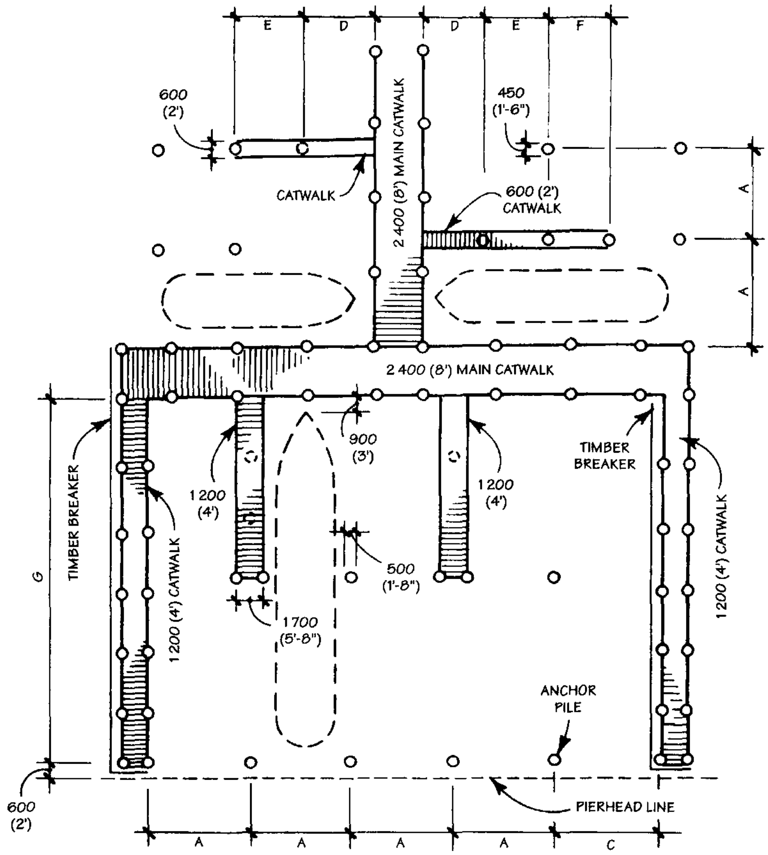

Figure 210-32. Boat slips and catwalk dimensions. *(Refer to table).*

TABLE OF DIMENSIONS FOR SLIPS AND CATWALKS TO BE USED WITH PLAN DIAGRAM

LENGTH GROUP FOR BOAT	BEAM TO BE PROVIDED FOR	MIN. CLEAR WIDTH OF SLIP	GROSS SLIP WIDTH TYPE A	GROSS SLIP WIDTH TYPE B	GROSS SLIP WIDTH TYPE C	1ST CATWALK SPAN LENGTH D	2ND CATWALK SPAN LENGTH E	3RD CATWALK SPAN LENGTH F	DISTANCE TO ANCHORAGE PILE
Up to 14'	2 005 mm (6'-7")	2 690 mm (8'-10")	3 275 mm (10'-9")	3 200 mm (10'-6")	3 405 mm (11'-2")	3 660 mm (12'-0")			5 180 mm (17'-0")
Over 14' to 16'	2 235 mm (7'-4")	2 945 mm (9'-8")	3 530 mm (11'-7")	3 455 mm (11'-4")	3 660 mm (12'-0")	3 660 mm (12'-0")			5 790 mm (19'0")
Over 16' to 18'	2 440 mm (8'-0")	3 175 mm (10'-5")	3 760 mm (12'-4")	3 685 mm (12'-1")	3 885 mm (12'-9")	4 265 mm (14'-0")			6 400 mm (21'-0")
Over 18' to 20'	2 615 mm (8'-7")	3 380 mm (11'-1")	3 960 mm (13'-0")	3 885 mm (12'-9")	4 090 mm (13'-5")	2 440 mm (8'-0")	2 440 mm (8'-0")		7 010 mm (23'-0")
Over 20' to 22'	2 820 mm (9'-3")	3 580 mm (11'-9")	4 165 mm (13'-8")	4 090 mm (13'-5")	4 295 mm (14'-1")	3 050 mm (10'-0")	2 440 mm (8'-0")		7 620 mm (25'-0")
Over 22' to 25'	3 125 mm (10'-3")	3 990 mm (13'-1")	4 570 mm (15'-0")	4 495 mm (14'-9")	4 700 mm (15'-5")	3 050 mm (10'-0")	2 440 mm (8'-0")		8 535 mm (28'-0")
Over 25' to 30'	3 430 mm (11'-3")	4 345 mm (14'-3")	4 930 mm (16'-2")	4 850 mm (15'-11")	5 055 mm (16'-7")	3 050 mm (10'-0")	3 050 mm (10'-0")		10 060 mm (33'-0")
Over 30' to 35'	3 735 mm (12'-3")	4 775 mm (15'-8")	5 360 mm (17'-7")	5 285 mm (17'-4")	5 485 mm (18'-0")	3 660 mm (12'-0")	3 050 mm (10'-0")		11 580 mm (38'-0")
Over 35' to 40'	4 040 mm (13'-3")	5 155 mm (16'-11")	5 740 mm (18'-10")	5 665 mm (18'-7")	5 865 mm (19'-3")	3 660 mm (12'-0")	3 660 mm (12'-0")		13 105mm (43'-0")
Over 40' to 45'	4 295 mm (14'-1")	5 460 mm (17'-11")	6 045 mm (19'-10")	5 970 mm (19'-7")	6 170 mm (20'-3")	4 265 mm (14'-0")	3 660 mm (12'-0")		14 630 mm (48'-0")
Over 45' to 50'	4 545 mm (14'-11")	5 790 mm (19'-0")	6 375 mm (20'-11")	6 300 mm (20'-8")	6 500 mm (21'-4")	2 745 mm (9'-0")	2 745 mm (9'-0")	3 050 mm (10'-0")	16 155 mm (53'-0")
Over 50' to 60'	5 030 mm (16'-6")	6 400 mm (21'-0")	6 985 mm (22'-11")	6 910 mm (22'-8")	7 110 mm (23'-4")	3 355 mm (11'-0")	3 355 mm (11'-0")	3 660 mm (12'-0")	19 200 mm (63'-0")
Over 60' to 70'	5 510 mm (18'-1")	7 010 (23'-0")	8 130 mm (26'-8")	7 520 mm (24'-8")	7 720 mm (25'-4")	3 355 mm (11'-0")	3 355 mm (11'-0")	3 660 mm (12'-0")	22 250 mm (73'-0")
Over 70' to 80'	6 020 mm (19'-9")	7 595 mm (24'-11")	8 710 mm (28'-7")	8 105 mm (26'-7")	8 000 mm (26'-3")	3 355 mm (11'-0")	3 355 mm (11'-0")	3 660 mm (12'-0")	25 300 mm (83'-0")

Table 210-3. LAND AREA REQUIREMENTS FOR COMMUNITY FACILITIES

	Neighborhood Population				
Type of development	1000 persons 275 families	2000 persons 550 families	3000 persons 825 families	4000 persons 1100 families	5000 persons 1375 families
One or Two-family Developments					
Area in component uses					
Acres in school site	1.20	1.20	1.50	1.80	2.20
Acres in playground	2.75	3.25	4.00	5.00	6.00
Acres in park	1.50	2.00	2.50	3.00	3.50
Acres in shopping center	0.80	1.20	2.20	2.60	3.00
Acres in general community facilities@	0.38	0.76	1.20	1.50	1.90
Aggregate area					
Acres: total	6.63	8.41	11.40	13.90	16.60
Acres per 1000 persons	6.63	4.20	3.80	3.47	3.32
Square feet per family	1050	670	600	550	530
Multifamily Development˚					
Area in component uses					
Acres in school site	1.20	1.20	1.50	1.80	2.20
Acres in playground	2.75	3.25	4.00	5.00	6.00
Acres in park	2.00	3.00	4.00	5.00	6.00
Acres in shopping center	0.80	1.20	2.20	2.60	3.00
Acres in general community facilities[t]	0.38	0.76	1.20	1.50	1.90
Aggregate area					
Acres: total	7.13	9.41	12.90	15.90	19.10
Acres per 1000 persons	7.13	4.70	4.30	3.97	3.82
Square feet per family	1130	745	680	630	610

Note: This table combines the recommended or assumed values.

[t]With private lot area of less than @@ acre per family (for private lots of acre or more park area may be omitted).

@Allowance for indoor social and cultural facilities (church, assembly hall, etc.) or separate health center, nursery school, etc.

˚Or other development predominantly without private yards.

Source: Adapted from *Architectural Systems Community Planning*

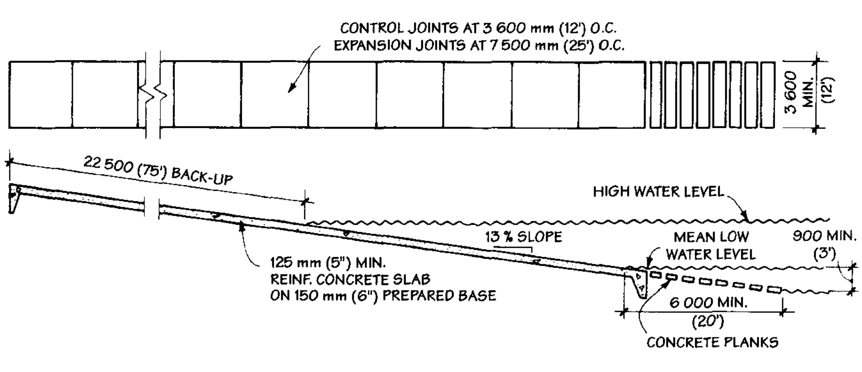

Figure 210-33. Boat launching ramp design criteria.

Table 210-4. PARKING SPACES REQUIRED FOR VARIOUS LAND USES

Use of site and/or building	Minimum number of parking spaces required
Residential	
Single family homes	2.0/dwelling unit
Multifamily:	
Efficiency	1.0/dwelling unit
One and two bedrooms	1.5/dwelling unit
Three and more apartments	2.0/dwelling unit
Dormitories, sororities, fraternities	0.5/units
Hotels and motels	1.0/dwelling unit
Commercial	
Offices and banks	3.0/1000 s.f. GFA
Business and professional services	3.3/1000 s.f. GFA
Commercial recreational facilities	8.0/1000 s.f. GFA
Bowling alleys	4.0/alley
Regional shopping centers	4.5/1000 s.f. GFA
Community shopping centers	5.0/1000 s.f. GFA
Neighborhood centers	6.0/1000 s.f. GFH
Restaurants	0.3/seat
Educational	
Elementary and junior high schools	1.0/teacher and staff
High schools and colleges	1.0/2-5 students
Medical	
Medical and dental offices	1.0/200 s.f. GFA
Hospitals	1.0/2-3 bed
Convalescent & nursing homes	1.0/3 bed
Public Building	
Auditoriums, theaters, stadiums	1.0/4 seats
Museums and libraries	1.0/300 s.f. GFA
Public utilities and offices	1.0/two employees
Recreation	
Beaches	1.0/100 s.f.
Swimming pools	1.0/30 s.f.
Athletic fields and courts	1.0/3000 s.f.
Golf courses	1.0/acre
Industrial	
Industrial manufacturing	1.0/2-5 employees
Churches	
Churches	1.0/4 seats

* The data was derived from existing conditions in North America. Special conditions including local codes and requirements may be quite different and should be used where appropriate. Study of comparable types of land uses nearby or in other similar situations is recommended. Access to and from the site/building via public transportation will affect significantly the number of parking spaces needed for most types of uses.

SECTION 220

Energy and Resource Conservation

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CONTENTS

1.0 INTRODUCTION

This section focuses on site-planning strategies and techniques for energy and resource conservation with regard to both site and building design to achieve greater human comfort and operational efficiencies. Sound site planning and design is prescriptive and strategic. It charts appropriate patterns of use for a site while incorporating construction methods that minimize site disruption and the expenditure of financial and building resources.

2.0 SITE ANALYSIS AND ASSESSMENT

The process of calculating the degree of resource use and the degree of disturbance of existing natural systems required to support a development begins with site selection. The most environmentally sound development is one that disturbs as little of the existing site as possible. Building projects also require connections to mass transit, vehicular infrastructure, and utility and telecommunication networks. Sound site planning and design should consider siting a building to take advantage of existing service networks.

The use, scale, and structural systems of a building affect its particular site requirements and associated environmental impacts. Building characteristics, orientation, and placement should be considered in relation to the site so that proper drainage systems, circulation patterns, landscape design, and other site-development features can be determined.

Site data on climate, topography, soils, water, vegetation, and other factors should be collected and analyzed to assess a site's compatibility with the proposed program from an energy and resource conservation perspective. In addition to traditional site planning information, the following data is typically collected and analyzed for the site:

Specific characteristics of climate zones: Different climates have specific temperature and precipitation characteristics that suggest particular siting and building practices. Figure 220-1 shows the U.S. divided into four general climate zones (hot-humid, hot-arid, temperate, and cold). Plant hardiness maps provide a more refined description of microclimates with general regions (refer to section 550: Plants and Planting).

Geographical latitude (solar altitude) and solar access: Exposure to solar radiation determines orientation of buildings for maximum use of passive solar resources for heating, daylighting, and photovoltaics.

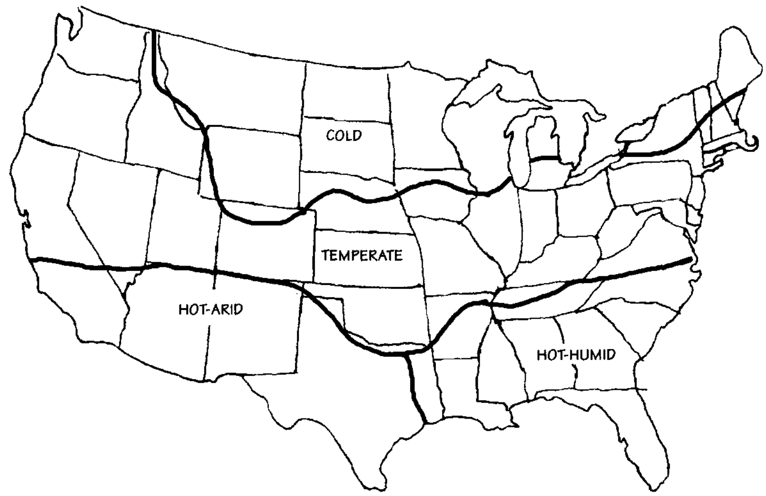


Figure 220-1. Distribution of general climate zones across the United States.

Wind Patterns: Air-movement, both annual and diurnal, particularly influence siting of multiple structures, to avoid damming of cold moisture-laden air, or blocking favorable cooling breezes during periods of overheating. Properly measured wind loads and pressure differentials are essential for designing interior air-handling systems or use of passive solar cooling strategies.

Topography: Site topography and adjacent landforms influence building proportions, wind patterns, drainage strategies, and key gravity-fed sewer-line corridors.

Soil Characteristics: Soil texture and load-bearing capacity determine building location and the type of footing required for stability. Site-grading processes are also dictated by the soil's potential for erosion. These factors influence the overall energy and resource consumption for design and construction.

Groundwater and surface runoff characteristics: Site drainage determines building locations as well as natural channels for diverting storm runoff and locations of runoff detention ponds. Use of the existing drainage system minimizes need for additional infrastructure.

Vegetation: Existing vegetation should be inventoried to identify significant plant communities. This may influence building location, surface runoff characteristics, and solar access to the site.

Adjacent land uses: Neighboring developments and proposed future developments may influence site design or proposed uses. Neighboring uses should pro-

KEY POINTS: Site Selection

The process of calculating the degree of resource use and the degree of disturbance of existing natural systems required to support a development begins with site selection.

1. The most environmentally sound development is one that disturbs as little of the existing site as possible. Adaptive re-use of existing buildings, or redevelopment of disturbed sites requires minimal disruption of natural systems and should be encouraged.

2. The best way to minimize transportation needs for a proposed development is to a) select a site which is located within or adjacent to residential, shopping, and/or work opportunities; or b) provide a mix of uses on-site to meet the needs of residents and/or employees.

3. Sites located within or adjacent to existing development allow for the most efficient and cost effective extension of utilities.

vide support services that compliment the proposed development in order to minimize transportation needs of residents and/or employees.

Circulation: Existing traffic and parking patterns in areas which are adjacent to or near the site may need consideration in relation to proposed building design and site circulation patterns, in order to minimize transportation infrastructure.

Utility Infrastructure: Potential sites should be analyzed for existing utility infrastructure and capacity. There may be insufficient existing infrastructure for the proposed project. The cost for required additional capacity and associated disruption to the surrounding area could make the project unfeasible.

3.0 SITE DEVELOPMENT AND LAYOUT

After a thorough analysis and assessment, ideal diagrammatic concepts are prepared with the objective of organizing all proposed built elements to achieve an effective fit between the site and the proposed development. The main goal of the concepts should be to minimize energy and resource consumption during construction and after occupation. It should be noted that during reclamation of disturbed sites, initial expenditures may be higher than normal and should be balanced by ongoing landscape management strategies (refer to Section 640: Disturbed Landscapes for further information on land reclamation).

The following steps serve to guide the initial conceptual design process:

1. Develop general area takeoff and overall building footprint to measure total site coverage of impermeable surfaces and determine run-off pollution potential (e.g. greater than 20 percent impermeable coverage of gross site area typically requires mitigation to clean stormwater before it enters drainage system). The site plan should also be analyzed to ensure an efficient layout with regard to required road, utility, and service access.
2. Identify alternative site design concepts to minimize resource costs and disruption. Develop several alternatives that explore grading and vegetation-removal consequences, as well as resulting infrastructure costs.
3. Identify topographic and hydrological impacts of proposed design and building use. Measure cut-and-fill potential and assess potential for erosion, siltation, and groundwater pollution (refer to Section 320: Site Grading and Section 330 Stormwater Management for further information).
4. Review financial implications of site development, building, and projected maintenance costs. Total cost of the project must include ongoing costs associated with the site design, development, and operations, as well as hidden energy costs associated with specific materials.
5. Develop matrix of use and site compatibility index. Each site may be assessed to reveal its development compatibility index with regard to a specific type of development. This index may reveal a pattern of incompatibilities, suggesting a different site be chosen or appropriate mitigation measures be undertaken.

Site development must consider the requirements of infrastructure, the proposed building, and the site. Strategies for each can inform site development and layout.

3.1 Infrastructure

Transportation:

The best way to minimize transportation needs is to a) select a site which is located within or adjacent to residential, shopping, and/or work opportunities; or b) provide a mix of uses on-site to meet the needs of residents and/or employees. If neither of these strategies are feasible, the following practices should be considered:

Use existing vehicular transportation networks: This practice minimizes the need for new infrastructure, and reduces impervious surface, parking requirements, and related costs.

Support use of alternative transportation: Where possible, mass-transit infrastructure and shuttle buses should be used. Carpooling strategies should be encouraged in addition to mass-transit use. To foster the use of bicycles, showers and lockers should be considered at place of employment. All of these transportation methods reduce parking and transportation costs for residents and/or employees.

Consider increased use of telecommuting strategies: Telecommuting and teleconferencing can reduce commute time and number of vehicular trips to and from the site. Plan for adequate telecommunications infrastructure and access in commercial and residential design.

Consolidate service, pedestrian, and automobile circulation: To minimize pavement costs, improve efficiency, and centralize runoff, the pattern of roads, walkways, and parking should be compact. This not only is a less expensive way to build, it also helps to reduce the amount of impervious surface.

Utilities:

Sites located within or adjacent to existing development allow for the most efficient and cost effective extension of utilities. The following energy and resource-conserving practices should also be considered:

Minimize road length, building footprint, and the actual ground area required for intended improvements: Such planning decreases the length of utility connections. Consult local codes regarding separation requirements for water, sewer, electrical, and gas lines.

Use gravity sewer systems wherever possible: Avoid pumped sewer systems that require ongoing power consumption.

Reuse chemical-waste tanks and lines: Existing chemical-waste tanks and lines should be inspected, protected, and reused to avoid creation of additional hazardous-materials problems.

Consolidate utility corridors when feasible: Where possible, common site utility corridors should be consolidated along previously disturbed areas or along new road or walk construction, both to minimize unnecessary clearing and trenching and to ensure ease of access for regular maintenance.

3.2 Building and Site Requirements

Land Features:

Previously disturbed sites such as unused urban lots and commercial sites may already be affecting the environmental quality of neighboring properties, the watersheds, and other features. Adaptive re-use of existing buildings, or redevelopment of disturbed sites requires minimal disruption of natural systems and should be encouraged. Furthermore, redevelopment is likely to improve the immediate community, potentially create jobs, and increase land values that have been affected by the abandoned or blighted property.

Stream channels, flood plains, wetlands, steep erodible slopes, and mature vegetation should be protected from development. To avoid high site-preparation costs, and to preserve important visual and ecological features, development activity should be configured to occupy those spaces between critical resources.

Building Orientation:

Climatic conditions, particularly solar access, should guide the placement of building and site features in energy-conserving design. The following practices should be considered:

1. Plan site clearing and planting to take advantage of solar access. Solar orientation, cloud cover, and topography are interrelated. A site's latitude determines the sun's altitude and associated azimuth for any given time of day, each day of the year. Site-clearing and planting strategies may be used to maximize solar access to the building or critical areas of the site.
2. Orient the building to take advantage of solar energy for passive and active solar systems. The building should take advantage of shade and airflows for cooling in summer, and of passive solar energy for heating and wind protection in winter. If solar collectors or photovoltaic systems are proposed, orientation should allow maximum access to sunlight.
3. Provide a north-wall design that minimizes heat loss. Provide entrances with airlocks, and limit glass to prevent heat loss. Large buildings in cold or temperate climates require air-handling systems that balance interior building pressure in such circumstances.
4. Provide a building-entrance orientation that maximizes safety, ease of access and protection from the elements.
5. Minimize solar shadows. Landscaped areas, open spaces, parking, and septic fields should be aggregated to provide the least solar shadow for southern orientations of the building project and adjoining buildings. Calculating total site shadow can prevent the creation of solar voids and cold-air-drainage dams. This is especially useful in cold and temperate climates.

The orientation of buildings and other site elements can also influence the extent of site disruption required for construction. Earthwork and clearing of the site can be reduced by aligning long buildings and parking lots with landscape contours. Half-basements and staggered floor levels can be used in areas of excess slope.

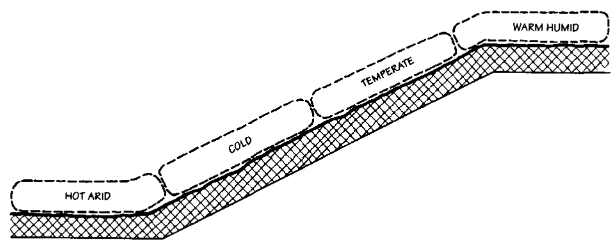


Figure 220-2. Theoretical "most favorable" microclimate location for each climate region.

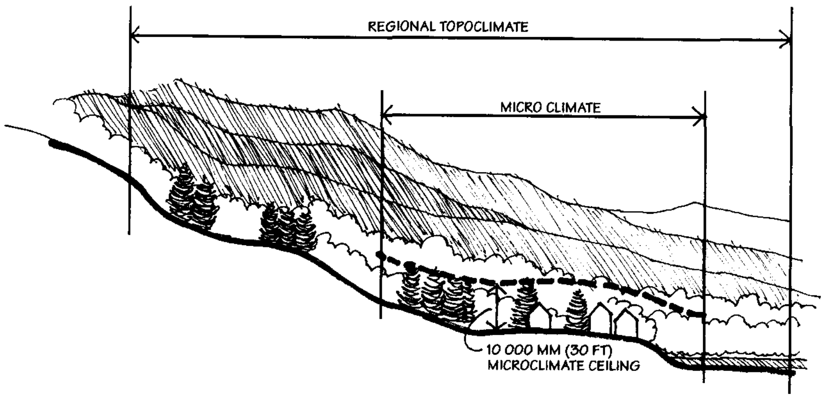


Figure 220-3. Local microclimate within a larger regional topoclimate.

Site Improvements:

Landscape design should seek to maximize human comfort, particularly in high-use areas such as plazas and outdoor gathering spaces. The designer needs to consider seasonal weather patterns and climate variables such as vapor pressure in hot-humid zones, desiccating winds and diurnal extremes in hot-arid zones, and annual temperature extremes in temperate and cold zones. A number of strategies can be used to modify the site's microclimate.

KEY POINTS: Site Layout and Construction

Site layout and construction should focus on eliminating unnecessary site disruption (e.g., excessive grading, blasting, clearing) and resource degradation (e.g., stream siltation, groundwater contamination, air-quality loss).

1. Design should seek to minimize the amount of impervious surface that is constructed. In addition, efficient site layout that utilizes existing transportation infrastructure, and alternative transportation strategies (e.g. mass-transit, carpooling, telecommuting) should be considered.
2. The length of utility connections should be minimized by site layout. Combining utility corridors along previously disturbed areas may reduce unnecessary site clearing.
3. Proposed layout should accommodate service via gravity sewer whenever possible, to eliminate the need for pumping stations.
4. Buildings should be oriented to take advantage of solar access. The orientation of buildings and other site elements can also influence the extent of site disruption required for construction.
5. Materials used in construction should be recycled and/or regionally available, if possible, and have a low life-cycle cost.

1. Existing water sources and landforms can be used to create winter heat sinks in cold climates, and temperature differentials for cooling air move ment in hot climates. Existing streams or other water sources can contribute to radiant cooling for the site. Color and surface orientation may also be used to favorably absorb or reflect solar energy.

2. Existing vegetation may be used to moderate weather conditions and provide protection for native wildlife. Vegetation can be used to provide shade and transpiration in the summer and wind protection in the winter. Additionally, vegetation can provide natural corridors for wildlife movement when provided in conjunction with a regional landscape plan.

3. Access roads, planting, grading, and ancillary structures should be designed to channel wind toward main buildings for cooling, or away from them to reduce heat loss.

4. Introduce structures and plantings that provide shelter from harsh elements and highlight desirable features. Modulation of tree-canopy heights and inclusion of water fountains and other built structures can fine-tune an exterior site by accelerating or decelerating site winds, casting shadows, or cooling by evaporation.

Construction Methods and Materials:

The construction methods employed should ensure that each step of the building process is focused on eliminating unnecessary site disruption (e.g., excessive grading, blasting, clearing) and resource degradation (e.g., stream siltation, groundwater contamination, air-quality loss). These strategies should harness features such as ventilating breezes and solar gain, while mitigating unfavorable features such as cold temperatures, moist air; desiccating winds; and increased stormwater runoff.

The construction process should be strategically charted in stages to avoid unnecessary site disruption, and to achieve an orderly construction sequence from site clearing to site finish. Such a strategy reduces costs and damage to the site. It requires close coordination between all sub-contractors (refer to Section 130: Site Construction Operations for further information on various methods and staging strategies).

Materials used in construction should be recycled and/or regionally available, if possible, and have a low life-cycle cost. Albido (solar reflectance index attributed to color) should also be considered when choosing site materials (refer to Division 800 for descriptions of various construction materials).

4.0 BIOCLIMATE FUNDAMENTALS

The concept of relating temperature and humidity conditions to design for human comfort is referred to as bioclimatic design. Bioclimate fundamentals can be used to develop a site plan and design that meets the needs of its occupants, while minimizing energy consumption. Figure 220-1 illustrates the distribution of general climate zones across the United States. Each climate zone has unique temperature and moisture characteristics that must be addressed by design.

Hot Arid Regions: Characterized by dry, hot summer temperatures [>20°C (68°F)] and mild to cool winters [>0°C (32°F)]. Annual precipitation is low, however seasonal flash-floods may occur. While freezing temperatures are uncommon, extreme diurnal temperature fluctuations are typical. Site planning and design should seek to balance daily temperature extremes by

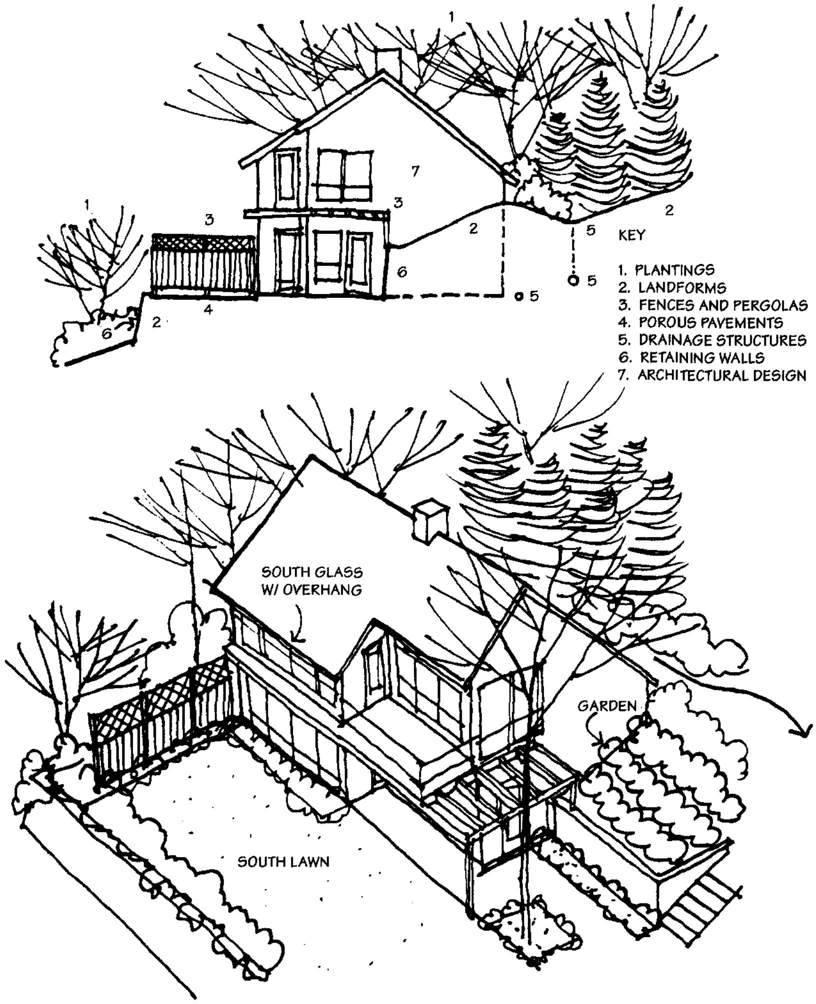


Figure 220-4. Selected design and construction techniques to encourage energy conservation.

1. *Planted wind screens require multi-row pattern.*
2. *Grade to divert water, winds, and cold moist air.*
3. *Structures take up less space and are useful in arid zones.*
4. *Porous pavements and earth cover allows infiltration.*
5. *Wet soil is highly conductive of cold and is best drained.*
6. *Walls may be used to create micro-climates and to channel air movements.*
7. *Special wall design, glass, and overhangs can help adapt to climate.*

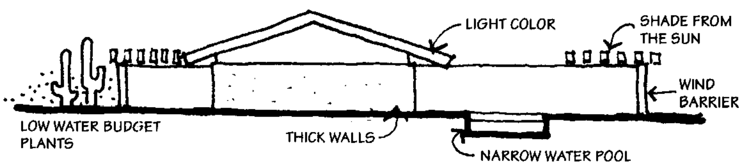


Figure 220-5. General site design strategies for hot arid regions.

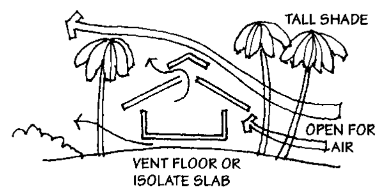


Figure 220-6. General site design strategies for hot humid regions.

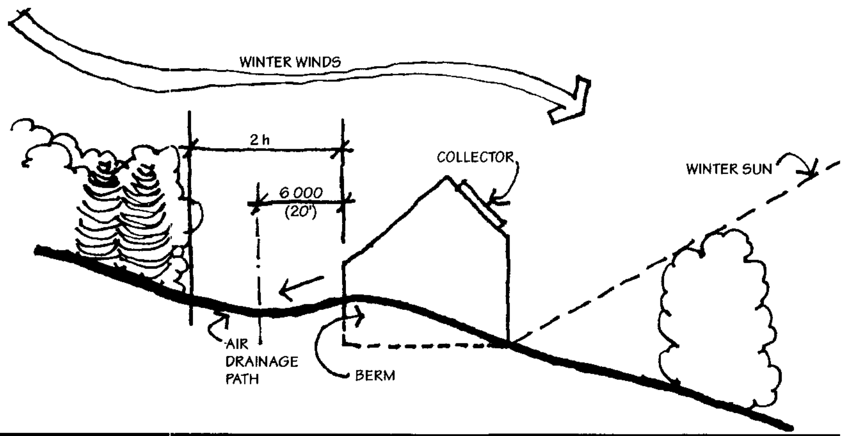


Figure 220-7. General site design strategies for temperate and cold regions.

Table 220-01. SUMMARY OF REGIONAL BIOCLIMATIC STRATEGIES

	Climate Zones			
Factors Modified by Landform, Vegetation, and Structures	**Hot Arid**	**Hot Humid**	**Temperate**	**Cold**
Sun	• Avoid heat absorbing materials use; thick walls or earthshelters • Use pergola and trellis structures for shade • Provide large overhangs on buildings • Avoid large area of exposed glass	• Maximize shade through the use of plantings • Use pergola and trellis structures for shade • Screened terraces provide relief from direct heating of main structure • Provide large overhangs on buildings • Use high ceilings and vent all roof systems	• Site structures on southerly slopes for solar gain in winter • Avoid northern entrances to buildings • Plant deciduous trees for afternoon shade • Use earthshelters to protect from summer sun	• Site structures on southerly slopes for solar gain in winter • Cold climate siting benefits from steeper slopes for better solar access • Avoid northern entrances to buildings • Plant deciduous trees for afternoon shade • Use earthshelter to protect from summer sun
Wind	• Site structures at toe of slopes for exposure to cold air flows at night • Use plant material to block desiccating winds • Deflect hot winds with walls and screens	• Site structure at top of slope for exposure to breezes • Avoid excessive earthmounding that may trap moist air • Maximize breezes through use of high canopy trees and with a loose open planting pattern • Avoid tall solid walls that block wind	• Site structure on middle to upper slope for access to light winds, but protection from high winds • Landforms, plants, and structures can be used to divert northerly winter winds while allowing cooling summer breezes • Use earthshelters to protect from winter winds	• Site structure on middle to lower slope for wind protection • Plant coniferous shelter belts to block cold winds • Avoid topographic depressions that collect cold air • Use earthshelters to protect from winter winds
Water	• Use moisture conserving plants-xeriscape • Limit mpervious surface to minimize runoff-porous paving can be used	• Avoid siting next to stagnant bodies of water • Maximize infiltration of stormwater runoff	• Use of retention/ detention ponds for stormwater provides for evaporative/cooling of the site • Foundations for structures and pavement must drain well to prevent damage from frost/thaw action	• Use of retention/ detention ponds for stormwater provides for evaporative cooling of the site • Foundations for structures and pavement must drain well to prevent damage from frost/ thaw action

storing energy, increasing humidity, and diverting desiccating winds.

Hot Humid Regions: Characterized by hot summer temperatures [>20°C (68°F)] and mild to cool winters [>0°C (32°F)]. Annual precipitation and humidity are high, with frequent rain showers. Freezing temperatures are uncommon, and relatively minor diurnal temperature fluctuations are typical. Site planning and design should seek to increase shade, cooling from evaporation, and breezes.

Temperate Regions: Characterized by hot, often humid, summers [>20°C (68°F)] and cold winters [<0°C (32°F)]. Annual precipitation is fairly high. The region is subject to repetitive freezing/thawing action, and significant seasonal temperature fluctuations are common. Site planning and design should seek to promote shade and evaporative cooling in warm periods, and block winds and promote heat gain in cool periods, without disrupting favorable summer wind pattern.

Cold Regions: Characterized by mild summer temperatures [>10°-20° C (50°-68° F)] and very cold winters [<0° C (32° F)]. Annual precipitation is typically low. Region is subject to extreme freezing/thawing action. Site planning and design should seek to control winter winds, and promote solar gain and storage.

Figure 220-2 illustrates a topographic section showing the theoretical "most favorable" microclimate location for each climate region. Hot Arid climates favor the eastern slope base to avoid harsh sun and to receive cool diurnal air drainage for the upper slope. Hot Humid climates favor the top of the eastern slope to avoid harsh west sun and to receive the evaporative cooling effect of winds due to turbulence at the hilltop. Temperate climates are most favorable at the south-east "military crest" to receive both sun and breezes, but to avoid cold winds at the true crest. Cold climates are ideal on the south to south-western lower slope to receive solar radiation and be protected from winter winds, but high

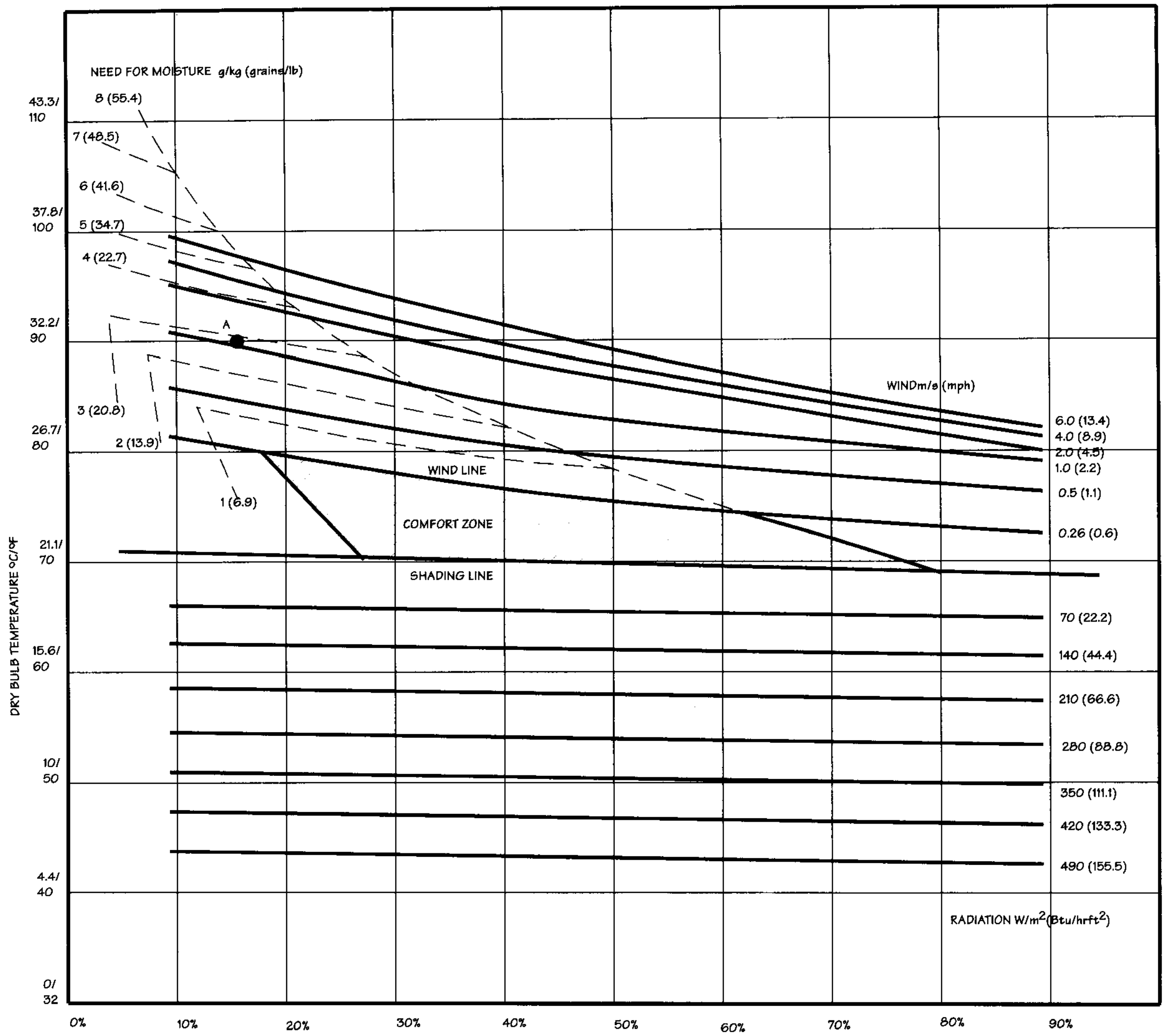


Figure 220-8. Outdoor bioclimatic human comfort chart. *If the temperature rises to 32°C (90°F) at 15% humidity, as indicated by point "A," then additional moisture is required to achieve human comfort through evaporative cooling. If radiation increases beyond shading line, then shade must be added.*

enough to avoid cold air drainage from upper slope.

Site planning seeks to identify favorable microclimates with the aim of further adaptation through design and construction techniques. Figure 220-3 diagrams a local microclimate within a larger regional climate zone. The climatic design variables of human comfort in any given climate zone are:

1. Solar radiation- Duration and intensity of thermal loading and absorption (insolation).
2. Air movement- Velocity and pattern.
3. Humidity- Vapor pressure and air temperature.

Specialized site design and construction methods allow each microclimate zone to be further adapted to maximize human comfort for both indoors and outdoors, and to minimize energy expenditure required for heating and cooling. This site zone is typically adapted for human use through structural orientation, vegetative clearing and planting patterns, grading, stormwater drainage, wind pattern augmentation, and the placement of paved surfaces. Figure 220-4 illustrates how these techniques may be applied to a residential landscape setting to achieve a more energy conserving fit.

4.1 Bioclimatic Strategies

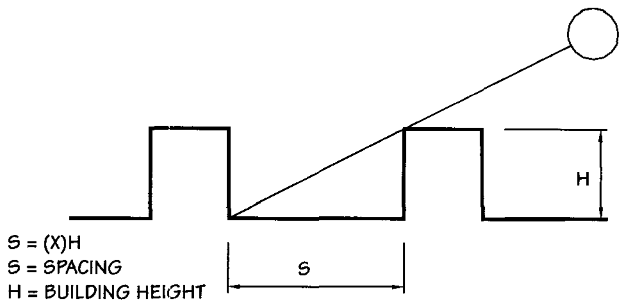
Bioclimatic design creates site patterns and applies materials and structural forms which are suitable for the region in general, and the site in particular. Table 220-1 summarizes various techniques for each climatic region. Figures 220-5 through 220-7 illustrate regional bioclimatic strategies for the four climate zones.

Hot Arid Regions:

Figure 220-5 illustrates general site design strategies for hot arid regions. Key strategies are:

1. Use moisture conserving plants.
2. Prevent heat build-up on structures (thick walled, in-ground architecture is useful).
3. Deflect hot winds with walls, screens, and earthwork.
4. Trap cool air for convection.

Table 220-02. DISTANCE REQUIRED BETWEEN BUILDINGS TO AVOID SHADOWS

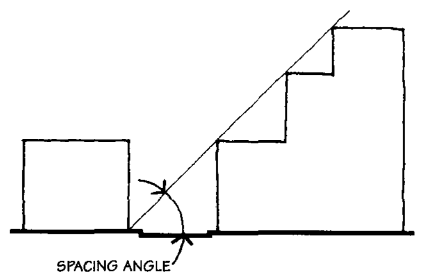


Values of x on December 21

Latitude	9 am	10 am	11 am	noon	1 pm	2 pm	3pm
24°N	1.4	1.2	1.1	1.1	1.1	1.2	1.4
28°N	1.7	1.4	1.3	1.3	1.3	1.4	1.7
32°N	2.1	1.7	1.5	1.5	1.5	1.7	2.1
36°N	2.5	2.1	1.8	1.7	1.8	2.1	2.5
40°N	3.1	2.4	2.2	2.1	2.2	2.4	3.1
44°N	4.0	2.9	2.6	2.5	2.6	2.9	4.0
48°N	5.7	3.7	3.3	3.1	3.3	3.7	5.7
52°N	9.5	5.1	4.3	4.0	4.3	5.1	9.5

Source: G.Z. Brown ,*Sun, Wind & Light: Architectural Design Strategies*. New York. John Wiley & Sons, 1985.

Table 220-03. MINIMUM SPACING REQUIRED TO ASSURE ADEQUATE LIGHT PENETRATION



Climate	Latitude	Minimum Spacing Angle
warm humid	1-10°	40°
composite	15°	45°
composite/desert	20°	50°
desert	25°	50°
mediterranean/desert	30°	45°
mediterranean	35°	40°
mediterranean/temperate	40°	35°
temperate	45°	30°
temperate	50°	25°
cold temperate	60°	22°

Source: G.Z. Brown. *Sun, Wind & Light: Architectural Design Strategies*. New York. John Wiley & Sons, 1985.

5. Use walls to create microclimate courts.
6. Use pergola and trellis structures on south and southwest walls.
7. Use large overhang calculated for winter sun.
8. Avoid large exposed glass.
9. Avoid heat absorbing materials.
10. Position structure to benefit from diurnal air currents.

Hot Humid Regions:

Figure 220-6 illustrates general site design strategies for hot humid regions. Key strategies are:

1. Maximize breezes and evaporation with high canopy trees and loose open planting patterns.
2. Avoid tall solid walls that block winds.
3. Seek high ground or rising slopes facing prevailing winds.
4. Avoid topographical depressions.
5. Use large overhangs calculated for severe sun angles (east and west)
6. Covered pergolas, or screened terraces adjacent to structure will help draw air currents.
7. Avoid excessive earth mounding which might trap moist, stagnant air.
8. Use high ceilings, and vent all roof systems.

Temperate and Cold Regions:

Figure 220-7 illustrates general site design strategies for temperate and cold regions which share similar techniques but vary in severity of worst case conditions. Key strategies are:

1. Promote solar gain in winter season.
2. Seek southern slopes (SSE to SSW) 5-15%.
3. Block wind chill with mixed deciduous and coniferous plants.
4. Maintain openings for cooling summer breezes.
5. Provide afternoon shade with deciduous trees.
6. Use garage, earth, and plantings to divert severe NE or NW winter winds.
7. Provide architectural entry lock to block cold air infiltration in winter.
8. Grade and plant for cold air drainage around structure.
9. Earth sheltered architecture is useful in these regions.
10. Drain all backfill soils and insulate perimeter foundation walls (Refer to subsection 4.5 Earthshelter Strategies).
11. Avoid northern entrances both for the site and architecture
12. Cold climate siting benefits from steeper slopes, up to 20%, and orientation to the southwest for increased solar receipt potential.

4.2 Human Comfort Factors

Human comfort is determined by ambient air temperature, humidity, and the velocity of air movement which allows the body to feel comfortably warm (but not overheated) and comfortably cool (but not chilled). Architectural interiors are heated and cooled using a bioclimatic chart which tracks these three factors. Figure 220-8 illustrates a bioclimatic chart for exterior spaces. In summary, the ideal comfort zone is within a narrow temperature range of 20°C to 27°C (68°F to 80°F), a corresponding humidity range of 80% to 20%, and a wind velocity of at least 0.26 m/s (0.6 mph). If the temperature-humidity combi-

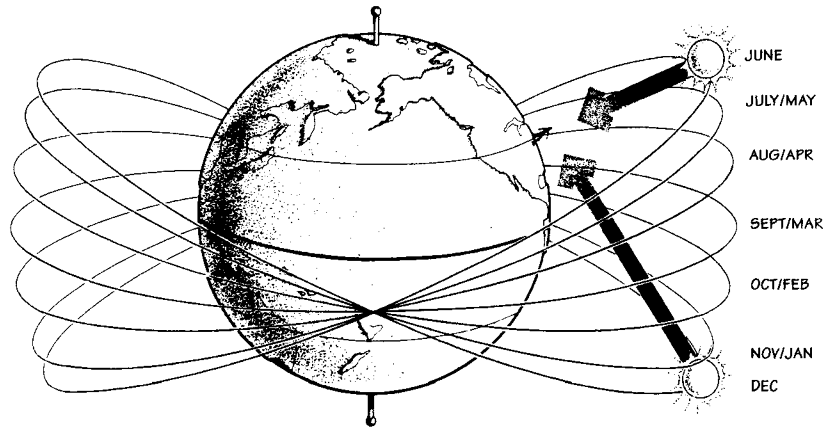


Figure 220-9. Solar path around the earth on the 21st day of each month of the year.

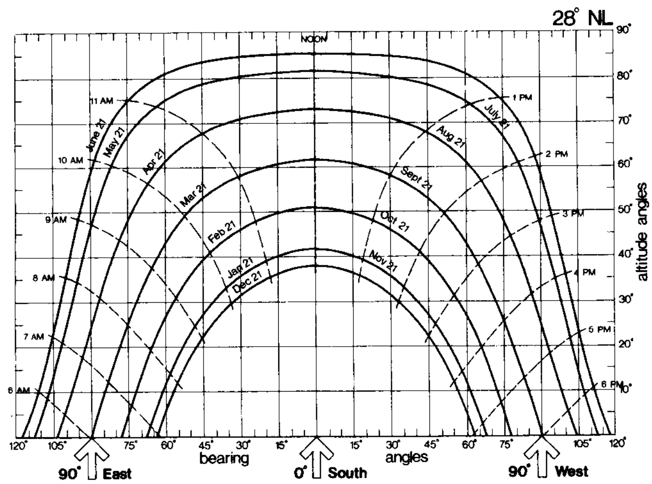


Figure 220-10. Solar altitude chart for 28° north latitude.

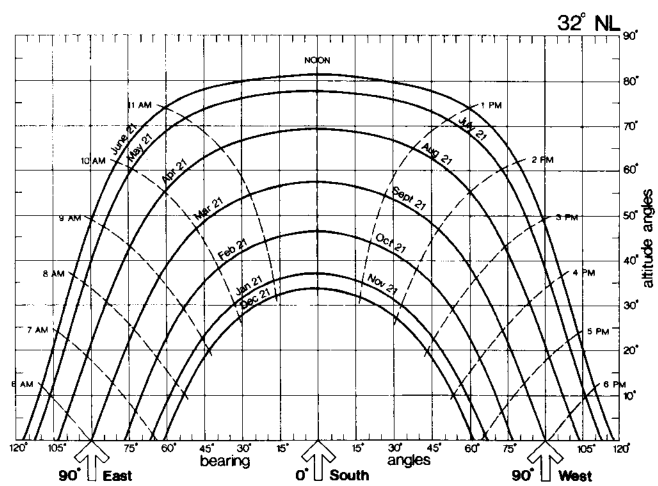


Figure 220-11. Solar altitude chart for 32° north latitude.

nation falls above the shading line, then shading is assumed. If the temperature-humidity combination is below the wind line, then still air is assumed. Use of this chart for outdoor spaces must consider mitigating factors of human comfort, such as the R-value of clothing, and the way people move about a particular site to cope with changing weather conditions (i.e. moving into or out of the sun, or seeking leeward shelter as breezes begin to accelerate). These factors are likely to alter the ideal conditions for human comfort.

4.3 Solar Path, Receipt, and Shadows

Each climate zone has an ideal solar orientation based upon theoretical models which track solar receipt and loss throughout the daily and annual solar cycles. However, modern super-insulated structures and sound site planning strategies combine to establish a general principle favoring SSE to SSW structure siting in northern latitudes, with eastern or western biases determined by local conditions. Figure 220-9 illustrates the solar path around the earth on the 21st of each month of the year. Figures 220-10 through Figure 220-17 show solar charts designed to plot the actual path of the sun as it would appear from the ground looking at the sky from various northern latitudes. These are useful for identifying the altitude angle of the sun at various times of year, to insure that buildings, topography, or vegetation do not obscure the sun from solar collectors, outdoor gathering spaces, or windows designed for passive gain.

Tree shadows:

The ultimate shadow length of an existing or proposed tree in northern latitudes can be calculated by using the altitude angle of the sun at noon on December 21. The height of the tree divided by the tangent value (tan) of the altitude (°) will provide the distance required between the structure and the tree or object that is casting the shadow. As Figure 220-18 illustrates, a 20% slope in a cold climate will allow a tall tree to be planted relatively close to a structure without obscuring solar access.

Building Spacing:

Table 220-2 indicates the relationship between the solar altitude at noon on December 21 by latitude position, and the distance required between buildings of a specified height so as to avoid an obscuring shadow. Table 220-3 shows the minimum spacing angle by climate type and latitude required to step back a building or other such

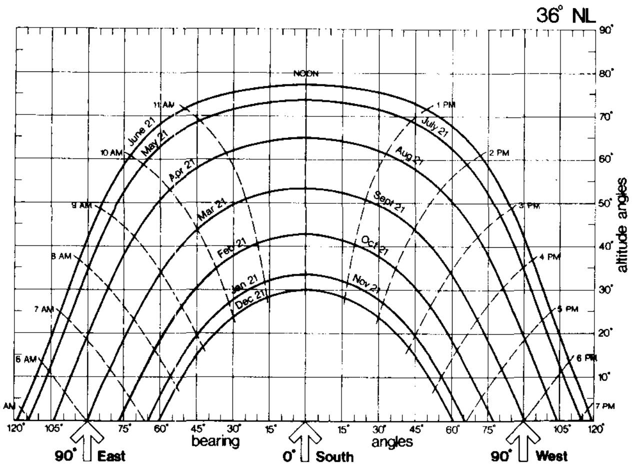


Figure 220-12. Solar altitude chart for 36° north latitude.

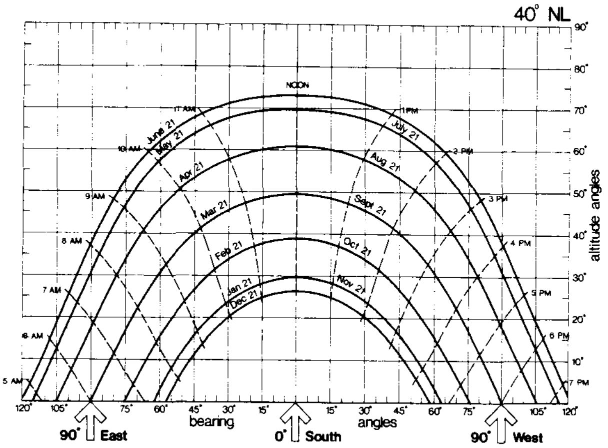


Figure 220-13. Solar altitude chart for 40° north latitude.

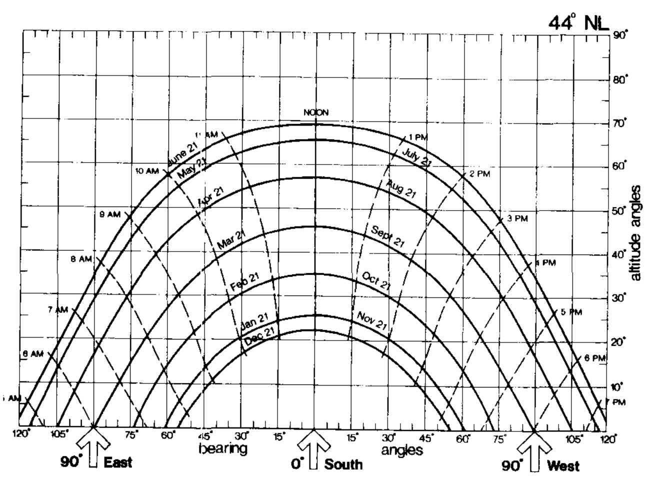


Figure 220-14. Solar altitude chart for 44° north latitude.

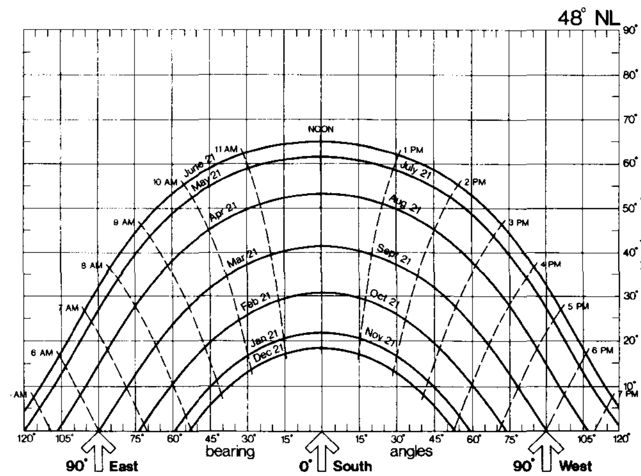


Figure 220-15. Solar altitude chart for 48° north latitude.

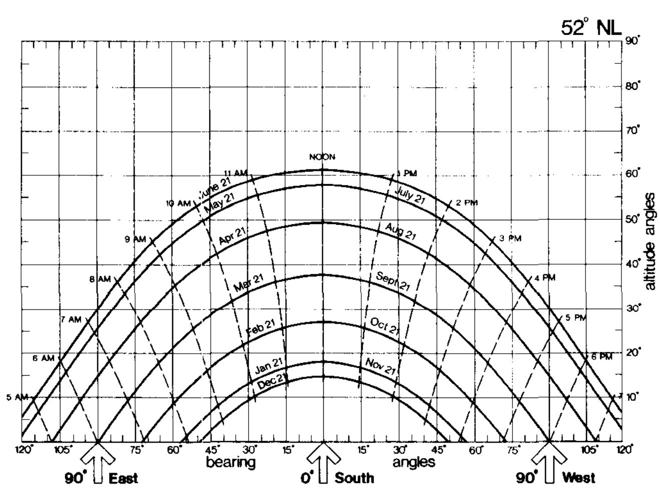


Figure 220-16. Solar altitude chart for 52° north latitude.

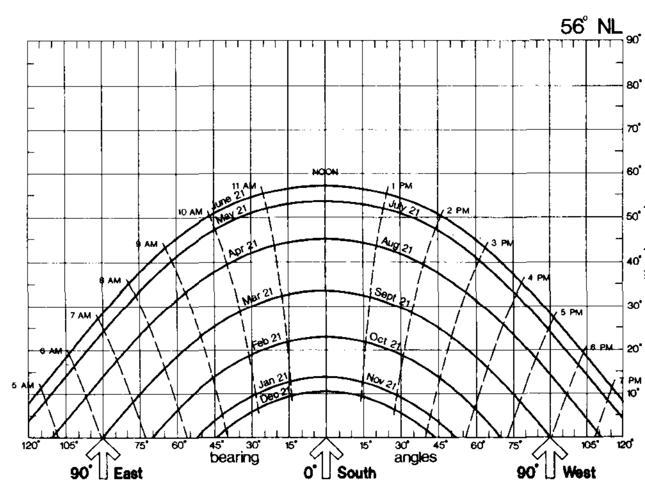
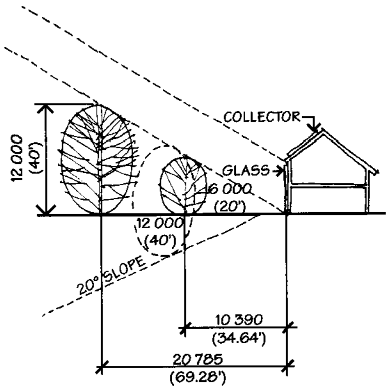


Figure 220-17. Solar altitude chart for 56° north latitude.



LATITUDE 36°
NOON SUN, DECEMBER 21 = 30°ALTITUDE
SHADOW FOR 12 000 mm (40') TREE:
=12 000/TAN 30°
=20 785 mm (69.28')

Figure 220-18. Tree shadow calculations.

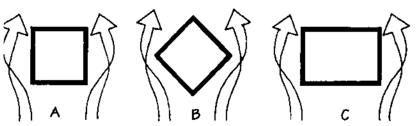


Figure 220-20. Structure orientation and wind flow.

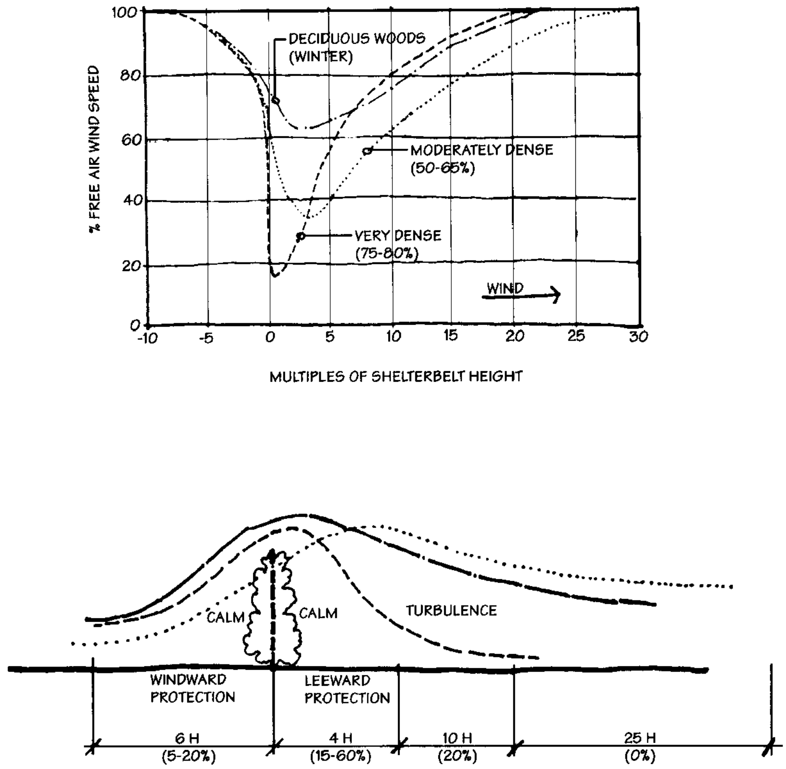


Figure 220-19. Shelterbelt wind flow dynamics showing effective wind shadow of light to very dense (mass to void ratio) shelterbelt plantings. *Note windward and leeward calm areas.*

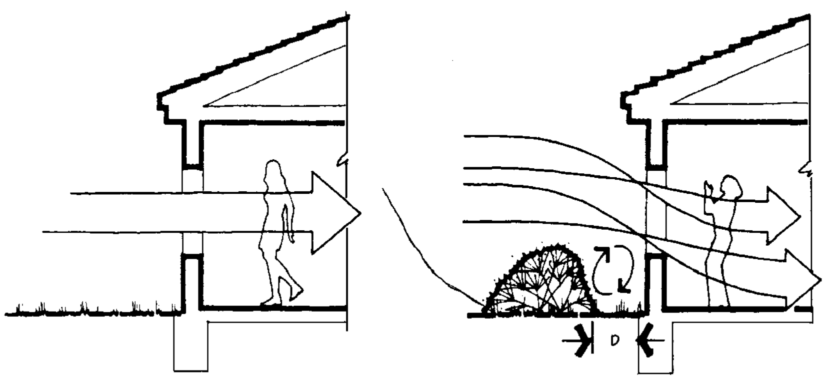


Figure 220-21. Wind deflection at building window.

structure to insure adequate light penetration during low sun periods in the winter.

4.4 Wind Management

Wind, both favorable cooling and unfavorable chilling, can be diverted by altering vegetative cover, using mitigating structural devices, and by strategic use of existing and proposed earthforms. Most studies of wind augmentation stem from agricultural research aimed at raising soil temperature in cold climates by reducing wind chill through the use of planted and structural shelterbelts.

Shelterbelt Design:

Figure 220-19 illustrates the results of shelterbelt studies and indicates that the longest wind shadow is produced by a shelterbelt density of 50-65% mass to void ratio. This translates into mixed deciduous and coniferous plantings or vertically slatted fencing. The figure further shows that shelterbelt plantings create a windward and a leeward zone of diminished wind velocity of 6 times and 25 times the shelterbelt height (H) respectively. It suggests two principles:

1. **Windward Siting:** Activities requiring the benefits of prevailing cooling breezes should be not be located too close to the windward side of a building, tree group, or topographic feature, because the breeze will lift over the mass and create a stagnant air pocket.

2. **Leeward Siting:** Activities requiring protection from chilling winds should be located within the 4-6H zone of reduced wind velocity for maximum effect, but should not preclude the beneficial effects of prevailing cooling breezes, which typically emanate from the opposite direction. If cooling

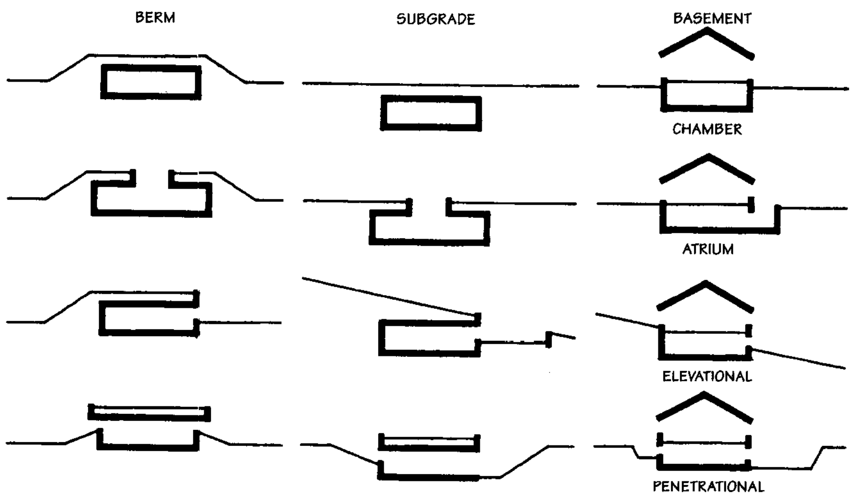


Figure 220-22. Various profile concepts for earth sheltered structures.

KEY POINTS: Bioclimatic Design

Bioclimatic design relates temperature and humidity conditions to design for human comfort. Bioclimate fundamentals can be used to develop a site plan and design that meets the needs of its occupants, while minimizing energy consumption.

1. Bioclimatic design suggests site layouts, materials and structural forms which are suitable for the different climatic regions. Table 220-1 summarizes various techniques for four general climate zones, and Figures 220-5 through 220-7 illustrate strategies for each region.

2. Generally, the human comfort zone is within a narrow temperature range of 20°C to 27°C (68°F to 80°F), a corresponding humidity range of 80% to 20%, and a wind velocity of at least 0.26 m/s (0.6 mph). However, factors such as the R-value of clothing, and the way people move about a particular site to cope with changing weather conditions are likely to alter these ideal conditions.

3. Modern super-insulated structures and sound site planning strategies favor SSE to SSW orientation for structures in northern latitudes, with eastern or western biases determined by local conditions.

4. Shelterbelts are an effective means of controlling air flow. The longest wind shadow is produced by a shelterbelt density of 50-65% mass to void ratio. This translates into mixed deciduous and coniferous plantings or vertically slatted fencing.

5. Generally, ventilating effects of the wind can be promoted by tall thin structures which are one room wide to allow cross flow, or by structures elevated on columns to promote under-venting.

6. In cold, temperate, and hot arid climates, temperature stabilization may be promoted by using earth sheltering construction techniques on sites with dry soil condition.

breezes are important in a particular climate zone, then the face of the structure or activity should be located 5-6H from the shelterbelt. This effectively translates into the rear of the structure being in winter calm, and the front of the structure being in summer breeze. Maximum winter calm in cold climates can be achieved at 2H from the shelterbelt. Roads and parking should be within 10-12H of the shelterbelt because at 15H, the snowthrow turbulence is most severe and drifting deposits are deepest.

Structural Orientation to the Wind:

The proportions of architecture are important with regard to wind augmentation. Figure 220-20 illustrates how structures oriented diagonally to the wind present greater width than the same structure oriented perpendicular to the wind. Generally, ventilating effects of the wind can be promoted by tall thin structures which are one room wide to allow cross flow, or by structures elevated on columns to promote under-venting. Research has shown that best ventilation occurs when structures are slightly oblique (20°-30°) to wind flow due to Venturi acceleration effects. Figure 220-21 illustrates the effect of low shrubs planted in front of windows resulting in a downward deflection for a distance (D) which ranges from 4 500-6 000 mm (15 to 20 ft).

4.5 Earth Shelter Strategies

In cold, temperate, and hot arid climates, temperature stabilization may be promoted by using earth sheltering construction techniques. This strategy takes advantage of the rather constant earth temperatures which exist 2 000-3 000 mm (6-10 ft) below the earth's surface. In warm climates, it is easier to maintain a cool ambient interior temperature, and in cold climates, it takes less heat energy to raise the interior temperature to achieve comfort. Figure 220-22 illustrate various profile concepts for earth sheltered structures. They consist of berming over at-grade structures, fully excavating sites, or partial sheltering through basement alternatives.

Earth shelter construction requires dry soils of low conductivity. Wet soils should be avoided, or with proper mitigation, berming may be acceptable. Earthsheltered buildings should be vented with an appropriate air exchanger and the slab should be sealed and vented for radon gas mitigation.

Figure 220-23 illustrates general steady state earth temperatures for various regions of the United States. These temperatures

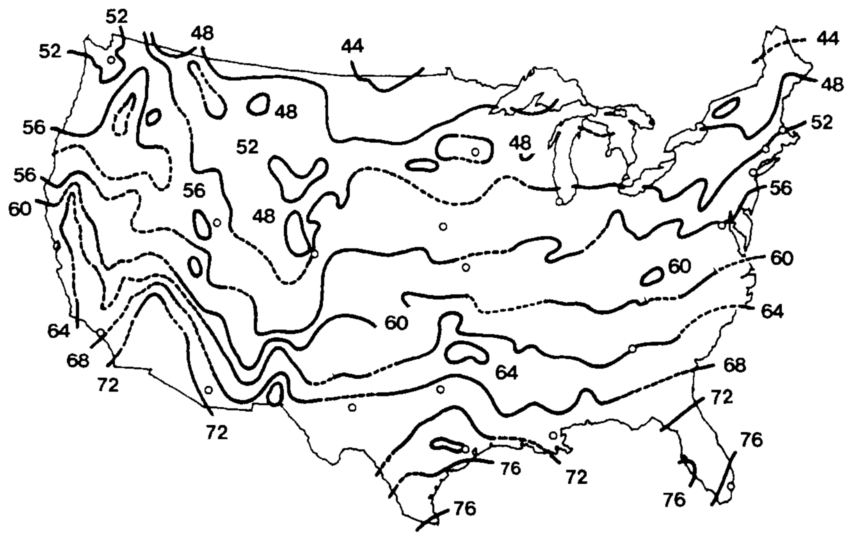


Figure 220-23. General steady state earth temperatures for the United States (Fahrenheit).

may be used to estimate heating and cooling loads for preliminary planning and design.

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SECTION 240

Outdoor Accessibility

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CONTENTS

1.0 INTRODUCTION AND PURPOSE

Passage of the Americans with Disabilities Act in 1990 has produced both published legal guidelines and recommendations for access to the U. S. outdoor environment. This section focuses on accessibility within outdoor environments such as parks, playgrounds, gardens, wilderness areas, beaches, and common urban environments. Specific design recommendations for fully accessible environments and additional guidelines based on a number of important design concepts and principles are provided.

Many individuals are unable to independently obtain access to the landscape because of barriers. Barriers in the landscape include designed surfaces which are not wheelchair-negotiable and misplaced bollards which create obstacles undetectable by cane. Yet barriers can often be avoided by creative or simple design solutions which take into account different users' needs. The concept of "Universal Design" has emerged to help designers address issues of concern to the widest possible range of individuals without segregating different users.

Information in this section has been prepared to complement the Uniform Federal Accessibility Standards (UFAS) and the Americans with Disabilities Act Accessibility Guidelines (ADAAG). Currently, the UFAS applies to many federal agencies while the ADAAG applies to the private sector. State or local government entities may follow either set of standards, but a site design must be uniform in application (i.e. the UFAS and ADAAG guidelines cannot be "mixed and matched" within one site).

For further information including specific recommendations, the Office of the Americans with Disabilities Act may be contacted directly. Expert guidance is available regarding the application of the Americans with Disabilities Act, the Americans with Disabilities Act Accessibility Guidelines (ADAAG), and the Uniform Federal Accessibility Standards (UFAS). Contact:

The Office of the Americans with Disabilities Act
Civil Rights Division
US Department of Justice
P.O. Box 66118
Washington, DC 20035-6118
1 (800) 514-0301
1 (800) 514-0383 TTD
1 (202) 514-6194 (Electronic Bulletin Board)
website: www.usdoj.gov

The Uniform Federal Accessibility Standards (1984) were developed to minimize the differences between the standards previously used by four federal agencies (the General Services Administration, the Department of Housing and Urban Development, the Department of Defense, and the U.S. Postal Service), and the standards recommended for facilities that are not federally funded or constructed. The UFAS include architectural and transportation guidelines as well as a large amount of basic information useful for formulating minimum dimensional criteria for many situations.

The Americans with Disabilities Act Accessibility Guidelines (1991) was subsequently developed by the US Architectural and Transportation Barrier Compliance Board. The ADAAG incorporates ANSI A117.1-1980, which were developed by the American National Standards Institute. The ADAAG sets guidelines for accessibility for the private sector, under the Americans with Disabilities Act of 1990. At this writing, it seems likely that the ADAAG will soon replace the UFAS as the single accessibility guideline standard in the U.S.

Copies of the UFAS standards may be acquired by contacting the US Architectural and Transportation Barriers Compliance Board.

2.0 IMPORTANT DESIGN CONCEPTS

Several concepts related to accessibility are important to understand prior to reviewing the guidelines outlined in this section.

2.1 Universal Design

Universal Design is a philosophicall approach to design which seeks to eliminate barriers while providing access and usability to the broadest possible range of people. A key to Universal Design is becoming aware of the wide variety of disability concerns. Designers following the UFAS or ADAAG standards may find that while the dimensional guidelines are highly useful, following UFAS or ADAAG does not automatically create an accessible or usable space. Understanding different types of impairments and how they might affect access is necessary in order to create usable landscapes. In addition, the guidelines permit flexibility, if equal or greater accessibility can be provided by a different or more creative design solution.

2.2 Accessible Route

Providing an accessible route is the most important way to ensure universal access.It connects the primary elements and spaces of a site, parking, entrances, facilities, and buildings. An accessible route must be provided which is continuous and free from obstructions, as specified in the ADAAG section 4.3 Accessible Route. This route must coincide with the route planned for the general public to the maximum extent feasible (Figure 240-1).

The particular site context usually dictates design strategies. Therefore, design considerations for continuous accessibility should emphasize specific elements and details. These elements relate to spaces such as interiors, waiting and rest areas, and parking; specific transition points at building entries and curb ramps; clearances between buildings and on paved surfaces, and details including lighting and signage. Pedestrian circulation systems should include loops rather than dead ends.

2.3 Graduated Difficulty of Access

A system of graduated difficulty of access is most applicable to the design and management of outdoor recreational facilities, particularly to hiking and camping areas (See 5.0 Accessible Recreation in this section for further information). The objective is to provide a wide variety of trail types with a range of opportunities and experiences to accommodate or challenge all abilities. The diversity of trail types is characterized by variations in degree of difficulty (with varying surfaces, widths, slopes, cross-slopes, lengths, edges, number of rest stops, etc.). A good system of signage is necessary for user selection of trail type. Such a system does not compromise the recreational experience for anyone, nor segregate users.

3.0 DESIGN CONSIDERATIONS FOR ACCOMMODATING DISABILITIES

The range of abilities among people is highly varied. The guidelines in this section address specific categories of impairment and design strategies required to accommodate them. They include visual, mobility, hearing, manual, and learning impairments. Other areas of concern include lack of stamina and extremes in size and weight. Hearing and manual impairments are sometimes accommodated by specific devices. Learning and mental impairments in the outdoor environment are often addressed by clarity of signage or the use

1. Parking areas should be related directly to the buildings which they serve. 'Handicapped' parking stalls should be no more than 30 000mm (100') from building entries.

2. Drop-off zones should be located as close as possible to primary entryways. No grade changes should exist between road surfaces and adjacent walkways. Vehicular connections to drop-offs, site entrance and parking areas should be direct.

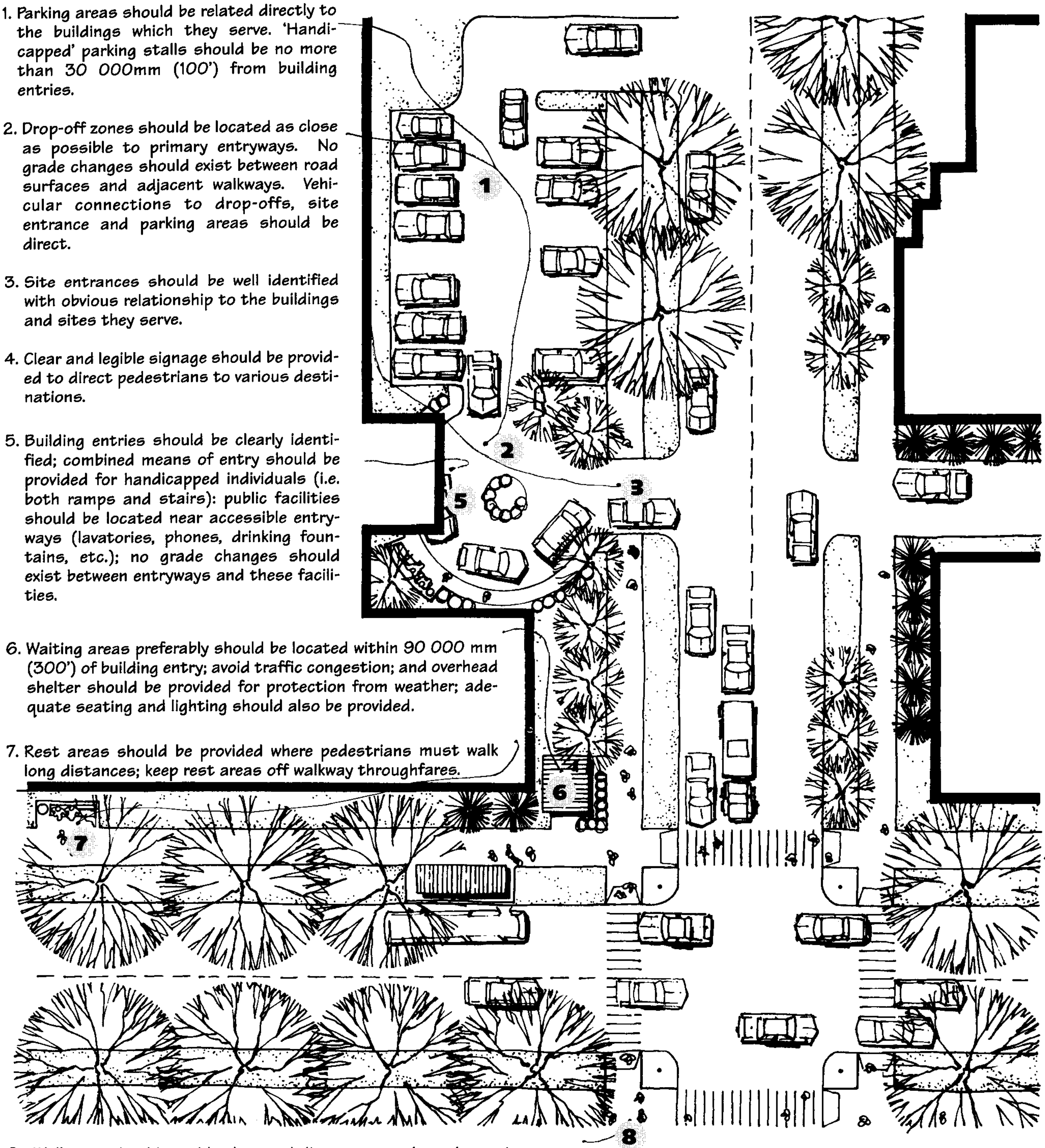
3. Site entrances should be well identified with obvious relationship to the buildings and sites they serve.

4. Clear and legible signage should be provided to direct pedestrians to various destinations.

5. Building entries should be clearly identified; combined means of entry should be provided for handicapped individuals (i.e. both ramps and stairs): public facilities should be located near accessible entryways (lavatories, phones, drinking fountains, etc.); no grade changes should exist between entryways and these facilities.

6. Waiting areas preferably should be located within 90 000 mm (300') of building entry; avoid traffic congestion; and overhead shelter should be provided for protection from weather; adequate seating and lighting should also be provided.

7. Rest areas should be provided where pedestrians must walk long distances; keep rest areas off walkway throughfares.



8. Walkways should provide clear and direct routes throughout sites: surfaces should be firm and level; curb cuts and ramps should be provided where necessary; accessible walkways should consist of closed loops rather than dead ends.

Figure 240-1. Accessible route. *An accessible route ensures that all people will have uninterrupted access to facilities.*

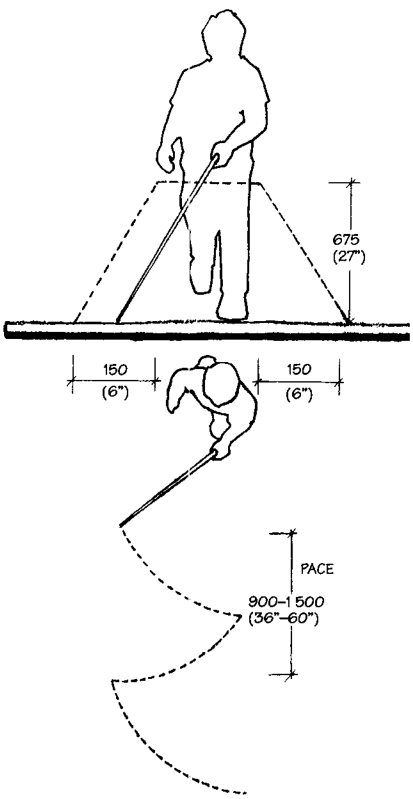


Figure 240-2. Cane technique. *The Typhlo cane is primarily used by those with limited vision and will detect objects only within a specific range. Objects should not protrude into pedestrian pathways above a 675 mm (27 in.) height.*

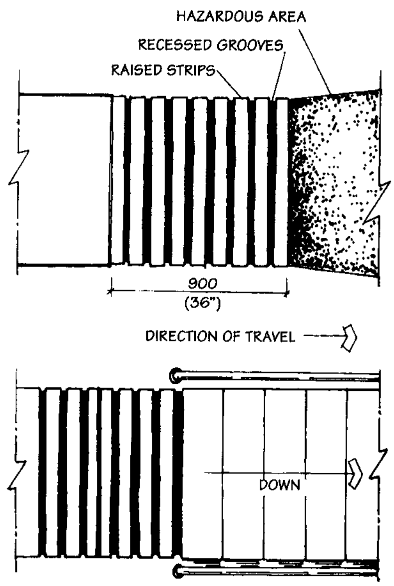


Figure 240-3. Tactile warning strips. *Tactile warning strips are not widely used and are not always recognized as such, but do have potential value as devices to warn of hazardous areas. Dimensions of warning strip should be sufficient to forewarn pedestrians.*

of landmark features to aid in site orientation. These strategies aim to achieve Universal Access.

3.1 Visual Impairments

Internationally there are an estimated 40 million people who are blind and another 20 million who have severe visual impairments. Of the 8-12 million U.S. citizens (1994) who are visually impaired, 4.8 million are severely impaired. 1.1 million are legally blind and 220,000 have no usable vision at all. There are 9.7 million people in the U.S. whose functional limitations in seeing which may affect orientation and negotiation through the landscape. Of the 4.8 million who are severely impaired, approximately 85,000 can read Braille.

Of those who are visually impaired in the U.S., 5 million are over 65. Therefore, most of those who are visually impaired also have the disadvantage of limited balance, stamina, reaction time, and general agility, as a function of age.

Ninety-six percent of those who are visually impaired became blind during adulthood and consequently understand the way urban environments are typically structured. Those with limited vision adapt to their gradually worsening vision and learn how best to use what remains of their sight. Simple perception of light, for example, helps one discriminate between night

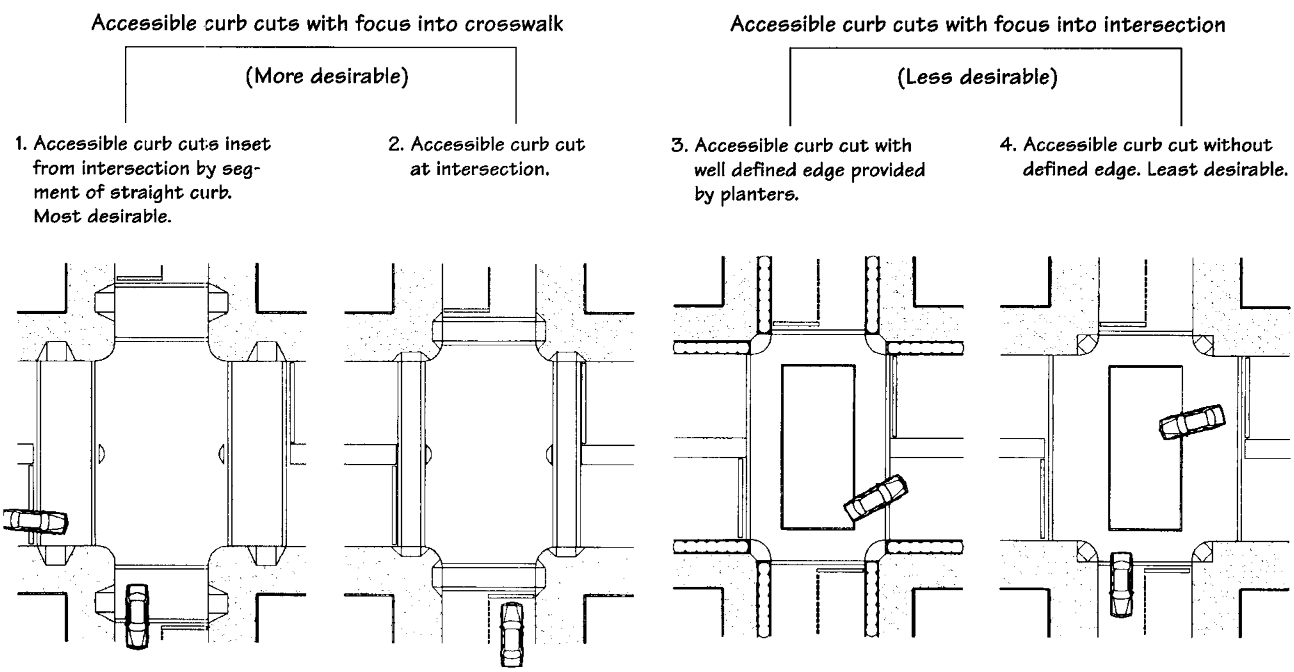


Figure 240-4. Curb ramps at marked crossings. *Curb ramps in order of preference for accessibility.*

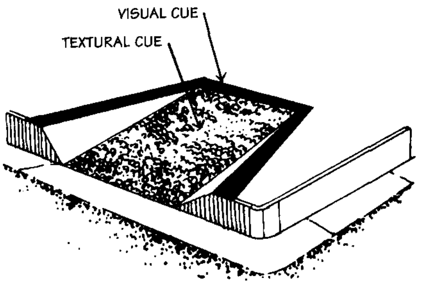


Figure 240-5. Components for visual and textural cueing. *Both visual and textural cues can be employed to forewarn handicapped pedestrians of hazardous areas.*

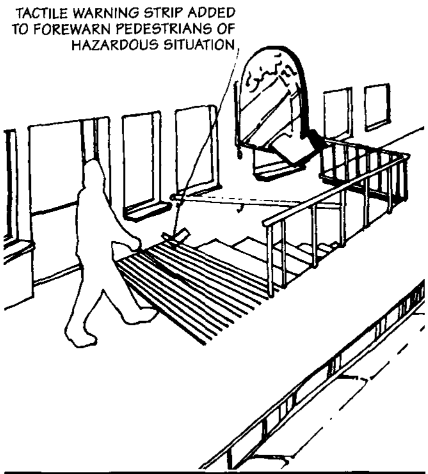


Figure 240-7. Unexpected level changes. *Unexpected level changes are hazardous and should not occur in the main line of pedestrian walkways. Existing situations can be modified to forewarn unsuspecting pedestrians.*

and day, sunlight and shadow, or the four cardinal directions.

Such individuals learn to rely upon the other senses of smell, hearing, and touch for identification and orientation through complex outdoor environments. The sense of smell is used to identify landmarks whose characteristic odors can be remembered and cognitively mapped. The direction and location of auto traffic can be determined from audible cues. To a practiced ear, the echo in a space can indicate its approximate size and the location of walls or openings.

The perception of wind or drafts against the skin can help identify street corners, tunnels, subway entrances, or narrow passages, as well as helping to determine spatial form to some extent. The perception of heat or cold can indicate the direction of the sun and the presence of street gratings, exhaust fans, or a doorway.

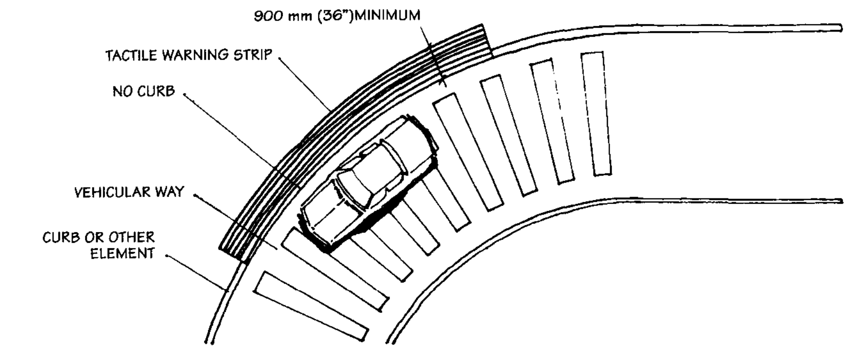


Figure 240-6. Tactile warning at hazardous vehicular areas. *Visual and/or textural cues can be used to forewarn motorists of pedestrian areas, and vice-versa.*

Differences in paving materials can provide tactile cues to aid negotiation and identify hazards. A sense of balance helps identify topographic gradients, the beginning or end of a ramp, the approximate width of a crowned road, or a drainage structure.

Many individuals with impaired vision rely on their limited vision and various environmental cues when negotiating the outdoor environment. Some travel by holding onto the arm or shoulder of a sighted person. Others employ a variety of mobility aids, including use of a long cane (i.e., the Typhlo or Hoover cane) (Figure 240-2). However, use of a cane does not always detect protruding objects at a height greater than about 675 mm (27 in). Railings, for instance, should have a second rail lower than 675 mm (27 in) for easier detection. Overhanging branches are also not easily detected.

3.2 Mobility Impairments

Impaired mobility can be the result of a wide variety of conditions, such as temporary or permanent injuries and the normal effects of aging.

Impaired mobility generally refers to an impaired function of the legs or an inability to walk. It can also refer to limited stamina, poor balance, extreme of size and weight, or a heart condition. A person with a mobility impairment may rely on walking aids, need areas to rest, or require a ramped incline for a wheelchair. When walking is possible, there is often difficulty in using stairs and ramps, especially if no hand railings are present. Hand railings are required by ADAAG on stairs and many ramps. Careful design of ramps, landings, stairways, stair nosings, and tread-riser ratios is important, as is the choice of surface materials. Walkway surfaces should not constitute a potential hazard in themselves.

Level changes which are not ramped create barriers for most users of wheelchairs. Accessibility for wheelchair users also implies adequate dimensioning of spaces, routes, ramps and doorways, and proper placement of street furniture. Kinetospheres, or reach limitations, are also important determinants. Both UFAS and ADAAG provide guidelines for positioning drinking fountains and telephones. ADAAG has an added section on the dimensions for Automated Teller Machines.

3.3 Hearing Impairments

Individuals with hearing impairments may encounter barriers that center around spoken information and audible warning communication, as vision is relied upon for informational needs. Danger may occur when alarms such as automobile horns or fire alarms are not accompanied by flashing lights or other visual cues. Clear signage and other visual indications for directional information are especially important to individuals with hearing impairments when verbal communication is not possible.

Assistive listening systems are required in certain assembly areas by ADAAG but specific guidelines have not yet been developed for outdoor recreation areas as of this writing. Recommendations, however, are available.

3.4 Manual Impairments

Manual impairments generally refer to dysfunctions of arms or hands. Some individu-

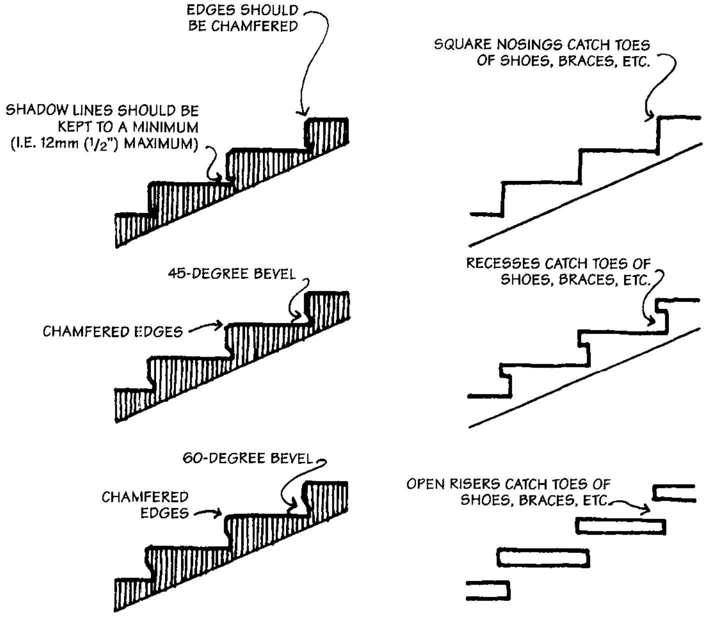


Figure 240-8. Outdoor step types. *Steps should be designed to safely accomodate those who will use them. Careful attention to nosing and shadowline details is especially important.*

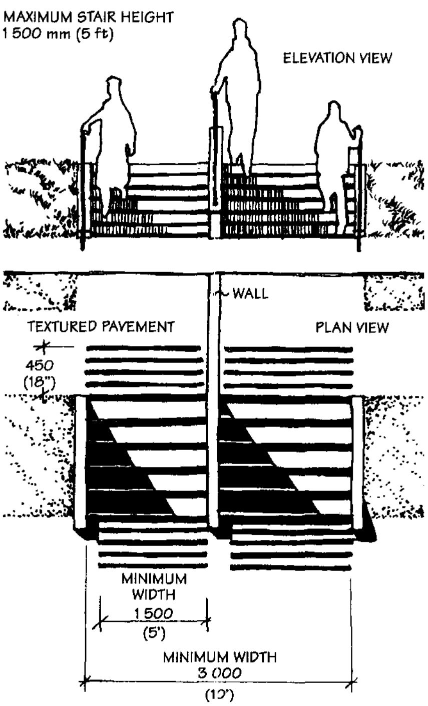


Figure 240-9. Stairway landings. *Vertical height between stairway landings should be minimized to accommodate individuals with limited strength. Note that minimum widths do not include the thickness of walls.*

als have manual difficulty as a function of reduced strength in arms and hands because of age or other temporary or permanent conditions.

Operating controls such as those found on elevators, vending machines, doorways, or gates often present barriers. Push plates and pull bars on gates or doors are recommended. Buttons or large swing knobs are preferable to small twisting or dialing mechanisms which require some degree of strength and may create a hindrance. Equipment that can be operated with a closed fist will accommodate most people.

Operating controls, such as a door opener which can be activated by a large push button should be placed so that a person using an electric wheelchair (such as breath-operated) can manipulate their position to push the button with their chair.

3.5 Learning Impairments

Individuals with learning difficulties require design consideration for several reasons. Many people have difficulty with orientation and route memory as a function of cognitive mapping difficulty. Graphic symbols can minimize the hazards to those with learning difficulties by calling out crosswalks, the edges of traffic, and dangerous and restricted areas. Graphic symbolization (banded crosswalks, for example) can stimulate memory in those with learning difficulties. Illiteracy can also be accommodated somewhat by the use of graphic symbolization. Landmarks can function as orientation devices in some cases.

4.0 DESIGN ELEMENTS AND DETAILS

General consideration of details in accessible design include dimensioning, materials selection, avoidance of hazards, and maintenance issues. Specific recommendations are provided below and references to guidelines are cited.

Accessible outdoor facilities should incorporate the following amenities as close to entryways as possible:

KEY POINTS: Design Considerations for Accommodating Disabilities

Physical impairments affect a broad based population and require specific design considerations.

1. Many individuals with impaired vision rely on their limited vision and various environmental cues when negotiating the outdoor environment. The Typhlo cane is primarily used by those with limited vision and will detect objects only within a specific range. Tactile warning strips are recommended to forewarn pedestrians of hazardous areas. Objects should not protrude into pedestrian pathways above a 675 mm (27 in) height (Figure 240-2 and 240-3).
2. A person with a mobility impairment may rely on walking aids, need areas to rest, or require a ramped incline for a wheelchair (see Figure 240-10 for ramp dimensions).
3. Assistive listening systems are required in certain assembly areas by ADAAG.
4. Operating controls such as those found on elevators, vending machines, doorways, and gates should have push plates, pull bars, buttons, or large swing knobs. Equipment that can be operated with a closed fist will accommodate most people.
5. Graphic symbols can minimize the hazards to those with learning difficulties by calling out crosswalks, the edge of traffic, and dangerous and restricted areas (see Figure 240-26: Universal Design Symbols).

1. Parking (for appropriate number of reserved accessible spaces, see Table 240-1).
2. Accessible rest room facilities
3. Accessible drinking fountain(s)
4. Accessible public telephone(s)
5. Accessible waiting area with appropriate seating
6. Informational and directional signage
7. Elevators, escalators when in use
8. Other amenities provided on site (ex. ATM machines)

For specific information, refer to the following sections:

ADAAG 4.6 Parking and Passenger Loading Zones

ADAAG 4.23 Bathrooms, Bathing Facilities, and Shower Rooms

ADAAG 4.15 Drinking Fountains and Water Coolers

ADAAG 4.31 Telephones

ADAAG 4.32 Fixed or Built-in Seating and Tables

ADAAG 4.30 Signage

ADAAG 4.10 Elevators and Escalators

ADAAG 4.34 Automated Teller Machines

The following design details commonly occur in outdoor environments:

4.1 Walkways, Street Crossings and Paved Surfaces

General:

The following recommendations provide general design guidelines; consult the appropriate sections in ADAAG or UFAS for specific scoping requirements.

Closed networks of pedestrian accessible routes rather than discontiguous units of accessible design are essential for a pleasant experience for most people. Small and large loops are generally desirable for all. Places to stop and rest should be provided. If a path is narrow, passing space for two wheelchairs must be provided at periodic intervals (most wheelchairs are 800-900 mm (32-36 in) wide and a 900 mm (36 in) path minimum is required on an Accessible Route). Maneuvering around fixed objects requires more space as well. Places to stop and rest should be level and large enough so that a wheelchair can "park" safely

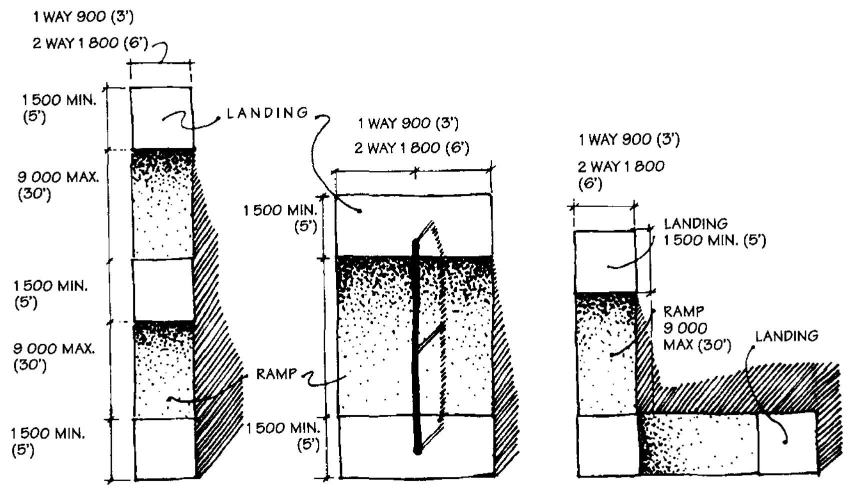


Figure 240-10. Typical ramp configurations. *Regardless of the ramp configuration, all inclines and landings should be sufficiently dimensioned.*

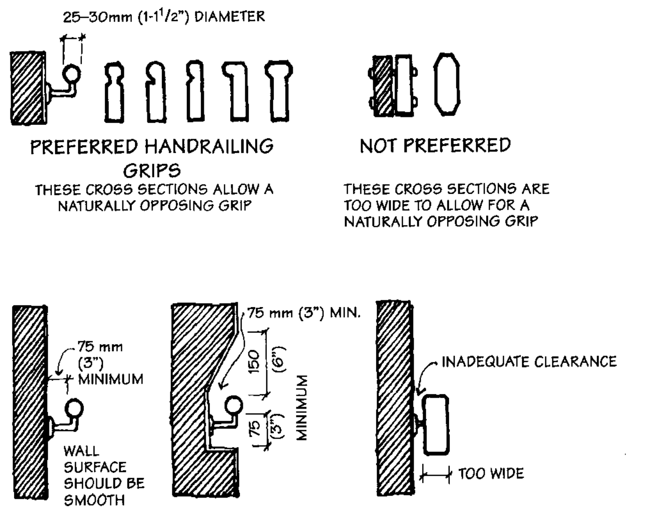


Figure 240-11. Handrailing cross sections. *The cross section of a handrailing should be designed to allow a firm, prehensile grasp.*

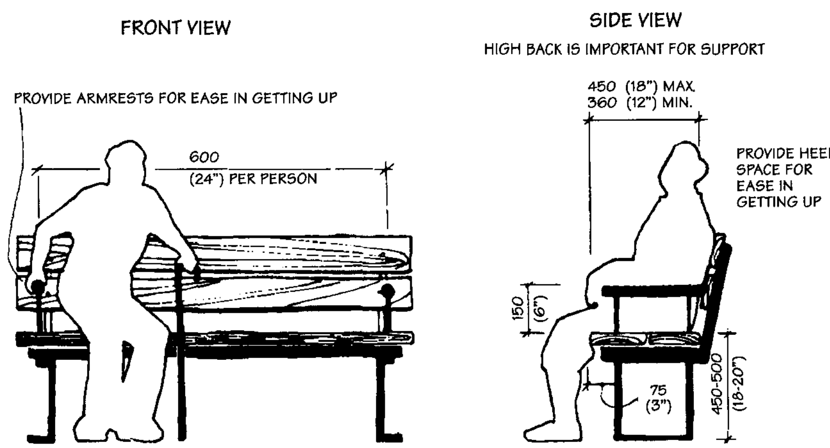


Figure 240-12. Typical bench requirements. *Benches should be designed to facilitate individuals with limited strength. Armrests and adequate heelspace are especially important details.*

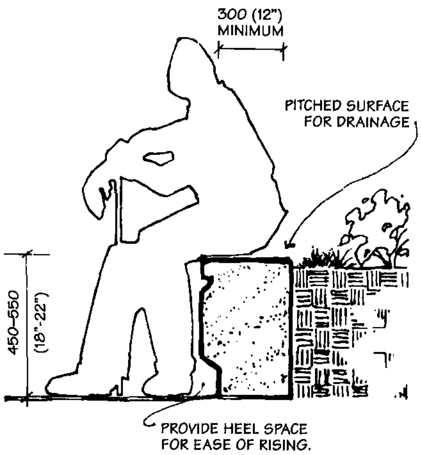


Figure 240-13. Typical seating wall requirements. *Although wall heights can vary, all should be designed to facilitate use by a wide range of user types.*

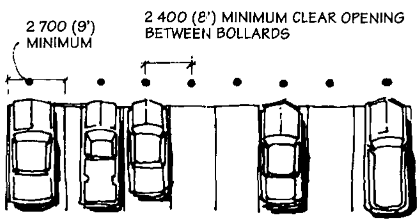


Figure 240-14. Bollard placement. *Bollards should be placed to minimize obstruction to pedestrian flow, including transverse flow from parking areas.*

without obstructing the Accessible Route. If a route is not accessible, signage referring to the entrance of an Accessible Route should be posted in a conspicuous place so as to avoid "dead-ends." However, the Accessible Route must coincide with the route for the general public to the maximum extent feasible, by law. Small level changes should be avoided or minimized, and surfaces should be chosen with care. Materials in a boardwalk, flagstones, and brick paving, for example, should be "flush" so that small level changes never exceed 12 mm (1/2 in).

Running slopes greater than 1:20 are difficult for many people, including most individuals who use manual wheelchairs and people with less stamina. Slopes greater than 1:20 are considered Ramps by ADAAG and fall under different design requirements. Ramps should not exceed 8.33% (1:12) for distances greater than 9 000 mm (30 ft). Cross slopes on paths and ramps should not exceed 2% in developed areas, and 3% in more natural or primitive areas (due to construction constraints). Objects which are non-detectable by cane and protrude into the Accessible Route must be avoided or marked according to specifications. Audible cues, such as falling water from a fountain and even vegetation, can aid greatly in non-visual orientation of a path system. The following ADAAG sections provide more information:

ADAAG 4.3 Accessible Route, for general requirements

ADAAG 4.4 Protruding Objects

ADAAG 4.5 Ground and Floor Surfaces

ADAAG 4.6 Parking and Passenger Loading Zones

ADAAG 4.8 Ramps

ADAAG 4.14 Entrances

Tactile Warning Strips (Detectable Warnings):

Tactile warning strips that warn of danger are used on walkway surfaces and at curb ramps and street crossings to warn pedestrians of abrupt grade changes, vehicular areas, potentially dangerous exits, reflecting or swimming pools, water fountains, and other obstructions or hazards. (Figures 240-3 through 240-6) They are needed at both the top and bottom of stairways (Figure 240-3), in front of doors that lead to potentially hazardous areas, and when a walking surface and vehicular way cross or adjoin and are not separated by curbs or other elements. Textured door knobs or handles are also beneficial. However, such warnings should not be used at emergency exits, as they can discourage use of the exit during real emergencies.

A linear tactile warning strip can define the zone along the outer edge of walkways, leaving a clear path without obstruction of street furniture and trees. (Refer to the following guidelines for specific dimensions and scoping requirements: ADAAG 4.7 Curb Ramps; ADAAG 4.29 Detectable Warnings).

The widely varying nature of walkway surfaces commonly used makes standardization of tactile warning strips difficult, but the standardization of textured warning surfaces within any one site or facility can be easily accomplished. Textural and color contrasts should be strong but should not constitute a safety hazard in themselves. Contrast in tone is the important criterion. State regulations should be checked.

Table 240-1. MINIMUM ACCESSIBLE SPACES.

TOTAL PARKING IN LOT	REQUIRED MINIMUM NUMBER OF ACCESSIBLE SPACES
1 TO 25	1
26 TO 50	2
51 TO 75	3
76 TO 100	4
101 TO 150	5
151 TO 200	6
201 TO 300	7
301 TO 400	8
401 TO 500	9
501 TO 1000	2% of total
1001 and over	20 plus 1 for each 100 over 1000

Source: U.S. Access Board, Americans with Disabilities Act Accessibility Guidelines, U.S. Architectural and Transportation Barriers Compliance Board, Washington, DC, September 1994.

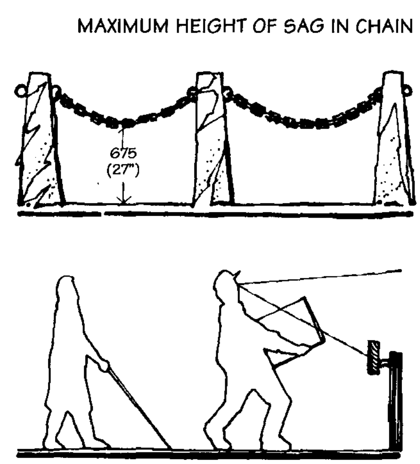
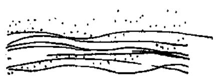
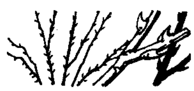
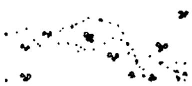


Figure 240-15. Chain barriers and guardrails. *Chain barriers can be very hazardous and should be used only with a high degree of discretion. Chains that sag below 675 mm (27in) in height are detectable by cane but are often unseen by others, especially the elderly. Guardrails must be high enough to be easily seen, but rail must be detectable within a 675 mm (27in) clear maximum height range.*

Table 240-2. HAZARDOUS AND NOXIOUS PLANT SPECIES

Hazard/nuisance	Species	Comments
 Poisonous plants	Holly, yew, privet, laurel, rhododendron	Children may be tempted to sample bright-colored berries or leaves
 Debris: fruits and nuts	Crab apple, plum, cherry, oak, chestnut, hickory, walnut	Long, strap-like rods, berries, cones, and nuts can be slippery or difficult to walk on. They are easily tracked into buildings and can stain clothing if sat upon.
 Cones	Pines, spruce, fir, larch, hemlock	Cones, while having many decorative uses, can cause problems for pedestrians and small-wheeled vehicles on walkway surfaces.
 Seed pods	Sweetgum, sycamore, London plane tree, honey locust, maple	Pods create unsure footing for pedestrians and hinder the move ments of small-wheeled vehicles.
 Branch breakage	Birch, silver maple, box elder, horse chestnut, poplar, willow, tulip tree, elm	Branch debris is difficult to walk on or to push small wheeled vehicles over. Large branches can cause extensive damage to items on which they might happen to fall, such as cars, small wood-frame structures, etc.
 Drooping branches	Birch, willow, pin oak, beech, magnolia	Branches can drop below minimum clearances on walkways or streets causing facial or eye injuries to pedestrians and hazards for motorists.
 Shallow Roots	Willow, red maple, silver maple, beech, cottonwood, poplar varieties	Surface root systems can cause walks to heave and break apart, and pedestrians may trip and fall. Uneven or broken surfaces can be extremely difficult for small-wheeled vehicles.
 Odor	Siebold viburnum, female ginkgo, Mimosa	Foul-smelling odors not only degrade the aesthetic appeal of an area but also tend to make some people nauseous.
 Thorns and spikes	Barberry, quince, hawthorne, locust, holly, rose varieties, privet	Plants with thorns or spikes can be painful and dangerous to brush against or fall into. Leaves, twigs, and branches that fall to the ground can also be hazardous to people in light footwear or walking barefoot.
 Insects and pests	Fruit trees (crab apple, cherry, plum, etc.), mountain laurel	Because of the severe reaction certain people have to insect bites and stings, the use of plant materials which attract these pests are not recommended for areas near walks and seating.

Source: Gary Robinette, ed., *Barrier Free Site Design*, Van Nostrand Reinhold, New York, 1985.

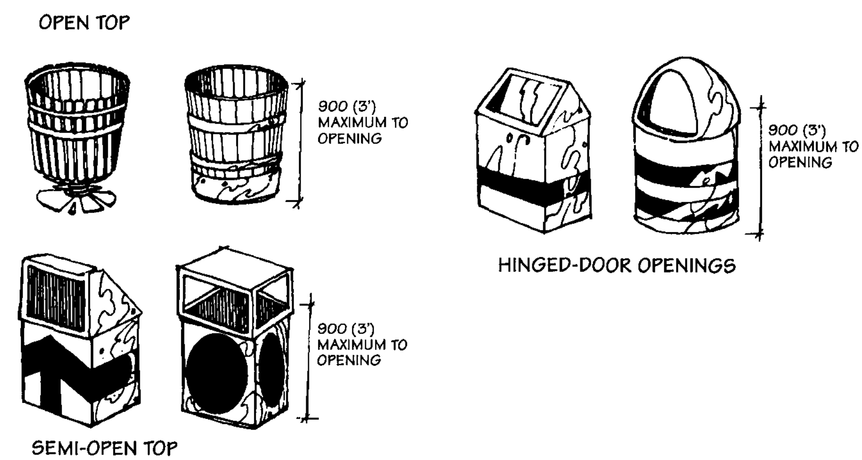


Figure 240-16. Trash receptacles. *Trash receptacle designs have various advantages and disadvantages depending on the climate and situation, including ease of use and exclusion of rain or snow.*

4.2 Outdoor Stairs and Landings

Stairways:

Stairways constitute the most formidable barrier and safety hazard for those with physical impairments. A large percentage of accidents by severely visually impaired individuals occur at level changes (Figure 240-7 and 240-8).

Open risers are not permitted under ADAAG. Specifics on treads and risers, nosings, handrails and detectable warnings are given in the section: ADAAG 4.9 Stairs.

Landings:

Outdoor landings to stairways should be adequately dimensioned to allow room for the convenient movement of people, especially for those who need assistance negotiating stairways. The maximum height between landings should be 1 500 mm (5 ft) for visual coherence and psychological invitation between adjacent levels. Lower heights are preferred (Figure 240-9).

4.3 Outdoor Ramps

Ramps are crucial for those who use wheelchairs but may not be easier to negotiate than stairs for others. Both means of access should be provided whenever possible (Figure 240-10) (Refer to the following sections: ADAAG 4.7 Curb Ramps; ADAAG 4.8 Ramps).

Ramps require level landings at both top and bottom of each ramp and between each ramp run. Clear floor space must be adequate to maneuver on and off of ramp, out of doors, etc. See section ADAAG 4.8.4 Landings

4.4 Handrailings

Hand railings are important for safety and can aid with mobility, orientation and cognitive mapping of the environment. Steps, ramps, soft ground, and irregular paving surfaces are non-negotiable for many people if no hand railings are present. In recreational settings, ropes with periodic knots have often been used as orienteering devices enabling some people with visual impairments to enjoy environments otherwise disorienting and previously inaccessible (Figure 240-11) (Refer to 5.0 Accessible Recreation in this section for more information). See the following sections for more information: ADAAG 4.9.4 Stair Handrails; ADAAG 4.8.5 Ramp Handrails.

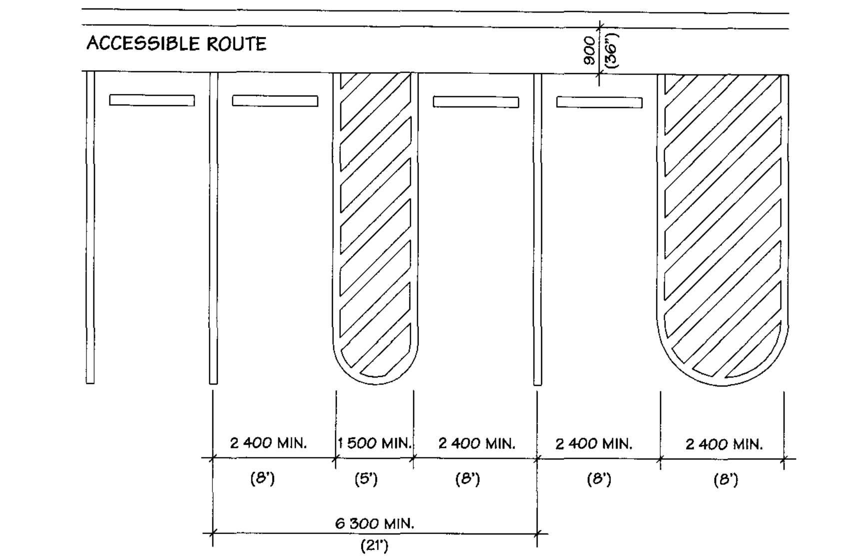


Figure 240-17. Van accessible space at end row.

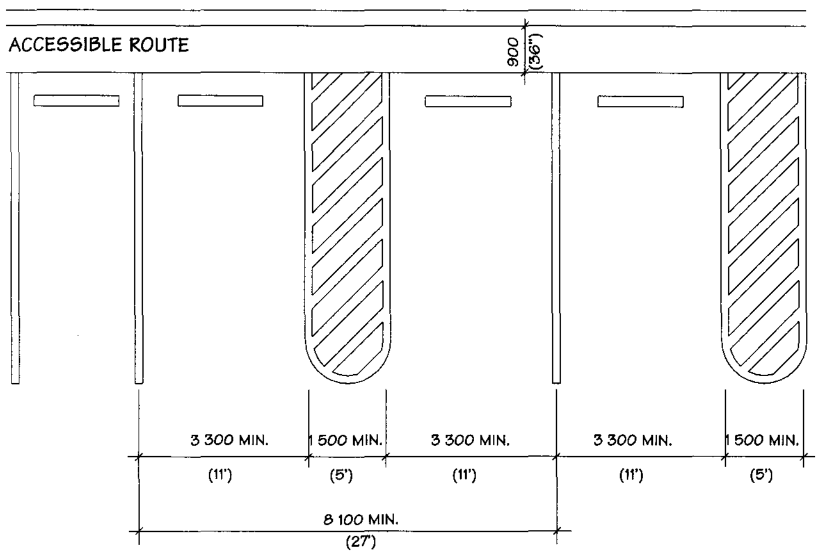


Figure 240-18. Universal parking space design.

4.5 Walls, Benches, and Outdoor Seating

Basic outdoor seating too often fails to address the needs of a broadly based user group. For example, many people often require arm rests when getting into or out of a seated position. Heel space is also necessary to make rising from a seated position easier (Figures 240-12 and 240-13). Wheelchair users often desire places to stop and rest and places to set packages. See the following sections for dimensions of outdoor seating and assembly areas: ADAAG 4.32 Fixed or Built-in Seating and Tables; ADAAG 4.33 Assembly Areas.

4.6 Walkway Furnishings

Walkway Furnishings:

Walkway furnishings should be carefully organized for safety and easier negotiation. Furnishings should be easily detectable by cane, either in themselves or by way of a hazard strip. A hazard strip (linear textured surface) can be used to separate walkway furnishings from clear walking space (Refer to 4.1 Walkways and Paved Surfaces in this section for more information on tactile warning strips).

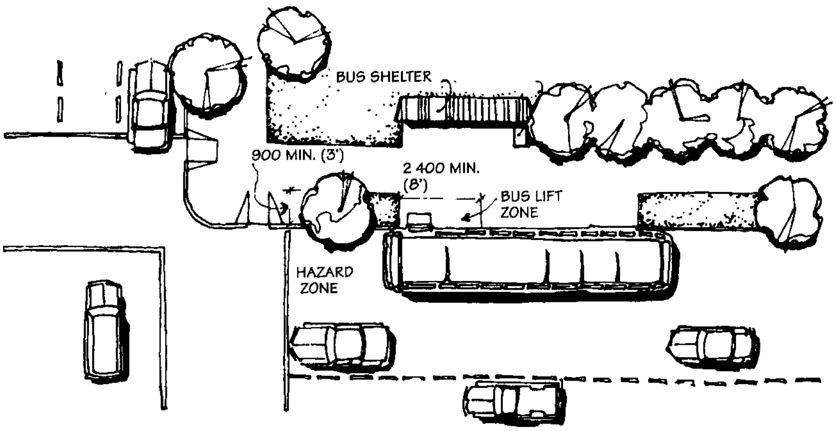


Figure 240-19. Accessible bus stop. *Bus stops should be part of an accessible pedestrian network and include an area designed for deployment of a lift. A clear view of approaching buses should be maintained.*

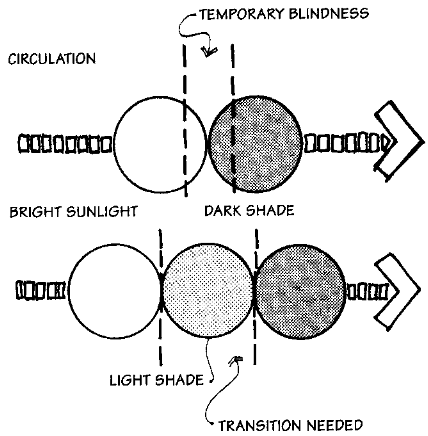


Figure 240-21. Transition between dark and sunlit areas. *As a function of aging, visual response to abrupt changes in light intensity becomes slower. Careful choice and placement of trees, arbors, trelliswork, and similar devices can soften the transition between darkly shaded and brightly sunlit areas.*

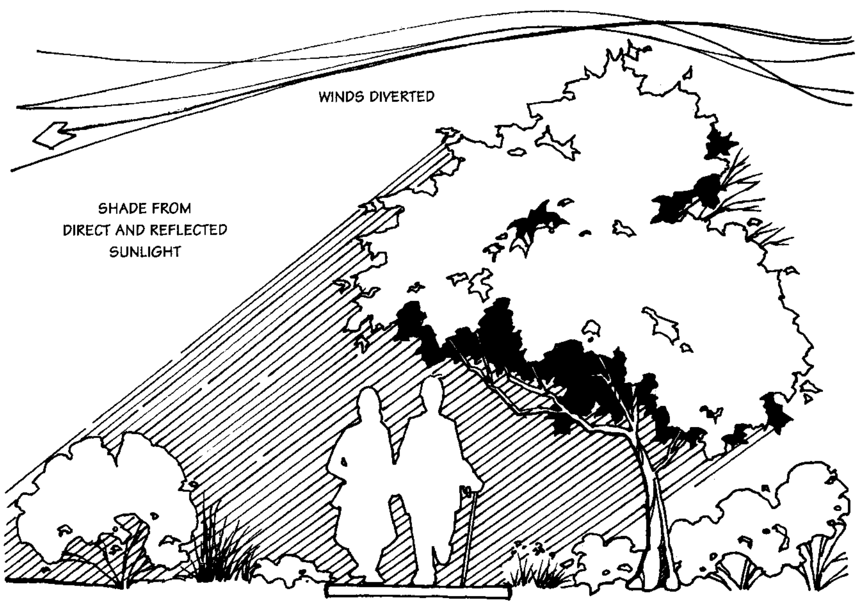


Figure 240-20. Microclimatic comfort. *Microclimatic control is especially important for elderly people, who are adversely affected by bright light, glare, cold drafts, and excessive heat. On warm, sunny days, for instance, a lightly shaded area without windiness is a preferred environment.*

Bollards:

Bollards, or post barriers, should not be placed in the main line of pedestrian travel and should be centered on parking stalls, when applicable, to allow free pedestrian travel to and from parking areas (Figure 240-14). The same principle applies to trees, planters, light standards, parking meters, trash receptacles, and the like (Figure 240-15).

Chain Barriers:

Chain barriers can be hazardous to pedestrians, bicyclists, and motorcyclists since these barriers are difficult to see, especially when lower than 790 mm (32 in) in height, and also at night (Figure 240-16). Chains at a height of 670 mm (27 in) or less are more easily detected by visually impaired cane users. Discretion should be used when designing chain barriers, and a means should be devised to increase their detection by all people (Refer to ADAAG 4.4 Protruding Objects for more information).

4.7 Parking and Passenger Loading Zones

The minimum number of Accessible Spaces in self-park parking lots are presented in Table 240-1.

The "Universal" Parking Space Design recommends that all accessible spaces to be 3 300 mm (11 ft) wide with a 1 500 mm (5 ft) access aisle in order to accommodate the increase in use of vans with side-mounted lifts or ramps (See Figure 240-17 and 270-18).

Specific dimensional information on parking and passenger loading zones is also given in the following section: ADAAG 4.6 Parking and Passenger Loading Zones.

4.8 Bus Shelters and Lifts

All bus shelters should have an unobstructed view of arriving vehicular traffic for both standing and seated individuals. The drop-off zone should be part of the Accessible Route.

The street adjacent to accessible bus stops should not have a high crown which would cause the bus lift to tilt, and the curb upon which the lift descends should be low enough to allow full deployment of the lift. A maximum curb height of 200 mm (8 in)

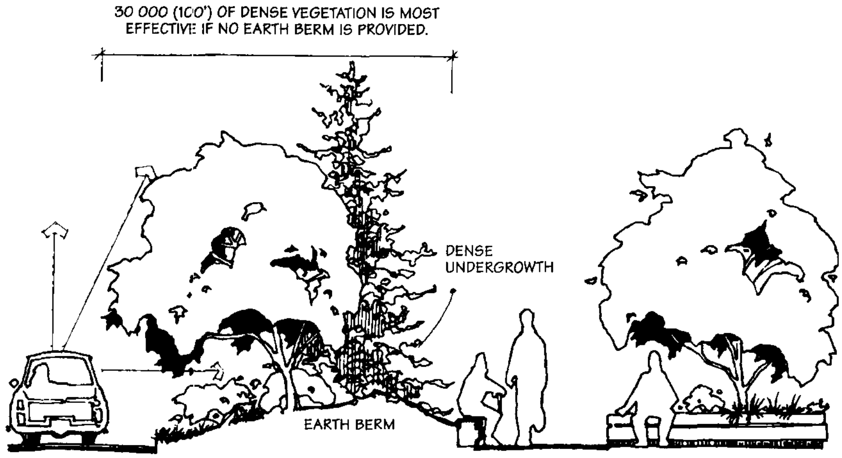


Figure 240-22. Noise buffer for easier outdoor conversation. *As a function of aging, elderly people often lose their ability to clearly distinguish between simultaneous sounds. Outdoor conversation areas should be buffered from interfering noise whenever possible.*

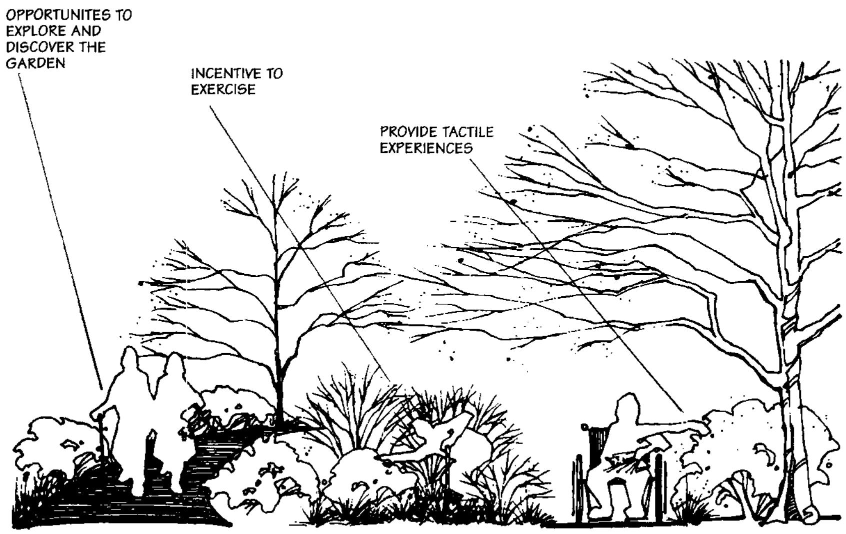


Figure 240-23. Gardens for elderly and handicapped people. *Gardens and gardening can provide pleasure as well as incentive to exercise for people with disabilities and others who would benefit from higher levels of physical activity.*

allows for the operation of standard lifts (Figure 240-19).

Bus shelters should be constructed so that there is enough room to maneuver from the public way into the shelter and onto the bus within the perimeter of the shelter. See sections: ADAAG 10.2 Bus Stops and Terminals; ADAAG 4.11 Platform Lifts for dimensional guidelines

4.9 Outdoor Plantings, Lawns, and Gardens

Planting:

Planting along public walkways should not constitute a potential hazard or nuisance. Species with branches that characteristically break under ice or snow, produce excessive litter, droop down over walkways, or produce poisonous or slippery fruits should be used with discretion (Table 240-2).

Microclimate control is especially important for elderly and handicapped people. Plant materials can be used to mitigate the discomforting effects of wind, glare, reflection, temperature, and humidity (Figure 240-20).

Elderly people typically have the visual problem of diminished depth perception and a slower adjustment to abrupt changes in light. With careful planting or other means, harsh transitions between areas of

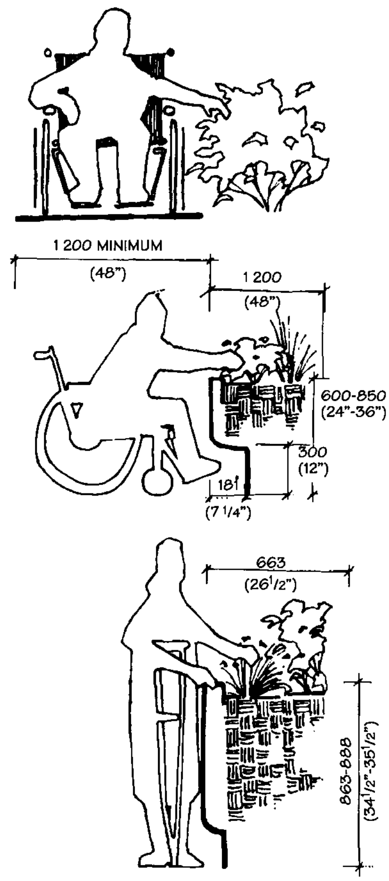


Figure 240-24. Raised plantings for individuals with reach limitations. *Opportunities for individuals with reach limitations is important, especially for those who use mobility aids.*

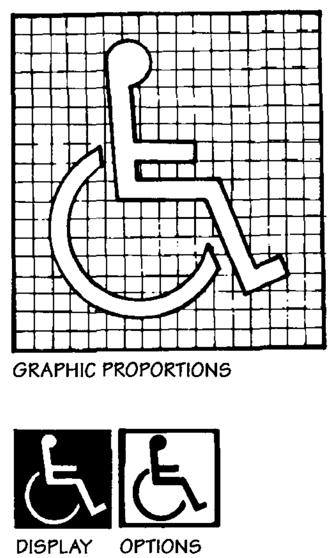


Figure 240-25. International symbol of accessibility.

PUBLIC SERVICES 1

1 Telephone	14 Toilets
2 Mail	15 Nursery
3 Currency Exchange	16 Drinking Fountain
4 Cashier	17 Waiting Room
5 First Aid	18 Information
6 Lost and Found	19 Hotel Information
7 Coat Check	20 Air Transportation
8 Baggage Lockers	21 Heliport
9 Escalator	22 Taxi
10 Stairs	23 Bus
11 Elevator	24 GroundTransportation
12 Toilets, Men	25 Rail Transportation
13 Toilets, Women	26 Water Transportation

CONCESSIONS 2

27 Car Rental	32 Barber Shop/ Beauty Salon
28 Restaurant	33 Barber Shop
29 Coffee Shop	34 Beauty Salon
30 Bar	
31 Shops	

PROCESSING ACTIVITIES 3

35 Ticket Purchase	39 Immigration
36 Baggage Check-in	40 Departing Flights
37 Baggage Claim	41 Arriving Flights
38 Customs	

REGULATIONS 4

42 Smoking	47 No Entry
43 No Smoking	48 Exit
44 Parking	49 Fire Extinguisher
45 No Parking	50 Litter Disposal
46 No Dogs	

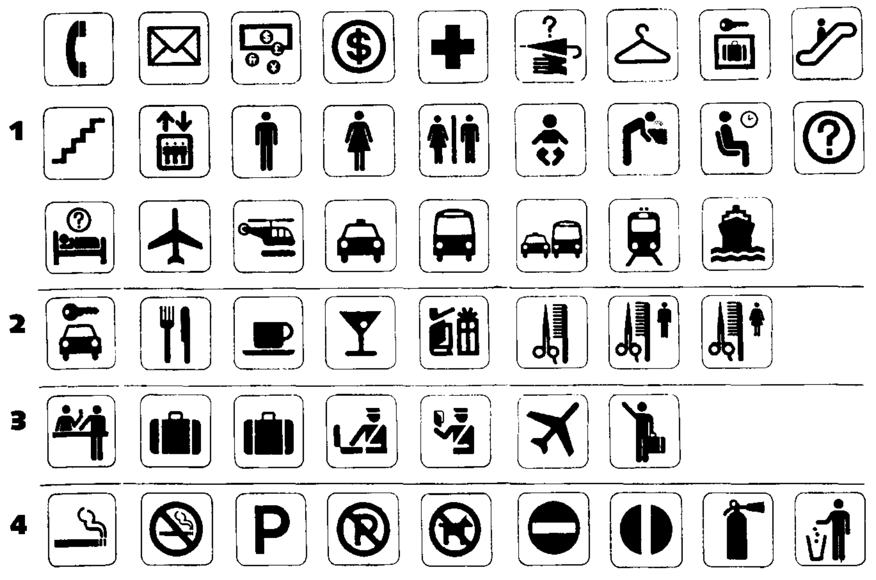


Figure 240-26 Universal Design Symbols. *These symbol signs are recognized internationally as substitutes for literal signage and are especially useful for those who are illiterate in either their own language or a foreign language.*

bright sunlight and deep shade can be softened (Figure 240-21).

Speech is often difficult to hear, especially by the elderly, who have trouble sorting simultaneous sounds. Unwanted noise sources near outdoor conversation areas should be buffered wherever possible. Refer to Section 660: Sound Control in this handbook for more information (Figure 240-22).

Lawns:

Regarding lawns, many people's basic desire is to be able to sit on the grass; this includes people who may have difficulty in doing so because of a mobility impairment and are using a wheelchair. Working with the topography of a site, transfer walls should be built in when possible to allow for easier access to grass from a seated position.

Gardens:

Gardens as well as gardening are an important source of enjoyment and can be designed to serve a wide variety of user groups; including people with visual impairments and those using wheelchairs (Figure 240-23). A pleasingly tactile, audible, and/or aromatic environment can be especially interesting. Opportunities to pick fruits, smell flowers, pull weeds, etc., can be provided, by the use of raised platforms

Table 240-3. CHARACTER HEIGHT (CANADIAN SYSTEM)

Character X height, mm (in)*	Reading distance, m (ft)	Traffic speed, K/hr (mph)
5 (0.20)	3.0 (10)	Pedestrian
6 (0.24)	3.7 (12)	
8 (0.32)	4.9 (16)	
10 (0.40)	6.2 (20)	
12 (0.48)	7.4 (24)	
15 (0.60)	9.2 (30)	
20 (0.80)	12.3 (40)	
25 (1.00)	15.4 (50)	
30 (1.20)	18.5 (60)	
40 (1.60)	24.6 (80)	Vehicular
50 (2.00)	30.0 (100)	3-6 (10-20)
60 (2.40)	37.0 (120)	3-6 (10-20)
80 (3.20)	49.3 (160)	6-9 (20-30)
100 (4.00)	61.6 (200)	6-9 (20-30)
120 (4.80)	73.9 (240)	12-19 (40-60)
150 (6.00)	92.4 (300)	12-19 (40-60)
200 (8.00)	123.2 (400)	12-19 (40-60)

* Note: Character X height refers to the height of the lower-case "x" character in a particular font or typeface.

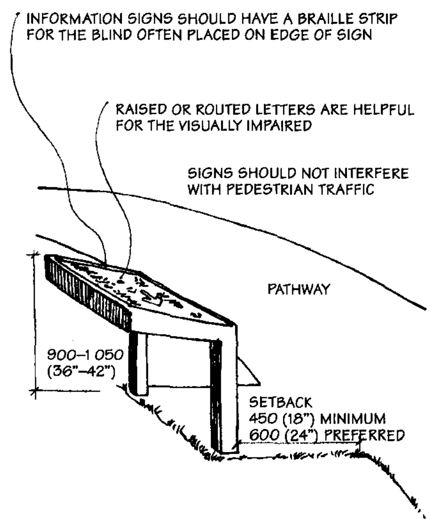


Figure 240-27. Placement of outdoor signage. *Accessible signage refers to graphic information that is accessible to everyone regardless of mobility impairment, and also includes accommodation for those with visual impairments and learning impairments.*

for potting; raised planting beds for non stooping access; and horticultural opportunities at above ground levels (e.g., berry picking from shrubs, dwarf fruit tree culture, upright flowering plants, and tall vegetables) (Figure 240-24). Gardens which attract songbirds and other forms of wildlife are greatly enjoyed by all people. Adaptive gardening areas should be integrated into the landscape where safety permits.

4.10 Outdoor Lighting

Lighting is especially important in places that are potentially hazardous. Fixtures should not protrude into Accessible Routes. Higher levels of illumination or a greater distribution of fixtures are beneficial to those with limited vision. Visual alarms should be integrated into the system where audible alarms are required. See sections: ADAAG 4.4 Protruding Objects; ADAAG 4.28.3 Visual Alarms for more information.

4.11 Signage

Clear and precise signage is a crucial aid to negotiation for all people. Essential functions include place identity, notice of accessibility, warnings, and directional information.

International Symbols:

Symbols of accessibility should be displayed where appropriate. The International Symbol of Accessibility (Figure 240-25) is required in four locations: accessible parking spaces, accessible loading zones, accessible site and facility entrances that are not the primary entrance, and accessible restrooms. The Universal Design Symbols (see Figure 240-26) should be used to indicate levels of accessibility on outdoor Accessible Routes. In the case of Accessible Routes, the Universal Design Symbols are preferable to the International Symbol of Access, which has a tendency to imply "reserved for people with disabilities."

Placement, scale, and consistent graphic style are important and should be readily observable from both seated and standing positions. Braille and raised or recessed letters provide signage for people with visual impairments, and raised-relief maps when provided are also particularly useful. Cassette tapes or audible tones are other possibilities with distinct advantages over written information, except for those with impaired hearing. Traffic signals and kiosks are especially amenable to audible signals. When possible, signage complemented by informational brochures can provide more detailed levels of information.

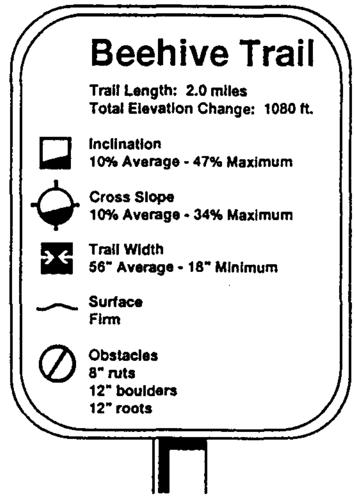
Braille strips can be added to the edges of signs that are reachable and located for that purpose.

Graphic symbols should not be too abstract, nor should they be the only means of communication, because they have no applicability for some. Readability in signage is a function of comprehension, tone contrasts, character height, and character proportion. Design criteria for literal signage have been developed to facilitate easier readability, (see appropriate ADAAG section for specifics). Signage with a matte finish and color contrast between characters and background is most readable. Table 240-3 illustrates the Canadian system for determining character height, based on reading distance for pedestrians.

The mounting location and height of signage should not constitute a hazard.

Placement of Signage:

Placement of signage is important. Signage for sighted people is most easily seen at approximately eye level, at an angle perpendicular to the path of travel or within a 30 degree angle to the centerline of the



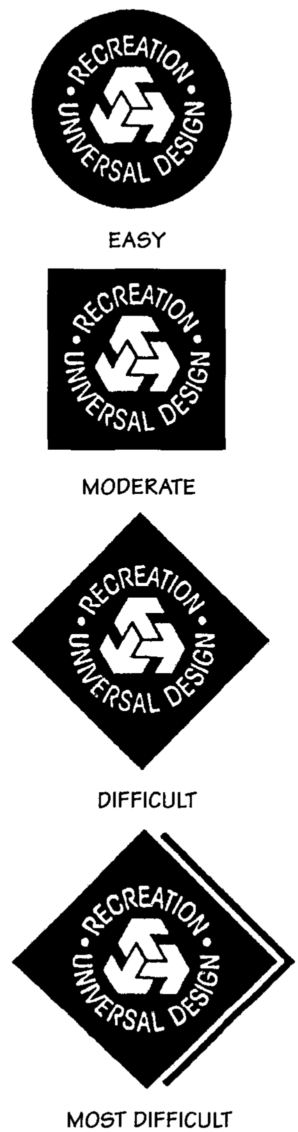


Figure 240-28. Universal Design Symbols for Recreation.

KEY POINTS: Design Elements and Details

Design elements and details in outdoor environments must be universally understood and easy to negotiate.

1. In general, details for accessibility must meet specific dimensions, some of which are required by law. The majority of figures within this section give a range of acceptable dimensions.
2. Materials selection is important as a visual and tactile cue to handicapped pedestrians. Materials can warn of hazardous areas (Figures 240-3 to 240-7) or help make accessible areas more comfortable (Figures 240-20 to 240-24).
3. It is important to avoid potential hazards or nuisances caused by designed elements and details. Plant material must be selected carefully to avoid hazardous or noxious plant species (Table 240-2).
4. For more specific information regarding details see The Americans with Disabilities Act Accessibility Guidelines (ADAAG).

Table 240-4. SUMMARY OF DESIGN STANDARDS FOR OUTDOOR RECREATION ACCESS ROUTES.

	LEVELS OF DEVELOPMENT		
ACCESS ROUTES	**High (Easier)**	**Moderate (Moderate)**	**Minimal (Difficult)**
clear width (minimum):	1 200 mm (48 in)	900 mm (36 in)	900 mm (36 in)
sustained running grade*(maximum):	5%	5%	8%
maximum grade allowed** for a maximum distance of:	8% 9 000 mm (30 ft)	10% 15 000 mm (50 ft)	10% 15 000 mm (50 ft)
cross slope (maximum):**	3%	3%	3%
passing space interval (maximum):	60 000 mm (200 ft)	90 000 mm (300 ft)	120 000 mm (400 ft)
rest area interval (maximum):	120 000 mm (400 ft)	270 000 mm (900 ft)	360 000 mm (1200 ft)
small level changes (maximum):	12 mm (1/2 in)	12 mm (1/2 in)	25 mm (1 in)

* Note: No more than 20% of the total length of the outdoor recreation access route shall exceed the maximum sustained running grade.

** Note: The measurement of a maximum grade and cross slope should be made over a 24" measurement interval to corre spond to the footprint of a wheelchair operating in that environment.

Source: Recreation Access Advisory Committee, Recommendations for Accessibility Guidelines: Receation Facilities and Outdoor Developed Areas, U.S. Architectural and Transportation Barriers Compliance Board, July I994.

Table 240-5. DEGREE OF ACCESS FOR OUTDOOR RECREATION ACCESS ROUTES.

Degree of Access	Level of Development	Required Clear Width
easier	high (urban/rural)	minimum 1 200 mm (48 in)
moderate	moderate (natural)	minimum 900 mm (36 in)
difficult	low (back country)	minimum 900 mm (36 in)
most difficult	none (primative)	not applicable

Source: Recreation Access Advisory Committee, Recommendations for Accessibility Guidelines: Recreation Facilities and Outdoor Developed Areas, U.S. Architectural and Transportation Barriers Compliance Board, July I994.

sign. Reading distance determines where it should be placed (see Table 240-3). Signs should not be obscured or confused with other graphics and should be easily recognized for what they represent. Signage intended for those with visual impairments should be well lit and/or located for easy access and touch (Figure 240-27).

Many situations require a system of sequential signs. Hospitals, college campuses, and other institutions should have posted signs, visual and textural cues, and pavement markings where applicable. Access to buildings or facilities with only one or two accessible entrances should be clearly marked with sequential signage.

For specific information on tone contrasts, lettering, placement of signage, etc., refer to the following section: ADAAG 4.30 Signage.

5.0 ACCESSIBLE RECREATION

Accessible design in recreation areas requires a diversity of quality experience, not an absolute standardization of all facilities nor the development of all natural and pristine areas. An appropriate method for accessible recreational design need not compromise the natural character of the landscape.

Accessibility guidelines for outdoor recreation areas are currently available in the form of recommendations. While not legally enforceable, these recommendations have been presented to the public for comment at this time. This section follows many of the recommendations given by the following publication:

Recommendations for Accessibility Guidelines: Recreational Facilities and Outdoor Developed Areas, developed for: U.S. Architectural and Transportation Barriers Compliance Board, July 1994, by the Recreation Access Advisory Committee. For more information or to comment on the recommendations, contact Access Board, Recreation Report, 1331 F Street, N.W., Suite 1000, Washington, DC 20004-1111.

Another source of information developed in part by the USDA Forest Service is Universal Access to Outdoor Recreation: A Design Guide, published by PLAE, Inc. in conjunction with other public and private partners including the USDA Forest Service and Sea Reach, Ltd., 1993, available from MIG Communications, 1802 Fifth Street, Berkeley, CA 94710 USA.

In general, when elements of the outdoor recreation environment coincide with indoor elements, the ADAAG and UFAS guidelines should be applied (e.g. picnic tables are covered under ADAAG 4.32 Fixed or Built-in Seating and Tables).

A difficulty in developing accessibility standards for the outdoor recreation environment has been in determining how much each site should be developed. To address this concern, the USDA Forest Service, for example, uses a recreation management approach called the "Recreation Opportunity Spectrum." The ROS systems allows for ratings of outdoor recreation areas with respect to user expectations, and resulting level of accessibility that should be the goal.

The ROS is based on the following:

- People purposefully choose a setting for their recreation activities.
- Expectations regarding accessibility are often central to that choice.
- Choices are made with the expectation of achieving particular recreation experiences.
- It is desirable to present a diverse spectrum of recreation settings, ranging from highly developed to primitive in accordance with the natural environment, from which people may choose.

The process of design for standardization of recreational facilities involves developing a positive attitude and awareness, minimizing of physical barriers, developing of programs, and involving many participants. Design standards and concepts must be considered in relation to each recreational facility, program, and participant. A systematic approach to facility and program development can facilitate higher-quality recreation choices.

Table 240-6. SUMMARY OF DESIGN STANDARDS FOR RECREATION TRAILS.

ACCESS ROUTES	Easier (urban/rural)	Moderate (natural)	Difficult (back country)
clear width(minimum):	1 200 mm (48 in)	900 mm (36 in)	700 mm (28 in)
sustained running grade*(maximum):	5%	8%	12%
maximum grade allowed*** for a distance of:	10% 9 000 mm (30 ft)	14% 15 000 mm (50 ft)	20% 15 000 mm (50 ft)
cross slope** (maximum):	3%	5%	8%
passing space interval (maximum):	60 000 mm (200 ft)	90 000 mm (300 ft)	120 000 mm (400 ft)
rest area interval (maximum):	120 000 mm (400 ft)	270 000 mm (900 ft)	360 000 mm (1200 ft)

*Note: No more than 20% of the total length of the outdoor recreation access route shall exceed the maximum sustained running grade.

**Note: Cross slope may not exceed 3% in maximum grade segments, or 5% in maximum grade segments on difficult access trails.

***Note: The measurement of a maximum grade and cross slope should be made over a 24" measurement interval to correspond too the footprint of a wheelchair operating in that environment.

Source: Recreation Access Advisory Committee, Recommendations for Accessiblity Guidelines: Recreation Facilities and Outdoor Developed Areas, U.S. Architectural and Transportation Barriers Compliance Board, July 1994.

Table 240-7. DEGREE OF ACCESS FOR RECREATIONAL TRAILS

Degree of Access	Recreation Setting	Required Minimum Clear Width
easier	highly developed (urban/rural)	minimum 1 200 mm (48 in)
moderate	moderately developed (natural)	minimum 900 mm (36 in)
difficult	minimally developed (back country)	minimum 700 mm (28 in)
most difficult	no development (primative)	not applicable

Source: Recreation Access Advisory Committee, Recommendations for Accessibility Guidelines: Recreation Facilities and Outdoor Developed Areas, U.S. Architectural and Transportation Barriers Compliance Board, July 1994.

5.1 Outdoor Recreation Access Route

The Outdoor Recreation Access Route is the site feature which determines accessibility at any developed recreation site, by connecting all essential elements of the site. This route must coincide with the route for the general public to the maximum possible extent. In general, the guidelines set by ADAAG 4.3 Accessible Route should be applied. The Universal Design Symbols for Recreation should be used (see Figure 240-28). These symbols are preferable to the International Symbol of Accessibility, which usually implies "reserved for people with disabilities" (See Table 240-4: Summary of Design Standards for Outdoor Recreation Access Routes and Table 240-5: Degree of Access for Outdoor Recreation Access Routes).

5.2 Hiking Trails

General:

Allowing for the physical negotiation of landscape and the enjoyment of natural beauty within the hiking experience should be planned in a diverse way for all potential users of a trail system. Providing opportunities for physically challenging recreation for those with mobility impairments and planning a high-quality sensory experience for those with visual impairments should not be overlooked.

The greatest diversity of people can be accommodated by providing a wide variety of trail types and challenges to choose from. Such a system also minimizes social segregation between user groups. (See Table 240-6: Summary of Design Standards for Recreation Trails and Table 240-7: Degree of Access for Recreation Trails).

Signage:

Signage should be compatible with the type of trail for which it is intended. In terms of extent, prominence, style, and message, signage should reflect the character of the particular trail experience. All potentially hazardous areas should be clearly marked, and include a means for safeguarding visitors. More information on appropriate signage follows.

Trail Planning Classification System:

Table 240-8 and Figure 240-29 illustrate a trail planning classification system and accompanying guidelines for a varying degree of accessibility in trail types. This system is an example of what can be done to provide quality recreational opportunities for a broadly defined population without compromising the natural landscape experience. Trail attributes which should be posted include: grade, cross-slope,and width and surface; showing average and minimum/maximum values. Total trail distance should also be noted, in addition to change in elevation, obstacles such as roots, ruts, rocks, water crossings, and vertical obstructions.

Data on recreation trails should be posted at trail heads, informational areas, and appear in brochures and maps when possible. A route map and grade profile should also be provided when possible.

5.3 Interpretive Trails

General:

Design solutions for interpretive experiences should provide a system of graduated difficulty of access and a diversity of experiences for people with varying interests and abilities.

Signage:

A comprehensive system of signs along interpretive trails is crucial. Essential messages at the beginning of the trail system should include:

1. A map in raised relief accompanied by raised or routed letters describing all trails and their respective lengths
2. A difficulty-of-access classification (or comparable description) for each trail
3. A general description of each trail, including its emphasis, character, and main features
4. A description of locations where users can expect to find additional signs along each trail
5. The meaning of special signals such as textural changes on trails, etc.

Essential messages along the trails should include:

1. Locations of special areas for rest, comfort, special features, danger, etc.
2. Descriptions of events and places, special features, things to view, touch,

Table 240-8. TRAIL PLANNING CLASSIFICATIONS

Class of trail	I	II	III	IV	V
Approximate length of trail	0-.4 km (0-1/4 mi)	.4-1.6 km (1/4-1 mi)	1.6-4.8 km (1-3 mi)	4.8-16.1 km (3-10 mi)	Over 16.1 km (10 mi)
Rest stop spacing and types (use natural materials whenever possible for benches, shelters, etc.)	30 000-45 000 mm (100-150 ft) benches,* shelter, interpretation	60 000-90 000 mm (200-300 ft) benches, shelter, interpretation	150 000-180 000 mm (500-600 ft) natural benches occasionally, interpretation	Rest area or interpretation every 1.6 km (1 mi)	None unless unique interpretation
Width of trail	1-way: 1 200 mm (4 ft) 2-way: 1 800 mm (6 ft)	1-way: 900-1 200 mm (3-4 ft) 2-way: 1 200-1 500 mm (4-5 ft)	900-1 200 mm (3-4 ft)	600-900 mm (2-3 ft)	Undefined
Shoulder of trail	450 mm (1 1/2 ft) grass; slight slope toward trail	Clear understory brush to 300 mm (1 ft) from trail; gradual slope either direction	Clear understory brush to 300 mm (1 ft) from trail; no abrupt drop-offs adjacent	Clear understory brush to 150 mm (1/2 ft) from trail	Undefined
Slope of trail	1:50	1:20 with 1 500 mm (5 ft) level space at 30 000 mm (100 ft) intervals	1:12 with 1 500 mm (5 ft) level space at 9 000 mm (30 ft) intervals	1:8 with occasional level space when possible	Steps or natural
Cross slope	None	1:50 for maximum of 9 000 mm (30 ft) and varied from one side of trail to other	1:25 for maximum of 15 000 mm (50 ft), vary from side to side	1:20	Undefined
Surface of trail	Concrete, asphalt	Asphalt, perpendicular wood planking, very fine crushed rock solidly packed	Firm surface, well-compacted	Bound woodchips, class 5 gravel mixture coarse	Sandy, rough unbound wood chips, rocks
Trail edge (rails, curbs, etc.; use natural materials whenever possible)	Curbs used where necessary for safety; 900 mm (3 ft) high rails for safety or for resting along lineal slope where necessary	Gradual ramping; rails for resting along lineal slope and to provide safety on cross slope or hazard area	Compacted earth, level with trail edge; definite texture change; rails for holding slope at steepest grade and for safety	Texture change with immediate drop to natural terrain from trail edge; rails used to guard hazard	Nothing

* Benches refers either to the commercial type or a big log or boulders suitable for sitting.
Source: From the Minnesota Department of Natural Resources.

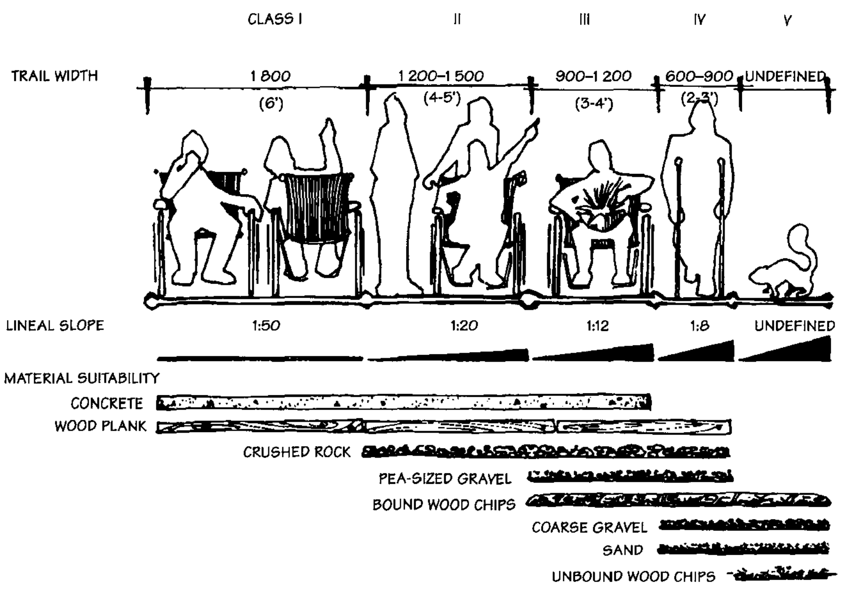


Figure 240-29. Trail classification system. *This recreation trail classification system was developed by the Minnesota Department of Natural Resources as part of a comprehensive scheme to accommodate all types of people in a statewide recreation model. The five trail classifications represent "graduated difficulty" in terms of accessibility.*

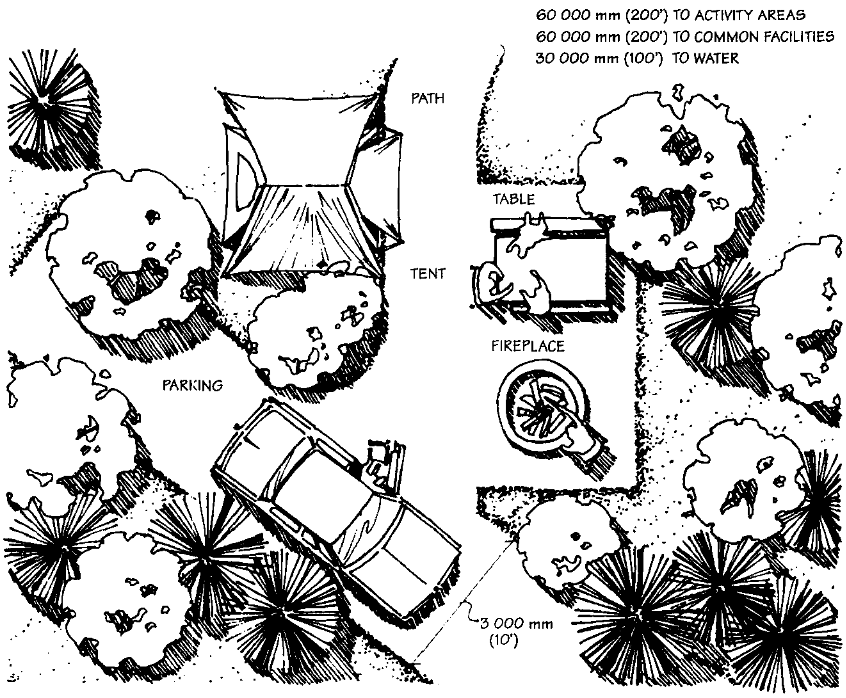


Figure 240-30. Typical accessible campsite (plan view). *Campsites should be organized to provide varying degrees of challenge and remoteness.*

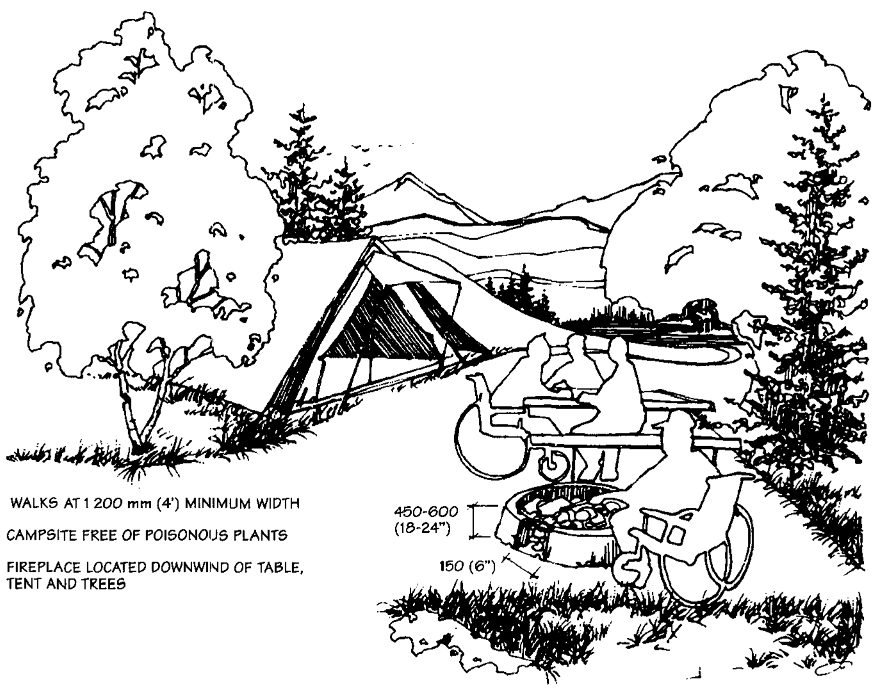


Figure 240-31 Typical accessible campsite.

smell, or hear, etc.

Signage should accommodate both those with visual impairments and the sighted population. Raised or recessed letters are preferable to Braille. Prerecorded messages can be either locally activated or contained in continuously worn headsets activated within a specified range.

Orienting devices such as high rope lines, textural cues, and barriers are beneficial and can ensure a reasonable level of safety. Knotted ropes or other periodic cues can both call out features and also serve as distance meters.

5.4 Outdoor Camping and Picnicking

Camping:

A diversity of recreational opportunities at or near the camping site itself, such as swimming, fishing, and remote hiking should be provided. A degree of remoteness is typically characteristic of the camping experience and can be maintained by allotting suitable acreages for each facility. Potable water and comfort facilities should be provided within a reasonable distance of each facility. Medical accommodation of some kind should also be readily available.

When camping areas are located in highly developed (urban/rural) and moderately developed (natural) settings, the basic guidelines outlined by ADAAG can be applied for such elements as picnic tables, water sources, fire rings and grills, trash receptacles, and restrooms. Reach ranges, surfaces, and safety should be relevant to the design.

Campsites should not be located near potentially hazardous areas. Hazardous obstructions and items—such as deadfalls, low-hanging branches, holes in the ground, poisonous plants, or thorns—should not exist near campsites. High-use areas—such as shelters, comfort stations, swimming pools, beaches, campsites, and food areas—should be located on relatively level ground that is easy to negotiate (Figures 240-30 and 240-31).

When accessible camping units can be provided, the units should be located in varying locations to give users a variety of choices and also to take advantage of the natural features of the site.

The unique experience of camping may suggest using a different type of signage system than that used for interpretive trail systems.

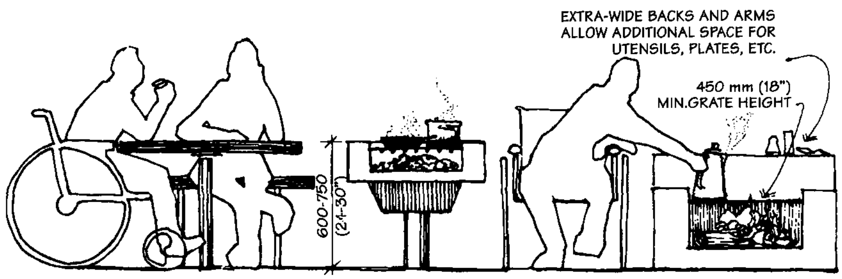


Figure 240-32. Typical accessible fireplace and grill. *Ground surfaces around campsites and fireplaces should be stabilized and free-draining.*

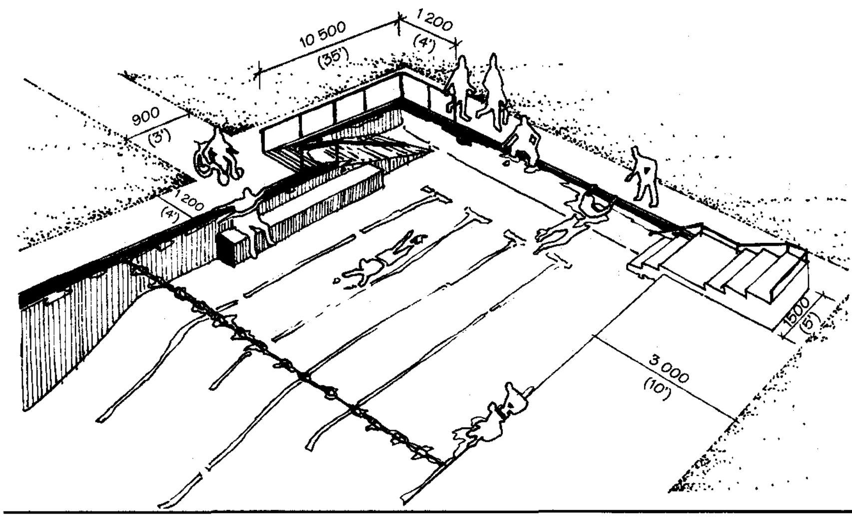


Figure 240-34. General considerations for pool swimming. *Note that a variety of means for entering the pool should be provided.*

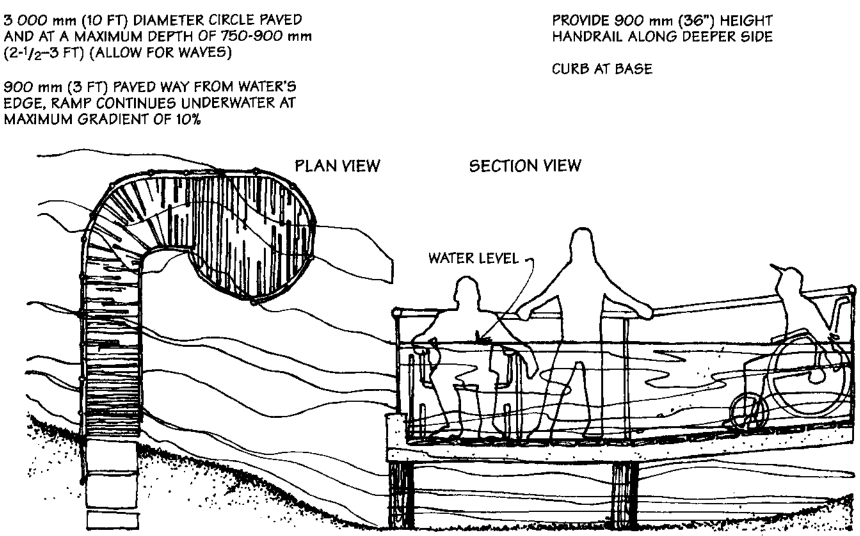


Figure 240-35. Underwater ramp for beach swimming. *The length of a ramped walk should be adjusted to the slope of the particular lake profile (10 percent maximum gradient), and should consider the size of anticipated waves.*

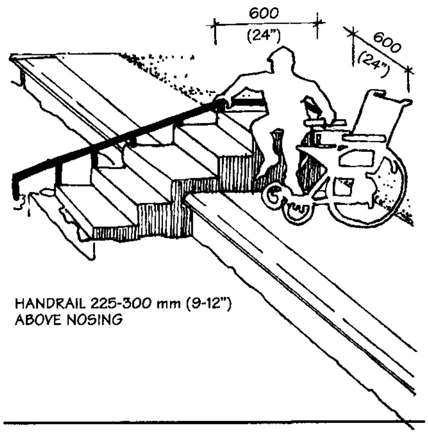


Figure 240-33. Tiered transfer platform for pools. *Tiered transfer platforms allow easy entry into the pool from wheelchairs.*

Picnicking:

Ground surfaces at picnic sites should be relatively level, free of obstructions, and appropriate in both their surfacing and size for wheelchairs.

A clear space of at least 675 mm (27 in) high, 750 mm (30 in) wide, and 475 mm (19 in) deep is necessary to accommodate most wheelchairs. The tops of accessible tables and counters should be from 700-850 mm (28-34 in) above the ground. See ADAAG 4.32 Fixed or Built-in Seating and Tables for specifics.

Cooking Facilities:

The two activities of fire building and cooking should be accommodated in all designs (Figure 240-32). A clear, level ground space around fire rings and pedestal grills should be at least 900 mm (36 in) on all sides, with 1 200 mm (48 in) being recommended. The height requirements for fire rings depend on the level of development of the site. For example, in highly developed sites, the fire-building surface should be equal or greater than 225 mm (9 in) above the ground. Fire rings with fixed grills should be constructed at 425-475 mm (17-19 in) above the ground. Fire rings with adjustable grills should have a cooking surface at 475-600 mm (19-24 in) above the ground. A pedestal grill should have a cooking surface 750-900 mm (30-36 in) above the ground, and the grill must be able to rotate 360 degrees to allow users to adjust based on wind direction. Pedestal grills must also have at least 675 mm (27 in) knee clearance.

Water faucets and drinking fountains should have a spout height at no higher than

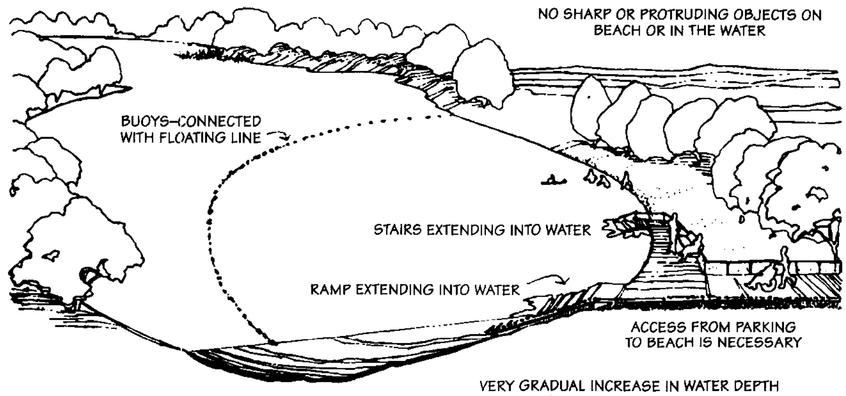


Figure 240-36. General considerations for beach swimming.

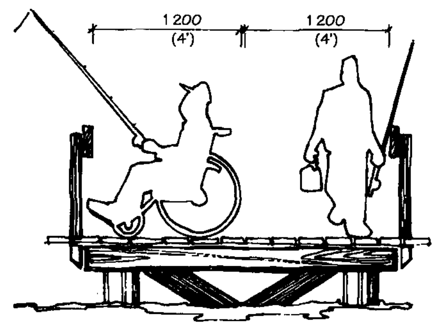


Figure 240-37. Accessible fishing docks and piers. *The width of a fishing dock or pier should allow the free movement of pedestrians when wheelchairs are perpendicular to the side railing.*

900 mm (36 in) from ground to spout outlet, and be easily operable. Placement of fixtures on a hard, relatively level ground surface is recommended. Adequate drainage is important. (Refer to ADAAG sections 4.15 Drinking Fountains and Water Coolers and 4.27 Controls and Operating Mechanisms for more information on economic considerations of facility design.)

5.5 Swimming Facilities

Swimming Pools:

The advantages of pools over beaches include the control they afford over water depth, water temperature, and sanitation. The disadvantages of pools include their hard and slippery edges and surfaces, high noise levels, and size limitations. Alternative, accessible means of access for swimming pools fall into three general categories: ramps, transfer tiers, and lifts.

Additional Recommendations:

1. A pool coping at sitting height, with grab bars, will allow easier access to the water for many individuals. The water level should not be too far below the coping.

2. A ramp descending into the water, with handrails on both sides at a height of 850-950 mm (34-38 in) should be provided at the shallow end of the pool. The ramp should have a curb edging and a nonslip surface.

3. A staircase descending into the water, also with handrails, should be provided at the shallow end of the pool. Tiered transfer platforms are recommended (Figure 240-33).

4. Underwater seating is necessary for resting and for those with limited mobility. The seating should be easily identifiable and should be isolated from swimmers jumping into the water from above.

5. Mechanical lifts and swings are commercially available for raising and lowering individuals into the water.

6. Moveable floors allow a person to transfer from a deck, which is then lowered to the pool.

7. A deep pool should not be specified unless diving is an objective. Floats and markings should warn swimmers of increasing water depth.

8. No sharp or protruding objects should exist anywhere, and all corners should be rounded. All paving near the pool should have a nonslip surface. Figure 240-34 shows an indoor pool designed according to the above-mentioned recommendations.

Beaches:

The advantages of beaches over swimming pools include their gradual water depth, their lack of slippery surfaces or hard edges, and the psychological benefit of an outdoor, natural environment. Waves, sunlight, breezes, wildlife, fragrance, spaciousness, and the general ambiance of the out-of-doors are beneficial qualities. Ideally, access to both a swimming pool and a nearby beach could accommodate the needs of all individuals and allow for diversity and flexibility in programming.

Additional Recommendations:

1. Accessibility to the beach from parking lots, shelters, camping grounds, picnic areas, and other points of origin should be provided. A network of accessible routes should be provided for a wide range of recreational opportunities with minimal assistance.

2. Beach gradients into the water should be 10 percent maximally. Drop-offs, abrupt bottom changes, bottom irregularities, obstructions, and sharp objects should not exist in the water or on the beach. Ramps, stairways, and boardwalks at the water's edge and leading into the water are important for many individuals (Figure 240-35). Connected floating buoys should be used to delineate the extent of the swimming area and to discourage entry to deeper water (Figure 240-36).

3. It is recommended that the accessible route extend to a point that is 900 mm (36 in) beyond the water's edge at high tide.

5.6 Fishing and Boating

Fishing:

A variety of accessible fishing locations, which offer different types and levels of experience, integrated with all users, should be provided (Figure 240-37 and 240-38).

Accessible networks leading to fishing piers, docks, and boarding areas are necessary. Floating piers have the advantage of closeness to the water level but are often unstable, especially for those who use wheelchairs.

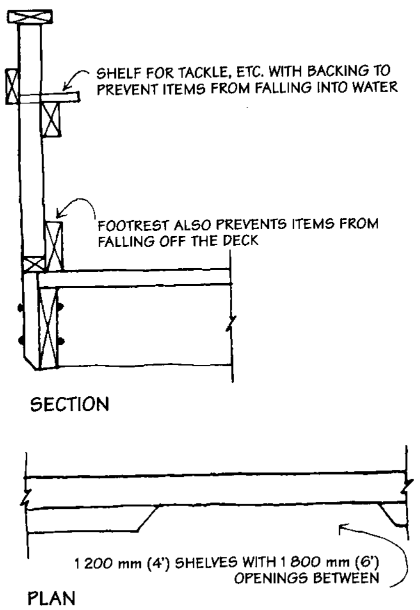


Figure 240-38. Handrailing detail for a fishing dock or pier. *Handrailings should have a number of important features.*

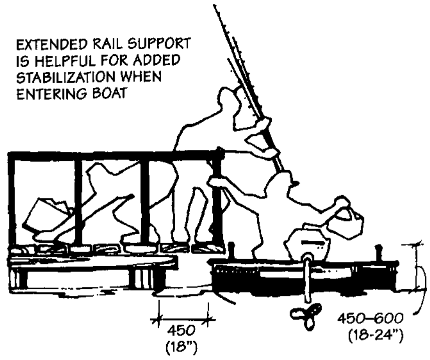


Figure 240-39. Boat access. *Devices which provide support both on the dock and in the craft itself are of crucial importance. Dock heights should be within 450-600 mm (18–24") of the water to facilitate easier transference of people and gear from the boat to the dock.*

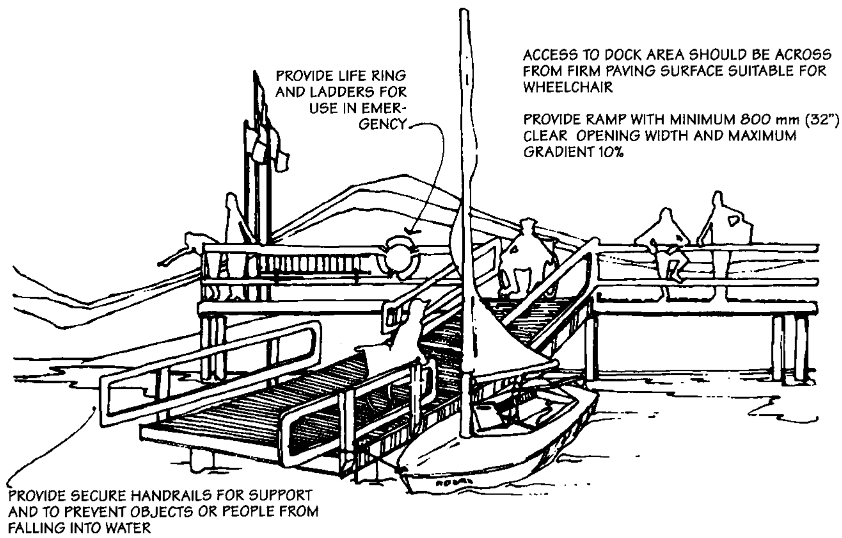


Figure 240-40 General considerations for boat launching areas. *Boat launching areas for handicapped individuals require a variety of considerations and devices.*

Basic considerations of Fishing Stations include the following:

1. **Location-** Fishing stations on an outdoor accessible recreation route should be located within 1/5 km (1/8 mi) from accessible parking and facilities, in a highly developed (urban/rural) area, and within 2/5 km (1/4 mi) in moderately developed (natural) areas. Capacity of fishing on a typical day's demand must be considered.

2. **Design-** Surfaces of accessible fishing stations must be firm, stable, and not exceed a 3% cross slope in any direction. A tactile distinction of the ground surface from the outdoor recreation access route is recommended. Anglers need a minimum of 1 500 mm (5 ft) per angler, or 3 600 mm (12 ft) for two anglers, along the waters edge. 2 400 mm (8 ft) of space behind the anglers are needed for unrestricted pedestrian circulation.

3. **Safety Rails-** In highly developed sites, safety rails are needed at a height of at least 800 mm (32 in) On moderately developed sites (more natural), safety railings may be constructed out of natural materials such as rocks, logs, etc. Other amenities should be provided, such as armrests, tackle box shelves, etc., using materials appropriate to the level of development at the site.

4. **Curbs and Drop-offs-** In highly developed areas, edge protection of 100 mm (4 in) high curbs should be provided.

5. **Seating-**should be provided to accommodate non-fishing companions.

6. **Shade and shelter-** should be provided, if not naturally occurring at site. However, vertical clearance should not be reduced to less than 3 600 mm (144 in) above the fishing station.

Boating:

Boarding a boat or small yacht is difficult, especially if the craft is small and buoyant. Railings are absolutely necessary and should extend beyond the edge or end of the dock, providing support to individuals even while aboard craft (Figure 240-39). Devices to stabilize the craft while individuals are boarding are very helpful. Supportive devices (grab bars, etc.) on the craft are essential. However, railings or grab bars should not indiscriminately be added to a previously unequipped small craft, as the balance in its design may be adversely affected.

Heavy, wide-bottomed boats with a low center of gravity offer the greatest stability and safety. Pontoons and platform boats are ideal. Narrow, buoyant boats such as canoes are easy to capsize and especially difficult to board. Boarding on the beach and then shoving off is advisable.

Dock heights within 450-600 mm (18-24 in) of the water level allow easier access to boats than do greater heights. Tide fluctuation may have to be accommodated by means of ramps, stable floating platforms, and the like (Figure 240-40).

The slopes of gangways should not exceed 1:12 (8.33%).

5.7 Spectator Areas

Spectator areas should be accessible by hard-surfaced ramps and safe stairways (Figure 240-41). (Refer to ADAAG sections 4.8 Ramps and 4.9 Stairs for more information.)

Additional Recommendations:

1. Provide a choice in seating areas to whatever extent possible, including areas for extended legs and wheelchairs. Comparable lines of sight, and choices of admission prices based on seating should be provided. Each wheelchair seating area must also contain fixed companion seating. Locate these areas near access ramps to minimize the need for negotiating through a crowd. Refer to the table below for number of required wheelchair positions based on capacity of seating.

2. Protect special seating areas from excessive sun, wind, and rain to whatever extent possible.

3. Refer to ADAAG section 4.33 Assembly Areas for more information on dimensional criteria, surfaces, access, etc.

5.8 Parks and Playgrounds

Parks and playgrounds should be accessible from adjacent communities and include a continuous accessible route throughout all play areas, connecting accessible activities within the play setting. The accessible route should promote social interaction and use of the play components between children. A designer should consider all the ways interaction can occur across ability levels by designing systems of graduated difficulty of access to challenge growing children of all abilities. Challenging equipment should be placed in the vicinity of less challenging equipment to facilitate interaction among different ability levels, safety permitting.

Playground surfaces must conform to unique safety standards. Within 2 400 mm (8 ft) of play equipment which is more than 500 mm (20 in) off the ground, an accessible path must also be shock-absorbing.

Both structured play facilities and opportunities for creative, imaginative, non structured play are important features of a play environment (Figure 240-42 and 240-43).

Preferences for these two types of play vary among individuals, some responding more positively to one type of play than to another. Diverse opportunities for children to interact with their environment should be provided to accommodate all levels of ability and need.

An accessible path is required to approach play equipment, at which point a low platform can serve as a transfer point onto the equipment. The platform should be 275-350 mm (11-14 in) off the ground for children under age five, and 300-425 mm (12-17 in) off the ground for children between five and twelve years old. An adjacent clear ground space of at least 1 500 mm (5 ft) in diameter is needed, in

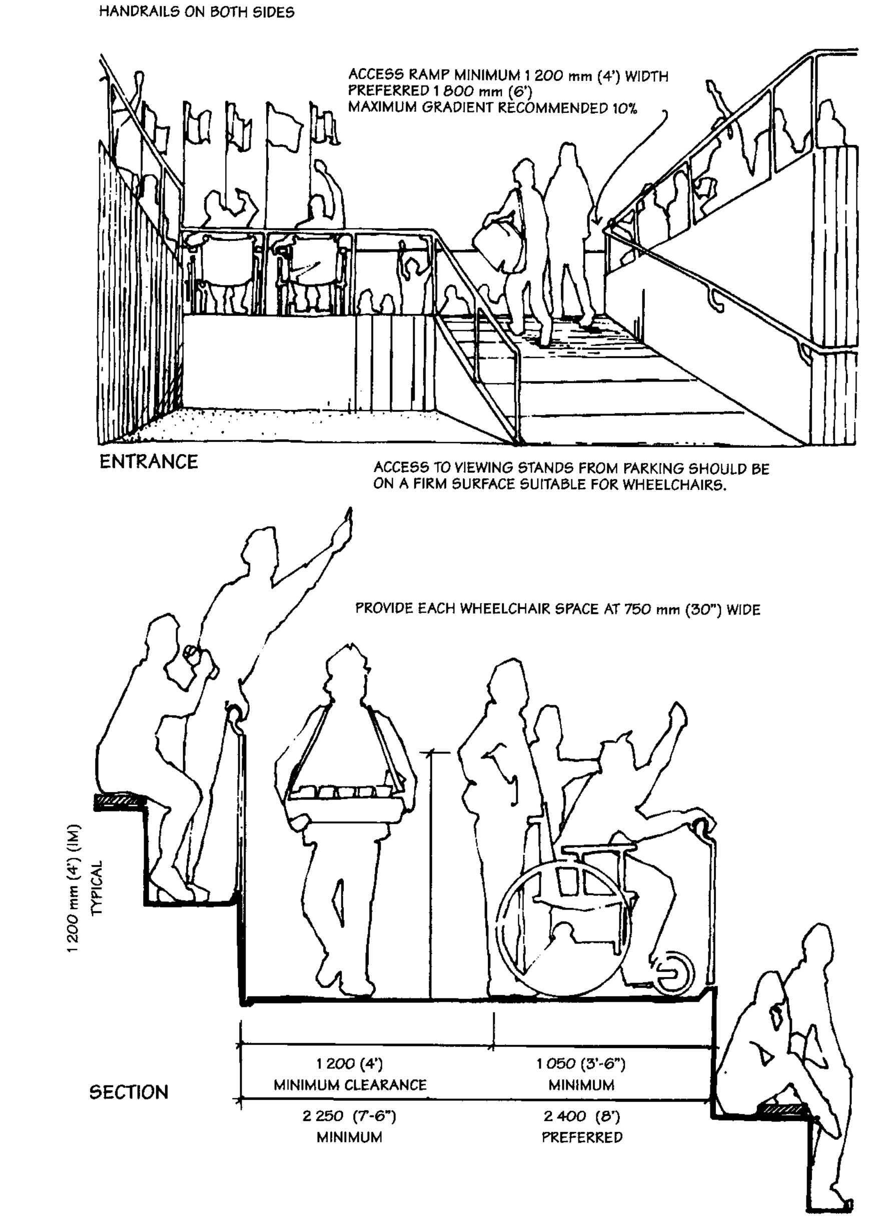


Figure 240-41. General considerations for accessible spectator stands. *Space for wheelchair users should be located near entrance ramps to minimize maneuvering through crowds. Access aisles should be maintained behind wheelchair users.*

Table 240-9. CAPACITY OF SEATING IN ASSEMBLY AREAS

Number of Required Wheelchair Positions	
4 to 25	1
26 to 50	2
51 to 300	4
301 to 500	6
over 500	6*

*plus 1 additional space for each total seating capacity increase of 100.

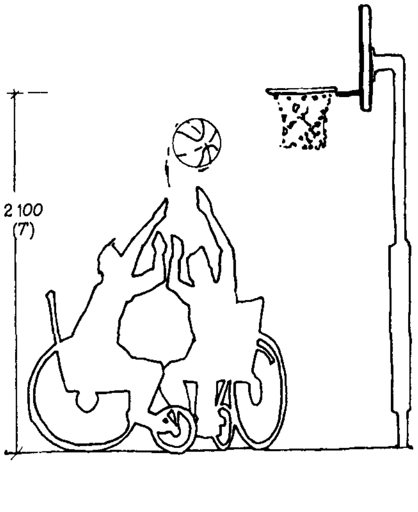


Figure 240-42. Accessible basketball. *Basketball hoops lowered to 2 100 mm (7 ft) from the standard 3 000 mm (10 ft) height allow wheelchair users and young children greater enjoyment of the game.*

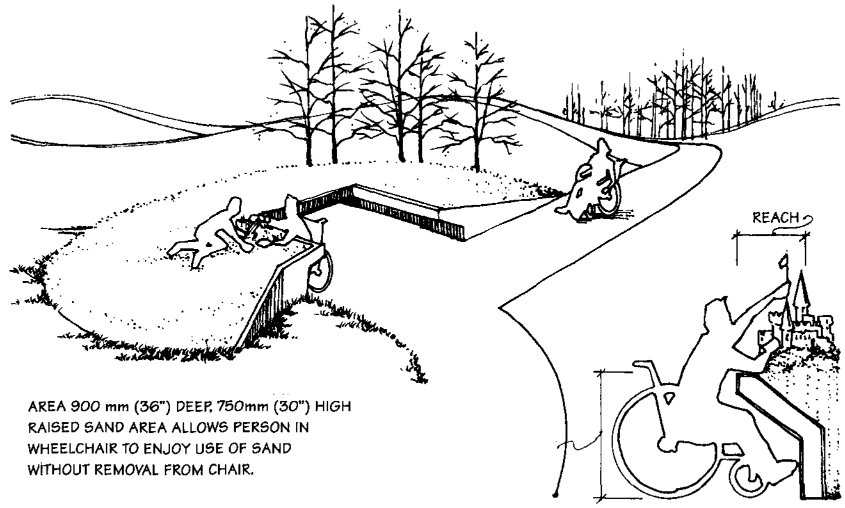


Figure 240-43. Accessible sand area. *Elevated areas containing sand or water allow access by wheelchair users.*

addition to space at least 750 by 1 200 mm (30 by 48 in) outside the fall zone for "parking" wheelchairs. The platform itself should have a surface of at least 600 mm (2 ft) wide and 350 mm (14 in) deep, with handholds recommended. A path is also required from the platform to the rest of the play equipment.

The physical organization of a park or playground should be readily comprehensible by those with visual impairments who rely on cognitive mapping for orientation.

Adult supervision of play areas is usually necessary. Its extent varies according to user abilities, user numbers, and the type of facility.

Recommendations for parks and playgrounds may also be found in the *Recommendations for Accessibility Guidelines: Recreational Facilities and Outdoor Developed Areas* publication, listed at the beginning of this section. In addition, books are available on the topic and the Office of the Americans with Disabilities Act is currently proposing a set of recommendations be published.

5.9 Jogging Paths

Dimensions of jogging paths and trails will vary according to use patterns and should

KEY POINTS: Accessible Recreation

There are several important factors which require consideration in the design and physical organization of accessible recreation facilities. These factors assure the safety, ease of mobility, ease of orientation and communication for a broadly defined user group.

1. Provide hard surfaces with adequate ramps for accessible networks which adjoin and circulate throughout facilities. Hard surfaces near play equipment must also meet shock-absorbing requirements.
2. Provide signage with visual and textural cues for information and descriptions (Figure 240-28).
3. Provide level ground surfaces for camping, picnicking, and fishing stations (Figure 240-30 - 240-32, Figure 240-37 and 240-38).
4. Provide accessible routes for swimming pools and beaches (Figure 240-33 - 240-36).
5. Provide varied lines of site for accessible seating in outdoor assembly areas (Figure 240-41).
6. Integrate accessible routes and equipment into parks and playgrounds.
7. Avoid hazardous elements such as steep slopes, dangerous or noxious plants, heavy vehicular traffic, and unexpected level changes, or provide significant barriers for safety.
8. Design trails for physical disabilites ranging from full wheelchair access to limited walking access, creating a variety of wilderness or recreation experiences and challenges (Table 240-6 and 240-7).
9. Provide amenities in central locations, preferably within maximum distances allowed for by regulations.

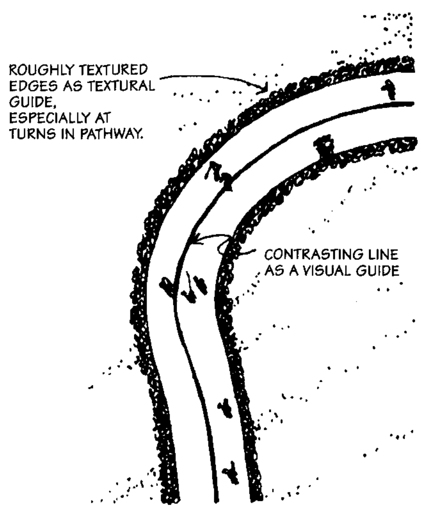


Figure 240-44. Jogging path for use by individuals with visual impairments. *Textural and visual cues along jogging paths, especially at turns in the pathway, can aid those with visual limitations.*

be made safe for all types of users. Where bicyclists, walkers, roller skaters and skateboarders will also use a pathway, an adequate means of separation or cooperation between user groups is advisable.

A variety of access points on long jogging or bike trails with accompanying accessible parking allows more users to get on and off the trail at different areas.

Signage is important and should accommodate those who are sighted, those with limited vision, and also those who are blind. Textural and visual cues on ground surfaces are helpful. Textured path edges, especially at turning points, also aid negotiation. A brightly colored or contrasting center stripe helps those with limited vision stay on course and can also serve to separate various functions (Figure 240-44).

AGENCIES AND ORGANIZATIONS

U.S. Federal Government

Architectural and Transportation Barriers Compliance Board

U.S. Department of Health, Education and Welfare, Washington, DC

U.S. Heritage Conservation and Recreation Service, Department of the Interior
Washington, DC

United States Library of Congress
Reference Section, Division for the Blind and Physically Handicapped
Washington, DC

U.S. National Park Service
Office of Special Programs and Populations, Department of the Interior
Washington, DC

Private

American Camping Association
Martinsville, Indiana

American Coalition of Citizens with Disabilities
Washington, DC

American Foundation for the Blind
New York, New York

American National Standards Institute (ANSI)
New York, New York
Access Recreation
3308 Valley Drive
Alexandria, Virginia

National Center for a Barrier-Free Environment
Washington, DC

Pedestrian Research Laboratory
Georgia Institute of Technology
College of Architecture
Atlanta, Georgia

Vinland National Center
Lorretto, Minnesota

International

Canadian Rehabilitation Council for the Disabled
Toronto, Ontario, Canada

ICTA Information Center
Swedish Central Committee for Rehabilitation (SUCR)
Fack, S-161-03
Bromma 3
Sweden

Rehabilitation International, USA
New York, New York.

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Americans with Disabilities Accessibility Guidelines for Buildings and Facilities, Transportation Facilities, *Transportation Vehicles, September 1994. US Architectural and Transportation Barriers Compliance Board (Access Board), 1331 F Street, N.W., Suite 1000, Washington, DC. 20004-1111.*

Recommendations for Accessibility Guidelines: Recreational Facilities and Outdoor Developed Areas, *developed for: US. Architectural and Transportation Barriers Compliance Board, July 1994, by the Recreation Access Advisory Committee. Access Board, Recreation Report, 1331 F Street, N.W., Suite 1000, Washington, DC. 20004-1111.*

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SECTION 252

Natural Hazards: Earthquakes

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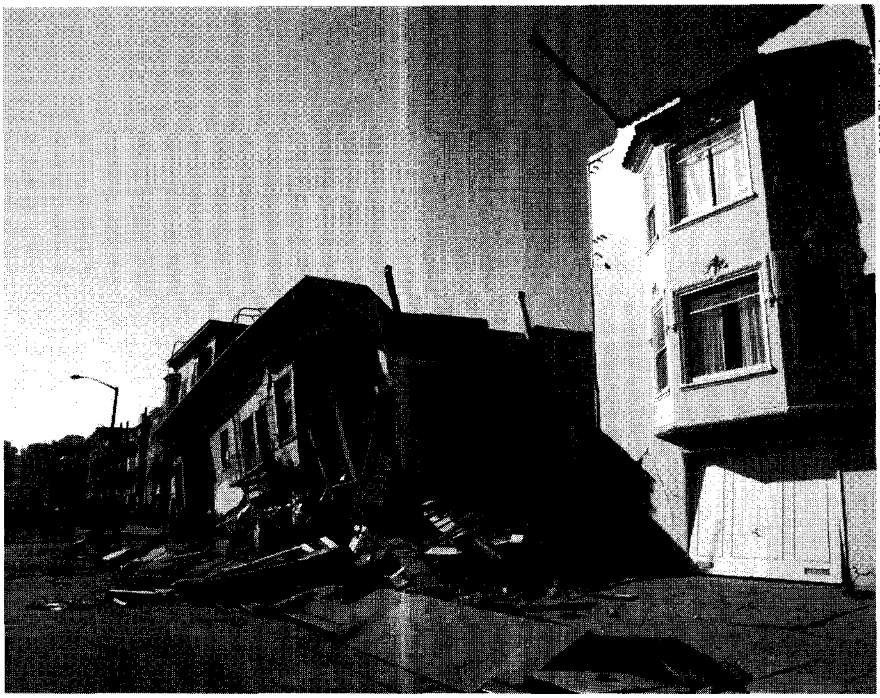

CONTENTS

1.0 INTRODUCTION

Earthquakes are essentially vibrations of the earth's crust caused by subterranean ground faults or movements. They can cause injury or death to people and animals, damage or destruction to structures and landscapes. They create primary hazards such as surface rupturing, displacement of land, ground shaking, earthquake-induced ground failures, and oscillation of water surfaces. Secondary hazards are landslides, fires, floods, subsidence, and tsunamis (large sea waves) [Refer to Sections 253 through 255 for information on other types of natural hazards].

The data presented in this section is not a general discussion of earthquakes. It seeks to focus on how the potential risks associated with earthquakes should influence (a) land use planning and (b) design and engineering of landscapes, structures and infrastructure systems. Some of the references listed at the end of this section contain additional general and technical information. In all cases, it is assumed that professional expertise will be needed to determine the detailed design and engineering requirements for all large man-made structures and major earthworks.

2.0 CAUSES OF EARTHQUAKES

2.1 Plate Tectonics

The earth's crust and upper mantle are composed of a mosaic of 80- to 100-km- (50- to 60-mile) thick rigid plates which move slowly and continuously over the interior of the earth resulting in pressure, separation or sliding at plate edges. As these plates move, strain accumulates, eventually causing faults along boundaries when the plates slip abruptly. The resultant release of stress, which usually occurs within a few cubic kilometers of the earth's crust, is called an earthquake. Figure 252-1 shows the major tectonic plates of the world. Figure 252-2 shows the world-wide distribution of earthquakes occurring in the mid- to late-20th century, up to 1987.

2.2 Other Causes

Other causes of earthquakes include volcanic activity, injection of liquid wastes into susceptible rock strata, and the weight of new large dams and their associated reservoirs.

Table 252-1. MODIFIED MERCALLI INTENSITY SCALE

I.	Not felt except for a very few under exceptionally favorable circumstances.
II.	Felt by persons at rest, on upper floors, or favorably placed.
III.	Felt indoors; hanging objects swing; vibration similar to passing of light trucks; duration may be estimated; may not be recognized as an earthquake.
IV.	Hanging objects swing; vibration similar to passing of heavy trucks, or sensation of a jolt similar to a heavy ball striking the walls; standing motor cars rock; windows, dishes, and doors rattle; glasses clink and crockery clashes; in the upper range of IV wooden walls and frames creak.
V.	Felt outdoors; direction may be estimated; sleepers wakened, liquids disturbed, some spilled; small unstable objects displaced or upset; doors swing, close, or open; shutters and pictures move; pendulum clocks stop, start, or change rate.
VI.	Felt by all; many frightened and run outdoors; walking unsteady; windows, dishes and glassware broken; knickknacks, books, etc., fall from shelves and pictures from walls; furniture moved or overturned; weak plaster and masonry D* cracked; small bells ring (church or school); trees and shrubs shaken (visibly, or heard to rustle).
VII.	Difficult to stand; noticed by drivers of motor cars; hanging objects quiver; furniture breaks; damage to masonry D, including cracks; weak chimneys break at roof line; fall of plaster, loose bricks, stones, tiles, cornices (also unbraced parapets and architectural ornaments); some cracks in masonry C*; waves on ponds; water turbid with mud; small slides and caving in along sand or gravel banks; large bells ring; concrete irrigation ditches damaged.
VIII.	Steering of motor cars affected; damage to masonry C or partial collapse; some damage to masonry B*; none to masonry A*; fall of stucco and some masonry walls; twisting and fall of chimneys, factory stacks, monuments, towers and elevated tanks; frame houses moved on foundations if not bolted down; loose panel walls thrown out; decayed piling broken off; branches broken from trees; changes in flow or temperature of springs and wells; cracks in wet ground and on steep slopes.
IX.	General panic; masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged; general damage to foundations; frame structures, if not bolted, shifted off foundations; frames racked; serious damage to reservoirs; underground pipes broken; conspicuous cracks in ground; in alluviated areas sand and mud ejected, earthquake fountains and sand craters appear.
X.	Most masonry and frame structures destroyed with their foundations; some well-built wooden structures and bridges destroyed; serious damage to dams, dikes, and embankments; large landslides; water thrown on banks of canals, rivers, lakes, etc.; sand and mud shifted horizontally on beaches and flat land; rails bend slightly.
XI.	Rails bent greatly; underground pipelines completely out of service.
XII.	Damage nearly total; large rock masses displaced; lines of sight and level distorted; objects thrown into the air.

***Masonry A, B, C, and D as used in MM Scale above:**
Masonry A: Good workmanship, mortar, and design; reinforced, especially laterally, and bound together by using steel, concrete, etc.; designed to resist lateral forces.
Masonry B: Good workmanship and mortar; reinforced, but not designed in detail to resist lateral forces.
Masonry C: Ordinaryworkmanshipandmortar;noextremeweaknesseslikefailingtotieinatcorners, but neither reinforced nor designed against horizontal forces.
Masonry D: Weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally

3.0 MEASUREMENT

Intensity and magnitude are two types of measurement that are used to determine the severity of earthquakes.

Intensity describes the degree of shaking at a specified place. The most widely used intensity scale is the modified Mercalli scale (MM) (Table 252-1). Other scales in international use are shown in Table 252-2.

Magnitude indicates the size of an earthquake, independent of the place of observation. It is calculated from amplitude measurements and is expressed in decimal numbers on a logarithmic scale. The most used magnitude scale is the Richter scale (M). Figure 252-3 shows energy release equivalents on the Richter scale and illustrates the magnitude of several well-known earthquakes.

4.0 EFFECTS OF EARTHQUAKES

Earthquakes create several separate, but often related actions and reactions. These are described briefly below. Data about each of their impacts on land uses, site and building planning, design and construction is provided in subsection 5.0.

4.1 Faults and Fault Displacements

A fault is a fracture within the earth's crust. Fault displacement is the movement of two sides of a fault caused suddenly during an earthquake, or develops slowly as a tecton-

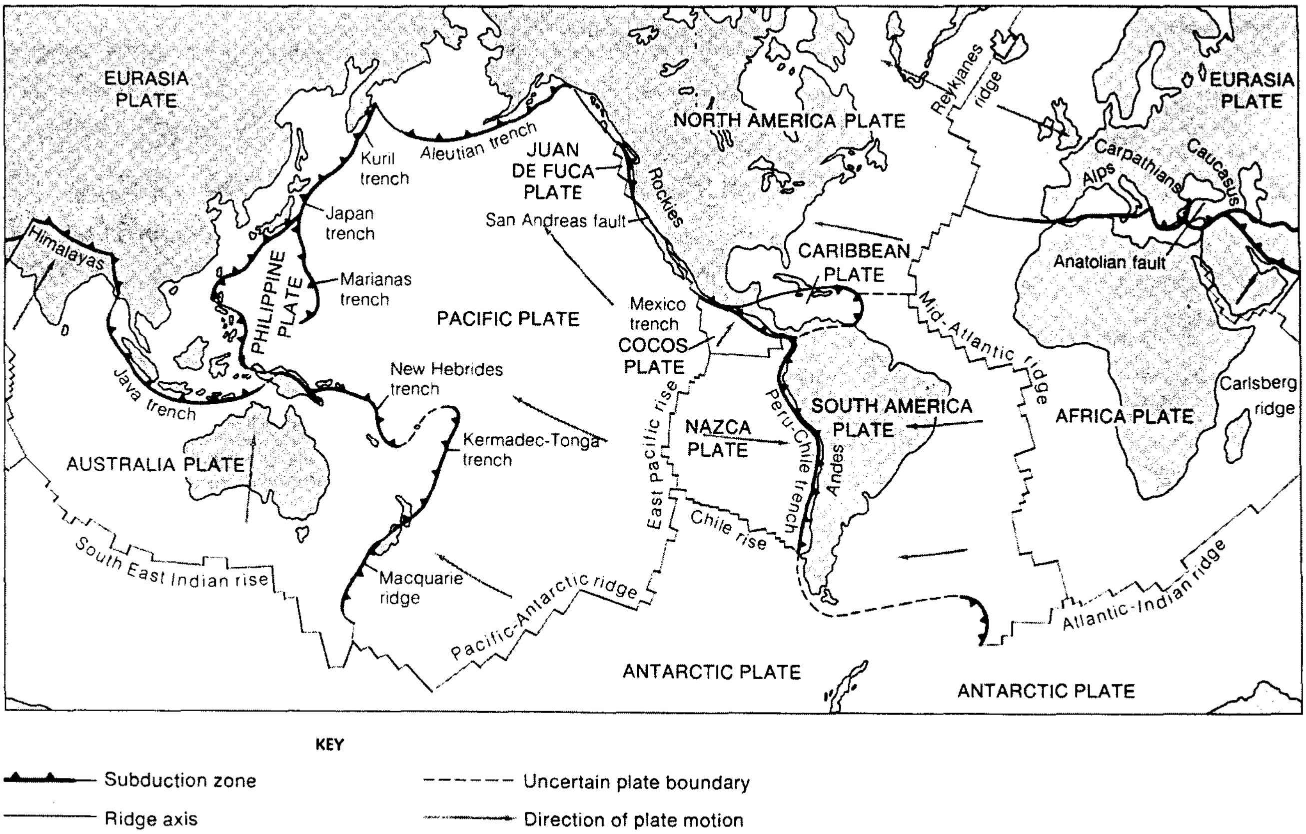

Figure 252-1. Major tectonic plates of the world, mid-ocean ridges, trenches and transform faults [After C. M. R. Fowler, 1990].

Table 252-2. CONVERSION TABLE FOR SEISMIC INTENSITY SCALES

Rossi Forel scale, 1873	Mercalli-Cancani-Sieberg European scale, 1917	Modified Mercalli scale (MM), 1931	Richter scale, 1935	Japanese scale, 1950	Scale of the USSR Academy of Sciences' Institute of Geophysics, 1952	MSK seismic scale, 1964
1	1	1	1	0	1	1
2	2	2	2	1	2	2
3	3	3	3	2	3	3
4	4	4	4	2-3	4	4
5-6	5	5	5	3	5	5
7	6	6	6	4	6	6
8	7	7	7	4-5	7	7
9	8	8	8	5	8	8
10	9	9	9	5-6	9	9
10	10	10		6	10	10
10	11	11		7	11	11
10	12	12		7	12	12

Source: Compiled by Medvedev, Sponheuer, and Karnik, *Disaster Prevention and Mitigation, vol. 5,* United Nations, 1978.

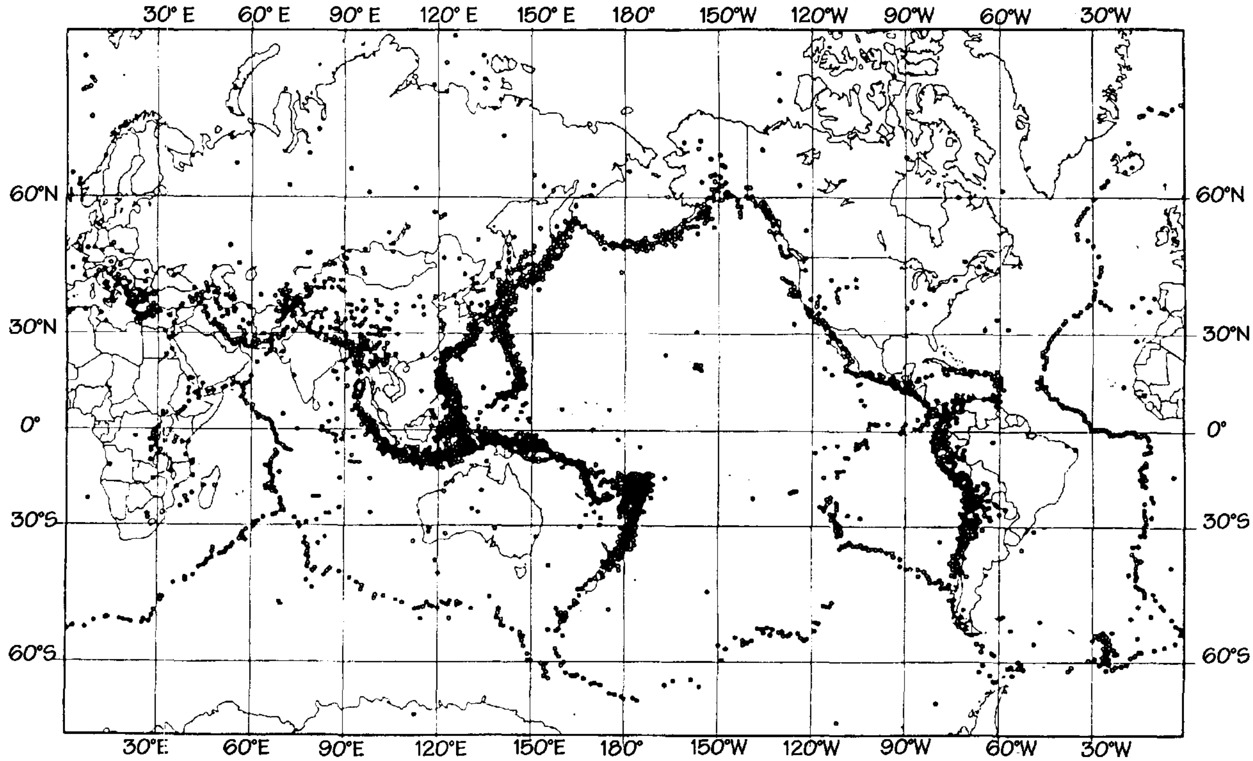

Figure 252-2. Seismicity map of the world. *The dots indicate the distribution of seismic events in the mid-to-late 20th century.*

ic creep. Displacement may be horizontal, vertical or both and vary from a few centimeters to several meters. Faults are classified based upon the geometry and direction of slippage. Figure 252-4 illustrates the types and names of their components. Typically, major faults have several parallel and interleaved minor breaks or "blind faults" in a zone of considerable width.

Most faults shown on geological maps are considered active if they have moved during the past 11,000 years. They are classified "possibly active" if they have moved during the past 3 million years, and faults that have not moved in the past 3 million years are considered inactive.

4.2 Ground Shaking and Directions of Seismic Waves

Ground shaking occurs when a fault ruptures during an earthquake sending seismic waves in all directions. This causes the ground to vibrate at frequencies ranging from about .1 to 30 Hz. Figure 252-5 is a diagrammatic illustration of surface seismic waves. Epicenter is the point on the earth's surface vertically above the subsurface point where the fault rupture originated. The frequency and amplitude of the surface vibrations or seismic waves are measured by the amount of mechanical energy released at the focus, the distance to and depth of the focus, and the structural properties of surrounding soil and bedrock.

Figure 252-6 is a map of peak horizontal ground acceleration expected within a 50-year period in the continental United States underlain by rock. There is a 10 percent probability that these values will be exceeded within a 50-year period.

During earthquakes there are often small areas of very high seismic intensities which may be caused by special conditions within or near this area. One such condition is where there are nearby rocky-hills or mountains adjacent to flatter land whose subsurface contains wedge-shaped layers of geological materials. Depending on the direction of propagation of the energy-waves, the results can be quite different. Figure 252-7 illustrates an example where the focal point of the earthquake is near the hill or mountain. As the wedge of materials deepens, it increases the amplification of the seismic energy-waves. Thus, any major structures located above this zone may be susceptible to much more damage.

The reverse can also happen. Figure 252-8 shows the direction of propagation toward hills or mountains through layers of decreasing depths. In such cases the unit of

KEY POINTS: Effects of Earthquakes

Earthquakes create several separate, but often related physical actions and reactions.

1. Faults, or fractures within the earth's crust, are the most obvious effect from seismic movement. Most faults are considered active if they have moved during the past 11,000 years.
2. Ground shaking is caused by seismic waves released during an earthquake. There are often small areas of very high seismic intensities which may be caused by special conditions, such as the presence of rocky hills or mountains.
3. Flow failures are the most catastrophic type of ground failure resulting from earthquakes. Failure by liquefaction is most dangerous in marshes, wetlands and along shorelines. Lateral spreading typically occurs in relatively flat landscapes, such as flood plains.

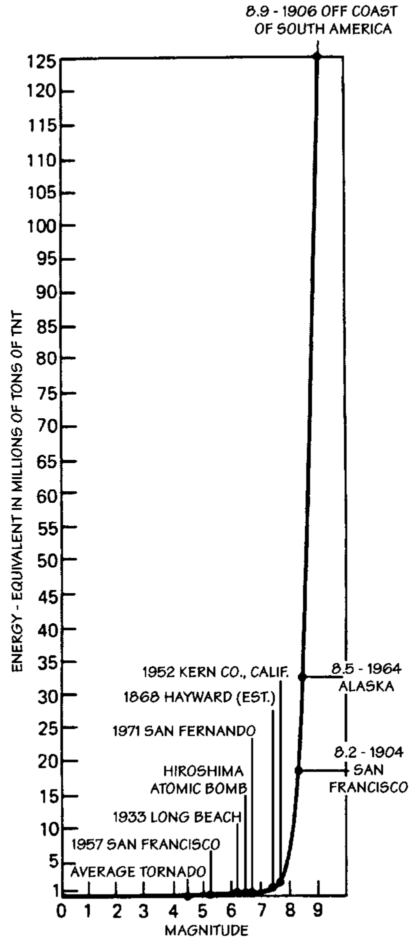

Figure 252-3. Richter magnitude scale. *This graph shows the amount of energy released by earthquakes of different magnitudes.*

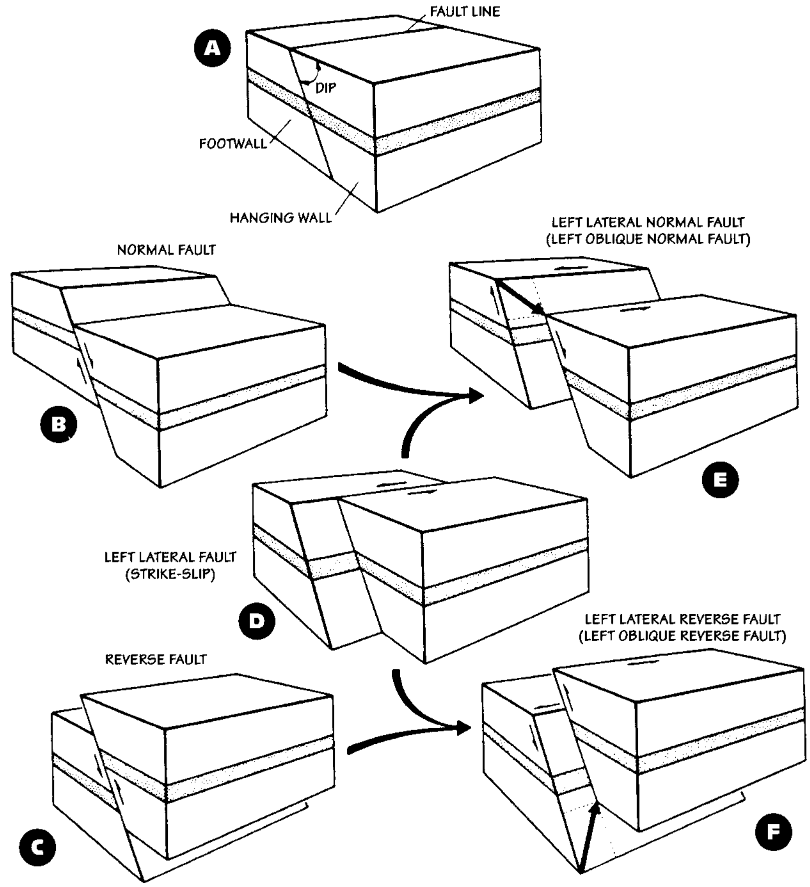

Figure 252-4 Types of faults.: *(a) names of components, (b) normal fault, (c) reverse fault, (d) left-lateral strike-slip fault, (e) left-lateral normal fault, and (f) left-lateral reverse fault.*

seismic energy increases as it nears the tip of the layer. Again, structures located above this zone can be subjected to much higher seismic energies and become more susceptible to structural and other types of damage.

4.3 Earthquake-Induced Ground Failures

There are three major types of ground failures. All have some connection with the liquefaction of underlying geological materials.

Liquefaction:

Liquefaction is a temporary condition when seismic waves pass through saturated layers of granular materials (such as sand or silt). These waves cause the voids in this material to collapse, or for a short time, causes the material to behave as a fluid and as a result lose its bearing capabilities. This material must be within about 30 m (100

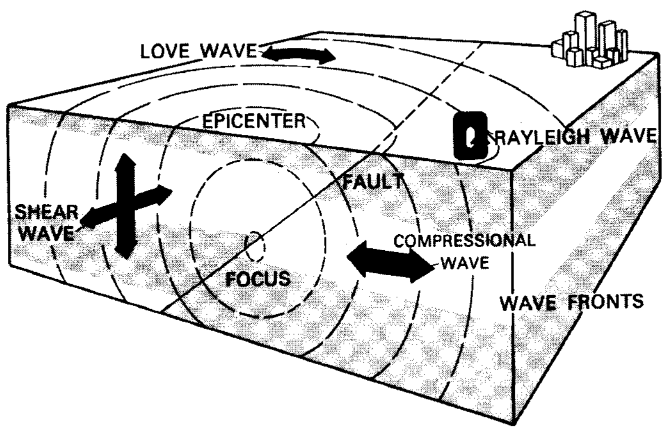

Figure 252-5. Directions of vibration *caused by body and surface seismic waves generated during an earthquake. When a fault ruptures, seismic waves are propagated in all directions, causing the ground to vibrate at frequencies ranging from about 0.1 to 30 Hz.*

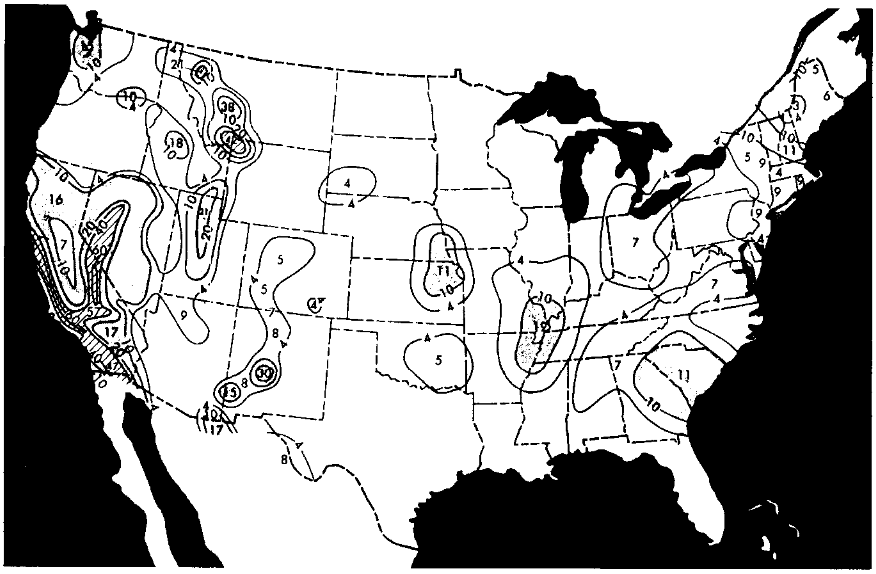

Figure 252-6. Peak horizontal ground acceleration expected at sites in the contiguous United States underlain by rock in a 50-year period (from Algermissen and Perkins, 1976). *This map represents the ground-shaking hazard in terms of the peak amplitude of horizontal acceleration, one characteristic of the strength of the seismic shaking. Locations having the same value of peak acceleration are connected with a contour line. Values shown on each contour and on the map are percentages of the acceleration of gravity. There is a 10 percent probability that these values will be exceeded in a 50-year period. This map takes into account the relative differences in rate of seismic activity in the eastern and western United States. Areas where peak acceleration exceeds 10 percent of the acceleration of gravity are shaded. The largest values shown, along the California coast, are 80 percent of gravity.*

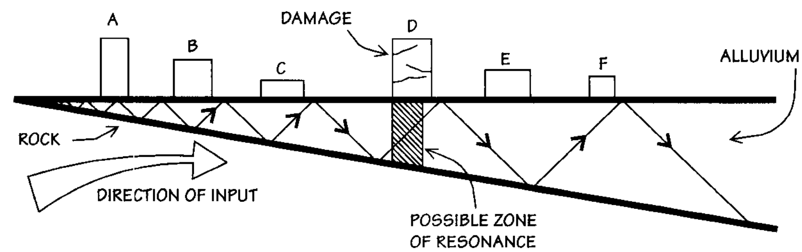

Figure 252-7. Propagation of seismic waves away from a hillside. *As the wedge of materials deepens, the amplification of the energy-waves increases, resulting in greater damage to structures located above the zone of resonance.*

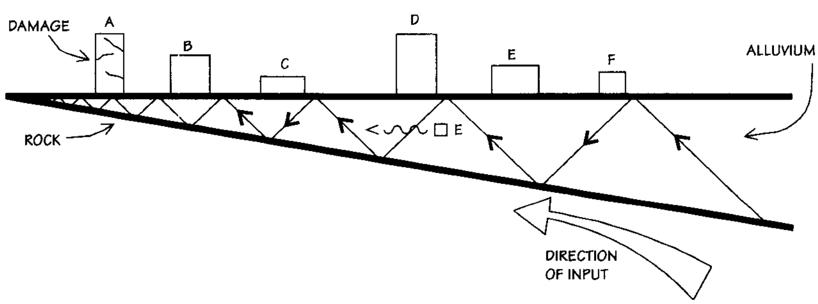

Figure 252-8. Propagation of seismic waves toward a hillside. *The seismic energy increases as it nears the surface of the alluvium. Structures located above this zone can be more susceptible to damage.*

ft) of the surface to have a dramatic effect. The greatest dangers from liquefaction will occur in marshes, wetlands or along shorelines.

Lateral spreads:

Lateral spreads occur when the earth's surface slowly moves in mass over a subsurface plane. Lateral spreads of 3 to 5 m (10 to 15 ft) can occur on relatively flat (1 to 7 percent) slopes. If the earth shakes for a long duration then the lateral spreads can become as great as 30 to 45 m (100 to 150 ft). Deposits of soil in flood plains are particularly vulnerable to lateral spreading toward river channels.

Flow failures:

Flow failures are the most catastrophic type of ground failure. They are caused by large blocks of intact material being moved on a layer of liquefied materials. These flows may be very large [e.g., 1.5 km^2 (1 mi^2) and may move many meters or even kilometers, at velocities reaching tens of kilometers per hour. Flow failures usually involve layers of saturated sands or silts on slopes greater than 6 or 7 percent. When these flow failures occur under water they can cause large sea waves (tsunamis) which can damage inhabited coastlines.

5.0 ASSESSING EARTHQUAKE RISKS AND LOSSES

This data is intended to help reduce the risks related to earthquakes in preliminary site and large area planning and design. Six steps are recommended to assess and mitigate the possible seismic risks for both local and regional use.

1. Evaluate Seismic Hazards and Risk. This involves estimating the various seismic risks for an area or site. This includes estimating the predicted location, duration, and intensity of future earthquakes. Despite numerous studies of recent earthquakes seismic scientists worldwide have little confidence in their ability to predict earthquakes.
2. Determine the Design Earthquake. The design earthquake is usually the hypothetical maximum event expected on the largest fault in the area. It may represent a single large earthquake or a series of earthquakes of different magnitudes. It is based upon the following data:
   a. Seismic history of any fault and its surrounding area to determine the rate of slip or ground deformation.

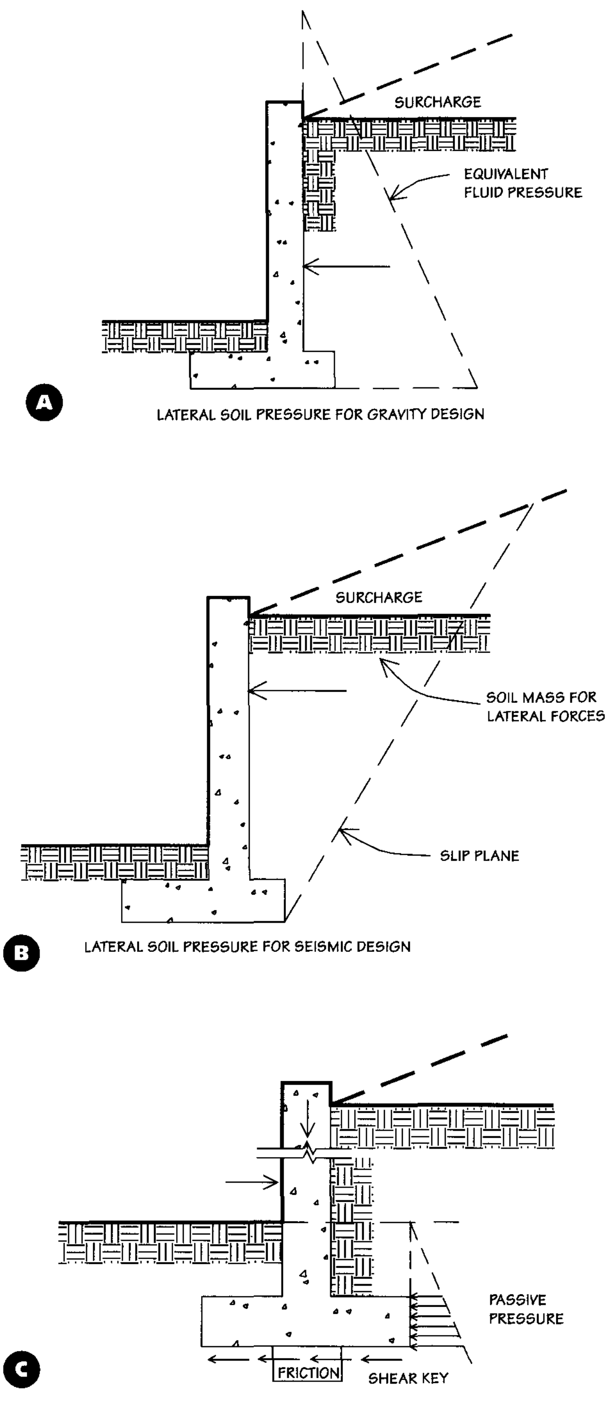

Figure 252-9. Diagrams of lateral soil pressures *for a) gravity design; b) gravity plus seismic design loads; and c) shear key to resist horizontal movement of footing.*

b. Geologic evaluation of the existing tectonic structure of the area and site.

c. The relationship between the magnitude of potential earthquakes and the length of present faults.

3. Seismic Inventory and Zonation. Seismic zonation involves inventory and mapping an area for its potential for each type of seismic hazard, such as surface faulting, ground shaking, flooding, liquefaction, and land-sliding. These maps are used to make composite maps showing the total potential seismic risks for each zone. The accuracy of establishing seismic zones depends on the level of detail and the accuracy of the basic geologic mapping. Geographical information systems (GIS) can be used to produce detailed computer generated maps showing the assessment of a variety of risks that could affect a particular city or a region. The application of GIS based upon data obtained from remote sensing and other sources should be a high priority for public authorities and private sector users of land who are concerned with disaster mitigation and management.

4. Evaluation of Land Uses, Structures & Human Occupancies. The next step in risk assessment is identification and evaluation of the vulnerability of various types of land uses and structures to damages related to earthquakes. This calls for an inventory and analysis of existing and proposed land uses, structures and associated dangers to humans that could be caused by the assumed design earthquake.

5. Regulations Based on Seismic Risk. In many locations (local, state and/or national), building codes and land use regulations are expected to help reduce seismic risks. For instance, in the U.S. there is a Uniform Building Code which is revised every year but only published every three years. In addition, some individual states and localities have subdivision regulations, zoning ordinances, and building codes that require special geological studies of an area if it is within an identified seismic risk zone.

6. Impacts of Earthquakes on Major Structures & Systems. This step determines specific mesaures to avoid, reduce, or mitigate any seismic risks found within the study site or area.

6.0 LAND PLANNING, DESIGN & CONSTRUCTION IN SEISMIC ZONES

It is far less risky and less expensive to not build in or near seismically active areas. Unfortunately, as Figures 252-2 and 252-6 show, many of the world's largest and most rapidly growing metropolitan regions are located in seismic areas. If potentially active seismic areas cannot be avoided, there are several useful guidelines to help reduce different types of potential seismic risks.

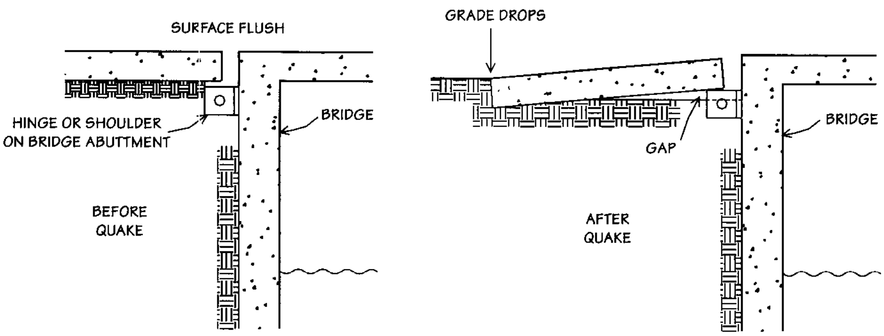

Figure 252-10. Methods to mitigate settlement of bridge buttresses.

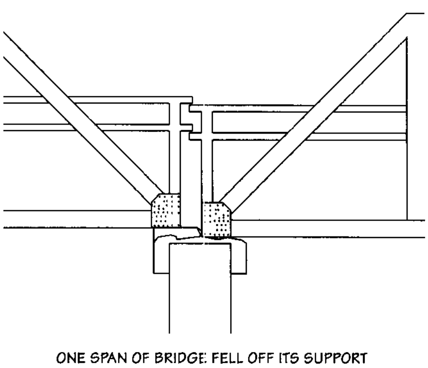

Figure 252-11. Diagram of bridge span that has fallen off of its support due to earthquakes.

In all cases, consultation with a professional engineer who specializes in seismic hazard is essential to help identify and determine the potential hazards and what measures that should be taken to overcome or mitigate threats associated with earthquakes. It should be noted that most seismic experts are seldom able to predict which types or magnitudes of earthquakes and resulting effects will occur in a specific place or to a specific structure. Thus, seismic experts must rely on use of a rational process based upon facts, as well as personal experience.

6.1 Responses to Potential Ground Failures and Faults

Identification of the potential ground failures and faults can only be estimated by detailed geological investigations guided and interpreted by professional engineers who specialize in such work. If potential hazards are identified for a site, use of deep foundations, pilings or other major counter measures may be necessary in areas subject to settlement or loss of bearing strength.

Major structures (buildings, roadways, bridges, storage tanks, and utility lines) should not be built on or near fault lines. For certain kinds of land uses where many human lives are involved (such as hospitals, schools, etc.) there may be a need for alternative or temporary ways to assure vehicular and utility access.

6.2 Dangers of Hilltops and Regraded Hillsides

Hillsides and ridges amplify seismic vibrations and motions. This is confirmed by research and field observations of the recent Northridge and Loma Prieta

Table 252-3. SEISMIC COEFFICIENTS FOR EARTH-RETAINING STRUCTURES

	Seismic coefficient α = (a/g)		
Importance category*	Zone† A	Zone† B	Zone† C
1	0.24	0.18	0.12
2	0.17	0.13	0.09

* 1: Major retaining walls supporting important structures or services where failure would have disastrous consequences, such as cutting vital services or causing serious loss of life.

2: Free-standing structures at least 20 ft (6 m) high, not in locations as in category 1, but where replacement would be difficult or costly and other consequences would be serious.

3: For less important structures than above, no specific provision for earthquake loading need be made.

† New Zealand Seismic Zones. Zone A represents moderately high seismic risk on a world scale, the maximum design earthquake being of magnitude 7.8, approximately.

Source: D. J. Dowrick, Earthquake Resistant Design, John Wiley & Sons, Ltd., Chicester, England, 1977.

KEY POINTS: Construction in Earthquake Hazard Zones

Development in areas of seismic activity should be avoided whenever possible. If these areas cannot be avoided, there are several useful guidelines and rules of thumb to help reduce different types of potential seismic risks.

1. Consultation with a professional engineer who specializes in seismic hazard is essential to determine the potential hazards, building code requirements, and appropriate measures that should be taken to overcome or mitigate threats associated with earthquakes.
2. Major structures should not be built on or near fault lines. If potential ground failures are identified for a site, use of deep foundations or pilings may be necessary.
3. Hillsides and ridges are particularly hazardous in areas of seismic activity. All efforts should be made to avoid development in these areas.
4. It is best to place the length of retaining devices perpendicular to the anticipated direction of the seismic waves, although the intricacies of many fault zones makes it difficult to predict the direction of seismic activity.
5. The design and configuration of buildings placed in earthquake hazard areas is important in minimizing damage. Generally, larger and taller structures are more susceptible to damage, and square plans are preferred (Figure 252-19).

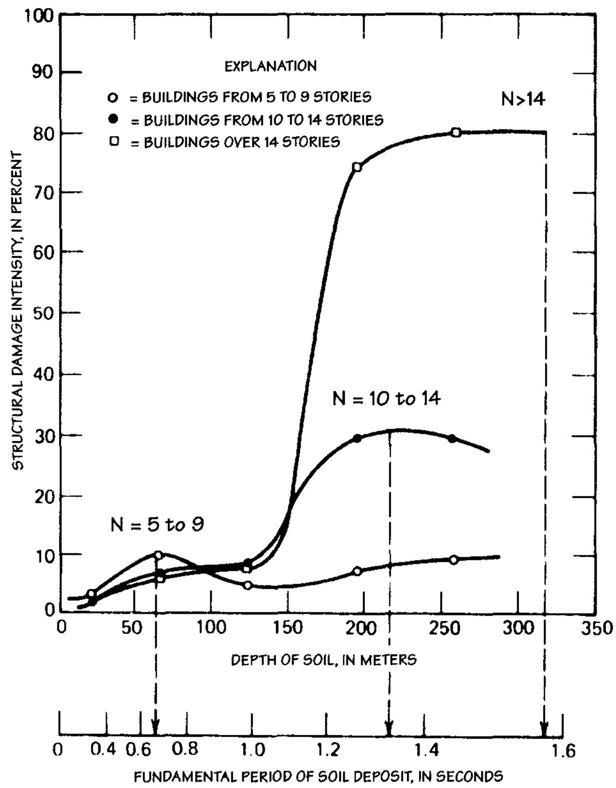

Figure 252-12. Structural damage intensity *for different-height buildings related to depth of soil and computed fundamental period of soil deposit. N = number of stories. Where the fundamental period of a soil deposit is short (between 0.6 and 0.8 sec.) the greatest damage will occur to buildings from five to nine stories tall. With longer soil periods, the damage intensity to higher structures increases.*

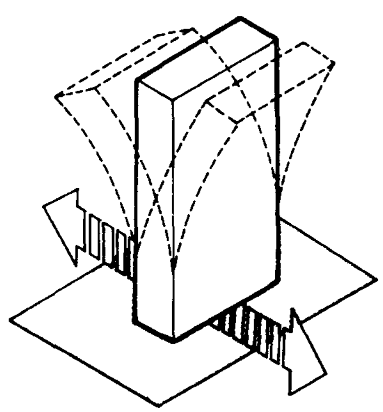

Figure 252-13. Pendulum action. *The building acts like a pendulum with respect to the ground.*

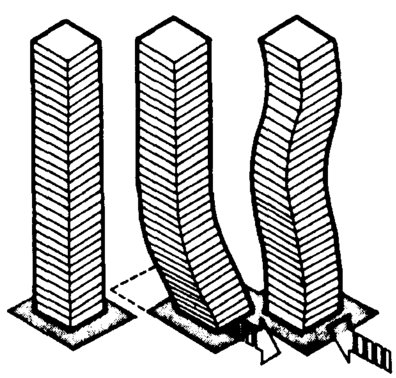

Figure 252-14. Effects of cyclic reversals of ground acceleration. *At the same time that the upper part of a structure begins to move to catch up with the initial displacement, the ground motion reverses itself.*

Earthquakes in California. Developing these sites tends to result in complicated foundations for major structures, and the dramatic reshaping of hilltops and hillsides which often requires use of retaining structures which can become unstable during earthquakes. As a result, development of these sites should be avoided whenever possible.

6.3 Retaining Walls and Similar Structures

Retaining walls or structures do not typically fail completely during earthquakes. More often, they are shaken out of alignment or suffer significant damage. Where possible, it is best to place the length of the retaining devices at right angles to the expected direction of the seismic waves. However, seismic areas may have many unknown minor or so-called "blind faults" which make it difficult to predict the direction of potential earthquakes. Table 252-3 shows how the New Zealand Ministry of Works classifies earth retaining structures and recommends seismic coefficients for these structures when they are located in seismic zones.

Figure 252-9 illustrates how retaining walls in seismic areas need to resist the normal assumed fluid pressure behind a wall with or without surcharge and the passive soil mass behind the wall. In situations where a footing rests on clay or a similar "slick" material, a shear-key should be added to help the wall resist passive soil movement created by earthquakes.

6.4 Bridges and Similar Structures

The design of major bridges for vehicular traffic is a special field for structural engineers (See publications by the U.S. Applied Technology Council on Seismic Design Guidelines for Highway Bridges: ATC-6 or 6-1 and 6.2.). Bridges for lighter vehicles, footbridges, decks and boardwalks, stairs, and ramps are often designed by landscape architects and building architects. Earthquakes can cause damage to these structures. The following describes a few common problems and solutions to be considered when planning, designing and constructing such structures in seismic areas (Refer to Section 470: Pedestrian Bridges, and Section 460: Wood Decks and Boardwalks for additional design information).

Earth settlement & loss of support:

Earthquakes cause settlement of most fill materials adjacent to and behind buttresses, retaining walls of bridges, and under the foundations for bridges, retaining walls,

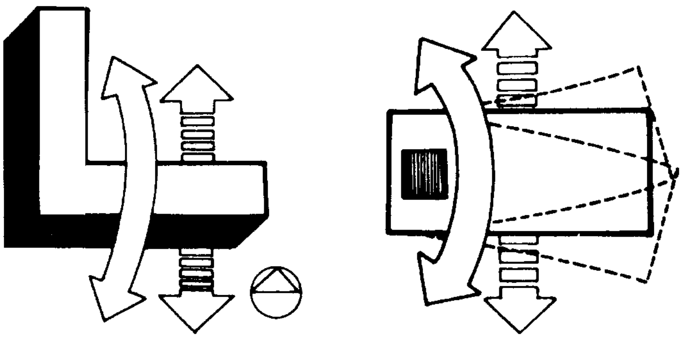

Figure 252-15. Torsion effect on a building plan. *Building on left shows rotation of the mass of an east-west wing relative to the mass of a north-south wing. The drawing on the right shows a regular plan building with asymmetrical stiffening. In a rectangular building with a very stiff off-center core area and with the remainder of the structure flexible, torsion will develop in the flexible portion around the stiffer core.*

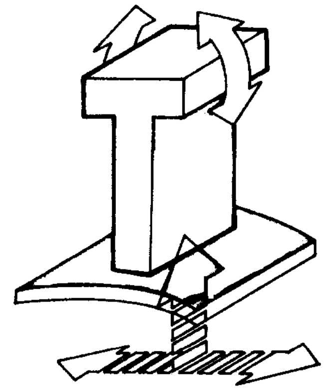

Figure 252-16. Oblique view of vertical torsion effect. *Where the upper stories of a tall structure have a greater floor area than those below, torsional problems can result because of vertical accelerations.*

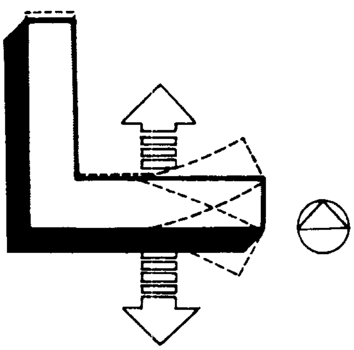

Figure 252-17. Stiffness of a structure related to building plan. *The north-south wing of an L-shaped building will be relatively stiffer if its long axis is parallel to the earthquake motion. The east-west is shallow in the direction of the earthquake motion, and unless designed to have adequate capacity to absorb and dissipate the forces, it can suffer greater damage.*

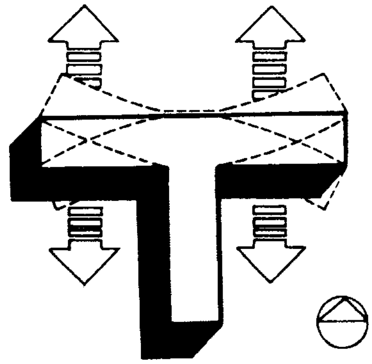

Figure 252-18. Stiffness of a structure related to building plan. *The north-south wing of a T-shaped building will be relatively stiffer if its long axis is parallel to earthquake motion. The east-west wing is shallow in the direction of the earthquake motion, and unless designed to have adequate capacity to absorb and dissipate the forces, it can suffer greater damage.*

and similar "earth-supported" structures. This settlement can interrupt the continuity of the travel surfaces leading to and from bridges by several millimeters, which could be dangerous or even prevent movement of most vehicles. Figure 252-10 illustrates one method to prevent or reduce such dangers.

Bridge structures moved off support:

Earthquakes cause lateral spreading of the buttresses and can rock bridges, aerial walkways, etc. off their bearing plates or off their supports unless appropriate restraining devices or other techniques are employed (Figure 252-11).

6.5 Buildings and Other Major Structures

Site selection and placement of buildings and other large structures are a fundamental initial consideration in seismically active areas.

The second most important consideration is the massing of the building elements and the continuity of various structural systems. These will affect the ability of a structure to resist or survive damage from seismic forces. Buildings with complex masses (different floor heights and wings), variations in the size and number of openings, etc., present very complex problems to quantitatively determine their resistance to seismic damage and provide for human safety. In the past, most structures were planned, designed and constructed without significant regard to their seismic implications (See reference list at end of this section for sources on seismic design of buildings).

Most damage to structures occurs during the first moments of the earth shaking nearest the epicenter. There can sometimes be greater danger from cumulative earthquake damages. These are caused by several earthquakes occurring over a period of time, each one causing limited damage. After a series of such events, even a minor aftershock could trigger major structural damage or collapse.

Tall structures (buildings, storage tanks or observation towers, etc.) and low, long structures (bridges, stadia, dams, retaining walls, etc.) are more vulnerable to the subsequent effects of seismic waves. Some structures respond by vibrating at various frequencies, depending on the shape, size, and structural system. Adjacent structures with different characteristics may each vibrate at their own frequencies. This may cause them to strike each other and may inflict severe damage.

Tall structures have longer rates of vibration, or fundamental periods, and therefore, are subject to greater damage if built on deep soils which may have equally long fundamental periods. Figure 252-12 shows the potential damage to buildings of different heights based upon the soil conditions, etc. Figures 252-13 through 252-18 show how some types of structures may be effected by earthquake vibrations. These vibrations cause the ground to oscillate in

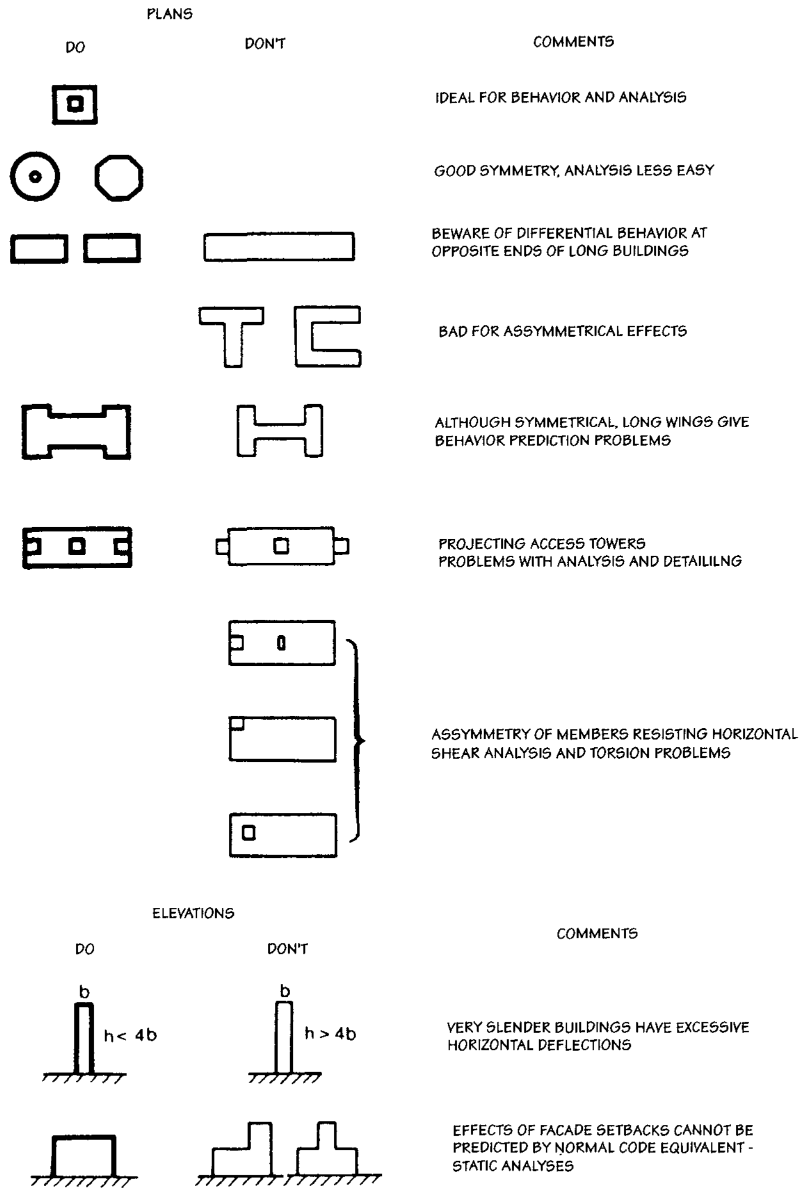

Figure 252-19 Simple rules for plan layouts and elevation shapes to minimize seismic hazards. *These rules should be broken only with dynamic analysis and careful detailing.*

all directions, creating random motions of varying frequencies. Torsional effects on such structures are difficult to assess and can be very destructive. Both the configuration of the plan and/or vertical massing of large structures can have significant influence on the structure's ability to withstand ground shaking.

Figure 252-19 shows simple rules for preparing plans and elevations for large structures. Generally, square or nearly square plans are preferred. Rigid vertical elements (such as stair towers, etc.) should be placed symmetrically within the structure. If a square plan is not possible, another alternative is to divide the structure into more-or-less free standing segments by creating gaps of at least 100 mm (4 in) in width. Detailing of these gaps is complex but will help prevent or reduce pounding.

6.6 Building Codes

Building codes have been established in most parts of the world to dictate minimum requirements for the construction of major buildings and other structures where human safety and welfare is a concern. Such codes typically include consideration of seismic factors. Building codes are typically national or local standards developed by governments. Often national professional and trade associations have established more stringent codes and guidelines

SOURCES OF TECHNICAL INFORMATION & ASSISTANCE

Earthquake Engineering Research Institute 499 14th Street, Suite 320, Oakland, CA 94612-1934

National Center for Earthquake Engineering Research, 304 Capen Hall, Science and Engineering Library, University of Buffalo, Buffalo, New York 14260-2200

National Earthquake Information Center, MS-967, PO Box 25046, Federal Center, Denver, CO 80225

Natural Hazards Research & Applications Info. Center, Univ. of Colorado, Campus Box 482, Boulder, Colorado

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SECTION 253

Natural Hazards: Landslides and Snow Avalanches

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CONTENTS

1.0 INTRODUCTION

This section describes the hazards of landslides and snow avalanches. Landslides are defined as the mass movement of any combination of rock or soil down a slope. Slope movement results from the action of gravity and climate on geologic materials. Figure 253-1 identifies and defines the common features of a landslide.

Snow avalanches are defined as the rapid downward movement of a mass of snow, originating on steep slopes, often carrying ice, rock, and debris that contribute to its potential destructiveness.

2.0 LANDSLIDES

2.1 Types of Landslides

The most widely used classification of landslides is based on the predominant type of mass movement that occurs and the type of material involved. Landslides are also described by their velocity.

Movement: The type of movement is one of the principal criteria for classifying landslides and determining an appropriate mitigation strategy. Table 253-1 lists the five distinct types of landslide movement. Complex landslides may also occur, consisting of two or more movement types occurring in succeeding stages.

Material: The type of material can be described as either rock or soil. Soil is further divided based on particle size into earth, predominantly fine soil particles, or debris, consisting of predominantly course particles.

Velocity: Table 253-2 lists the landslide velocity scale. The destructive significance of a landslide is often affected by the velocity of movement. Escape is unlikely with extremely rapid landslides [5 m/sec (17 ft/sec)]. In contrast, very slow and extremely slow movement [less than 1.6 m/year (5 ft/year)] will cause little damage in some cases and may even be imperceptible.

2.2 Causes of Landslides

Landslides occur when the strength of a mass of soil and/or rock comprising a slope is less than the downhill pull of gravitational force upon it. The balance of forces on a stable slope can be shifted either by increasing the weight of materials or by decreasing its resistance to sliding.

Table 253-3 lists common causes of landslide movement, and table 253-4 describes geologic conditions that are highly susceptible to landslides. Landslides often accompany flooding or heavy rains. Unusually wet conditions will increase the weight of the slope and decrease the friction between soil particles. Erosion or cuts at the base of a slope can cause weakening and sliding. Earthquakes are another important cause of landslides. Landslides can also be caused by human activity. Construction, removal of protective vegetation, or activities which cause vibration in the soil (blasting, heavy equipment, etc.) can upset the balance of forces acting on a slope. Common human activities that increase the potential for landslides include:

1. The placement of earth and other heavy fill materials on a slope, which increases the downward force acting on the slope
2. The construction of roads, buildings and other types of structures, which increases both the load and the water infiltration.
3. The use of on-site sewage disposal systems, the construction of ponds, and the use of sprinkler systems, all of which increase the infiltration of water into a slope and increase its tendency to slide.
4. The grading of a site which results in undercutting the toe of a vulnerable slope.

2.3 Estimation of Landslide Hazard

Figure 253-2 is a landslide susceptibility map developed by the U.S. Geological Survey; the map is based on both the physical conditions which make landslides possible (bedrock geology, soils, slopes, and pattern of rainfall) and on recorded occurrences of landslides. Systematic mapping and registration of landslides has been conducted in a number of countries where slope instability has caused serious problems. This data is useful for ascertaining a generalized view of the landslide potential of a region during the land planning process. Such maps are not meant to be used to determine the potential for landslides on a particular site.

In the United States, more-detailed maps of landslide hazards have been prepared by the U.S. Geological Survey for areas where the problems have been most severe. State geological survey units or mining regulation agencies may also provide landslide hazard maps.

In many areas of the United States and elsewhere in the world, such detailed information on landslide hazards is not available. Soil survey maps can be useful as an interim source of information until more precise studies are available. A preliminary investigation of a site by a geological engineer, using air photo analyses or other methods, can give indications as to whether more comprehensive geotechnical investigations are required.

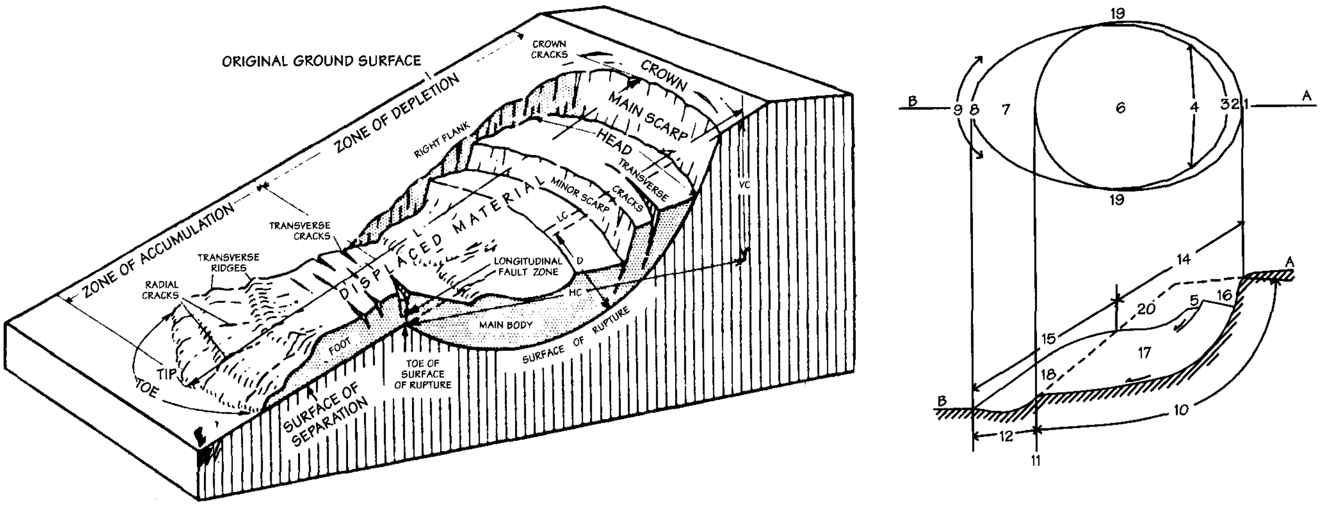
Certain combinations of surface disturbances can signify former landslides or areas of high landslide potential. These key features are described in Table 253-5.

Aerial photographs can reveal the location of former landslides. Zones of previous sliding activity are evident by characteristic crescent-shaped scarps and hummocky topography. It is more difficult to identify areas that have a potential for future landsliding. Large-scale photographs (greater than 1:9600) are most useful for this task because the identifying features are rather small. Surface evidence is often hidden by vegetation or is so subtle that only field observation will reveal the need for more thorough studies.

As part of the geotechnical investigation of a potentially hazardous site, the presence of unstable materials should be determined by investigation of surface and subsurface features. Surface investigations should include hydrologic aspects of the site, such as seepage zones and the groundwater's depth and seasonal fluctuations. Borings may be necessary to provide

KEY POINTS: Landslide Types and Causes

1. Landslides are typically classified by the type of movement that occurs (Table 253-1). Complex landslides consist of two or more movement types occurring in succeeding stages.
2. The destructive significance of a landslide is affected by the velocity of movement, as described in Table 253-2.
3. Landslides may be caused by susceptible geologic, morphologic, or other physical conditions such as heavy rainfall. Human activity such as construction or removal of protective vegetation can also cause landslides. Table 253-3 lists likely causes of landslides.

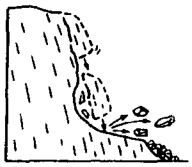


NUMBER	NAME	DEFINITION
1	Crown	Practically undisplaced material adjacent to highest parts of main scarp
2	Main scarp	Steep surface on undisturbed ground at upper edge of landslide caused by movement of displaced material (13) away from undisturbed ground; it is visible part of surface of rupture (10)
3	Top	Highest point of contact between displaced material (13) and main scarp (2)
4	Head	Upper parts of landslide along contact between displaced material and main scarp (2)
5	Minor scarp	Steep surface on displaced material of landslide produced by differential movements within displaced material
6	Main body	Part of displaced material of landslide that overlies surface of rupture between main scarp (2) and toe of surface of rupture (11)
7	Foot	Portion of landslide that has moved beyond toe of surface of rupture (11) and overlies original ground surface (20)
8	Tip	Point on toe (9) farthest from top (3) of landslide
9	Toe	Lower, usually curved margin of displaced material of a landslide, most distant from main scarp (2)
10	Surface of rupture	Surface that forms (or that has formed) lower boundary of displaced material (13) below original ground surface (20)
11	Toe of surface of rupture	Intersection (usually buried) between lower part of surface (10) of a landslide and original ground surface (20)
12	Surface of separation	Part of original ground surface (20) now overlain by foot (7) of landslide
13	Displaced material	Material displaced from its original position on slope by movement in landslide; forms both depleted mass (17) and accumulation (18)
14	Zone of depletion	Area of landslide within which displaced material (13) lies below original ground sur face (20)
15	Zone of accumulation	Area of landslide within which displaced material lies above original ground surface (20)
16	Depletion	Volume bounded by main scarp (2), depleted mass (17), and original ground surface (20)
17	Depleted mass	Volume of displaced material that overlies surface of rupture (10) but underlies original ground surface (20)
18	Accumulation	Volume of displaced material (13) that lies above original ground surface (20)
19	Flank	Undisplaced material adjacent to sides of surface of rupture; compass directions are preferable in describing flanks, but if left and right are used, they refer to flanks as viewed from crown
20	Original ground surface	Surface of slope that existed before landslide took place

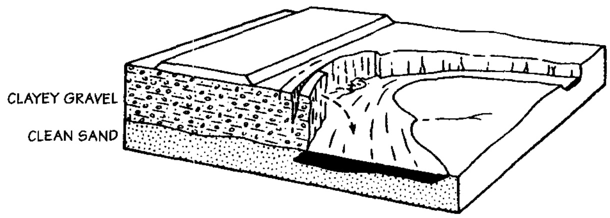
Figure 253-1. Common features of a landslide.

Table 253-1. CLASSIFICATION OF LANDSLIDES

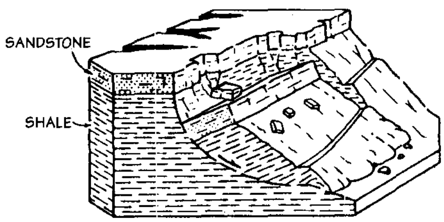
TYPE OF MOVEMENT	RATE	DESCRIPTION
FALLS	Very rapid to extremely rapid	Material travels most of the distance through the air.



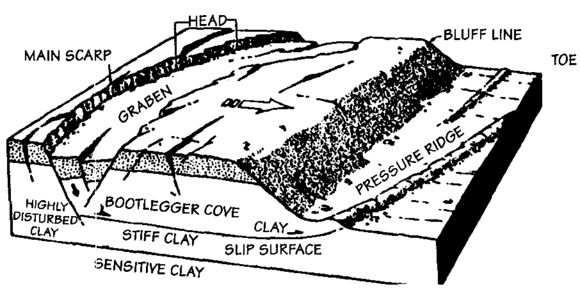
TYPE OF MOVEMENT	RATE	DESCRIPTION
TOPPLES	Extremely slow to extremely rapid	Material tilts forward over a pivot point, resulting in a fall or slide.



TYPE OF MOVEMENT	RATE	DESCRIPTION
SLIDES		
Rock Slump	Extremely slow to moderate	Rotational (slumps): concave surface of rupture. Material moves along one or more identifiable surfaces.



TYPE OF MOVEMENT	RATE	DESCRIPTION
Earth Block Slide	Very slow to rapid	Translational (slides): generally planar or undulating surface of rupture. Frequently these are caused by structural weaknesses related to faults, bedding planes, etc.



TYPE OF MOVEMENT	RATE	DESCRIPTION
LATERAL SPREADS	Very rapid to slow	Material in a fractured mass moves laterally, often as a result of liquefaction or plastic flow in subadjacent material.

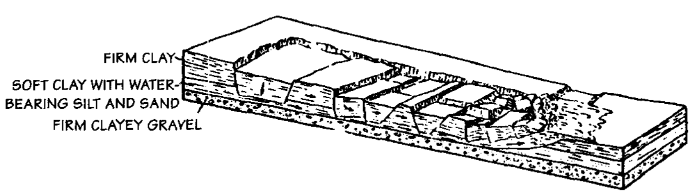
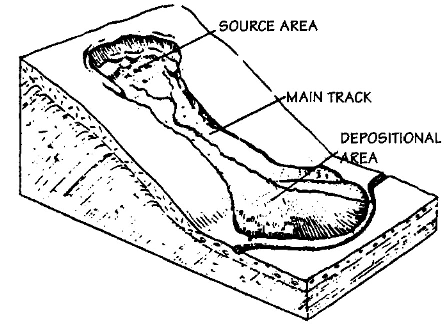
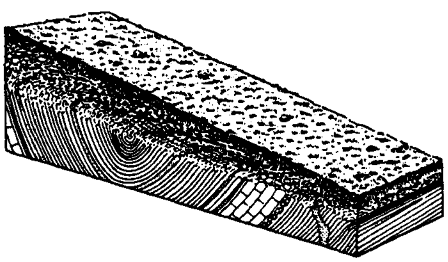


Table 253-1. CLASSIFICATION OF LANDSLIDES (continued)

TYPE OF MOVEMENT	RATE	DESCRIPTION
FLOWS		
Earth Flow	Extremely rapid to extremely slow	Material moves as a viscous fluid.
		
Soil Creep	Extremely slow usually as a result of soil particle movement.	Material moves downslope at imperceptible rates,
		
COMPLEX		Movement is a combination of two or more of the above types, occurring in succeeding stages.

Source: D. J. Varnes, *"Slope Movement Types and Processes," in Landslides: Analysis and Control,* Special Report 176, Transportation Research Board, NationalAcademy of Sciences, Washington, D.C., 1978.

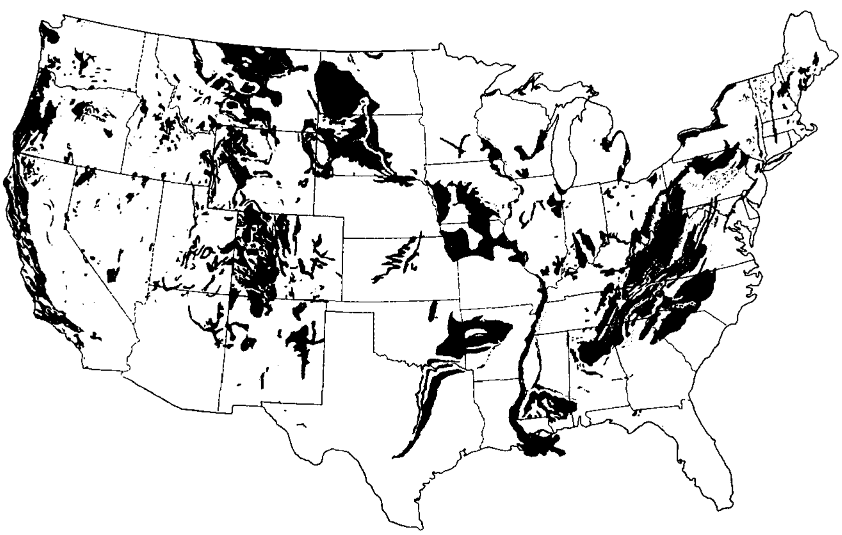


Figure 253-2. Landslide susceptibility map of the United States.

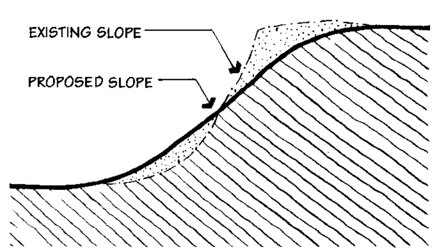


Figure 253-3. Flattening a slope.

Table 253-2. LANDSLIDE VELOCITY SCALE

Velocity Class	Description	Potential Destructive Significance	Typical Velocity
7	Extremely Rapid	Catastrophe of major violence; buildings destroyed by impact of displaced material; many deaths; escape unlikely	5 m/sec (17 ft/sec)
6	Very Rapid	Some lives lost; velocity too great to permit all persons to escape	3 m/min (10 ft/min)
5	Rapid	Evacuation possible; structures, possessions, and equipment destroyed	1.8 m/hr (6 ft/hr)
4	Moderate	Some temporary and insensitive structures can be temporarily maintained	13 m/month (45 ft/month)
3	Slow	Remedial construction can be undertaken during movement; insensitive structures can be maintained with frequent maintenance work if total movement is not large during a particular acceleration phase	1.6 m/year (5 ft/year)
2	Very Slow	Some permanent structures undamaged by movement	16 mm/year ($^5/_8$ in/year)
1	Extremely Slow	Imperceptible without instruments; construction possible with precautions	

Source: Adapted from Turner, A. Keith and Robert L. Schuster (eds.). *Landslides: Investigation and Mitigation, Special Report* 247, National Academy of Sciences, Transportation Research Board, Washington, DC, 1996.

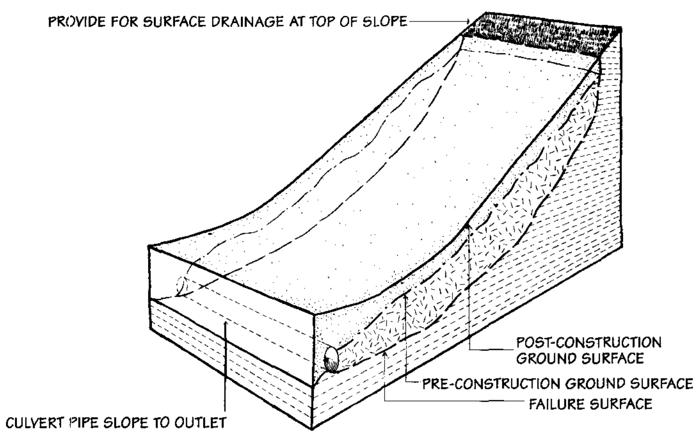


Figure 253-4. Regrading with toe loading.

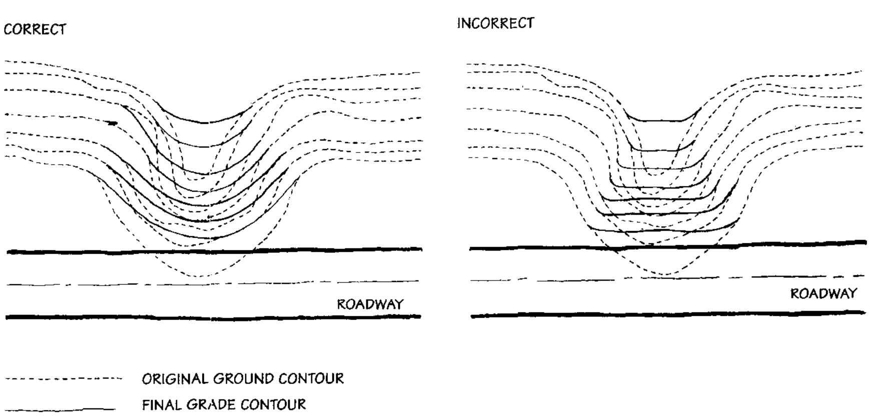


Figure 253-5. Rounding cut slopes

Table 253-3. COMMON LANDSLIDE CAUSES

Cause	Description
Geologic	Weak or sensitive materials
	Weathered or sheared materials
	Jointed or fissured materials
	Adversely oriented mass discontinuity (bedding, schistosity, etc.)
	Adversely oriented structural discontinuity (fault, unconformity, contact, etc.)
	Contrast in permeability
	Contrast in stiffness (stiff, dense material over plastic materials)
Morphologic	Tectonic or volcanic uplift
	Glacial rebound
	Fluvial erosion of slope toe
	Wave erosion of slope toe
	Glacial erosion of slope toe
	Erosion of lateral margins
	Subterranean erosion (solution, piping)
	Deposition loading of slope or its crest
	Vegetation removal (by forest fire,drought)
Climatic	Intense rainfall
	Rapid snow melt
	Prolonged exceptional precipitation
	Rapid drawdown (floods and tides)
	Thawing
	Freeze-and-thaw weathering
	Shrink-and-swell weathering
Human	Excavation of slope or its toe
	Loading of slope or its crest
	Drawdown (of reservoirs)
	Deforestation
	Irrigation
	Mining
	Artificial vibration
	Water leakage from utilities

Source: Adapted from Turner, A. Keith and Robert L. Schuster (eds.). Landslides: Investigation and Mitigation, Special Report 247, National Academy of Sciences, Transportation Research Board, Washington, DC, 1996.

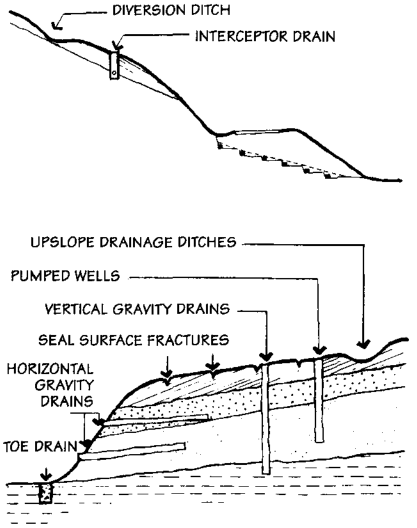


Figure 253-6. Surface drainage of slope by diversion ditch and interceptor drain.

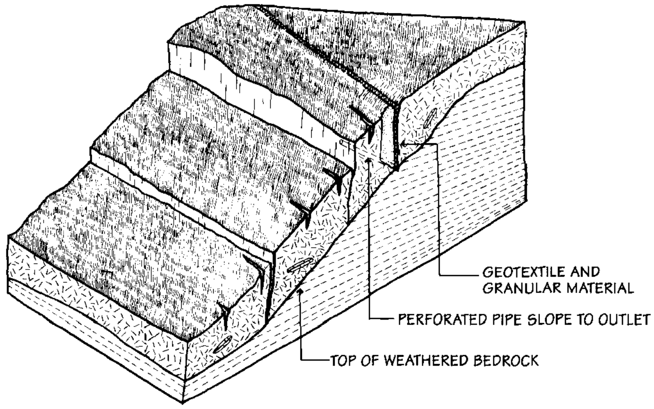


Figure 253-7. Subsurface interceptor trench drain and surface-runoff diversion ditch.

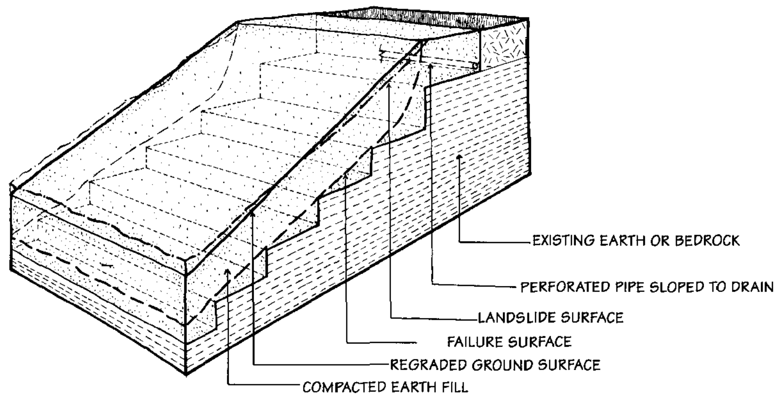


Figure 253-8. Regrading with subsurface drain.

information on the vertical stratification of soils. The compactness of granular soils and the consistency of cohesive soils should also be ascertained. The investigation should be conducted by a geotechnical engineer, who should also assess both the short- and long-term stability of the site and the possible effects of any development on adjoining areas.

2.4 Landslide Loss Prevention and Reduction

The best way to prevent damages resulting from landslides is to avoid sites that have a potential for sliding. However, landslide-prone areas often offer spectacular views and are frequently considered prime land for development. Both the regulation of future development and the protection of existing development are important in reducing landslide hazards.

Regulation:

The regulation of future development can be achieved through zoning, subdivision, and sanitary regulations, or through special regulations for hillsides identified as landslide-prone areas. Zoning can restrict intensive development and/or prohibit land uses that would be vulnerable to landslide damage. Subdivision regulations can require that landslide hazard areas be identified and reserved for open-space uses. Sanitary regulations can restrict the use of on-site disposal systems that could trigger landslides by wetting vulnerable areas. Hillside and slide-prone area regulations can limit densities, prohibit certain uses, (e.g.the storage of hazardous materials), restrict activities that could trigger sliding (e.g. off-road vehicles), establish certain grading practices, and call for the preservation of existing vegetation. Special regulations can also discourage the siting of roads and bridges in these hazardous areas. If alternative locations cannot be found for roads or bridges, they should be designed to require minimal cuts and fills and should be able to withstand expected landslide conditions.

Prevention and Correction:

The protection of existing development through prevention or correction of landslides is a complex problem. Each slide has its own characteristics, making corrective measures difficult to standardize. Experts in geotechnical engineering and geology should be consulted.

Stabilization of Soil Slopes:

Table 253-6 describes a range of useful methods for the stabilization of soil slopes. These methods seek to reduce shearing stresses or increase shearing resistance. They include: excavation, drainage, vege-

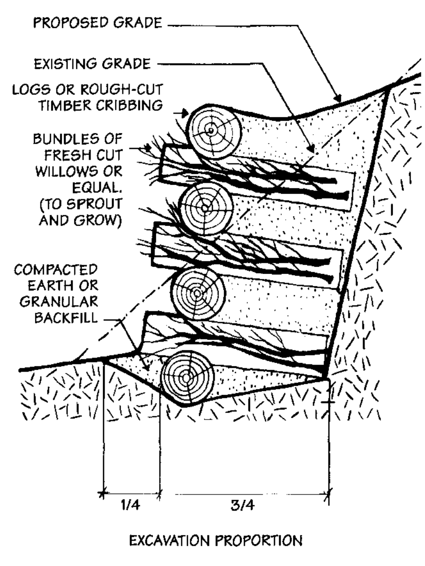


Figure 253-9. Live wooden crib wall.

tation, restraining structures, and a variety of less common methods.

Excavation: Excavation can be one of the least expensive methods for stabilizing a slope. By unloading the head of a potential slide mass and depositing the material at the toe of the slope, either temporarily or permanently, the driving force is reduced and the resistance increased. It is extremely important to round off the slope at the head and toe. Where the sliding mass is shallow, the entire mass may have to be removed. See Figures 253-3 to 253-5.

Drainage: One of the first corrective measures is to control the surface drainage of the hazard area through a variety of techniques, including diversion ditches and interceptor drains (Figure 253-6). Streams, springs, and surface run-off must be diverted away from the threatened area. Subsurface drainage via trench or similar methods is another effective technique (Figures 253-7 and 253-8). At large construction sites, the pumping of groundwater (dewatering) can temporarily reduce hazards, but this approach offers no long-term benefits.

Vegetation: Vegetation can be a relatively inexpensive method for the control of shallow debris slides. The physical binding action of deep roots can help anchor earth volumes prone to sliding. Landslides with deep-lying slide surfaces cannot effectively be stopped through revegetation alone, although it does help reduce water infiltration into the threatened area. The most suitable species are those that consume the most water and have the highest transpiration rates. For slopes subject to toe erosion by waves and/or currents, a combination of vegetation and structural measures at the toe is often the essential first step in landslide control.

Plants can also directly or indirectly contribute to slope failures under some conditions. On rocky slopes, root wedging and windthrow can precipitate failures. Large trees also add weight to a slope, the effect of which must be assessed on a case-by-case basis. Caution must also be exercised when installing new plantings on unstable slopes, since watering can increase the landslide potential.

Restraining Structures: Restraining structures should be considered a last resort for slope stabilization. They are often expensive and should be employed only when there are no other alternatives.

Walls for landslide restraint can range from relatively low, strong dikes designed

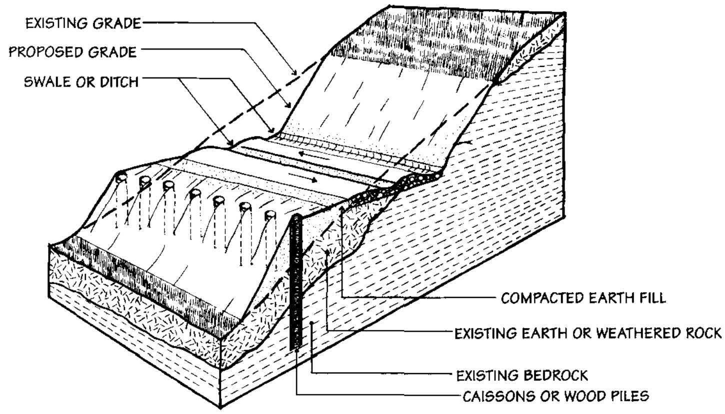


Figure 253-10. Drilled caisson wall relying on soil arching.

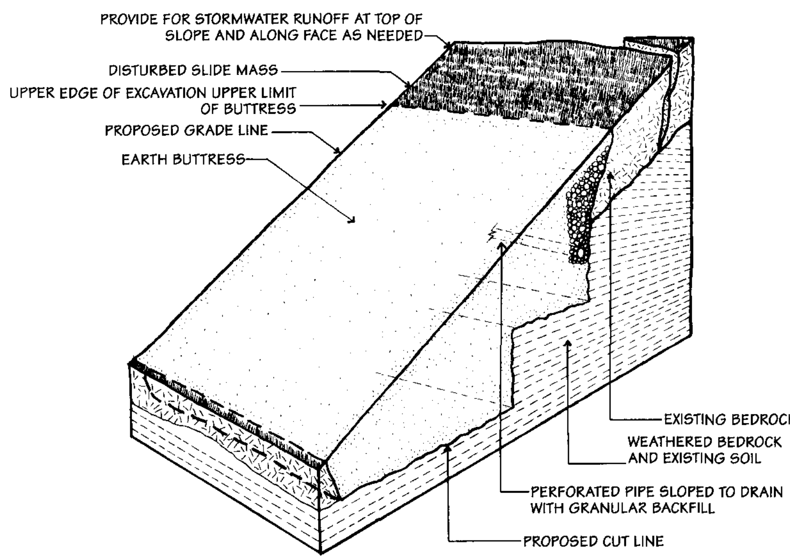


Figure 253-11. Earth buttresses with subsurface drain.

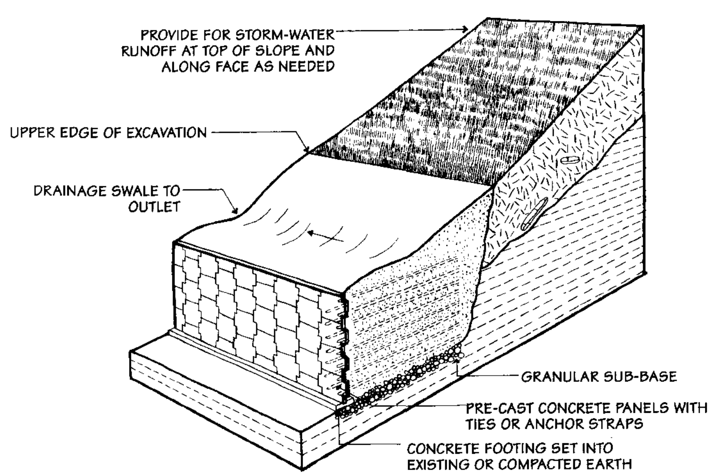


Figure 253-12. Reinforced earth wall and buttress.

Table 253-4. CONDITIONS SUSCEPTIBLE TO SLIDING

CONDITION	DESCRIPTION
Saturated cohesive, clayey soils	Sloped areas of cohesive, clayey soils are sliding because of an increase in weight due to the absorbed water.
Loose, granular materials with low shear strength	Loose, granular materials readily absorb moisture, thus increasing their weight and causing slides, slumps, and flows.
Interbedded sedimentary rock parallel to hillslopes	Interbedded sedimentary rock with joints parallel to valley walls are susceptible to sliding due to the increased weight of the water. Bedding planes or joints are lubricated by water, which causes slippage.
Highly foliated metamorphic rock	Foliations parallel to valley walls cause conditions similar to those for interbedded sedimentary rocks. The occurrence of minerals such as micas and serpentine increases the slipperiness of a slope.
Rotten or decomposed igneous or metamorphic rock	Rotten, loose, granular rock debris is susceptible to increases in moisture content and can create potential sliding conditions.
Fractures and faults	When fractures or faults parallel or intercept a slope, and there is no lateral support, or when seepage lubricates rock surfaces, there is an increased danger of sliding.
Interbedded materials of differing resistance or permeability	Interbedded materials with differences in their resistance to weathering result in the deterioration of the softer materials, thereby allowing water to accumulate in the elevated rock layers. Conditions such as limestones over shale or clay, sandstone underlaid by an impervious stratum, and lava flows over tuff can result in the development of cliffs and overhangs and conditions susceptible to falls.
Seepage of water along hillsides	The appearance of seepage water along hillslopes may indicate the development of high pore or hydrostatic pressures, especially if the water is found near the toe of the slope.
Colluvial soils	These and other soils formed by earlier mass-wasting indicate previously unstable conditions which may still exist.
Water and land edges after rapid decreases in water level	The recession of flood waters or the lowering of reservior levels can create temporary unstable conditions along the land edges.
Borrowed fills	Fill areas are susceptible to slumping or sliding if hydrostatic pressures build up, if seepage occurs under the fill, or if the fill is placed on a soil of high volume change. Such fills should be anchored and well-drained.
Coastal slopes and river banks	Coastal slopes and river banks are subject to erosive action of waves and currents.

Source: Adapted from Douglas S. Way, *Terrain Analysis: A Guide to Site Selection Using Aerial Photographic Interpretation*, Douglas S. Way, Columbus, Ohio, 1978.

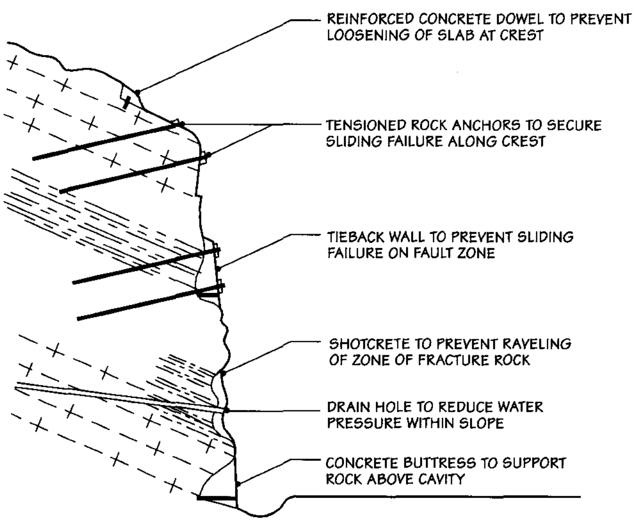


Figure 253-13. Rock slope reinforcement strategies.

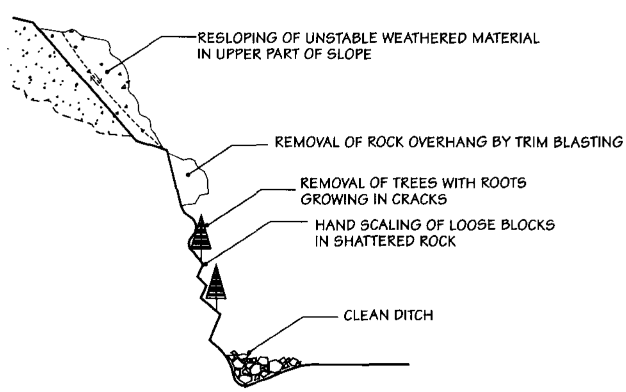


Figure 253-14. Rock removal strategies for stabilization.

Table 253-5. FEATURES INDICATING LANDSLIDES OR AREAS WITH HIGH LANDSLIDE POTENTIAL

FEATURE	SIGNIFICANCE
Structural damage	Road settlement or uplift; broken pipes or power lines; spalling or cracking of concrete structures; closure of expan sion joints in bridge plates or rigid pavement; loss of alignment; leaking pools; doors or windows that jam.
Hummocky, dissected topography	Common feature in old and active progressive slides (slides with many individual components). Slide mass is prone to gullying.
Abrupt change in slope	May indicate either an old landslide area or a change in the erosion characteristics of underlying material. Portion with low slope angle is generally weaker and often has higher water content.
Scarps and cracks or "stair step" topography	Definite indication of an active or recently active landslide. Age of scarp can usually be estimated by the amount of vegetation established upon it. Width of cracks may be monitored to estimate relative rates of movement.Graben Indication of progressive failure. Complex or nested series of rotational slides can also cause surface of slope to appear stepped or tiered.
Lobate slope forms	Indication of former earth flow or solifluction area.
Hillside ponds	Local catchments or depressions formed as result of scarps and cracks act as infiltration source which can exacerbate or accelerate landsliding.
Hillside seeps	Common in landslide masses. Area with high landslide potential can usually be identifed by associated presence of denser or phreatophyte vegetation (cattails, equisetum, alder, etc.) in vicinity of seep.
Incongruent vegetation	Patches or areas of much younger or very different vegetation (e.g., alder thickets); may indicate recent landslides or unstable ground.
"Jackstrawed" trees	Leaning or canted trees on a slope are indicators of previous episodes of slope movement or soil creep.
Bedding planes and joints dipping downslope	Potential surface of sliding for translational slope movements.
Accumulation of debris in valleys and stream channels	Accumulations of soil materails in these areas indicate previous sliding and slumping, commonly associated with stream undermining of embankments.
Light tones along upper edges of hillsides or cliffs	These tones, especially when linear, may indicate the formation of subsurface cracks; these facilitate drainage and cause the lighter tone. The appearance of these tones may precede the occurrence of actual breaks and scarps in the land surface.
Changes in tone along upper areas of cliffs or embankments	Changes in tone near edges of embankments may indicate moisture differences in the subsoil, reflecting moisture accumulation and the development of hydrostatic water pressures.

Source: Adapted from Donald H. Gray and Andrew T. Leiser, *Biotechnical Slope Protection and Erosion Control*, Van Nostrand Reinhold Company, New York, 1982; and Douglas S. Way, *Terrain Analysis: A Guide to Site Selection Using Aerial Photographic Interpretation*, Douglas S. Way, Columbus, Ohio, 1978.

to divert potential mudflows around existing development, to various types of retaining walls designed to prevent future movement of a slope. In areas of known landslide hazard, the design of retaining structures should be made adequate to carry the potential extra load. (Refer to Section 410: Retaining Walls, for information on construction of these structures).

Other restraining structures useful for the reduction of landslide hazard include:

1. Live wooden crib walls (Figure 253-9 and see Section 410: Retaining Walls, for more data)
2. Drilled (not driven) caisson walls (Figure 253-10)
3. Earth or gravel buttresses (Figure 253-11)
4. Reinforced earth wall buttresses (Figure 253-12 and see Section 410: Retaining Walls, for more data)

KEY POINTS: Landslide Estimation, Prevention and Correction

1. Detailed information on landslide hazard is not available in many areas. A preliminary investigation by a geological engineer can determine if more comprehensive geotechnical studies are required.

2. Certain combinations of surface disturbances can signify former landslides or areas of high landslide potential (Table 253-5). Large-scale aerial photographs (greater than 1:9600) can be used to reveal crescent-shaped scarps and hummocky topography that is characteristic of previous sliding.

3. The best way to prevent damages from landslides is to avoid sites that have the greatest potential for sliding. Regulations can be used to restrict development on vulnerable sites.

4. Geotechnical engineer should be consulted to determine appropriate correction strategies. Table 253-6 describes a range of possible methods for stabilization of soil slopes. Table 253-7 lists methods for stabilizing rock slides.

Stabilization of Rock Slopes:

Table 253-7 lists a number of methods for protecting and stabilizing rock slopes. They consist of reinforcement measures, rock removal strategies, and techniques to protect people and property from falling rock. Figure 253-13 illustrates various reinforcement strategies. Figure 253-14 illustrates various rock removal strategies.

When rock falling onto an area presents a hazard, the use of restraining cables, nets or walls may be the only feasible solution. Various net and wall combinations are shown in Figures 253-15 to 253-16. Where space permits, catchment ditches may be used to retain falling rock. Table 253-8 gives suitable design criteria for rock catchment ditches.

Table 253-6. METHODS OF SOIL SLOPE STABILIZATION

METHOD	PROCEDURE	BEST APPLICATION	LIMITATIONS	REMARKS
Reduce shearing stresses				
	Regrading	During preliminary design phase of project	Will affect areas adjacent to landslide hazard area	
	Drained surface	In any design scheme; must also be part of any remedial design	Will only correct surface infiltration or seepage due to surface infiltration	Slope vegetation should be considered in all cases
	Drained subsurface	On any slope where lowering of groundwater table will increase slope stability	Cannot be used effectively when sliding mass is impervious	Stability analysis should include consideration of seepage forces
	Reduced weight on slope	At any existing or potential slide	Requires lightweight materials that may be costly or unavailable; excavation waste may create problems; requires right-of-way	Stability analysis must be performed to ensure proper placement of lightweight materials
Increase shearing resistance				
Apply external force	Buttress and counterweight fills; toe berms	At an existing landslide; in combination with other methods	May not be effective on deep-seated landslides; must be founded on a firm foundation; requires right-of-way	Consider reinforced steep slopes for limited right-of-way
	Structural systems	To prevent movement before excavation; where right-of-way is limited	Will not control large deformations; must penetrate well below sliding surface	Stability and soil-structure analyses are required
	Anchors	Where right-of-way is limited	Requires ability of foundation soils to resist shear forces by anchor tension	Study must be made of in situ soil shear strength; economics of method depends on anchor capacity, depth, and frequency
Increase internal strength	Drained subsurface	At any landslide where water table is above shear surface	Requires experienced personnel to install and ensure effective operation	
	Reinforced backfill	On embankments and steep fill slopes; landslide reconstruction	Requires long-term durability of reinforcement	Must consider stresses imposed on reinforcement during construction
	In situ reinforcement	As temporary structures in stiff soils	Requires long-term durability of nails, anchors, and micropiles	Design methods not well established; requires thorough soils investigation and properties testing
	Biotechnical stabilization	On soil slopes of modest heights	Climate; may require irrigation in dry seasons; longevity of selected plants	
	Chemical treatment	Where sliding surface is well defined and soil reacts positively to treatment	May be reversible; long-term effectiveness has not been evaluated; environmental stability unknown	Laboratory study of soil-chemical treatment must precede field installations; must consider environmental effects
	Electro-osmosis	To relieve excess pore pressures and increase shear strength at a desirable construction rate	Requires constant direct current power supply and maintenance	Used when nothing else works; emergency stabilization of land slides
	Thermal treatment	To reduce sensitivity of clay soils to action of water	Requires expensive and carefully designed system to artificially dry or freeze subsoils	Methods are experimental and costly

Source: Adapted from Turner, A. Keith and Robert L. Schuster (eds.). *Landslides: Investigation and Mitigation, Special Report* 247, National Academy of Sciences, Transportation Research Board, Washington, DC, 1996.

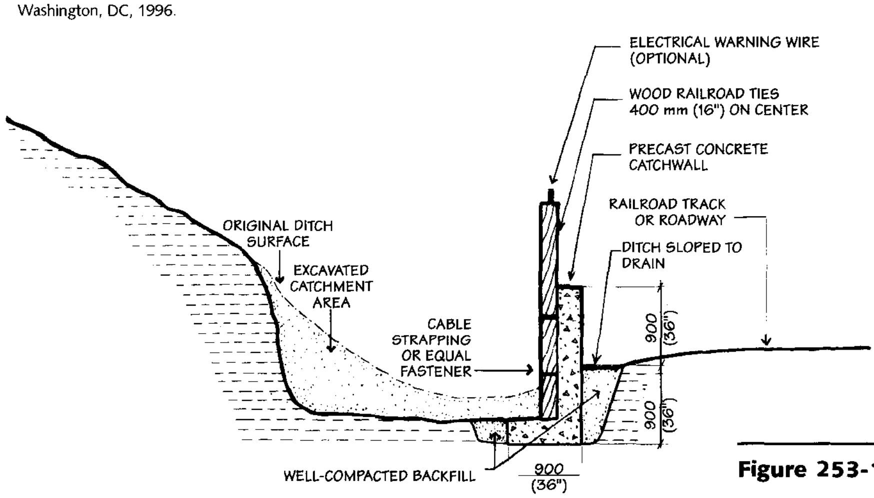


Figure 253-15. Precast concrete catch wall.

Table 253-7. METHODS OF ROCK SLOPE STABILIZATION AND PROTECTION

	PROCEDURE	DESCRIPTION	REQUIREMENTS
Protection Measures			
	Catchment Ditches	Catches fallen rock at base of slope	Requires space to accommodate necessary dimensions
	Catch Fences	Stops fallen rock at base of slope; may be used in combination with ditches	Design depends on slope, anticipated loading and bounce height; Flexible materials are used to absorb impact
	Draped Mesh	Contains fallen rock close to the face, and allows them to migrate down into catchment ditch	Top of mesh should be placed close to source of rock fall to minimize momentum
	Warning Fences	Detects rock falls, and triggers warning signal	Most appropriate along lightly-traveled transportation routes; Requires significant maintenance to minimize false alarms
	Rock Sheds	Directs rocks over traffic route or structure	Used only in areas of extreme hazard, where stabilization is not a viable option; costly maintenance and installation
	Tunnels	Redirects traffic route through rock slope to avoid hazard zones	Used only in areas of extreme hazard, where stabilization is not a viable option; costly maintenance and installation
Stabilization Measures			
Reinforcement	Rock Bolting	Secures sliding failure along crest	Requires method of anchoring bolt in the rock; must be protected from corrosion
	Dowels	Prevents passive loosening of slabs at crest	Most effective with no prior movement of rock; can only support slabs up to approximately 2 m (6 ft) thick
	Tied-Back Walls	Prevents sliding failure in fractured rock	Drainage must be provided behind wall
	Shotcrete	Prevents the fall and raveling of fractured rock	Surface must be free of loose rock, soil, vegetation and ice; Drainage must be provided behind wall
	Buttresses	Supports rock above cavity	Must be placed on clean, sound surface
	Drain Holes	Reduces water pressure within the rock slope	Must intersect rock fractures that hold water; drained water must not be allowed to infiltrate toe of the slope
Rock Removal	Resloping	Removal of unstable, weathered material in upper part of slope	Excavation requirements may vary throughout slope; additional weathering may take place after excavation;
	Trim Blasting	Removal of rock overhangs	Controlled blasting must not damage rock behind the face; ground vibrations should be kept to a minimum
	Hand Scaling	Manual removal of loose rock, soil and vegetation on slope face	Removal of vegetation is critical to prevent loosening and infiltration due to root growth; may require periodic maintenance

Source: Adapted from Turner, A. Keith and Robert L. Schuster (eds.). *Landslides: Investigation and Mitigation, Special Report* 247, National Academy of Sciences, Transportation Research Board, Washington, DC, 1996.

3.0 SNOW AVALANCHES

3.1 Causes and Types of Snow Avalanches

Snow avalanche is a type of slope failure that is common in mountainous and hilly terrain, whenever snow is deposited on slopes steeper than about 20 degrees. When the shearing stress developed by the weight of the snow and the angle of the slope exceeds the shearing strength of the snow pack, an avalanche release will occur. Natural release typically results from rapid loading of the slope by heavy snowfall, or a loss of strength due to snow melt. Artificial release results from human activity such as skiers, snowmobilers, or hikers crossing an avalanche starting zone, or through mitigation strategies such as the use of explosives to trigger small avalanches.

Two basic types of avalanches may occur, depending on conditions at the starting zone. A point release, or loose snow avalanche, typically occurs with newly fallen snow, or with wet snow from melting conditions. When the angle of repose for the snow is less than the slope, the loose snow slides down the slope, spreading out into a characteristic inverted V-shaped pattern. Point releases typically involve small volumes of snow and present only a slight hazard risk.

Slab avalanches occur when a layer of cohesive snow fractures along a line as a continuous unit and slides down the slope (Figure 253-17). These fractures may extend for great distances across a slope and incorporate a large volume of snow. Slab avalanches are difficult to predict because the failure occurs well below the surface. The hazard from such avalanches is high due to the large volume of snow that can be released.

The size and impact pressure of avalanches determines its potential hazard. Potentially destructive avalanches travel at high rates of speed. Average velocities observed at the Snow Research Station in

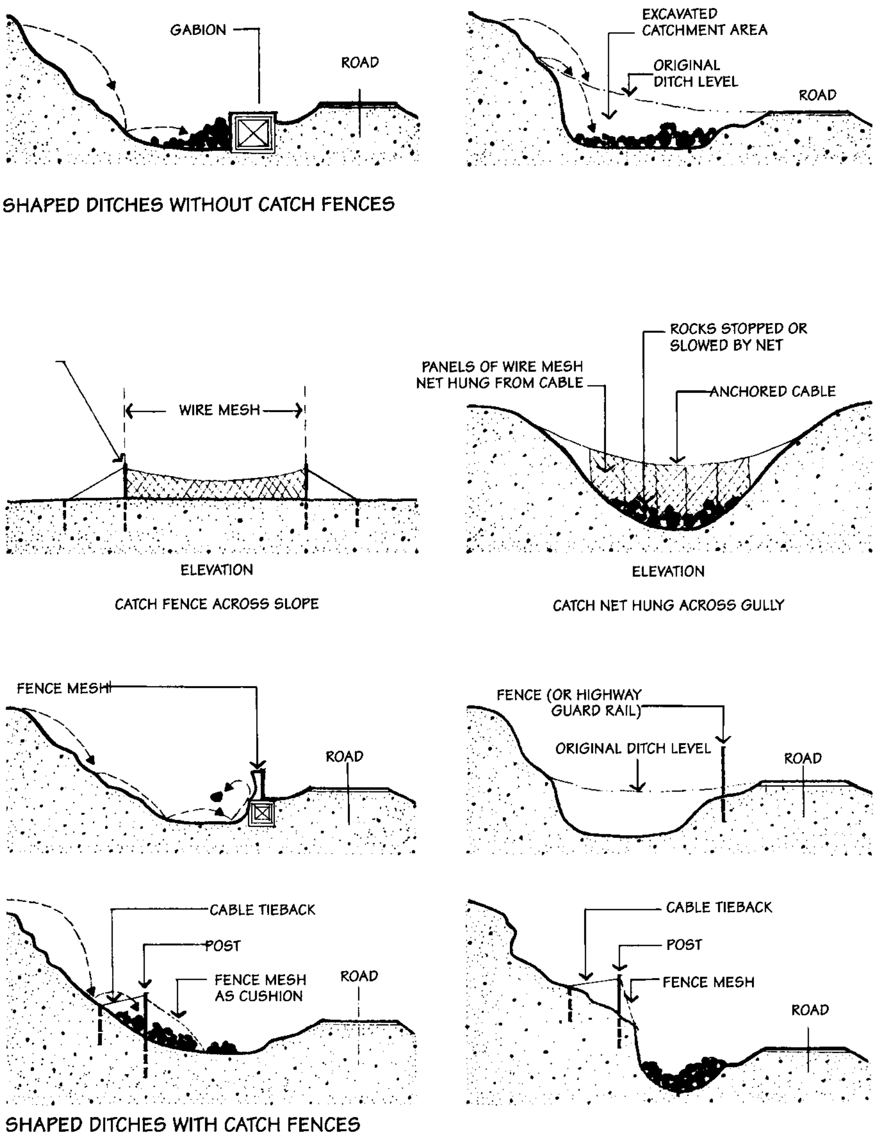


Figure 253-16. Catchment ditches and fences.

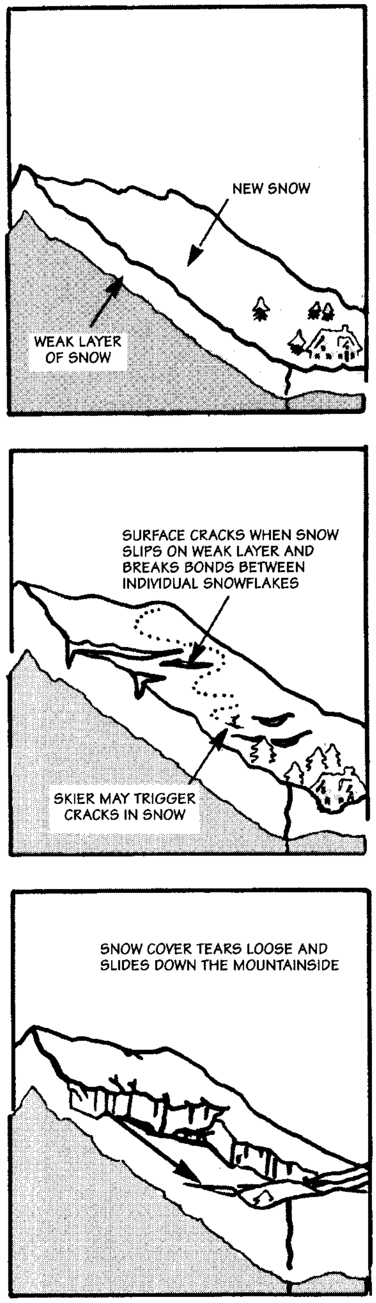


Figure 253-17. Anatomy of a slab avalanche.

Japan ranged from 40 to 60 km/h (25 to 40 mph), however, speeds of 200 to 300 km/h (125 to 190 mph) have been observed. Velocity is a function of shearing strength, density of snow, the angle of slope, and length of the avalanche path. Many avalanches carry significant amounts of rock, soil, and vegetative debris, which makes them more destructive as they travel down a slope.

3.2 Estimation of Avalanche Hazard

Local knowledge of weather conditions and the history of previous avalanching is invaluable when estimating hazards. The complex temperature and structural changes which occur in a snow mass make the prediction of avalanches on a given slope extremely difficult. However, it is possible to map high-risk areas because avalanches tend to reoccur in the same locations. The technique of mapping avalanche hazard is well-developed in many countries prone to these hazards.

Maps used to delineate hazard zones should have a minimum scale of 1:25000 for general planning purposes. More detailed maps, 1:10000 to 1:2000, should be used in areas requiring greater accuracy.

Figure 253-18 shows a map illustrating the microzonation of avalanches and the estimated impact pressures on a village in Colorado.

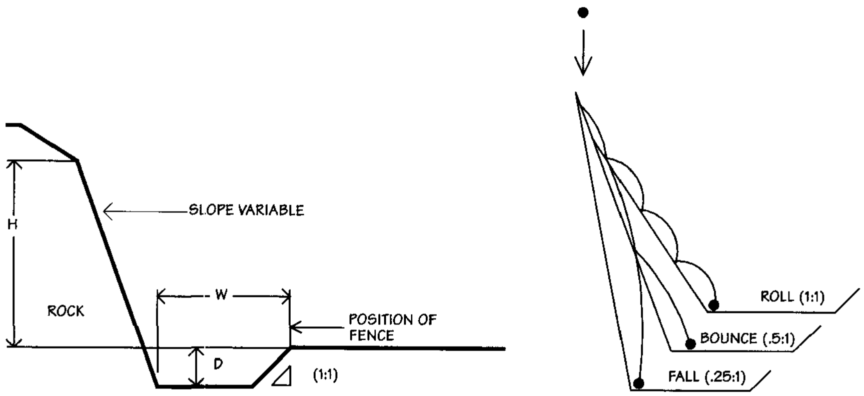


Table 253-8. ROCK TRAJECTORY FOR VARIOUS SLOPE ANGLES AND DESIGN CRITERIA FOR CATCHMENT DITCHES

Angle	Height (H), m (ft)	Fallout area width (W), m (ft)	Ditch depth (D),m(ft)
Near vertical	5-10 (16-32)	3.7 (12)	1.0 (3)
	10-20 (32-65)	4.6 (15)	1.2 (4)
	>20 (>65)	6.1 (20)	1.2 (4)
0.25-0.3:1	5-10 (16-32)	3.7 (12)	1.0 (3)
	10-20 (32-65)	4.6 (15)	1.2 (4)
	20-30 (65-100)	6.1 (20)	1.8 (6)*
	>30 (>100)	7.6 (25)	1.8 (6)*
0.5:1	5-10 (16-32)	3.7 (12)	1.2 (4)
	10-20 (32-65)	4.6 (15)	1.8 (6)*
	20-30 (65-100)	6.1 (20)	1.8 (6)*
	>30 (>100)	7.6 (25)	2.7 (9)*
0.75:1	0-10 (0-32)	3.7 (12)	1.0 (3)
	10-20 (32-65)	4.6 (15)	1.2 (4)
	>20 (>65)	4.6 (15)	1.8 (6)*
1:1	0-10 (0-32)	3.7 (12)	1.0 (3)
	10-20 (32-65)	3.7 (12)	1.5 (5)*
	>20 (>65)	4.6 (15)	1.8 (6)*

*May be 1.2 m (4 ft) if catch fence is used.

Source: Adapted from Douglas R. Piteau and F. Lionel Peckover, Landslides: Analysis and Control, Special Report 176, Transportation Research Board, National Academy of Sciences, Washington, D.C., 1978,

3.3 Avalanche Loss Prevention and Reduction

Avoidance of known avalanche hazard areas when siting structures, roads, power lines, and other facilities is the best way to minimize losses. However, increasing development pressures in mountainous regions are requiring greater protection and mitigation measures. Both the regulation of future development and protection of existing development are important in minimizing avalanche hazard.

Regulation:

A number of countries have developed legislation regulating land use in avalanche hazard areas. These regulations are most restrictive in Switzerland, France, and select regions of the United States (e.g. Colorado). These regulations typically prohibit placement of structures, roads, or other facilities within avalanche hazard zones. If development within these zones is permitted, structures are required to meet specific design standards to withstand avalanches, or incorporate various avalanche defense systems. Regulations may also be used to control the use and management of avalanche hazard areas. Clear-cutting or other logging operations on slopes may increase the risk of avalanches.

Prevention and Correction:

When avoidance of a hazard area is not feasible, several strategies have been developed to reduce hazards. In ski areas, slopes and weather conditions are monitored, and small avalanches are occasionally triggered through the use of explosives in an effort to minimize the hazard. Avalanche starting zones are also often stabilized through compaction by "boot packing," skiing, or machine methods.

Structural avalanche control includes the anchoring of snow pack in starting zones, the redistribution of the snow pack, or the structural protection of people and property. Many methods are costly and should be considered only as a last resort, when avoidance or other mitigation techniques are not possible.

Figures 253-19 and 253-20 show several devices used to control different parts of an avalanche-prone slope. Additionally, layer or strip terraces can be used to roughen smooth, steep slopes in order to hold the snow cover better. These horizontal terraces are usually 30 000 mm (100 ft) wide and 100 000 mm (300 ft) apart. Square miniberms arranged in a checkerboard pattern are also used for the same purpose.

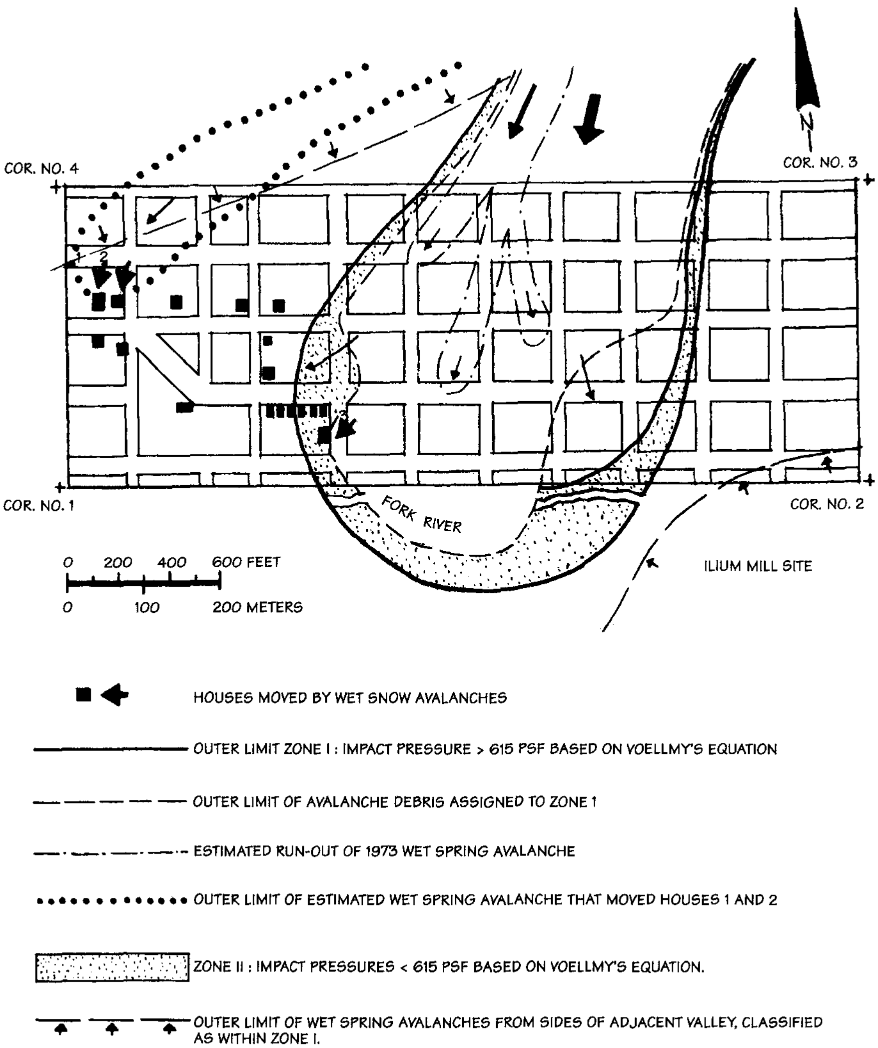


Figure 253-18. Mapping of avalanche microzonation.

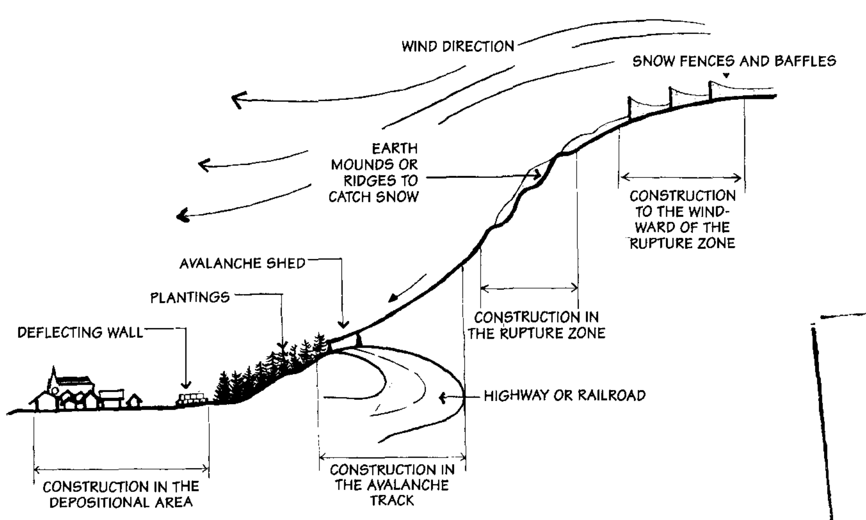


Figure 253-19. Avalanche control structures. *A number of different types of structures can be built in the rupture zone, path, and depositional site of an avalanche.*

KEY POINTS: Snow Avalanches

1. Avalanche releases typically result from natural occurrences, such as heavy snowfall or melting conditions, or from human activity, such as skiers or hikers crossing a starting zone.

2. Slab avalanches occur when a layer of cohesive snow fractures as a continuous unit and slides down the slope. These are by far the most dangerous type of avalanche due to the large volume of snow that can be released and the large area that can be affected.

3. The complex temperature and structural changes in a snow mass make it difficult to predict avalanches. However, it is possible to map high-risk areas because avalanches tend to reoccur in the same locations.

4. Avoidance of known avalanche hazard areas is the best way to prevent damage. A number of communities have developed regulations to restrict development in hazard areas.

5. Hazards can be reduced by artificially triggering small avalanches to prevent snow buildup, or by compaction of the starting zone snow to stabilize the slope.

6. Structural avalanche control strategies include the anchoring or redistribution of the snow pack, or the structural protection of people and property (Figures 253-19 and 253-20). Many methods are costly and should only be considered as a last resort.

These berms are approximately 900 mm (3 ft) square in size and are placed 900 to 1 500 mm (3 to 5 ft) apart. These areas are often reforested to provide additional surface roughness.

Although expensive, tunnels or avalanche sheds can be cost-effective when full protection is essential. Braking and deflection structures, which usually consist of heavy masonry deflecting walls or inclined permeable steel braking barriers, can be useful in the depositional area when developed areas need protection. Large-scale deflecting systems for altering the flow direction of avalanches should be designed only by specialists. They are expensive and require continual maintenance but offer maximum protection to large areas and fixed installations.

SOURCES OF TECHNICAL INFORMATION AND ASSISTANCE

American Association of Avalanche Professionals, Truckee, California.

National Landslide Information Center, Denver, Colorado.

International Landslide Information Center, Palo Alto, California.

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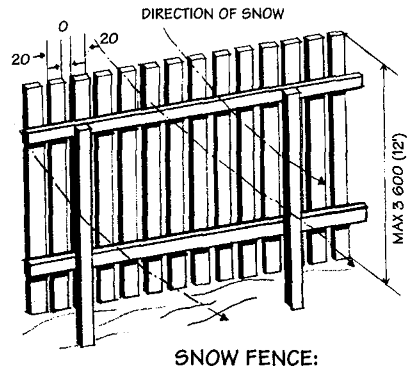
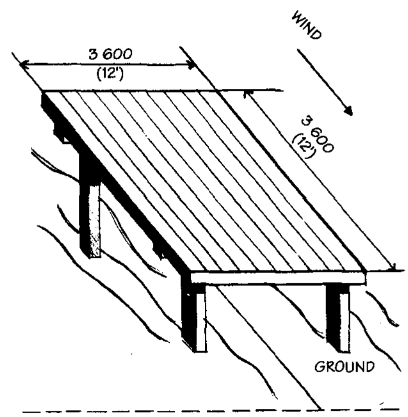
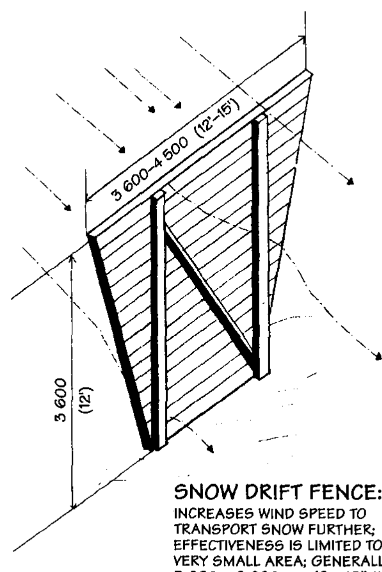


SNOW FENCE:
DIRECTS SNOW DEPOSITS ONTO DESIGNATED AREAS GENERALLY 900 mm TO 1 800mm (3 TO 6') HIGH.



JET ROOFS:
DIRECTS AND ACCELERATES THE WIND TO MOVE SNOW TO A LESS HAZARDOUS LOCATION.



SNOW DRIFT FENCE:
INCREASES WIND SPEED TO TRANSPORT SNOW FURTHER; EFFECTIVENESS IS LIMITED TO A VERY SMALL AREA; GENERALLY 3 000 – 6 000 mm (9 – 18') WIDE AND 2 000 – 4 000 mm (6 – 12') HIGH.

Figure 253-20. Snow fences and deflecting structures.

SECTION 254

Natural Hazards: Land Subsidence

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CONTENTS

1.0 GENERAL CONSIDERATIONS

Land subsidence is defined as any displacement of a generally level ground surface resulting from surface or subsurface causes. This section addresses subsidence resulting from the alteration of surface or internal loading, the removal of subsurface materials, and other subsurface failures. Tectonic activity, landslides, and expansive soils are not addressed in this section (Refer to Sections 252-Natural Hazards:Earthquakes,253-Natural Hazards: Landslides and Snow Avalanches, and 255-Natural Hazards: Expansive Soils, for additional information).

1.1 Hazards from Subsidence

The effect of land subsidence on a structure is dependent on the relationship between the dimensions of the structure and the size of the area which is subsiding. A subsidence basin of several kilometers or miles in diameter will have little effect on small structures within the subsiding area. It may, however, have serious effects on larger structures, such as canals, large bridges, roadways, railways, and drainage systems. Subsidence occurring over relatively small areas, and on short time scales have the highest potential for causing major damage.

Subsidence may lead to increased risk from other hazards, particularly increased flood risk and increased rates of coastal erosion. Surface drainage patterns can be altered, creating additional problems.

1.2 Determination of Hazard

Land subsidence and displacement can occur at a wide range of speeds and extend over areas ranging from a few square meters (feet) to thousands of hectares (acres). Detection of subsidence hazards can be difficult, because the processes that cause it can operate for long periods without visible effects. The first indications of subsidence may be changes noticed by survey crews or unusually high road maintenance demands. The precise amount of subsidence and its distribution must be determined through surveying. Detailed understanding of a particular subsidence basin depends upon the correlation of historical survey information from various sources with current survey information. Unless the historical data are very accurate, considerable uncertainty is likely.

To estimate the degree of hazard resulting from subsidence, the cause, magnitude of displacement, and the time over which movement takes place must be known. Geological and geophysical information is essential in order to estimate the hazard. Information on some types of subsidence is available from government sources; in the United States, information can be obtained from the U.S. Geological Survey, state surveys, other geologic-related agencies of states and communities, geology departments of local colleges and universities, and private consultants.

Potential hazards must typically be identified on the basis of a site-by-site evaluation, because subsidence can be caused by a variety of natural processes and human activities. City or county engineers, consulting engineers, and geologists may be sources of the types of site-specific information needed. Mine development plans on file with federal, state, or local agencies and local mining firms may indicate areas of past, present, or future underground openings. In regions of karst terrain or where mine plans do not exist, it may be necessary to undertake geophysical exploration and drilling programs to ensure that a site is free of caverns, cavities, or mine openings.

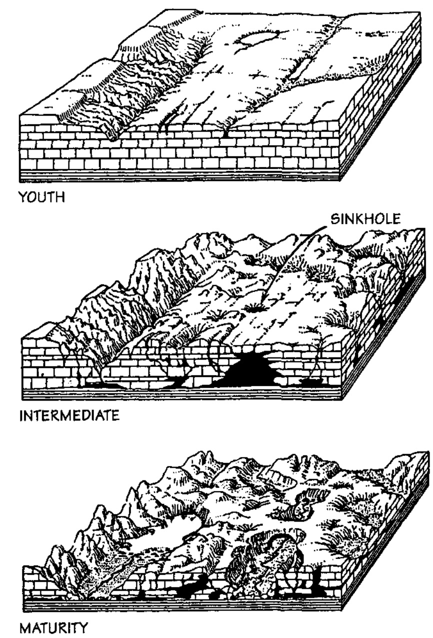

Figure 254-1. Sinkhole Formation. *Sinkholes are formed when ground collapses into subsurface cavities. Illustration shows the formation of karst topography from relative youth to maturity.*

1.3 Hazard Prevention and Correction

Hazard prevention and correction efforts must seek to reduce damage to existing development, and protect future development from the effects of subsidence. Restriction of human activities in areas identified as being susceptible to subsidence is the best overall strategy for reducing hazards and potential losses. Land use controls and zoning may be used to protect property and lives by directing intensive activities away from hazardous areas. Mining operations, groundwater use, or other potentially hazardous activities can also be directed to areas where hazard potential is low, or may require the use of methods that will reduce subsidence potential.

Existing development can be protected through a variety of mitigation and construction strategies. The type of strategy that is most appropriate is dependent on the cause of the subsidence, the type of development, and the size of the area that is affected.

KEY POINTS: Land Subsidence General Considerations

1. Detection of subsidence can be difficult, because the processes that cause it can operate for long periods without visible effects. Detailed understanding of a particular subsidence basin depends upon the correlation of historical survey information with current survey information. Unless the historical data are very accurate, considerable uncertainty is likely.
2. Restriction of human activities through zoning or other land use controls in areas identified as being susceptible to subsidence is the best overall strategy for reducing hazards and potential losses.
3. If avoidance is not feasible, development can be protected through a variety of mitigation and construction strategies, dependent on the cause of the subsidence, the type of development, and the size of the area that is affected.

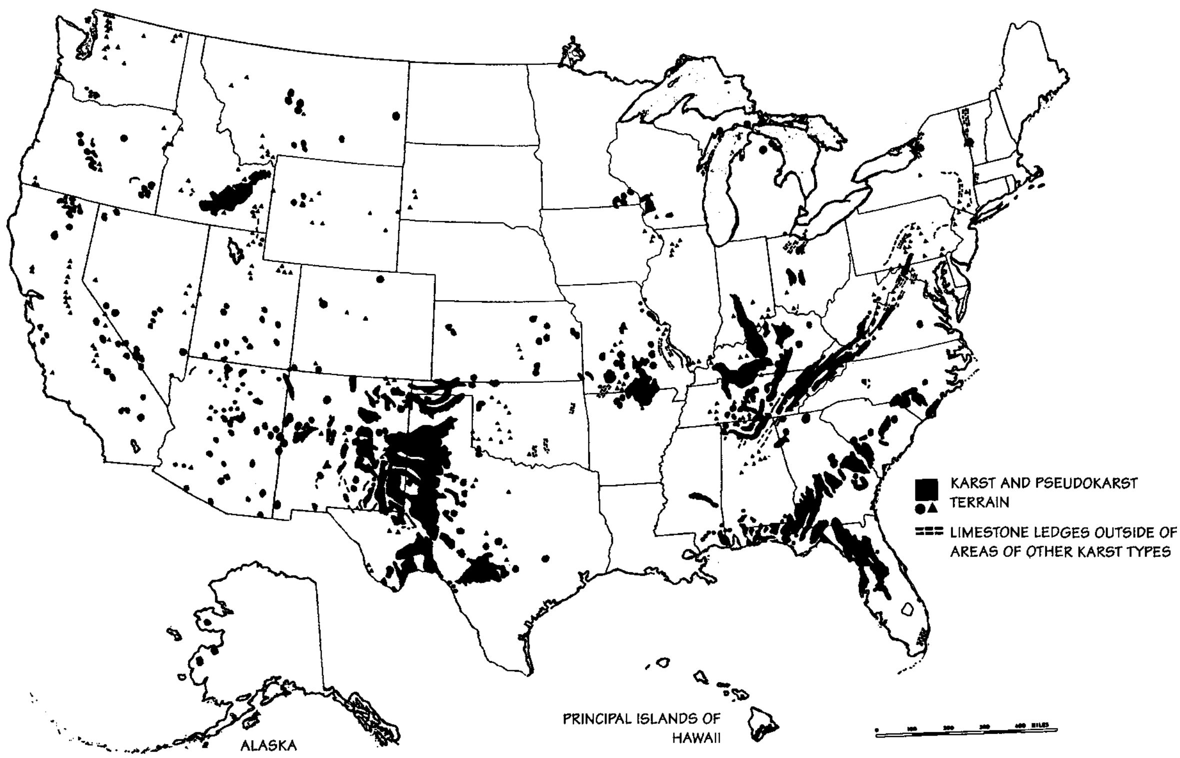

Figure 254-2. Areas of karst topography in the United States.

2.0 SUBSIDENCE CAUSED BY SURFACE OR INTERNAL LOADING

2.1 Causes

Surface loading causes slow, gradual compaction, or consolidation, of compressible materials. With suitable soil conditions, the load caused by buildings or engineering structures can cause subsidence over an area 2 to 3 times greater than their own dimension. Inadequately compacted areas of artificial fill material are subject to far greater subsidence. Old refuse dumps, spoil heaps, and filled land should be regarded as potentially hazardous. Even if properly placed and compacted, fill can be subject to subsidence if it lies over a mud layer that can compress under a load or flow out from beneath the filled area.

2.2 Estimation of Hazard

The amount of compression and the time over which it occurs must be investigated to determine the potential hazard. The total amount of compression that will occur is calculated based on the compressibility of the soil layer, its thickness, and the magnitude of the load. The calculation of how the compression of the soil layer develops with time is complex and, if the compressible material is saturated, depends upon the movement of water in the soil. The rate at which drainage can take place depends on the permeability of the soil and on the availability of drainage boundaries. Free-draining granular soils will settle very quickly. Clays and silts of low permeability will allow water to escape very slowly, and settlement may take months or years. Geotechnical engineers should be consulted to calculate anticipated compression.

2.3 Mitigation

Laboratory testing of soil samples can be used to predict the total settlement and the behavior of the soil based on anticipated loading. Where settlement caused by the weight of material on the ground surface is anticipated, analyses are performed to ensure that the design of the structure can withstand forces resulting from differential settlement. If the total settlement is expected to be more than a few millimeters or inches, precautionary measures are taken.

KEY POINTS: Subsidence Caused by Surface or Internal Loading

1. Inadequately compacted areas of artificial fill are subject to subsidence from surface loading. Old refuse dumps, spoil heaps, filled land, and other compressible materials should be regarded as potentially hazardous.

2. The total amount of compression that will occur is calculated based on the compressibility of the soil layer, its thickness, and the magnitude of the load. Geotechnical engineers should be consulted to calculate anticipated compression.

3. If the total settlement is expected to be more than a few millimeters or inches, precautionary measures are taken. These measures may include placing structures on pilings, placing structures on floating foundations, or consolidation of base prior to construction.

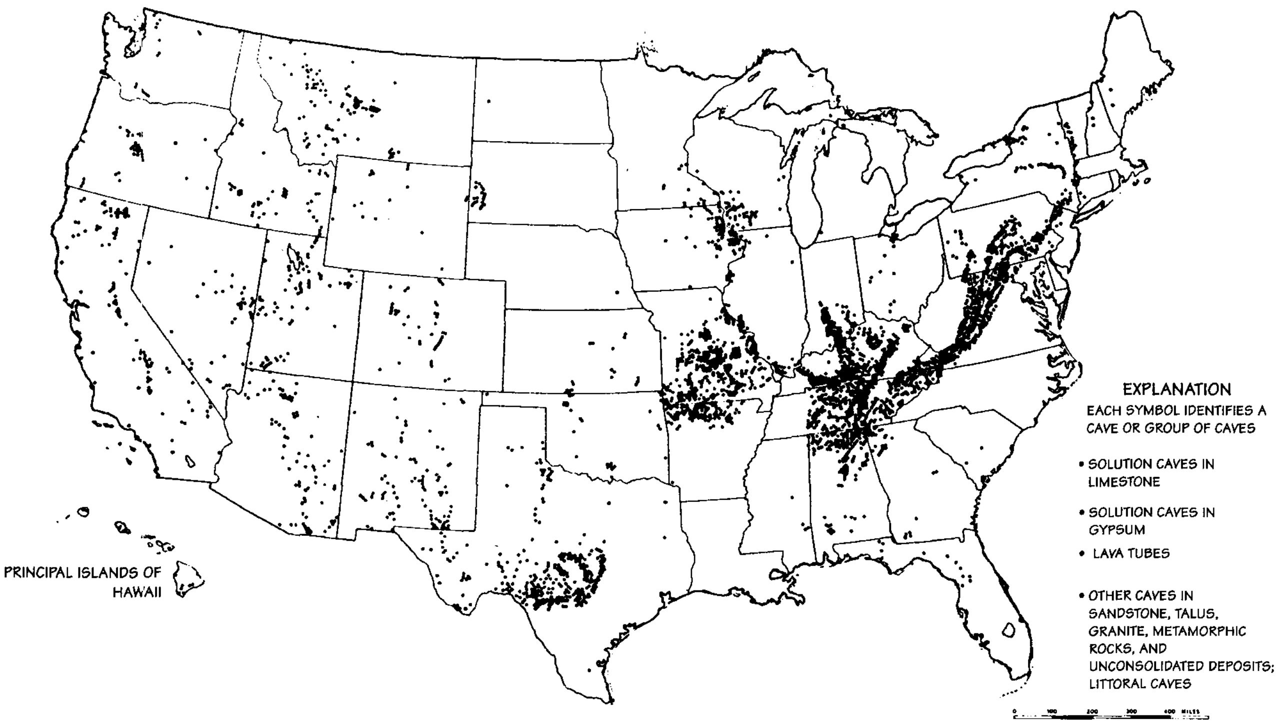

Figure 254-3. Areas of known caverns in the United States.

These measures may include:

1. Placing structures on pilings. The structure may be founded on piles which carry its weight to a non-compressible stratum.
2. Placing structures on floating foundations. The structure is designed with a deep basement, so that the weight of the excavated material is equal to the weight of the building.
3. Consolidation prior to construction. In some cases, a load equal to the weight of a structure, usually in the form of an earth fill, is applied to the site in advance of construction. When settlement has occurred, the weight is removed and construction is begun.

Geotechnical engineers should be consulted to determine the most appropriate mitigation strategy.

3.0 SUBSIDENCE CAUSED BY REMOVAL OF SUBSURFACE MATERIALS

The removal of subsurface materials as a result of natural processes or of human intervention can cause significant subsidence. Natural processes that remove subsurface materials include subterranean solution withdrawal and volcanic activity. Human activities, such as underground mining and solution mining result in similar hazards created by the existence of underground voids and cavities. The removal of water, oil, and gas generally does not create large subsurface voids, but causes widespread lowering of surface levels.

3.1 Subterranean Solution Withdrawal and Volcanic Activity

Subsurface deposits of limestone and other carbonate rocks are subject to solution in groundwater, particularly in hot, humid climates. Underground voids called solution cavities are created as mineral material is carried away dissolved in groundwater. Where the cavities are shallow or the overlying material is weak, collapsing areas result in surfaces sinkholes and depressions.

Figure 254-1 illustrates the formation of sinkholes. The characteristic pockmarked topography resulting from the widespread presence of limestone in a humid climate is called karst topography. Figure 254-2 shows the general distribution of karst and pseudokarst topography in the United States.

Volcanic activity can also cause a similar effect. Lava flows that reach the earth's surface, cool and solidify, can result in a hollow structure if the molten material is not replaced by later flows. These voids are generally created in the form of shallow

KEY POINTS: Subsidence Caused byRemoval of Subsurface Materials – Natural Processes

1. Sinkholes and depressions can form in areas of karst topography, where large subsurface deposits of limestone dissolve in ground water and create underground cavities susceptible to collapse. (Figure 254-1).
2. Volcanic activity can cause a similar effect as hollow lava tubes are formed when molten material surfaces and is not replaced by later flows.
3. Subsurface cavities may be located by electrical, seismic, or gravimetric methods or by direct boring of test holes. Ground surfaces adjacent to these subsurface cavities may also be subject to subsidence.

tunnels, called lava tubes, and overlying areas are subject to collapse.

Figure 254-3 shows areas of solution caves, areas where lava tubes are common, and other known caverns in the United States. Subsurface cavities may be located by electrical, seismic, or gravimetric methods or by direct boring of test holes. Ground surfaces adjacent to but not directly over subsurface cavities may also be subject to subsidence. The width of this area varies, depending upon local conditions.

3.2 Underground Mining

Underground mining of solid materials, particularly shallow coal workings, is a significant cause of subsidence hazard. Construction of a tunnel close to the surface typically results in surface settlement. If the material into which the tunnel is driven is weak or inadequately supported, a process called caving or stopping can occur, in which rock in the roof collapses, leaving a void above it. Repeated caving results in the void migrating upward, eventually resulting in the formation of a sinkhole at the surface. Figure 254-4 shows the effect of the collapse of a relatively deep mine.

Figure 254-5 shows the general locations of coal fields in the United States. In regions where coal is present, subsidence resulting from previous mining activities should be regarded as a potential hazard. If abandoned mine workings are located on a site, several engineering methods have been developed to overcome the problem. It is always expensive, however, and many methods involve considerable uncertainty. Avoidance of such a site is preferred.

Calculation of anticipated subsidence resulting from tunneling or mining is particularly difficult because of the limited knowledge of conditions at the time of tunneling (which affects stresses in the surrounding materials), the material properties involved, and complex spatial considerations. Often, records of mining operations are incomplete, and identification of exact tunnel locations is difficult.

Pillar and stall mining, also referred to as room and pillar mining, is a common extraction method. As coal is removed, rectangular pillars of coal are left at intervals to support the roof of the workings, creating an underground maze of caverns. In cases where future subsidence must be prevented, shallow workings can be grouted with an injection of cement slurry. Grouting is very expensive and can be ineffective if water is present underground; it can also be difficult to control the flow of grout and to verify that the grouting operation has been successful.

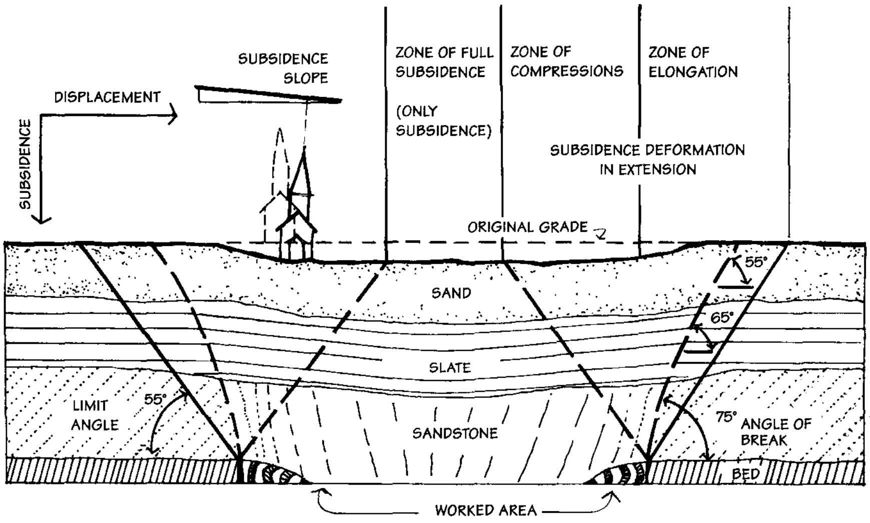

Figure 254-4. Subsidence due to mine collapse. *The limit angle is defined by the line joining the edge of the collapsed area underground to the edge of the area of surface sinking. The angles of break will vary depending upon the geological characteristics of the rock formations.*

Figure 254-6 illustrates a method for injecting a slurry of water and sand or other material, using a hydrostatic pumping technique which allows a more complete filling of voids and which can require only a single injection well for an area of up to 1.2 ha (3 acres). Grouting may require injection points only a few meters or yards apart.

3.3 Solution Mining

The removal of subsurface materials by solution mining can cause a serious subsidence hazard, made particularly difficult to manage because of the difficulty of identifying the limits of the affected area. Solution mining is the removal of water soluble materials such as salt, gypsum, or potash from beneath the surface by an injection of water which dissolves the material. The solution is then pumped to the surface and the water is evaporated, leaving the desired material. The resulting subsurface voids can be very large and are subject to collapse, much like the naturally occurring cavities in limestone regions.

KEY POINTS: Subsidence Caused by Removal of Subsurface Materials – Human Activities

1. Mining may result in a maze of underground caverns, making prediction of subsidence difficult. Grouting or other techniques that fill known voids may be used in areas where future subsidence must be prevented.

2. The removal of subsurface materials by solution mining can cause a serious subsidence hazard that is particularly difficult to assess because of the difficulty of locating the limits of the affected area.

3. Construction should be avoided in areas susceptible to piping (subsurface drainage conduits occurring in relatively insoluble soils as a result of the passage of sediment-laden water). If construction is necessary, avoiding a concentration of runoff in vulnerable areas is essential.

4. In areas where the withdrawal of groundwater by wells is causing subsidence, the development of a surface water supply system may be necessary.

5. Subsidence caused by the withdrawal of oil, gas, or water has been reduced or arrested by the addition of imported water to subsurface sediments, replacing the material that was withdrawn.

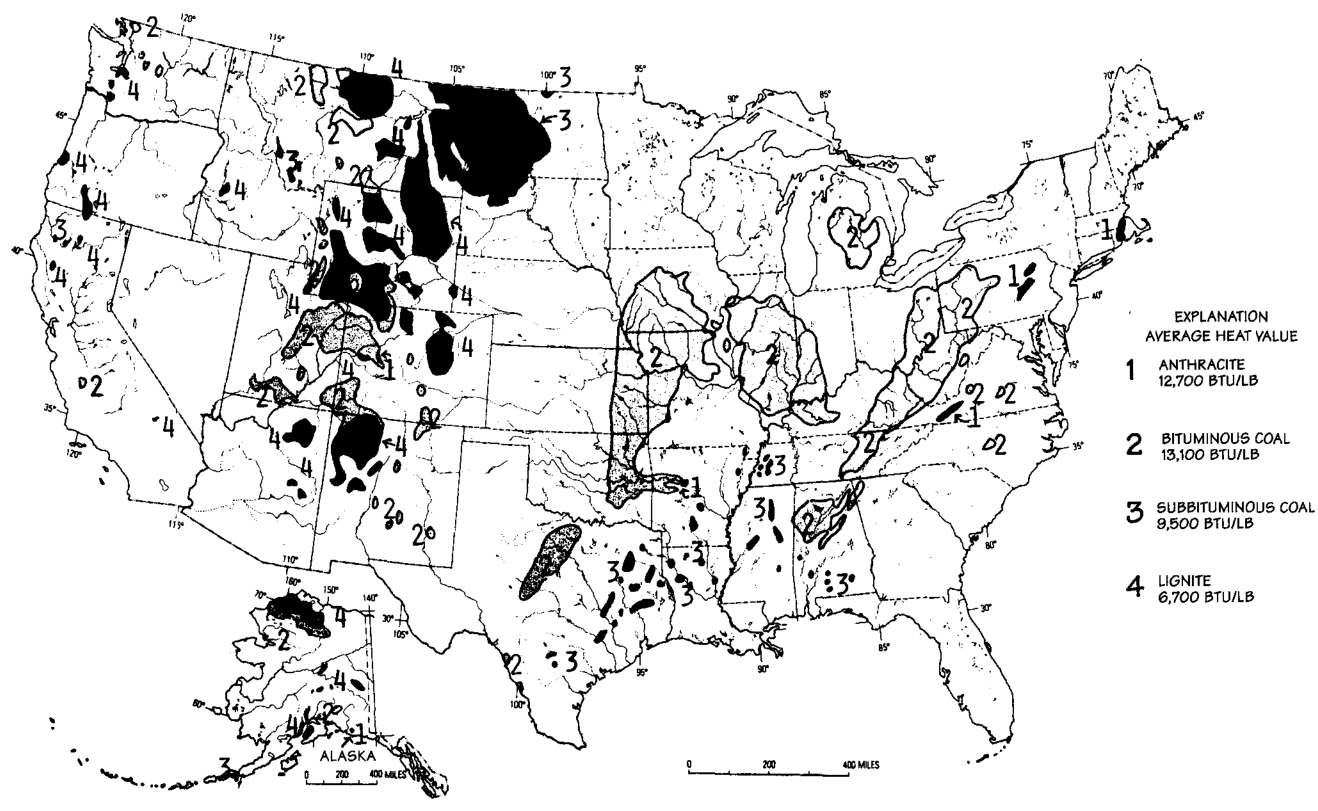

Figure 254-5. Location of coalfields in the United States.

3.4 Piping

Piping is the term used to describe subsurface drainage conduits occurring in relatively insoluble soils as a result of the passage of sediment-laden water. Piping occurs in relatively weak, incoherent soil layers, such as loess, tuff, volcanic ash, fine-grained alluvium or colluvium, and some rocks (claystone, mudstone, and siltstone). Water moving through saturated layers toward either a naturally occurring or constructed free face carries with it some sediment in suspension. As the water removes material, drainage is directed to the more permeable area, resulting in the formation of a small hole on the free face, which, as drainage continues, expands into the cliff, ultimately causing substantial underground voids. Collapse and subsidence may occur, in some cases, creating a pseudokarst topography. Figure 254-7 shows highway damage resulting from piping in the southwestern United States.

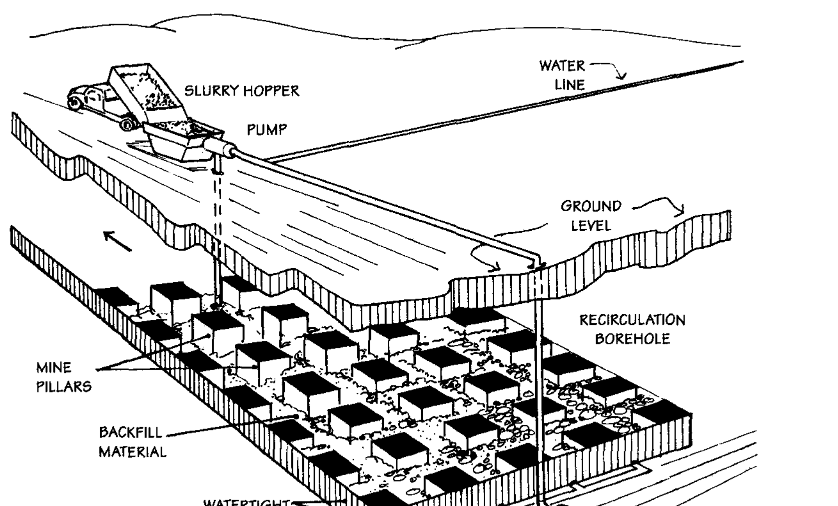

Figure 254-6. Hydraulic backfilling of an abandoned coal mine.

Piping is classified into three types, based on its mode of origin:

1. Desiccation, with stress cracks: soils which become dry and cracked are subjected to rainfall which enters the cracks and travels to a free face, forming drainage conduits.
2. Entrainment: occurs when dewatered building foundations or a rise in water level behind or under dams or levees causes changes in hydraulic head pressures and subsequent subsurface channeling. Entrainment of water and saturated materials to downgradient outflow points can result in sand boils, mud volcanoes, and a collapse of sediment and overlying structures.
3. Variable permeability subsidence: occurs when sufficient hydraulic head

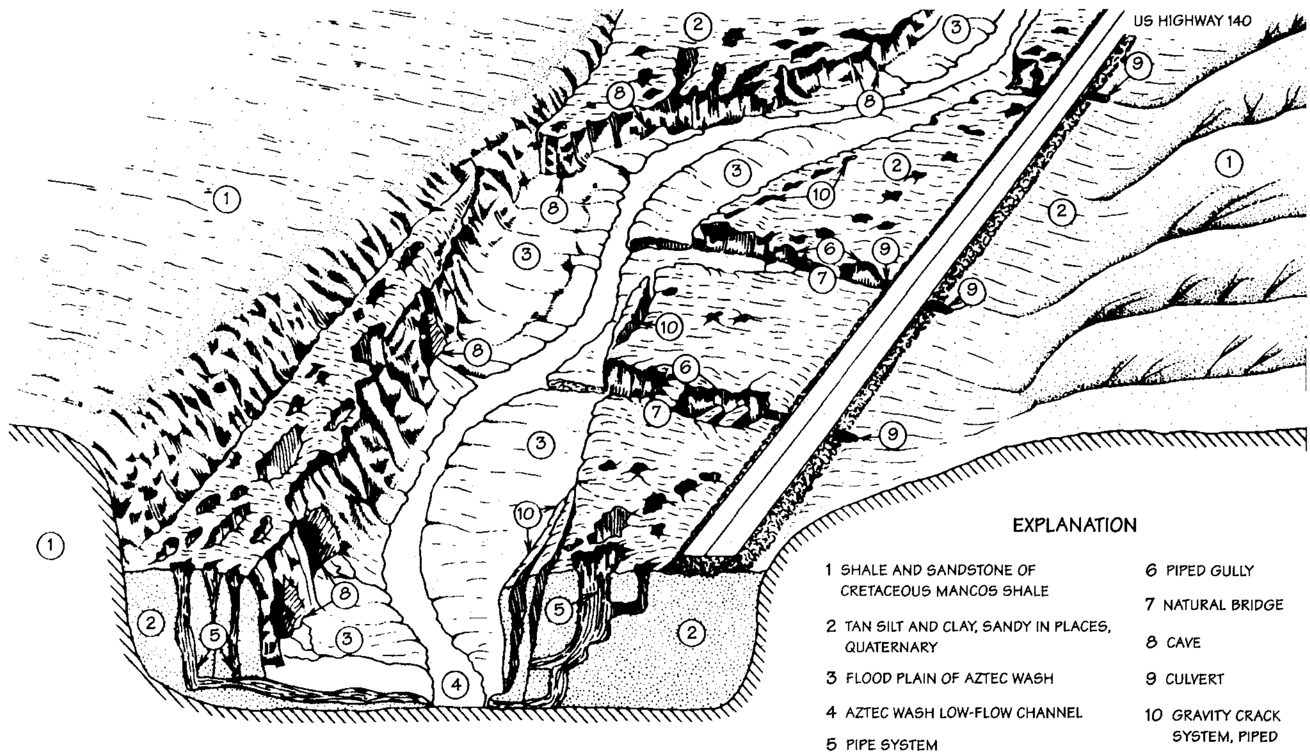

Figure 254-7. Structural failure of highways (western United States) caused by piping of valley fill.

exists to move sediment-laden water through a stratum to the face of a gully or embankment. The conduits formed in this way grow from the outlet back into the cliff face.

Construction should be avoided in areas where piping is likely. If construction is unavoidable, the careful design of drainage systems to avoid a concentration of runoff in vulnerable areas is essential. Runoff should be conveyed in closed culverts to points away from vulnerable structures.

3.5 Removal of Water, Oil, and Gas

The removal of water, oil and gas can cause significant displacement over a widespread area. The amount of subsidence depends on the amount of material removed, the depth of the layer from which it is extracted, and the stiffness or rigidity of the overlying soil materials. Generally, water is removed from shallower layers of fairly compressible materials, and gas and oil are removed from deeper layers of less compressible material.

When water is withdrawn from a well, the water level is lowered, reducing the pore pressure and allowing the soil material above to compress the water-bearing strata. If a single well is used, a dish-shaped depression results. If a large well field is operated, widespread vertical displacement can occur, resulting in severe damage to utilities and large structures, as well as disrupting surface drainage patterns.

Engineering methods can be used to reduce the subsidence hazards resulting from the withdrawal of water, oil, or gas. In areas where the withdrawal of groundwater by wells is causing subsidence, the development of a surface water supply system may be necessary.

Subsidence caused by the withdrawal of oil, gas, or water has been reduced or arrested by the addition of imported water to subsurface sediments, replacing the material that was withdrawn.

4.0 SUBSIDENCE IN PERMAFROST ZONES

Subsidence is also a hazard in regions of permafrost or where large masses of underground ice exist. At temperatures below freezing, large blocks of ice provide stable support. When permafrost is disturbed or subjected to warming, thawing decreases its support of overlying soils and causes subsidence. Soil particles formerly held together by ice are freed, resulting in subsidence as free-flowing water accumulates at the surface or drains away, leaving lowered levels of saturated soils. Disturbed areas can turn into mud-filled depressions that expand with each season's thaw. In winter, effects include heaving, the formation of ridges and ice dikes, as water trapped between the permanently frozen strata and the recently frozen surface expands upon freezing. Subsidence will then occur during the spring thaw.

Figure 254-8 shows areas in the northern hemisphere of continuous permafrost (where the entire seasonally thawing layer refreezes each winter) and of discontinuous permafrost (where the seasonal thaw layer does not totally refreeze to the depth of the permanently frozen layer). Figure 254-9 gives a block diagram of permafrost morphology.

A number of engineering strategies have been developed to overcome the difficulties encountered in permafrost regions. Granular frozen permafrost, in which soil grains are in contact with each other and excess ice is not present, typically causes few serious engineering difficulties. Hard frozen permafrost, where some water remains unfrozen, does present problems. Common approaches in these conditions are to thaw the area and remove the excess water, or to maintain the permafrost in its natural thermal condition. Preservation of permafrost can be achieved by ensuring that no additional heat is introduced into the ground. Construction may be carried

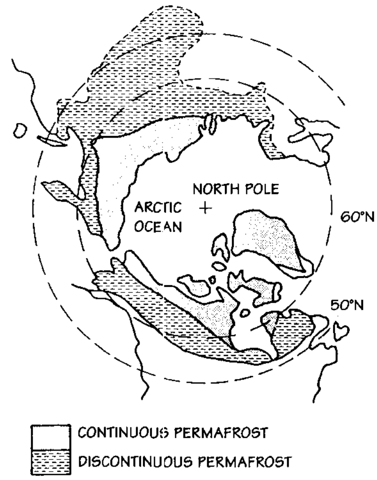

Figure 254-8. General distribution of permafrost in the northern hemisphere.

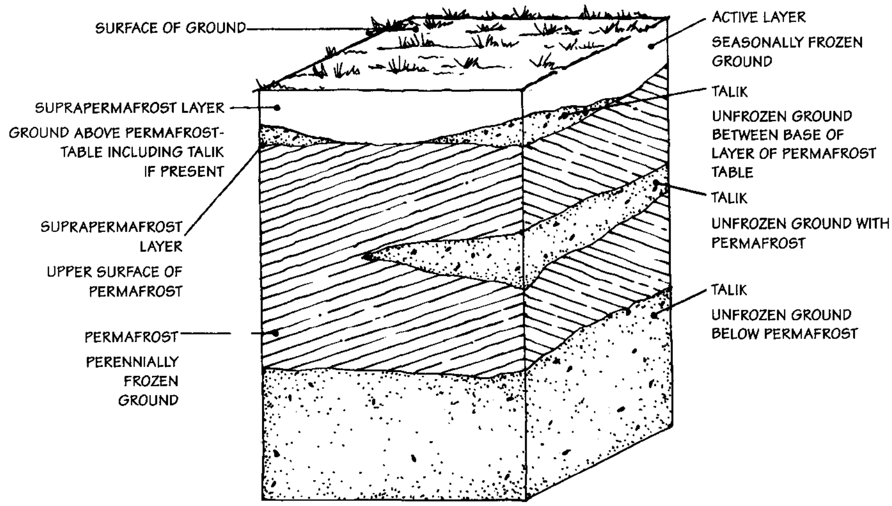

Figure 254-9 Block diagram of permafrost morphology.

out on an insulating pad of gravel over the site or may be raised on thermally isolated pilings.

Preservation of existing vegetation in permafrost regions is particularly important, since its removal will allow direct sun to heat the surface and cause increased seasonal thawing.

5.0 SUBSIDENCE CAUSED BY COLLAPSING OR HYDROCOMPACTIVE SOILS

Collapsing soils are those that rely on a water soluble mineral cement to maintain their strength. When wet, the mineral cement dissolves and these soils collapse, leaving a bumpy terrain. Loess and some other soils of a loose, open structure are subject to this type of subsidence.

A similar effect is observed in hydrocompactive soils. In arid regions, alluvial fan deposits and soils which were originally deposited as a result of mudflows or mudslides and have a loose structure containing a relatively large quantity of air can form hydrocompactive soils. Wetting causes a reorientation of the soil particles and can result in significant subsidence [4.5 m (15 ft) in California after the introduction of irrigation water].

In regions where hydrocompactive soils or collapsing soils are common, site-specific geologic reports that assess potential subsidence should be obtained.

These soils should be avoided for most types of development. When avoidance is impossible, a common engineering approach is to compact the area by the addition of water prior to construction. Maintenance of existing structures depends on strict management of surface water.

6.0 SUBSIDENCE CAUSED BY ORGANIC SOILS

Highly compressible organic soils are subject to subsidence due to the withdrawal of water. The drainage of marshes for agricultural purposes and the dewatering of peat bogs has resulted in widespread subsidence, usually resulting from the combined effects of drying, oxidation, and wind erosion.

Organic soils should be avoided for most construction purposes. When unavoidable, common approaches are either to dump solid fill material on the site until settlement ceases or to replace the soft material with suitable fill.

KEY POINTS: Subsidence Caused by Permafrost or Soil Conditions

1. When permafrost is disturbed or subjected to warming, thawing decreases its support of overlying soils and causes subsidence. Common approaches in these conditions are to thaw the area and remove the excess water, or to maintain the permafrost in its natural thermal condition.

2. Hydrocompactive and collapsing soils may caused subsidence due to excessive moisture. These soils should be avoided for most types of development. When avoidance is impossible, a common engineering approach is to compact the area by the addition of water prior to construction.

3. Highly compressible organic soils are subject to subsidence due to the withdrawal of water. These soils should be avoided for most construction purposes. When unavoidable, common approaches are either to dump solid fill material on the site until settlement ceases, or to replace the soft material with suitable fill.

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Natural Hazards: Expansive Soils

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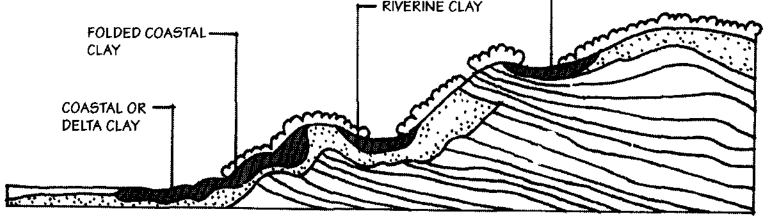

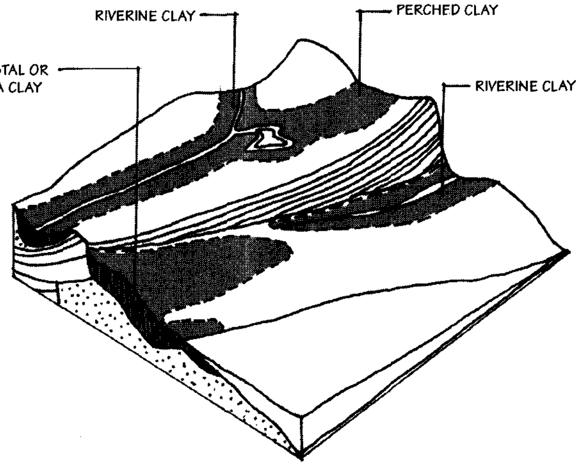

CONTENTS

1.0 GENERAL CONSIDERATIONS

Soils and soft rocks which shrink or swell as a result of changes in moisture content are commonly known as expansive soils. Expansive soils are usually clays, but some types of shales also exhibit shrinking and swelling. Aluminum silicate minerals of volcanic origin decompose to form expansive clays of the smectite group, the best known of which is montmorillonite. Pure montmorillonite may swell up to 15 times its dry volume, but most natural soils contain other materials that swell less. Few natural soils swell to more than 1-1/2 times their original volume (Figure 255-1). For more data about soils in general, refer to Section 810: Soils and Aggregates.

To represent a hazard due to shrinking and swelling, the soil must:

1. Contain a mineral component which is subject to significant swelling.
2. Experience fluctuating changes in moisture content.
3. Exert significant movement due to a thick soil strata.

Volume increases of 3 percent or more are potentially damaging and require specially designed foundations. In the United States, the majority of houses built on expansive clays suffer minor damage, and up to 10 percent will suffer major damage. Property damage caused by expansive soils exceeds the damage from floods, hurricanes, tornadoes, and earthquakes combined. Roads, bridges, pipelines, and other rigid structures which rest on or pass through expansive soils are also affected.

Uneven moisture distribution throughout the soil and subsequent pressure changes will create problems during construction. Small buildings, bridges, and roads impose minor loads on expansive soils in comparison to its swelling pressures, which may exceed 480 000 Pa (10,000 psf).

Expansive soils create differential movement under structures. Seasonal changes in moisture and water-table levels cause expansive soil to move under natural conditions. This zone of seasonal change can extend to a depth of about 2 m (7 ft). Normal seasonal change and drying (desiccation) are usually prevented once an area is covered by a road or structure. Desiccation and wetting still occur around the perimeter but gradually decrease toward the center.

Other common characteristics of differential movement include:

1. Doming or downward-warping of soil occurs as the soil shrinks at the perimeter (Figure 255-2).

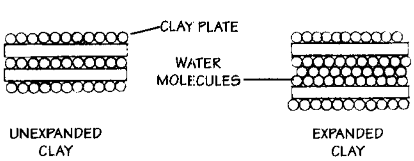

Figure 255-1. Diagram of a Montmorillonite Clay Particle. *Note that water is incorporated within the clay structure itself.*

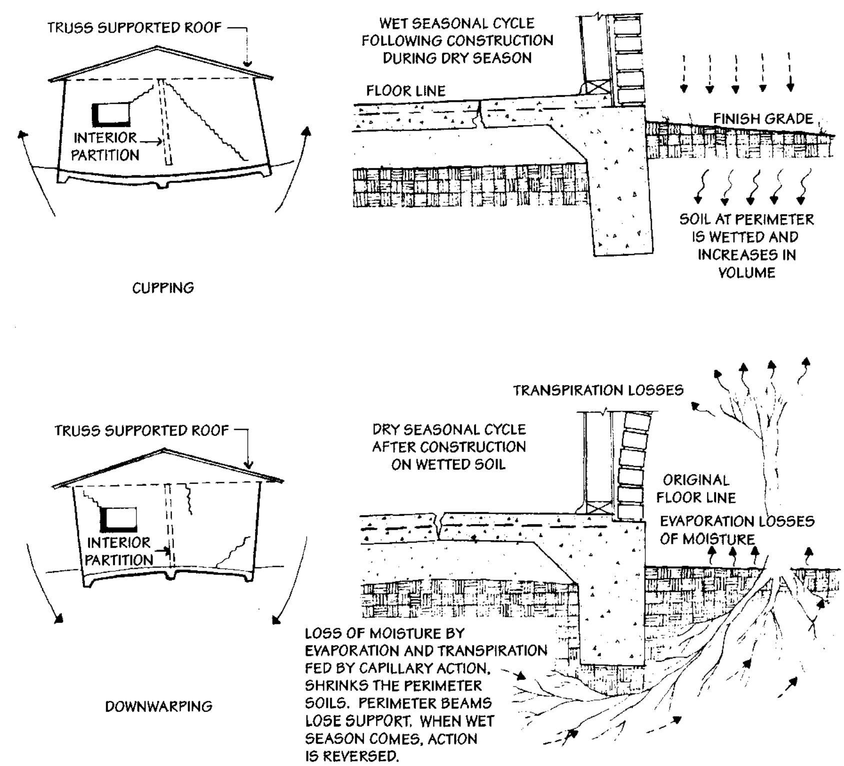

Figure 255-2. Heaving Patterns Beneath Structures with Slabs on Grade. *The problems with expansive soils varies with the amount of natural rainfall and depth of water table.*

KEY POINTS: Characteristics of Expansive Soils

1. Expansive soils that shrink or swell as a result of changes in moisture are usually clays, but some types of shales also exhibit shrinking and swelling.
2. Most expansive soils will swell to more than 1-1/2 times their original volume when wet, and apply swelling pressures that may exceed 480 000 Pa (10,000 psf). Volume increases of 3 percent or more are potentially damaging to structures and require specially designed foundations.
3. When roads or structures are placed on expansive soils, desiccation and wetting occur around the perimeter, resulting in doming, warping, or cupping (Figure 255-2).

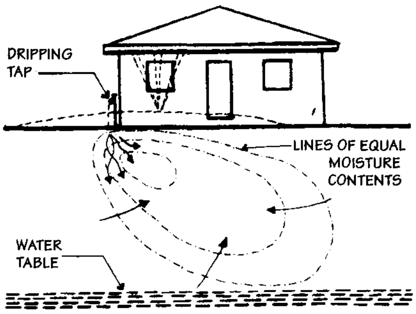

Figure 255-3. Distorted Heaving Pattern. *Where sources of water vary from one side of a slab to another.*

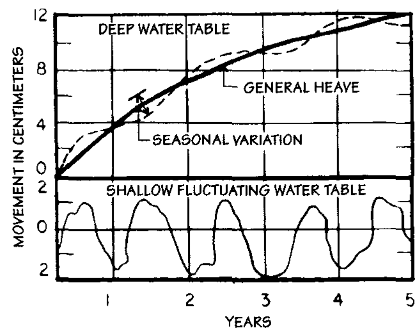

Figure 255-4. Relationship between soil heave and fluctuations of rainfall and water table.

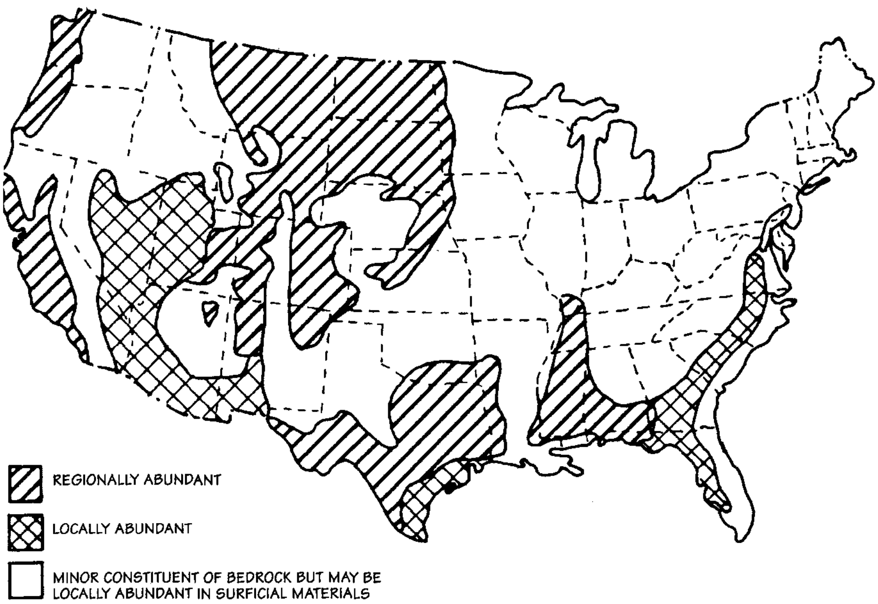

Figure 255-5. Generalized Map of Expansive Soils in the United States.

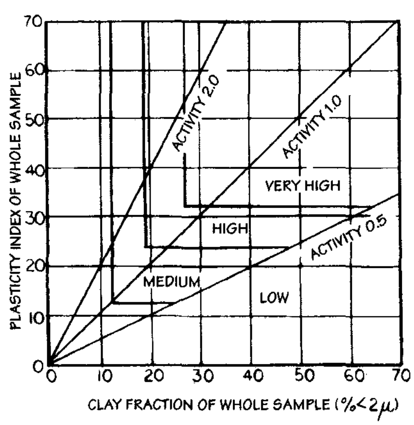

Figure 255-6. Plasticity index versus soil composition as an indicator of the severity of soil expansivity.

2. Cupping results from wetting formerly dry areas at the perimeter (Figure 255-2).

3. Asymmetrical soil patterns (Figure 255-3) related to:

   a. leaking water or sewer connections

   b. shade patterns created by structures

   c. surface runoff from adjacent slope collecting against a building or roadway.

Two forms of heaving exist, superimposed on each other. These are general heave and seasonal heave (Figure 255-4).

2.0 ESTIMATION OF HAZARD

Figure 255-5 shows a generalized map of expansive soil hazards in the United States. Small local deposits are not shown, and careful site investigation is required if there is reason to suspect the presence of expansive soils.

Professional geotechnical engineers should be consulted for positive identification of expansive soils. A combination of several signs should indicate its presence including:

1. The soft, puffy, popcorn appearance of clay soil when dry

2. Soil that is very sticky when wet

3. The presence of substantial open cracks in dry clay soil

4. Soil that is very highly plastic and weak when wet, but rock hard when dry

Existing structures in the vicinity should be inspected for signs of damage which could indicate expansive soils.

The soil plasticity index (Figure 255-6, and further described in Section 810: Soils and Aggregates) is an indicator of a soil's tendency to expand based on the percentage of clay in a sample. It can be used to estimate the severity of the problem. The plasticity index (PI) indicates expansivity as follows:

PI	Expansivity
0–14	Non critical
14–25	Marginal
25–40	Critical
Over 40	Highly critical

However, the plasticity index alone does not adequately define the expansive potential of a soil profile. A thorough understanding of the soil structure and depth of the active zone is necessary in order to predict the expansive potential of a given site. Consideration must be given to geologic, ground water, and soil conditions at each site prior to selecting a foundation design.

Laboratory testing can give a precise estimate of expansion potential. Several methods of testing have been developed to estimate heave on a particular site.

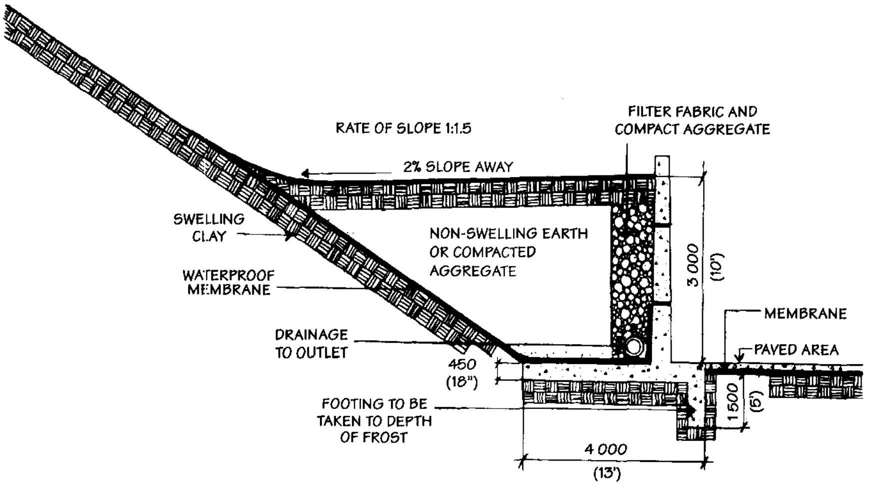

Figure 255-7. Design of retaining wall in swelling clay soil.

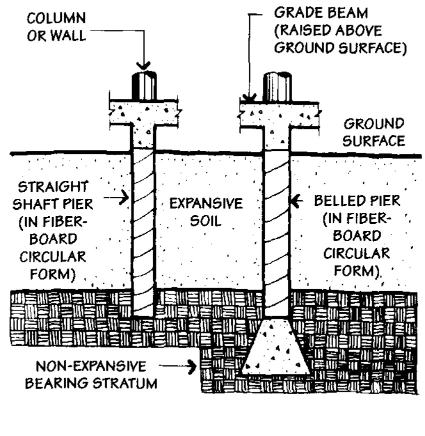

Figure 255-8. Two types of machine-drilled piers.

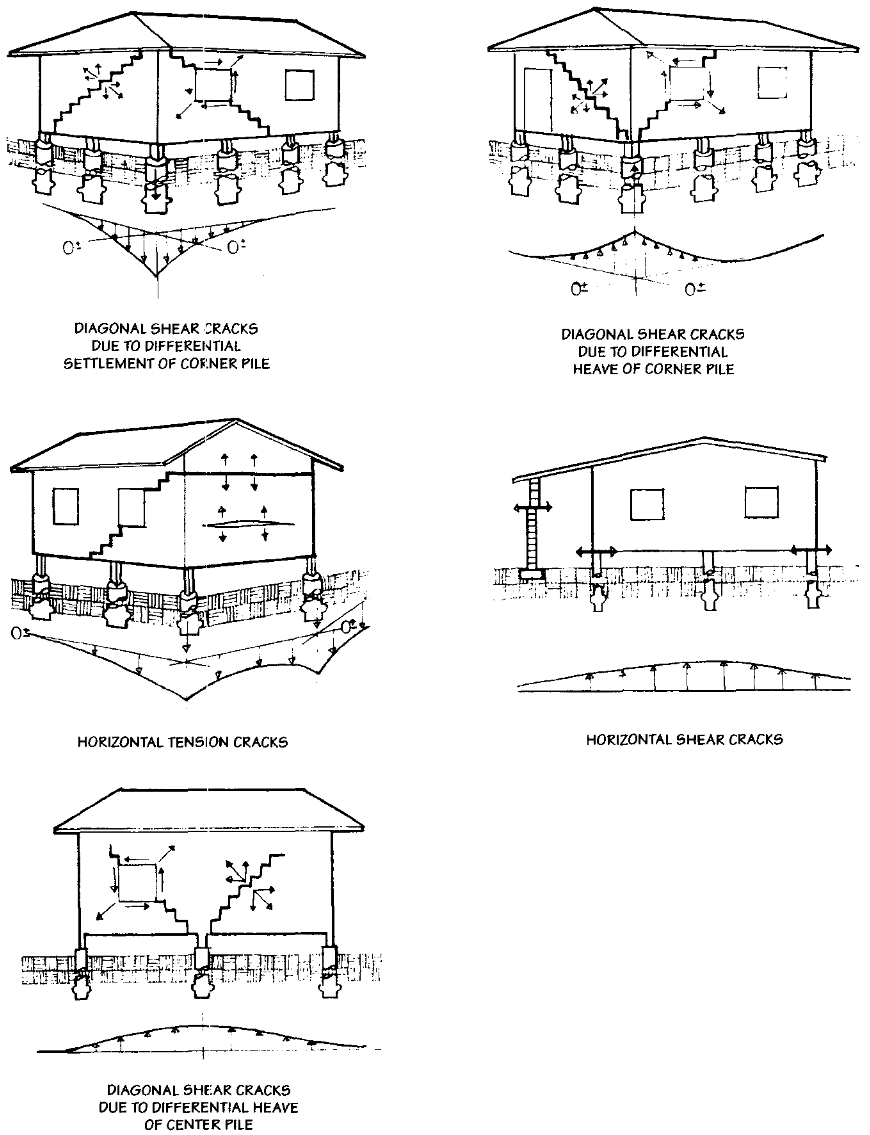

Figure 255-9. Failures of buildings caused by movement of pile foundations.

3.0 LOSS PREVENTION AND REDUCTION

A comprehensive approach tailored to particular site conditions for reducing damage is recommended.

3.1 Avoidance of Hazardous Sites

The best method to prevent loss from expansive soils is to find an alternative construction site. If this is not possible, a number of strategies for coping with expansive soils have been developed.

3.2 Isolation from Expansive Soils

Damage can be prevented by isolating structures from the stresses caused by the shrinking and swelling of expansive soils. It may be feasible to excavate and replace soils with non-expansive fill in areas where the stratum of expandable soil is relatively shallow. If the stratum is deep, it may be effective to excavate a greater than normal depth of soil, backfill with non-swelling material, and immediately cover it to prevent drying.

Expansive soils also create horizontal stresses when confined by vertical structures such as basement walls or retaining walls. Figure 255-7 shows the recommended practice for construction of large retaining walls in areas of expansive soils. The procedure to control changes in soil moisture behind the wall is to remove the expansive material, replace it with non-swelling material, and install waterproof membranes.

The intended structure may be placed on piers encased in fiberboard circular forms which are founded in the non-expansive bearing stratum and effectively isolate the structure from the effects of unequal movement and uplift forces (Figure 255-8). Piers may be preferable to pilings to avoid the heave and vibration associated with pile driving.

Pier or pile foundations should be designed by a qualified engineer, since improper design can result in serious failures of buildings and other large structures (Figure 255-9). Piers or piles are subject to upward forces produced by expansive soils. These forces must be resisted by the load on the pier or pile, or by the restraining force of the foot of the bellied pier, as shown in Figure 255-8.

3.3 Flexibility in Design

The design of structures to accommodate the heaving by expansive soils includes the use of floating slabs in basements (Figure 255-10) and the provision of clear space under slabs on-grade.

Figure 255-11 shows two types of fiberboard void forms, which are available in various thicknesses, usually 100, 150, and 200 mm (4, 6, and 8 in). These forms are strong enough to support the weight of fresh concrete placed over them, but under pressure from expanding soil below they are weak enough to crush and allow the soil to move freely. Figure 255-12 shows a typical use of void forms to isolate a concrete slab from expansive soil. Since the slab is not supported on soil, it must be designed to span between piers under gravity (down) loads. The size of void required is based on the estimated vertical rise of the soil beneath the structure.

Another approach uses rigid elements joined by flexible ones which can accommodate movement. Elements which bridge from a rigid protected structure to the ground surface should be isolated from the main structure by use of a flexible filler to absorb movement, thereby protecting the structure from damage. Figure 255-13 illustrates the entry steps of a house built on piles.

Underground utilities are also subject to disruption from expansive soils. It is particularly important to assure stable drainage connections to avoid the leakage into sensitive soils. Figure 255-14 shows one approach to making drainage connections.

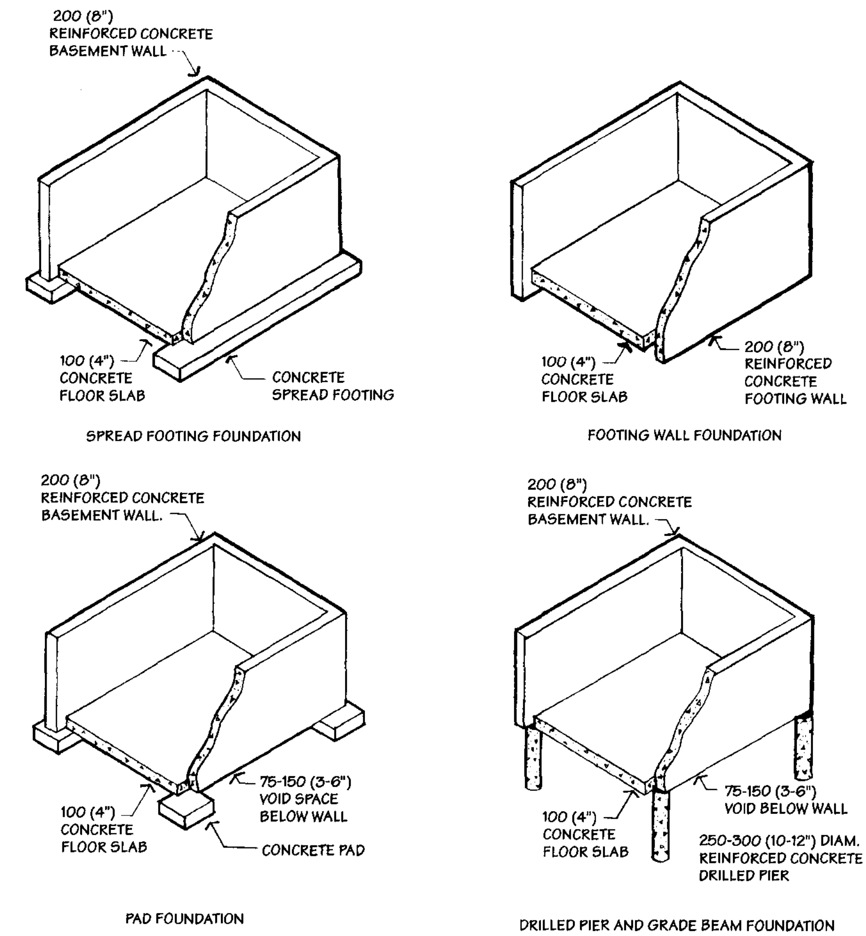

Figure 255-10. Four Alternative Designs for Residential Basements. *In all cases a floating floor slab may be used; otherwise, an air space of several inches is left beneath to permit soil swell.*

3.4 Soil Treatments to Reduce Potential Volume Change

Compaction:

The compaction of expansive soils may reduce its permeability. Compaction can slow the subsequent expansion of soils which have a low to moderate expansion potential. It is most effective on granular, non-cohesive soils. In some cases, compaction at high degrees of saturation is accompanied by changes in soil structure, which in turn affect swelling characteristics. A kneading compaction to a moderate density by a sheepsfoot roller under wetter than optimum conditions, may result in less swell. The excavation and recompaction of existing soil prior to its use as subgrade may be necessary.

Compaction should be done with caution, however, since the overcompaction of very active soils can result in rebound, which will exaggerate the swelling effects. Laboratory tests to determine the effects of compaction should be based on the soil structure as found on the site.

Prewetting:

The prewetting of a site prior to construction either by ponding or spraying has proven successful in controlling expansivity. Wetting is intended to bring the moisture content of the soil to the level expected at equilibrium after completion of construction. This requires a knowledge of the swelling characteristics of the soil and the distribution and magnitude of the loads to be applied.

This method has several drawbacks. A period of 30 days is typically required to allow the wetting to penetrate to a depth of 1 200 to 1 500 mm (4 to 5 ft). When the wetting has been completed, the site may be so soft and sticky that construction equipment cannot function effectively. Soil strength may be reduced to the extent that

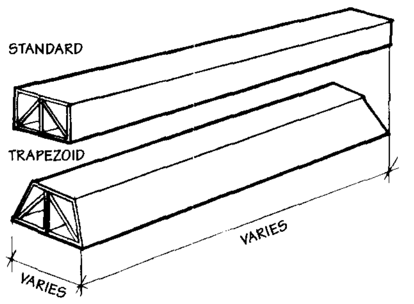

Figure 255-11. Typical folded "void forms" made of fiberboard.

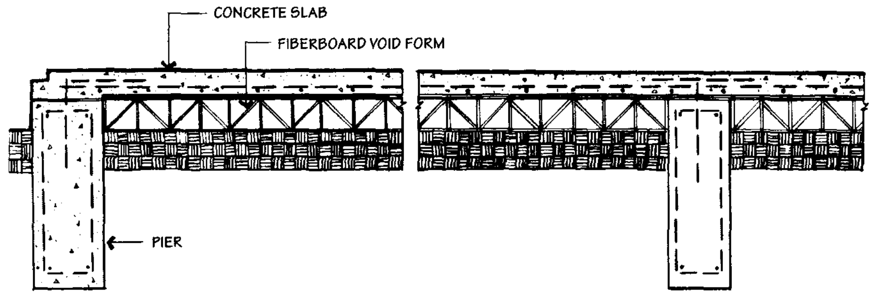

Figure 255-12. Detail of fiberboard void forms used to provide space for soil expansion below concrete slab.

the addition of lime is necessary to create a suitable working platform. Although wetting is a slow process, drying can be very rapid under warm weather conditions. To prevent drying, complete the construction and seal the pre-wetted soil mass as quickly as possible. Later drying of the site may cause shrinkage.

Heat Treatment:

Heating expansive clays to ±200 degrees C (±400 degrees F) may significantly reduce their ability to swell or shrink. One thousand degrees C (±1830 degrees F) causes soil to fuse, but the cost of this method is seldom justified.

Chemical Additives:

The application of hydrated lime or other chemicals has been successful in controlling soil expansivity. Studies have shown that the ionic character of water has a major effect on volume change. The addition of chemicals for control of expansivity is summarized in Table 255-1.

3.5 Drainage and Control of Surface Runoff

Techniques for managing the amount of moisture change in expansive soils include the provision of vertical moisture barriers to isolate the soil under a structure from the surrounding soil. Two types of moisture barrier are commonly used. One uses impermeable material such as low-grade concrete or ground rubber tires in an asphalt emulsion binder. The other uses crushed rock to create a capillary barrier. Since most of the movement of water through clay is by capillary action, breaking the contact between masses of expansive soil temporarily stops moisture change. Capillary barriers may be less desirable than impermeable barriers in areas where trees exist, since the long-term effect of tree roots may be detrimental to capillary barriers.

After installation of the moisture barrier, the supporting soil is pre-wetted to bring its moisture content up to 1 to 2 percent above the plastic limit. Construction should proceed quickly, to prevent loss of soil moisture (Figure 255-15).

Providing down-spouts and drain blocks is another technique to carry roof run-off to an area at least 1.5 m (5 ft) away from the structure. The provision of a wide paved area around a structure is often recommended to reduce the differential movement by spreading it over a larger area. Sites on the tops of mounds, either natural or artificial, are preferable to sites on slopes because positive surface drainage away from the structure in all directions is easier to achieve.

The use of slab-on-grade subdrains should be carefully considered. Unless outfalls and trenches can be protected from surcharged conditions, foundation drains may introduce backflow into the areas they are designed to keep dry during periods of heavy rainfall. An alternative approach recommended by the U.S. Federal Housing Administration is the use of impervious backfill at the building perimeter and proper control of surface runoff and roof water.

KEY POINTS: Loss Prevention and Reduction

The best method to prevent damage from expansive soils is to find an alternative construction site. If this is not possible, a number of strategies for coping with expansive soils have been developed.

1. Damage can be prevented by isolating structures from shrinking and swelling by replacing soils with non-expansive fill, installing waterproof membranes, and placing structures on piers or pilings.
2. Floating slabs in basements can be used to accommodate soil heaving (Figure 255-10), or clear space can be provided under slabs on-grade (Figure 255-12).
3. Compaction, prewetting, heat and chemical treatment of the soil are various methods of reducing potential volume change. Each has specific advantages and disadvantages depending on site conditions.
4. Surface runoff must be prevented from infiltrating the perimeter of structures. Vertical moisture barriers, down-spouts and drain blocks are techniques for preventing heaving due to moisture change.
5. Plant root activity causes desiccation of the soil, particularly during dry seasons of the year. Construction should be avoided within the root zone of trees.
6. If trees are removed during construction, care must be taken to maintain soil moisture levels during and after construction, or the site should be allowed to establish its new moisture level.

TABLE 255-1. Methods for Volume Change Control Using Additives

Method or additive	Effects on soil	Method of application	Comments
Lime treatment	Reduce or eliminate swelling by ion exchange, flocculation, cementation, alteration of clay minerals	• Remove, mix, replace, or mix in place	• Only suitable for shallow depths • Mixing difficult in highly plastic clays • Delay between initial addition of lime and final mixing and placement improves ease of handling and compaction • 2-6% lime usually required
		• Deep-plow	• Treat depths to 1m (36") • Can use conventional equipment • Requires careful quality control
		• Lime slurry injection; lime piles	• Controversial, very sensitive to initial moisture conditions • Limited by slow lime diffusion rate • May not be effective in dry, fissured material or accepted if soil is wet
		• Mixing in place: piles and walls	• Not yet investigated • Might be suitable in highly plastic soils for treatment to large depth • Could use dry lime, lime mortar, or slurry
Cement treatment	Reduce or eliminate swelling by cementation, ion exchange, and alteration of clay minerals	• Remove, mix, replace; plant mix	• Cement may be less effective than lime in highly plastic clays • Mixing difficult in highly plastic clays • Reduction in swelling noticeable for cement contents >4-6%
		• Mixing in place	• No excavation and backfilling required • Has been used for construction of piles and walls • Better, more economical equipment needed
Chemicals: hydroxides, chlorides, phosphoric acid, carbonates, sulfates, lignins, siliconates, asphalts, quaternary ammonium chloride Proprietary: "compaction aids"	Various effects have been measured or hypothesized, including reduced plasticity, improved compaction, reduced swell, waterproofing, preservation of soil structure, increased strength, increased or decreased permeability.	• Usually remove, mix, and replace or mix in place • In some instances spraying or injection is used • Electro-osmosis may be useful in special cases • Diffusion may be effective	• Problems of mixing or injection may be significant • No chemical additives for control of volume change appear to be available that are effective, permanent, and economically competitive with lime or cement when large volumes of soil must be treated • Calcium chloride may be effective at least temporarily in soils with expanding lattice clays. It may be useful in soils with a high sulfate content • A number of proprietary formulations have been marketed. The beneficial effects of these materials have not generally been documented

Source: Modified from James K. Mitchell and Lufti Rand, *Control of Volume Changes in Expansive Earth Materials, vol. 2: Proceedings: Expansive Clays and Shales in Highway Design and Construction,* FHA.

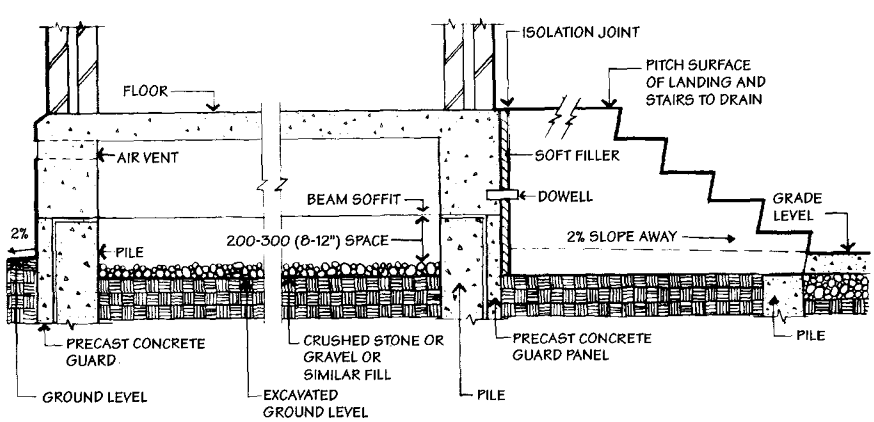

Figure 255-13. Detail of grade beam on piled foundation.

3.6 Management of Vegetation

Vegetation is an important consideration when planning construction on sites with expansive soils. Plant root activity causes desiccation of the soil, particularly during dry seasons of the year. This results in shrinkage of the soil, which is only partially offset by the plant's shading of the soil. Artificial irrigation of planting can also cause soil expansion.

Existing mature trees whose root systems are not actively expanding may cause relatively less damage than newly planted or young trees in active growth. Soils under paving or structures tend to become wetter than surrounding soil because of capillary action. Thus, they will attract tree roots.

The Royal Botanic Garden, Kew, Tree Root Survey (1971–1979) reported the damage to buildings on shrinkable clays caused by the activity of tree roots. The survey reported experience in the humid climate of Great Britain and included the extreme drought of 1975–1976, which caused extensive soil shrinkage and damage to structures. The study was based on 3000 reports of damage, chiefly from London and the south of England, mostly in urban situations. *Quercus, Populus,* and *Salix* species were found to cause the greatest damage in the survey.

Based upon the findings of the Kew survey and consultation with American landscape architects experienced in dealing with expansive soils, the following actions are suggested to reduce possible damage caused by vegetation.

1. Good maintenance, including frequent and copious watering of vegetation to prevent excessive soil desiccation.
2. Avoid building within the root zone of existing trees or within the area into which the roots will grow during the expected life of the structure. Depending upon the species and the site conditions, avoid construction within a zone approximately equal to the mature height of an existing tree.

If construction must take place within an active or potential root zone, one of the three following techniques may be appropriate:

1. Pre-wet the soil prior to construction, and maintain a constant high moisture level through artificial irrigation.
2. Keep the soil as dry as possible so that roots are not encouraged to develop in the critical area.
3. Construct a subterranean impervious barrier similar to that shown in Figure 255-14 to prevent tree roots from penetrating vulnerable areas.

If none of these methods are feasible, large existing trees that could cause major damage should be considered for removal.

In many parts of the world existing vegetation is considered so valuable that it is undesirable to remove it unless absolutely necessary. Some professionals would rather risk minor damage to landscape construction (such as retaining walls, steps, or paving) than remove existing trees or not plant proposed trees on a site with expansive soils.

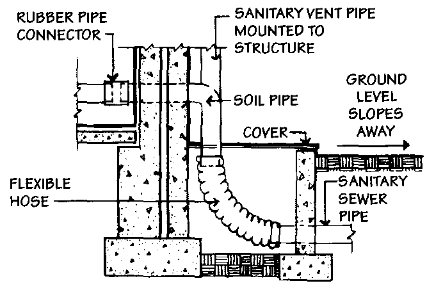

Figure 255-14. Typical flexible drainage connection.

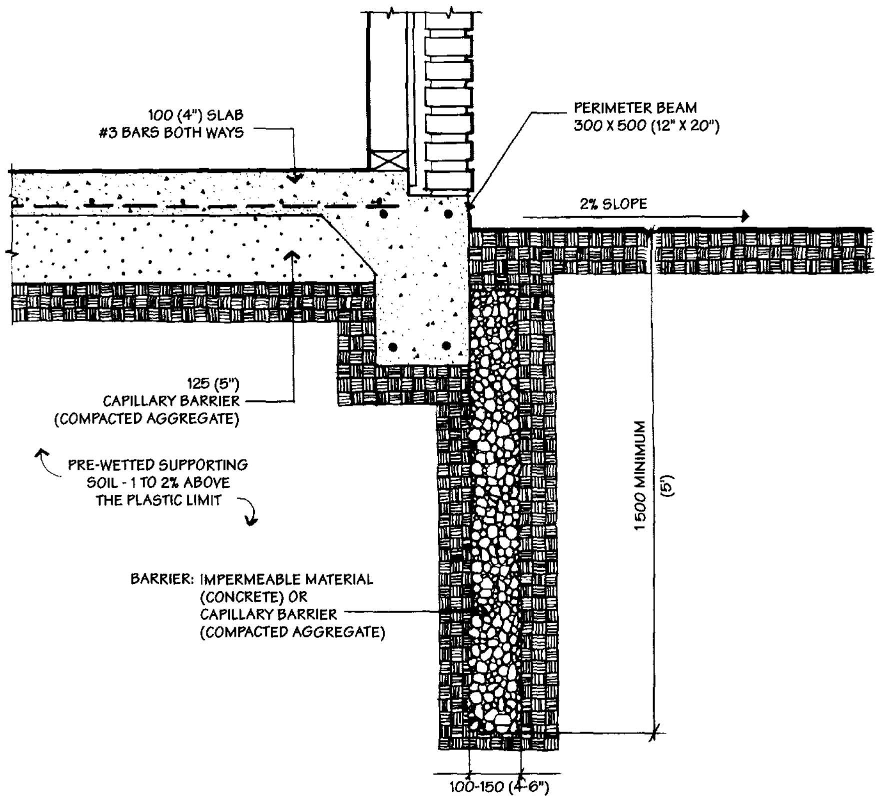

Figure 255-15. Detail showing stabilization of expansive clay foundation soil. *Expansive clay foundation soils can be stabilized by prewetting and by installing a barrier that prevents the loss of moisture from the zone of seasonal change at the perimeter.*

When building on a site formerly occupied by trees, a careful assessment should be made as to whether the moisture level of the soil at the time of the removal of the trees will be maintained during and after construction. If this cannot be assured, then the cleared and regraded site should be allowed to establish its new moisture level. This may take as long as a year, and other measures should be taken to protect the existing or proposed construction.

New planting in expansive soils can be accomplished in several ways. Attention should be paid to drainage patterns, so that excess water from artificial irrigation is not directed toward vulnerable areas. Where the planting of trees near buildings is desired, the use of above- or below-grade tubs or impervious barriers can isolate the roots from the surrounding soil. Although this solution may create other problems, such as restricted growth and high maintenance demands, it may be the only acceptable solution in extreme circumstances.

Local experience is particularly important in devising an appropriate strategy for the management of vegetation on sites with expansive soils. Consultation with individuals familiar with local conditions and practice is essential. The general information supplied in this section should be modified and supplemented as appropriate for specific site conditions.

SOURCES OF TECHNICAL INFORMATION AND ASSISTANCE

American Society of Civil Engineers
New York, New York

Natural Hazards Research and Applications Information Center
University of Colorado, Boulder, Colorado

U.S. Federal Housing Administration
Washington, D. C.

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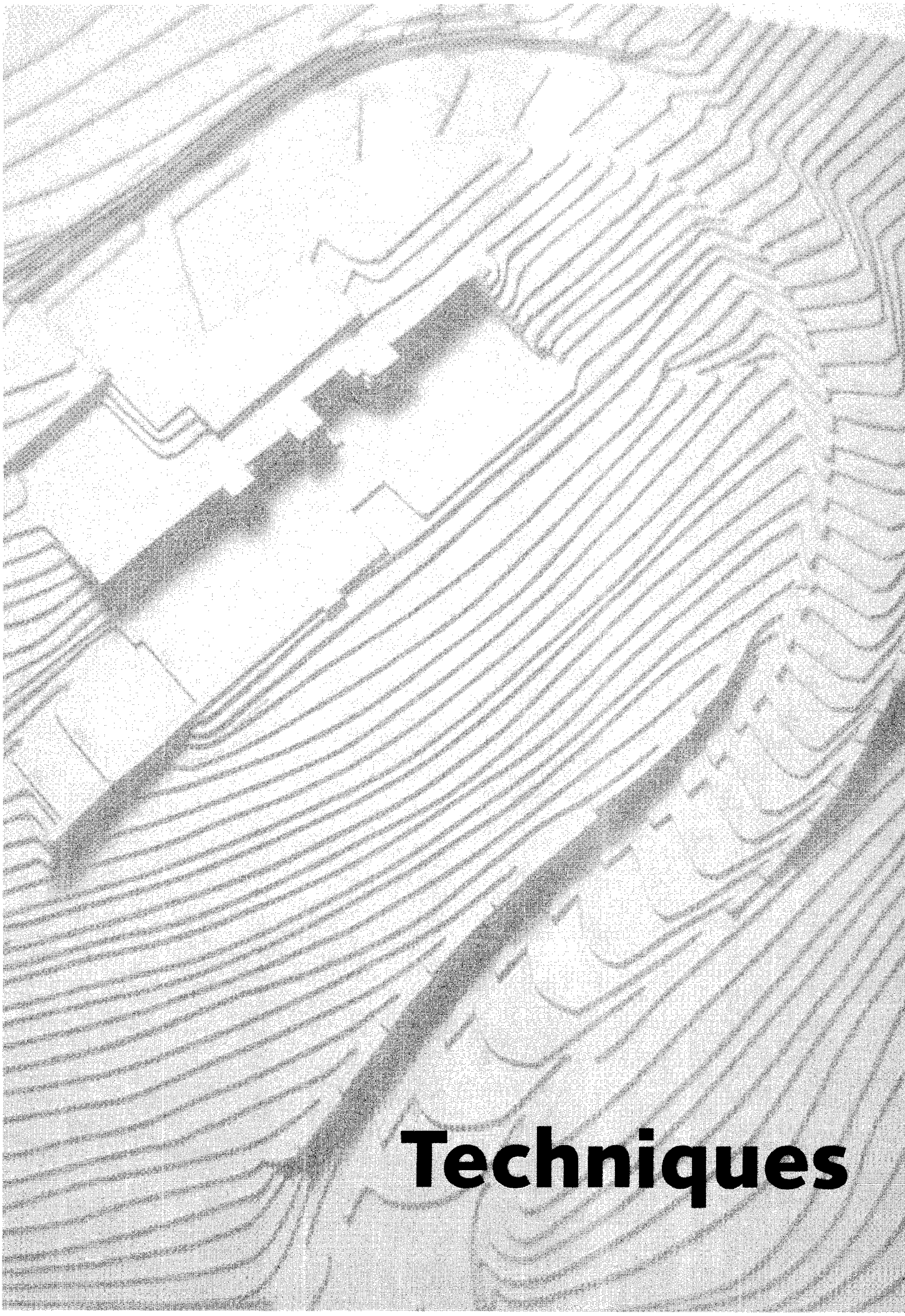
Holty, Wesley, G., and Stephen S. Hart. Home Construction on Shrinking and Swelling Soils, *American Society of Civil Engineers, New York*

*Joachim, Candace L.,*Home Landscaping and Maintenance on Swelling Soil *Colorado Geological Survey Special Publication 14, Denver, Colorado*

Lamb, Donald R., and Steven J. Hanna Proceedings of Workshop on Expansive Clays and Shales in Highway Design and Construction, *vols. 1 and 2, May 1973 Federal Highway Administration, U.S. Government Printing Office*

International Conference on Expansive Soils *See Proceedings for periodic conferences held at different places and dates starting with the First in 1965 in Austin, Texas. The reader should seek the list of all such conferences and identify which ones may have produced proceedings that may contain the most useful information .*

DIVISION 300



Techniques

Site Grading

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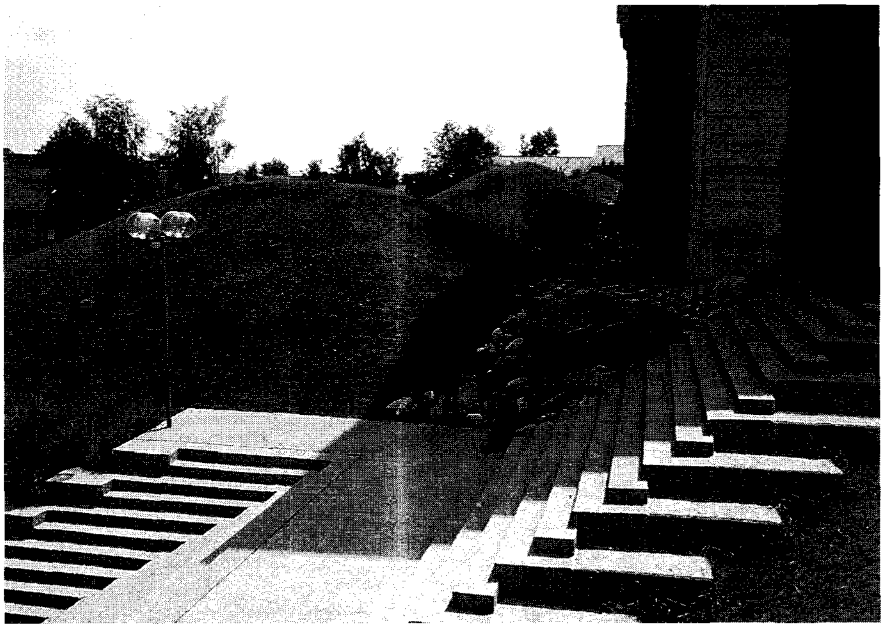
N. Dines

CONTENTS

1.0 INTRODUCTION

1.1 Importance of Grading

Landscape architects and other designers must ensure that grading becomes an integral part of the design process, on a par with the location of buildings, circulation planning, and the recognition and use of all landscape qualities. In many cases the grading scheme is a primary determinant in the total design.

1.2 Functional and Aesthetic Reasons for Grading

Grading may be done for a number of functional and/or aesthetic reasons. Figures 320-1 through 320-9 show a range of typical examples.

2.0 STANDARDS

2.1 Abbreviations on Grading Plans

Landscape architects, engineers, and architects who do grading plans, as well as the contractor who does the actual grading, should understand a common terminology. Table 320-1 shows abbreviations that are commonly used on grading plans.

2.2 Methods of Expressing Slope

Slope is expressed in terms of a percentage, a proportional ratio, or a degree of slope. Each of these is described in the following paragraphs.

Table 320-1. GRADING ABBREVIATIONS

Abbreviation	Meaning
CI	Contour interval
TC	Top of curb
BC	Bottom of curb (include spot elevation)
TW	Top of wall (include spot elevation)
BW	Bottom of wall (include spot elevation)
HP	High point (include spot elevation)
LP	Low point (include spot elevation)
TS	Top of steps (include spot elevation)
BS	Bottom of steps (include spot elevation)
IE	Invert elevation (include spot elevation)
RE	Rim elevation
DI	Drain inlet (needs RE and IE)
SD	Storm drain (needs RE and IE)
MH	Manhole (needs RE and IE)
CB	Catch basin (needs RE and IE)
PL	Property line
ROW	Right of way

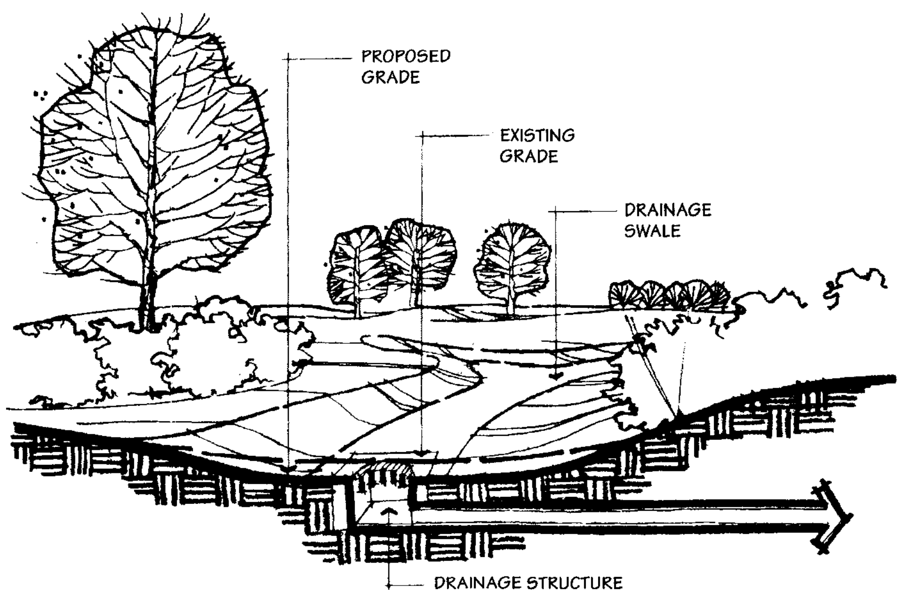

Figure 320-1. Grading for drainage. *Surface drainage can be achieved by pitching surfaces to natural drainage features and systems.*

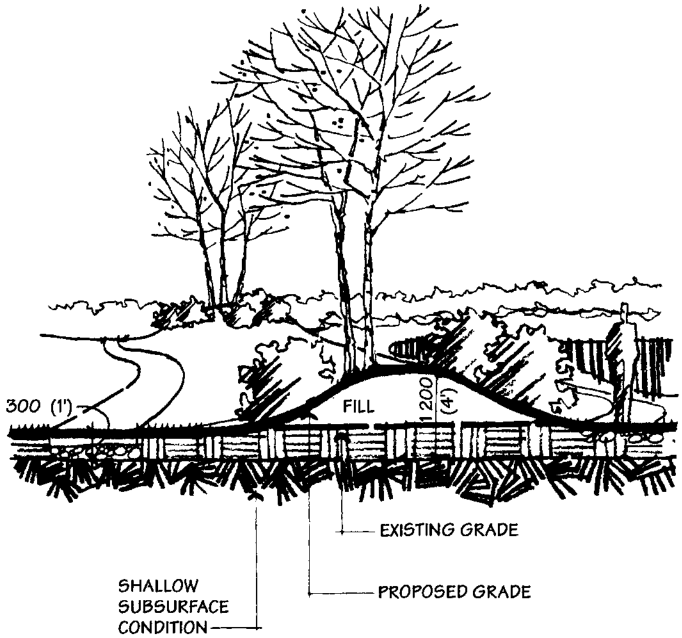

Figure 320-2. Grading to create berms. *Berms can be created for noise and wind barriers or for additional soil depth above unfavorable subgrade conditions, such as a high groundwater table.*

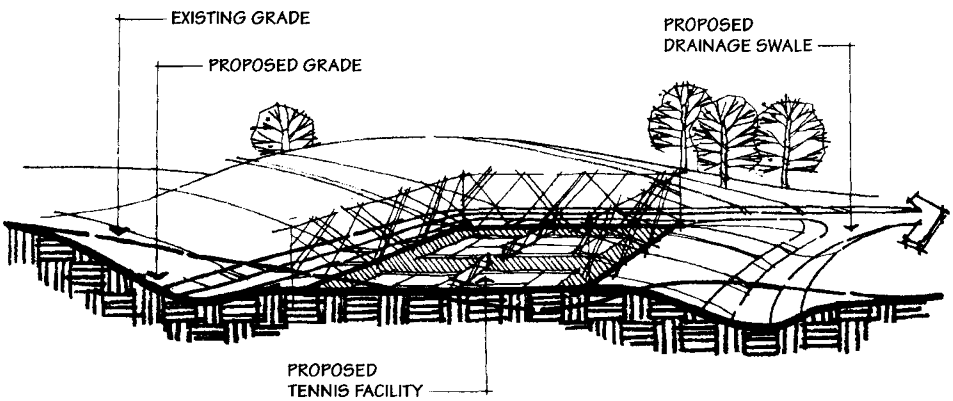

Figure 320-3. Grading to create level areas. *Relatively flat gradients are needed for sports fields, outdoor terraces, and sometimes for areas near buildings.*

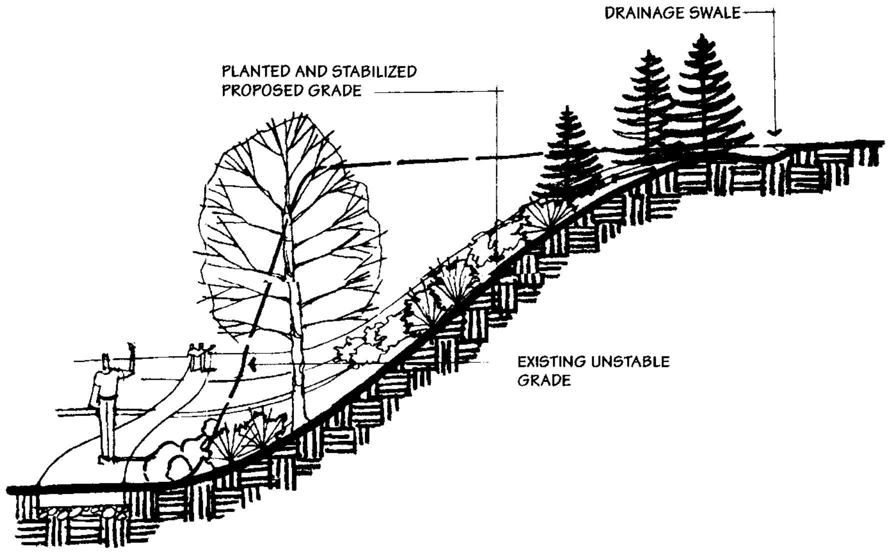

Figure 320-4. Grading to modify existing landforms. *Deep gullies, narrow ridges, or steep slopes can be modified to create more useful and attractive landforms.*

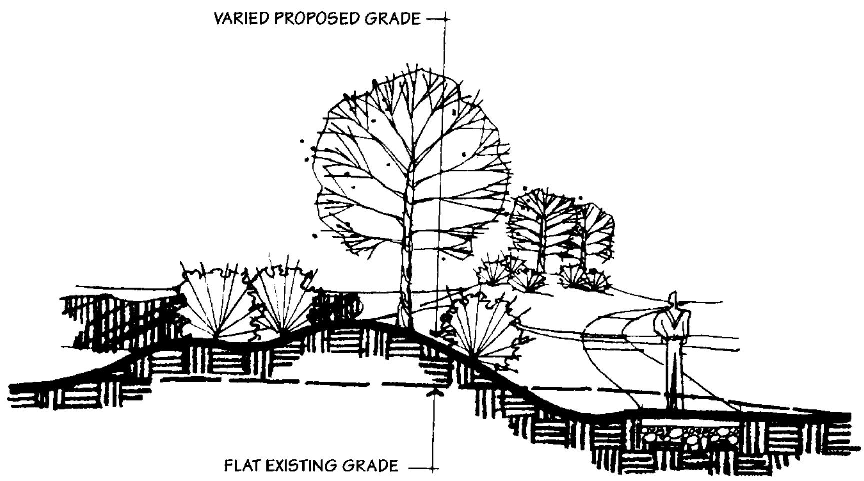

Figure 320-5. Grading for increased site interest. *Grading can help emphasize a site's topography or add interest to an otherwise flat site.*

Percentage (of Slope):

Percentage of slope is expressed as the number of meters (feet) rise in 100 m (100 ft) of horizontal distance, typically referred to as rise/run. If the slope rises 2 m (2 ft) in 100 m (100 ft), it is considered a 2 percent slope. The percentage of slope can be calculated by the following formula:

$$G = \frac{D}{L} \times 100$$

where D = vertical rise, mm (ft)
L = horizontal distance, mm (ft)
G = gradient, %

Figure 320-10 shows an example problem where part a is the longitudinal or centerline profile of a proposed roadway and part b is the same roadway shown in plan. The actual calculations for the example are:

Elevation of point B = 48 347 mm (158.62 ft)

Elevation of point A = 47 463 mm (155.72 ft)

Vertical difference D = 884 mm (2.90 ft)

Horizontal difference L = 35 357 mm (116.00 ft)

Therefore:

$$G = \frac{D}{L} \times 100$$

$$= \frac{884}{35\ 357} \times 100$$

$$= 2.5\ \%$$

It is common practice to indicate the direction and rate of slope by use of an arrow, which always points down the slope.

Proportion (of Slope):

Slope can also be expressed as a ratio of the horizontal distance to the vertical rise, such as three to one (3:1). The ratio method is used typically for slopes 4:1 (25%) or steeper.

Degree (of Slope):

Slope is expressed in degrees only on large-scale earth-moving projects such as strip-mining and other extractive operations.

Spot Elevations:

Spot elevations are used to establish limits of slope, to locate contour lines, and to provide detail for establishing control points that cannot be obtained via contour lines.

The elevation of any point on an accurately drawn contour plan may be determined by interpolation. On Figure 320-11,

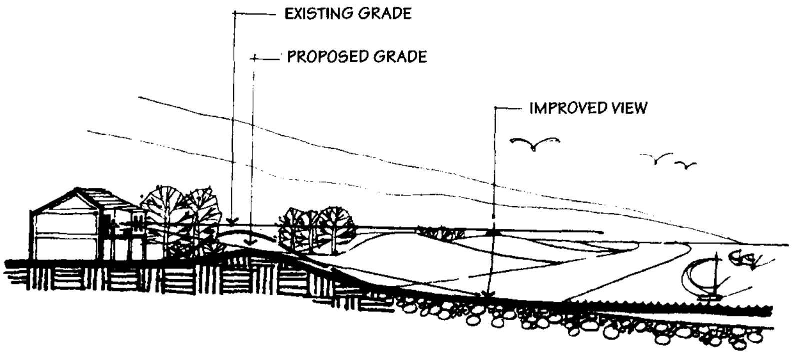

Figure 320-6. Grading related to good views.

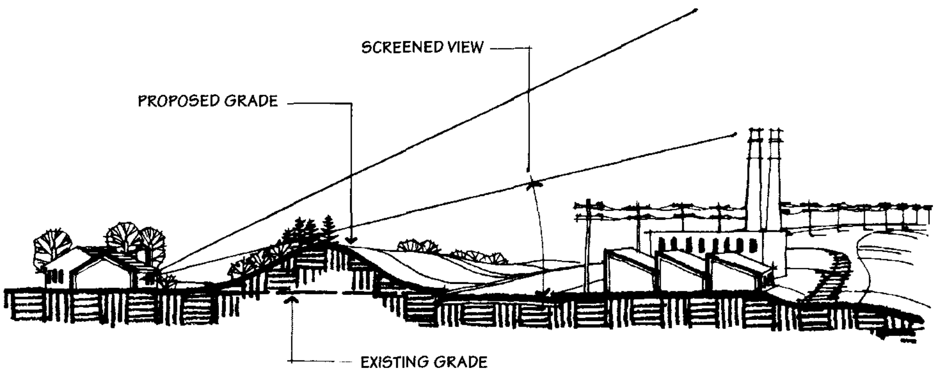

Figure 320-7. Grading related to bad views.

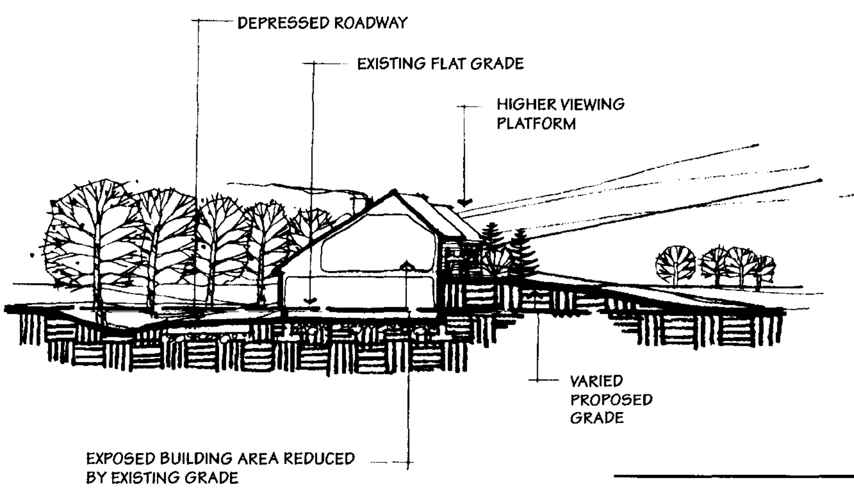

Figure 320-8. Grading to fit structures to sites.

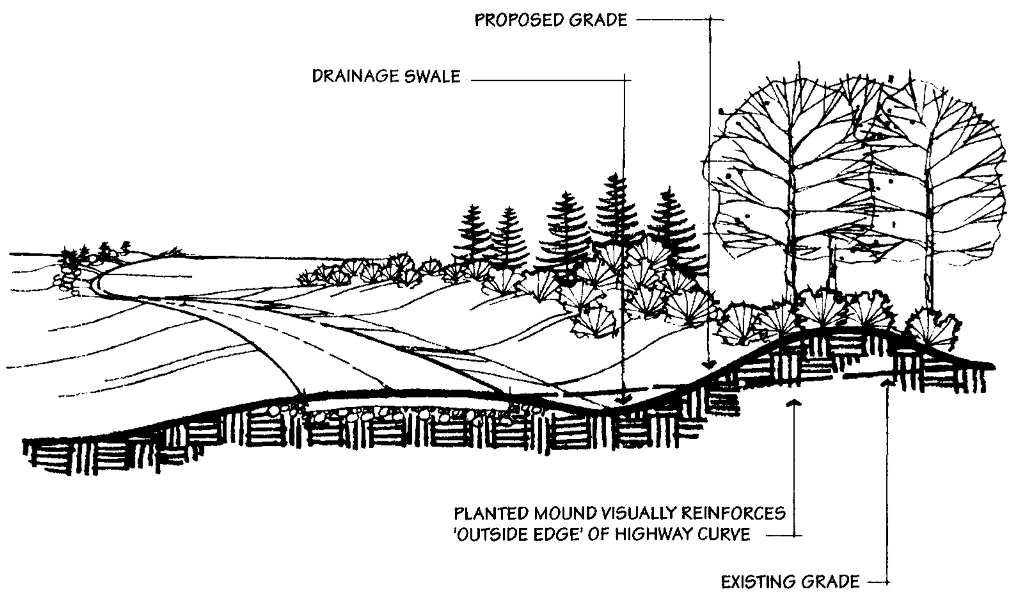

Figure 320-9. Grading to emphasize or control circulation.

point A lies about 7/10 the distance from contour 53 to contour 54; thus, A has an approximate elevation of 53.7. Interpolation assumes, of course, that slopes are uniform, which in many cases is not true in reality. Therefore, interpolated figures are approximations and should not be relied on as much as surveyed spot elevations for crucial measurements.

2.3 MAKING A CONTOUR MAP

Field Survey:

All intersection points of a grid are marked on the ground with temporary stakes; the elevations of each intersection point are taken with a transit or level and the elevation data is plotted on a gridded plan of the site (Figure 320-12). Normally, the elevations of critical high or low points that fall between the intersections are also located on the plan.

Plotting Contours:

Once all spot elevations have been determined, contours at regular intervals [typically 1 000 mm, 500 mm, or 250 mm (5 ft, 2 ft, or 1 ft)] can be located and plotted on a map, as shown in Figure 320-13. Often this can be done by eye, since few contour maps require great precision.

3.0 GRADING CONCEPTS

3.1 Schematic Grading Alternatives for a Defined Area

Slopes of less than about 2 percent in the open landscape appear flat to the human eye. However, in areas adjacent to built structures, even the slightest slope becomes noticeable because of the relationship of the grade to mortar joints, roof lines, and other level architectural features.

Perimeter Edge Level:

Figures 320-14 through 320-19 schematically illustrate alternative methods for manipulating a surface for drainage while allowing at least one peripheral edge to remain level.

Two Perimeter Edges Level:

Figures 320-20 and 320-21 schematically illustrate drainage schemes applicable when two perimeter edges need to be level.

Entire Area Level:

Some circumstances, such as rooftop landscapes or enclosed courtyards, require that the entire surface of the enclosed area be level. Figures 320-22 and 320-23 illustrate two ways that an area can remain level and still drain properly by the use of porous surface material, such as sand/gravel, or by the use of individually elevated pavers. Each case requires an adequate drainage system beneath the pavers to carry off the required rainfall effectively. Refer to Section 610: Roof and Deck Landscapes, for more data related to drainage of rooftops.

3.2 Schematic Grading Alternatives for Open Areas

There are several ways to solve grading problems when surrounding buildings do not fully enclose an area to be graded and there is sufficient peripheral space for transition to surrounding areas. Such a wide range of alternatives gives the designer the opportunity to resolve aesthetic objectives while solving the engineering problems involved. Figures 320-24 through 320-26 show schematic alternatives for grading open areas; these alternatives are especially applicable to relatively flat surfaces, such as tennis courts and other types of game courts.

3.3 Preparing a Site Grading Plan

Grading of a site should be thought of as a systematic process that begins with the analysis and understanding of the existing site and ends with an overall detailed grading plan. Figures 320-27 through 320-31 help illustrate this procedure. Figure 320-

82 at the end of this section shows an example of a metric grading plan.

Site Analysis:

Study the general lay of the land by using topographic maps and site visits.

1. Determine high points, low points, ridges, and valleys.
2. Note natural drainage systems and directions of flow that exist on the site.

Site Use Concept:

Determine how existing landforms would affect proposed use areas, such as building locations, roads, parking areas, walkways, plazas, and lawn areas.

Schematic Grading Plan:

Define general use areas, set building floor areas by spot elevations, and diagram drainage flow using slope arrows pointing along the direction of flow. This will help in the following procedures:

1. Developing a general landform concept.
2. Locating swales and surface water flow.
3. Locating drainage receptacles.
4. Calculating water runoff for various areas.
5. Defining an area that could be altered (raised or lowered) with limited impact on drainage or existing trees. This area could be used to help balance any surplus cut or fill.

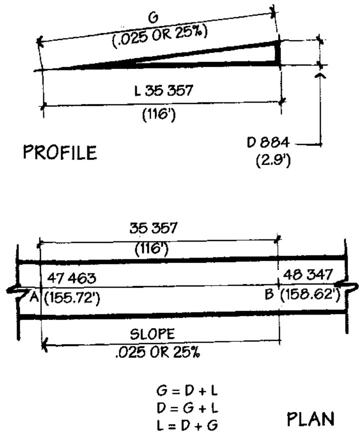

Figure 320-10. Figuring slopes as percent.

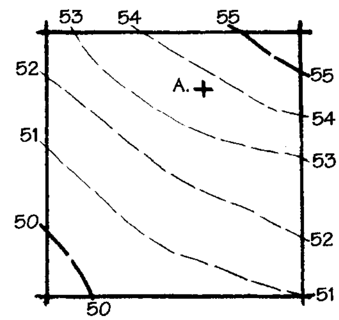

Figure 320-11. Spot elevation by interpolation

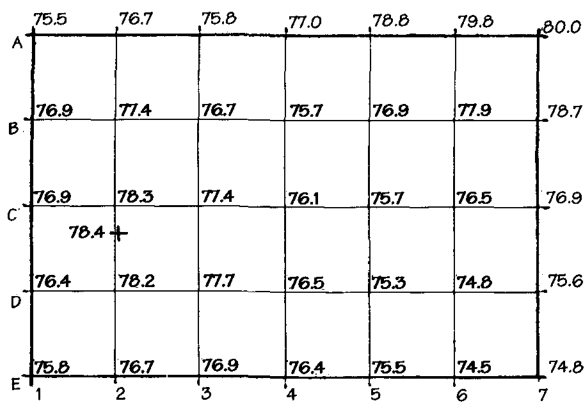

Figure 320-12. Transit survey grid.

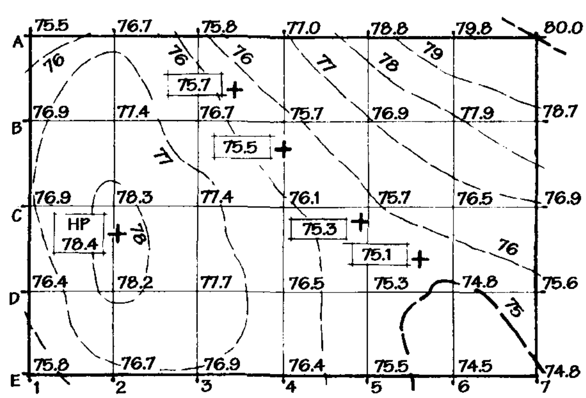

Figure 320-13. Contours interpolated from grid.

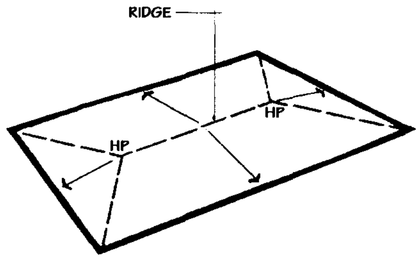

Figure 320-14. Perimeter edge level—drain from ridge line to all edges.

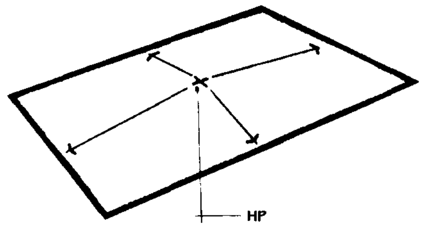

Figure 320-15. Perimeter edge level—drain from single high point.

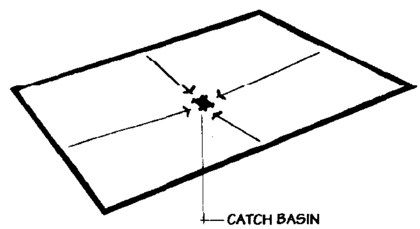

Figure 320-16. Perimeter edge level—slope to center drain inlet.

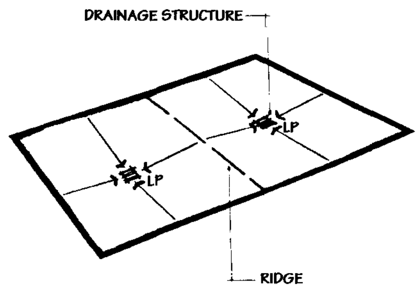

Figure 320-17. Perimeter edge level—all slopes to drain inlets at the same gradient.

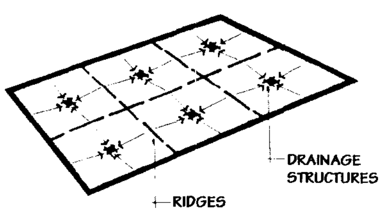

Figure 320-18. Perimeter edge level—all slopes to drain inlets at the same gradient.

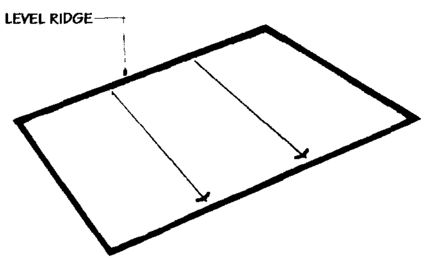

Figure 320-19. Perimeter edge level—slope away at uniform gradient.

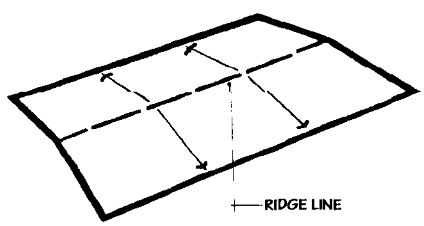

Figure 320-20. Two perimeter edges level—slope from ridge line.

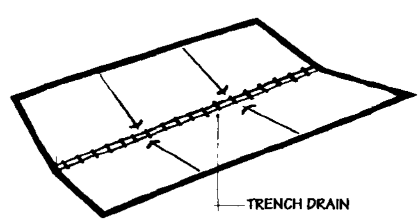

Figure 320-21. Two perimeter edges level—minimum slopes to trench drain.

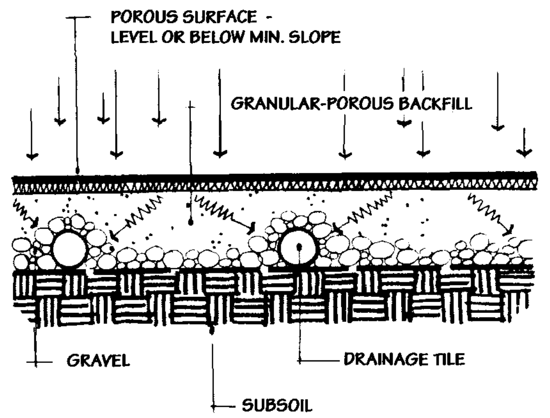

Figure 320-22. Level surface with porous paving.

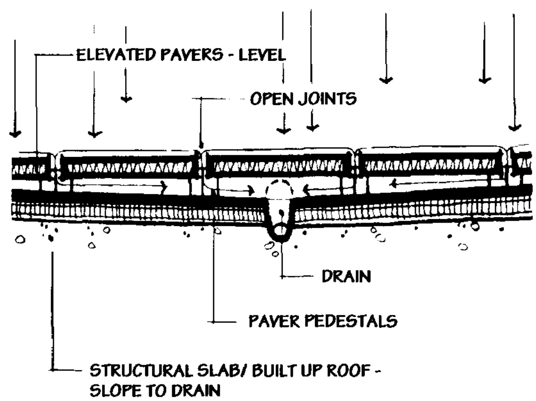

Figure 320-23. Level surface with elevated pavers.

Grading by Spot Elevations:

Grade by spot elevations and form preliminary contouring, using the following steps in the order shown (always strive to keep disturbed areas as small as possible):

1. Set tentative gradients and spot grades on roads, walks, and swales. Establish critical spot elevations.
2. Set the building grade circuit, i.e., floor elevation, steps, walls, terraces, etc.
3. Draw in preliminary contours at 1 500 mm or 30 000 mm (5- or 10-ft) intervals, depending upon the scale of the project and topographic change. Make certain that all gradients and slopes are within the maximum/minimum criteria for a particular use, i.e., lawn, roadway, terrace, and cut slope or embankment.
4. Complete all contour alterations within the property line or project limits.

Preliminary Cut-and-Fill Calculations:

Do preliminary calculations (if needed) to determine whether there is a balance between the amount of earth to be cut out and the amount of earth needed for fill.

Final Grading Plan:

1. Prepare final road profiles.
2. Indicate changes in direction or rate of slopes.
3. Show spot elevations for all critical points, including manholes, inverts, drainage structures, tops and bottoms of all walls, steps, and curbs at intersections and/or other critical points.
4. Draw proposed contours and complete

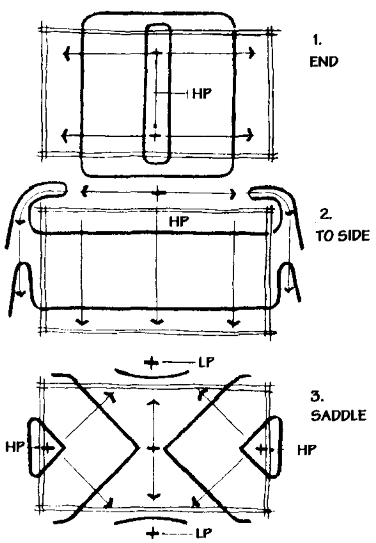

Figure 320-24. Examples of basic area grading.

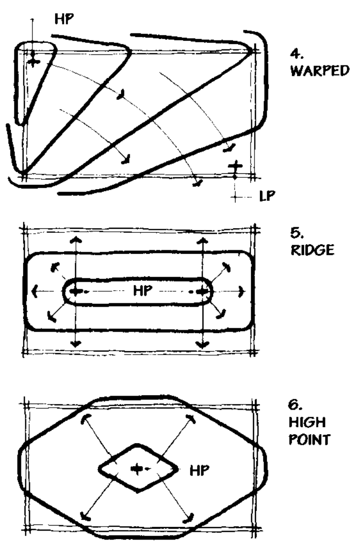

Figure 320-25. Examples of basic area grading.

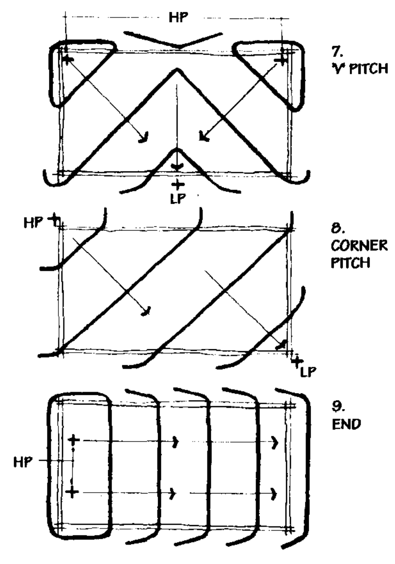

Figure 320-26. Examples of basic area grading.

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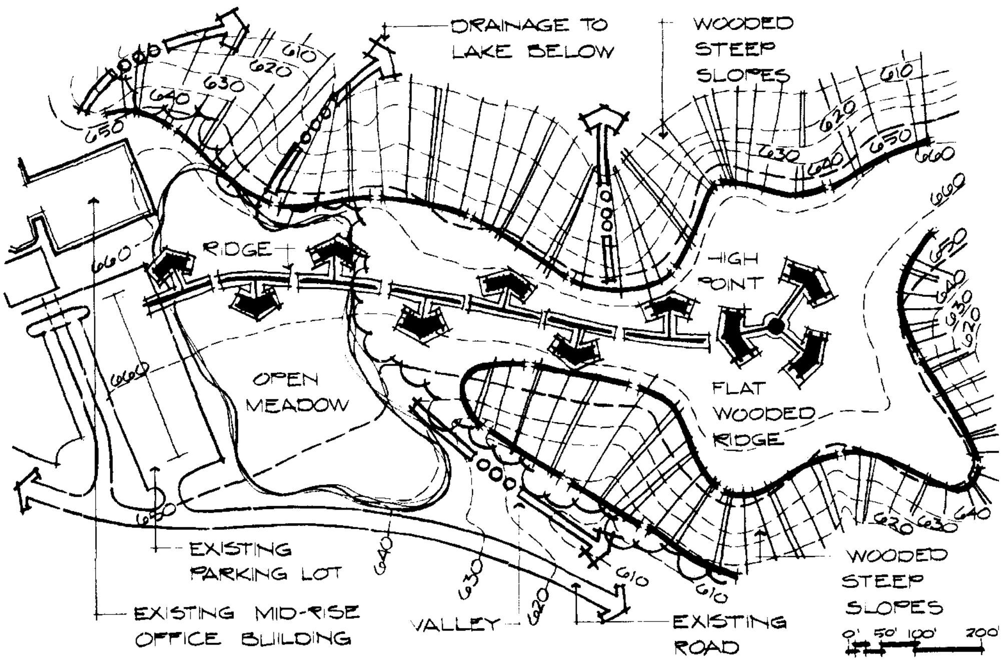

Figure 320-27. Site analysis (example).

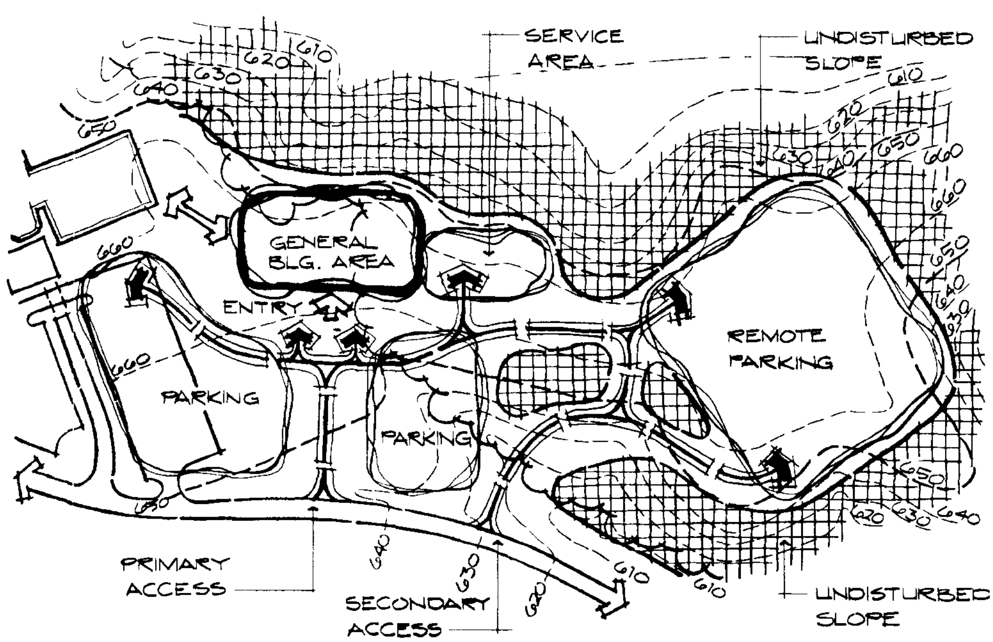

Figure 320-28. Site use concept (example).

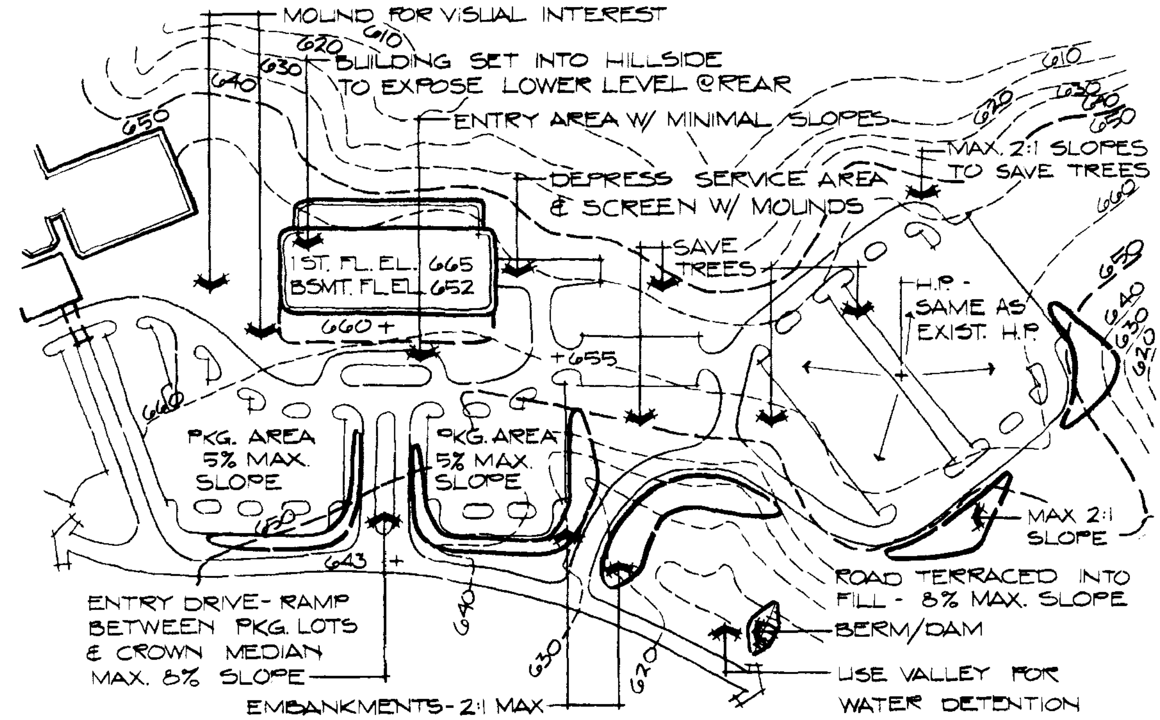

Figure 320-29. Schematic grading plan (example).

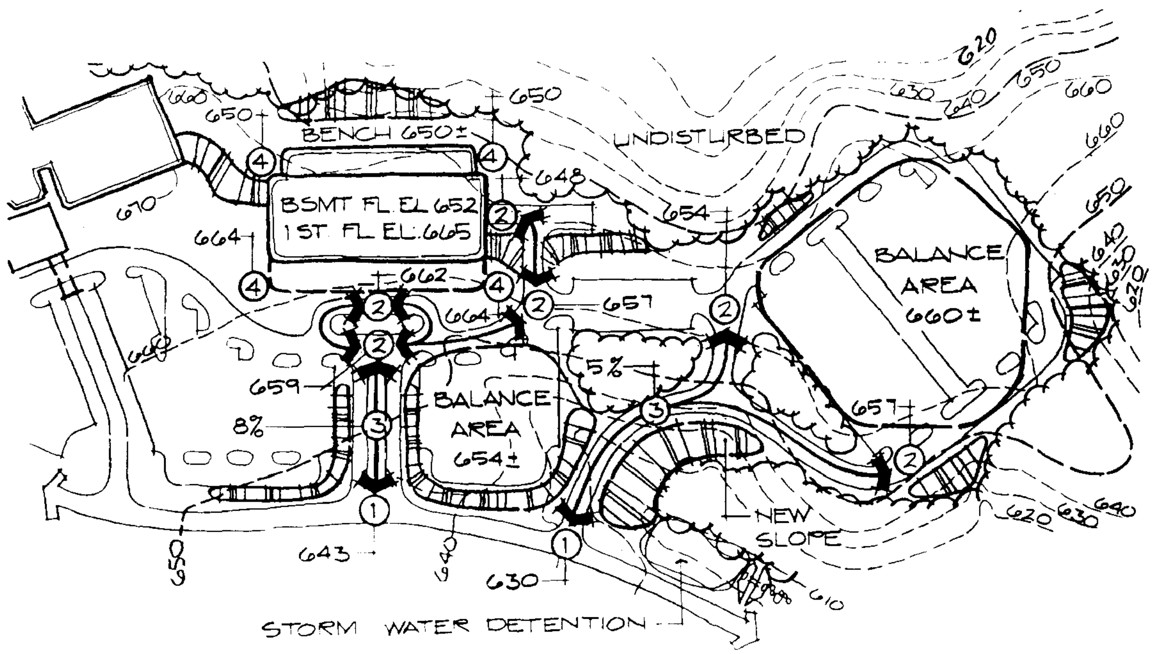

Figure 320-30. Grade by spot elevations (example) — Schematic Diagram

Consider land form, circulation, and structures together in determining proposed grades.

1. *Determine beginning grade at existing road.*
2. *Determine spot elevation at building unit (limited cut/fill) or other critical tie-in areas, i.e.,parking, etc.*
3. *Determine the percentage of slope by measuring distance and rise or fall between points. Gradient must be compatible to criteria for use intended.*
4. *Set grades adjacent to structure in keeping with architectural character and functional requirements of building.*
5. *Determine parking areas or lawn areas as relates to slope criteria (parking area slope and embankment slope).*
6. *Determine storm water retention and sedimentation basins.*

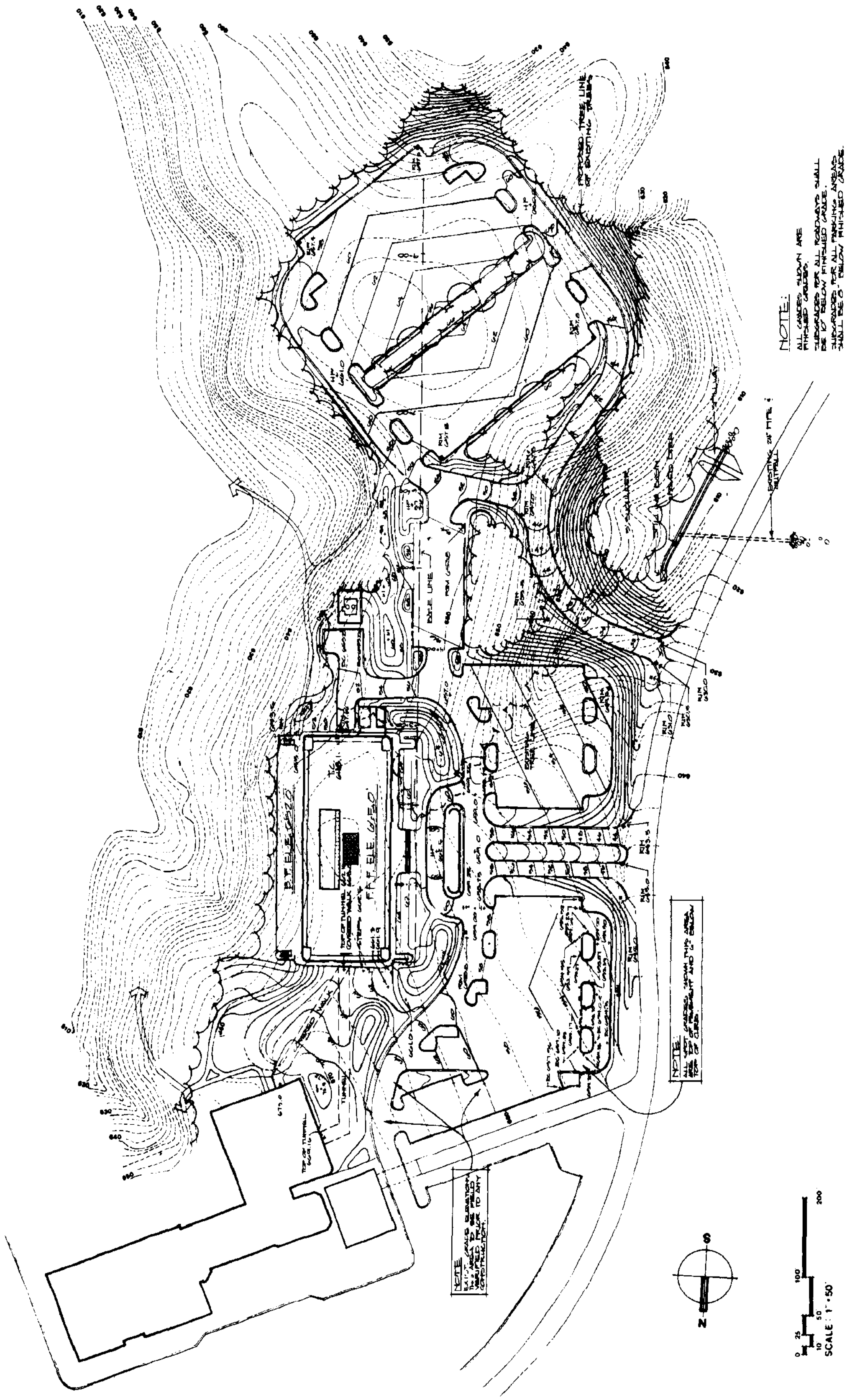

Figure 320-31. Final grading plan (example).

the final grading plan.

5. Complete an estimate of the amount of cut and fill based upon the proposed grading plan, and, if needed, adjust the amount of one or both to make them balance.

4.0 GRADING CRITERIA

4.1 General Landscape Elements

Recommended Gradients:

Grading of outdoor areas is aimed at controlling surface stormwater runoff while providing safe and efficient pedestrian and vehicular movement. Essentially, all surfaces should have some slope, or pitch, for proper drainage. It is better to use the preferred rather than the minimum gradients shown in Table 320-2 to allow for the difficulties of installation and imperfections during the repair of surfaces. Figure 320-32 is an example of typical gradients used for small structures, such as residences.

Earth Fill against Buildings:

Earth fill against buildings may be desirable for insulation or aesthetic reasons. It is important to note, however, that soil and related moisture may cause decay and/or promote the growth of insects that may damage or destroy some of the materials used in the construction of the building.

The exterior surfacing and structural system of a building determine the height to which fill may be brought up against a structure. Figures 320-33 through 320-38 are representative examples.

4.2 Athletic Fields

Recommended Gradients for Outdoor Sports:

Table 320-3 shows recommended gradients for outdoor sports areas and playing surfaces. (Refer to Section 520: Recreation and Athletic Facilities for more information.)

Baseball and Softball:

The construction of playing fields usually involves a combination of turf and dirt surfaces. Use minimum gradients for these surfaces unless subdrains are introduced or other special drainage provisions are made.

The expected skill levels of players and the rules of appropriate sport organizations, such as the National Collegiate Athletic Association (NCAA) in the United States, typically determine the standards for grad-

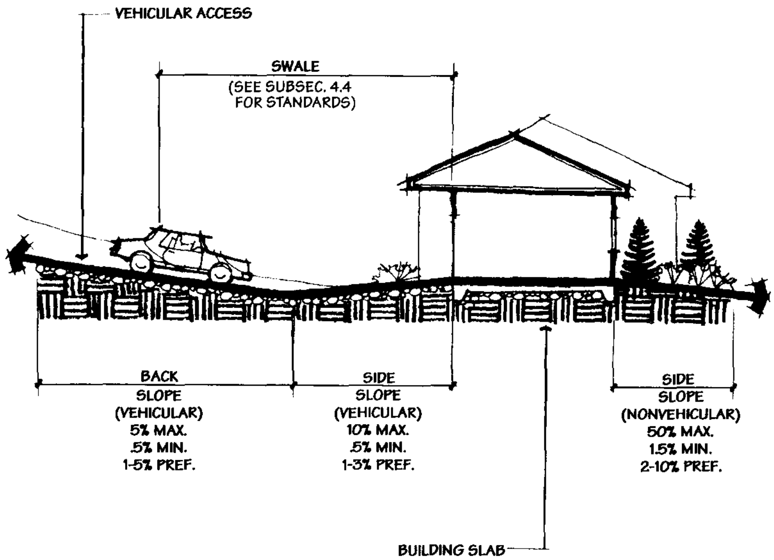

Figure 320-32. Standards for grading around a typical building.

Table320-2: RECOMMENDED GRADIENTS: GENERAL

Types of areas	Maximum, %	Minimum, %	Preferred, %
Streets, driveways, and parking areas			
Crown of improved streets	3	1	2
Crown of unimproved streets	3	2	2.5
Slope of shoulders	15	1	2-3
Longitudinal slope of streets	20	0.5	1-10
Longitudinal slope of driveways	20	0.25	1-10
Longitudinal slope of parking areas	5	0.25	2-3
Cross slope of parking area	10	0.5	1-3
Concrete walks			
Longitudinal slope of sidewalks	10	0.5	1-5
Cross slope of sidewalks	4	1	2
Approaches, platforms, etc.	8	0.5	2
Service areas	10	0.5	2-3
Terrace and sitting areas			
Concrete	2	0.5	1
Flagstone, slate, brick	2	0.75	1
Lawn areas			
Recreation, games, etc. (noncompetitive)	5 1	2-3	
Grassed athletic fields	2	0.5	1
Lawns and grass areas	25	1	5-10
Berms and mounds	20	5	10
Mowed slopes	25 (3:1)		20
Unmowed grass banks	Angle of repose		25
Planted slopes and beds	10	0.5	3-5

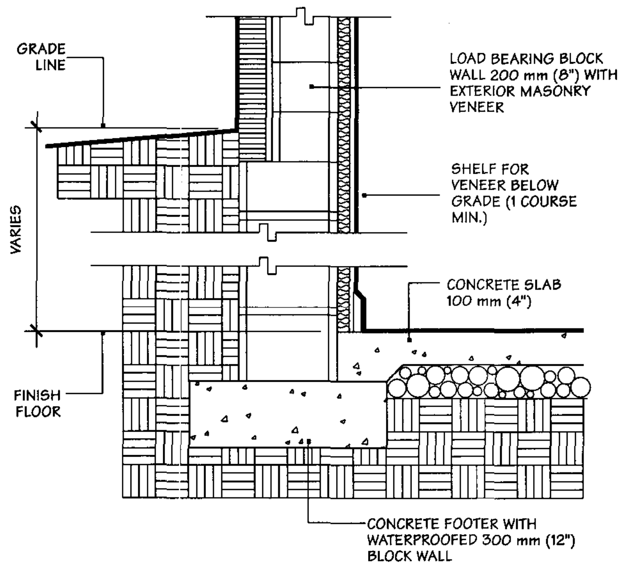

Figure 320-33. Typical masonry veneer-type exterior wall.

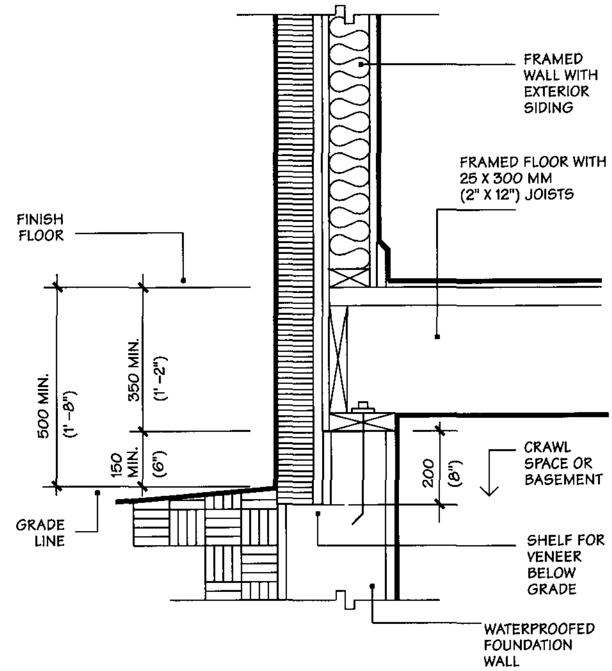

Figure 320-34. Typical wood-framed wall with exterior siding set into a slope.

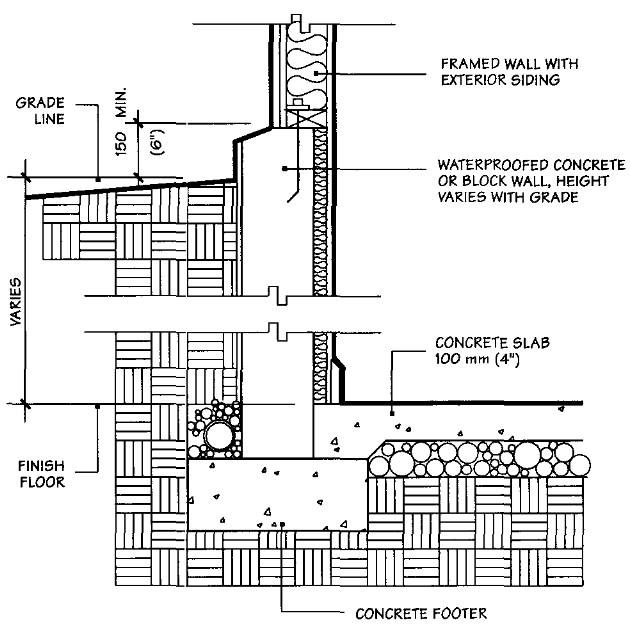

Figure 320-35. Typical veneered wall with crawl space or basement.

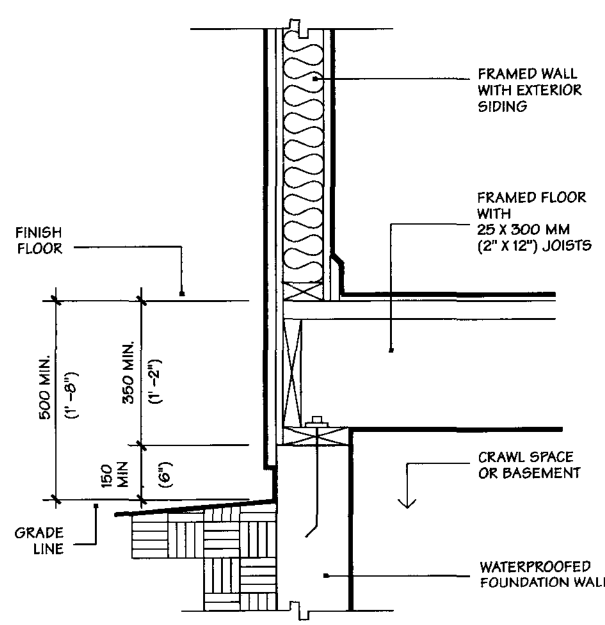

Figure 320-36. Typical wood-framed and -sided wall with crawl space or basement.

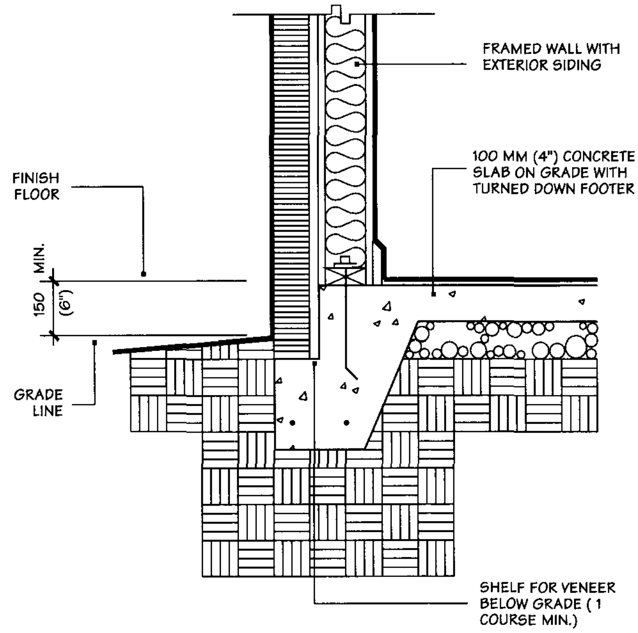

Figure 320-37. Typical slab construction with masonry exterior wall.

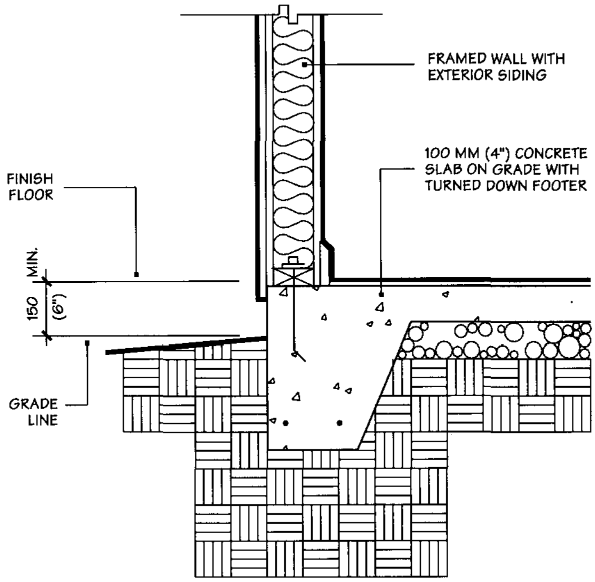

Figure 320-38. Typical slab construction with frame wall and siding.

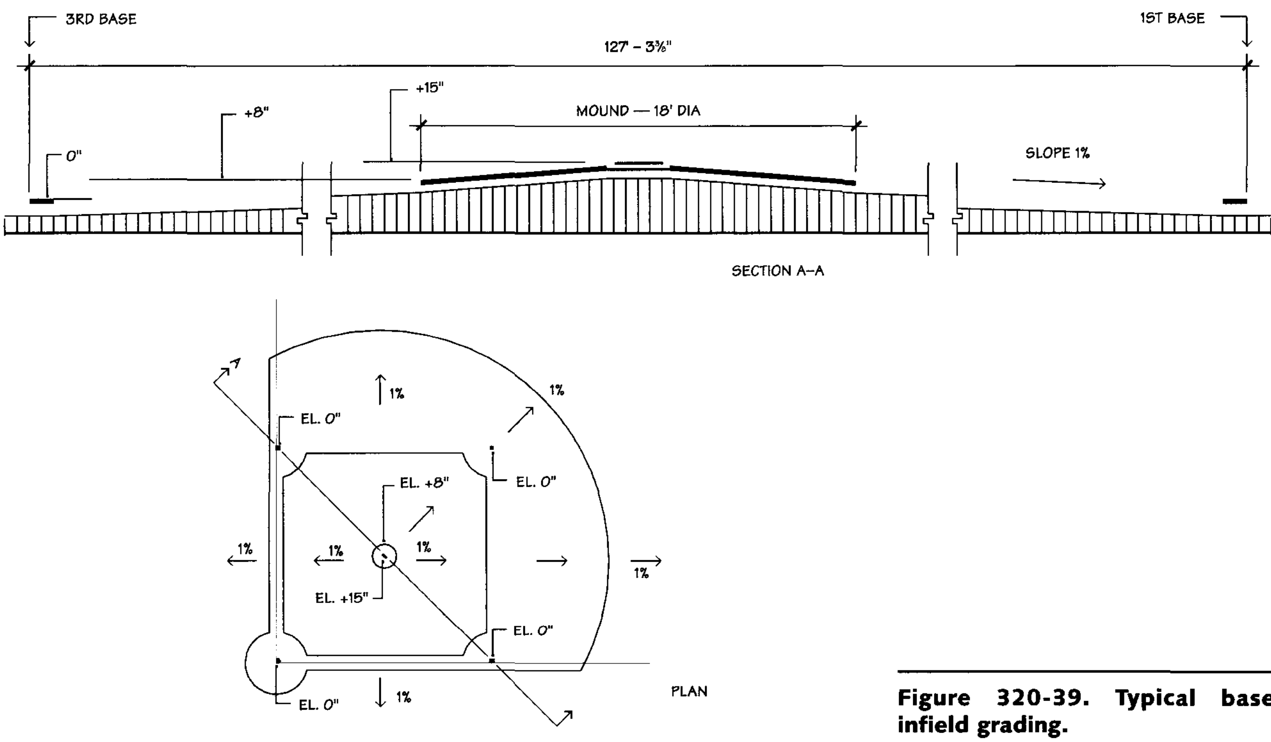

Figure 320-39. Typical baseball infield grading.

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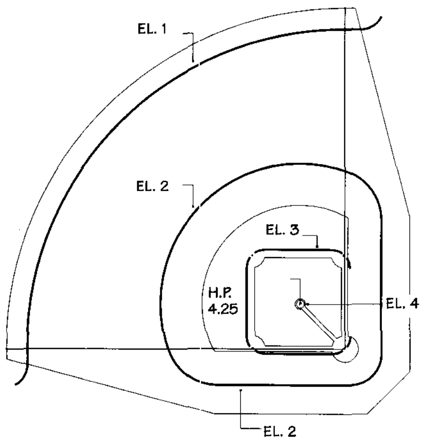


Figure 320-40. Alternative grading pattern for baseball field.

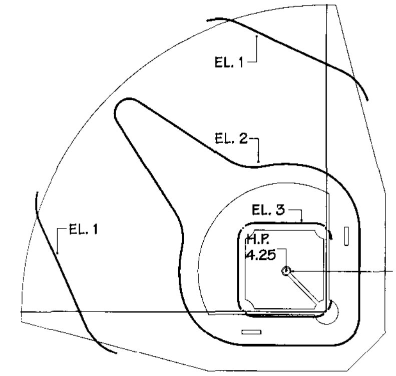


Figure 320-41. Alternative grading pattern for baseball field.

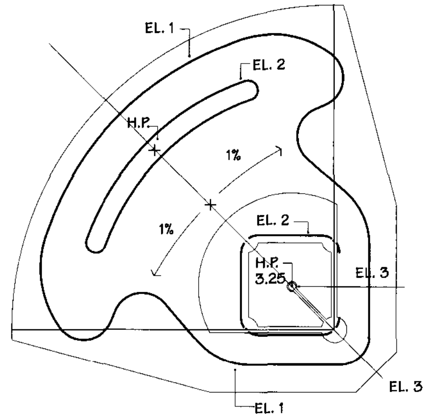


Figure 320-42. Alternative grading pattern for baseball field.

ing. Figures 320-39 through 320-42 show typical alternatives.

Football/Soccer/Field Hockey:

Turf football fields require a crowned surface sloping from the center of the field to a drainage system beyond the sidelines (Figure 320-43). Soccer and field hockey can have a 1 percent slope in one direction or can be played on a football field with center crowning.

Court Games:

Most court games should have a relatively flat surface, with no perceptible swales or ridges (except at the net line for tennis courts) (Figures 320-44 and 320-45).

4.3 Roadways

Grading and Alignment:

The principles and criteria for the design of major urban and rural highways have been established by the American Association of State Highway and Transportation Officials (AASHTO). The standards for streets and local access roads in residential, institutional, commercial, and industrial areas are determined by local city or county standards.

Roadway design consists of two major phases: (1) alignment of the road—giving it horizontal and vertical direction—and (2) grading the adjacent landscape to the road edge. The designer of a roadway should go beyond merely satisfying the engineering requirements and see the user as an active player to be choreographed through the landscape.

The following criteria should be considered during the grading phase of the roadway:

1. Remove extra soils to expose potential vistas (Figure 320-46).
2. Use roadside mounds to screen undesirable views (Figure 320-47).
3. Improve the soil adjacent to a road to enhance the growth of plants (Figure 320-48).
4. Blend the new slopes with the existing terrain (Figure 320-49).

Criteria for Road Design:

1. For cut side of section, see Figure 320-50 and Table 320-4.
2. For fill side of section, see Figure 320-51 and Table 320-4.

4.4 Details and Special Conditions

Several typical elements found in a landscape involve special grading. Some of the most common ones are discussed below.

Swales and Ditches:

Typically, swales are shallow, have a parabolic cross section, and are very wide, while

KEY POINTS: Grading Criteria

1. The percentage of slope can be calculated by the following formula: G=D/L X 100, where D=vertical rise, L=horizontal distance, and G=gradient (%).
2. Grading of outdoor areas is aimed at controlling surface stormwater runoff while providing safe and efficient pedestrian and vehicular movement. Essentially, all surfaces should have some slope, or pitch, for proper drainage. It is better to use the preferred rather than the minimum gradients shown in Table 320-2. Table 320-3 shows recommended gradients for outdoor sports areas and playing surfaces.
3. Roadway design consists of two major phases: (1) alignment of the road—giving it horizontal and vertical direction—and (2) grading the adjacent landscape to the road edge.
4. Typically, swales are shallow, have a parabolic cross section, and are very wide, while ditches are deeper and have a narrower geometric configuration (Figure 320-52).
5. Grass swales (Figure 320-54) tend not to erode if velocities do not exceed 1 200 mm (4 ft) per second. If velocities exceed 1 800 mm (6 ft) per second, then some form of nonvegetative material should be used to construct the swale, such as gravel, crushed stone, or riprap (Figure 320-55).
6. Several site grading techniques can be employed to limit the size, shape, length, and gradient of these slopes and channels, thereby reducing the volume and velocity of runoff (Figures 320-64 to 320-67).
7. The use of gravel, crushed stone, porous asphalt, or other types of porous paving allows either flatter or steeper gradients than bare soil, but their use may not justify radical changes from the grading and drainage standards normally used in a region.

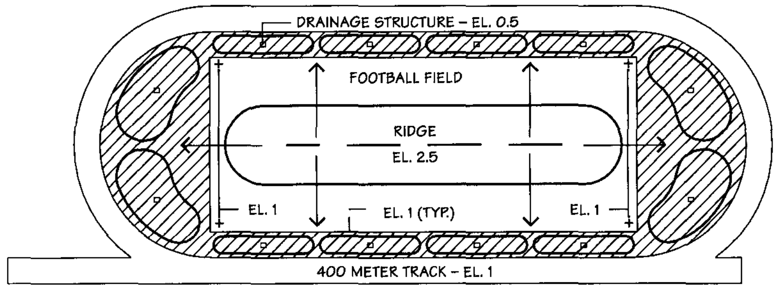
Table 320-3. RECOMMENDED GRADIENTS: SPORTS

Play area	Gradiant, %
Archery	1.5–2 (cross slope)
Turf	1 (along length)
Aerial darts	Same as tennis
Badminton	
Concrete	1.25–1.5
Asphalt	1.5
Clay	1.5
Grasstex or equal	0.8–1
Synthetic turf	0.8–1
Baseball	
Skinned infield	1–1.25
Infield turf	1.25–1
Mound	See Figure 320-39
Outfield turf	1.25–1.5
Synthetic turf infield/outfield	0.5
Batting area clay, earth, etc.	0.5–0.8
Bocci	0.5 (along length)
Basketball	
Concrete	1–1.5
Asphalt	1.25–1.5
Grasstex or equal	0.8–1
Bicycle	
Little effort	0–3
Medium effort	8
Walk bike	20
Bowling (lawn)	
Turf	0–0.25
Curling	Level
Croquet	
Sand, clay, or equal	0–0.25
Deck tennis	Same as tennis
Field hockey	Same as football
Football	
Turf	1.5–2 to sides
Synthetic turf	0.5–1
Fencing	Level
Handball court	0.5–1
Horseshoe (longitudinal ridge level)	1.5–2 to sides
Lacrosse	Same as football
Paddle tennis	Same as tennis
Quoits	Level
Quoitennis	Same as tennis
Roller skating, recreational	
Linear straightaway, concrete	1–1.25 (pitch to side)
Curved	2–4 (bank)
Running track, straightaway	
Clay or soil surface	0.5–1 (to drain)
Synthetic surface	0.50.8 (to drain)
Running track, straight with circular ends	
Clay or soil surface	0.5–0.8 (to curb) 0.3–1 (100–300 mm) (superelevation)
Synthetic surface	0.5–0.8 (to curb) 0.3–1 (100–300 mm) (superelevation)
Shuffleboard	Level
Skeetshoot, general area	1.5–2
Soccer	Same as football
Softball	Same as football
Speedball	Same as football
Tennis courts	
Concrete	0.5–1 (cross slope) 0.4–0.5 (end to end)
Asphalt, rolled on base	1
Clay and grass	0.9–1
Synthetic surface	0.5–0.8
Synthetic turf	0.5–0.8
Tetherball	1–2 (from poled)
Track-field events	
Shot put, turf area	1 (axial crown)
Hammer throw, turf area	Same
Javelin, turf area	Same
High jump	Essentially level
Long jump	Essentially level
Pole vault	Essentially level

Note: Refer to rules published by NCAA and USLYA for more information.

Source: From Jot D.Carpenter, *Handbook of Landscape Architectural Construction,* Landscape Architecture Foundation, Washington, D.C.

Figure 320-43. Schematic grading for football/soccer/field hockey.



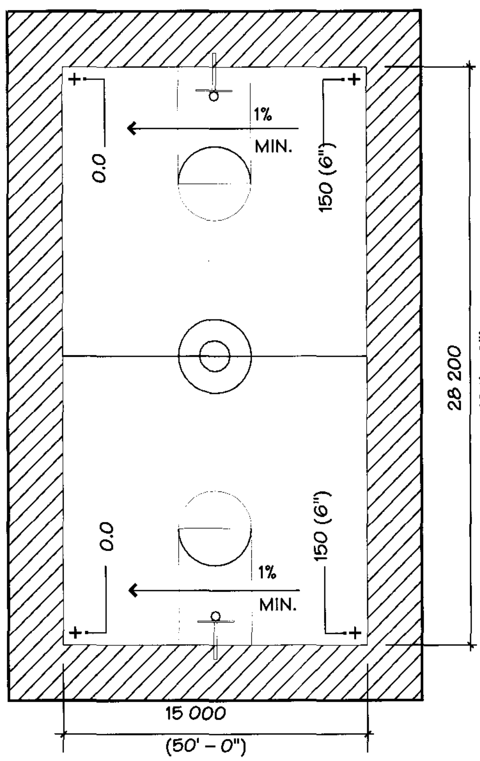


Figure 320-44. Schematic grading for outdoor basketball court.

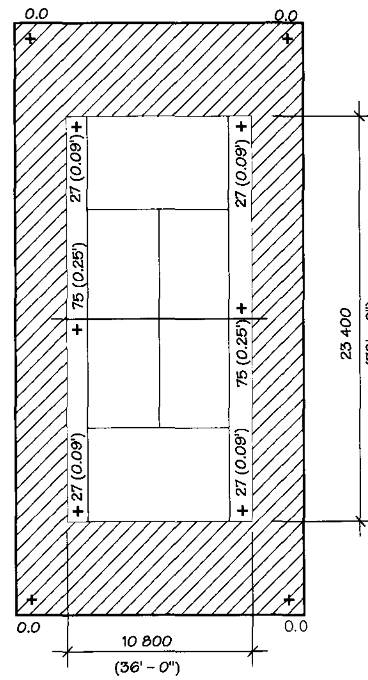


Figure 320-45. Schematic grading for outdoor tennis court.

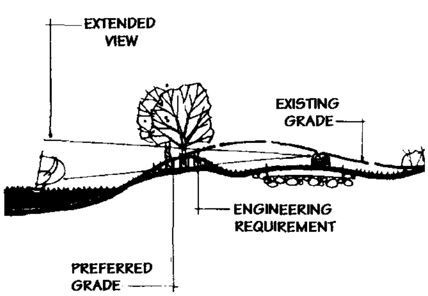


Figure 320-46. Grading to expose vista.

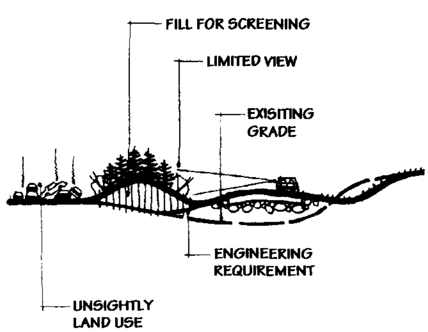


Figure 320-47. Grading to screen undesirable view.

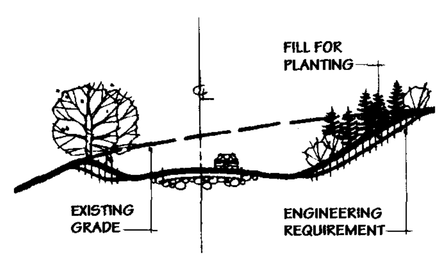


Figure 320-48. Grading to facilitate better plant growth.

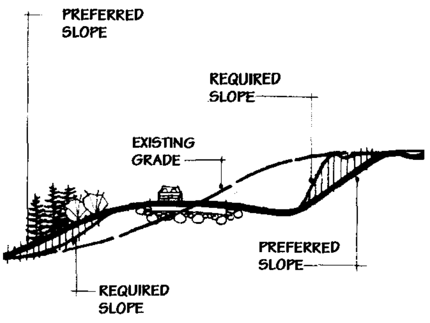


Figure 320-49. Grading to blend slopes with existing terrain.

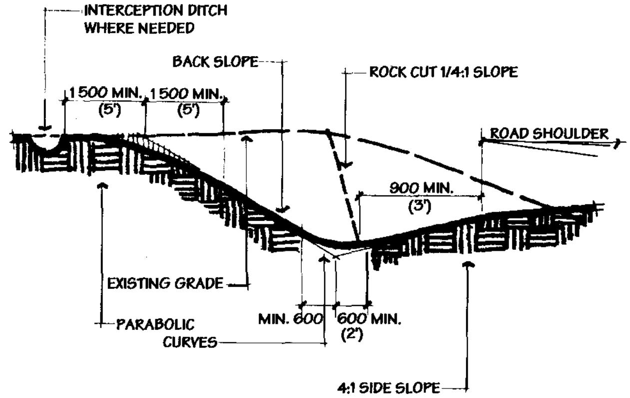


Figure 320-50. Cut side of cross section through road.

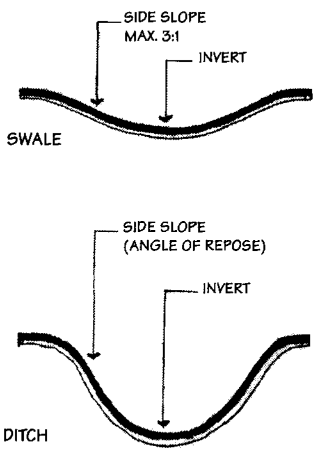


Figure 320-52. Swale and ditch cross sections.

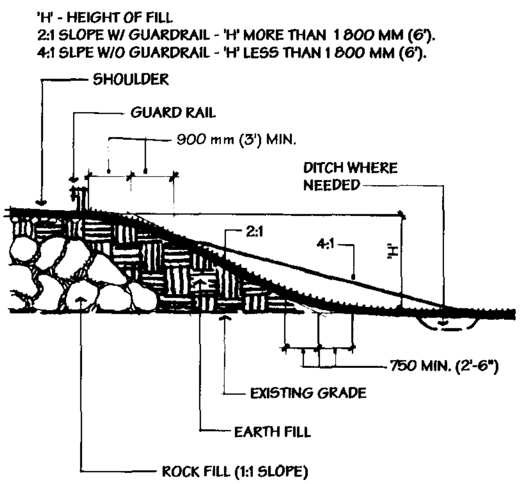


Figure 320-51. Fill side of cross section through road.

ditches are deeper and have a narrower geometric configuration (Figure 320-52).

Empirical data related to the hydraulic properties of ditches can be found in Section 330: Stormwater Management Swales are commonly used in grading to move water gently from one part of the site to another. Their function is to collect and divert the flow of surface runoff away from critical parts of a site. At their terminus, swales must either spread the channelized water into sheet drainage or empty the water into a ditch, stream, or underground drainage system. Figure 320-53 illustrates the use of a swale to divert water away from a building site.

The slope of the channel determines the velocity of flow and consequently the erosive potential. Since the side slopes of the swale do not affect this rate of flow, they

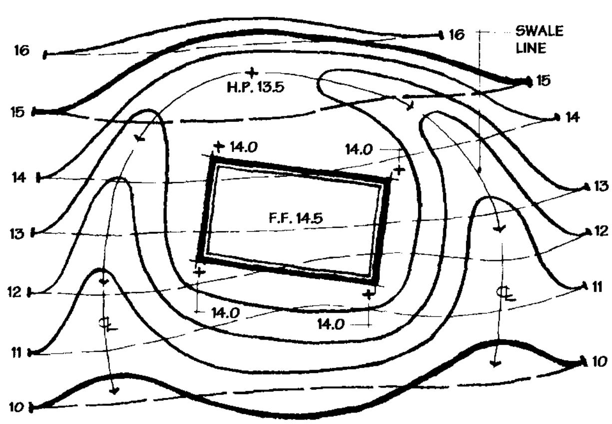


Figure 320-53. Swales to divert water around building. *Note that the channel widens and the slope diminishes as the swale approaches existing grade.*

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may be much steeper and respond to other design criteria.

Grass swales (Figure 320-54) tend not to erode if velocities do not exceed 1 200 mm (4 ft) per second for established blue-grass turf or 1 800 mm (6 ft) per second for established tall fescue turf. Spreading grasses, such as Bermuda or St. Augstine, exhibit similar resistance to erosion. The durability of grasses will vary considerably throughout various climatic regions. In the United States, regional Natural Resource Conservation Services can be consulted about which native grasses to use for erosion control.

If velocities exceed 1 800 mm (6 ft) per second, then some form of nonvegetative material should be used to construct the swale, such as gravel, crushed stone, or riprap (Figure 320-55).

Drainage Channels with Unprotected Soil:

Table 320-5 lists the velocities that will not erode aged drainage channels.

1. Aging means allowing time to increase the density and stability of the channel bed material through the deposit of silt

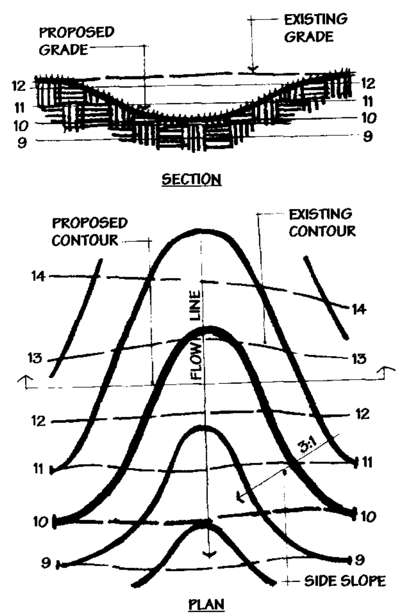

Figure 320-54. Typical grass swale grading.

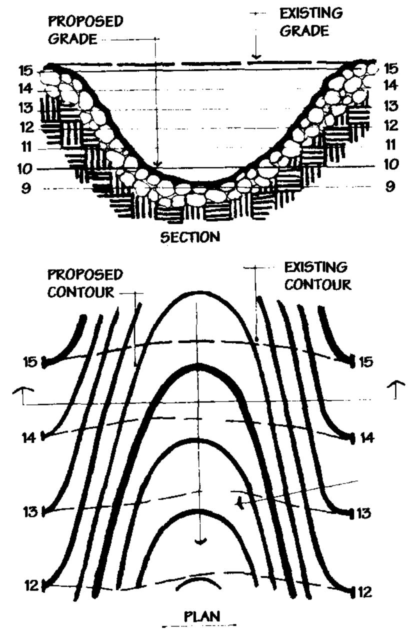

Figure 320-55. Typical ditch grading.

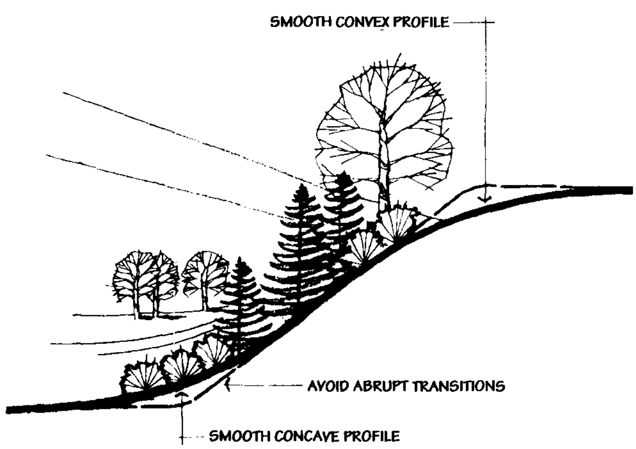

Figure 320-56. Grading of a typical head wall.

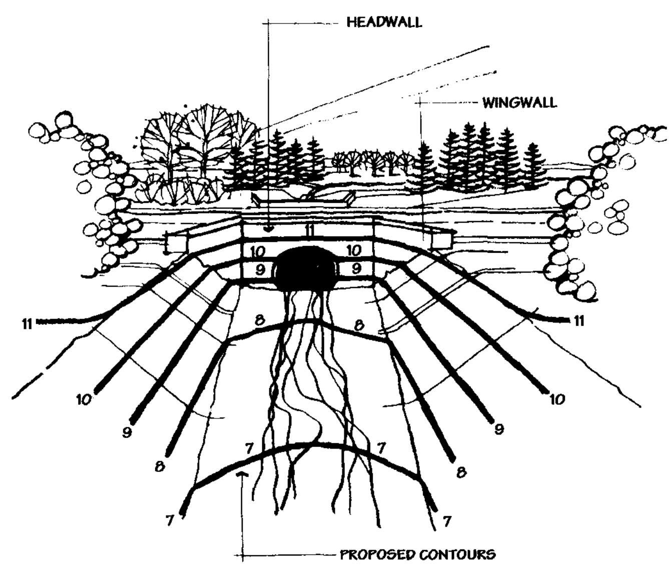

Figure 320-57. Grading criteria for slopes.

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Table 320-4. SPATIAL STANDARDS FOR ROADS

Pavement widths	
Single-lane road	3 000-4 200 mm (10-14 ft)
Two-lane road	6 000-7 200 mm (20-24 ft)
Four-lane road	6 000-7 200 mm (20-24 ft) either direction
Pavement crown	
Natural soil	15 mm : 300 mm (1/2 in : 1 ft)
Gravel, crushed stone	10-15 mm : 300 mm (3/8-1/2 in : 1 ft)
Intermediate-type bituminous	5-10 mm : 300 mm (1/4-3/8 in : 1 ft)
High-type bituminous	3-5 mm : 300 mm (1/8-1/4 in : 1 ft)
Concrete	2.5-4 mm : 300 mm (1/10-3/16 in : 1 ft)
Brick or stone	5 mm : 300 mm (1/4 in : 1 ft)
Shoulders	
Minimum width	300 mm (1 ft)
Minimum desirable width	600 mm (2 ft)
Preferred width	2 400-3 000 mm (8-10 ft)
Slope	15 mm : 300 mm (1/2 in : 1 ft) (approximately 4%)
Side slopes	
Slope	4 : 1
Back slopes	
Earth, minimum	1 1/2 : 1
Earth, preferred	2 : 1 or 3 : 1
Ledge rock, minimum	1/4 : 1
Shale	1/2 : 1
Fill slopes	
Earth, minimum	2 : 1
Earth, preferred	4 : 1
Ditches	
Minimum depth	300-600 mm (1-2 ft) below shoulder elevation
Maximum inslope	3 : 1

Source: From Public Roads Administration, American Association of State Highway Officials, State Highway Departments.

in the interstices and the cementation of the soil by colloids. New channels may be safely operated at less than maximum design velocities by the use of typical erosion control measures, including temporary check structures.
2. Velocities should be reduced for depths of flow under 150 mm (6 in) and for water which may transport abrasive materials.

Culverts and Headwalls:

The grading scheme and the design of the headwall for a culvert must be totally integrated. Figure 320-56 illustrates how a headwall and wings serve as a retaining wall to allow full exposure of the culvert pipe.

Slopes and Berms:

The angle of slopes should be considered in regard to aesthetic, drainage, and maintenance needs.

Figure 320-57 shows how steep slopes used for earth berms or mounds can be graded, using the following rules of thumb:
1. Provide for nonerosive drainage at the tops and bottoms of slopes.
2. Grade the tops of banks to be smoothly convex and the toes smoothly concave.
3. Grade the slopes to blend in with the surrounding landscape.

Stairs and Ramps:

Standards for outdoor stairs and ramps are discussed more fully in Section 240: Outdoor Accessibility. Stairs and ramps should be designed as an integral part of any overall grading plan (Figure 320-58).

Existing Trees:

Grading around existing trees should be managed with great care, using one or more of the following techniques:
1. Figure 320-59 shows how to avoid grading, cutting, or filling above the root zone of a tree. For most species this means staying outside the drip line of the tree. Also, the weight of the grading equipment driven over the root zone will tear root hairs and compact the soil, thereby restricting vital water and air from flowing to and being assimilated by the roots.
2. If filling around an existing tree cannot be avoided, then the tree must be protected. Figures 320-60 and 320-61 illustrate a typical method of protection.This technique permits adequate flow of air and water to the roots of the tree.
3. Figure 320-62 shows another way to create a flat area and at the same time

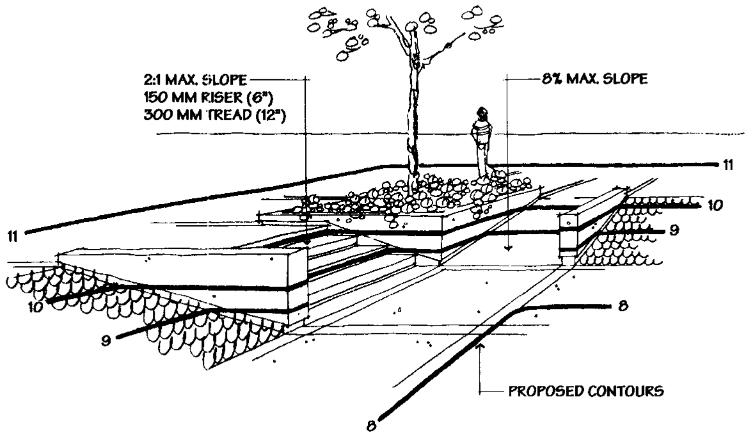

Figure 320-58. Grading of stairs and ramps. *Note that tread/riser ratios greater than 2:1 are advisable whenever possible.*

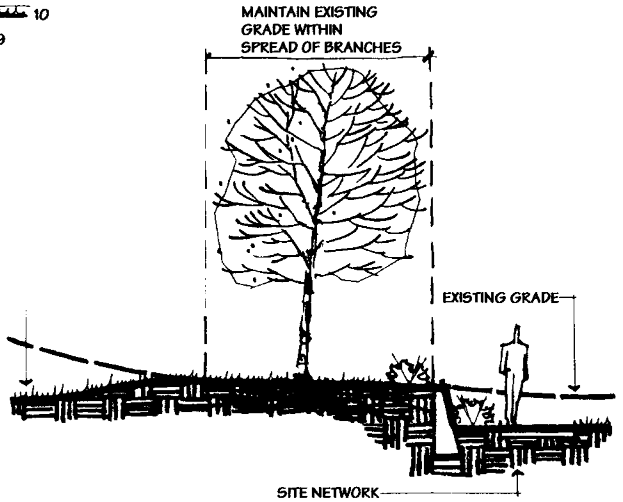

Figure 320-59. Grading near existing trees.

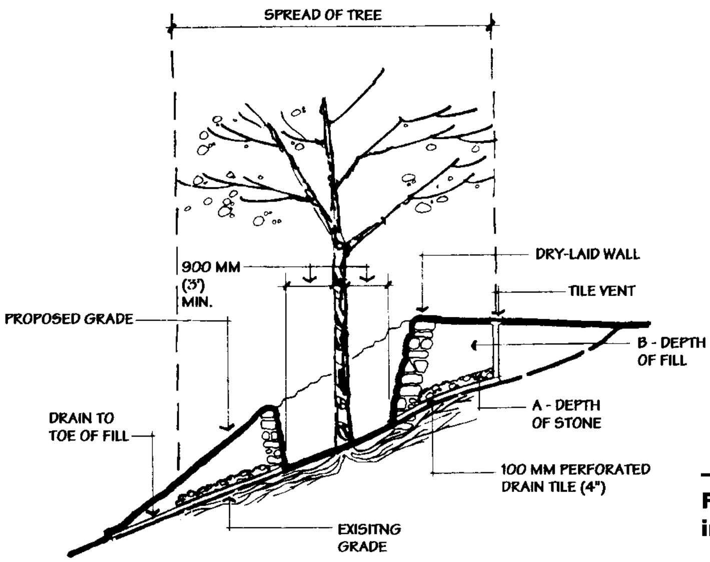

Figure 320-60. Retaining wall and drainage for existing tree in area of fill (section).

protect existing trees. A deck is constructed, with footings that do not disturb the root system around a tree. The deck's layout can be adjusted to the specific site conditions. When buildings or other such structures are involved, as shown in Figure 320-62, it is better to use lightweight footings with crawl spaces rather than on-grade slabs with compacted subgrades.

Figure 320-63 shows how grade beams and piers can be used to support walls and other structures without having to cut the major roots of existing trees.

Erosion Control by Grading:

Most erosion is caused by flowing water. The size and shape of a watershed, the porosity of its soils, and the length and gradient of its slopes and channels are key determinants controlling the volume and velocity of runoff and the risk of erosion. Several site grading techniques can be employed to limit the size, shape, length, and gradient of these slopes and channels, thereby reducing the volume and velocity of runoff.

Gradients can be reduced by extending the length of a slope. This uses more land, but it does reduce the amount of erosion and the potential slumping of hillsides (Figure 320-64).

Used singly or in combination, diversion swales, ditches, and dikes can intercept and divert runoff from the face of a slope (Figure 320-65).

Soil Slippage:

Several factors may cause soil masses altered by either cutting or filling to slide. The most common causes are improper cuts or fills and insufficient attention to surface and subsurface drainage characteristics. (In some regions where there are unstable soils there may be local standards that have to be met, including the use of

Table 320-5. ERODIBILITY OF DRAINAGE CHANNELS WITH UNPROTECTED SOILS

	Acceptable Velocity	
Material of channel bed	**Shallow ditch, m/s (ft/s)**	**Deep canal, m/s (ft/s)**
Fine sand or silt, noncolloidal	0.15-0.45 (0.50-1.50)	0.45-0.76 (1.50-2.50)
Coarse sand or sandy loam, noncolloidal	0.30-0.45 (1.00-1.50)	0.53-0.76 (1.75-2.50)
Silty or sand loam, noncolloidal	0.30-0.53 (1.00-1.75)	0.60-0.90 (2.00-3.00)
Clayey loam or sandy clay, noncolloidal	0.45-0.60 (1.50-2.00)	0.68-1.05 (2.25-3.50)
Fine gravel	0.60-0.76 (2.00-2.50)	0.76-1.50 (2.50-5.00)
Colloidal clay or noncolloidal gravelly loam	0.60-1.0 (2.00-3.00)	1.00-1.50 (3.00 5.00)

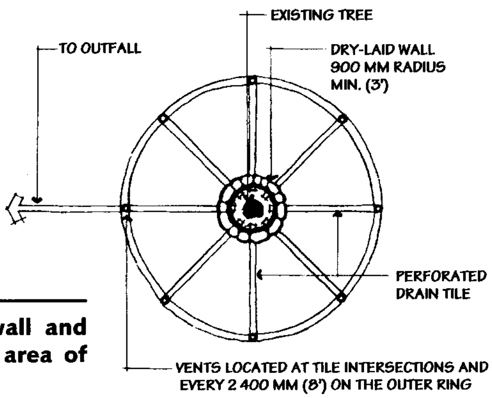

Figure 320-61. Retaining wall and drainage for existing tree in area of fill (plan).

vegetative or mechanical anchors.) Figures 320-66 and 320-67 illustrate alternatives for grading to stabilize cut-and-fill banks. Erosion control techniques are covered more fully in Section 640: Disturbed Landscapes.

Grading for Porous Paved Surfaces:

The use of gravel, crushed stone, porous asphalt, or other types of porous paving allows either flatter or steeper gradients than bare soil, but their use may not justify radical changes from the grading and drainage standards normally used in a region.

Some artificial turf systems require an extremely porous subbase so that water will immediately penetrate the surface. This water must then be carried away by a subsurface drainage system of an appropriate capacity. Using such a system allows play surfaces to be graded flat.

Parking Areas:

Grading of Parking Areas- The minimum and maximum gradients required for vehicular access and parking areas are often the major determinants for the grading plan of a site. Figure 320-68 illustrates how a parking lot can be stepped down a steep slope.

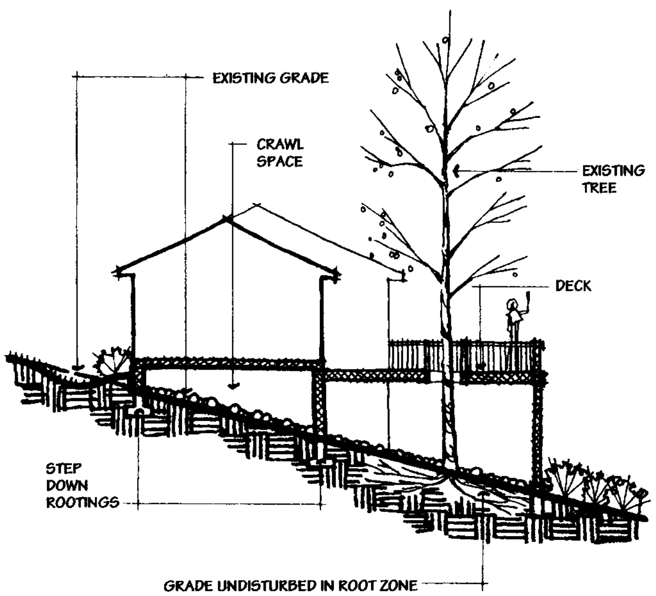

Figure 320-62. Crawl space and decking near existing trees.

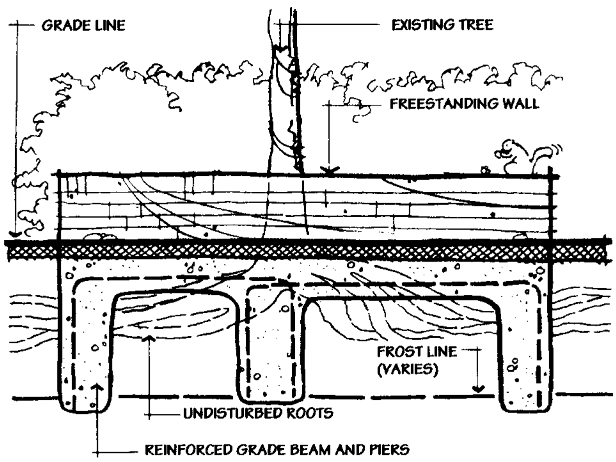

Figure 320-63. Grade beam method of tree root protection.

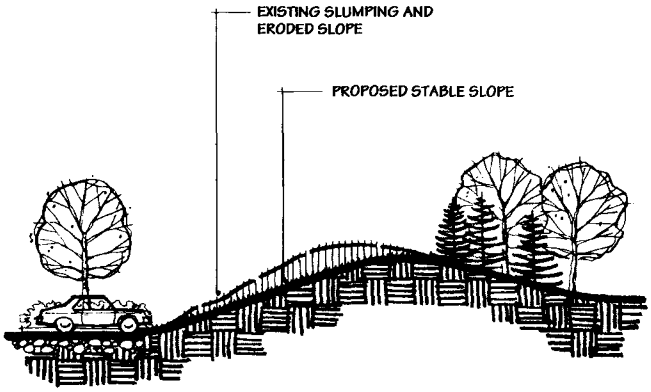

Figure 320-64. Erosion control by reducing gradient of slopes.

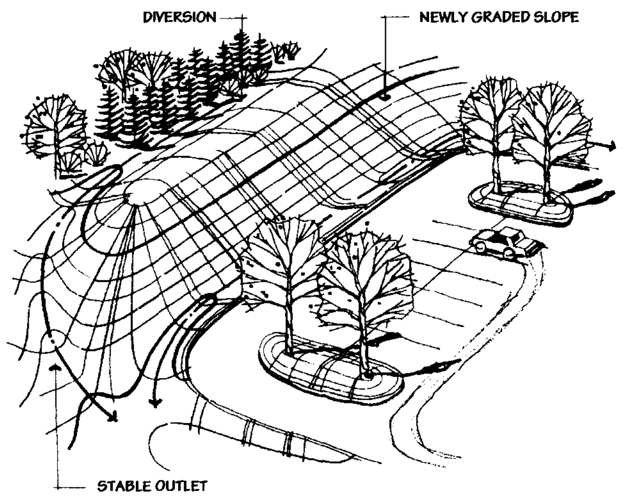

Figure 320-65. Grading to divert runoff.

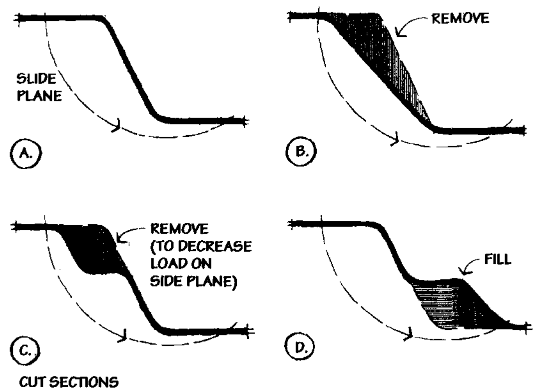

Figure 320-66. Stabilization techniques for cuts on hillsides.

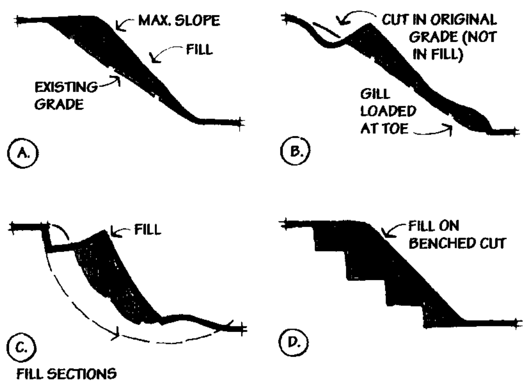

Figure 320-67. Stabilization techniques for fills on hillsides.

As shown in Table 320-2, the recommended maximum cross slope for a parking area is 10 percent. The steeper transitional area between bays can be taken up by a planting bay and a ramp (maximum 15 percent slope) (Figures 320-69 and 320-70).

Figure 320-71 shows how in extreme circumstances single-loaded parking bays may be used to fit steep sites. Similarly, a combination of ramps and segmented parking bays may be used to achieve a grading solution on a slope with existing vegetation (Figure 320-72).

Runoff Control from Parking Areas- More municipalities require that the increased stormwater runoff caused by new paving and structures should be contained within a site. The manner in which this is achieved is usually determined during the grading process. Quantities of water to be retained can be calculated with the data provided in Section 330: Stormwater Management.

Figure 320-73 illustrates the alternative of using an overflow parking area as a detention basin when a separate detention basin cannot be fitted into the scheme.

Figures 320-74 through 320-76 illustrate how swales may be filled with a porous material, such as rock, to give a level appearance and yet act as multiple retention basins between parking bays. This method, in addition to controlling runoff, serves to recharge the groundwater and increase the moisture content of surrounding soils.

5.0 EARTHWORK PROCESSES

5.1 Grading As Part of a Sequential Design Process

Although circumstances may vary from site to site, most grading operations proceed according to the following steps.

Preparation of the Site:

Clearing, Grubbing, and Removal-Remove designated trees and other types of vegetation from an area to be graded. Note that in some cases it is recommended that all

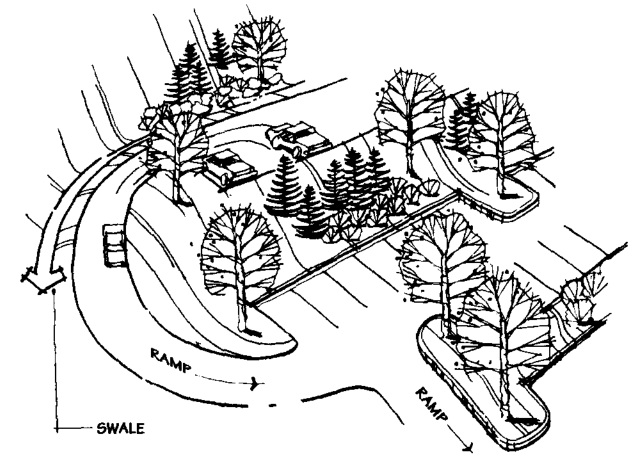

Figure 320-68. Example of a stepped-down parking area.

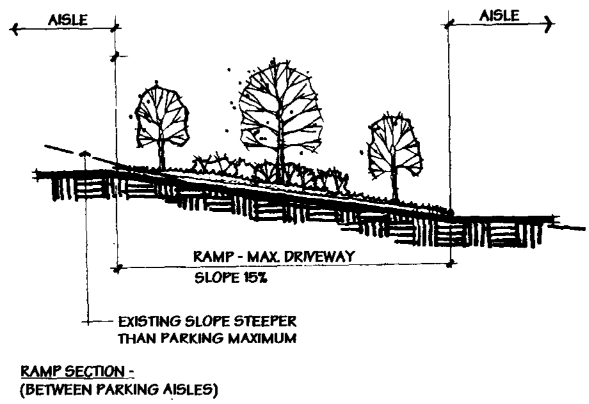

Figure 320-69. Example of a ramp section between parking aisles.

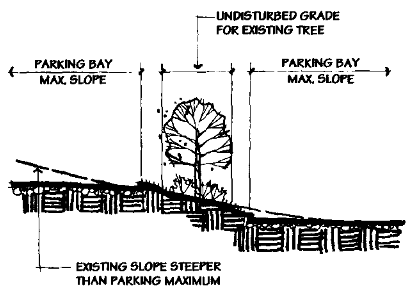

Figure 320-70. Example of an island section between parking bays.

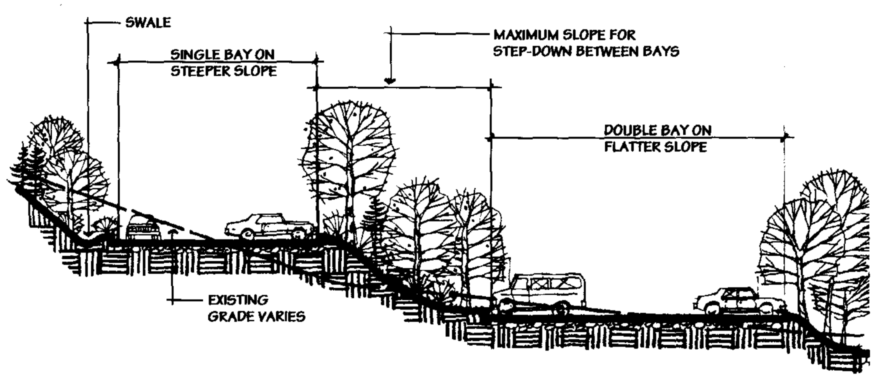

Figure 320-71. Combined single and double parking bays to adapt to steep slope.

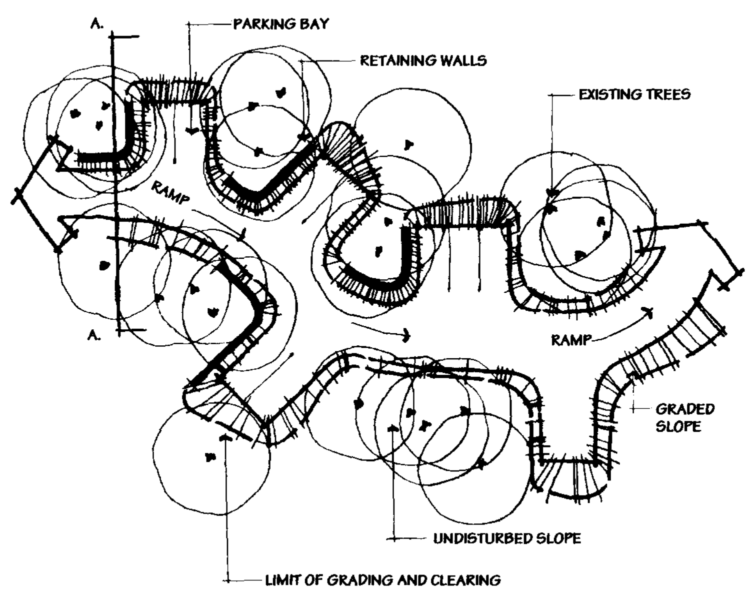

Figure 320-72. Segmented parking with walls and ramps to save existing trees.

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TABLE 320-6. Earth and Rock-Moving Equipment

Machine	Characteristics	Use
Bulldozer	Front-fitted rectangular blade can be raised or lowered	Push earth or rock. Limited capacity over large distances
Angledozer	Same principle as for a bulldozer	Push earth aside to left or right rather than ahead
Sideboom dozer	Cantilevered blade on side of machine adjustable in vertical plane	Trim slopes to an even batter
Grader	Curved section steel blade rotates in horizontal or vertical positions	Excavate shallow cuts. Cannot operate on vertical sites
Ripper-scarifier	Steel teeth, or tines, mounted on a frame	Break up or scarify hard, compacted earth
Face shovel	Operates at its own level. Open-type bucket or dipper is filled by driving it into material being excavated	Excavate clay, chalk, and loosened rock
Skimmer	Similar to face shovel, with more restricted movement and lower output. Will produce accurate finished level	Shallow digging
Backshovel or dragshovel	Working stroke is toward the machine. Excavates at a level below that of the machine's tracks	Ideal for use in confined spaces
Trencher or digger	Alternative to the backshovel	Excavating narrow, vertical-sided trenches
Dragline	Excavating bucket filled by dragging it toward the machine. Excavates at a level below that of the machine's tracks	Excavating in soft materials and swampy sites

existing plant material to be removed should be chopped and mixed with topsoil. This technique often proves to be an excellent way to help reestablish a similar type of vegetative cover. Sod should be removed or broken up by disks to prevent lumping during reuse.

Topsoil Stripping-

1. Strip to a specified depth determined by evaluation of the soil. This depth may vary from 75 to 600 mm (3 in to 2 ft).
2. Stockpile the stripped topsoil in locations outside of the no-cut/no-fill limits of the project, close to where it will be used later.

Excavation and Preparation of Subgrade:

1. Cut to the elevations indicated on the grade stakes set by the engineer or surveyor. Cutting and filling can be conducted simultaneously. The fill portion must be compacted according to predetermined construction standards.
2. Fill for planted areas should be compacted only enough to retain 30 percent minimum porosity.
3. Fill material must be put down in 150-200 mm (6-8 in) layers. Compact and test each layer to conform with specified densities.
4. Topsoil is added last to bring the grades to the levels and slopes shown on the grading plans.

5.2 Earth and Rock-Moving Equipment

There are many types of equipment that can be used to do grading. Table 320-6 shows some of the more common types and describes their characteristics, including typical uses.

5.3 Information on Soil and Rock Material

The initial site design and the eventual grading plan should be prepared based upon knowledge of the composition and other characteristics of the soil and/or rock to be moved. This data can be obtained in a variety of ways, depending upon the level of detail needed.

Sources of Information:

General soil data in the United States is published by the U.S. Department of Agriculture (USDA) and the National Resource Conservation Service (NRCS) for most states, on a county-by-county basis.

Specific information on soils can be obtained by borings or test pits at selected places on a site. These soil profiles can be analyzed to determine their effect on design and/or construction costs.

Data on depth to bedrock can be obtained by rod soundings for small-scale projects or by borings made by power augers.

Typical Soil Profile:

Figure 320-77 illustrates a typical soil profile for the central United States. Similar data can be found for other parts of the United States via the NRCS, local university or state agricultural departments, and other local sources of information. In other countries there are often similar sources of generalized soil data.

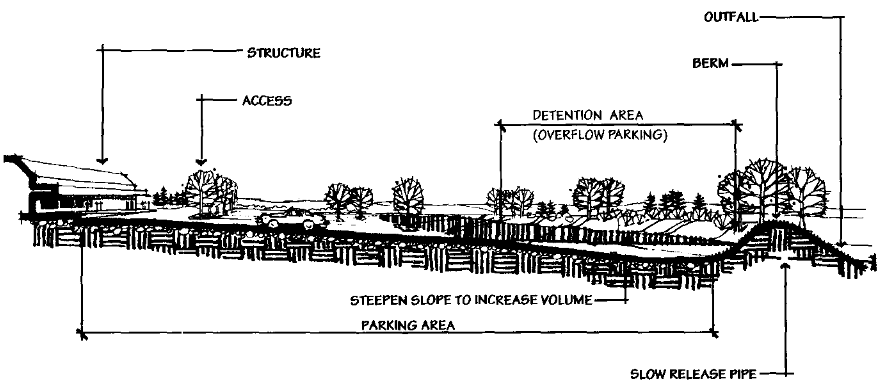


Figure 320-73. Overflow parking area used to detain stormwater.

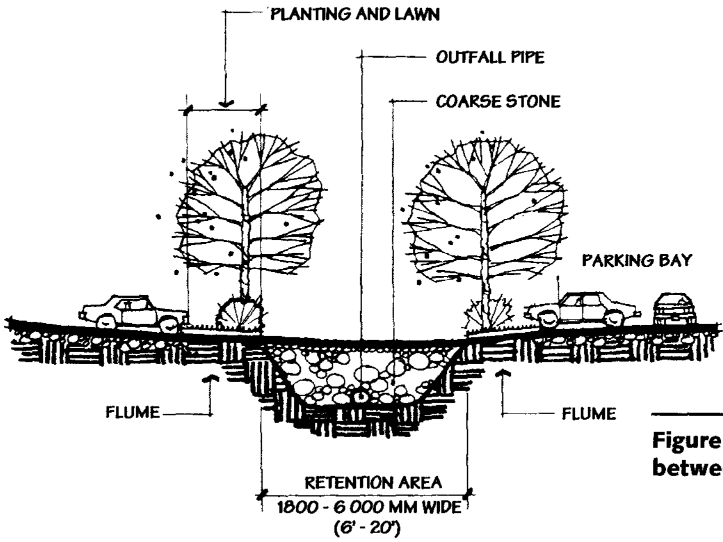


Figure 320-74. Porous-fill stormwater detention area between parking bays (section).

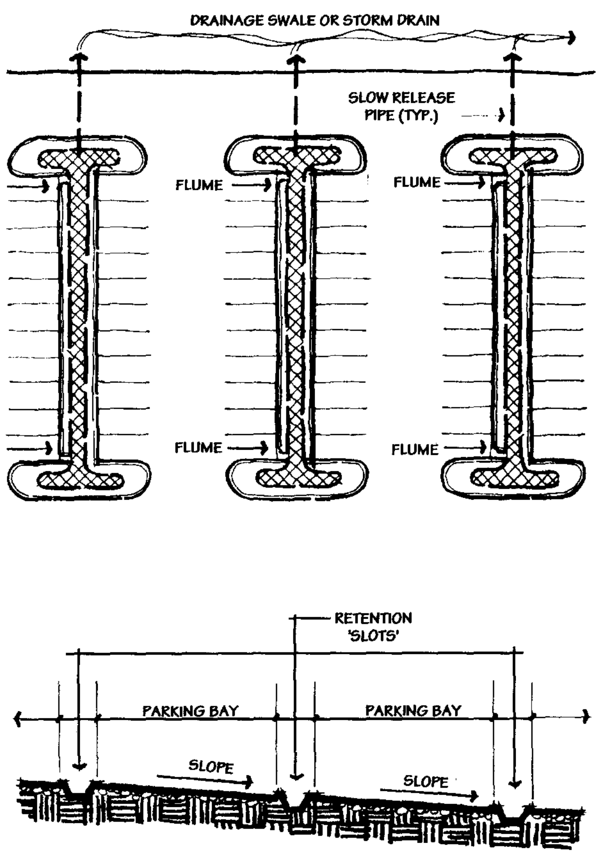


Figure 320-76. Porous-fill or slot swales for stormwater retention.

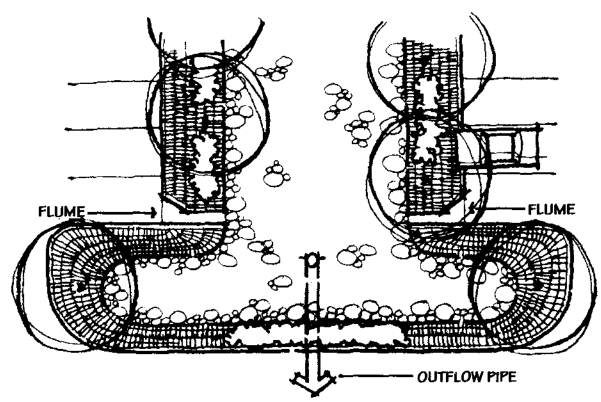
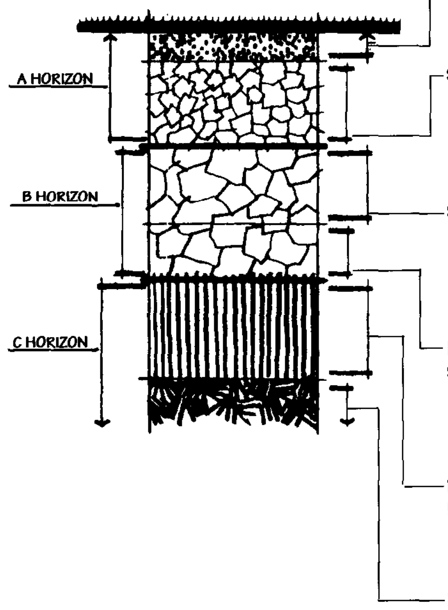


Figure 320-75. Porous-fill retention area between parking bays (plan).



	TYPICAL RANGE	DESCRIPTION	HOW TO USE
SURFACE SOIL	150-600 mm (6"-24")	Dark gray colored - high organic matter, high biotic activity,abundant roots, commonly leached.	Should be stripped from construction site, stockpiled for backfill in planting areas - not suitable for fill under construction.
SUBSURFACE	150-600 mm (6"-24")	Moderately dark — many roots, moderate organic matter, commonly leached.	May be used as fill under topsoil and may respond to compaction under some construction.
SUBSOIL	150-2 400 mm (6"-8')	Below plow depth - brown or reddish colored - more clay than surface, fewer roots.	Not desirable for plant growth but may make good compacted subsurface for construction.*
LOWER SUBSOIL	150-2 400 mm (6"-8')	More yellowish and less clay - fewer roots than subsoil, less aeration than above	Not desirable for plant growth but may make good compacted subsurface for con struction.*
PARENT MATERIAL		Unconsolidated - slightly weathered rocky mass from which soil develops. No biotic activity, . few roots	Good base course material when properly placed and compacted for construction.
BEDROCK		Consolidated rock.	

*Depends upon soil quality and type of construction anticipated.

Figure 320-77. Typical soil profile. *A soil horizon is a significant layer of soil that has distinct characteristics produced by soil-forming processes.*

Rock in Relation to Grading:

Rock is generally considered to be any material which requires blasting before it can be dug or moved by machines.

In preparing a grading plan that involves rock, the most useful data includes: (1) the amount of soil cover, or depth of earth to rock, (2) how much of the top layer rock is loose and can be easily broken, (3) how much of the rock will have to be blasted, and (4) the basic type of rock. As a general rule of thumb, the cost of blasting and moving rock is typically 7 to 10 times higher than moving dry, deep, moderately cohesive soil.

Rock is typically classified into three major groups. Only a brief description of each is included here.

Igneous: Igneous rock is solidified from a molten state, either at or beneath the surface of the earth. It is crystalline, typically not exhibiting a grain. Thus, it breaks irregularly depending on its composition.

Sedimentary: Sedimentary rock is made from the sedimentation of soil, plant, and animal remains that have hardened as a result of pressure, time, and the deposition of natural cements, typically at ocean depths. It will fracture along the planes of sedimentation.

Metamorphic: Metamorphic rock consists of previously igneous or sedimentary rock that has been altered by extreme heat and pressure, either at great depths or along tectonic fault lines, etc. It often exhibits some veining or foliation, which may fracture naturally as well as during blasting and excavation.

Swell and Shrinkage:

When soil or rock is dug or blasted out of its original position, it breaks into particles or chunks, which creates more spaces and adds to its bulk. This increase in volume is called swell. When soil is placed in a new location with nominal compaction, these voids are filled and some shrinkage occurs. Rock, on the other hand, swells. Compaction will not compress rock excavation to its original volume. Table 320-7 shows a guide to help estimate the amount of shrink or swell involved with different types of materials. The percentage of swell and shrink can be calculated using the following formula:

Swell: $Sw = \left(\frac{B}{L} - 1\right) \times 100$

Shrinkage: $Sh = \left(1 - \frac{B}{C}\right) \times 100$

Where:

Sw= % Swell
Sh = % Shrinkage
B = Weight of undisturbed bank
L = Weight of loose earth
C= Weight of compacted earth

Example: Find the % swell and % shrinkage for earth whose weights are:

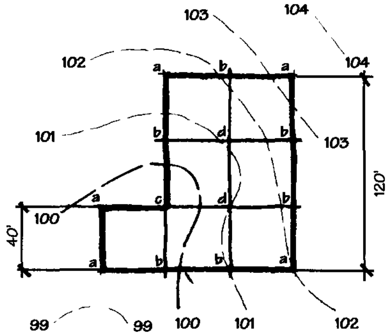
Bank measure undisturbed	1 474 kg/m^3
Loose measure	1 218 kg/m^3
Compacted	1 730 kg/m^3

Swell: $Sw = \left(\frac{B}{L} - 1\right) \times 100$

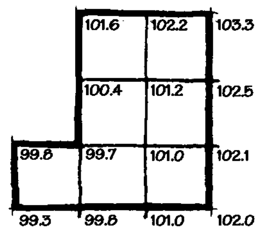
$$= \left(\frac{1474}{1218} - 1\right) \times 100 = 21\%$$

Shrinkage: $Sh = \left(1 - \frac{B}{C}\right) \times 100$

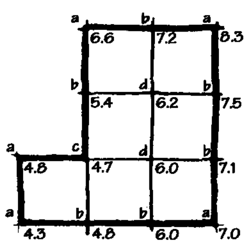
$$= \left(1 - \frac{1474}{1730}\right) \times 100 = 15\%$$



A.



B.



C.

Then, using the formula

$$\text{Volume} = \frac{a + 2b + 3c + 4d}{4} \times A$$

where A = aSTRS PG 40 x 40 ft. square, or 1,600 sq. ft. Then

$$\text{Volume} = \frac{31.0 + 2(38.0) + 3(4.7 + 4(12.2))}{4} \times 1600$$

$$= \frac{31.0 + 76.0 + 14.1 + 48.8}{4} \times 1600$$

$$= \frac{169.9}{4} \times 1600 = 67{,}960 \text{ cu. ft.}$$

$$\frac{67{,}960}{27} = 2{,}517 \text{ cu. yd.}$$

The area to be graded is divided into squares and the corners of the squares are labeled a,b, c, and d, depending on the number of squares each corner pertains to. The bottom of the excavation is to be at elevation 95.00. Figure B shows the existing elevations of the earth surface obtained by interpolating between the contours. Figure C shows the depth of cut at each of the corners, obtained as follows:

'a' Corners

101.6	103.3	99.8	99.3	102.0
−95.0	−95.0	−95.0	−95.0	−95.0
6.6	8.3	4.8	4.3	7.0

= 31.0 total cut

'b' Corners

102.2	200.4	102.5
−95.0	−95.0	−95.0
7.2	5.4	7.5
102.1	99.8	101.0
−95.0	−95.0	−95.0
7.1	4.8	6.0

= 38.0 total cut

'c' Corners

99.7
−95.0
4.7

= 4.7 total cut

'd' Corners

101.2	101.0
−95.0	−95.0
6.2	6.0

= 12.2 total cut

Figure 320-78. Grid method for estimating earth volume.

Weights of Soil and Rock Material:

Table 320-8 shows typical weights for a range of materials, when in place and after excavation.

5.4 Estimating Cut and Fill

General Considerations:

Techniques for estimating earthwork quantities are only approximations. This is true for several reasons: (1) spot grades from field surveys are typically accurate only to 30 mm (0.1 ft), (2) contours shown on survey maps are legally accurate only to one-half of the contour interval, and (3) the amount of swell or shrinkage cannot be predicted with any high degree of precision.

Not all estimates of cut and fill need to involve the same degree of accuracy. For instance, in the early stages of a site plan it may be important to know in only general terms whether there can be a balance of cut and fill.

Estimating Required Grading Quantities:

Preparation of a preliminary site plan and related grading plan can determine whether there will be a serious imbalance of cut or fill. Often an imbalance can be corrected by raising or lowering noncritical areas of a site design or even by raising or lowering the finish grades for an entire site.

Table 320-9 provides a quick estimate of the amount of raising and/or lowering required to correct an imbalance of cut and fill, once the amount of such imbalance is known.

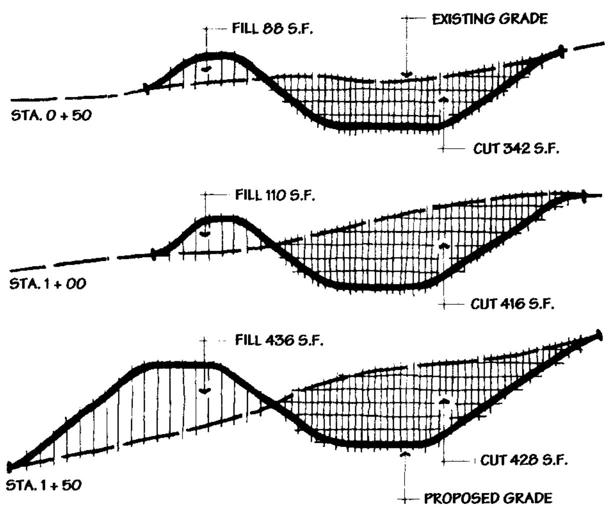
Three methods are commonly used to prepare estimates of the quantities of grading needed. Each one is briefly discussed below

Grid or Borrow Pit Method:

The grid method is relatively simple, quick, and easy to use. It is useful for estimating the excavation of buildings, etc. This method provides a considerable degree of accuracy (Figure 320-78).

Average End-Area Method:

The average end-area method is commonly used to estimate volumes on linear elements, such as roads and highways. Cross sections are taken at 15 000 - 30 000 mm (50-100 ft) intervals perpendicular to the centerline. The simplest average end-area procedure is to average areas, multiply by the distance between them, and then, assuming that this results in a cubic-foot



Sample Problem :

Stations	CUT	FILL
0 + 00 to 0 + 50:	$\frac{0 + 342}{2} \times 50 = 8550\ ft^3$	$\frac{0 + 88}{2} \times 50 = 2200\ ft^3$
0 + 50 to 1 + 00:	$\frac{342 + 416}{2} \times 50 = 18{,}950\ ft^3$	$\frac{88 + 110}{2} \times 50 = 4950\ ft^3$
1 + 00 to 1 + 50:	$\frac{416 + 428}{2} \times 50 = 21{,}100\ ft^3$	$\frac{110 + 436}{2} \times 50 = 13{,}650\ ft^3$
1 + 50 to 1 + 60:	$\frac{428 + 0}{2} \times 50 = 2140\ ft^3$	$\frac{436 + 0 \times 10}{2} = 2180\ ft^3$
	$= \frac{50{,}740}{27} ft^3$	$= \frac{22{,}980}{27} ft^3$
	$= 1879\ yd^3$ CUT	$= 851\ yd^3$ FILL

Figure 320-79. Average end-area method for estimating earth volume (sample problem). *Calculate taper to existing grade Station 0 to Station 50, and last station to the end of grading, by averaging.*

figure, divide by 27 to convert to cubic yards.

Contour Method:

This method, when combined with the Contour Method Tabulation Form and Summary Sheet (Table 320-10), provides the following information:

1. Total area stripped
2. Topsoil stripped
3. Topsoil replaced (including shrinkage)
4. Subsoil removed
5. Subsoil replaced (including shrinkage)
6. Total area and volume of hardscape
7. Total area of softscape

This method is widely used by landscape architects because it is very accurate for making final grading adjustments and for preparing cost estimates. The step-by-step process for using the contour method is outlined below.

Step 1: Delineate the no-cut/no-fill zone throughout the entire project (Figure 320-80 and 81) and calculate the gross area in cut and the gross area in fill. Gross area refers to area delimited by the no-cut / no-fill line and the limits of grading line in cut and fill zones respectively.

Step 2: Measure the total surface area of each contour in cut or each contour in fill separately and enter this area on the appropriate line next to the contour number. Drawings are commonly in digital format allowing area to be calculated using the computer; otherwise, a planimeter is used.

Step 3: Determine the depth of topsoil to be stripped and calculate the cubic volume separately for cut and fill using the gross areas entered at the top of the table. Enter these figures (TS) in the summary chart section of Table 320-10 on the appropriate Cut and Fill lines.

Step 4: Measure the proposed hardscape areas in the cut zone and the fill zone and enter the measurements under column H area on the respective Cut and Fill lines.

TABLE 320-7. Estimating Shrink and Swell

Material	After excavation during transport or stockpile	Borrow yard*	Amount produced by 1 meter (1 yd), replaced with only moderate compaction
Sand	0.83 m3 (1.11 yd^3) 111 % swell	0.75 m^3 (1 yd^3)	0.66 m^3 (0.88 yd^3) 12 % shrink
Common earth	0.94 m3 (1.25 yd^3) 125 % swell	0.75 m^3 (1 yd^3)	0.60 m^3 (0.82 yd^3) 18 % shrink
Clay	1.00 m3 (1.43 yd^3) 143 % swell	0.75 m^3 (1 yd^3)	0.65 m^3 (0.87 yd^3) 13 % shrink
Shot rock	1.30 m3 (1.67 yd^3) 167 % swell	0.75 m^3 (1 yd^3)	
Gravel, loose		0.75 m^3 (1 yd^3)	0.67 m^3 (0.89 yd^3) 11 % shrink

* Materials used for compacted subbase will exhibit higher shrinkage levels under the appropriate moisture conditions and compaction technique.

Table 320-8. WEIGHTS OF SOIL AND ROCK MATERIALS

Material	Weight in bank, kg/m³	(lb/yd³)	Loose weight, kg/m3	(lb/yd³)
Clay				
Dry	1 044	(2300)	835	(1840)
Light	1 271	(2800)	981	(2160)
Dense, tough, or wet	1 362	(3000)	1 021	(2250)
Earth				
Dry	1 271	(2800)	1 017	(2240)
Wet	1 530	(3370)	1 256	(2700)
With sand and gravel	1 407	(3100)	1 198	(2640)
Earth and rock mixture, such as unclassified excavation	1 135-1 362	(2500-3000)	872-1 048	(1920-2310)
Gravel				
Dry	1 475	(3250)	1 317	(2900)
Wet	1 634	(3600)	1 453	(3200)
Loam	1 226	(2700)	1 017	(2240)
Rock, hard, well-blasted				
Sand	1 816	(4000)	1 216	(2680)
Dry	1 475	(3250)	1 317	(2900)
Wet	1 634	(3600)	1 453	(3200)
Sandstone	1 880	(4140)	1 353-1 185	(2980 2610)

Source: Herbert L. Nichols, Jr., *Moving the Earth,* D. Van Nostrand Company, Princeton, New Jersey, 1955.

Step 5: Calculate the volumes for hardscape in the cut and the fill zones and enter these volumes under H vol. in the summary chart at the appropriate Cut and Fill lines.

Step 6: To determine the total non-paved area to receive topsoil for planting, subtract total hardscape area (H area) from the total no-cut / no-fill zone project area by first, subtracting the area of hardscape in the cut zone from the total area in the cut zone; then, subtracting the area of hardscape in the fill zone from the total area in the fill zone. Enter the resulting area in column S (softscape) at the lines appropriate for Cut and Fill.

Step 7: Determine the thickness to which the topsoil is to be replaced and calculate separately the required volumes for the cut and the fill areas respectively found in Step 6. Enter the volumes in column TR (topsoil replaced) on the appropriate lines for Cut and Fill.

Step 8: Calculate the gross cut and gross fill volume separately by using the formula:

$$i\left(\frac{5A_1}{6} + A_2 + A_3 + A_4 \ldots \frac{5A_n}{6}\right)$$

where:

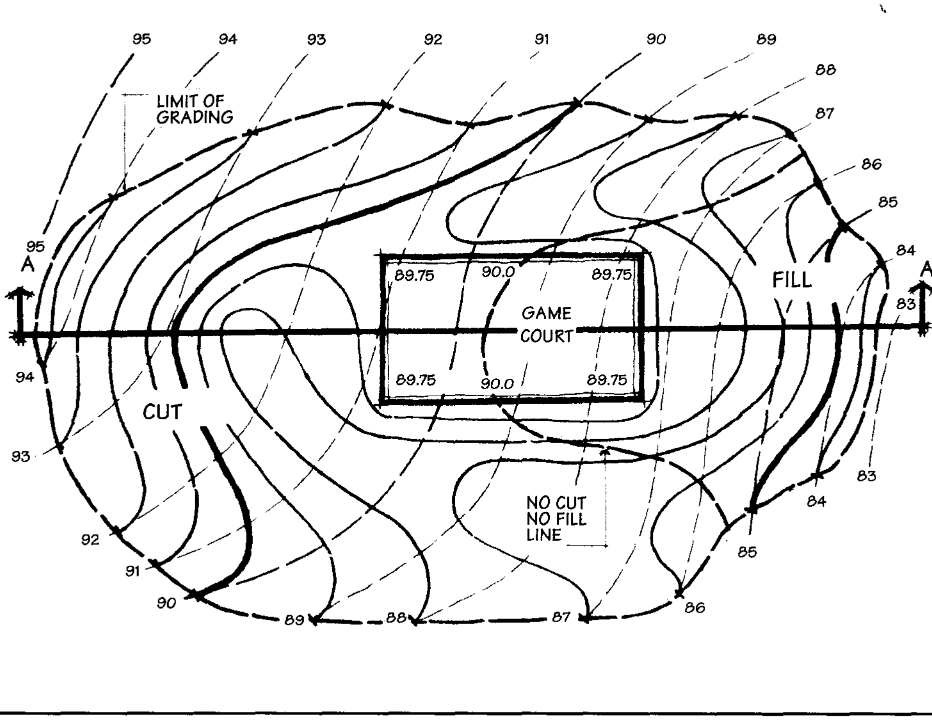


Figure 320-80. Contour plan method for estimating earth volume.

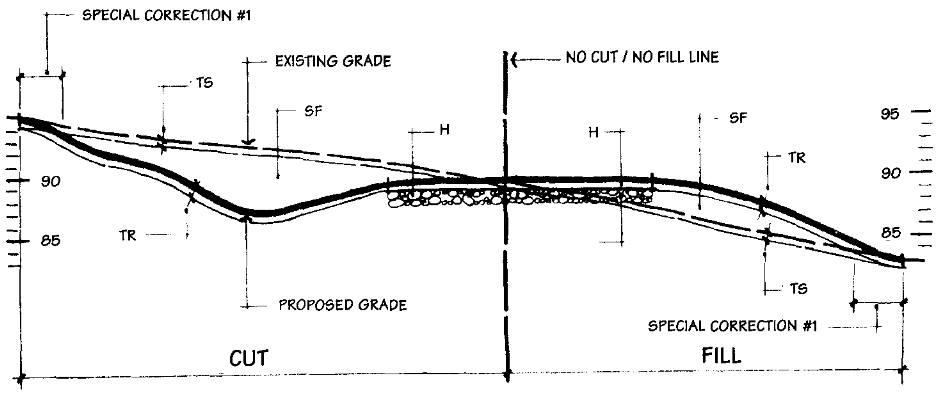


Figure 320-81. Section for contour method.

A= area of contour planes measured between original and finished contours

i= contour interval (vertical distance between contours)

Enter the volume for the cut area under C (cut) on the Cut line. Enter the volume for the fill area under F (fill) on the Fill line.

Step 9: Using the formula SC = –C + R + TR – TS, calculate the subsoil cut. Enter the volume cut in column SC (subsoil cut) on the Cut line.

Step 10: Using the formula SF = –F + TS – TR – R, calculate the subsoil fill. Enter the volume fill in column SF (subsoil fill) on the Fill line. (A negative answer can be interpreted as an indication that additional subsoil may need to be removed in order to make room for hardscape materials.)

Step 11: Complete the summary chart by adding the columns vertically and incorporating shrinkage factors where appropriate.

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Parker and MacGuire, James Ambrose (ed.) Simplified Site Engineering for Architects and Builders, *Wiley, New York, 1991.*

Untermann., Richard K. Grade Easy, *ASLA Foundation, Washington, DC, 1974.*

Weddle, Arnold. Techniques of Landscape Architecture, *Heinemann, London, 1979.*

Table 320-10: CONTOUR METHOD FORM AND SUMMARY SHEET

CUT

Gross area in cut = __________*

Contour Number	Area

FILL

Gross area in fill = __________*

Contour Number	Area

* Gross area refers to area delimited by no-cut/no-fill line and limits of grading line in cut and fill zones respectively.

Volume in cut or Volume in filll can be calculated as follows:

$$\text{Volume} = i\left(\frac{5A_1}{6} + A_2 + A_3 + A_4 + \ldots + \frac{5A_n}{6}\right)$$

Where A = Area of contour planes measured between original and finished contours.
I = contour interval

Note: If calculating area with a planimeter in square feet, the result of the above equation must be multiplied by the square of the drawing scale divided by 27 in order to yield cubic yards.

Summary

	C	SC	F	SF	TS	H Vol.	H Area	TR	S
CUT									
FILL									
SUBTOTAL									
%SHRINKAGE									
TOTAL									

C=Volume of Cut
SC = Subsoil Cut (–C+H vol.+TR–TS)
F=Volume of Fill
SF=Subsoil Fill (–F+TS–TR– H vol.)
TS=Volume of Topsoil Stripped

H vol. = Volume of Hardscape (paved)
H area = Area of Hardscape (paved)
TR = Volume of Topsoil Replaced
S = Area of Softscape (non-paved)

KEY POINTS: Earthwork Processes

1. Most grading operations proceed according to the following steps: preparation of the site, topsoil stripping, excavation and preparation of subgrade.
2. The initial site design and the eventual grading plan should be prepared based upon knowledge of the composition and other characteristics of the soil and/or rock to be moved. This data can be obtained from the National Resource Conservation Service (NRCS), or equivalent international agencies. More specific information can be collected through soil borings and test pits.
3. When soil or rock is dug or blasted out of its original position, it breaks into particles or chunks, which creates more spaces and adds to its bulk (Table 320-7).
4. Preparation of a preliminary site plan and related grading plan with cut and fill calculations can determine whether there will be a serious imbalance of cut or fill.
5. The grid method is useful for estimating the excavation of buildings.
6. The average end-area method is commonly used to estimate volumes on linear elements, such as roads and highways.
7. The contour method is widely used by landscape architects because it is very accurate for making final adjustments to the grading and for preparing cost estimates.

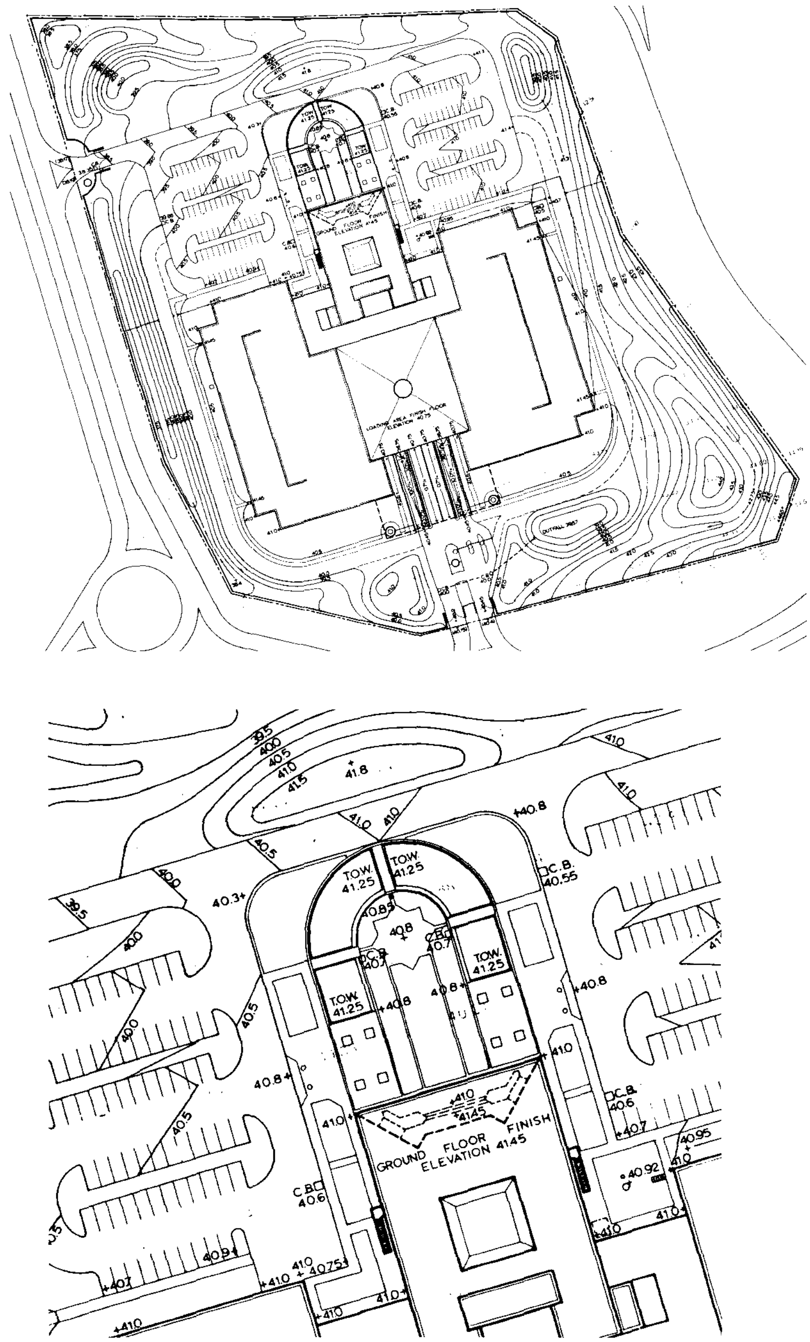

Figure 320-82. Metric grading plan example: *Kuwait Postal Services Complex, TAC, Inc.*

Stormwater Management

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CONTENTS

1.0 INTRODUCTION

Stormwater management in landscape architecture includes a broad range of applications and issues. It includes long-term regional planning concerning land areas measured in square kilometers. It also includes site design where land areas are more appropriately measured in square meters. At every level, stormwater management is the prediction and direction of the movement of stormwater runoff.

Many of the standards provided in this section vary with locality and regional climate. Also, the information relative to water quality design is provided in the context of a rapidly developing knowledge base and evolving practice. Stormwater management is as much an art as a science, requiring judgement in the use of available data and application of calculations and techniques. Readers should check local practice and standards before applying the information presented.

2.0 DESIGN INFORMANTS

2.1 Hydrologic Cycle

The hydrologic cycle is the global process of the earth's water movement. The energy that operates the system comes from the sun and the earth's gravity (Figure 330-1). In general, urbanization locally disrupts the hydrologic cycle by sealing the ground surface with imperviousness and compacted soils, shifting precipitation from the infiltration and subsurface runoff path to the surface runoff path.

2.2 Precipitation and Runoff

Precipitation occurs as rainfall, snowfall, or mixtures of each. Snow and snowmelt are not typically major factors in small watersheds. For site planning and design, stormwater management focuses on the estimation of runoff from rainfall.

2.3 Watershed Conditions

The amount of runoff water that flows to a particular point in the landscape is dependent upon the size of the watershed, the portion of landscape that contributes or drains runoff to that point. The watershed has a topographically determined boundary, consisting of a line of ridges and saddle points that divides the land contributing runoff water to the particular point of concern, from areas that contribute runoff elsewhere.

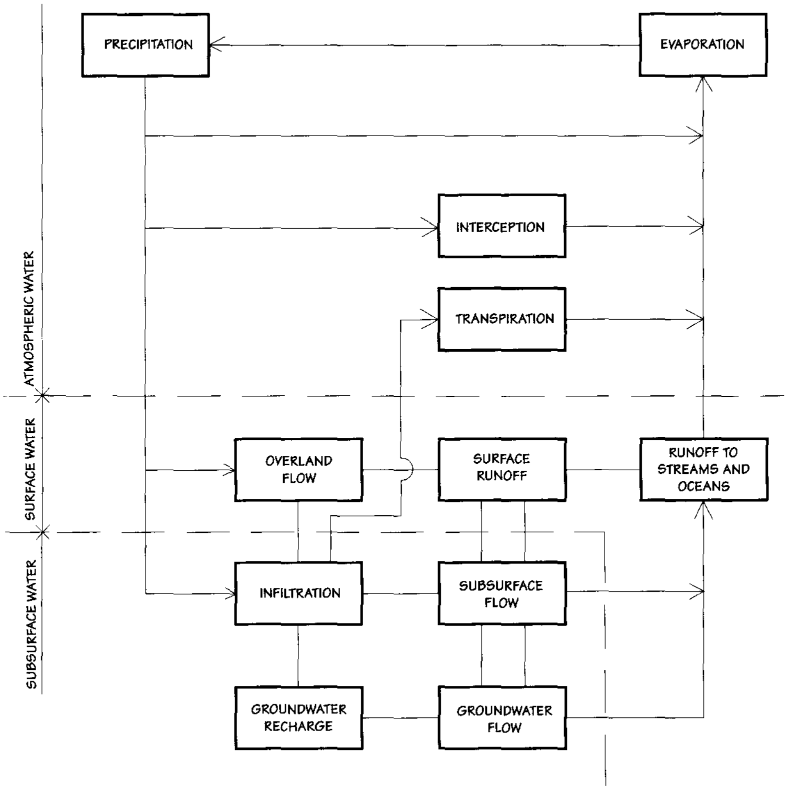


Figure 330-1. The Hydrologic Cycle.

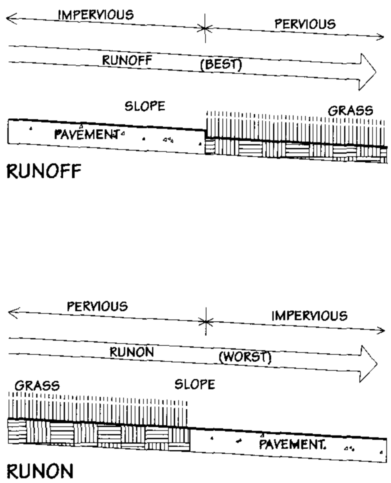


Figure 330-2. Diagrammatic sections showing runoff and runon.

Land Cover:

The character of land cover affects interception of rainfall. Generally, land cover with greater complexity will intercept more precipitation. The most complex land covers are highly layered plant communities with vast amounts of leaf area that must be wetted before runoff is shed. One of the effects of urbanization is the simplification of surfaces. Artificial surfaces tend to be substantially less complex than native surfaces, and intercept comparatively less rainfall.

Soils and Infiltration:

Infiltration into the ground is the primary cause of rainfall loss. Soil type is the principal determinant of infiltration. Sandy soils infiltrate more water at a faster rate than clay soils. Paved surfaces negate the infiltration capacity of soils. Urban soils can act very much like pavement because the porous structure of the soil has been destroyed by compaction.

Imperviousness:

A major impact of urbanization on stormwater is the establishment of large areas of impervious surfaces. Imperviousness radically alters the water balance of a site by increasing runoff in terms of both volume and peak discharge.

The arrangement of impervious areas relative to drainageways has a powerful influence over the amount of runoff generated (Figure 330-2). Where runoff drains directly from impervious surfaces into drainageways, runoff is maximized. Where runoff drains from impervious surfaces as sheet flow onto pervious surfaces (e.g. grass), runoff is minimized. The former case is termed connected imperviousness because it is directly connected to the drainage system. The latter case is termed disconnected imperviousness. Site design that seeks to maximize disconnected imperviousness will result in less stormwater runoff and better water quality.

Moisture Conditions:

Wet surfaces produce more runoff than dry surfaces. Assumptions must be made about antecedent moisture conditions prior to a design rainfall. Typically, normal or average moisture conditions are assumed.

Slope:

The average slope of a watershed affects the amount of runoff generated. Rain falling on flatter slopes is shed more slowly, allowing more rainfall to infiltrate than on steep slopes.

3.0 STORMWATER DESIGN ISSUES

Many traditional drainage techniques were developed to address a narrower set of issues than required by today's standards. This section focuses on principal design issues for modern stormwater management.

3.1 Flood Protection

Flood protection is typically defined by two general categories in terms of level of risk: Major flooding and minor flooding. Major flooding puts lives and significant structures at risk. Minor flooding puts convenience and minor structures at risk. (Figure 330-3).

Minor System:

The minor system minimizes the inconveniences associated with frequently occurring storms. Typical examples of these systems are storm sewers and roadside or backyard swales. These systems are usually designed to accommodate the 2, 5, or 10 year storm. Minor flooding occurs when these systems overflow into adjacent areas, resulting in a temporary loss of their use for a short period of time, but no significant damage.

Major System:

The major system is used whenever the minor system capacity is exceeded. This is caused by the occurrence of an infrequent event such as the 25, 50, 100 year storm, or maximum probable rainfall event. Major systems may or may not be designed. In either case, when runoff flow exceeds the minor system capacity, it takes an alternative route through the landscape. Watersheds that have major structures and populations located in the flow path of the major system are subject to major flood damage.

In the United States, creeks and rivers that are part of the major system are included in flood insurance studies required by the Office of Insurance and Hazard Mitigation of the Federal Emergency Management Agency (FEMA). Flood insurance studies typically estimate the magnitude of floods associated with recurrence intervals from 10 to 500 years. Flood insurance studies also produce maps designating official flood hazard areas expected to be inundated by the 100 year and 500 year floods (or maximum probable rainfall event). Flood hazard maps are typically available for review at county and municipal offices.

KEY POINTS: Watershed conditions

The amount of runoff water that flows to a particular point in the landscape is dependent upon the size of the watershed and its physical characteristics.

1. Complex land covers (e.g. highly layered plant communities) result in less runoff. Urbanization tends to simplify land cover, often causing an increase in runoff volumes.

2. Soil type is the principal determinant of infiltration rates. Urbanization tends to result in greater impervious surface, as well as compaction of the earth, reducing the potential for infiltration of stormwater.

3. The placement of impervious surface within a watershed can significantly affect runoff rates. Site design that seeks to maximize disconnected imperviousness will result in less stormwater runoff and better water quality.

4. A watershed with steep slopes, tight soils, high imperviousness, and moist, simple surfaces will produce far more runoff than the same size watershed with flat slopes, coarse soils, no imperviousness, and dry, complex plant communities.

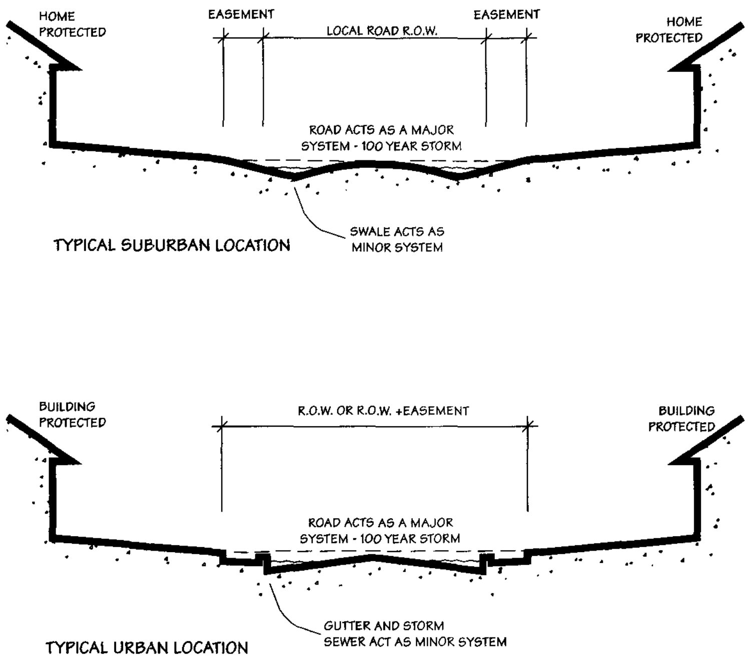


Figure 330-3. Major and minor flooding systems in suburban and urban locations.

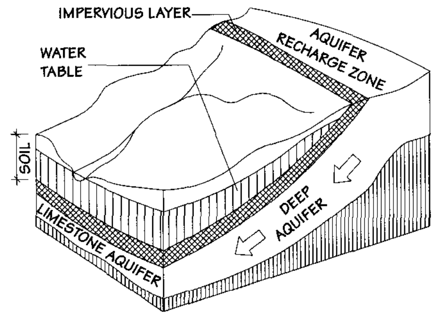


Figure 330-4. Shallow and deep infiltration/aquifer recharge.

3.2 Water Quality Protection

In 1989 the United States Environmental Protection Agency found that non-point source pollution contributed over 65 percent of the total pollution load to inland surface waters. Since then, significant regulatory efforts have been made to reduce non-point source contamination of surface waters based on sections 401 and 402 of the Clean Water Act. Water quality protection systems are typically designed to treat runoff from a 30 mm (1.25 inch) rainfall, and a two year rainfall, to protect from erosion.

Sediment:

The erosion and sedimentation process delivers the largest load of pollutants into water bodies that receive runoff. Erosion is the removal and suspension of soil into runoff from its normal position by fast water velocities. Sedimentation is where soil particles drop out of the runoff flow with a reduction in the velocity of flow.

Oxygen Demand:

The sustenance of plants, animals and microorganisms in water bodies is dependent upon the availability of dissolved oxygen (DO). Oxygen demand can be estimated by direct measure of DO, or by indirectly measuring biological oxygen demand (BOD), chemical oxygen demand (COD), oils and greases, and total organic carbon (TOC). The most common cause of depletion of dissolved oxygen is excessive nutrient loads delivered to the water body.

Nutrients:

Nutrient loading is a major contributor to surface water quality degradation. A major source of these pollutants is careless use of fertilizers. Carbon (C), Nitrogen (N), and Phosphorus (P) are the principal nutrients associated with degradation of water quality. Common measurements are total nitrogen, organic nitrogen, total Kjeldahl nitrogen (TKN), nitrates, ammonia, total phosphate (TP) and total organic carbon (TOC).

Heavy Metals:

Many metals can reach toxic levels of concentration in stormwater. The most common metals in urban stormwater are copper (Cu), lead (Pb) and zinc (Zn). Others found include arsenic (As), cadmium (Cd), chromium (Cr), iron (Fe), mercury (Hg), nickel (Ni), and selenium (Se). Sediment levels of streams, lakes and ponds provide an indication of pollution from heavy metals.

Chemical Contaminants:

Chlorine (Cl) is toxic to plants and animals in sufficient concentrations. Sources of chlorine contamination include treated potable water from municipal water supplies, and heavily chlorinated swimming pool water dumped into storm drains during seasonal flushing.

Chloride is a significant runoff contaminant in areas where sodium chloride (salt) is used as a winter deicing chemical on pavements.

Other chemical contaminants, such as industrial chemicals and pesticides, are commonly found in urban waters and sediment. These include oil and grease, polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs). Pesticides found in urban runoff and sediments include aldrin, alpha chlordane, gamma chlordane, DDD, DDE, DDT, dieldrin, heptachlor, lindane, methoxychlor, and trans-nonachlor.

Pathogens:

Urban runoff pollutants include disease causing bacteria and viruses. A common measure of pathogens in surface water is fecal coliform bacteria. Limits for various levels of contact are often based on the number of bacteria colonies per 100 milliliters of water sampled. A common limit for body contact (swimming) is 400 c/100ml. Parasite contamination is becoming increasingly important in stormwater quality. Such parasites include: *Cryptosporidium parvum*, *Entamoeba hystolytica* and *Giardia lamblia*.

Thermal Pollution:

In the summer, sustained water temperatures above 20° C (70° F) can be stressful if not lethal to cold water organisms such as trout and salmon. Such temperature changes are commonly associated with the influx of impervious surfaces into a watershed. In the summer, unshaded impervious surfaces can have local air and ground temperatures 5° to 7° C (10° to 12° F) higher than vegetated fields and forests. Runoff passing over these surfaces is heated and delivered to surface water bodies.

3.3 Groundwater Recharge

The replenishment of groundwater by rainfall infiltration is known as recharge. If groundwater is not recharged, the water table drops. Porous soils, and areas where the ends of tilted porous bedrock layers are exposed to infiltrating stormwater, are zones where groundwater recharge occurs (Figure 330-4). The layers of water bearing soil and rock are aquifers. Impervious surfaces eliminate aquifer recharge capacity when placed in recharge areas.

3.4 Soil Stability

Clays, silts and organic soils become unstable when wet. Poorly managed surface and subsurface drainage can wet these soils causing them to swell with moisture or heave with frost action. Refer to Section 255: Expansive Soils for more information.

3.5 Wildlife Habitat

Plants and animals depend on particular water regimes and levels of water quality. Urbanization can change the availability and quality of water needed to sustain habitat. It tends to drastically reduce or eliminate base flow. In such cases the original plant species are replaced by others more adapted to the new regime. The animal species that depended on the original plants also change.

3.6 Water Supply

Runoff is harvested for drinking water in many communities. Water drawn (and treated) from rivers, lakes and major streams for municipal water supply systems comes from stormwater runoff. Untreated or partially treated stormwater is frequently used on site for irrigation and fire protection purposes, particularly in rural areas.

3.7 Quality-of-Life

Studies have found that constructed ponds and wetlands are regarded as positive attributes of places to live and work. Their presence provides open views and vistas. New ponds and wetlands can define neighborhood and community boundaries and establish impressions of positive character at their entry points and along roads. Other stormwater management elements make important contributions to the total character of a neighborhood. For example, the presence or absence of curb and gutter drainage sends a subtle but unmistakable visual message about whether a place is urban or rural. These quality-of-life elements are linked to stormwater management decisions. Furthermore, when integrated as parts of overall project design, stormwater elements may contribute to higher real estate market values.

4.0 DESIGN PROCEDURES

To design an adequate stormwater system, and assess its effect on the surrounding landscape, it is typically necessary to consider larger drainage systems that extend well beyond the site boundaries. Sites are usually part of larger watersheds, which may be regulated by soil and water conservation districts or watershed districts. In the United States, there are also state and federal departments with regulatory interests in stormwater management and surface water.

4.1 Data Gathering & Mapping

Rainfall Data:

In the United States, many municipal and county engineering departments develop and maintain standardized rainfall data for the design of stormwater management facilities. State departments of transportation are also good sources of current rainfall data. Another good source is the U.S. Natural Resources Conservation Service (NRCS) through their state engineering offices. In many cases, stormwater systems will be required to meet these rainfall amounts. For schematic design, or where local rainfall data is not available, the rainfall maps and design storm information provided in subsection 5.0 Runoff Calculations, may be used.

Storm Works and Flow Data:

Local county and municipal engineering departments should also have flow data on the streams, channels and storm sewer lines that will be receiving stormwater from the site. This information should be gathered prior to design.

Other important stormwater works data includes but is not limited to: As-built storm sewer plans and profiles, locations and elevations of inlets (on and off site), pipe data (including size, shape, material and length), normal and designed water surface elevations of nearby wetlands, lakes and ponds (natural or constructed) that are part of the regional stormwater management infrastructure, and type, inverts and sizes of any water control structures associated with that infrastructure.

Topography:

Good topographic data is essential to determine watershed and catchment boundaries. In many cases, the logical measuring point for site discharges lies outside the site boundaries. In other cases, areas upstream drain through the site and must be accommodated by design proposals. As a result, the quantification of runoff may require off-site topography information.

KEY POINTS: Stormwater design issues

Modern stormwater management must address a wide variety of issues not required of traditional techniques.

1. Protection from flooding is typically controlled by minor or convenience systems, to handle frequently occurring storms, and major systems that accommodate larger, infrequent events (i.e. 100 year rainfalls).
2. Water quality protection from non-point source pollution begins by controlling sediment, the largest contributor of pollutants into water bodies. Contaminants include nutrient loading, heavy metals, chemicals and pathogens.
3. Areas of groundwater recharge should be preserved where possible. Urbanization in recharge areas may restrict infiltration capacity due to impervious surface.
4. Expansive soils may swell or become unstable when wet. Surface and subsurface drainage may be critical, particularly if structures are placed in these areas.
5. Plant and animal life that depend on particular water regimes can be adversely affected by urbanization, as the amount and quality of water changes.
6. Quality-of-life values such as open views, community identity, and recreational opportunities are linked to stormwater management decisions. These amenities often translate to higher real estate market values.

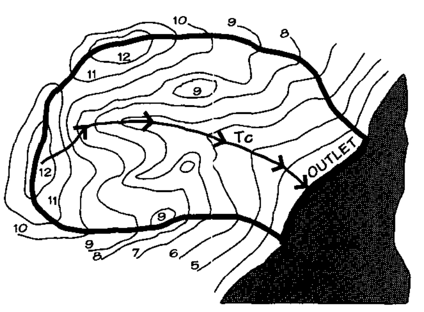


Figure 330-5. Watershed outlet –where outlet appears to be an edge.

KEY POINTS: Schematic Design

Most governmental controls require designs to hold runoff discharges at or below pre-development conditions. This can be achieved in schematic design through a number of strategies:

1. Use stormwater design to slow runoff velocities to pre-development conditions. Holding runoff volumes on site will reduce velocity while preventing sedimentation and erosion.

2. Use infiltration strategies to mitigate the loss of pervious surface that is characteristic of development.

3. Use site design to minimize impervious surfaces, and remove them from drainage pathways to the greatest extent possible (Figure 330-9). This often means revisiting fundamental assumptions about design.

4. Fit development to the terrain, and place it in the least critical areas of the site, away from drainageways, steep slopes, complex plant communities, and porous soils.

5. Use the natural drainage system whenever possible. When feasible, urban streams should be buffered with a minimum of 8 meters (25 ft) of undisturbed forest, and an additional 15-30 meters (50-100 ft) of managed vegetated area.

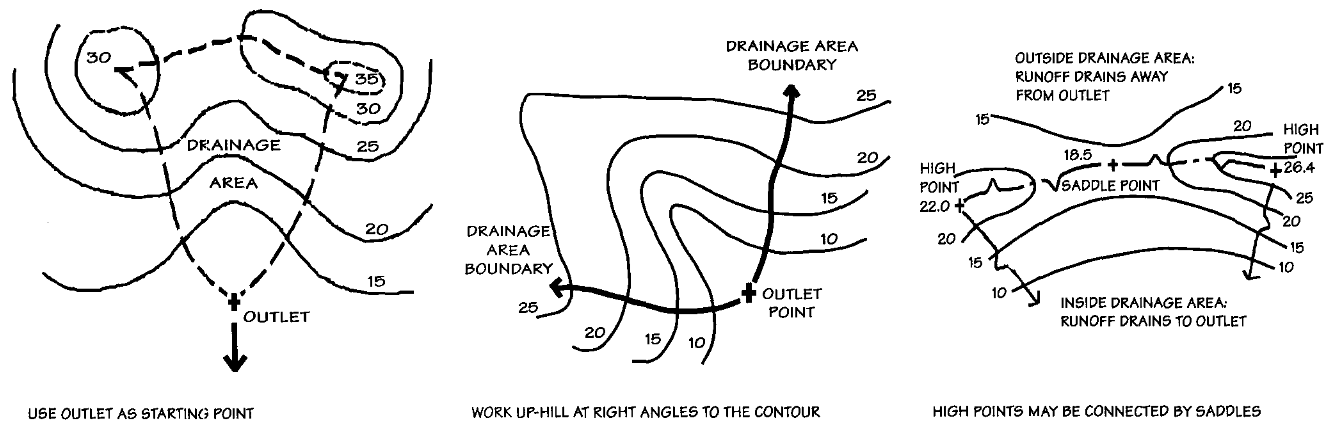


Figure 330-6. Watershed boundary delineation.

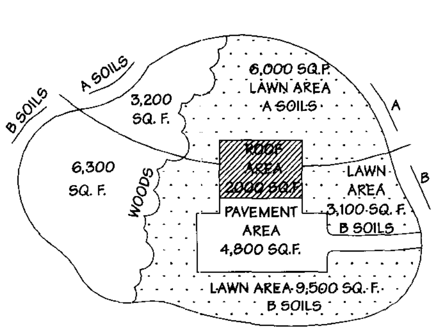


Figure 330-7. Delineating areas of cover and soil type.

Land Cover:

Land cover for existing or pre-development stormwater runoff estimation is best assessed in the field. A trial delineation can be completed from aerial photographs for field verification. Land cover data for proposed stormwater runoff estimation is assessed from site planning or schematic design documents.

Soils:

Soils data are essential for all runoff estimation techniques. In the United States, the Department of Agriculture soils surveys are a standard source of soils data for this purpose. Estimates of soil texture and infiltration performance can also be made based on vegetation types present on the site and by direct observation of the soils.

Bedrock and Water Table Depths:

Depth to bedrock and water table also influence site runoff potential. Shallow impervious bedrock and high water table conditions can cause even sandy soils to have limited absorption of rainfall. High bedrock and high water table conditions also limit the range of runoff management techniques available for use. Stormwater infiltration and storm sewer techniques are particularly limited by high bedrock and high water table conditions. Excavated ponds for stormwater detention are unfeasible in high bedrock areas. Constructed wetlands, wet ponds and wet swales are more feasible with high water table.

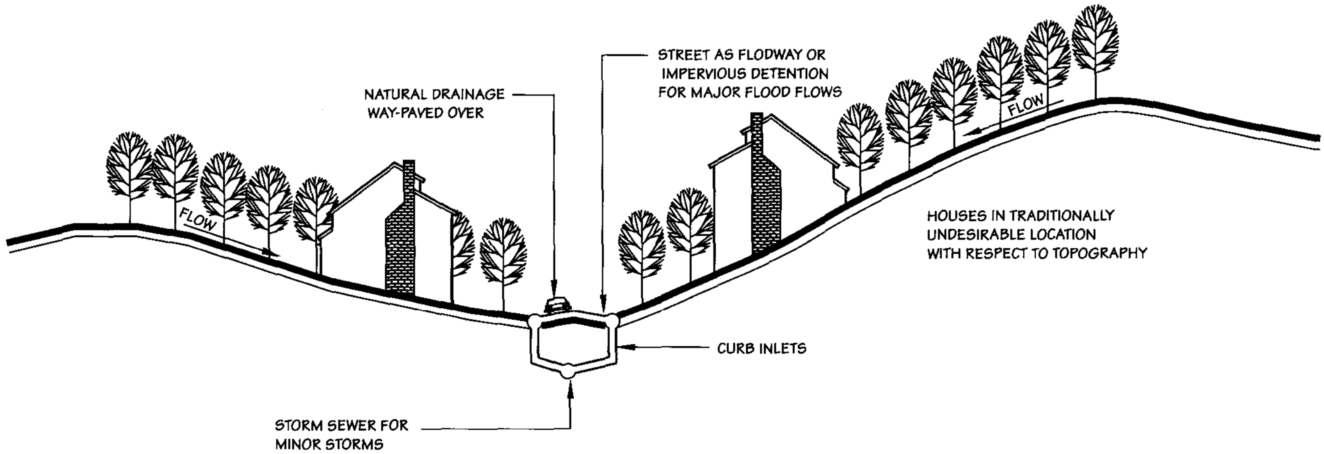


Figure 330-8. Location of imperviousness relative to drainageways in conventional development.

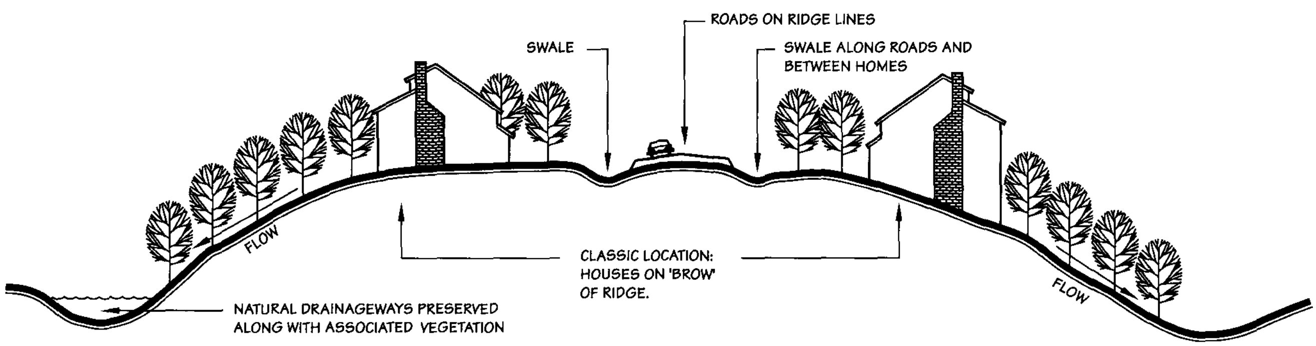


Figure 330-9. Impervousness placed high in the landscape. *Note the lack of storm sewers.*

4.2 Base Line Runoff Analysis

A base line runoff analysis should be developed against which design proposals can be compared for performance. Most local controls require designs to hold runoff discharges at or below existing conditions. The base line analysis demonstrates performance of existing conditions. Analysis is typically made in terms of peak discharge from a specified design storm.

The analysis should focus on the points where runoff leaves the site, delineating the watersheds that contribute water to these points. Runoff calculations are performed for existing (pre-development) conditions, establishing the peak discharge and volume at each dispersal point. Post-development runoff analysis must be made at these same points using the proposed site plan, even though the watershed boundaries may have different configurations and areas due to development changes.

In some situations, the 'point' of analysis may seem to be an edge. One example of this is where a site abuts a lake. The time of concentration path may follow a swale to a point on the lake edge. However, the actual runoff quantity is contributed all along an edge of the pond because runoff is generated by a subcatchment defined by the topography (Figure 330-5). This can also occur at site boundaries.

Watershed Boundary Delineation:

Once the points of analysis are selected the watershed boundaries must be plotted. The outlet is the most convenient starting point (Figure 330-6). Work uphill from the outlet, in both directions, at right angles to the contour. When the two lines join, the watershed boundary has been completely defined.

Soil-Cover Classification:

Once the watersheds are defined, areas with combinations of similar cover and soil type must be delineated so that they may be assigned a runoff factor. For example, if a block of woodland exists over two different soil areas, the woodland must be subdivided along the boundary separating the two soil types (Figure 330-7).

4.3 Schematic Design Strategies

Good site planning can avoid increases in runoff and reduce potential impacts on surface water quality. Design performance criteria should include: Peak discharges, runoff volumes, watershed infiltration capacity, ground water recharge, and water quality. They can be addressed by focusing on the following strategies.

Reproducing Pre-Development Hydrological Conditions:

The strategy of reproducing pre-development conditions can be pursued by setting pre-development velocities as the speed targets for post-development conditions.

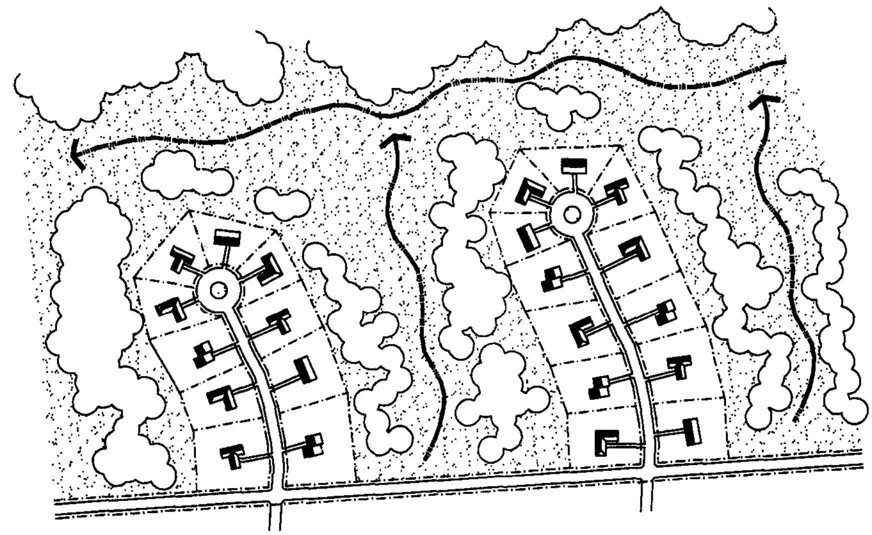
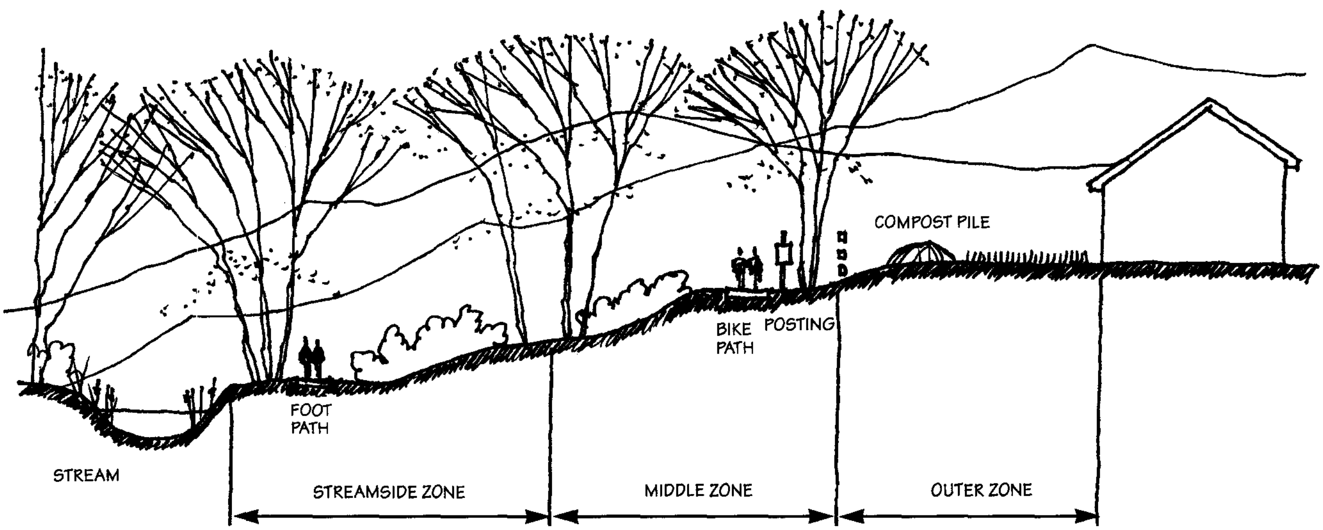


Figure 330-10. Cluster development used to preserve natural drainageways.

Velocity is the product of surface friction, surface shape, and slope. These characteristics are determined by the types of surfaces included in design proposals and their relationship to each other.

Greater volume must be held on site in order to reduce the speed of water moving through the outlets. Detaining water volume also provides the fundamentals for water quality treatment. More than half the contaminants in surface water are from sediments, and high velocity is the cause of erosion that produces sediment. The designer that works to slow water is working for prevention of water quality impacts from erosion.

Water volumes that are detained can be reduced by infiltrating it into the ground. Pre-development conditions almost always have larger amounts of infiltrating surface than post-development conditions. The use of infiltration techniques replicates natural infiltration, maintains groundwater recharge, and reduces surface flow.



CHARACTERISTICS	STREAMSIDE ZONE	MIDDLE ZONE	OUTER ZONE
FUNCTION	Protect the physical integrity of the stream ecosystem	Provide distance between upland development and streamside zone	prevent encroachment and filter backyard runoff
WIDTH	Min. 8 m (25'), plus wetland and critical habitats	15 to 30 m (50'-100') depending on stream order, slope, and 100 year floodplain	8m (25') minimum setback to structures
VEGETATIVE TARGET	Undisturbed mature forest. Reforest if grass	Managed forest, some clearing allowable	Forest encouraged, but usually turfgrass
ALLOWABLE USES	VERY RESTRICTED (e.g., flood control, utility right of ways, footpaths, etc.)	RESTRICTED (e.g., some recreational uses, some stormwater BMPs, bike paths, tree removal by permit)	UNRESTRICTED (e.g., residential uses including lawn, garden, compost, yard wastes, most stormwater BMPs)

Figure 330-11. Urban stream buffer system.

Impervious surfaces contribute to higher flow velocities. Unnecessary pavement is often built into standard assumptions about design, especially in residential development. Excessive front yard set backs and wider roads to accommodate on-street parking often add pavement area. Revisiting fundamental assumptions can often yield savings of pavement area and costs.

The relationship of imperviousness to drainage pathways is also critical. Placing pavements and roofs at high points in the landscape provides greater opportunity for vegetated pervious surfaces to slow and infiltrate runoff. Figure 330-8 shows a conventional approach to street placement driven by an assumption that curbs and storm sewers should be used. Figure 330-9 shows an alternative that places pavement and roofs at higher elevations while using natural drainageways as much as possible. Storm sewers are unnecessary because runoff flow near the houses is minimal and easily diverted around the houses, even for 100 year events.

Place Development in Least Critical Areas:

Structures and paved surfaces should not be placed on or near shorelines, natural drainageways, steep slopes, areas of dense vegetation, and areas where soils are porous or erodible.

Fit Development to Terrain:

Road patterns and building types should be selected to fit landforms. For example, where topography is dendritically dissected, use a road pattern such as a branched cul-de-sac to fit the branched drainage. Keep impervious surfaces small and place at higher elevations to maximize sheet drainage from their edges.

Utilize the Natural Drainage System:

The natural drainage paths should be identified as part of the site analysis, along with sufficient buffers to insure long term integrity. Figure 330-10 shows the use of cluster or open space development to preserve streams and drainageways. The Center for Watershed Protection recommends a minimum of 8 m (25 ft) of undisturbed mature forest on each side of urban streams, with an additional 15 to 30 m (50 to 100 ft) of managed vegetated area (Figure 330-11).

4.4 Types of Runoff Analyses

The major and minor flood protection systems, and the water quality system should be analyzed for each schematic design. Major flood protection is usually designed for the 100 year, 24 hour design storm in the U.S. using the SCS runoff methods or other comparable methods. The method of analysis for a minor or convenience system depends on the type of system planned. If a system of storm sewers is used for the minor system, it is typically designed for a frequent, short duration storm: typically a 2, 5 or 10 year, one hour storm using the Rational Method. If the minor system is an overland system of swales, the SCS runoff methods and a 10 year, 24 hour rainfall event is more common.

Water quality treatment works should be designed using the small storm hydrology methods. In the United States, some jurisdictions are now also requiring overland conveyance works (swales and channels) to be designed for stability at flows produced by the 2 year, 24 hour design storm to protect against erosion. A water balance analysis should be conducted for designs that rely on maintaining permanent ponds, to ensure that they won't dry up.

KEY POINTS: Stormwater Management Systems

There are three primary types of stormwater management systems. Selection of the appropriate analysis method depends on the type of system, the available data, and local practice:

1. Minor System: Provides protection against inconveniences caused by frequent storms. Examples include storm sewers and roadside swales. Designed for 2, 5, or 10 year storms. Also known as the convenience system. May be designed using the Rational Method (more common for storm sewers) or SCS runoff methods (more common for overland systems).

2. Major System: The path of runoff taken by infrequent storms when minor system is overwhelmed – may be designed or natural. Designed examples include emergency spillways for storm ponds and designated floodways that protect against loss of life and property. Designed for 100 year rainfall or greater, typically using the SCS runoff methods in the U.S.

3. Water Quality Protection System: Traps sediment, filters and infiltrates runoff to remove contaminants. Typically designed to treat the volume of runoff from a 30 mm (1.25 in) rainfall, and protect against erosion from 2 year rainfalls. These systems should be designed using small storm hydrology methods.

5.0 RUNOFF CALCULATIONS

5.1 Runoff Terms

Velocity (V): Velocity is distance traveled over a given time. It is the critical factor for estimating and understanding runoff movement. Runoff velocities are typically expressed in meters per second (m/s) or feet per second (ft/sec).

Discharge (Q): Discharge is rate of runoff flow, or volume traveling at a particular velocity. Discharge is expressed in cubic meters per second (m^3/s) or cubic feet per second (ft^3/sec). Runoff discharge (Q) for cross-sectional shapes, such as channel and pipe sections, is equal to velocity (V) times area of flow (a) [$Q = Va$].

Volume of Flow (Qvol): As discharge continues through a cross-section for a period of time, the discharge can be multiplied by the length of time to arrive at a total volume of flow (Qvol). Total volume of flow is typically expressed in cubic meters (cubic feet), or hectare-meters (acre-feet). Change in volume (ΔQvol) with respect to the filling or emptying of a container of water, such as a pond or a length of stream or channel, is simply the difference between rate of inflow ($Qvol_{in}$) and rate of outflow ($Qvol_{out}$) over a period of time [$\Delta Qvol = Qvol_{in} - Qvol_{out}$].

Hydrograph: A hydrograph is a summary of stormwater flows. It is a record of flow rates at a specific location over a given period of time. A hydrograph can be expressed in tabular form showing discharges at specific times in the period (Table 330-1), or as a graph plot of discharge versus time (Figure 330-12). In the case of a graph, the area under the curve plot is the total volume of flow for the plot period.

Peak rate of flow: The peak of the hydrograph is the maximum rate of flow. Predicting and accommodating the maximum or peak rate of flow is important. This peak rate of flow occurs when the flow through the point of analysis consists of a drop of water from every point in the watershed area.

Table 330-1. EXAMPLE OF A TABULAR HYDROGRAPH

Hydrograph Time (hrs)	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	12.9	13.0
Discharge (cfs)	0.3	0.8	1.4	2.1	3.5	2.8	2.5	2.2	2.0	1.7	1.4

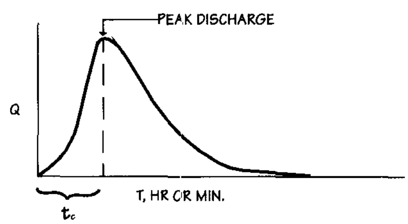


Figure 330-12. Example hydrograph plot.

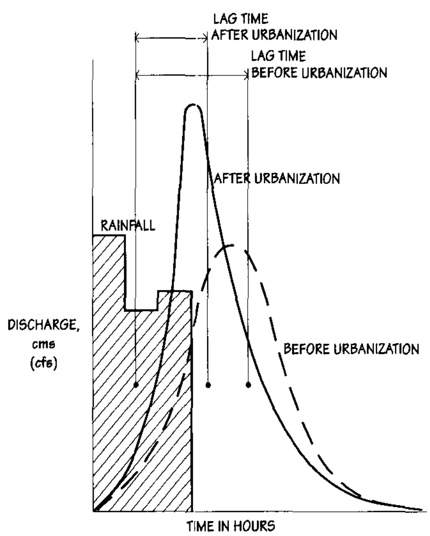


Figure 330-13. Effects of urbanization on pre-and post-development hydrograph plots.

Table 330-2. TYPICAL DESIGN STORM STANDARDS

Element/System	Design Storm
Minor system	
storm sewers	2, 4, 5, 10 year (Rational)
swales, stability design for erosion protection	2 year, 24 hour
swales, design for capacity	10year, 24 hour
Roads	
high volume, crests & tangents	10 year
high volume, sag points	50 year
collector, crests, tangents, sag points	10 year
local, 250 ADT and under, crests & tangents	5 year
local, over 250 ADT, crests & tangents	10 year
local, sag point	10 year
Detention structures	
principal spillway, equal pre-dev. discharge all storms	2,5,10,50, 100 year
emergency spillway	100 year
storage volume, temporary (construction sedimentation pond)	10 year
storage volume, permanent	100 year
Protection of occupied and high value structures	100 year

Design storms are usually specified in terms of duration and frequency, for example: a 100 year, 24 hour rainfall event. This means that in a given year, the probability of a rainfall of this magnitude or greater actually being observed is one percent every time it rains.

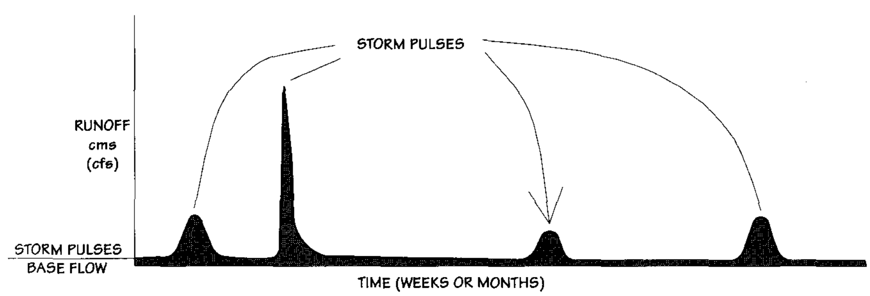


Figure 330-14. Baseline hydrograph with storm pulses.

Time of Concentration (t_c): The time water takes to flow from the most distant point in a watershed to its outlet.

Travel time (t_t): The average time for water to flow through a reach or other stream or valley segment that is less than the total length. Travel times can be computed for segments of a time of concentration path and summed to arrive at a time of concentration ($t_t+t_t+t_t...+t_t = t_c$).

Storm Flows: Storm flows are large, infrequent flows of runoff characterized by high peak discharges. They can cause flooding or erosion if they are not properly accommodated by design. Storm flows are usually displayed in a hydrograph with a time line in hours or minutes. Urbanization tends to drastically change the hydrographs. Peak discharges and volumes of runoff increase, and time of concentration becomes shorter (Figure 330-13).

Base Flows: Base flows are the steady flows that continue to occur after the pulse of flow from a storm has subsided. Base flow is the base line upon which the hydrographs of storm flows are plotted. In natural watersheds, stream base flows are high, maintained by slow surface runoff and substantial subsurface or groundwater flows that emerge in the stream bed. Base flows provide a continuing supply of water with the runoff from rainstorms producing a pattern of peaks as perturbations in the base flow (Figure 330-14).

5.2 Converting Rainfall to Runoff

Several methods have been developed using mathematical models to systematically account for rainfall losses in the conversion of rainfall to runoff volumes. The rainfall losses are termed abstractions. Initial abstractions consist of losses from conditions that consume rainfall and must be satisfied before rainfall can become runoff. Continuing abstractions are losses of rainfall that keep occurring after runoff has begun. Components of initial abstraction include: Wetting of dry surfaces, evaporation, transpiration, filling of minor depressions, and infiltration into the soil. Continuing abstractions include: Evaporation, transpiration and continuing infiltration. Infiltration is typically the largest component of rainfall volume loss.

Runoff models generally produce runoff volumes and peak discharges from rainfall data. Peak discharges are calculated by estimating the time to peak discharge (time of concentration).

Many methods and computer programs are available to convert rainfall to runoff, and to estimate peak discharges. This section is limited to presenting methods that are most commonly accepted in the U.S.

5.3 Design Storms

Design storms, or rainfall events, are statistical abstractions drawn from rainfall records. They represent probability estimates of expected rainfall amounts in terms of intensity, duration and frequency. Table 330-2 lists typical design storms used for different elements.

Rainfall events are constructed for specific durations and frequency and produce statistical rainfall depths. Duration is the length of time over which historical rainfall depths are distributed for purposes of analysis, typically expressed in hours. Frequency is the probability of recurrence of an event that produces a rainfall depth, typically expressed in years. Frequency is sometimes called the return period. These statistical rainfall depths are used for design.

Intensity is the rate at which the rain falls, expressed in millimeters per hour (inches per hour). In design storms, the intensity is the average intensity for the duration. Design depths are converted to average intensities by dividing by the duration.

U.S. Weather Bureau Maps:

In 1961 Hershfield produced isohyetal maps of design rainfall depths for the entire United States. They were published in the U.S. Weather Bureau Technical Paper No. 40, commonly referred to as TP-40. It included durations from 30 minutes to 24 hours and return periods for one year to 100 years. These maps have become a standard source of design rainfall events. The maps for the 2, 5, 10 and 100 year, 24 hour rainfall events are reproduced here as Figures 330-15 through 330-18. Twenty-four hour events provide the rainfall data needed to use the SCS methods.

Steel Formula:

The Steel formula integrates statistical data on rainfall intensity, duration and frequency to provide a means of directly computing rainfall intensity given the storm duration return period, and region of the United States. It may be used to find rainfall intensity for use with the Rational Method :

$$I = \frac{K}{t_c + b}$$

Where:

I = Intensity of rainfall in millimeters per hour (in/hour)

t_c =Time of concentration in minutes

K and b = Coefficients for region of the U.S. and storm frequency

Values for K and b are provided in Table 330-3 for the regions of the U.S. shown in Figure 330-19.

5.4 Time of Concentration Techniques

Time of concentration may be estimated by dividing the flow path into segments of similar land cover and slopes, deriving travel time for each segment and then calculating the sum of the travel times. Different types of flow require different techniques for estimating travel time velocities. These include:

1. Sheet flow (Manning Kinematic Solution).
2. Shallow Concentrated Flow (SCS Shallow Concentrated Flow Graph).
3. General Overland Flow– combines sheet flow and shallow concentrated

Table 330-3. COEFFICIENTS FOR STEEL FORMULA

Frequency in years	Steel Coefficients	Regions of the United States						
		1	2	3	4	5	6	7
2	K	206	140	106	70	70	68	32
	b	30	21	17	13	16	14	11
4	K	247	190	131	97	81	75	48
	b	29	25	19	16	13	12	12
5	K	247	190	131	97	81	75	48
	b	29	25	19	16	13	12	12
10	K	300	230	170	111	111	122	60
	b	36	29	23	16	17	23	13
25	K	327	260	230	170	130	155	67
	b	33	32	30	27	17	26	10
50	K	315	350	250	187	187	160	65
	b	28	38	27	24	25	21	8
100	K	367	375	290	220	240	210	77
	b	33	36	31	28	29	26	10

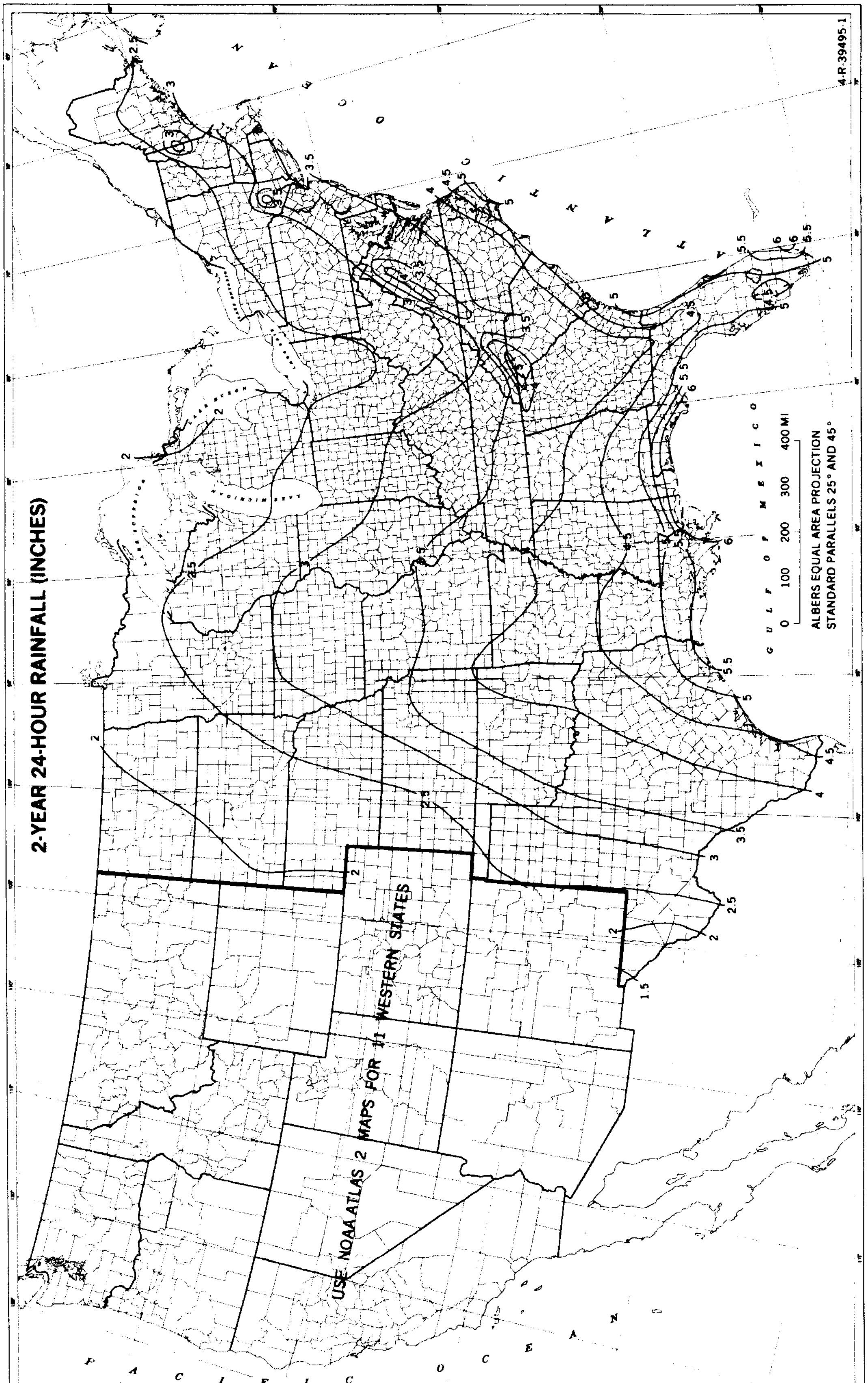


Figure 330-15. Two Year, 24 Hour Rainfall Map of the United States (After Hershfield, TP-40)

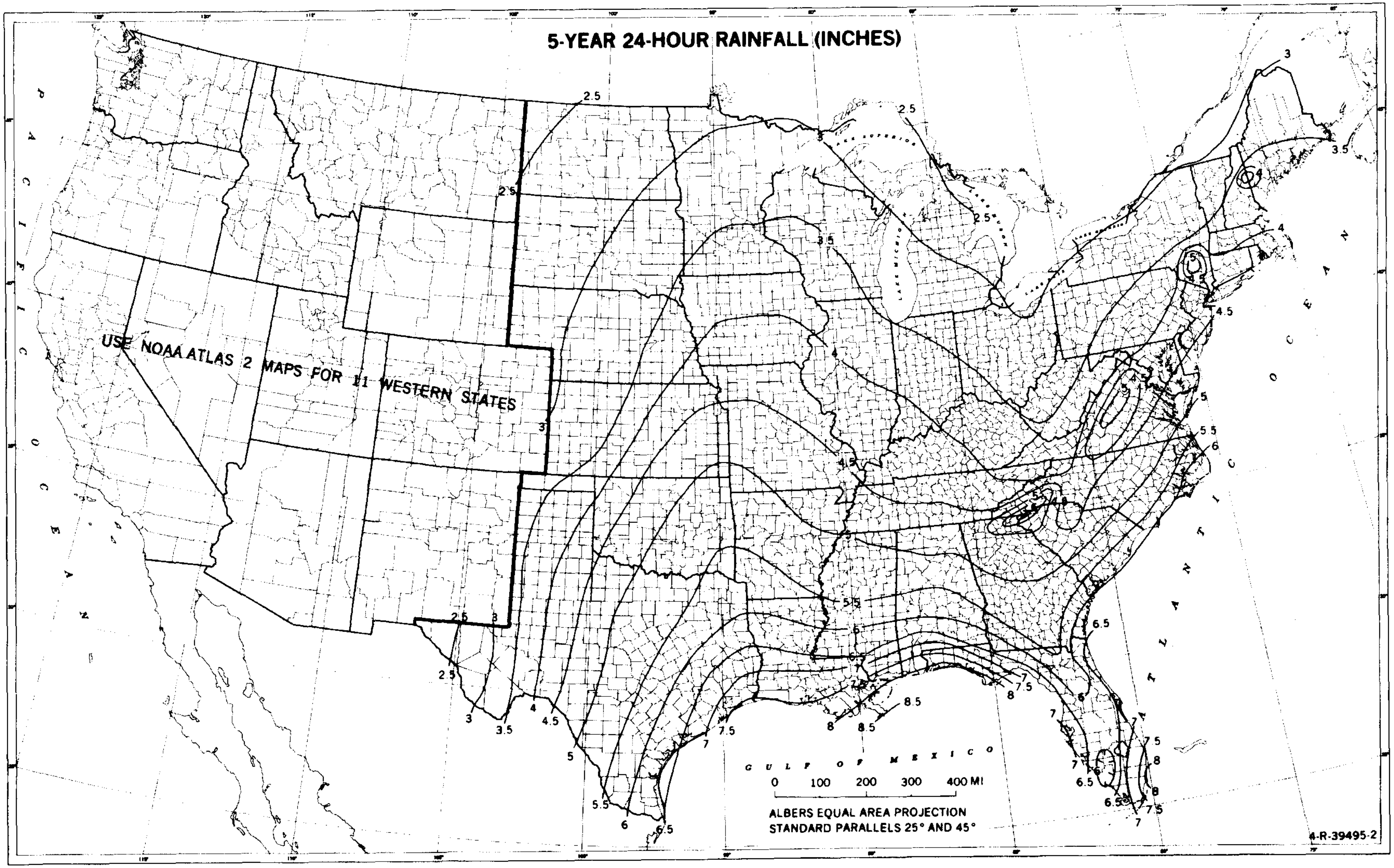


Figure 330-16. Five Year, 24 Hour Rainfall Map of the United States (After Hershfield, TP-40)

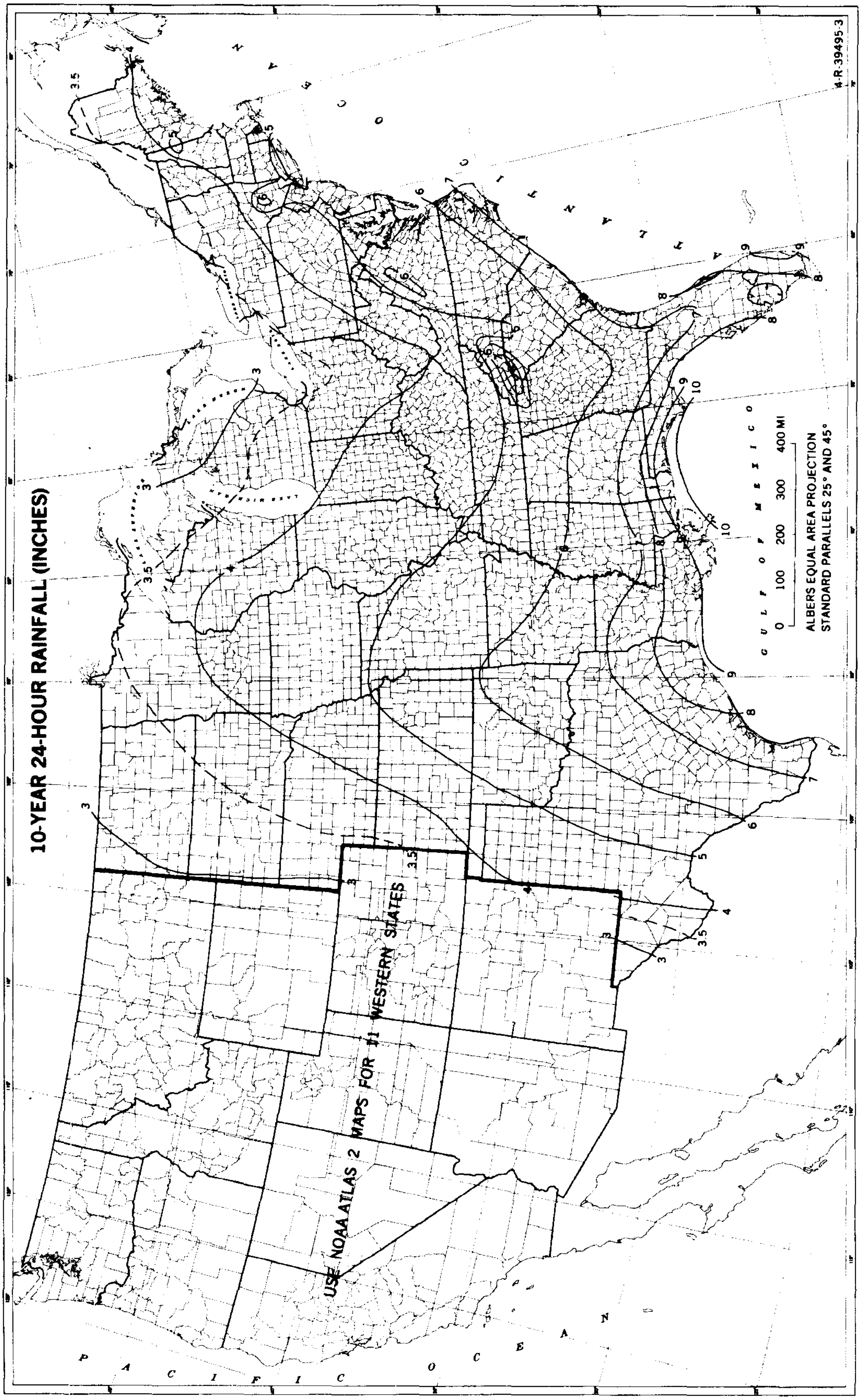


Figure 330-17. Ten Year, 24 Hour Rainfall Map of the United States (After Hershfield, TP-40)

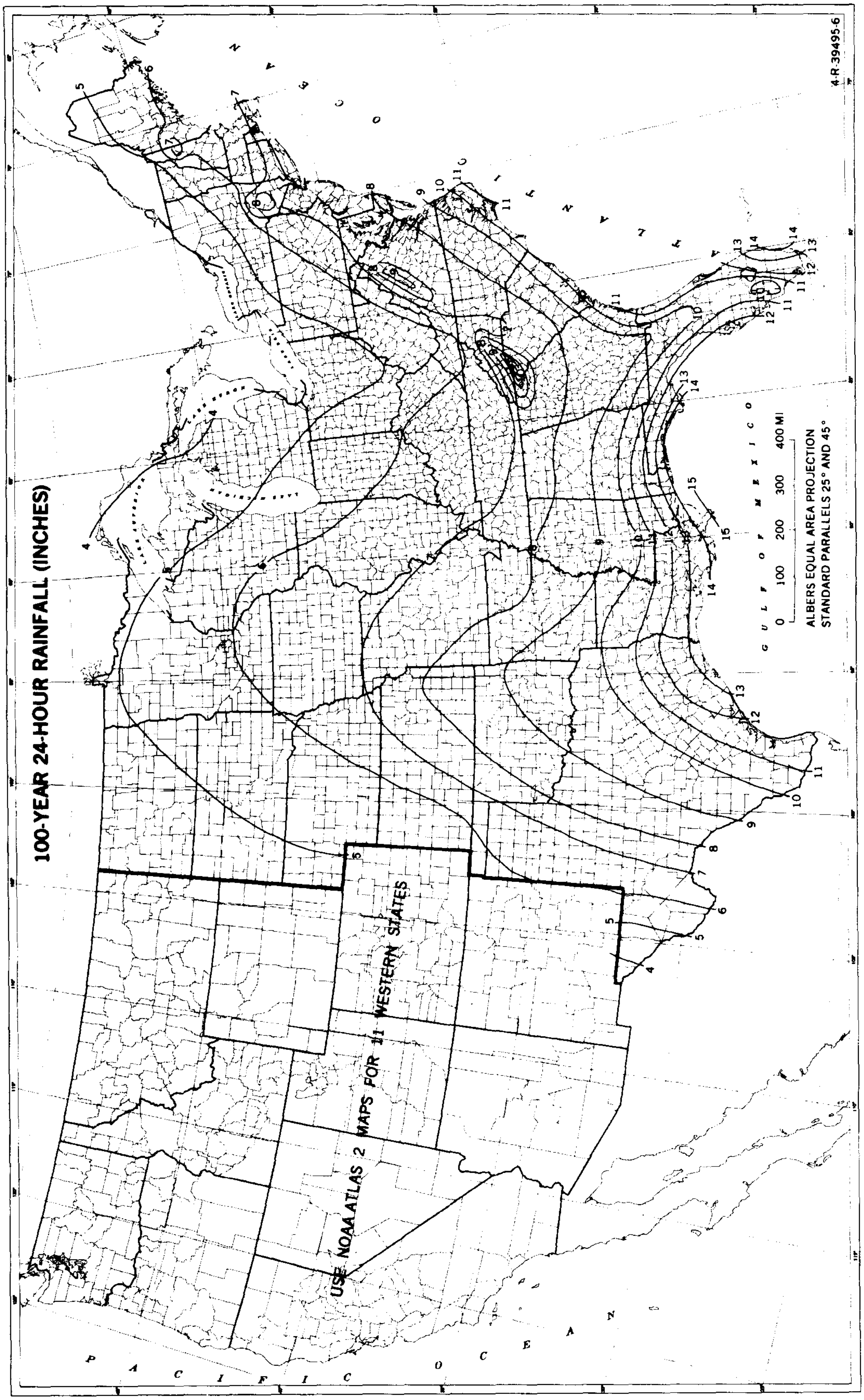


Figure 330-18. One Hundred Year, 24 Hour Rainfall Map of the United States (After Hershfield, TP-40)

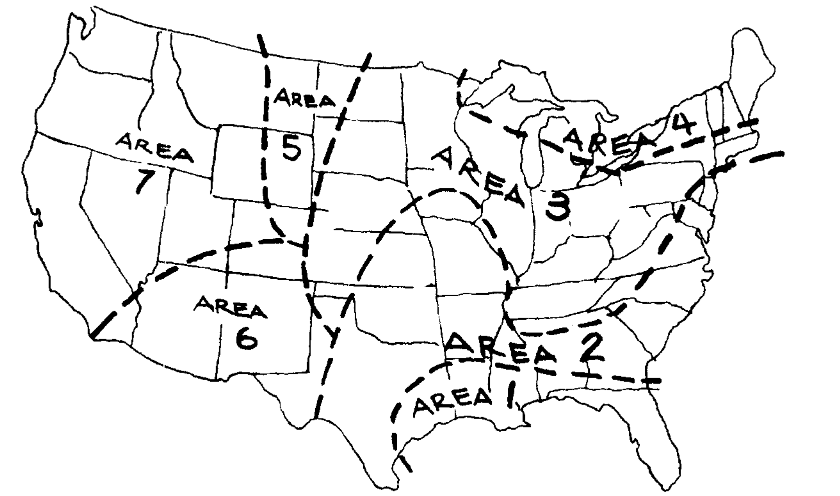


Figure 330-19. Regions of the United States for use in the steel formula.

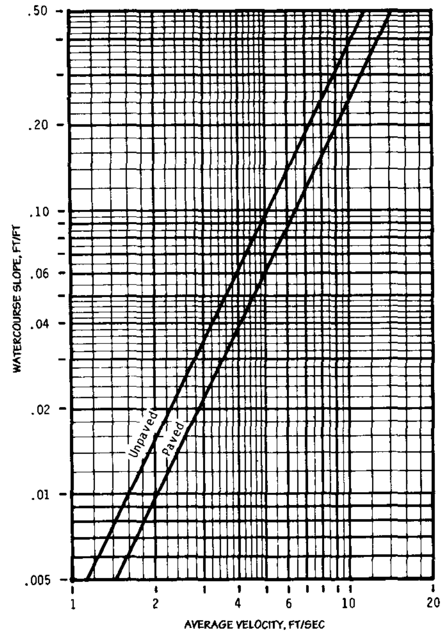


Figure 330-20. SCS graph of average velocities for estimating travel time for shallow concentrated flow (U.S. units).

flow (Kirpich Formula).

4. Channel Flow (Manning's Equation—refer to subsection 6.1).

Sheet Flow:

Sheet flow is flow over a plane surface. In urban areas sheet flow is limited to about 25 meters (75 ft) over a paved surface and 45 meters (150 ft) over a lawn surface. In no case does sheet flow continue for more than 90 meters (300 ft). Beyond these distances, flow is considered shallow concentrated.

The Manning Kinematic Solution may be used to calculate velocity of sheet flow in U.S. units. This method must be used to calculate the sheet flow segments of t_c for the SCS Graphical Peak Discharge Method.

Manning Kinematic Solution:

$$T_t = \frac{0.007\,(nL)^{0.8}}{(P_2)^{0.5} S^{0.4}}$$

Where:

T_t = travel time in hours

n = Manning's roughness coefficient (Table 330-15)

L = flow length in feet

S = slope of the the hydraulic grade line (flow path) in feet per foot

P_2 = 2 year, 24 hour rainfall in inches.

Shallow Concentrated Flow:

Shallow concentrated flow continues until it finds a defined channel in the topography. The velocity of flow for natural or constructed channels must be calculated using Manning's Equation (refer to subsection 6.1).

The SCS Shallow Concentrated Flow graph (Figure 330-20) may be used to determine the velocity of shallow concentrated flow in U.S. units. This method must be used to calculate the shallow concentrated flow segments of t_c when using the SCS Graphical Peak Discharge Method. Once a velocity is determined for shallow concentrated flow, travel time may be computed by the following formula:

$$T_t = \frac{L}{3600V}$$

Where:

T_t = travel time in hours

L = flow length in feet

V = velocity in feet per second

General Overland Flow:

The Kirpich formula may be used with the Rational Method to estimate the overland flow portion of time of concentration, combining sheet and shallow concentrated flow. It may be applied to separate segments of flow to account for the different travel times generated by lengths of different overland flow surfaces.

Kirpich Formula:

$$t_c = KL^{0.77}S^{-0.385}$$

Where:

t_c = time of concentration in minutes

K = Constant (0.0195 for S.I. units; 0.0078 for U.S. units)

L = the length of travel in m (ft)

S = the average slope of the time of concentration flow path in meters/meter (ft/ft).

Slope is calculated by dividing vertical difference in the end point elevations of the flow path in meters (ft) by the horizontal length of the flow path in meters (ft). This method is directly applicable for natural watersheds, bare earth overland flow or mowed grass overland flow. Adjustments should be made for other conditions:

—For general overland flow and grassed channels multiply t_c by 2.

—For concrete or asphalt surfaces multiply t_c by 0.4.

—For concrete channels multiply t_c by 0.2.

5.5 Soil Conservation Service Runoff Curve Number Method (U.S. Units)

The Soil Conservation Service (SCS) runoff curve number method is most accurate for rainfall amounts in the range of 1 to 12 inches. For rainfalls under one inch, the small storm methods are recommended. Other limitations include:

1. It should not be used for watersheds large than 20 square miles.
2. It should only be used if the curve

Table 330-4. SCS CURVE NUMBERS (CN) FOR SELECTED AGRICULTURAL, SUBURBAN AND URBAN LAND USES (AMCII, I_a = 0.2S)

Land Use Description			Hydrologic Soil Group A	B	C	D
Bare soil, newly graded areas			77	86	91	94
Cultivated land:	without conservation treatment		72	81	88	91
	with conservation treatment		62	71	78	81
Pasture or range land grazed:	poor, < 50% ground cover		68	79	86	89
	fair, 50 to 75% ground cover		49	69	79	84
	good, >75% ground cover		39	61	74	80
Meadow, good condition, protected from grazing, hay mowed			30	58	71	78
Wood or forest land:	thin stand, poor cover, no mulch		45	66	77	83
	good stand, grazed, some mulch		36	60	73	79
	good stand, underbrush, mulch		30	55	70	77
Open spaces, lawns, parks, golf courses, cemeteries, etc.			equivalent to pasture (above)			
Commercial and business areas (72% impervious)			89	92	94	95
Industrial areas (72% impervious)			81	88	91	93
Residential areas*	*average lot size*	*average % impervious***				
	500 m²(1/8 acre) or less	65	77	85	90	92
	1000 m²(1/4 acre)	38	61	75	83	87
	1400 m² (1/3 acre)	30	57	72	81	86
	2000 m²(1/2 acre)	25	54	70	80	85
	4000 m²(1 acre)	20	51	68	79	84
Farmsteads – buildings, lanes, driveways, surrounding lots			59	74	82	86
Paved parking areas, roofs, driveways, etc.***			98	98	98	98
Streets and roads (including right-of-way area):						
	paved; with curbs and storm sewers***		98	98	98	98
	paved; with open roadside ditches		83	89	92	93
	gravel		76	85	89	91
	dirt		72	82	87	89

*Curve numbers are computed assuming roofs and pavements drain directly into streets, parking areas where runoff is carried away by storm sewers. Pervious areas calculated as lawns in good condition.

**Curve numbers are computed assuming connected impervious surfaces, i.e., the runoff from the house and driveway is directed towards the street with a minimum of roof water directed toward lawns where additional infiltration could occur. Pervious areas calculated as lawns in good condition.

***A curve number of 95 is sometimes used in warmer areas of the United States.

Table 330-5. SCS CURVE NUMBERS (CN) FOR SELECTED AIRD AND SEMI-ARID LANDS (AMCII, I_a = 0.2S)

Cover Type	Hydrologic Condition*	Hydrologic Soil Group A**	B	C	D
Herbaceous – mix of grasses, weeds, small amount low brush	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak-aspen – mountain brush mix of oak brush, aspen,	Poor		66	74	79
mountain mahogany, bitter brush, maple	Fair		48	57	63
and other brush	Good		30	41	48
Pinyon-Juniper – pinyon juniper or both; grass understory	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sagebrush with grass understory	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub – major plants include saltbush, greasewood	Poor	63	77	85	88
creosotebush, blackbrush, bursage, palo verde,	Fair	55	72	81	86
mesquite and cactus	Good	49	68	79	84

* Poor is less than 30% ground cover (litter, grass and brush overstory); Fair is 30 to 70% ground cover; Good is more than 70% ground cover.

** Curve numbers for group A haveonly been developed for desert shrub.

Table 330-6. EXAMPLE CALCULATION OF SCS RUNOFF METHOD USING A COMPOSITE WEIGHTED CN (U.S. UNITS)

Compute the runoff from 2.8 inch rainfall (P) on a 50 acre catchment in acre-feet. The land uses break down as follows: 30 acres of residential area that is 30 percent impervious (half in B soils, half in C soils); 6 acres of residential area that is 65 percent impervious (all in C soils); 9 acres of road with curbs and storm sewers (4 in B soils, 5 in C soils); and 5 acres of open space with good cover (all in C soils).

1. Select curve numbers from Table 330-4 for each soil-cover combination.
2. Compute a weighted curve number to represent the entire catchment.

Land cover—soils	Acres	CN	Acres x CN
Residential (30% impervious) B soils	15	72	1080
Residential (30% impervious) C soils	15	81	1215
Residential (65% impervious) C soils	6	90	540
Road with curbs and storm sewers, B soils	4	98	392
Road with curbs and storm sewers, C soils	5	98	490
Open Space, good condition, C soils	5	74	370
Totals	50		4087

Weighted (acres) $CN = \frac{4087}{50} = 81.7$ (use 82)

3. Use the weighted CN to calculate potential maximum retention (S):

$$S = \frac{1000}{CN} - 10$$

$$S = \frac{1000}{82} - 10 \qquad = 2.2 \text{ inches}$$

4. Use S = 2.2 and P = 2.8 inches to calculate runoff depth (Q):

$$Q = \frac{[P - (0.2 \times S)]^2}{P + (0.8 \times S)}$$

$$Q = \frac{[2.8 - (0.2 \times 2.2)]^2}{2.8 + (0.8 \times 2.2)}$$

$$Q = \frac{5.6}{4.6} \qquad = 1.2 \text{ inches}$$

5. Solve for acre-feet of runoff from the watershed.

$$\text{Acre-feet} = \frac{Q \times \text{watershed area in acres}}{12 \text{ inches per foot}}$$

$$\text{Acre-feet} = \frac{1.2 \times 50}{12} \qquad = 5.0 \text{ Acre-feet}$$

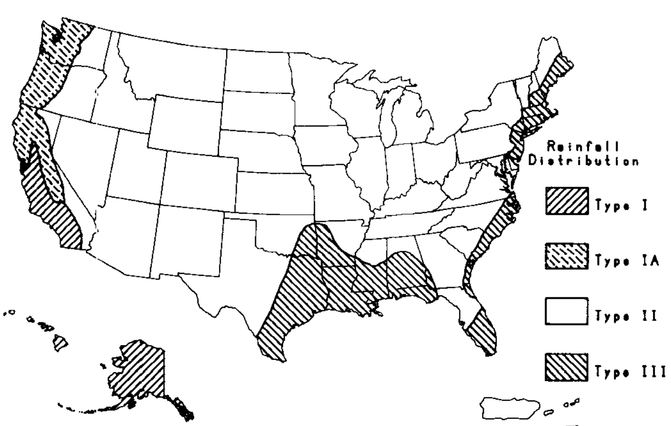


Figure 330-21. Map of approximate boundaries for SCS storm distribution types for the United States.

number is greater than 40.

3. T_c values must be in the range from 0.1 to 10 hours.
4. The watershed may have only one main stream, or if more than one, the branches must have nearly equal times of concentration.

SCS Runoff Volume Calculations:

In 1972 the U.S. Soil Conservation Service (SCS) developed a method for computing runoff from rainfall for urban areas. This method is represented in practical form by:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S}$$

Where:

Q = depth of direct runoff in inches,

P = rainfall depth in inches from a 24-hour duration storm

S = potential maximum retention in inches, including initial abstraction.

P may be found from the 24 hour duration rainfall maps of the United States shown as Figures 330-15 through 330-18. S can be calculated by selecting an appropriate curve number (CN) and using the following formula:

$$S = \frac{1000}{CN} - 10$$

SCS Curve Numbers:

Curve numbers (CNs) have been determined for most land cover conditions by the Soil Conservation Service. Because infiltration is a major variable, they have been classified into four soil hydrologic groups by soil character:

Group A: Sand, loamy sand, or sandy loam soil textures. Have water transmission rates greater than 8 mm.(0.30 in) per hour.

Group B: Silt loam or loam soil textures. Chiefly moderately deep to deep, moderately well to well drained soils. Have water transmission rates in the range of 4 to 8 mm (0.15 to 0.30 in) per hour.

Group C: Sandy clay loam soil textures. Low infiltration rates when wet. Have water transmission rates in the range of 1 to 4 mm (0.05 to 0.15 in) per hour.

Group D: Clay loam, silty clay loam, sandy clay, silty clay or clay soil textures. Have water transmission rates in the range of 0.0 to 1 mm (0.0 to 0.05 in) per hour.

Table 330-7. I_a VALUES FOR RUNOFF CURVE NUMBERS (IN U.S. UNITS)

CN	I_a (in.)	CN	I_a (in.)	CN	I_a (in.)
40	3.000	60	1.333	80	0.500
41	2.878	61	1.279	81	0.469
42	2.762	62	1.226	82	0.439
43	2.651	63	1.175	83	0.410
44	2.545	64	1.125	84	0.381
45	2.444	65	1.077	85	0.353
46	2.348	66	1.030	86	0.326
47	2.255	67	0.985	87	0.229
48	2.167	68	0.941	88	0.273
49	2.082	69	0.899	89	0.247
50	2.000	70	0.857	90	0.222
51	1.922	71	0.817	91	0.198
52	1.846	72	0.778	92	0.174
53	1.774	73	0.740	93	0.151
54	1.704	74	0.703	94	0.128
55	1.636	75	0.667	95	0.105
56	1.571	76	0.632	96	0.083
57	1.509	77	0.597	97	0.062
58	1.448	78	0.564	98	0.041
59	1.390	79	0.532		

Table 330-9. EXAMPLE CALCULATION OF PEAK DISCHARGE USING THE SCS GRAPHICAL METHOD (U.S. Units)

Find the peak discharge from a 2 year, 24 hour rainfall near Milwaukee, Wisconsin for a 50 acre watershed with a curve number of 75, a time of concentration of 17 minutes, and no wetlands.

1. Using Figure 330-15 find the design rainfall amount (P):

   P = 2.5 inches

2. Find watershed area in square miles:

   $$\frac{50 \text{ acres}}{640 \text{ acres}} = 0.078 \text{ sq. mi.}$$

3. Find time of concentration in hours:

   17/60 = 0.28 hours

4. Find potential maximum retention (S):

   $$S = \frac{1000}{CN} - 10$$

   $$S = \frac{1000}{75} - 10$$

   = 3.33 inches

5. Find Depth of runoff (Q):

   $$Q = \frac{[P - (0.2 \times S)]^2}{P + (0.8 \times S)}$$

   $$Q = \frac{[2.5 - (0.2 \times 3.33)]^2}{2.5 + (0.8 \times 3.33)}$$

   $$Q = \frac{3.35}{5.16}$$

   = 0.65 inches

6. Find Ia/P using CN and Table 330-7:

   Milwaukee is in a Type II rainfall distribution region (Figure 330-21)

   Ia = 0.667 inches

   Ia/P = 0.267

7. Find unit peak discharge (q_u) from Figure 330-23:

   q_u = 700 c.s.m.

8. Find pond and swamp adjustment factor (F_p) from Table 330-8:

   Fp = 1.0

9. Substitute the found variables and solve:

   $q_p = q_u A_m Q F_p$

   q_p = 90(0.078)(0.65)(1.0)

   q_p = 4.56 c.f.s.

Table 330-8. ADJUSTMENT FACTOR (F_P) FOR PONDS AND SWAMP AREAS SPREAD THROUGHOUT THE WATERSHED.

Percentage of Pond and Swamp Areas	F_p
0.0	1.00
0.2	0.97
1.0	0.87
3.0	0.75
5.0	0.72

The values of CN for various land uses and cover types are given in Tables 330-4 and 330-5. A composite weighted CN is used for a watershed made up of several combinations of soil types and uses. The values given assume that before the design rainfall occurs, a normal amount of rainfall occurred in the previous five-day period (for curve numbers representing conditions different from those in these tables, consult the SCS TR-55 publication).

Table 330-6 illustrates a sample calculation of runoff, using the Soil Conservation Service Runoff Curve Number Method.

SCS Graphical Peak Discharge Calculations:

The peak discharge from a watershed in U.S. units (cubic feet per second) may be calculated for 24 hour duration rainfall events using the SCS Graphical Peak Discharge Method. It is limited in application to a single watershed, with only one main branch (or if more than one, the branches should have nearly equal times of concentration); and it cannot be used for routing. It is calculated using the following formula:

$$q_p = q_u A_m Q F_p$$

Where:

q_p = peak discharge in cubic feet per second (ft³/sec)

q_u = unit peak discharge in ft³/sec per square mile per inch of runoff

A_m = drainage area in square miles

Q = runoff depth in inches

F_p = pond and swamp adjustment factor

Runoff depth is derived using precipitation and curve numbers. Watershed area is calculated by direct map delineation and measurement. Time of concentration is

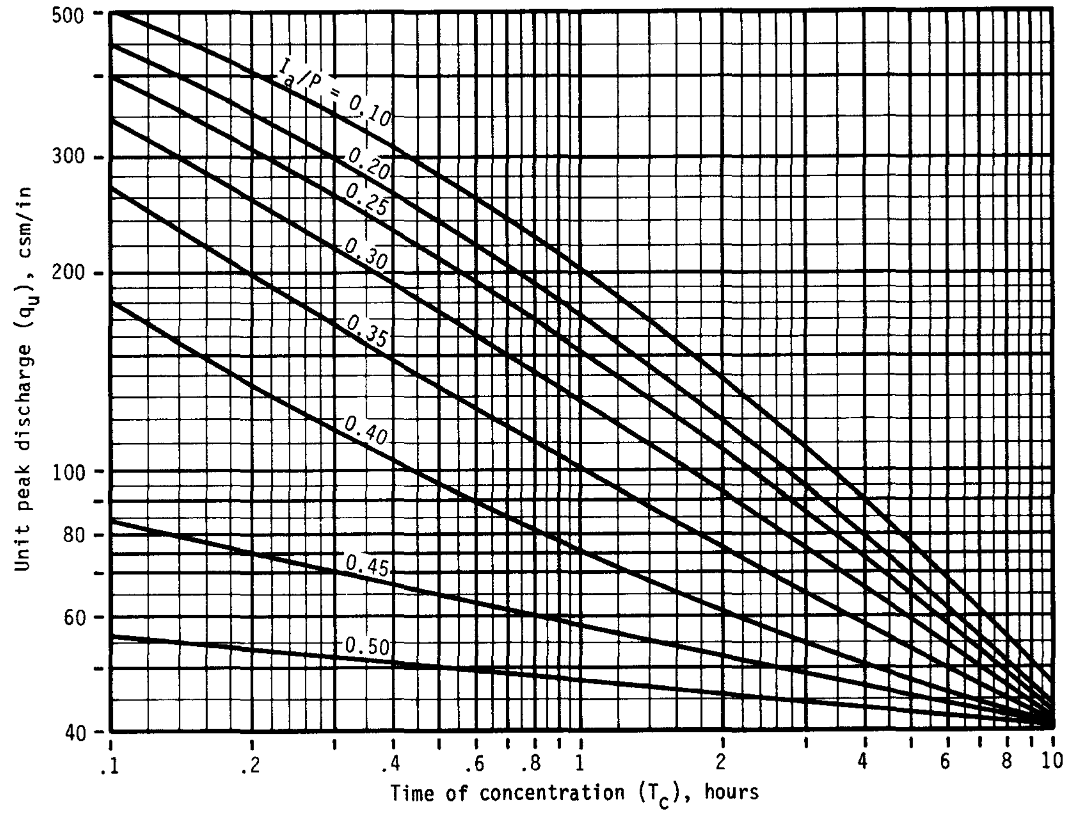


Figure 330-22. Unit Peak Discharges (qu) for Type I Distribution Storms (U.S. units).

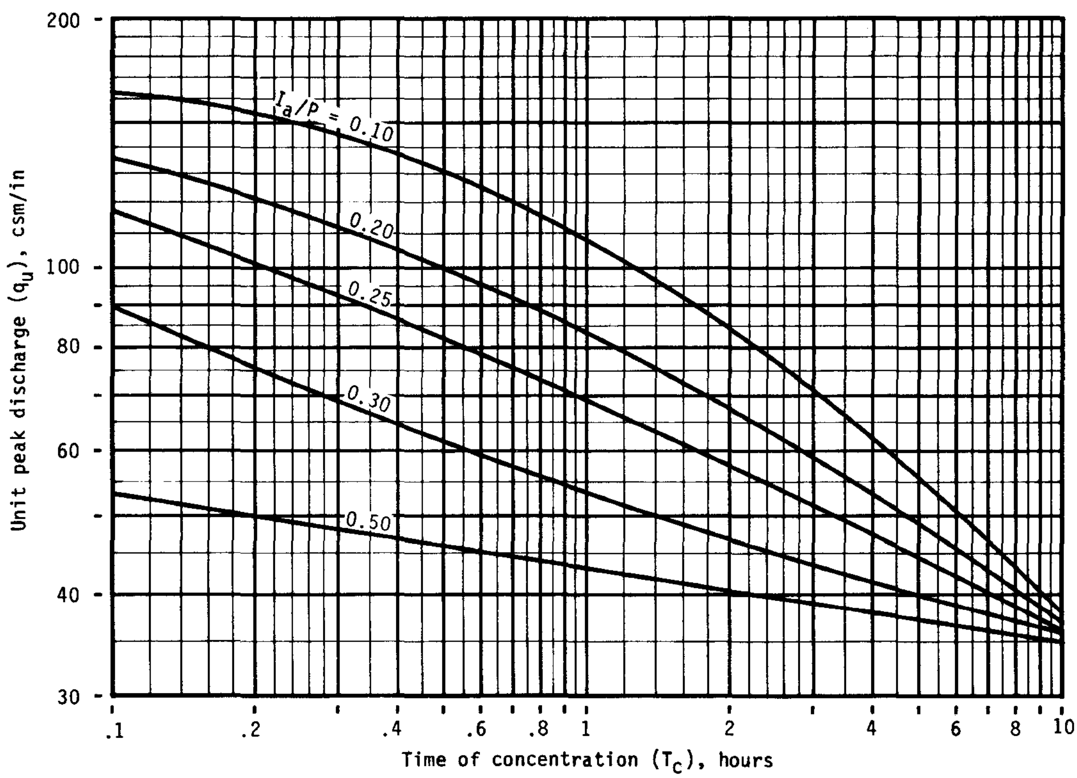


Figure 330-23. Unit Peak Discharges (qu) for Type IA Distribution Storms (U.S. units).

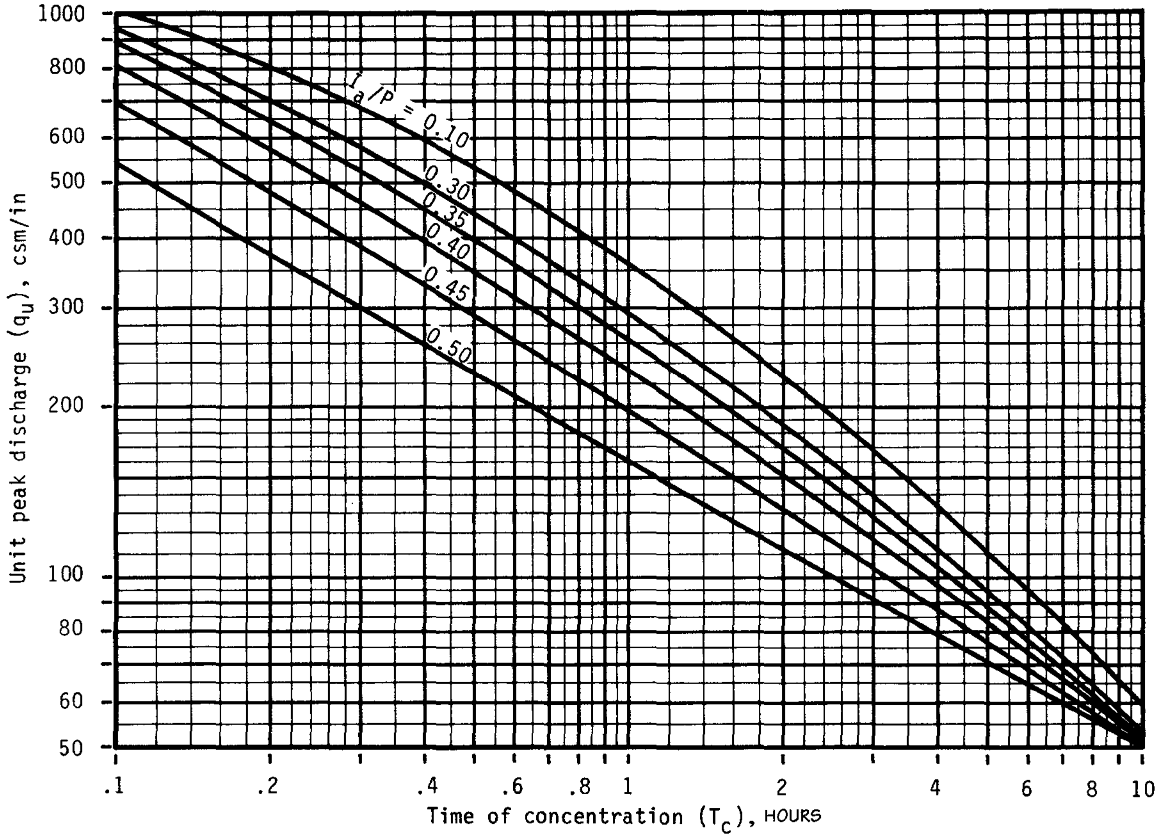


Figure 330-24. Unit Peak Discharges (qu) for Type II Distribution Storms (U.S. units).

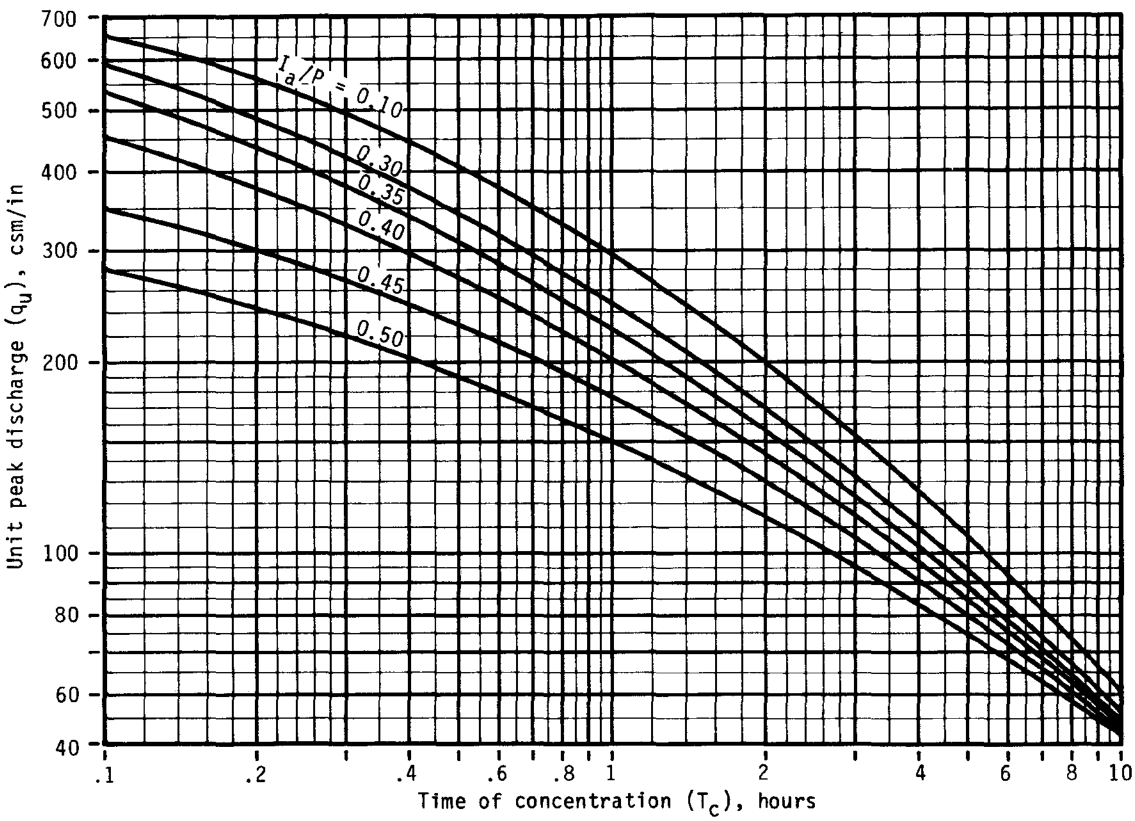


Figure 330-25. Unit Peak Discharges (qu) for Type III Distribution Storms (U.S. units).

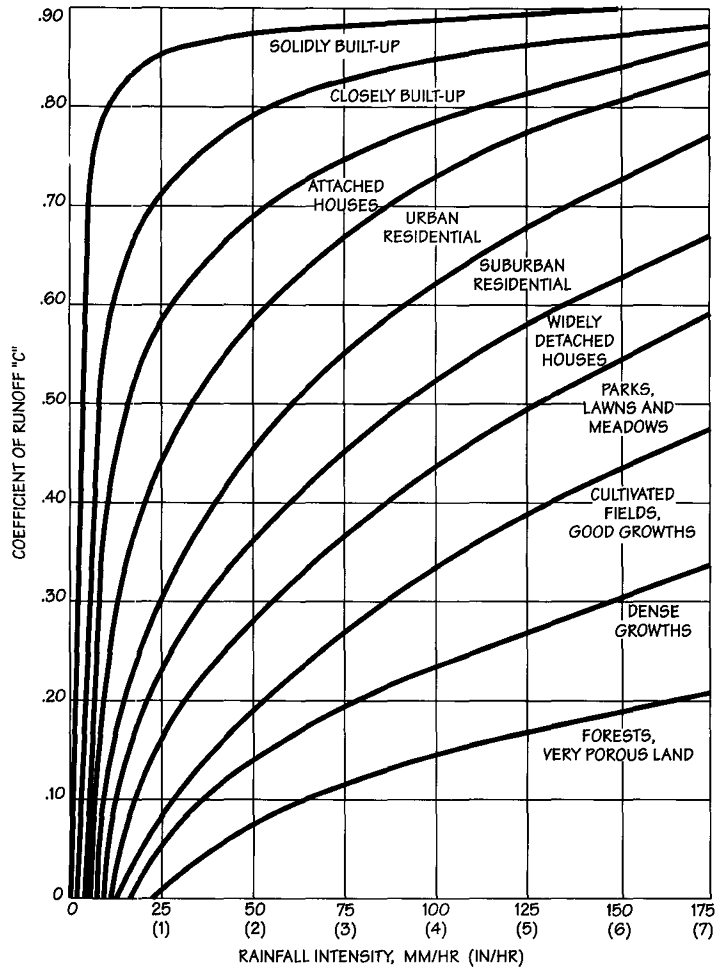
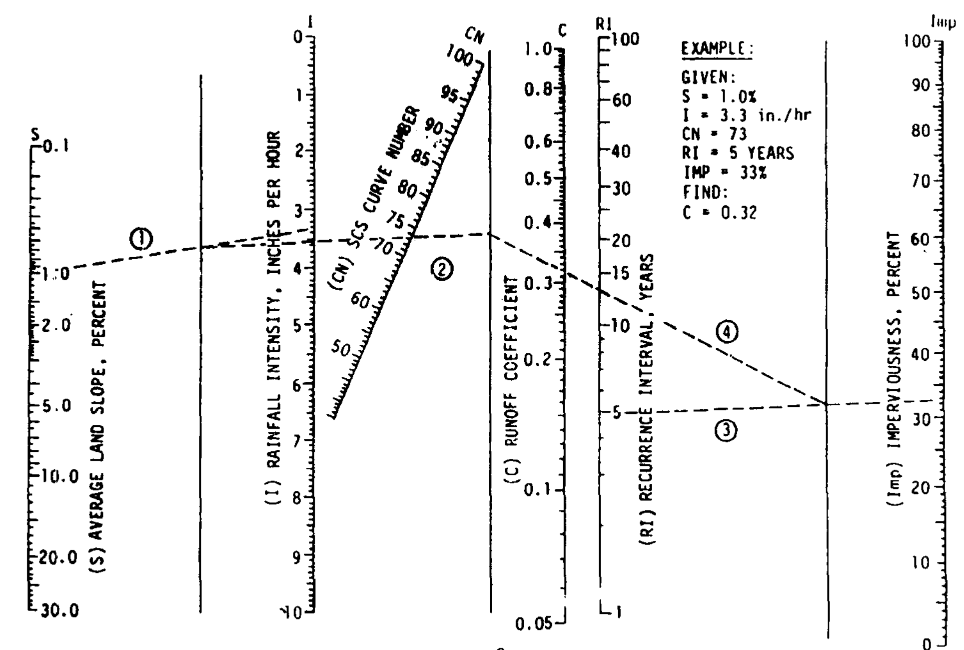


Figure 330-26. Plots of rational runoff coefficients vs. rainfall intensity (after Rossmiller).

found using SCS methods described in subsection 5.4. The SCS rainfall distribution type is identified using Figure 330-21. The unit peak discharge, q_u, is calculated using the ratio of initial abstraction to rainfall (I_a/P).

Table 330-7 lists I_a values for runoff curve numbers. Unit peak discharge charts for the various rainfall distribution types are illustrated in Figures 330-22 through 330-25. Values of I_a/P falling between the curves may be interpolated, however values of I_a/P should never be less than 0.10, or greater than 0.50.

The pond and swamp adjustment factor (F_p) is found by calculating the percentage of pond and swamp area of the watershed, and consulting Table 330-8. No pond or swamps may be located on the time of concentration path. If they are, the SCS Tabular Method or other routing method must be used to find the peak discharge (refer to TR-55 *Urban Hydrology for Small Watersheds*, 1986 edi-



$$C = 7.2(10)^{-7} CN^{3} RI^{.05} ((.01CN)^{.6})^{-S^{.2}} (.001CN^{1.48})^{.15-.11((Imp+1)/2)^{.7}}$$

Figure 330-27. Nomograph for the solution of the Rossmiller Equation (U.S. units).

Table 330-10. RECOMMENDED RATIONAL FORMULA RUNOFF COEFFICIENTS "C"

Surface		C values Min.	C values Max.
Street, asphalt		0.70	0.95
Street, concrete		0.80	0.95
Drives and walks		0.75	0.85
Roofs		0.75	0.95
Pervious areas, A soils*	0-1% slopes	0.04	0.09
	2-6% slopes	0.09	0.13
	steep slopes	0.13	0.18
Pervious areas, B soils*	0-1% slopes	0.07	0.12
	2-6% slopes	0.12	0.17
	steep slopes	0.18	0.24
Pervious areas, C soils*	0-1% slopes	0.11	0.16
	2-6% slopes	0.16	0.21
	steep slopes	0.23	0.31
Pervious areas, D soils*	0-1% slopes	0.15	0.20
	2-6% slopes	0.20	0.25
	steep slopes	0.28	0.38
Composite values			
Residential	single-family detached	0.30	0.50
	multi-units, detached	0.40	0.60
	multi-units, attached	0.60	0.75
	suburban lots, < .2 ha (0.5 acre)	0.25	0.40
	suburban lots, ≥ .2 ha (0.5 acre)	0.30	0.45
Apartment dwelling areas		0.50	0.70
Industrial	light areas	0.50	0.80
	heavy areas	0.60	0.90
Parks and cemeteries		0.10	0.25
Playgrounds		0.20	0.40
Railroad yard areas		0.20	0.40
Unimproved areas	pasture (flat-steep)	0.10	0.42
	cultivated (flat-steep)	0.31	0.44

**Use minimum value for dense, layered woods; maximum value for good grass; soils refer to SCS hydrologic groups*

Table 330-11. RECOMMENDED ANTECEDENT MOISTURE CORRECTION FACTORS FOR THE RATIONAL FORMULA COEFFICIENT OF RUNOFF "C"

Recurrence Interval in Years	Correction Factor C_f
2 to 10	1.0
25	1.1
50	1.2
100	1.25

Note: the correction factor is applied: $C_f \times C$. The product should not exceed 1.0

tion, published by the Soil Conservation Service for further information).

Table 330-9 illustrates a sample calculation of peak discharge, using the SCS Graphical Method.

5.6 Rational Method

In 1889, Kuichling introduced the Rational Formula for estimating peak discharges of runoff from rainfall in urban areas. It remains one of the most widely used and accepted methods of computing runoff. The formula is:

$$Q = KCIA$$

Where:

Q = Peak discharge of runoff in $m^3/$ (ft^3/sec)

K = Constant (0.0028 for S.I units; 1.0 for U.S. units)

C = Runoff coefficient (ratio of runoff to rainfall)

I = Rainfall intensity at time of concentration in mm/hr (in/hr)

A = Watershed area in hectares (acres)

Application and Limitations:

Assumptions intrinsic in the Rational Method are:

1. Rainfall intensity is uniform throughout the duration of the storm and area of watershed.
2. Peak discharge occurs at the time of concentration (i.e. it is still raining at t_c).
3. Duration of the rainfall is equal to the time of concentration.
4. Time of concentration includes time for satisfaction of initial abstractions, and should never be considered to be less than six minutes.

While these assumptions are not actually true for all rainstorms, they yield practical results for small watersheds.

Runoff Coefficients:

Values of the runoff coefficient (C) can be selected from Table 330-10, or Figure 330-26 can be used to select values of C if the rainfall intensity (I) is known. To account for antecedent moisture conditions, C values chosen from Table 330-10 should be adjusted for storms with return periods over 10 years using the multipliers shown in Table 330-11. Values taken from Figures 330-26 and 330-27 do not need this adjustment.

If SCS Curve Numbers (CN_s) have been determined, values of C can be computed by

Table 330-12. EXAMPLE COMPUTATION OF A WEIGHTED RATIONAL RUNOFF COEFFICIENT.

Assume a watershed in Ohio with 3.5 acres of suburban development, 0.5 acres of park land, and 0.7 acres of asphalt roadway pavement. The time of concentration is 30 minutes. Find the peak discharge from a four year rainfall event in cubic feet per second.

1. Compute intensity (I) by using the Steel formula:

Ohio is in area 3 (Figure 330-19); therefore, K = 131 and b=19 (Table 330-3).

$$I = \frac{K}{T_c + b}$$

$$I = \frac{131}{30 + 19}$$

$$= 2.7 \text{ in/hr}$$

2. Find the coefficients of runoff (C) for suburban development and park land using Figure 330-26. Find the coefficient for asphalt pavement from Table 330-10. Calculate a weighted coefficient.

Cover Type	A (acres)	C	Product (C x A)
Suburban development	3.5	0.53	1.86
Park land	0.5	0.34	0.17
Roadway pavement	0.7	0.95	0.67
Totals:	4.7	–	2.7

Weighted C = 2.7 ÷ 4.7 = 0.57

3. Find the peak discharge (Q) using the rational formula:

$$Q = KCIA$$

$$Q = (1.0)(0.57)(2.7)(4.7)$$

$$= 7.2 \text{ ft}^3/\text{sec}$$

Table 330-13. SMALL STORM VOLUMETRIC COEFFICIENTS (Rv) FOR URBAN RUNOFF

Rainfall (mm)	Rainfall (inches)	Flat roofs and large unpaved parking lots	Pitched roofs and large impervious areas (large parking lots	Small impervious areas and narrow streets	Paved streets	Pervious areas, sandy soils group A	Pervious areas, clayey soils groups C &D
1	0.04	0.00	0.25	0.93	0.26	0.00	0.00
3	0.12	0.30	0.75	0.96	0.49	0.00	0.00
5	0.20	0.54	0.85	0.97	0.55	0.00	0.10
10	0.39	0.72	0.93	0.97	0.60	0.01	0.15
15	0.59	0.79	0.95	0.97	0.64	0.02	0.19
20	0.79	0.83	0.96	0.67	-	0.02	0.20
25	1.00	0.84	0.97	0.70	-	0.02	0.21
30	1.25	0.86	0.98	0.74	-	0.03	0.22
38	1.50	0.88	0.99	0.77	-	0.05	0.24
50	2.00	0.90	0.99	0.99	0.84	0.07	0.26
80	3.15	0.94	0.99	0.99	0.90	0.15	0.33
125	4.92	0.96	0.99	0.99	0.93	0.25	0.45

Source: Pitt, Robert E. (April 1997)" Section 5. Small Storm Hydrology" text for *Stormwater Quality Management Through the Use of Detention Basins – A Short Course on Stormwater Detention Basin Design Basics by Integrating Water Quality with Drainage Objectives.* Minneapolis, Minnesota: University of Minnesota Continuing Education and Extension.

Table 330-14. REDUCTION FACTORS TO VOLUMETRIC RUNOFF COEFFICIENTS (R_v) FOR DISCONNECTED IMPERVIOUS SURFACES*

Rainfall (mm)	Rainfall (inches)	Strip commercial and shopping center	Medium to high density residential with paved alleys	Medium to high density residential without alleys
1	0.04	0.00	0.00	0.00
3	0.12	0.00	0.08	0.00
5	0.20	0.47	0.11	0.11
10	0.39	0.90	0.16	0.16
15	0.59	0.99	0.20	0.20
20	0.79	0.99	0.29	0.21
25	1.00	0.99	0.38	0.22
30	1.25	0.99	0.46	0.22
38	1.50	0.99	0.59	0.24
50	2.00	0.99	0.81	0.27
80	3.15	0.99	0.99	0.34
125	4.92	0.99	0.99	0.46

*For low density residential, use connected values for pervious surfaces with clayey soil from Table 330-13.

Source: Pitt, Robert E. (April 1997)" Section 5. Small Storm Hydrology" text for *Stormwater Quality Management Through the Use of Detention Basins – A Short Course on Stormwater Detention Basin Design Basics by Integrating Water Quality with Drainage Objectives*. Minneapolis, Minnesota: University of Minnesota Continuing Education and Extension.

use of the Rossmiller Equation. The nomograph shown in Figure 330-27 may be used to graphically solve the Rossmiller Equation for Rational coefficients in U.S. units.

Peak Discharge Calculation:

The Rational Method assumes uniform cover of the land surface producing runoff represented by the runoff coefficient C. If the cover surfaces are complex, a composite coefficient must be computed by weighted averaging of C by area.

Rainfall intensity (I) is calculated for the design storm and time of concentration using the Steel Formula (refer to subsection 5.3). Time of concentration is calculated using the Kirpich Formula for overland portions (inlet time), and the Manning Formula for channel flow portions (ditch or gutter time).

Table 330-12 illustrates an example calculation that uses the Rational Method with a composite coefficient.

5.7 Small Storm Hydrology

Design for water quality management focuses on capturing and treating the volume of water rather than the peak discharge. The vast majority of annual runoff is produced by the small storms that occur more frequently than twice a year. Generally, treatment of runoff from a 25 mm (1 in) rainfall event will treat 85 to 90 percent of the annual rainfall volume. In most areas, the flood-producing infrequent rainfall events result in only about two percent of the annual rainfall volume. The Center for Watershed Protection in Silver Spring, Maryland recommends using a 30 mm (1.25 in) rainfall event as the design storm for water quality treatment. The volume of runoff produced by small storms is the water quality volume (WQV).

SCS methods of converting rainfall to runoff are not calibrated to produce accurate results for small storms. Two methods for making accurate WQV calculations are Schueler's Short Cut Method, and the Small Storm Hydrology WQV Method.

Schueler's Short Cut Method:

Schueler's Short Cut Method offers a reliable alternative for sites that have predominantly one land cover type or where a quick, general volume estimate is desired. To use the short cut method, find the volumetric runoff coefficient (R_v) for the watershed under analysis using the formula:

$$R_v = 0.05 + 0.009I$$

Where I is the percentage of watershed imperviousness (e.g., use 70 where 70% of the watershed area is impervious surface). WQV in watershed millimeters (inches) may then be calculated by substituting the design rainfall amount in millimeters (inches) for P in the formula:

$$WQV = (P)(R_v)$$

Example: Calculate the runoff volume for a 1.2 hectare shopping center with 85% imperviousness, for a 30 millimeter rainfall event:

$R_v = 0.05 + 0.009(85)$

$R_v = 0.815$

P = 30 mm (design storm)

WQV = (30)(0.815)

= 24.45 watershed millimeters

= 24.45 mm(1/1000 mm/m)(1.2 hectare)(10,000 m^2/hectare)

= 293.4 cubic meters of runoff

Small Storm Hydrology WQV Method:

The Small Storm Hydrology Method uses runoff studies developed by Pitt and others to identify values of R_v to calculate WQV. This method provides greater accuracy than the Short Cut Method. It can be

Table 330-15. RECOMMENDED VALUES FOR MANNING'S COEFFICIENT OF FRICTION (n)

Conveyance Type and Description	Values of n Minimum	Design	Maximum
Closed Conduits: Concrete pipe, (design = flowing full)	0.011	0.012	0.013
Standard corrugated metal, rnd. & pipe arch (design=flowing full, plain or fully coated)	0.018	0.024	0.024
Struc. plate (field bolted), corrugated metal, flowing full	0.030	0.030	0.033
Vitrified clay pipe	0.012	0.013	0.014
Plastic pipe, smooth wall		0.011	
Open channels, lined, straight alignment:			
Concrete, formed, no finish	0.013	0.013	0.017
Concrete, formed, trowel finish	0.012	0.012	0.014
Concrete, formed, float finish	0.013		0.015
Gravel bottom, sides formed concrete	0.017		0.020
Gravel bottom, sides random stone in mortar	0.020		0.023
Gravel bottom, sides dry rubble or rip-rap	0.023		0.033
Brick	0.014		0.017
Constructed channels & swales, maintained vegetation, flow 0.6-1.8 800 m/s (2-6 ft/sec):			
Depth of flow up to 200 mm (8 in):			
Bermuda grass, Kentucky Bluegrass, Buffalo grass:			
Mowed to 50-100 mm (2-4 in) [flow≤ 100 mm (4 in)]			0.15
Grasses 50-100 mm (2-4 in) tall	0.03		0.15
Good stand, any grass: Height about 300 mm (12 in)	0.09		0.18
Height to about 600 mm (24 in)	0.15		0.30
Fair stand, any grass: Height about 300 mm (12 in)	0.08		0.14
Height to about 600 mm (24 in)	0.13		0.25
Depth of flow 200-450 mm (8-18 in):			
Bermuda grass, Kentucky Bluegrass, Buffalo grass:			
Mowed to 50 mm (2 in)	0.035		0.05
Grasses 100-150 mm (4-6 in) tall	0.04		0.06
Good stand, any grass: Height to about 300 mm (12 in)	0.07		0.12
Height to about 600 mm (24 in)	0.10		0.20
Fair stand, any grass: Height to about 300 mm (12 in)	0.06		0.10
Height to about 600 mm (24 in)	0.09		0.17
Streets and gutters: Concrete gutter, troweled finish		0.012	
Concrete gutter w/asphalt pavement, range smooth to rough		0.013-0.015	
Gutters w/flat slopes where sediment may accumulate add to above	0.002		
Asphalt pavement, range smooth to rough		0.013-0.016	
Concrete pavement, float finish		0.014	
Concrete pavement, broom finish		0.016	
Natural stream channels, surface width at bankfull flow less than 30 meters (100 ft):			
Fairly regular section:			
Some grass and weeds, little or no brush	0.030		0.035
Dense growth of weeds, flow depth well above weed height	0.035		0.05
Some weeds, light brush on banks	0.035		0.05
Some weeds, heavy brush on banks	0.05		0.07
Some weeds, dense willows on banks	0.06		0.08
For trees in channel, with some branches submerged at high flow, increase all of above values by		0.01-0.02	
For irregular sections, with pools, slight channel meander, increase all of above values by		0.01-0.02	
Mountain streams, no vegetation in channel, steep banks, trees and brush along banks submerged at high flow:			
Bottom of gravel, cobbles, few boulders		0.04-0.05	
Bottom of cobbles to large boulders		0.05-0.07	

applied at any design level and can be used to estimate a peak discharge as well as a runoff volume. It has four steps:

1. For rainfall depth, P, select a runoff coefficient from Table 330-13 for each land surface.
2. Compute a weighted runoff coefficient, R_v.
3. For disconnected impervious surfaces, multiply the appropriate reduction factor from Table 330-14 by the R_v to find a corrected value. To use the reduction factors, the impervious area above the pervious surface should be less than half the pervious area. Also, the flow path through the pervious area should be twice the impervious flow path.
4. Calculate WQV using the formula:

$$WQV = (P)(R_v)$$

Example: Calculate the runoff volume for a 2.6 acre small shopping center watershed having a 0.8 acre flat roof, 1.5 acres of paved parking lot and 0.3 acres of open space (clayey soils). Assume a 1.25 inch rainfall event and no disconnection of impervious surfaces. The weighted volumetric runoff coefficient is:

flat roof:	0.8 acres x 0.86 =	0.7
parking lot:	1.5 acres x 0.98 =	1.5
open space:	0.3 acres x 0.22 =	0.1
total:	2.6 acres	2.3

Weighted Rv = 2.3/2.6 = 0.88

Calculate water quality volume
$WQV = (P)(R_v)$

= (1.25)(0.88) = 1.1 watershed inches

= 1.1 in ($^1/_{12}$ in/ft)
(2.6 acres)(43,560 ft^2/acre)

= 10,382 cubic feet of runoff

Small Storm Hydrology Peak Discharge Method:

Where small storm peak discharges are needed in U.S. units, SCS curve numbers can be adjusted for use with the SCS TR-55 Graphical Peak Discharge Method. The WQV is used with the rainfall amount to calculate a new curve number (CN) by the following formula:

$$CN = \frac{1000}{10 + 5P + 10Q(Q^2 + 1.25QP)^{0.5}}$$

Where:
P = design rainfall depth in inches
Q = WQV in inches.

Time of concentration is computed using SCS methods (use a minimum of 0.1 hours). A unit peak discharge (q_u) is calculated using the normal SCS Graphical Peak Discharge Method described in subsection 5.5. The peak discharge, q_p, is found by:

$$q_p = q_u(A)(WQV)$$

Where:
q_p = peak discharge in ft^3/sec.

q_u = the unit peak discharge in ft^3/sec per square mile per inch of runoff

A = the drainage area, in square miles

WQV = water quality volume, in watershed inches.

6.0 CONVEYANCE TECHNIQUES

The fundamental conveyance techniques are: channels and swales, culverts, and storm sewers. Their critical design relationships are velocity and volume to rate of discharge. Velocity is the most complex parameter, expressed in Manning's Equation.

6.1 Manning Formula

With the exception of culverts, standard design of conveyance structures assumes steady, uniform, open channel flow conditions, not pressure flow conditions. Flow is caused by gravity. Uniform flow means depth, slope, velocity and cross-section remain constant over the length of the channel.

Elements of Open Channel Flow:

The cross-sectional components of open channel flow are shown on Figure 330-28. In design calculations, the effect of channel shape is considered by using the hydraulic radius of the flow cross-section, based on the formula:

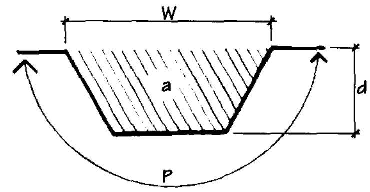
$$R = \frac{A}{P}$$

Where:
R = the hydraulic radius in meters (feet)

A = the cross-sectional area in square meters (square feet)

P = wetted perimeter in meters (feet)

The wetted perimeter is the perimeter of the containing cross section in contact with water at the design depth of flow. Figure



CROSS SECTION

W = CHANNEL WIDTH
a = CROSS SECTIONAL AREA
P = WETTED PERIMETER
d = DEPTH OF FLOW

Figure 330-28. Flow components of channel sections.

330-29 shows the formulas for computing the elements of channel cross sections for different channel shapes.

Manning's Equation:

The flow in open channels is a function of velocity and the cross-sectional area of flow. Velocity is a function of slope, surface roughness and cross-sectional shape. The Manning Formula is used to compute velocity:

$$V = \left(\frac{K}{n}\right) R^{0.67} S^{0.5}$$

Where:
V = velocity of flow in meters per second (ft/sec)

n = Manning's coefficient of friction

R = hydraulic radius of flow cross-section in meters (ft)

S = longitudinal slope of the hydraulic grade line (water surface) in m/m (ft/ft)

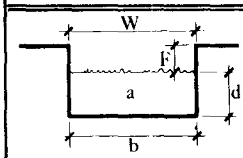
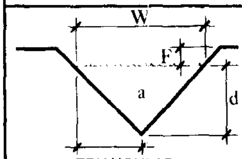
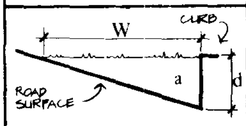
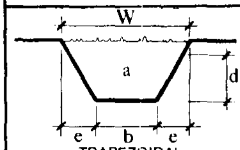
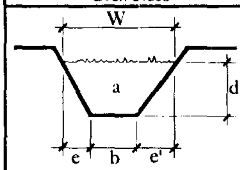
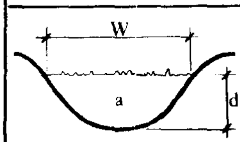
K = constant (1.0 for S.I. units; 1.486 for U.S. units)

In steady, uniform open channel flow, the slope of the water surface is parallel to the slope of the channel bottom. Table 330-15 gives values for Manning's coefficient of friction (n).

Two other arrangements of the Manning formula are convenient in conveyance design. Discharge (Q) can be expressed in terms of the Manning Formula using the following formula (Where A = area of cross-section of water flow and V = velocity):

$$Q = VA$$

$$\therefore Q = \left(\frac{K}{n}\right) A R^{0.67} S^{0.5}$$

TYPE SECTION	WIDTH W	BASE b	DEPTH d	AREA a	WETTED PERIMETER P	HYDRAULIC RADIUS A/P
 RECTANGULAR	b or $\frac{a}{d}$	W or $\frac{a}{d}$	$\frac{a}{b}$	wd	$W+2d$	$\frac{d}{1+\frac{2d}{W}}$
 TRIANGULAR	$2e$		$\frac{a}{e}$	ed	$e\sqrt{e^2+d^2}$	$\frac{ed}{2\sqrt{e^2+d^2}}$
 TRIANGULAR Curb & Gutter	$\frac{2a}{d}$		$\frac{2a}{W}$	$\frac{Wd}{2}$	$d+\sqrt{d^2+W^2}$	$\frac{2Wd}{d+\sqrt{e^2+W^2}}$
 TRAPEZOIDAL Even Sides	$b+2e$	$W-2e$	$\frac{a}{b+e}$	$d(b+e)$	$b+2\sqrt{e^2+d^2}$	$\frac{d(b+e)}{b+2\sqrt{e^2+d^2}}$
 TRAPEZOIDAL Uneven Sides	$b+e+e'$	$W-(e+e'$	$\frac{a}{b+\left(\frac{e+e}{2}\right)}$	$d\left(b+\frac{e+e'}{2}\right)$	$b+\sqrt{e^2+d^2}+\sqrt{e^2+d^2}$	$\frac{d\left(b+\frac{e+e'}{2}\right)}{b+\sqrt{e^2+d^2}+\sqrt{e^2+d^2}}$
 PARABOLIC	$\frac{a}{0.67d}$		$\frac{a}{0.67W}$	$0.67\ Wd$	$W+\left(\frac{8d^2}{3W}\right)$	$\frac{a}{W+\left(\frac{8d^2}{3W}\right)}$

NOTE: 0.3' to 0.5' Recommended Freeboard (F)

Figure 330-29. Hydraulic elements of channel sections.

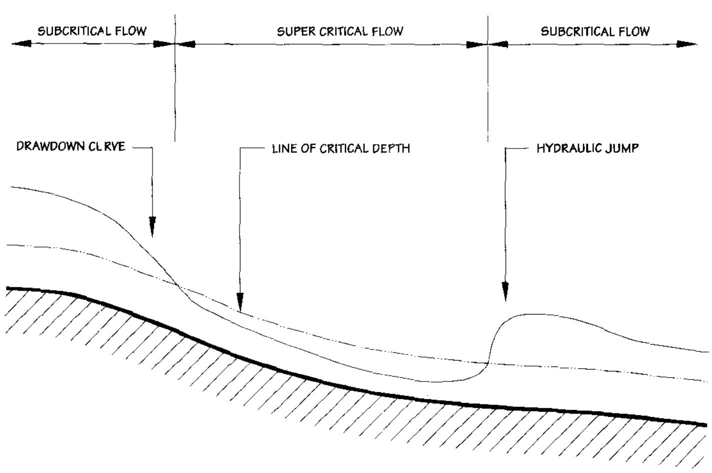


Figure 330-30. Critical Depth and flow character of channels.

Slope (S) can then be expressed:

$$S = \left(\frac{Vn}{KR^{0.67}}\right)^2$$

Flow Stability and Critical Depth:

The velocity of flow relative to the other cross-sectional characteristics is important to stability. Critical velocity occurs at critical depth, the depth of flow at which the discharge of the section is maximum for a specific energy of flow. Flow becomes very unstable as critical flow is approached. When flow is deeper than critical depth (subcritical flow), velocity is lower than at critical depth (Figure 330-30). When flow is shallower than critical depth (supercritical flow), velocity is higher than at critical depth.

A common test of channel section suitability is to check the design depth or velocity against critical depth, or the critical velocity for the section. If design values are within ten percent of critical values, the design is considered unstable.

6.2 Channels and Swales

Open vegetated channels and swales are typically components of the minor system, and are designed to convey peak discharges of runoff. All vegetated channels provide significant amounts of storage and infiltration, and are excellent techniques for reproducing pre-development hydrologic conditions. For example, the use of roadside swales instead of curb and storm sewer in many cases can reduce peak discharges below pre-development conditions. This results from the sheer quantity of swale length and volume.

For ease of construction and hydraulic performance, swales are typically designed with trapezoidal cross-sections. Cross-section design fits size and depth to accommodate peak discharge using hydraulic design charts. A bottom width and depth of flow are selected to handle the discharge from a two year rainfall without reaching erosive velocity [1.2 to 1.5 m/s (4.0 to 5.0 ft/sec) maximum]. Additional depth is added to accommodate the discharge from a ten year rainfall without eroding [2.1 m/s (7.0 ft/sec) maximum].

Swales and channels can be enhanced to treat water quality volume (WQV). In these cases design starts by selecting bottom width, depth and length sufficient to hold the WQV. Additional depth for the two year and ten year rainfalls is provided. Flow at WQV depth should be no faster than 0.3 m/s (1.0 ft/sec) and long enough to

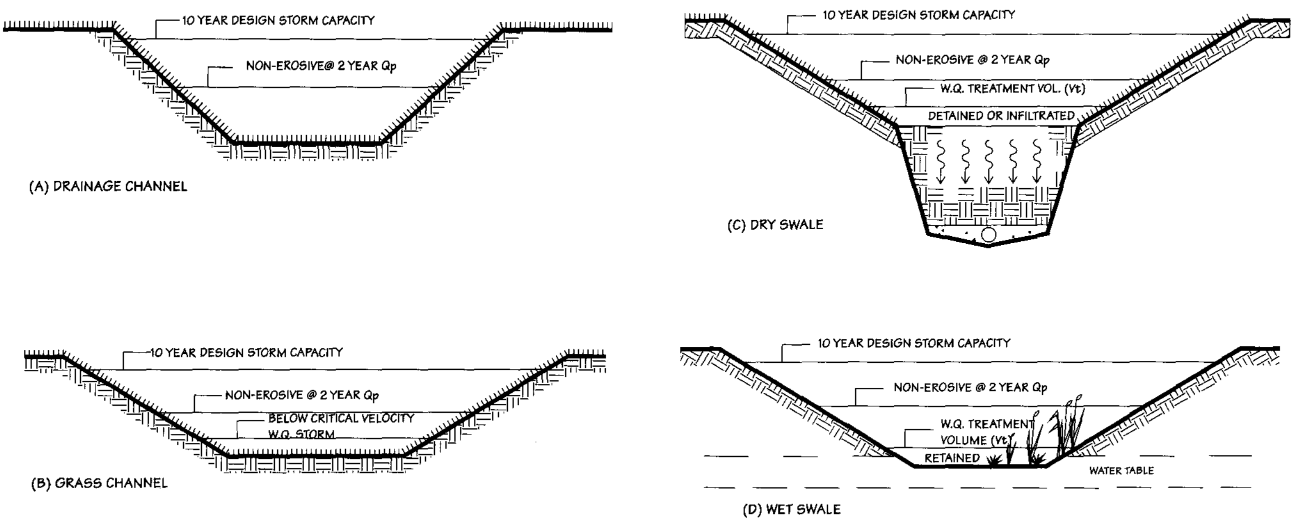


Figure 330-31. Basic channel and swale types.

create at least 10 minutes of travel time over its length. Example sections of four basic channel and swale types are shown on Figure 330-31. Design charts for trapezoidal sections with 2:1 side slopes are shown as Figures 330-32 through 330-34. Bottom widths should not be wider than 1 800 mm (6 ft) to prevent braiding at low flows. Other shapes, side slopes and bottom widths can be designed using a computer model to solve Manning's Equation.

Grassed Channels:

Figure 330-31a is a drainage channel designed to just convey runoff without erosion or over-topping. Figure 330-31b is a grassed channel designed for filtering the WQV peak discharge. Flow depth for WQV should not exceed 100 mm (4 in). Longitudinal slopes should not exceed 4% or be less than 1%. Use n = 0.15 for water quality depth. For deeper flows, n varies from 0.15 to 0.03.

Dry and Wet Swales:

Figure 330-31c is a dry swale that ponds and infiltrates the WQV beneath the swale outlet. Figure 330-31d is a wet swale that stores the water quality volume beneath the swale outlet and exposes the water table to create a wetland in the swale bottom. Storage should drain slowly over 24 hours and is best controlled with a v-notch weir cut into a check dam. Both types of swale should have a forebay made with a check dam at the culvert entry into the swale. The forebay should hold a volume equal to 0.05 times the impervious area draining into the culvert. Longitudinal slopes should be between 1% and 2% without the use of check dams. Slopes may be steeper if check dams are placed along the length. For dry swales a 750 mm (30 in) deep gravel bed with underdrain should be used over the bottom width, and the underlying soil bed should be moderately permeable. Soils under the wet swale should be undisturbed. Flow depth for WQV should not exceed 450 mm (18 in).

Design Charts:

WQV volume or discharge (Q) in U.S. units for swales and channels is found using design charts. An initial cross-section is determined by selecting a trial n and channel bottom width. Select the chart corresponding to bottom width from Figures 330-32 through 330-34. Use Qn to enter the chart (bottom) and find a corresponding Vn and depth at the design longitudinal slope. Velocity is found by dividing Vn by n. The process is repeated for each design storm using an appropriate n value. Channels with slopes within 10% of the critical slopes shown on the charts should be discarded, and a different configuration (bottom width) considered.

6.3 Culverts

Culverts are designed to work under pressure flow conditions as they cause water to back up at the inlet end of the pipe. Figure 330-35 shows the various culvert components. The height of water created at the inlet may be caused by inlet or outlet constriction. Standard procedure is to calculate the headwater created by each condition and assume the worst case prevails. Where headwater exceeds 1.2 diameters of pipe above the culvert inlet, anti-seep collars should be attached every 6 m (20 ft) along the culvert barrel, to prevent seepage cavitation around the culvert.

Figure 330-36 shows an example of a standard calculation with the steps outlined. Figure 330-37 is a nomograph for solution of headwater depth for inlet control. Figure 330-38 is a nomograph for the solution of head depth for outlet control. Both nomographs are for corrugated metal pipes. Calculations for other pipe types and shapes can be accomplished with computer programs or with nomographs found in *Hydraulic Design of Highway Culverts — Hydraulic Design Series No. 5* (1985) published by the Federal Highway Administration (FHWA-IP-85-15). Figure 330-39 is a nomograph for finding values of critical depth, d_c, in circular pipes. The basic entrance conditions and flow coefficients for metal pipe culverts are shown in Figure 330-40.

In acid soils, metal culverts should be fully paved or concrete culverts should be used. Figure 330-41 shows minimum depths of cover over culverts required to distribute wheel loads over the arch of the barrel. Culvert slopes may be almost flat, and little additional flow advantage is gained above a 2% slope.

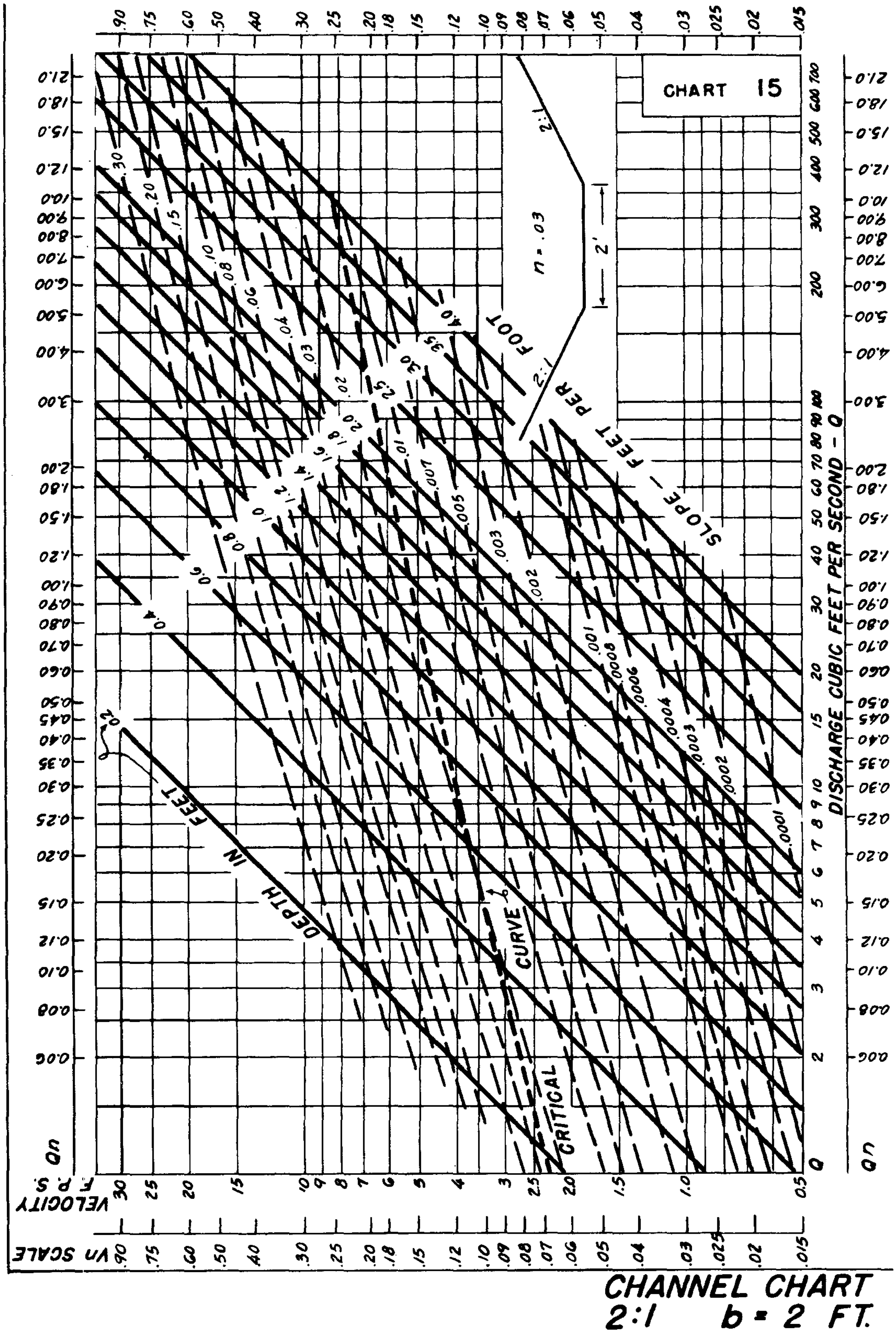


Figure 330-32. Design chart for trapezoidal channels (2 ft. bottom width, 2:1 side slopes).

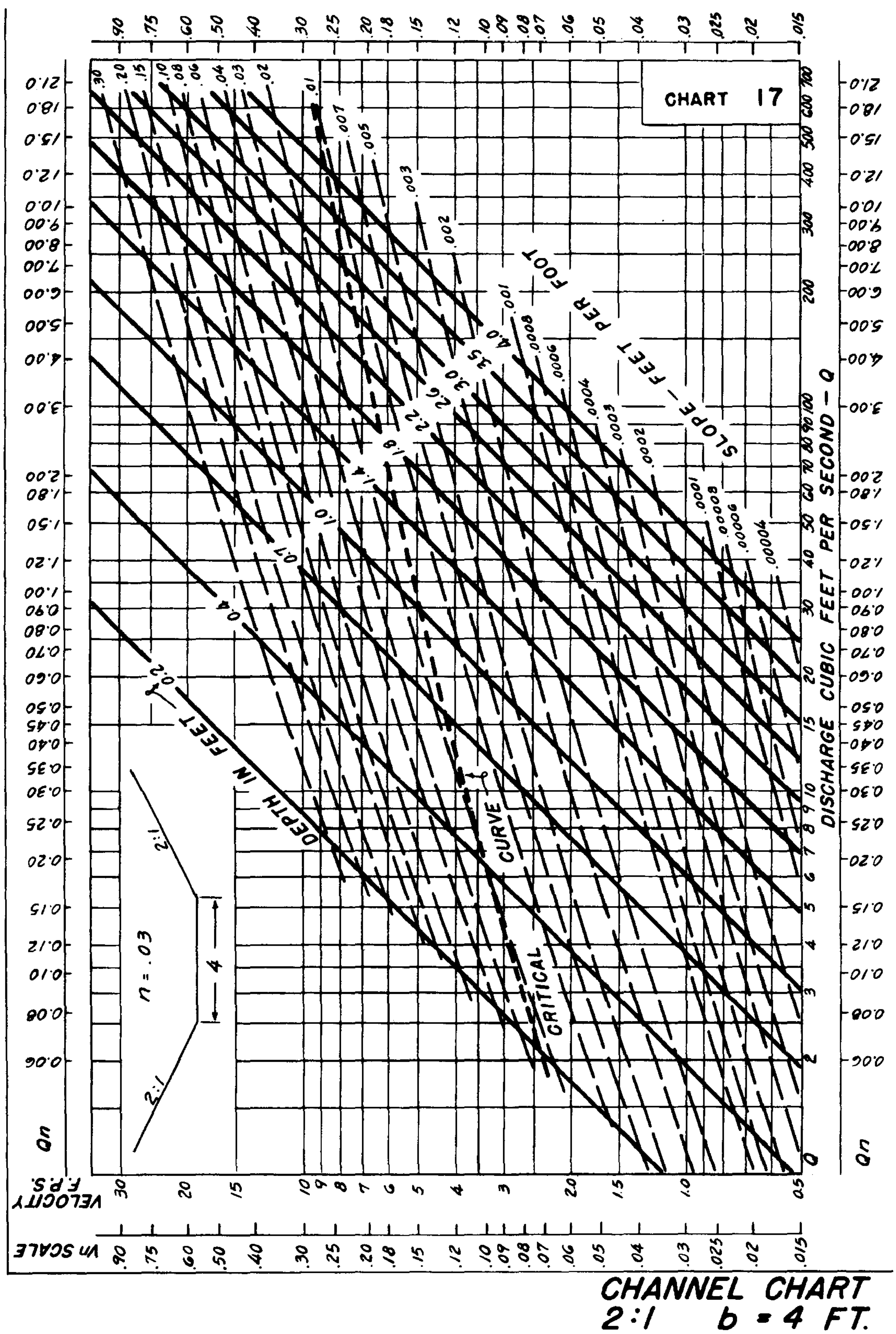


Figure 330-33. Design chart for trapezoidal channels (4 ft. bottom width, 2:1 side slopes).

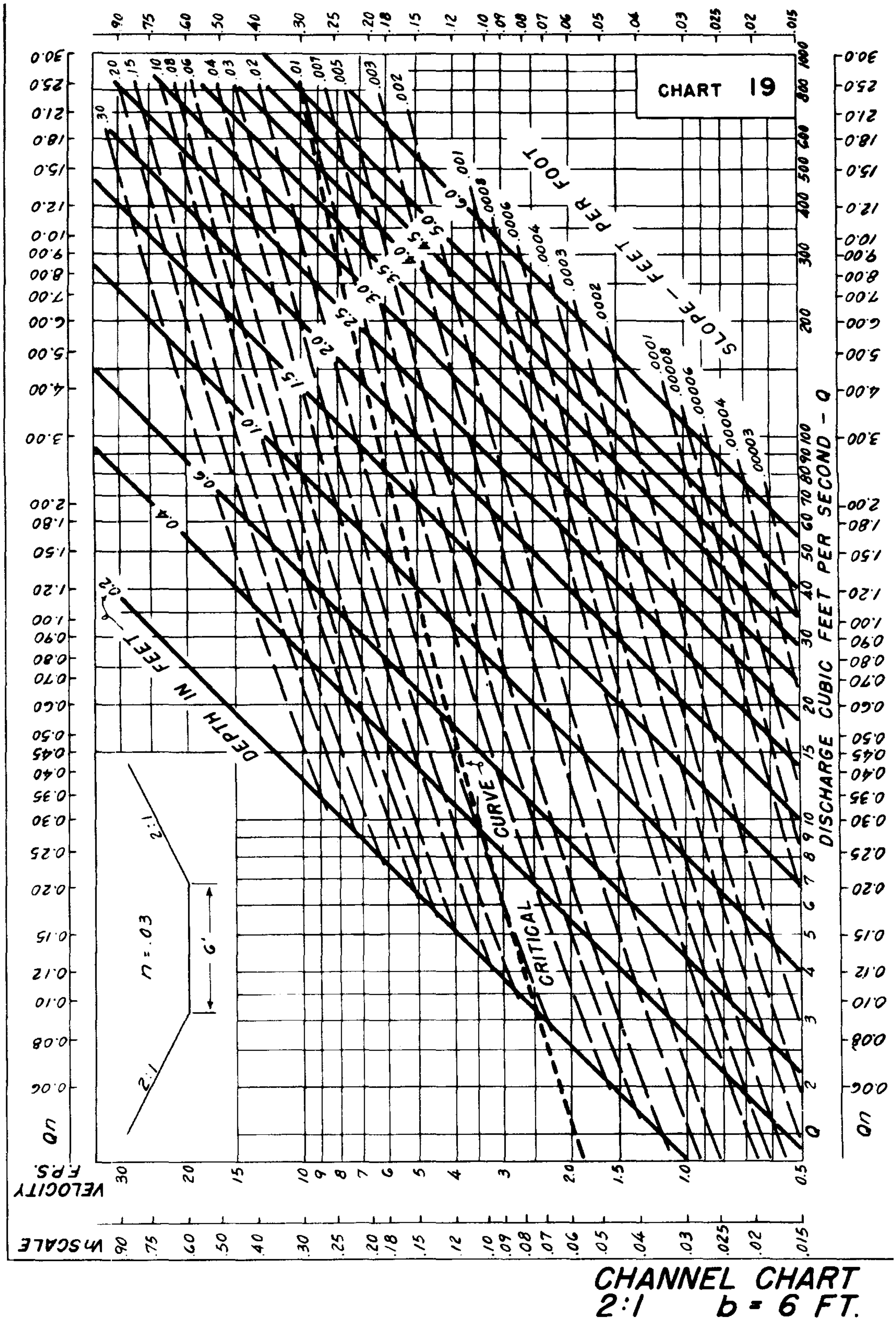


Figure 330-34. Design chart for trapezoidal channels (6 ft. bottom width, 2:1 side slopes).

6.4 Storm Sewers

Storm sewers are usually designed using the Rational Method for the 10 year rainfall event. Duration is assumed equal to the time of concentration at the point where flow is calculated. For small systems, design begins by identifying inlet and manhole locations, and connecting straight pipe runs between manholes (Figure 330-42). Manholes provide pipe-end access for cleaning and inspection, and may or may not be used as inlet structures. Pipes from inlets to manholes are not typically sized, as minimum pipe size is rarely exceeded by inlet flow. Minimum pipe size is dependent on the type of pipe used. Polyvinyl Chloride (PVC) pipe may be as small as 200 to 250 mm (8 to 10 inches), while concrete pipe is typically at least 300 mm (12 inches). Design focuses on selecting pipe sizes between manholes to carry design flows and setting invert elevations and pipes slopes. Profiles cut through the centerline of pipes and manholes are used to control manhole depths, and pipe slopes and inverts.

Design Flows:

Maximum discharge through circular pipes occurs when depth of flow is about 90 percent of pipe diameter. Storm sewers are typically designed to flow full to the pipe top. This allows a margin of safety in design calculations. Pipe sizes and slopes can be selected to match calculated runoff discharges using Table 330-16.

To set pipes at other slopes, use Figure 330-43 to select pipe sizes and solve Manning's Equation in U.S. units. Velocity and depth of flow for design discharges of partially full pipes can be calculated using Table 330-17. Full-pipe discharge is found multiplying velocity by area. Area and velocity are found for the full pipe section (hydraulic radius of circular pipes = Diameter ÷ 4). Design discharge as a ratio of full pipe discharge is used with the table to find the design depth of flow and the design velocity from the ratio of full pipe velocity.

Design Calculations:

Design calculations work downstream from the uppermost manhole, sizing the pipe leaving the manhole to accommodate the sum of all flows entering the manhole. The routing of flows through the system is handled by using a progressively longer time of concentration to account for flow time to the point of concern. Time of concentration to the uppermost manhole is the time of overland flow (minimum 5 minutes). For subsequent subcatchments, overland flow time is ignored. The sum of overland flow

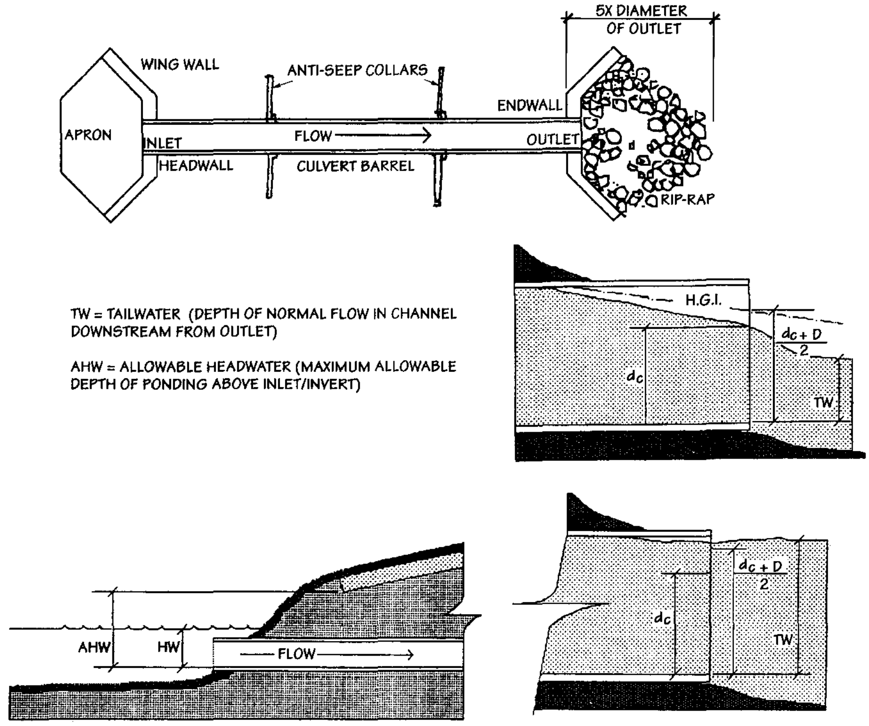
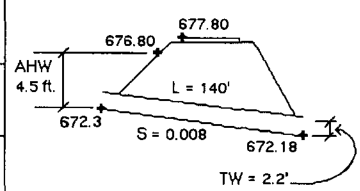


Figure 330-35. Components of culverts.

Hydrologic Data:
P = 5.0 Design Storm 25 yr. 24 hr.
CN = 75 Drainage area = 10.5 acres/ 0.01 sq. mi.
Q = 2.42 inches
T.O.C. = 0.15 ~~min. or~~ hrs. Peak discharge = 42.6 c.f.s.

Channel: slope 0.008 ft./ft.
Condition — sod over erosion resistant soils

Highwater Data: Elev. None available
Comments: No problems noted
AHW: Based on — Elev. of lowest pav't edge = 677.80' less 1.0 ft. of freeboard. AHW = el. 676.80 or 4.50'



CULVERT TYPE	Q (c.f.s.)	SIZE	HEADWATER COMPUTATION: Inlet Control HW/D	HW	Outlet Control K_e	TW	d_c	$\frac{d_c+D}{2}$	h_o	H	LS_o	HW	Controlling HW	Outlet Velocity f.p.s.
Headwall C.M.P.	42.6	36"	1.16	3.48	0.5	2.20	2.25	2.63	2.63	2.8	1.12	4.31	4.31	4.6

Figure 330-36. Example culvert design calculation form.

to the first inlet plus pipe flow time to the manhole of interest is used for the time of concentration for the subsequent subcatchments. Where branches converge, the longest flow time is used.

Velocities:

A standard minimum design velocity of 0.6 m/s (2.0 ft/sec) is used to prevent sediment build-up in pipes. A velocity of 0.9 m/s (3.0 ft/sec) will remove heavy sands. Maximum velocity is usually 3 m/s (10 ft/sec).

Turbulence causes velocity loss at manholes. To compensate, the inverts of pipes exiting the manhole must be lower than those of entering pipes. Since exiting pipes are larger in diameter than entering pipes, the drop is accomplished by holding the

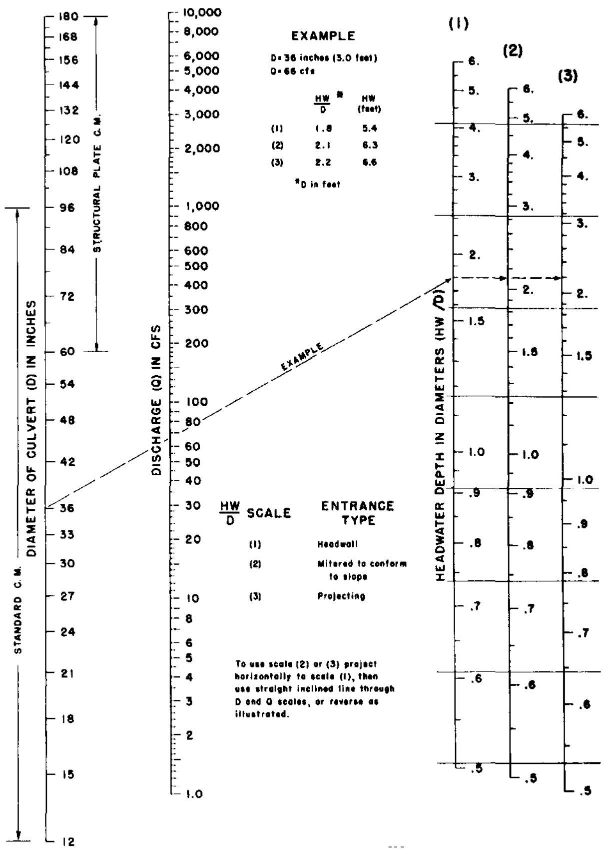


Figure 330-37. Headwater depths for corrugated metal pipe culverts with inlet control (U.S. units).

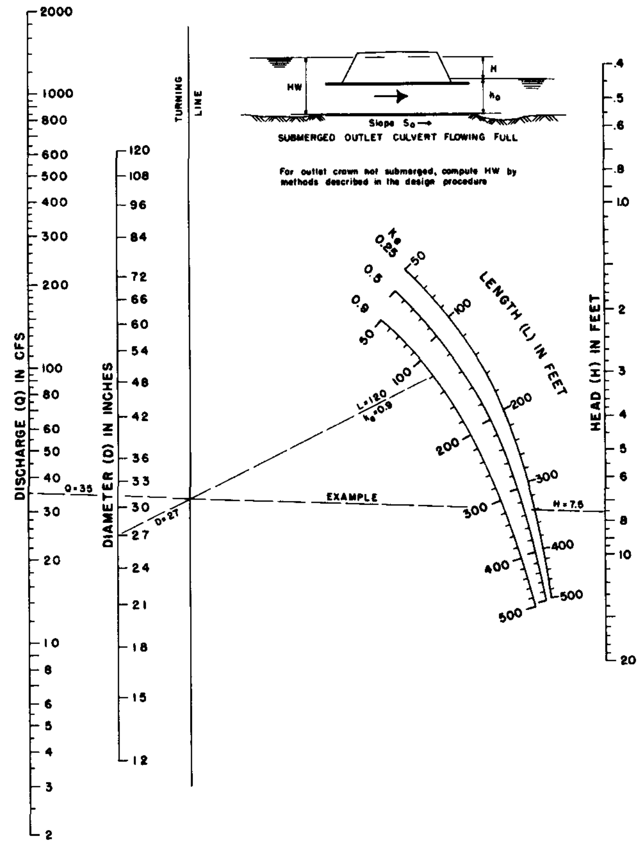


Figure 330-38. Head for standard corrugated metal pipe culverts flowing full [outlet control, n=0.024] (U.S. units).

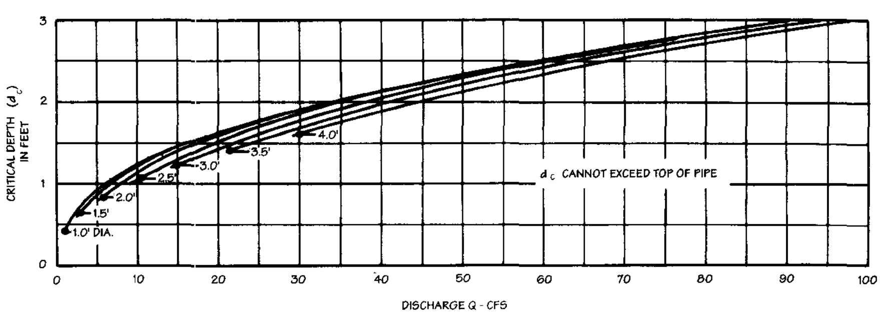


Figure 330-39. Critical depth, dc, nomograph for circular pipe (U.S. units).

pipe tops (crowns) at the same elevation. At manholes where the pipe run deflects over 45° the minimum invert drop should be 75 mm (3 in).

Manholes:

The maximum spacing between manholes is a function of cleaning equipment capability, and is typically specified by local governments. Maximum manhole spacing ranges from 100 to 150 meters (300 to 500 ft). Minimum manhole depth is a function of headroom needed for maintenance workers. Standard interior manhole diameter is 1 200 mm (4.0 ft). Pipe lengths are measured to the inside of manhole walls. Manholes are usually custom fabricated of precast concrete or heavy corrugated metal, but may also be laid up with unit masonry in the field.

Pipe Materials:

Typical pipe materials include reinforced concrete pipe (RCP), corrugated metal pipe (CMP), high density polyethylene (HDPE) plastic pipe and polyvinyl chloride (PVC) plastic pipe. A minimum diameter of 200 mm (8 inches) is recommended to minimize blockages. Pipes are also available in oval and arch shapes.

7.0 STORAGE TECHNIQUES

Storage is used to reduce the peak discharge from developed conditions to the pre-development level. Wet detention can be used to improve water quality. Detention for flood protection is best provided on a regional basis rather than on an individual site basis. Generally, storage provided in the upper third of a watershed will reduce downstream flooding. Storage located in the lower third of a watershed will generally increase flooding. Water quality detention can be provided anywhere in the watershed that provides capture of the water quality volume of runoff. Water quality detention is typically most econom-

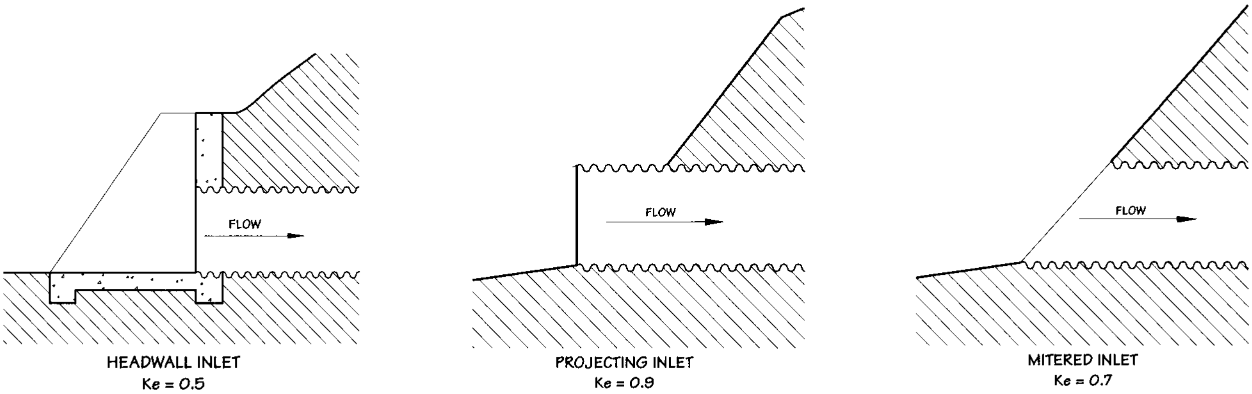


Figure 330-40. Basic entrance conditions for culverts

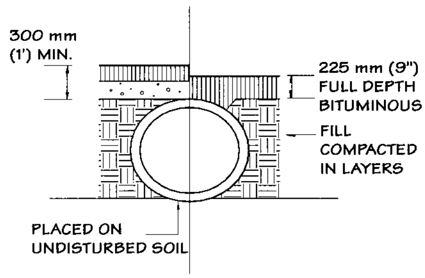


Figure 330-41. Minimum pipe cover over culverts.

Table 330-16. QUANTITIES, VELOCITIES AND SLOPES FOR CIRCULAR SEWERS FLOWING FULL (U.S. Units)

Pipe Dia. inches		2.0 fps	3.0 fps	4.0 fps	5.0 fps	6.0 fps	7.0 fps	8.0 fps
8	Q	0.70	1.1	1.4	1.8	2.1	2.4	2.8
	S*	3.3	7.5	13.3	20.8	30.0	40.7	53.2
10	Q	1.1	1.6	2.2	2.7	3.3	3.8	4.4
	S*	2.5	5.6	9.9	15.5	22.3	30.3	39.6
12	Q	1.6	2.4	3.1	3.9	4.7	5.5	6.3
	S*	1.9	4.4	7.8	12.1	17.5	23.8	31.0
15	Q	2.5	3.7	4.9	6.1	7.4	8.6	9.8
	S*	1.4	3.2	5.8	9.0	13.0	17.8	23.0
18	Q	3.5	5.3	7.1	8.8	10.6	12.4	14.2
	S*	1.1	2.5	4.5	7.1	10.1	13.8	18.1
21	Q	4.8	7.2	9.6	12.0	14.4	17.8	19.2
	S*	0.92	2.1	3.7	5.8	8.3	11.3	14.7
24	Q	6.3	9.4	12.6	15.7	18.8	22.0	25.2
	S*	0.77	1.7	3.1	4.8	7.0	9.5	12.4
27	Q	8.0	11.9	15.9	19.9	23.9	27.9	31.9
	S*	0.66	1.5	2.6	4.1	5.9	8.1	10.5
30	Q	9.8	14.7	19.6	24.5	29.4	34.4	39.3
	S*	0.57	1.3	2.3	3.6	5.2	7.0	9.2
33	Q	11.9	17.8	23.8	29.7	35.7	41.7	47.6
	S*	0.50	1.1	2.0	3.1	4.5	6.2	8.1
36	Q	14.1	21.2	28.3	35.4	32.4	49.5	56.6
	S*	0.45	1.1	1.8	2.8	4.0	5.5	7.2
42	Q	19.2	28.9	38.4	48.1	57.7	67.3	76.9
	S*	0.36	0.82	1.5	2.3	3.3	4.5	5.8
48	Q	25.2	37.7	50.3	62.8	75.4	88.0	101.0
	S*	0.30	0.68	1.2	1.9	2.7	3.7	4.9

*Slopes are in *thousandths* of feet per foot

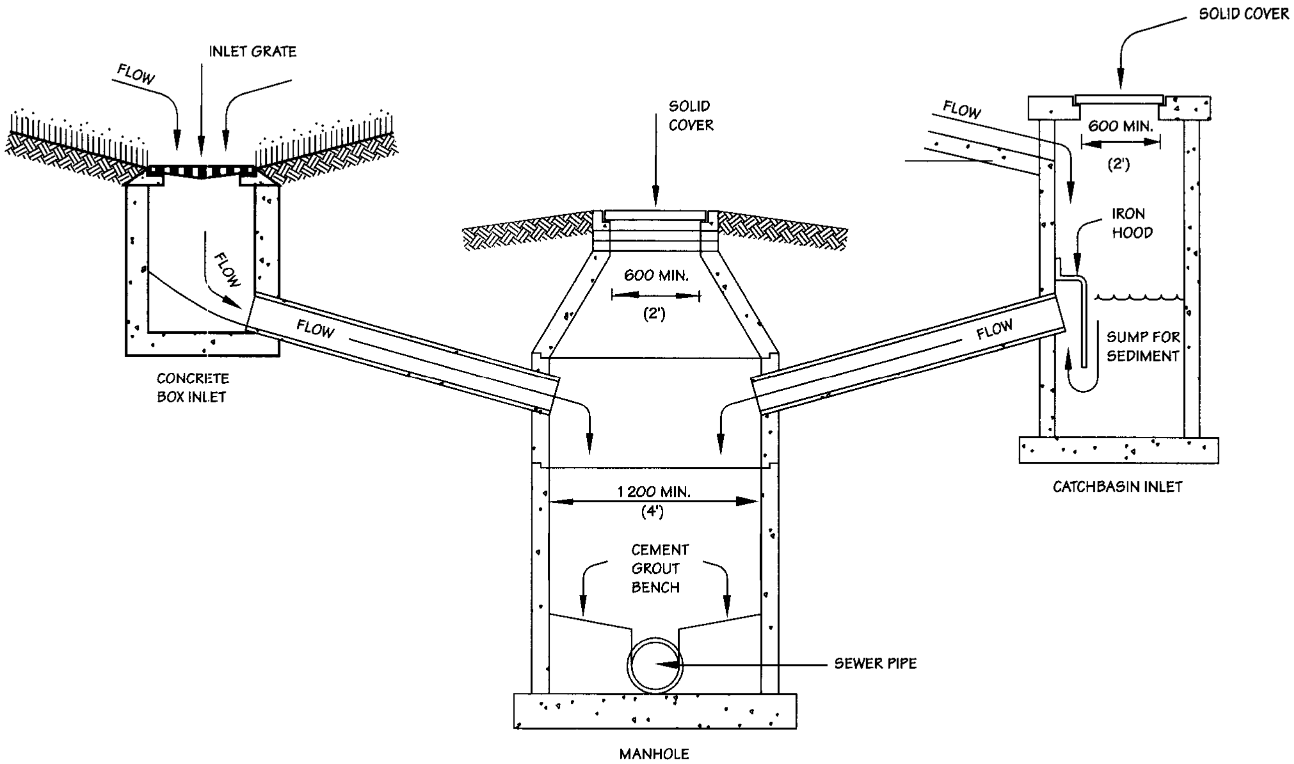


Figure 330-42. Typical manhole with inlets.

Table 330-17. HYDRAULIC CHARACTERISTICS OF CIRCULAR PIPE

Depth of flow / Inside diameter	Partial area / Total area	Discharge part full / Discharge flowing full	Velocity partly full / Velocity flowing full
0	0	0	0
0.05	0.019	0.005	0.25
0.10	0.052	0.021	0.40
0.15	0.094	0.049	0.52
0.20	0.143	0.088	0.62
0.25	0.196	0.137	0.70
0.30	0.252	0.195	0.77
0.35	0.312	0.262	0.84
0.40	0.374	0.336	0.90
0.45	0.437	0.416	0.95
0.50	0.500	0.500	1.00
0.60	0.627	0.671	1.07
0.70	0.748	0.837	1.12
0.80	0.858	0.977	1.14
0.90	0.950	1.067	1.12
0.95	0.982	1.075	1.09
1.00	1.000	1.000	1.00

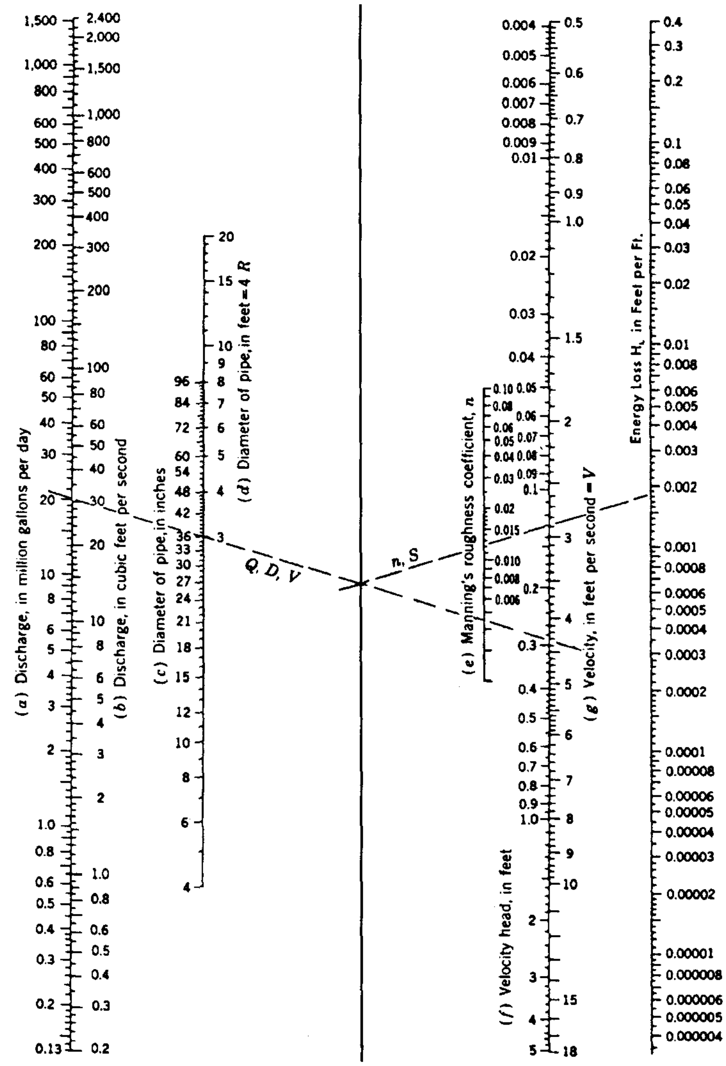


Figure 330-43. Nomograph for pipe sizing and solution of Manning's Equation (U.S. units).

ical if provided as part of a district or regional plan.

Most storage basins are constructed as excavated basins if possible. Excavating is typically less technical, and less expensive, than constructing earth-fill dams for embankment ponds. For schematic design, pond volume may be roughly estimated by the following formula:

$$V = \frac{1}{3} DA$$

Where:

V = volume of water in cubic meters (cubic feet)

D = maximum depth in meters (feet)

A = surface area of pond in square meters (square feet)

7.1 Stage-Storage Curves:

Precise pond volumes may be determined using contours and volume estimation. This methodology is used to develop stage-storage curves for pond level determination and for setting pond outlet elevations. A stage-storage curve is a plot of volume stored at each possible water surface elevation. The points of the curve are usually plotted for each meter (foot) of pond depth, and then visually integrated into a curve that connects the points (Figure 330-44).

7.2 SCS Storage Volume for Detention Basins

This is a quick manual method of estimating the relationship between storage volume and discharge in detention ponds without actual routing calculations. It is intended mainly for schematic design and has a bias toward oversizing ponds. It should not be used for final pond design where an error in storage of 25 percent cannot be tolerated. More accurate estimation can be provided by computer programs.

Figure 330-45 may be used to find either the volume of storage (V_r) needed to reduce a peak discharge, or to find the runoff discharge (q_o) from a given volume of pond storage in U.S. units. The first case (most common) is used when runoff from developed conditions must be held at or below pre-development peak discharge rates. The second case is typically used to determine the effect of a known pond volume on peak discharge from a given design storm.

7.3 Rational Mass Inflow Method

This method constructs a synthetic curve representing cumulative storm runoff over time using the Rational Formula and an IDF curve. This method should only be used for small catchment areas such as roofs and parking lots. Outflow discharge rate is generally fixed or assumed. The inflow curve is calculated from runoff, the outflow 'curve' is calculated from the discharge rate. The maximum difference between the two is the storage volume needed.

Table 330-18 illustrates a sample storage calculation using the Rational Mass Inflow method.

7.4 'Chainsaw' Water Balance Analysis

Where a permanent pond is intended, it is a good practice to conduct a water balance analysis to see what will likely happen to the water surface over time. A water balance is a monthly accounting of the effect on water surface elevation of runoff, evaporation, and infiltration. Monthly calculations are continued until an annual pattern is repeated. This approach is dubbed 'Chainsaw' because it is very rough, but sufficient to get a general idea of pond performance. Table 330-19 shows a portion of an example calculation.

Data needs are: local average monthly precipitation depths, local average monthly evaporation rates from lake and reservoir surfaces, and an estimate of monthly infiltration based on soils under the pond. In the

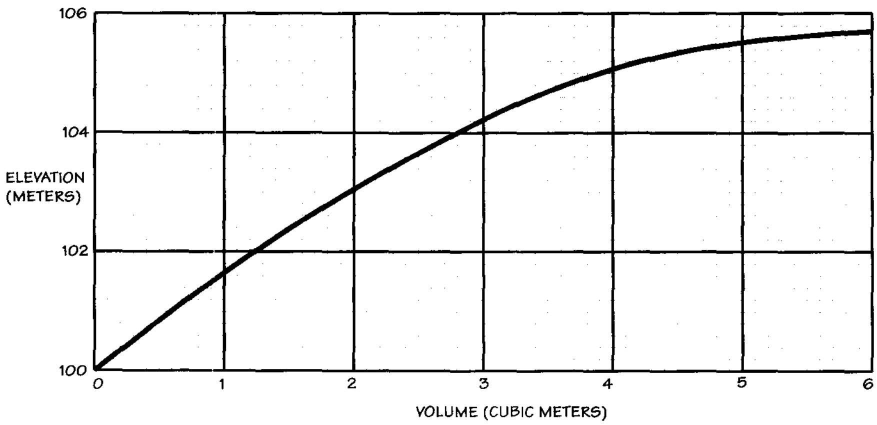


Figure 330-44. Example of a stage-storage curve.

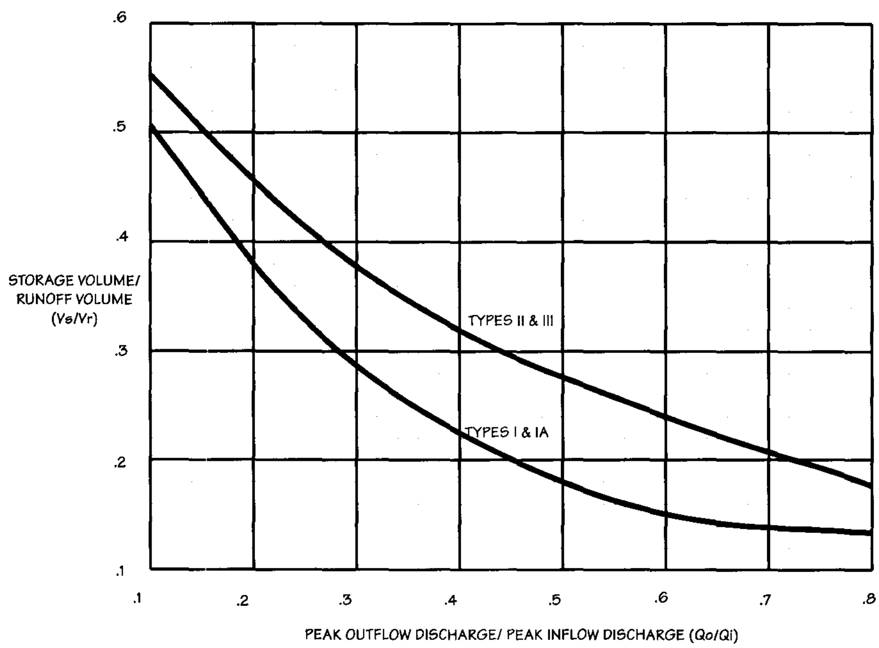


Figure 330-45. SCS Approximate detention basin routing for rainfall types I, IA, II and III.

U.S. the monthly precipitation and evaporation rates are plotted on maps that may be obtained from the state NRCS engineering office. Infiltration rates can be developed from soil data, or more accurately from field tests. In addition, standard watershed data is needed and a stage storage-curve for the pond must be constructed.

7.5 Dry Detention Ponds

Dry detention ponds are typically designed to drain within 72 hours after a rainstorm. Discharge rate is controlled at or below pre-development peak discharge. The design volume for small ponds may be determined by either the SCS Method or the Rational Mass Inflow Method.

All ponds should have at least two types of outlets: (1) a principal spillway and (2) an emergency or overflow spillway (see Figure 330-46). The principal spillway is an outlet sized to a release rate for the designed pond volume. The emergency spillway provides an alternative release path for cases when the principal spillway is blocked or the capacity of the pond is exceeded. In permanent ponds, the principal spillway design storm ranges from 10 year to 100-year, 24-hour rainfall. Emergency spillways are designed to pass a 100 year, 24 hour storm. Temporary ponds are usually wet detention ponds for trapping sediment, with their respective design storms being 2-year and 10-year, 24 hour events.

Spillways may be designed as culverts with anti-seep collars or as combinations of weirs. Outflow device inlets are placed at the pond bottom to drain the pond completely (Figure 330-47).

Maximum depth of storage is established using a stage-storage curve and the design pond volume. The emergency spillway invert elevation is usually set 150 mm (6 in) above the water surface of the principal spillway design storm.

7.6 Wet Detention Ponds

Wet detention ponds are designed to have a permanent pool of water with additional volume above the water surface for handling runoff pulses. Wet detention has become a standard requirement for removal of sediment from runoff. Temporary storage depths can be added above the sediment treatment design if desired.

The standard components of a wet detention pond sediment removal are: a forebay, a storage basin and an outlet structure (Figure 330-48). The forebay slows and spreads runoff flow using rip-rap or a level-spreader or both. For the greatest efficiency, the storage basin should be long and narrow, with a temporary detention depth of 900 to 1 200 mm (3.0 ft. to 4.0 ft).

Figure 330-49 shows a typical cross-section for a wet detention pond. Safety is a concern in pond design. Slopes along the shoreline should be gradual (1:4 or less) and/or protected by dense upland plantings. A 6 000 mm (20 ft) flat shelf (1:10 slope or less) should be provided at the water's edge if possible. Safety fencing should be avoided, unless no other alternative is available.

Regulations for sediment settling typically target a 5 micron or 20 micron particle for sediment removal performance. Table 330-20 shows the minimum water surface area for wet sedimentation ponds. Tables 330-21 through 330-23 show minimum water surface sizes for satisfactory removals at each stage of head over outlet inverts for various outlet types. In general, v-notch weirs provide the greatest precision of flow control and the smallest pond areas.

Table 330-18. EXAMPLE RATIONAL MASS INFLOW STORAGE VOLUME CALCULATION (U.S. units)

Determine the amount of storage needed on a 40,000 s.f. (0.92 acres) roof top (A) for a year storm, given a roof drain that will discharge a maximum of 0.16 c.f.s. Assume runoff coefficient (C) of 1.0.

The calculations to produce the volumes for the inflow and outflow curves, and the resulting storage requirements at each time interval are shown in the following table:

a	b	c	d	e	f	g	h
Time in Min.	**A x C**	**I, in./hr.**	**Time in Seconds**	**Inflow volume in cu. ft. (col. b · c · d)**	**Outflow discharge rate in cfs**	**Outflow volume in cu. ft. (col. d · f)**	**Storage required cu. ft. (col. e – g)**
10	0.92	7.02	600	3,875	0.16	96	3,779
15	0.92	5.76	900	4,769	0.16	144	4,625
30	0.92	3.80	1,800	6,293	0.16	288	6,005
60	0.92	2.31	3,600	7,651	0.16	576	7,075
120	0.92	1.28	7,200	8,479	0.16	1,152	7,327
360	0.92	0.59	21,600	11,724	0.16	3,456	8,268*
720	0.92	0.38	43,200	15,102	0.16	6,912	8,190
1440	0.92	0.22	86,400	17,587	0.16	13,824	3,763

* Maximum storage volume required on roof.

Table 330-19. PARTIAL "CHAINSAW" WATER BALANCE CALCULATION EXAMPLE (U.S. units)

1	**element/month**	**Apr.**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Jan.**
2	**mo. precipitation, in.**	2.1	3.2	4.1	3.5	3.6	2.5	1.9	1.3	1.6	1.6
3	**start water surface el.**	100.0	102.0	102.5	103.0	102.0	102.5	102.5	102.2	101.5	103.4
4	**+runoff volume flow into pond (ac. ft.)**	2.2	3.4	4.4	3.7	3.8	2.7	2.0	1.4	1.7	1.7
5	**new water surface el.**	103.4	105.4	105.9	105.7	105.5	105.2	104.9	104.0	103.9	105.0
6	**- depth of monthly infiltration (clay at 0.04 in/hr) in ft.**	1.1	2.5	2.4	2.5	2.5	2.4	2.5	2.4	0	0
7	**- depth of avg. mo. evap., ft.**	.3	0.4	0.5	0.5	0.5	0.3	0.2	0.1	0.4	0.4
8	**end pond surface el. (row 5- rows 6 &7)**	102.0	102.5	103.0	102.0	102.5	102.5	102.2	101.5	103.4	104.6

The starting water surface elevation (Row 3) is the pond bottom for the first month the pond will collect runoff. For each month thereafter it is the end pond surface elevation (Row 7) from the previous month.

Runoff volume (Row 4) is found using the small storm hydrology method to convert average monthly rainfall depth into average monthly runoff depth (WQV).

Row 5 is found using the pond stage-storage curve. Using the curve's storage scale, the runoff volume from Row 4 is added to the volume for the depth in Row 3. The corresponding new elevation is found on the curve's stage scale.

Row 6 values account for leakage of the pond through a silty-clay seal (loss rate per hour times hours in the month). In the example, a shallow pond is assumed to have no infiltration losses while frozen in the winter.

Note, precipitation and evaporation are still used in winter months to crudely account for snowfall and evaporation from snow. Two year's worth of calculations are usually sufficient to determine whether the pond will fill and maintain a water surface.

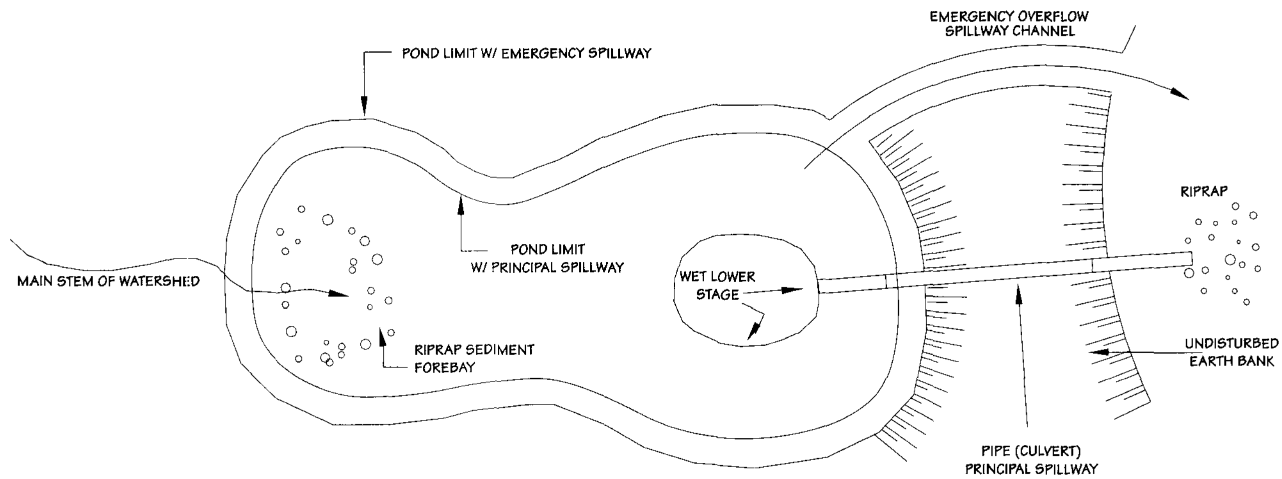


Figure 330-46. Detention pond with principal and emergency spillways.

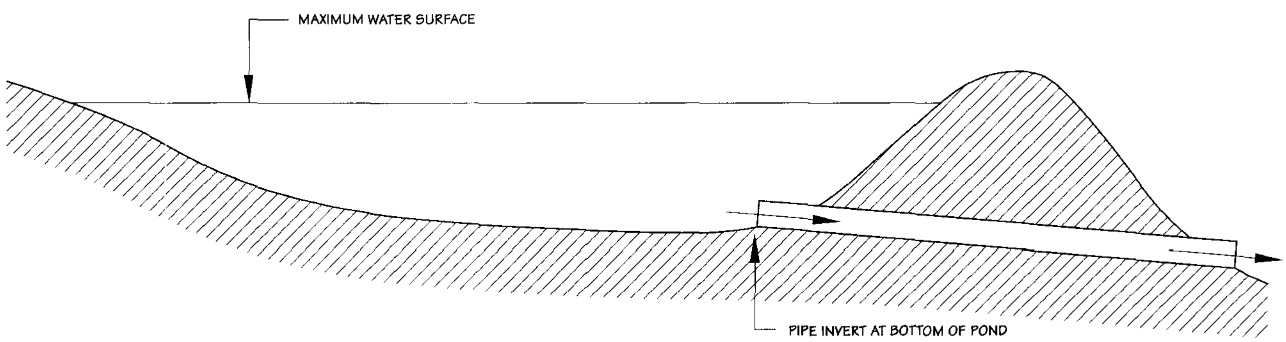


Figure 330-47. Schematic profile of dry detention pond.

8.0 FLOW CONTROL TECHNIQUES

8.1 Off-line Diversions

Water quality control facilities are protected from sediment scour by diverting flows in excess of the WQV around them, putting them "off-line" from large storm flows. The best method for accomplishing this is to set a diversion weir within the facility to be protected that is equal to the design WQV elevation. The overflow weir is sized to pass discharges in excess of the WQV.

Diversion structures can also be installed in the drainage network upstream from the facility to be taken off-line. In piped systems, a control box structure (Figure 330-50) is used. In open channel systems, a check dam can be set diagonally to divert the WQV to the treatment facility and bypass excess flows over the dam. Drainage network diversions may be sized by the following procedure:

1. Compute peak discharge for WQV using the small storm method.
2. Compute the peak discharge for the "bypass" storm using the Rational Formula or SCS TR-55.
3. Size WQV discharge slots, openings or pipe using the weir formula for sizing grate inlets (see subsection 8.3 Drain Inlets).
4. Size overflow weir for "bypass storm" (see subsection 8.2 Weirs).

8.2 Weirs and Level Spreaders

Weir flow is illustrated in Figure 330-51. Flow (Q) in m³/s (ft³/sec) over crested weirs may be computed using the weir flow equation:

$$Q = C_w L H^{1.5}$$

Where:

Q = quantity of discharge in m³/s (ft³/sec)

C_w = weir flow coefficient from Table 330-24

L = the length of the weir in meters (ft)

H = head or height of the water surface above the weir crest measured in meters (feet), short distance upstream from the weir

Level spreaders are used to distribute flows evenly over a wide area to minimize erosion or maximize filtering by vegetated surfaces. Where the weir has a rectangular crest, or the crest is an earthen bank, and is positioned transversely across the direction of flow use the above equation to calculate the flow. Where the weir is positioned parallel to the flow (Figure 330-52) diverting excess flow to the side of the main direction of flow (rectangular crest) use the Engels version of the weir flow formula:

$$Q = 3.32 L^{0.83} H^{1.67}$$

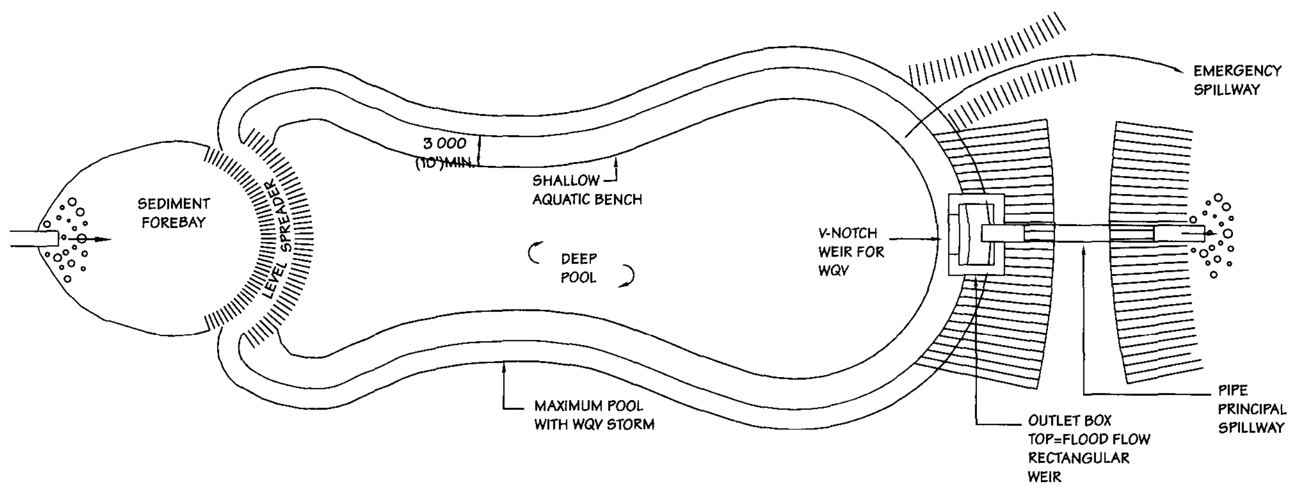


Figure 330-48. Wet detention pond for sediment removal.

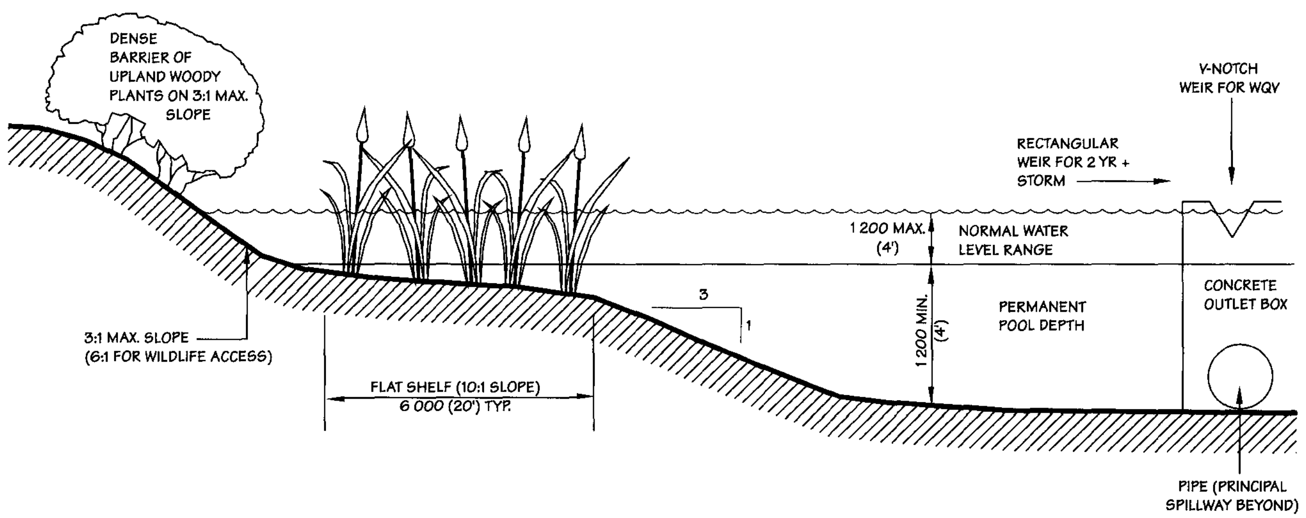


Figure 330-49. Recommended cross section for wet detention pond.

8.3 Drain Inlets

Flow through inlet grates is best determined with computer programs, or using design charts for specific inlet gratings and types.

Grate Inlets at Low Points:

Where the ponding over the grate is 0.4 ft or less, use the following arrangement of the weir formula to calculate the discharge through the inlet in U.S. units:

$$Q = 3PH^{1.5}$$

Where:

Q = quantity of discharge in ft^3/sec

P = perimeter of inlet opening (ignoring bars) in ft.

D = depth of ponding over the inlet in ft.

Where the ponding over the grate is greater than 0.4 ft, use the orifice flow to calculate the discharge through the inlet:

$$Q = 0.6A\sqrt{2gD}$$

Where:

Q = quantity of discharge in ft^3/sec

A = total area of clear opening in ft^2

g = acceleration from gravity, 32.2 ft/sec^2

D = depth of ponding over the inlet in ft.

Curb Inlets:

Where the inlet is a curb opening and 100% of the flow is diverted into the inlet, flow may be computed in U.S. units by:

$$Q = 0.7L\,(A + D)^{1.5}$$

Where:

Q = quantity of discharge in ft^3/sec

L = length of inlet opening in ft.

a = any additional depression of the curb inlet below the gutter in ft.

D= depth of ponding over the gutter bottom in ft.

If the curb inlet also has a gutter grate, ignore the effect of the grate in sizing the

Table 330-20. MINIMUM POND WATER SURFACE AREA AS A PERCENTAGE OF DRAINAGE AREA FOR SEDIMENT PARTICLE CONTROL BY LAND USE TYPE.

Land Use	for 5 micron control	for 20 micron control
Totally paved areas	3.0%	1.1%
Freeways (urban)	2.8%	1.0%
Industrial areas	2.0%	0.8%
Commercial areas	1.7%	0.6%
Institutional areas	1.7%	0.6%
Residential areas	0.8%	0.3%
Open space areas	0.6%	0.2%
Construction sites	1.5%	0.5%

Source: Pitt, Robert E. (April 1997) text for *Stormwater Quality Management Through the Use of Detention Basins – A Short Course on Stormwater Detention Basin Design Basics by Integrating Water Quality with Drainage Objectives*. Minneapolis, Minnesota: University of Minnesota Continuing Education and Extension.

Table 330-21. MINIMUM POND SURFACE AREA REQUIREMENTS IN U.S. UNITS (acres) FOR 5 MICRON PARTICLE SIZE CONTROL FOR STANDARD DEGREE V-NOTCH WEIRS

Notch Angle	22.5°			30°			45°		
Head (ft)	Flow (cfs)	Req'd. storage (ac-ft)	Req'd. area (acres)	Flow (cfs)	Req'd. storage (ac-ft)	Req'd. area (acres)	Flow (cfs)	Req'd. storage (ac-ft)	Req'd. area (acres)
0.5	0.1	<0.01	0.01	0.1	<0.01	0.02	0.2	<0.01	0.03
1.0	0.5	0.03	0.1	0.7	0.05	0.1	1.0	0.05	0.2
1.5	1.4	0.1	0.2	1.9	0.2	0.3	2.9	0.2	0.5
2.0	2.8	0.3	0.5	3.8	0.3	0.7	5.9	0.6	1.0
3.0	7.8	1.2	1.4	11	1.6	1.8	16	1.6	2.8
4.0	16	3.3	2.8	22	4.4	3.8	33	5.9	5.8
Notch Angle	**60°**			**90°**			**120°**		
Head (ft)	**Flow (cfs)**	**Req'd. storage (ac-ft)**	**Req'd. area (acres)**	**Flow (cfs)**	**Req'd. storage (ac-ft)**	**Req'd. area (acres)**	**Flow (cfs)**	**Req'd. storage (ac-ft)**	**Req'd. area (acres)**
0.5	0.3	<0.01	0.05	0.4	0.02	0.08	0.8	0.04	0.1
1.0	1.4	0.07	0.3	2.5	0.2	0.4	4.4	0.3	0.8
1.5	4.0	0.3	0.7	6.9	0.6	1.2	12	1.7	2.1
2.0	8.2	0.8	1.4	14	1.5	2.5	25	3.3	4.4
3.0	28	3.5	3.9	39	6.2	6.8	69	12	12
4.0	46	9.5	8.1	80	17.0	14	140	30	25

Table constructed for removal of 5 micron particles (settling rate of 0.004 cm/sec)
For removal of 20 micron particles (settling rate of 0.06 cm/sec) multiply table values by 0.067

Source: Pitt, Robert E. (April 1997) text for *Stormwater Quality Management Through the Use of Detention Basins – A Short Course on Stormwater Detention Basin Design Basics by Integrating Water Quality with Drainage Objectives*. Minneapolis, Minnesota: University of Minnesota Continuing Education and Extension.

Table 330-22. MINIMUM POND SURFACE AREA REQUIREMENTS IN U.S. UNITS (acres) FOR 5 MICRON PARTICLE SIZE CONTROL FOR STANDARD RECTANGULAR WEIR WIDTHS

Weir Width	2.0 ft.			5.0 ft.			10.0 ft.		
Head (ft)	Flow (cfs)	Req'd. storage (ac-ft)	Req'd. area (acres)	Flow (cfs)	Req'd. storage (ac-ft)	Req'd. area (acres)	Flow (cfs)	Req'd. storage (ac-ft)	Req'd. area (acres)
0.5	2.1	0.1	0.4	5.7	0.3	1.0	12	0.5	2.0
1.0	6	0.5	1.1	16	1.2	2.8	33	2.4	5.7
1.5	10	1.2	1.8	29	3.2	5.0	59	6.3	10
2.0	15	2.3	2.6	43	6.4	7.6	90	13	16
3.0	24.	5.7	4.2	80	17	14	160	35	29
4.0	32	11.0	5.6	110	34	20	250	71	43
Weir Width	15 ft.			20 ft.			30 ft.		
Head (ft)	Flow (cfs)	Req'd. storage (ac-ft)	Req'd. area (acres)	Flow (cfs)	Req'd. storage (ac-ft)	Req'd. area (acres)	Flow (cfs)	Req'd. storage (ac-ft)	Req'd. area (acres)
0.5	17	0.8	3.0	23	1.0	4.1	35	1.5	6.1
1.0	49	3.7	8.6	66	5.1	12	99	7.3	17
1.5	90	9.9	16	120	13	21	180	20	32
2.0	140	20	24	190	27	32	280	40	49
3.0	250	54	44	340	72	59	510	110	89
4.0	380	110	66	510	150	89	780	220	140

Table constructed for removal of 5 micron particles (settling rate of 0.004 cm/sec)
For removal of 20 micron particles (settling rate of 0.06 cm/sec) multiply table values by 0.067

Source: Pitt, Robert E. (April 1997) text for *Stormwater Quality Management Through the Use of Detention Basins – A Short Course on Stormwater Detention Basin Design Basics by Integrating Water Quality with Drainage Objectives*. Minneapolis, Minnesota: University of Minnesota Continuing Education and Extension.

Table 330-23. MINIMUM POND SURFACE AREA REQUIREMENTS IN U.S. UNITS (acres) FOR 5 MICRON PARTICLE SIZE CONTROL FOR STANDARD DIAMETER DROP-TUBE STRUCTURES.

Pipe Dia.	8 inch			12 inch			18 inch		
Head (ft)	Flow (cfs)	Req'd. storage (ac-ft)	Req'd. area (acres)	Flow (cfs)	Req'd. storage (ac-ft)	Req'd. area (acres)	Flow (cfs)	Req'd. storage (ac-ft)	Req'd. area (acres)
0.5	0.5	0.02	0.9	0.9	0.04	0.2	1.6	0.07	0.3
1.0	0.7	0.07	0.1	2.2	0.2	0.4	4.4	0.3	0.8
1.5	0.7	0.1	0.1	2.2	0.4	0.4	6.5	0.8	1.1
2.0	0.7	0.2	0.1	2.2	0.6	0.4	6.5	1.4	1.1
3.0	0.7	0.3	0.1	2.2	0.9	0.4	6.5	2.5	1.1
4.0	0.7	0.4	0.1	2.2	1.3	0.4	6.5	3.6	1.1
Pipe Dia.	24 inch			30 inch			36 inch		
Head (ft)	Flow (cfs)	Req'd. storage (ac-ft)	Req'd. area (acres)	Flow (cfs)	Req'd. 2.1storage (ac-ft)	Req'd. area (acres)	Flow (cfs)	Req'd. storage (ac-ft)	Req'd. area (acres)
0.5	1.6	0.07	0.3	1.9	0.08	0.3	2.0	0.09	0.4
1.0	5.6	0.4	1.0	6.3	0.4	1.1	7.2	0.5	1.3
1.5	11	1.1	1.8	13	1.3	2.3	16	1.5	2.8
2.0	14	2.1	2.4	21	2.8	3.7	27	3.4	4.7
3.0	14	4.5	2.4	25	6.9	4.4	42	9.4	7.3
4.0	14	6.9	2.4	25	11	4.4	42	17	7.3

Table constructed for removal of 5 micron particles (settling rate of 0.004 cm/sec)
For removal of 20 micron particles (settling rate of 0.06 cm/sec) multiply table values by 0.067

Source: Pitt, Robert E. (April 1997) text for *Stormwater Quality Management Through the Use of Detention Basins – A Short Course on Stormwater Detention Basin Design Basics by Integrating Water Quality with Drainage Objectives*. Minneapolis, Minnesota: University of Minnesota Continuing Education and Extension.

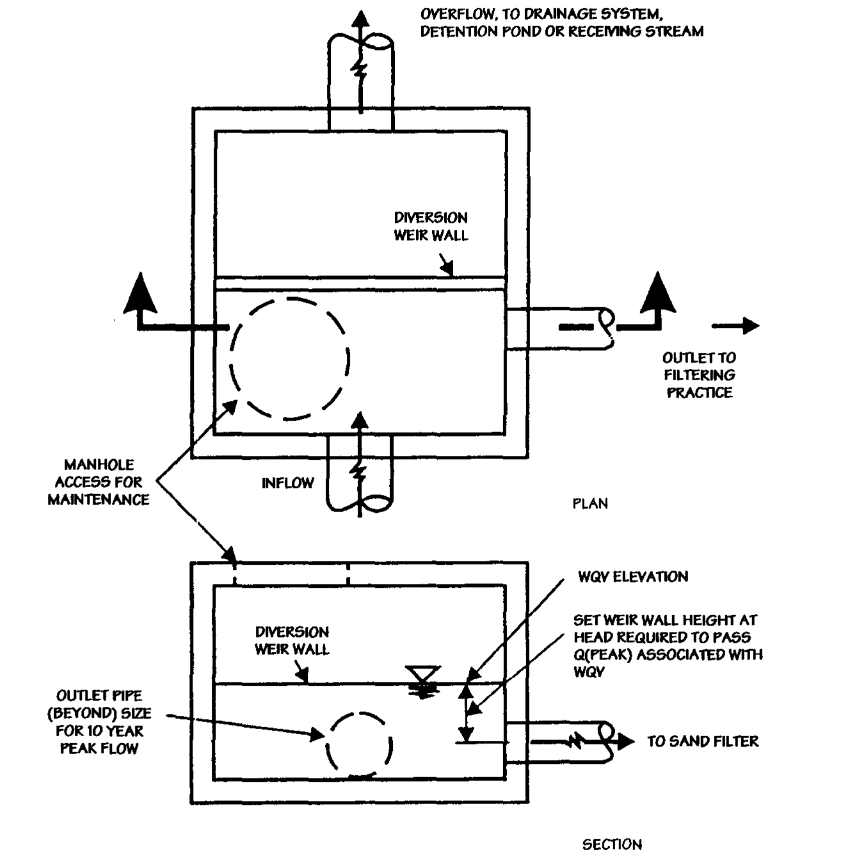


Figure 330-50. Off-Line control structure with diversion.

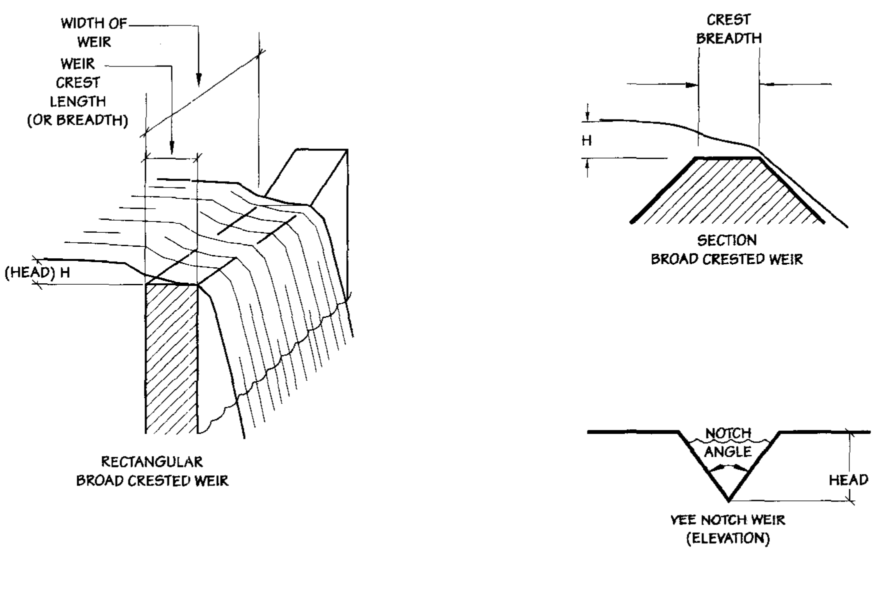


Figure 330-51. Weir flow types and elements

curb inlet to allow for clogging of grate by debris.

9.0 FILTRATION TECHNIQUES

9.1 Filter Strips

Filter strips treat water accepted as sheet flow from surfaces through combined filtering and ponding (Figure 330-53). The ponding portion is designed to hold the WQV. Filter strip length must be equal to the edge of the surface sheeting runoff to it. Drainage area is limited by overland sheet flow limits of 25 meters (75 ft) for pavements and 45 meters (150 ft) for pervious surfaces. Table 330-25 gives sizing criteria. Storms exceeding WQV are bypassed through berm overflow spillways.

9.2 Sand Filters

Sand filters are surface or underground facilities used to clean runoff water in urbanized areas where space is limited (see Figure 330-54). They generally consist of three chambers. The first chamber is an off-line diversion structure to limit sand treatment to the WQV. The second is a pretreatment chamber to capture sediment and floatable trash. The third chamber is the sand filter bed. The sand filter bed has an 450-600mm (18-24 in) sand layer that traps and strains pollutants from stormwater before it is collected by an underdrain system. Pure sand or a mix of peat and sand may be used for filter media.

The volume of the sand filter chambers should be at least 0.75WQV. This volume should be split between the pretreatment chamber, the volume above the sand bed and the volume of voids in the sand bed. The pretreatment and sand bed chambers should have length to width ratios of 2:1 or greater. The overflow weir in the pretreatment

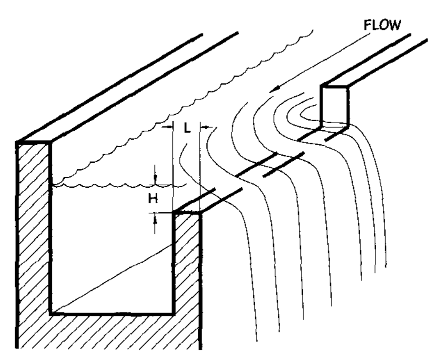


Figure 330-52.Side diversion weir.

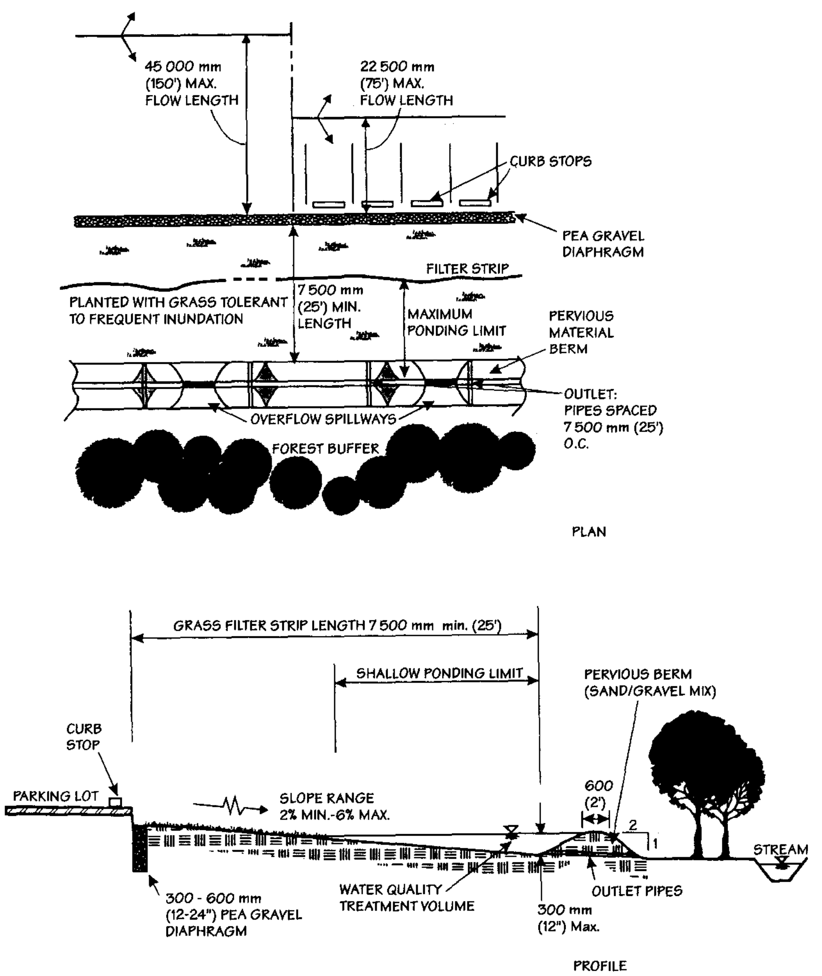


Figure 330-53. Filter Strip.

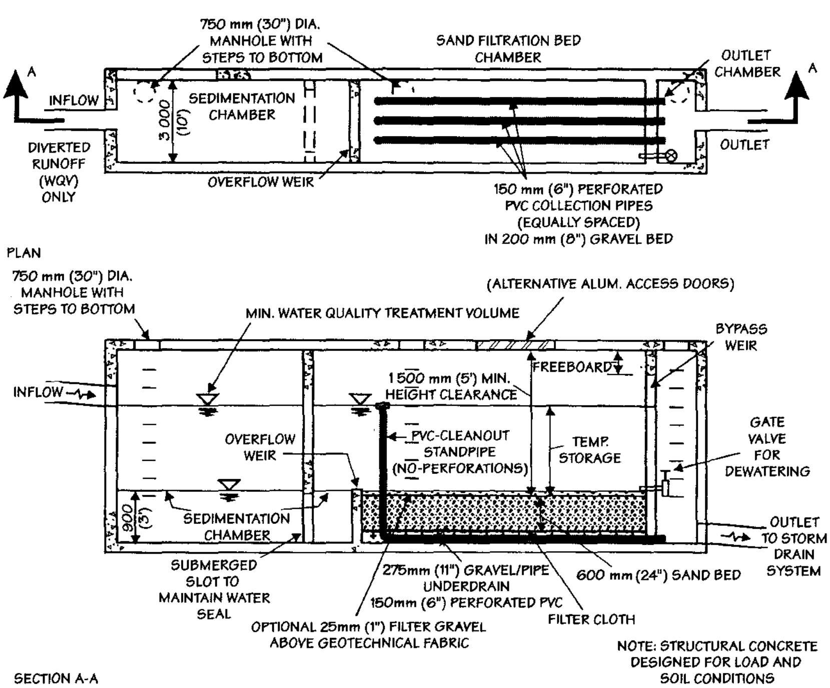


Figure 330-54. Subsurface Sand Filter.

chamber should be sized for 0.67 WQV peak discharge. The overflow weir in the sand chamber should be sized for 0.33 WQV peak discharge. The area of the sand filter bed is found by the formula:

$$A_f = WQV \left[\frac{d_f}{(t_f)(k)(h_f + d_f)} \right]$$

Where:

A_f = surface area of sand bed in square meters (ft^2)

d_f = sand filter bed depth in meters (ft)

k = coefficient of permeability in meters/day (ft/day)

t_f = time for WQV to filter through sand bed (use 40 hrs.)

h_f = average height of water above sand in meters (ft) hf = $0.5h_{max}$.

Use k = 1.05 (3.5) for sand and k = 0.825 (2.75) for 50-50 mixture of peat and sand (pure peat floats). Sand bed is typically 0.45 m (1.5 ft) deep, but should not exceed 0.6 m (2.0 ft) Sand should be medium aggregate concrete sand. Peat should be loose, clean, shredded Reed Sedge Hemic type.

10.0 INFILTRATION TECHNIQUES

10.1 General

Infiltration techniques counter the addition of impervious surfaces brought by urbanization. They are practical where soil textures permit reasonably rapid infiltration rates. Soils with saturated infiltration rates less than 6.9 mm/hour (0.27 in/hour) are not recommended for infiltration techniques. Table 330-26 shows infiltration rates for saturated soils.

Siting Considerations:

The bottom of infiltration basins must be at least 600 to 1 200 mm (2 to 4 ft) above the high water table and at least 900 mm (3 ft) above bedrock to prevent pollution of groundwater . The edge of infiltration basins and beds should be at least 30 meters (100 ft) from wells, and 3 meters (10 ft) from buildings. The bottom of the infiltration rock bed should be set below the frost line.

Table 330-27 shows selection criteria for infiltration facilities, including drainage area and land use. Runoff from potentially contaminated sources (e.g. combined sewer overflows, snowmelt from roads and parking lots, manufacturing or construction

Table 330-24. VALUES OF WEIR FLOW COEFFICIENT C_w

Head, H, in meters (ft)	Breadths of crest of weir in meters (ft) 0.15 (0.50)	0.20 (0.75)	0.30 (1.00)	0.45 (1.50)	0.60 (2.00)	0.75 (2.50)	0.90 (3.00)	1.20 (4.00)	1.50 (5.00)	3.00 (10.00)	4.50 (15.00)
.06 (0.2)	2.80	2.75	2.69	2.62	2.54	2.48	2.44	2.38	2.34	2.49	2.68
.12 (0.4)	2.92	2.80	2.72	2.64	2.61	2.60	2.58	2.54	2.50	2.56	2.70
.18 (0.6)	3.08	2.89	2.75	2.64	2.60	2.60	2.68	2.69	2.70	2.70	2.70
.24 (0.8)	3.32	3.04	2.85	2.68	2.66	2.60	2.67	2.68	2.68	2.69	2.64
.30 (1.0)	3.32	3.14	2.98	2.75	2.70	2.64	2.65	2.67	2.68	2.68	2.63
.36 (1.2)	3.32	3.20	3.08	2.86	2.77	2.65	2.64	2.67	2.66	2.69	2.64
.42 (1.4)	3.32	3.26	3.20	2.92	2.89	2.68	2.64	2.65	2.65	2.67	2.64
.48 (1.6)	3.32	3.29	3.28	3.07	2.88	2.75	2.68	2.66	2.65	2.64	2.63
.54 (1.8)	3.32	3.32	3.31	3.07	2.85	2.74	2.68	2.66	2.65	2.64	2.63
.60 (2.0)	3.32	3.31	3.30	3.03	3.07	2.76	2.72	2.68	2.65	2.64	2.63
.75 (2.5)	3.32	3.32	3.31	3.28	3.20	2.89	2.81	2.72	2.67	2.64	2.63
.90 (3.0)	3.32	3.32	3.32	3.32	3.32	3.05	2.92	2.73	2.66	2.64	2.63
1.05 (3.5)	3.32	3.32	3.32	3.32	3.32	3.19	2.97	2.76	2.68	2.64	2.63

sites) should not be allowed to enter infiltration facilities:

Infiltration facilities must be located off-line. Pre-treatment devices, such as sediment forebays, should intercept runoff before it is directed into the infiltration structure. Sedimentation is the chief cause of infiltration facility failure.

Design Considerations:

Preliminary design calculations may be based on the soil infiltration rates shown in Table 330-26. Final design of infiltration facilities should be based on field infiltration tests conducted at the elevation of the proposed bottom of the infiltration basin or bed.

Infiltration facilities should be designed to infiltrate the WQV for the drainage basin they serve. Depth is the critical factor controlling the configuration of volume. The depth of infiltration facilities is limited by the need to empty it within an allowable maximum ponding time, typically 48 to 72 hours.

Protection During Construction:

The soil areas used for infiltration must be protected during construction to prevent compaction. Hold final excavation of the last 600 mm (2 ft) needed to reach the bottom of the infiltration basin or bed until

Table 330-25. FILTER STRIP DESIGN CRITERIA.

Parameter	Criteria
Size	Length, depth, width needed to provide surface storage for WQV
Width	Equal to area draining to filter
Length	8 m (25 ft), minimum
Slope	2.0% minimum, 6.0% maximum
Drainage area, pervious surfaces	Maximum overland flow length = 45 m (150 ft)
Drainage area, impervious surfaces	Maximum overland flow length = 25 m (75 ft)

Table 330-26. APPROXIMATE SATURATED INFILTRATION RATES FOR DIFFERENT SOIL TEXTURE CLASSE

Soil texture class	SCS Hydrologic soil group	Approximate saturated soil infiltration rates (in/hr)	(min/in)	(cm/hr)	(min/cm)
Sand	A	8.27	7.25	21.01	2.9
Loamy Sand	A	2.41	24.9	6.12	9.8
Sandy Loam	A	1.02	58.8	2.59	23.2
Loam	B	0.52	115.4	1.32	45.5
Silt Loam	B	0.27	222.2	0.69	87.0
Sandy Clay Loam	C	0.17	352.9	0.43	139.5
Clay Loam	D	0.09	666.7	0.23	260.9
Silty Clay Loam	D	0.06	1000.0	0.15	400.0
Sandy Clay	D	0.05	1200.0	0.13	461.5
Silty Clay	D	0.04	1500.0	0.10	600.0
Clay	D	0.02	3000.0	0.05	1200.0

Table 330-27. INFILTRATION TECHNIQUE SELECTION CRITERIA.

Technique	Soil Type and Minimum Infiltration Rate, cm/hr (inches/hour)						
	Sand 21.01 (8.27)	Loamy Sand 6.12 (2.41)	Sandy Loam 2.59 (1.02)	Loam 1.32 (0.52)	Silt Loam 0.69 (0.27)	Sandy Clay Loam 0.43 (0.17)	Clays <0.43 (<0.17)
Grassed Swales with Check Dams	•	•	•	•	•	•	
Filter Strips	•	•	•	•	•	•	
Infiltration Basins	•	•	•	•			
Recharge Trenches	•	•	•	•			
Bioretention Ponds	•	•	•	•			
Infiltration Beds	•	•	•	•			
Infiltration Wells	•	•	•	•			
Porous Pavements	•	•	•	•			
	Drainage Area Served, hectares (acres)						
	0-2 (0-5)	**2-4 (5-10)**	**4-6 (10-15)**	**6-8 (15-20)**	**8-10 (20-25)**	**10-12 (25-30)**	**12-20 (30-50)**
Grassed Swales with Check Dams	•	•	•	•	•	•	
Filter Strips	•						
Infiltration Basins		•	•	•	•	•	•
Recharge Trenches	•	•					
Bioretention Ponds	•	•					
Infiltration Beds	•	•					
Infiltration Wells	•						
Porous Pavements	•						
	Other Restrictions						
	Ground-water Table Depth, m (ft)	**Slope in Percent**	**Min. Distance to Well, m (ft)**	**Min. Distance to Building, m (ft)**	**Buffer Requirements, m (ft)**	**Site Constraint**	**Normal Depth Range, m (ft)**
Grassed Swales with Check Dams	0.6-1.2 (2-4)	<20					
Filter Strips	0.6-1.2 (2-4)	<20					
Infiltration Basins	0.6-1.2 (2-4)	<20	>30 (>100)	>3 (>10)	>6 (>20)		0.6-1.5 (2-5)
Recharge Trenches	0.6-1.2 (2-4)	<20	>30 (>100)	>3 (>10)	>6 (>20)		0.6-1.5 (2-5)
Bioretention Ponds	1.8-2.4 (6-8)	<20	>30 (>100)	>3 (>10)	>6 (>20)		0.6-1.5 (2-5)
Infiltration Beds	1.2-1.8 (4-6)		>30 (>100)	>3 (>10)	>6 (>20)		
Infiltration Wells	0.6-1.2 (2-4)	<20	>30 (>100)	>3 (>10)	>6 (>20)	Residential Roof top	0.6-1.5 (2-5)
Porous Pavements	0.6-1.2 (2-4)		>30 (>100)	>3 (>10)	>6 (>20)		

after all other site surfaces have been finished and erosion control measures are established. This prevents the soil structure from being plugged with construction sediment.

10.2 Infiltration Basins:

Infiltration basins are ponds designed to "leak" into the underlying soil. These facilities have a high failure rate and short life if not protected by an upstream sedimentation basin. Depth is limited by subsurface conditions and the infiltration capacity of the soil. Maximum depth based on soil infiltration is computed by the formula:

$$D_{max} = (F)(T_p)$$

Where:

D_{max} = maximum allowable depth based on infiltration

F = infiltration rate of the soil in hours

T_p = maximum allowable ponding time in hours (typically 72 hours).

D_{max} may be further reduced to account for any limitations from bedrock or water table to arrive at an allowable design depth (D). Pond area is found by trial and error, holding the design depth constant and

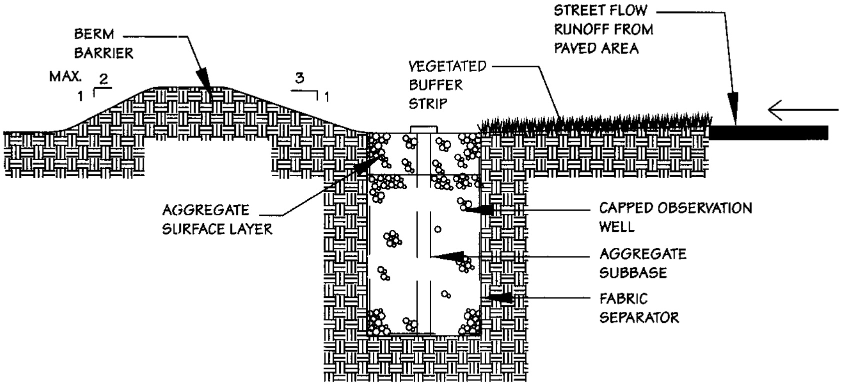


Figure 330-55. Recharge trench.

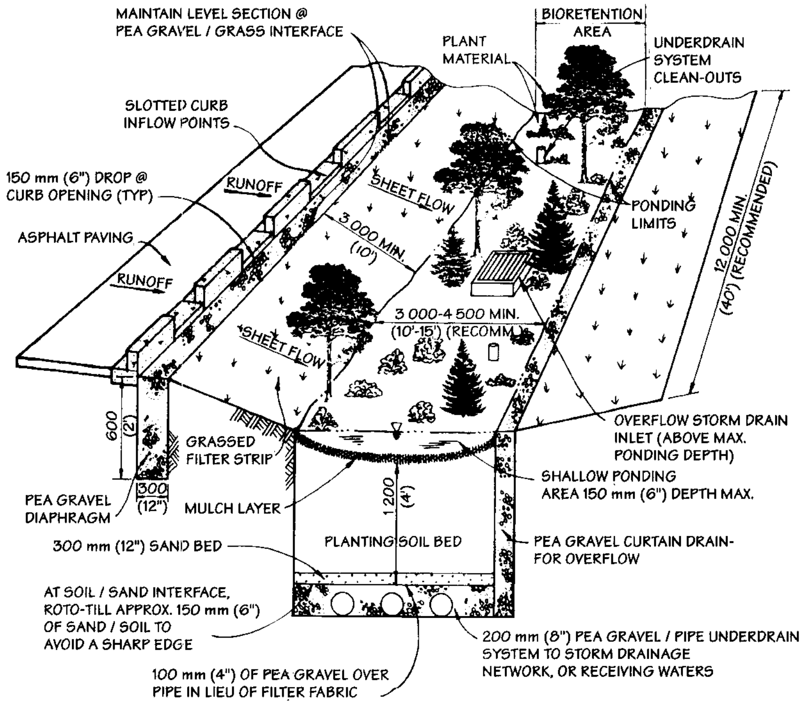


Figure 330-56. Bioretention pond.

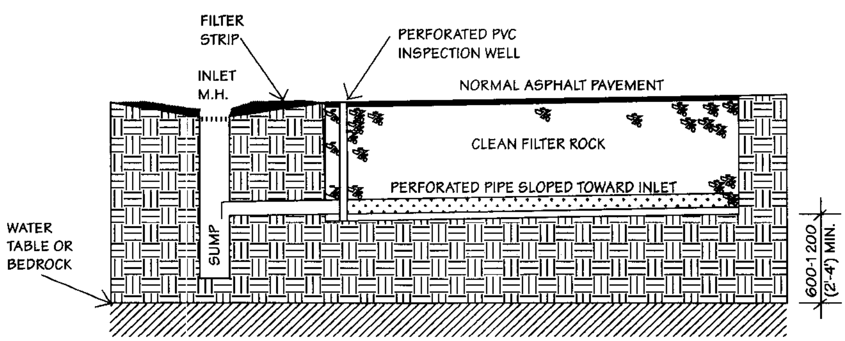


Figure 330-57: Infiltration Bed

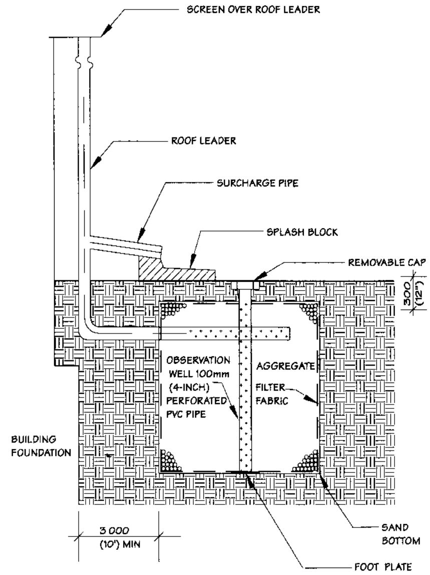


Figure 330-58: Infiltration Well

varying pond configuration and area until pond volume equals WQV.

The pond bottom should be essentially flat, with no pilot channel. Flow into the pond should be distributed with a level spreader or fanned by rip-rap to flow evenly across the pond bottom.

10.3 Recharge Trenches

A recharge trench is a modern French Drain (Figure 330-55). These facilities are generally placed off-line and protected by a filter strip located upstream.

Design is approached similarly to detention basins by determining the maximum allowable depth of the infiltration rock portion of the trench cross-section. Maximum depth based on soil infiltration is computed by a modification of the above formula:

$$D_{max} = (F)\left(\frac{T_p}{V_r}\right)$$

Where V_r is the void ratio of the infiltration rock. An infiltration rock void ratio of 0.40 is typically specified. D_{max} is further reduced as needed to arrive at an allowable design depth (D). A trench width (W) is assumed to meet site needs and an effective cross-sectional void area (A_v) is computed by the formula:

$$A_v = DWV_r$$

Trench length is then found by dividing WQV by A_v.

The infiltration rock should be completely wrapped with filter fabric to prevent sediment plugging. The top gravel layer is replaced as needed to restore inlet capacity.

10.4 Bioretention Ponds

The concept of bioretention was developed by the Prince George's County, Maryland, Department of Environmental Resources for use in commercial parking lots, roadsides and setback areas. It combines physical filtering of runoff with biological processing of runoff pollutants. It is similar to an infiltration pond but with a deep layer of planting soil mix at the bottom (Figure 330-56). Bioretention works best with small drainage areas.

Bioretention ponds should be located off-line with overflow provided to remove runoff amounts in excess of the WQV. Pretreatment of off-line flow to the pond should consist of a vegetated swale at least 6 meters (20 ft) long. The bioretention surface area (A_f) should be:

$$A_f = 0.05 A_d R_v$$

Where:

A_f = surface area of bioretention facility, m^2 (ft^2)

A_d = drainage area, m^2 (ft^2)

R_v = volumetric runoff coefficient, small storm hydrology method

Check the volume capacity against that required to treat the WQV, by the formula:

$$A_f = WQV \left[\frac{d_f}{(t_f)(k)(h_f + d_f)} \right]$$

Where:

A_f = surface area of bioretention facility, m^2 (ft^2)

d_f = planting soil depth [1.2 m (4.0 ft.)] + sand layer [0.3 m (1.0 ft)]

k = 0.15 m/day (0.5 ft./day) (silt loam soil)

t_f = 3 days (time to empty)

h_f = 0.1 m (0.25 ft) [h_{max} = 0.15 m (0.5 ft)]

The infiltration area is planted with species simulating a terrestrial forest community and mulched. Planting should be dominated by canopy trees, but should also include understory tree, shrub, and herbaceous ground cover layers.

10.5 Infiltration Beds

Infiltration beds are an underground version of the recharge trench (Figure 330-57). These facilities are generally placed off-line and protected by a forebay and diversion located upstream.

Design is the same as for infiltration recharge trenches (refer to subsection 10.3), except that additional void area is introduced into the cross-section area by the perforated pipe used to pour water into the infiltration rock area. This additional void space is incorporated by the formula:

$$A_v = (DW - A_p)\, V_r + A_p$$

Where A_p is the cross section area of the perforated pipe. Very large perforated pipe sections may be used to provide a more space efficient bed cross-section as soil depths allow.

Both the infiltration rock and perforated pipe should be completely wrapped with filter fabric to prevent sediment plugging. The pipe should be placed sloping toward the inlet manhole to concentrate any sediment where it can easily be removed.

10.6 Infiltration Wells

Infiltration wells are used to infiltrate runoff from roof downspouts and other very small drainage areas with fairly clean runoff (Figure 330-58). Design is essentially the same as for a recharge trench or bed. A critical design feature is an above ground overflow outlet to prevent water from backing up downspouts or damaging the infiltration well itself.

10.7 Porous Asphalt Pavement

Porous asphalt pavement is basically a recharge trench with a porous bituminous top layer used instead of gravel. The porous pavement is a lean asphalt mix over a sand layer. A design guide and specifications for porous pavement can be obtained from the Asphalt Institute (refer to Section 440: Surfacing and Paving, and Section 820: Asphalt for further information). Design is the same as for a recharge trench.

Porous pavement is best used where it accepts runoff only from porous surfaces (grasses, etc.) It should not be used for parking areas because contaminants from autos move directly into the recharge trench. In areas with ice and snow, porous pavement should not be used where it is subject to tracking of de-icing salts onto the pavement surface.

To keep asphalt pores open, porous pavement must be frequently vacuumed. Areas with porous pavement should be well signed to warn against hazards to function. Hazards include lawn chemicals in spills and runoff, and use of normal asphalt for repairs or replacement.

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Pedestrian Circulation

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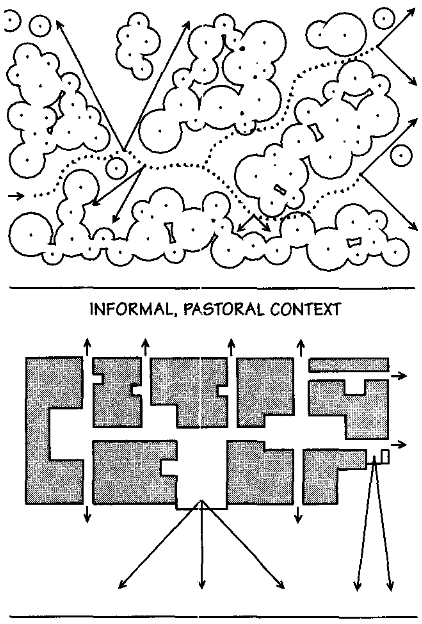


Figure 340-1. Spatial modulation. *Modulation of space can occur both vertically and horizontally in an informal, pastoral context or an urban context.*

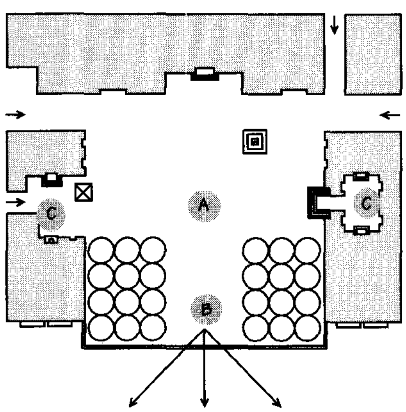


Figure 340-2. Hierarchical ordering of outdoor space. *Note the relationships between (a) primary, (b) secondary, and (c) tertiary spaces.*

1.0 INTRODUCTION

Pedestrian circulation is not easily discussed in specific terms because of the large differences in purpose between various types of systems. Most urban pedestrian circulation systems are typically perceived and utilized as a functional device more than as media for aesthetic experiences, a characteristic representative of park systems and other recreational open spaces. Moreover, because pedestrian circulation is an integral part of any particular design scheme, it is difficult to discuss the subject removed from the context in which it plays a role.

Consequently, this section is limited to a "general" discussion of various aspects of pedestrian circulation. Specific situations may require research beyond the scope of this section and decisions based on professional judgment.

1.1 General

Pedestrian circulation systems fall into two broad categories: (1) those where the basic structure of a system already exists and (2) those where no circulation currently exists.

With existing systems, projects typically involve aesthetic enhancement of the system by provision of various amenities, improved views, conveniences, and imageability. This type of work involves improvement of the "pedestrian experience" as much as it involves improvement of the functional aspects of the system.

In the case of new systems, circulation must first be laid out according to proposed origin and destination points and must have adequate width to accommodate expected loads of pedestrian traffic during peak periods of use. Part of this process includes studying aesthetic aspects which will be carefully integrated with the functional aspects of the proposed system.

Additional information on various aspects of pedestrian circulation can be found in other sections of this handbook, including 210: Spatial Standards; 240: Outdoor Accessibility; 510: Site Furniture and Features; and 540: Outdoor Lighting.

1.2 The Pedestrian Experience

Convenience:

The functional aspect of a pedestrian system is of primary importance, and the quality of this functional aspect is measured in terms of the "convenience" offered by the system. In addition to the obvious requirement of connecting all origin and destination points with walkways of adequate width, the two factors of orientation and negotiation play an important role.

In terms of orientation, landmark features and visual cues can suggest purpose and expected behavior to the pedestrians using the system. These may include walkway width (e.g., wider walkways suggesting greater importance), formality (e.g., curvi-linear walkways suggesting a more relaxing experience), paving material (e.g., expensive or highly articulated materials suggesting greater importance), and the presence and quality of ancillary features (the nature of which may suggest the predominant purpose of the walkway).

Carefully designed visual cues (including signage) can aid the pedestrian in wayfinding and in general orientation within a larger environmental context. This is especially important in complex environments.

Negotiation refers to the relative ease of moving from one destination to another. Pedestrian density, including conflicts at intersections and potential gathering spots, plays an important role in this regard. But other aspects also contribute to difficulty of negotiation. These include physical obstructions (e.g., trash receptacles, light fixtures, flag poles, parking meters, water hydrants, telephones, benches, etc.); the presence of water or ice on the walkway; the nuisance of excessive litter; seed and fruit droppings from overhanging vegetation; and excessive wind problems.

Pathways should be accessible to all types of pedestrians, and sometimes on a selective basis, to emergency vehicles such as police cars, ambulances, and firefighting equipment.

Amenities:

The purpose of any pedestrian circulation system is the connection it offers between various natural or cultural amenities, including the attraction of human activity. Social interaction, both passive and active, is extremely important and in many cases is the primary determinant regarding enjoyment of a place.

Because the activity of watching other people is appealing to many, spaces to gather with ample opportunities to sit are crucial to the success of most places, especially those in urban contexts.

It has been observed that the availability of food and the activity of eating is a strong stimulus which attracts significant numbers of people to a place. For this reason, ven-

Table 340-1. COMMON SENSORY STIMULI IN PEDESTRIAN ENVIRONMENTS

Sensory category	Examples of common stimuli
Tactile	Temperature
	Humidity
	Wind and breezes
	Precipitation
	Benches and seatwalls
	Sittable ground surfaces
	Bars, knobs, and handles
	Handrailings and armrests
	Telephones, vending and banking machines
	Textures under foot
	Vegetation within reach
	Water
	Architectural facades
	Food and drink
	Human contact
Auditory	Normal traffic noise
	Excessive truck traffic
	Underground rumblings
	Air traffic
	Distant highway noise
	Echo
	Conversation
	Play activity
	Music and song
	Professional and amateur entertainment
	Wind
	Water
	Wildlife
	Bells, chimes, and whistles
	Wind-blown flags and fabrics
	Movable furniture
	Vendors
	Machinery
	Heating, ventilation, and cooling systems
	Foot traffic on various pavements
Visual	Spatial perception (form, scale, etc.)
	Form of objects
	Proportion and scale of objects
	Social activity
	Vehicular activity
	Prominent landforms
	Vegetation
	Water features
	Miscellaneous natural features
	Sun and shadow
	Rain, snow, fog, mist
	Smoke
	Litter
	Signage
	Storefront advertisements
	Window displays
	Posted bills
	Billboards
	Walls and fences
	Street furniture and features
	Overhead wires and cables
	Architecture
	Vegetation
	Wildlife
	Overall character of a place
	Sites under construction
	Surface textures
	Color compositions
	Tonal contrasts
	Diurnal change
	Seasonal change
	Moonlight
	Night-lighting
	Glare and albedo
	Viewsheds from important vantage points
	General order
	Overall congruencies
Olfactory	Vehicular emissions
	Odorous smoke
	Fresh air
	Fragrant vegetation
	Restaurant doorways
	Outdoor cafes
	Odorous litter and debris
	Refuse areas
	Exhaust fans

dors are often encouraged to operate in pedestrian environments.

Spatial Considerations:

The most comfortable human environments are those characterized by a relatively strong degree of spatial enclosure. It is important to remain cognizant not only of weak spatial structures in outdoor environments but also of the differences between transitional space and nodal space.

Because movement through an environment is a visual-spatial sequential (kinesthetic) experience, the "modulation" of transitional space and the "hierarchical ordering" of nodal space are important design principals.

Figures 340-1 and 340-2 illustrate these two principles in general terms.

Sensory Stimuli and Related Considerations:

Aesthetic aspects of pedestrian circulation refer to the myriad of sensory and intellectual "experiences" enjoyed by pedestrians when moving through various environments. Designers should remain aware of the many environmental factors that contribute to the enjoyment of outdoor places, providing a richness of experience and a depth of meaning to all who may enjoy participation in designed or managed environments.

Table 340-1 is a checklist of various sensory stimuli, some of which are related to pleasant experiences and others which are unpleasant, and therefore, are normally avoided or mitigated. Obviously, a checklist of this sort cannot be comprehensive, but it does provide a starting point for sensory assessment of existing or proposed pedestrian environments.

2.0 PHYSICAL CHARACTERISTICS OF THE PEDESTRIAN

Basic information on the pedestrian is useful in instances where spatial standards do not exist or where existing spatial standards are inapplicable. Reference can be made to physical characteristics of the human figure itself in order to make rational decisions about required spatial dimensions and other details of a proposed pedestrian environment.

2.1 Dimensional Criteria

Human Dimensions and Activity:

Figure 340-3 illustrates approximate dimensions of human figures in various activity positions (see Section 210: Spatial Standards, for more data). Spatial requirements differ in various regions and between different cultures as a function of accustomed densities of people, heritage, and social and environmental values.

Forward Spatial Bubbles:

Forward spatial bubbles, as illustrated in Figure 340-4, refer to the extent of unobstructed forward vision held to be psychologically comfortable for the average pedestrian under various circumstances. As mentioned previously, the spatial requirements for psychological comfort will differ across regions and cultures.

This information is useful when calculating the amount of clear space necessary to accommodate expected numbers of people when the intent is to maintain a reasonable degree of psychological comfort.

Use of a mathematical formula to determine minimum walkway widths requires that a decision be made on an acceptable spatial bubble for each walkway being considered. Refer to 3.1 in this section for use of this formula.

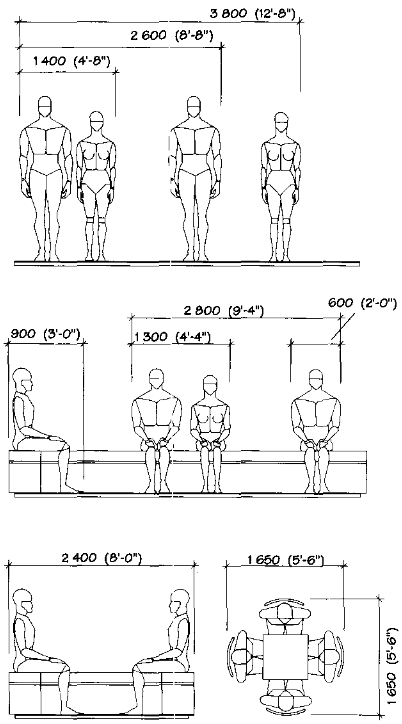


Figure 340-3. Human dimensions in various activity positions. *These dimensions are approximate average spatial requirements which are used primarily as an aid to professional judgment, rather than as standard criteria.*

2.2 Movement Criteria

Walking Rates:

Table 340-2 shows average walking rates of adult pedestrians. The average walking rate of a pedestrian will decrease as pedestrian density on a walkway increases and/or the clear space ahead of the pedestrian becomes less than approximately 4 500 mm (15 ft). Pedestrian walking rates are not significantly affected by grade changes of 6 percent or less, but intersections, stairways, escalators, and turnstiles will slow down movement.

Refer to 3.1 in this section for information on calculating minimum walkway widths based on pedestrian walking rates.

Acceptable Walking Distances:

Figure 340-5 illustrates the average range of walking distances that people (in the United States) are typically willing to walk. Acceptable distances will vary from these averages depending on the purpose of the trip, cultural differences, climactic conditions, etc., but these averages give a rough idea of the kind of behavior to expect from pedestrians in parking lots, or on trips within their communities.

Pedestrian Density Criteria:

Figures 340-6 and 340-7 show pedestrian flow volume, speed, and density for walkways and stairways. This information can be used as a visual guide for estimating existing or proposed pedestrian traffic volumes and speed, and for determining minimum walkway widths by use of the mathematical formula given in 3.1 of this section.

2.3 Visual Criteria

Eye Levels and Cone of Vision:

The eye level of an average adult in a standing position and a sitting position is illustrated in Figure 340-8. Pedestrians will focus most of their attention at eye level and below during normal perception of their surroundings.

The human cone of vision (i.e., the fixed eye) is approximately 30 degrees vertically and 60 degrees horizontally, with angles of acute vision somewhat less than this, as illustrated in Figure 340-9.

Eye levels and cones of vision are especially important in terms of the placement and orientation of pedestrian signage.

Visual Perception:

Sense of Spatial Enclosure: An external enclosure is most comfortable when its vertical planes are one-half to one-third as high as the width of the space enclosed. If the ratio falls below one-fourth, the space begins to lack a sense of enclosure (Figure 340-10).

Social Communication: For a variety of reasons, the scale and form of a space will influence pedestrian behavior and the type of social communication that may occur within that space. Physical distances that bring people into close proximity, or separate them, are important design considerations. Settings meant to be conducive to active social communication, or those meant to allow a certain degree of privacy, require careful thought as to the degree of eye contact possible, and probable, within the scale and layout of the setting.

It is helpful to possess a general understanding of the capabilities and limitations of normal human vision in terms of social communication. Several examples are illustrated in Figure 340-11.

Table 340-2. AVERAGE WALKING RATES OF ADULT PEDESTRIANS

Type	mm/min	ft/min	km/hr
Average adult	78 000	260	4.3
Elderly (75 yrs)	64 500	215	4
Bunching	60 000	200	3.7
Stairways (going down)	45 600	152	2.8
Stairways (going up)	33 900	113	2

KEY POINTS: Physical Characteristics of the Pedestrian

1. Spatial bubbles are necessary in calculating accommodations for an expected number of people in various situations, with the intent of maintaining psychological comfort (Figure 340-4).
2. The average range of walking distances that people (in the United States) are typically willing to walk between activities or from parking areas are subject to variation depending on purpose of the trip, climactic conditions, or cultural differences Most people are not willing to walk distances greater than about 220 m (700 ft.).(Figure 340-5).
3. The human cone of vision has approximately a 30 degree vertical range and a 60 degree horizontal range. The eye level (Figure 340-8) of an average adult is 1 525 mm (5'-2") standing and 1 125 mm (3'-9") sitting. Cones of vision and eye levels are important in terms of placement and orientation of pedestrian signage.
4. An external enclosure is the most comfortable when the ratio of vertical plane to horizontal plane is 1:4. If the ratio falls below 1:4, the space begins to lack a sense of enclosure (Figure 340-10).

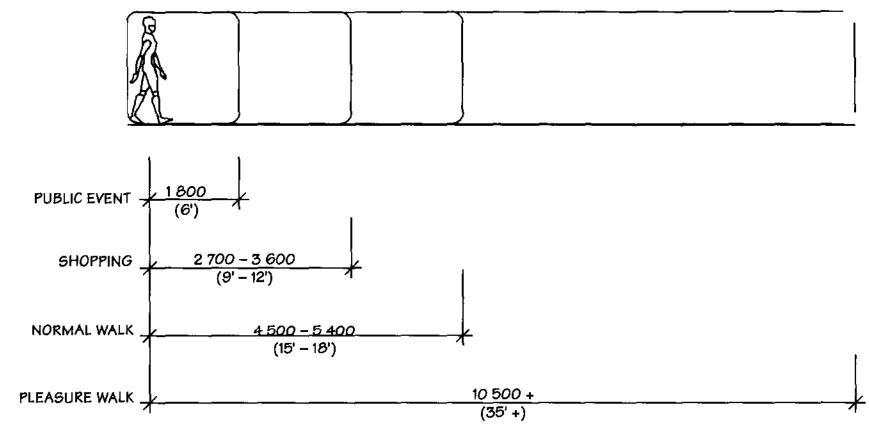


Figure 340-4. Forward spatial bubbles.

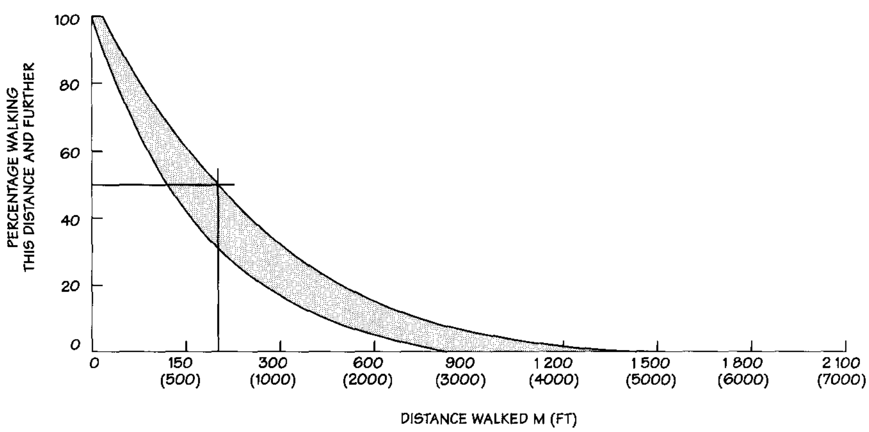


Figure 340-5. Range of acceptable walking distances (U.S. cities). *Most people are not willing to walk distances greater than about 220 m (700 ft).*

3.0 SPATIAL STANDARDS

3.1 Pathway Width and Slope Criteria

General Considerations:

Widths of pedestrian pathways vary depending on the purpose and the existing or expected intensity of use. In general, a 600 mm (24 in) width for each pedestrian is necessary, which suggests a minimum pathway width of 1 200 mm (4 ft) for public walkways. When pedestrian flows are significant and greater precision required in the determination of walkway width, minimum acceptable widths of a pathway can be calculated using the formula given below.

It is important to remember that pedestrians as a group typically do not use the entire width of most walkways. The edge of a walkway adjacent to a curbed roadway (i.e., 750 mm (30 in) from the street edge) is avoided by pedestrians, as is the edge of a walkway along a building facade (i.e., 450 to 750 mm (18 to 30 in). These edges are used only under conditions of high pedestrian density.

The presence of street furniture and features such as fire hydrants, trees, parking meters, telephones, trash receptacles, fountains, sculpture, and kiosks also reduces the effective width of a pathway.

Calculation of Walkway Width (by Formula):

Minimum width for a pedestrian pathway can be determined by mathematical calculation as a function of expected pedestrian volume, acceptable density, and desirable rate of movement. The number of pedestrians (volume) passing a stationary point on a pathway is expressed by unit measurements of time, such as "pedestrians per minute" or "pedestrians per hour." Density refers to personal buffer zones, expressed in terms of square meter (square feet) per pedestrian. Given these criteria, pathway widths can be calculated using the standard flow theory shown below.

In this formula, pedestrian volume (V) refers to the number of pedestrians that are expected to pass any one point on the pathway each minute. (Refer to Figures 340-6 and 340-7 for information on pedestrian flow volumes.) Space modules (M) typically range from a minimum of 0.46 m^2 (5 ft^2) per person to 3.22 m^2 (35 ft^2) or greater. (Refer to Figure 340-4 for information on space modules.) Walking speed (S) typically averages about 78 000 mm/min (260 ft/min), but of course can vary significantly depending on the predominant activities in the area, the types of pedestrians, etc. (Refer to Table 340-2 for information on walking speeds.)

Expected loads of pedestrian traffic are determined through observation of similar projects in other areas, formal studies, and professional judgment.

$$\text{Pathway Width} = \frac{V(M)}{S}$$

where V =volume, pedestrians/minute

M = space module, m^2 (ft^2)/pedestrian

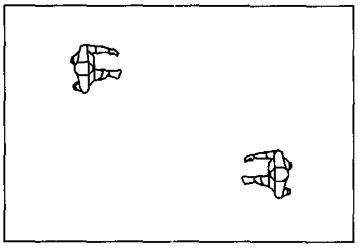
S = walking speed, m (ft)/minute

Example calculation: Given volume of pedestrians=200/minute, minimum space module desired = 1.67 m^2 /pedestrian (18 ft^2), pedestrian walking speed (normal) = 79.25 m/min (260 ft/minute)

$$\frac{200 \times 1.67}{79.25} = \frac{334}{79.25} = 4.22 \text{ m}$$

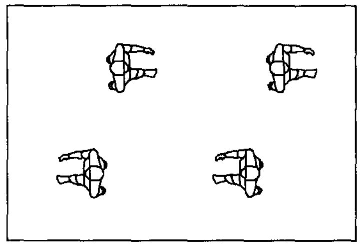
In this example, the walkway width would have to be at least 4 200 mm (13.3 ft) wide to accommodate the given flow of pedestrians.

Note that this formula can yield answers suggesting very narrow walkway widths when light pedestrian traffic loads are calculated. Such answers imply that a common walkway width of 1 200 mm or 1 500 mm (4 or 5 ft) would be adequate to accommodate the expected traffic load.



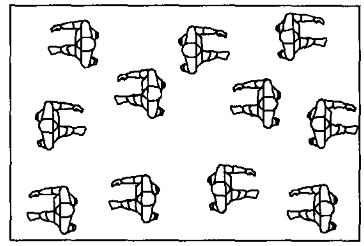
Average Flow Volume: 23 PMM* or less (7 PFM or less)
Average Speed: 79 m/min (260 ft/min)
Average Pedestrian Area Occupancy: 3.3 m²/person or greater (36 ft²/person or greater)

Description: Virtually unrestricted choice of speed; minimum maneuvering to pass; crossing and reverse movements unrestricted; flow approximately 25% of maximum capacity.



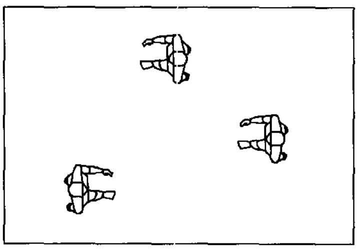
Average Flow Volume: 33-49 PMM (10-15 PFM)
Average Speed: 70-76 m/min (230-250 ft/min)
Average Pedestrian Area Occupancy: 1.4-2.3 m²/person (15-25 ft²/person)

Description: Walking speeds partially restricted; passing restricted but possible with maneuvering; crossing and reverse movements restricted and require significant maneuvering to avoid conflict; flow reasonably fluid and about 40-65% of maximum capacity.



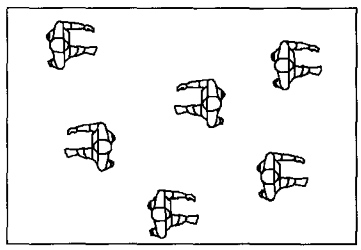
Average Flow Volume: 66-82 PMM (20-25 PFM)
Average Speed: 34-61 m/min (110-200 ft/min)
Average Pedestrian Area Occupancy: .5-.9 m²/person (5-10 ft²/person)

Description: Walking speeds restricted and frequently reduced to shuffling; frequent adjustment of gait required; passing impossible without conflict; crossings and reverse movements severely restricted with unavoidable conflicts; flows attain maximum capacity under pressure, but with frequent stoppages and interruptions of flow.



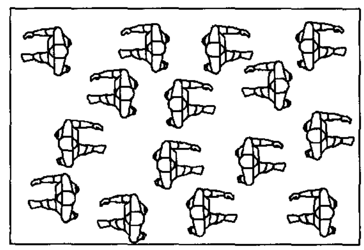
Average Flow Volume: 23-33 PMM (7-10 PFM)
Average Speed: 76-79 m/min (250-260 ft/min)
Average Pedestrian Area Occupancy: 2.3-3.2 m²/person (25-35 ft²/person)

Description: Normal walking speeds only occasionally restricted; some occasional interference in passing; crossing and reverse movements possible with occasional conflict; flow approximately 35% of maximum capacity.



Average Flow Volume: 49-66 PMM (15-20 PFM)
Average Speed: 61-70 m/min (200-230 ft/min)
Average Pedestrian Area Occupancy: .9-1.4 m²/person (10-15 ft²/person)

Description: Walking speeds restricted and reduced; passing rarely possible without conflict; crossing and reverse movements severely restricted with multiple conflicts; some probability of momentary flow stoppages when critical densities might be intermittently reached; flow approximately 65-80% of maximum capacity.



Average Flow Volume: 82 PMM or more (25 PFM or more)
Average Speed: 0-34 m/min (0-110 ft/min)
Average Pedestrian Area Occupancy: .5 m²/person or less (5 ft²/person or less)

Description: Walking speed reduced to shuffling; passing impossible; crossing and reverse movements impossible; physical contact frequent and unavoidable; flow sporadic and on the verge of complete breakdown and stoppage.

*PMM=pedestrians per meter width of walkway, per minute.
(PFM=pedestrians per foot width of walkway, per minute.)

Figure 340-6. Average flow volume, speed, and density (walkways).

It is important to note that this formula does not take into account the spatial requirements of street furniture, social gathering places, or minimal use of walkway edges. If such features or circumstances are involved, then adjustments have to be made to the overall width of the pathway. Moreover, this formula yields minimum (functional) walkway widths, not optimal widths based on aesthetic criteria. Often walkway widths are designed to be much greater than necessary for reasons of scale, proportion, etc.

Consequently, this formula is more often used as a check against a proposed design scheme rather than as a rigid method for determining walkway widths.

Walkway Slope Criteria:

Figure 340-12 provides longitudinal and cross-slope criteria for walkways under various circumstances. Longitudinal slope criteria are based on user abilities and design objectives, and cross-slope criteria are based on the need for positive drainage, depending on paving material. Porous paving, for instance, does not require as much of a cross-slope for drainage as a nonporous paving material.

3.2 Stairways

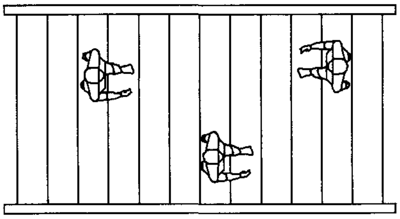
Widths:

Minimum width for public stairways should be 1 500 mm (60 in). Minimum width for private stairways should be 1 050 mm (42 in).

Tread-Riser Ratios:

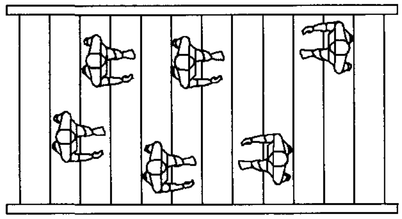
Tread-riser ratios are always held constant within any particular stairway or set of stairways, for ease of ascent or descent, and for safety reasons. On rare occasions riser heights in stairways will vary (e.g., stairways built obliquely into a slope), but these are hazardous and should be avoided whenever possible. On very gentle slopes of 0.5 to 2.0 percent, a stairway can be built to slope with the grade rather than remain level, in order to keep the bottom riser at a constant dimension. In addition, or as an alternative, the bottom of stairway grade (B.S.) can be warped to maintain a constant along the edge of the bottom tread.

Occasionally, tread widths also vary for aesthetic reasons and this is generally found to be acceptable as long as it is understood that ascending or descending such stairways, typically referred to as terraced plazas, is often cumbersome. This is generally acceptable because terraced plazas are typically used as informal gathering places rather than purely utilitarian transitional spaces.



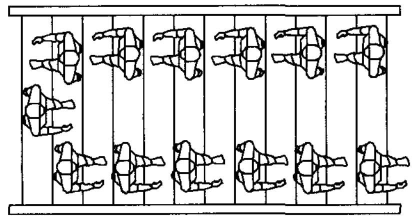
Average Speed: 38 m/min or more (125 ft/min or more)
Average Pedestrian Area Occupancy: 1.9 m²/person (20 ft²/person)

Description: Unrestricted choice of speed; relatively free to pass; no serious difficulties with reverse traffic movements; flow approximately 30% of maximum capacity.



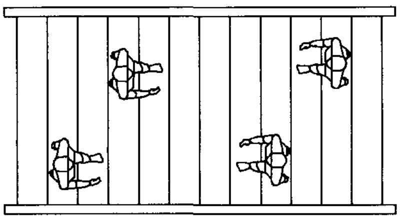
Average Flow Volume: 16-23 PMM (5-7 PFM)
Average Speed: 37-38 m/min (120-125 ft/min)
Average Pedestrian Area Occupancy: 1.4-1.9 m²/person (15-20 ft²/person)

Description: Restricted choice of speed; passing encounters interference; reverse flows create occasional conflicts; flow approximately 34% of maximum capacity.



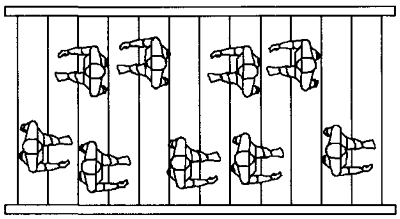
Average Flow Volume: 23-33 PMM (7-10 PFM)
Average Speed: 35-37 m/min (115-120 ft/min)
Average Pedestrian Area Occupancy: .9-1.4 m²/person (10-15 ft²/person)

Description: Speeds partially restricted; passing restricted; reverse flows partially restricted; flow approximately 50% of maximum capacity.



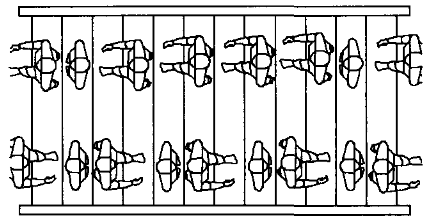
Average Flow Volume: 33-43 PMM (10-13 PFM)
Average Speed: 32-35 m/min (105-115 ft/min)
Average Pedestrian Area Occupancy: .7-.9 m²/person (7-10 ft²/person)

Description: Speeds restricted; passing virtually impossible; reverse flows severely restricted; flows approximately 50-65% of maximum capacity.



Average Flow Volume: 43-56 PMM (13-17 PFM)
Average Speed: 26-32 m/min (85-115 ft/min)
Average Pedestrian Area Occupancy: .4-.7 m²/person (4-7 ft²/person)

Description: Speeds severely restricted; passing impossible; reverse traffic flows severely restricted; intermittent stoppages of flow likely to occur; flows approximately 65-86% of maximum capacity.



Average Flow Volume: 56 PMM or greater (17 PFM or greater)
Average Speed: 0-26 m/min (0-85 ft/min)
Average Pedestrian Area Occupancy: .4 m²/person or less (4 ft²/person or less)

Description: Speed severely restricted; flow subject to complete breakdown with many stoppages; passing as well as reverse flows impossible.

*PMM=pedestrians per meter width of stairway, per minute.
(PFM=pedestrians per foot width of stairway, per minute.)

Figure 340-7. Average flow volume, speed, and density (stairways).

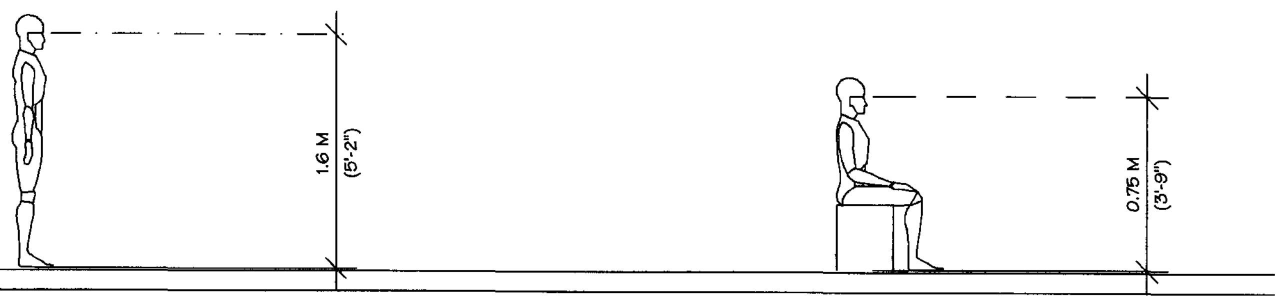


Figure 340-8. Eye levels of an average adult.

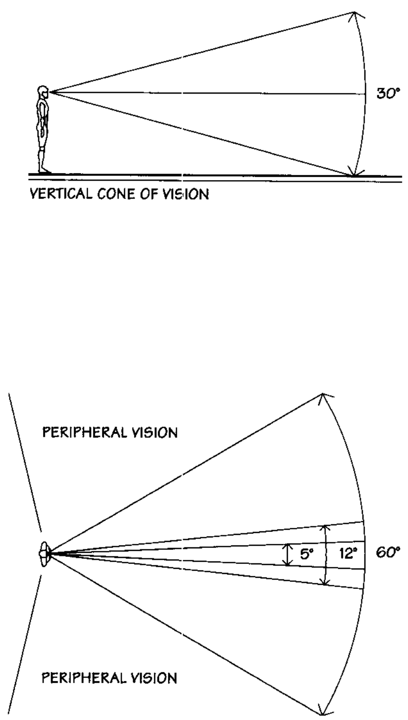


Figure 340-9. Normal cone of vision.

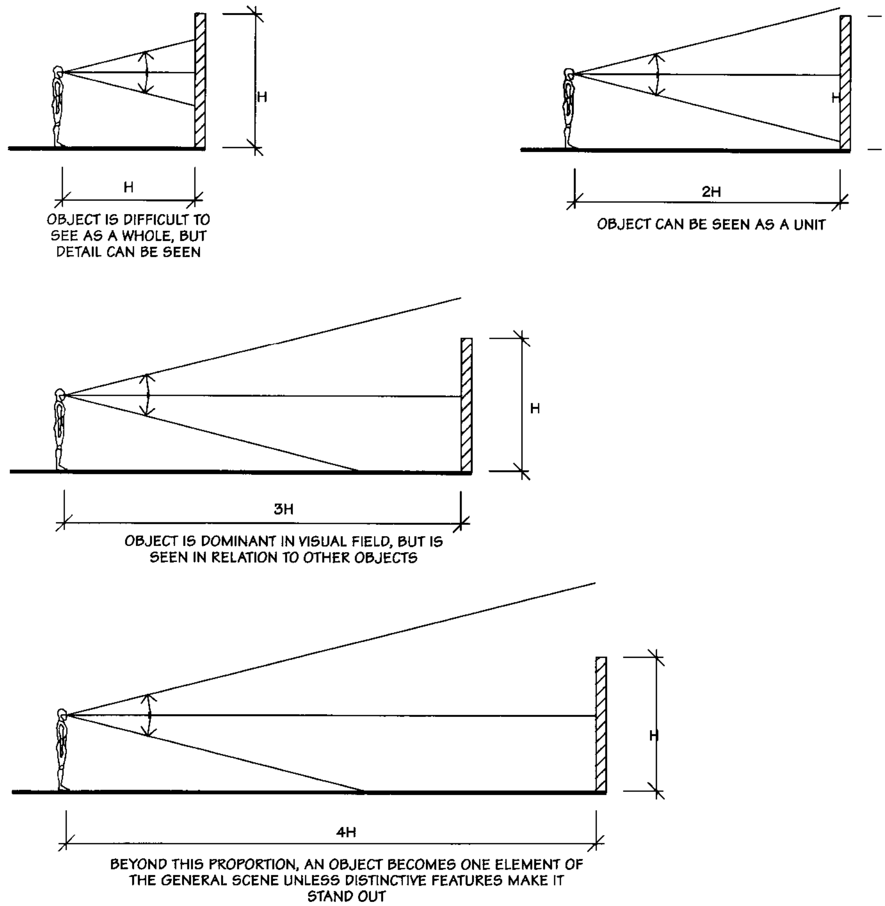


Figure 340-10. Sense of spatial enclosure outdoors.

In dimensionally unconstrained situations, employing a tread-riser ratio is up to the discretion of the designer. Choice of a ratio will depend on the desired appearance and kinesthetic experience.

In dimensionally constrained situations (i.e., where the elevations of both the top and the bottom of a stairway, or a set of stairways, are given) an appropriate tread-riser ratio has to be determined that will allow a given number of steps (including landings if necessary) to "fit" into the space.

Figure 340-13 is a quick-reference chart of typical tread-riser ratios for outdoor stairways. As an alternative to tread-riser charts, the following formula is commonly used to determine acceptable tread-riser ratios for outdoor stairways, especially when fractions of an inch are involved.

$2R + T = 650$ to 675 mm (26 to 27 in)

where R = riser
T = tread

Additional Considerations:

1. Outdoor stairways should be made easier to ascend and descend than interior stairways. People tend to move at greater rates outdoors than they do indoors.
2. Inherent to a particular tread-riser ratio is the ease at which the stairway can be ascended or descended, and consequently, the sense of rhythm to be experienced by the pedestrian. Ideally, the kinesthetic character of a stairway should be congruent with the character of the environment in which the stairway is a part.
3. Single steps in a walkway are very dangerous and should never be specified. At least two steps, but preferably three, should be specified, and their presence should be announced conspicuously with railings, plantings, or lighting.
4. Risers for outdoor stairways should be a minimum of 115 mm (4.5 in) and a maximum of 150 mm (6 in). Under utilitarian circumstances a 175 (7 in) riser may be considered.
5. Treads should be pitched downgrade 2 percent for drainage.

Nosing and Shadow Line Profiles: Shadow lines are often included in steps for aesthetic reasons, used mainly to give a "refined" look to a stairway. They can, however, be hazardous if large enough to catch the toes of pedestrians. Nosings can also catch toes unless they are rounded.

Figure 340-14 shows various nosing and shadow line profiles, some of which are potentially hazardous and therefore not recommended, particularly in public areas. (Refer to Section 240: Outdoor Accessibility, for more information.)

Height between Landings:

Height between stairway landings is an important criterion for psychological reasons as well as for reasons of human endurance. Although many building codes state maximum heights of 3 600 mm (12 ft), lesser heights are recommended.

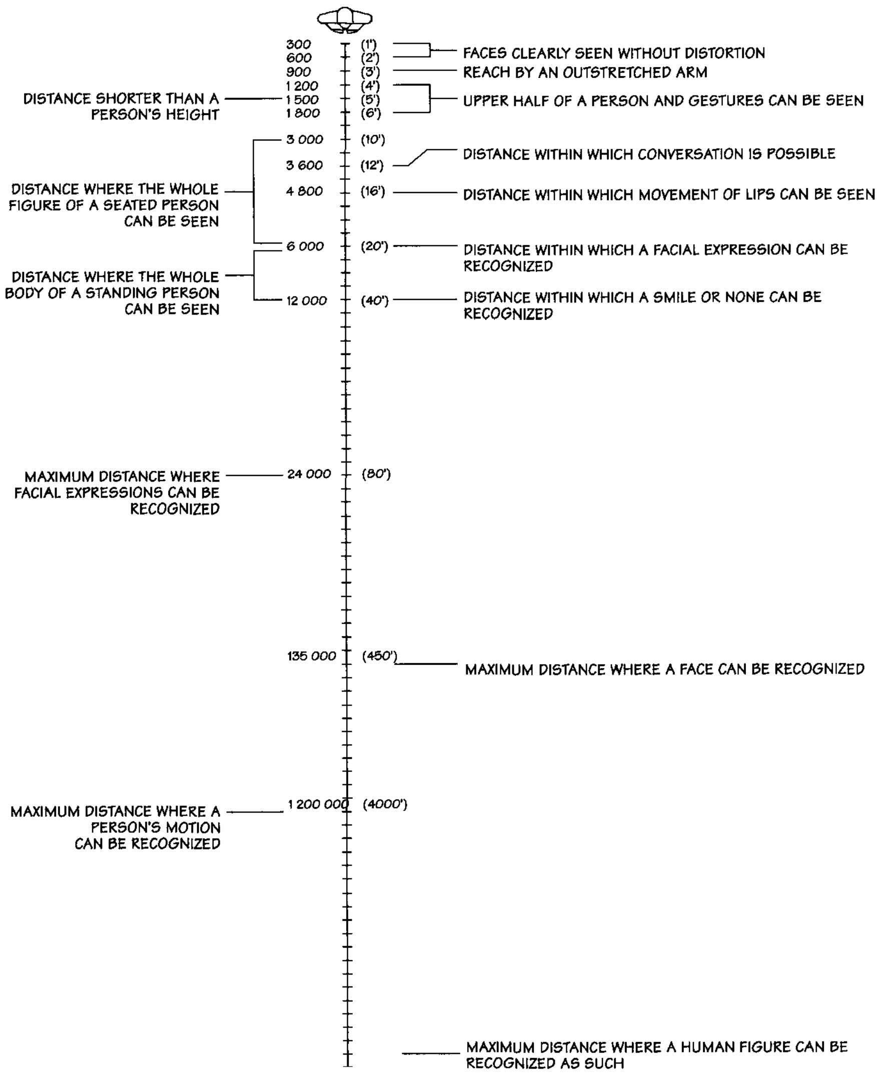


Figure 340-11. Inherent capabilities of human vision in terms of social communication (not to scale).

In terms of environmental psychology, it is known that abrupt changes in ground levels, even as little as 300 to 500 mm (1 to 1-1/2 ft) can decrease incentive to proceed. Changes of 1 800 mm (6 ft) or more are found to be strongly discouraging. For this reason, heights between stair landings are best designed so an adult of average height standing on one landing can see the ground plane of the next higher landing (i.e., 1 500 mm (5 ft) or less (Figure 340-15). Conversely, height between landings is sometimes made to be greater than 1 500 mm (5 ft) to effectively control sightlines in conjunction with other design elements.

In terms of human endurance, it should be remembered that elderly and handicapped individuals use stairways, and their abilities are more limited than the average, physically healthy adult. For this reason, all changes in elevation should be designed with an understanding of the diversity of human ability that exists among members of the population. (Refer to Section 240: Outdoor Accessibility, for more information on the abilities of elderly and handicapped individuals.)

Figure 340-15 summarizes several important considerations for the design of outdoor stairways and landings.

3.3 Ramps

Widths:

Ramp widths are determined according to the type and intensity of use. One-way travel requires a minimum width of 900 mm (3 ft) clear, whereas two-way travel requires a clear minimum width of 1 500 mm (5 ft) (Figure 340-16). If turns occur at landings, adequate space for maneuvering wheelchairs must be provided. (Refer to the Americans with Disabilities Act Accessibility Guidelines (ADAAG) for a comprehensive compilation of dimensional criteria and to state and local codes.)

Slope Criteria:

Ramp slopes should be no greater than 1:12 or 8.33 percent (Figure 340-12). Curb cuts are an exception, 1:8 or 12 percent being acceptable if the running distance is less than 900 mm (3 ft).

Distance between Landings:

Landings should be provided within every 9 000 mm (30 ft) or less of ramp length (Figure 340-16).

3.4 Seating Criteria

Benches should be designed to ensure greatest comfort for the individual. Figure 340-17 illustrates preferred height and seating angle for outdoor benches. (Refer to Section 510: Site Furniture.)

Seat walls are typically 400 to 450 mm (16 to 18 in) wide and between 400 to 450

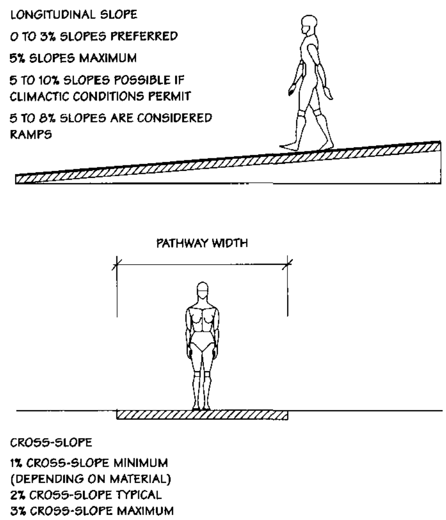


Figure 340-12. Walkway slope criteria.

RISER	TREAD
100	450 - 475
(4")	(18 - 19")
106.25	437.5 -462.5
(4.25")	(17.5 - 18.5")
112.5	425 - 450
(4.5")	(17 - 18")
118.75	412.5 - 437.5
(4.75")	(16.5 - 17.5")
125	400 - 425
(5")	(16 - 17")
131.25	387.5 - 412.5
(5.25")	(15.5 - 16.5")
137.5	375 -400
(5.5")	(15 - 16")
143.75	362.5 -387.5
(5.75")	(14.5 - 15.5")
150	350 - 375
(6")	(14 - 15")
156.25	337.5 -362.5
(6.25")	(13.5 - 14.5")
162.5	325 - 350
(6.5")	(13 - 14")
168.75	312.5 - 337.5
(6.75")	(12.5 - 13.5")
175	330 - 325
(7")	(12 - 13")
181.25	287.5-312.5
(7.25")	(11.5"-12.5")

Figure 340-13. Quick reference chart *of typical tread-risers ratios for outdoor stairways in mm (ft). Check state codes where applicable.*

mm (14 and 18 in) in height, 400 mm (16 in) being most preferred. Refer to Section 931: Seating Walls, in this handbook for examples of seating wall details.

3.5 Handrailings

Handrailings are important on all stairways and ramps, and should allow a secure and comfortable grip for maximum support. (Figure 340-18).

Handrailing heights for outdoor stairways and ramps typically range from 750 to 850 mm (30 to 34 in) (Figure 340-19). Municipal codes should always be checked to ensure conformance of proposed heights. The ends of railings should extend beyond the top and bottom step by 300 to 450 mm (12 to 18 in) and should be rounded off or turned under for safety reasons. This detail is especially important for individuals with impaired vision. (Refer to ADAAG for more information.)

Additional Considerations:

1. Handrailings on both sides of a stairway or ramp are important because some people have one-sided strength.
2. Extra-wide stairways should have center railings for greater convenience. Handrailings should be no more than 6 000 mm (20 ft) apart.
3. Railings should continue across intermediate landings.
4. Railings should be capable of supporting 114 kg (250 lbs) of weight.
5. Handrailings for children, at a lower height than that specified for adults, are sometimes advisable and are also useful on ramps for individuals who use wheelchairs.

3.6 Pedestrian Signage

Design and placement of signs for use by pedestrians involves consideration of visual field, scale of letters, proportion of letters, and contrast between letters and background (Figures 340-20 and 340-21).

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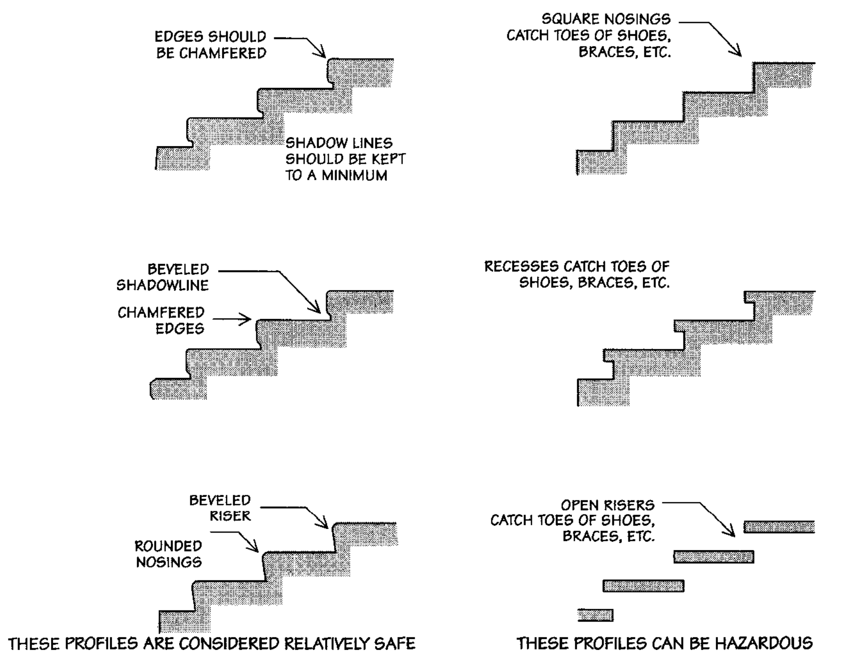


Figure 340-14. Typical nosing and shadow line profiles. *Check state codes where applicable.*

KEY POINTS: Spatial Standards

1. Minimum width for a pedestrian pathway can be determined by mathematical calculation as a function of expected pedestrian volume(V), acceptable density(M), and desirable rate of movement(S). Therefore, pathway width = V(M)/S.

2. Minimum width for stairways should be 1 500 mm (60 in) for public spaces and 1 050 mm (42 in) for private spaces.

3. Recommended tread-riser ratios for outdoor stairways can be calculated using the formula 2R(riser) + T(tread) = 650 to 675 mm (26 to 27 in). Risers for outdoor stairways should be a minimum of 115 mm (4.5 in) and a maximum of 150 mm (6 in). Under utilitarian circumstances a maximum 175 (7 in) riser may be considered.

4. Landings should be provided every 9 000 mm (30 ft) or less of ramp length. Heights between stair landings should be a maximum of 1 500 mm (5 ft) to allow an average adult standing on one landing to see the ground plane of the next higher landing.

5. Ramp slopes should be no greater than 1:12 or 8.33% (Figure 340-12). Curb cuts may be 1:8 or 12% if the run is less than 900 mm (3 ft).

6. Seatwalls are typically 400 to 450 mm (16 to 18 in) wide and between 350 and 450 mm (14 and 18 in) in height.

7. Handrailing heights for outdoor stairway and ramps typically range from 750 to 850 mm (30 to 34 in). The railing ends should extend beyond the top and bottom step by 300 to 450 mm (12 to 18 in).

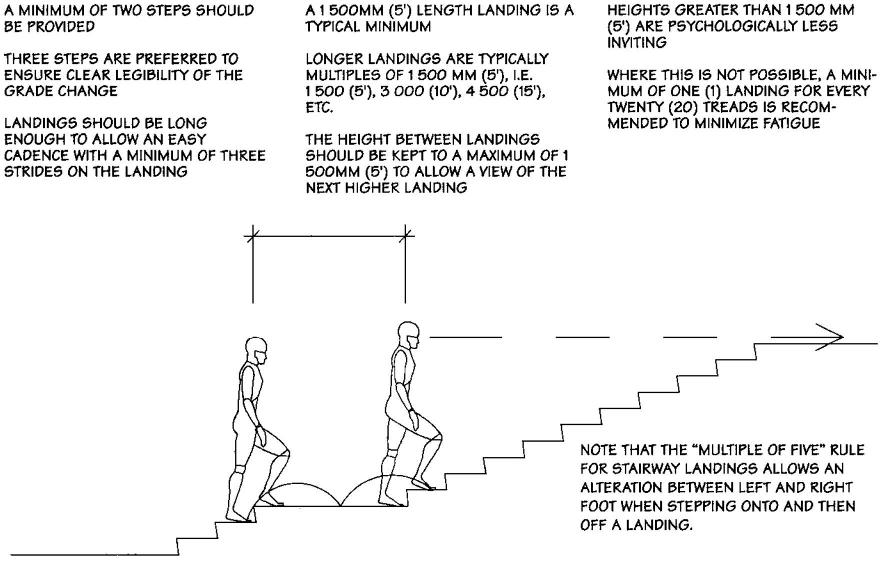


Figure 340-15. Stairway height and landing proportions. *Check state codes where applicable.*

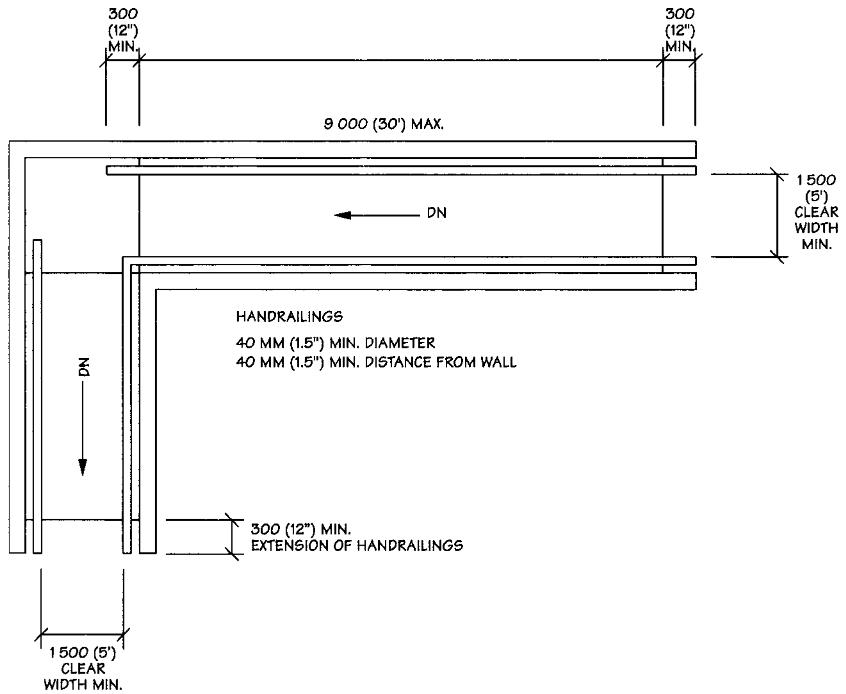


Figure 340-16. Dimensional criteria for two-way handicap ramp. *Minimum clear width for one-way travel is 900 mm (36 in.). Check state codes where applicable.*

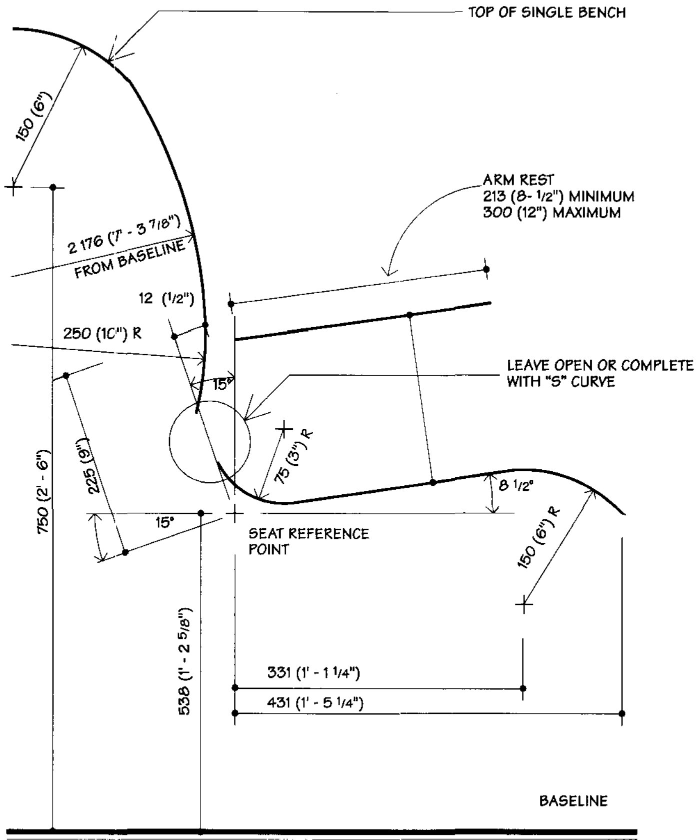


Figure 340-17. Preferred height and seating angle for outdoor benches. *Dimensions shown are for optional double- and single-bench contour.*

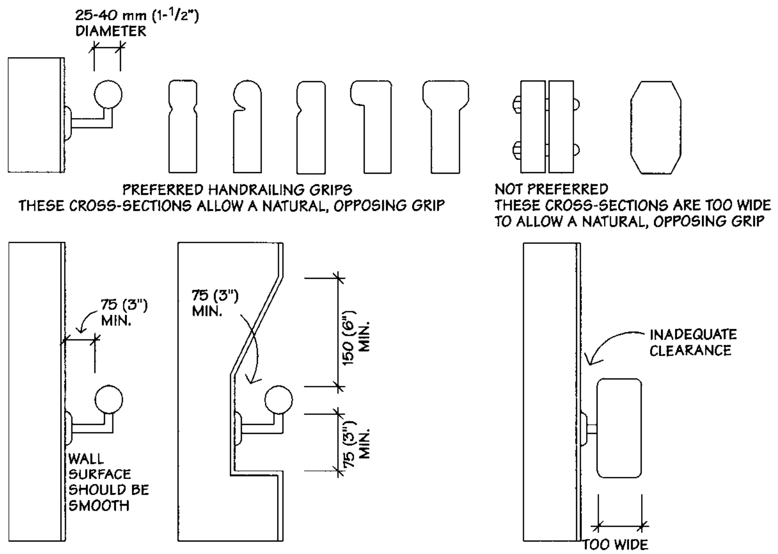


Figure 340-18. Preferred handrailing profiles.

HANDRAILING HEIGHTS	RISER/TREAD RATIOS
825 mm (2' - 9")	150/350 mm (6"/14") TO 175/ 325 (7"/13")
850 mm (2' - 10")	125/800 mm (5"/16") TO 150/ 337 (6"/13.5")
HANDRAILING HEIGHTS FOR RAMPS: 800 to 850 mm (2' - 8" to 2' - 10")	

Figure 340-19. Handrailing heights for exterior stairs and ramps.

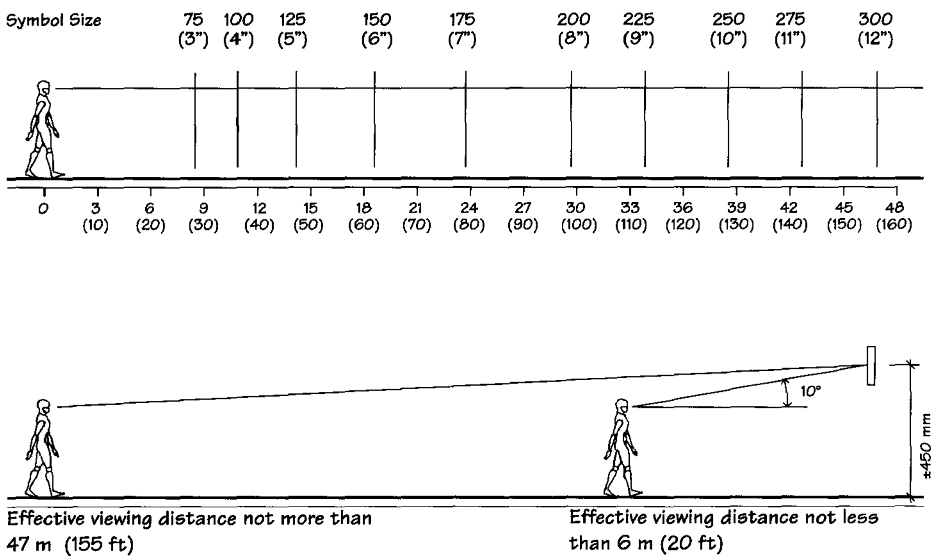
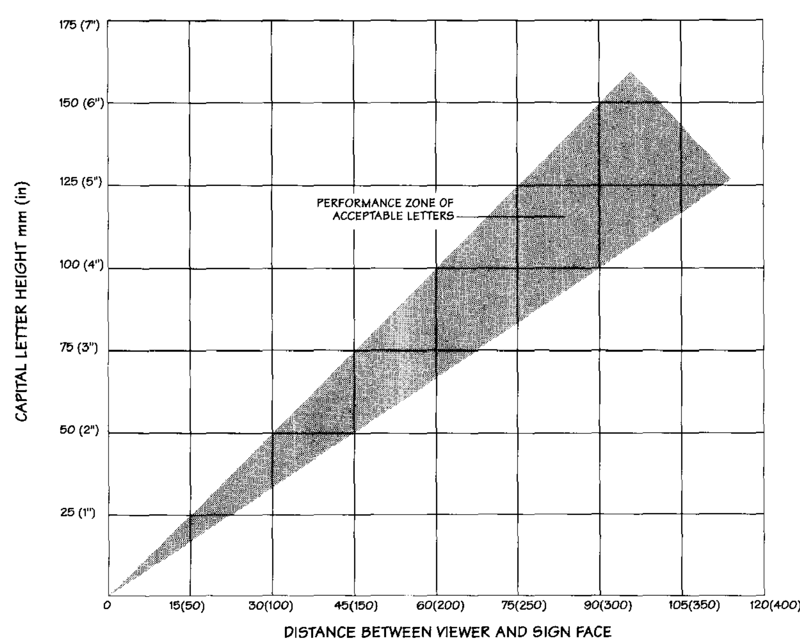


Figure 340-20. Pedestrian signage criteria.

Figure 340-21. Minimum legibility for capital letter height for pedestrian signage. *Under normal daylight conditions with an angular distortion of 0 degrees, approximately 15m/25m of capital letter height can be taken as a guideline for minimal legibility.*



Bicycle Circulation

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CONTENTS

1.0 INTRODUCTION

The increasing use of bicycles in the United States makes it imperative to design bicycle facilities with fewer conflicts between such systems and other modes of travel.

Such improved systems are normally found in the form of a bikeway, defined as "any road, path, or way, which in some manner is specifically designated as being open to bicycle travel, regardless of whether such facilities are designated for the exclusive use of bicycles or are to be shared with other modes of transportation" (American Association of State Highway and Transportation Officials).

To design quality bicycle facilities, an understanding of bicyclists and their objectives is important.

2.0 TYPES OF USERS

2.1 Bicyclists

Bicyclists fall into two major categories:

1. The recreational bicyclist, who uses the bicycle for pleasure or exercise
2. The functional bicyclist, who uses the bicycle as an alternative form of transportation to school, to work, or to shop

Most bicyclists use a bicycle for both functional and recreational reasons. Bikeways must be designed to accord with a corridor's existing characteristics rather than with narrowly defined user traits or purposes.

Minimum standards must be emphasized to accommodate a full range of user types while optimizing safety for all.

2.2 Mountain Bikes

Although the primary focus of this section is the design of facilities for touring bicycles, the use of mountain bikes is increasingly popular. Mountain biking typically occurs on all trail systems, and the integration of biking into existing trail systems is a challenge for providers around the country.

3.0 PRIMARY TYPES OF BIKEWAYS

The American Association of State Highway and Transportation Officials (AASHTO) classifies four primary types of bikeways. These are described below.

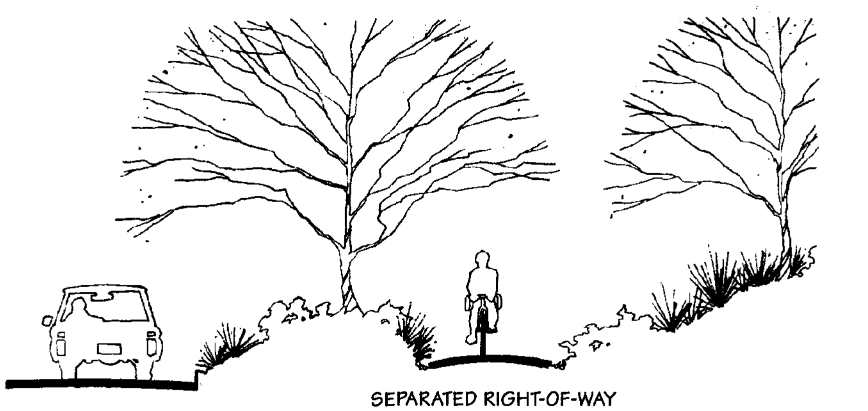

Figure 341-1. Bicycle path.

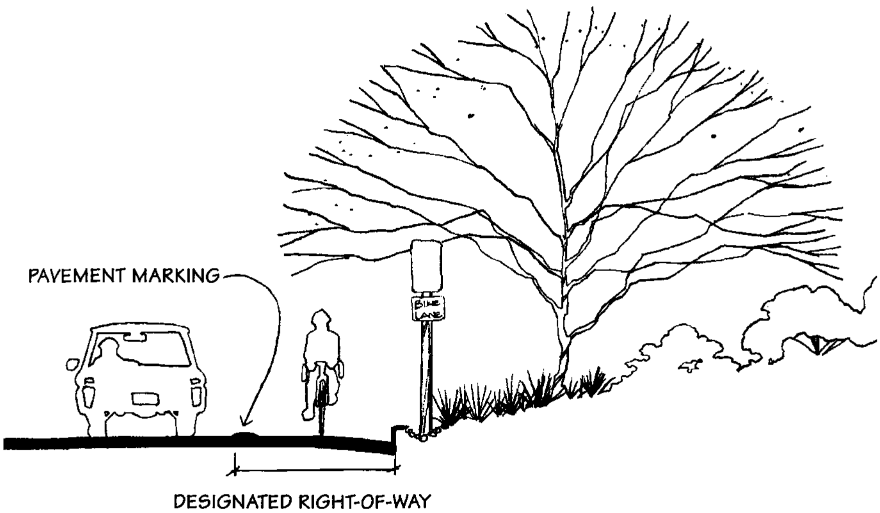

Figure 341-2. Bicycle lane.

3.1 Bicycle Path

Bicycle path refers to a facility separated from motor traffic by an open space or barrier either within the road right-of-way or an independent right-of-way, and for the primary use of bicycles (Figure 341-1).

KEY POINTS: Types of Bikeways

There are four primary types of bikeways which are designed to accommodate the recreational and functional needs of bicyclists.

1. **Bicycle path:** Ideal with dedicated right-of-way and separate furnishings, 2 400-3 600 mm (8-12 ft) min.
2. **Bicycle lane:** Part of road but separated by markings or textured strip, 1 500-1 800 mm (5-6 ft) min.
3. **Wide outside lane:** Less desirable, but common, 4 200 mm (14 ft) min.
4. **Shared roadway:** Common, but has highest potential for conflict with autos, 1 500-1 800 mm (5-6 ft) min.

3.2 Bicycle Lane

Bicycle lane refers to a portion of a roadway which has been designated by striping, signing, and pavement markings for preferential or exclusive use by bicyclists (Figure 341-2).

3.3 Wide Outside Lane

Wider right-most through traffic lanes, (usually 4 200 mm (14 ft) min.) to allow the bicyclist and motorist to share the same lane with minimal conflict and no adverse effects on traffic flow.

3.4 Shared Roadway

Shared roadway refers to a right-of-way designated by signs or permanent markings as a bicycle route, but which is also shared with pedestrians and motorists (Figure 341-3).

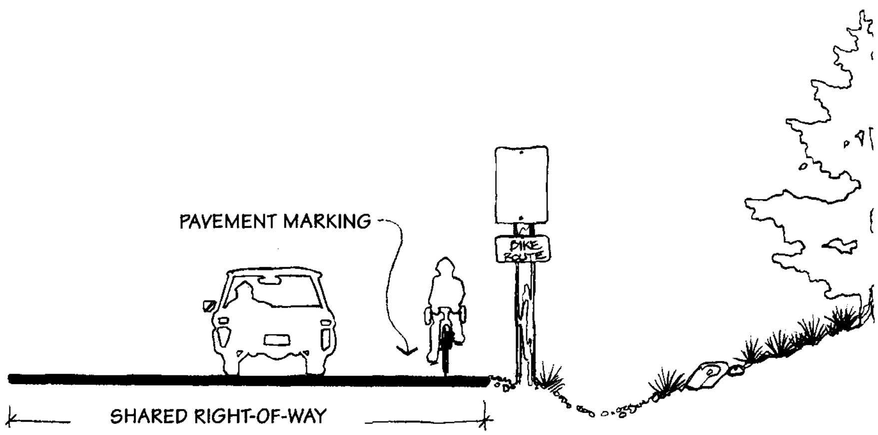

Figure 341-3. Shared roadway or wide outside lane.

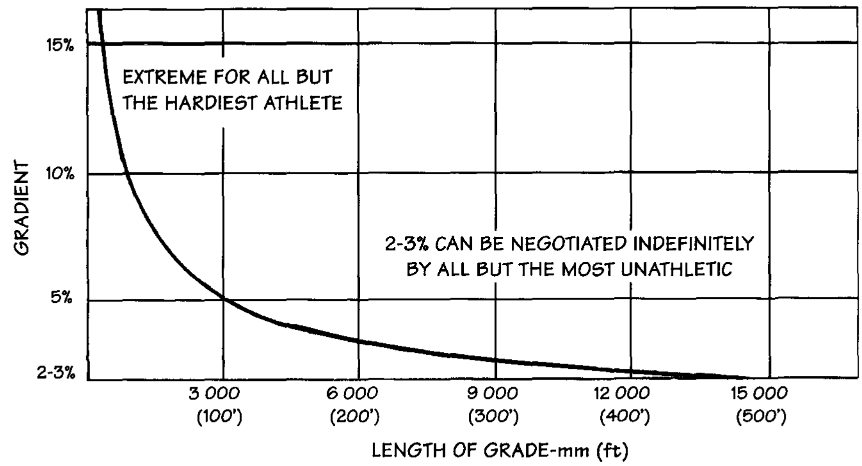

Figure 341-4. Maximum uphill grades.

4.0 ROUTE SELECTION AND PLANNING

The selection and planning of a bikeway route depends on a combination of several factors: (1) bicycle traffic generators, (2) scenic and recreational amenities, (3) continuity, (4) terrain, (5) adequate space, and (6) negative factors.

4.1 Bicycle Traffic Generators

An estimated range of 5 to 10 km (3 to 6 mi) covers most recreational and functional bicycle trips. These can be identified with a specific traffic generator including:

1. Residential concentrations
2. Schools
3. Parks and recreational facilities
4. Community activity centers
5. Employment concentrations
6. Shopping and commercial centers

NOTE: For most types of trips in urban areas of up to 8 km (5 mi), the bicycle and the motor vehicle require about the same travel time.

4.2 Scenic and Recreational Amenities

The value of a bikeway as an amenity is enhanced by its close proximity and connection to parks or other scenic and recreational attractions. The most varied and attractive routes will be used most often.

4.3 Terrain

Studies indicate that if gradients exceed 5 percent there will be a sharp drop in the length of uphill grade that bicyclists will tolerate. Figure 341-4 illustrates commonly accepted maximum uphill grades (based on length of grade).

KEY POINTS: Route Selection

Proper route selection requires:

1. Identification of traffic generators and anticipated user types within a 5-10 km (3-6 mi) circuit.
2. Linking scenic and recreational potential of multi-use route to secure broad user interest.
3. Mapping and inspecting physical route conditions to determine:
   a. Extent of uphill grades to stay within acceptable gradient/distance ratios.
   b. Potential for uninterrupted and direct pathways to encourage frequent use.
   c. Available widths to allow for proper setbacks for signs, lights, benches, etc. (Refer to Figure 341-5).
   d. Obstacles and negative contextual physical factors, including adjacent structures or transportation mode conflicts

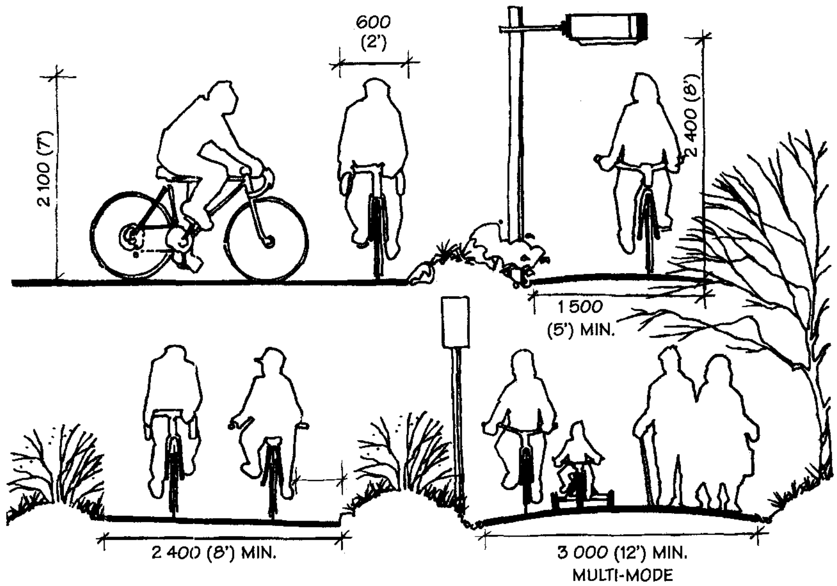

Figure 341-5. Widths of bikeways.

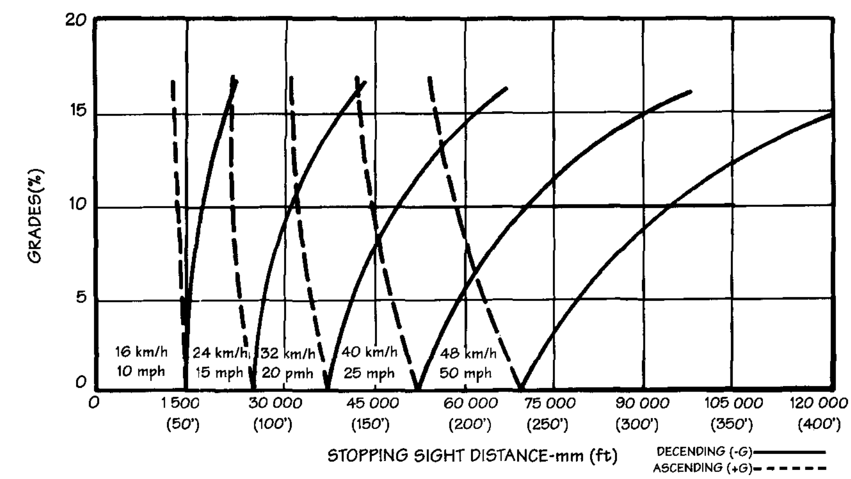

Figure 341-6. Minimum sight/stopping distances

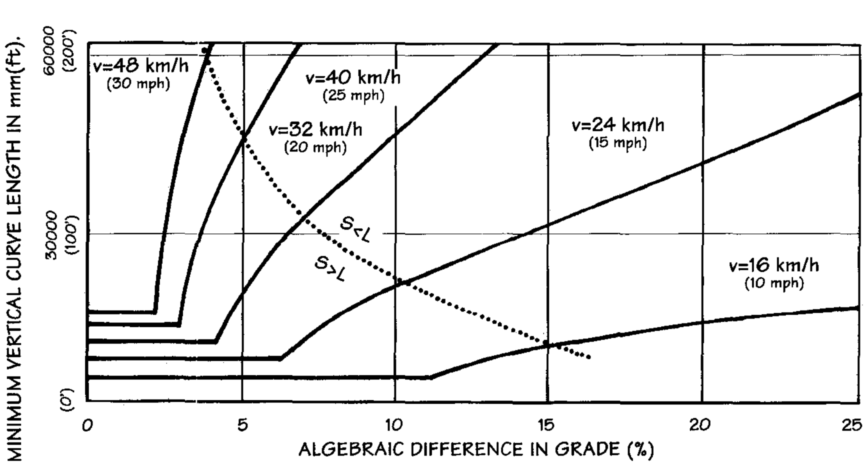

Figure 341-7. Sight/stopping distances for crest vertical curves.

4.4 Continuity

Continuity is important to assure a relatively direct trip and continuous path without excessive out-of-the-way travel (which tends to discourage use).

4.5 Width of Bikeways

Factors to consider when determining widths for bikeways must include:

1. The spatial dimensions of bicyclist and bicycle
2. Maneuvering space required for balancing
3. Additional clearances required to avoid obstacles (Figure 341-5)
4. Anticipated volumes of traffic

NOTE: Designers should assume that in many cases two-way travel will occur on separated bicycle paths, regardless of design intentions. Appropriate widths should be provided.

4.6 Negative Factors

Factors that negatively influence the selection of a route for a bikeway include physical obstacles such as elevated embankments, freeways and interchanges, busy arterials, and potential conflicts with other modes of travel.

5.0 DESIGN CRITERIA

Minimum levels of safety can be provided by carefully considering bicycle speed, sight/stopping distances, curve radii, intersection design, widths, surfacing, and protection from hazards.

5.1 Bicycle Speed

Design speed refers to the speed for which a bicycle path is designed. A design speed should be chosen that is at least as fast as the preferred speed of the faster bicyclists. In general, a minimum design speed of 32 km/h (20 mph) should be used. However, when downhill grades exceed 4 percent or where strong tail winds often exist, a higher minimum design speed of 48 km/h (30 mph) may be advisable. On unpaved surfaces, a lower minimum design speed can be used.

5.2 Sight/Stopping Distance

Sight/stopping distance is the physical distance required for a bicyclist to see an obstruction and come to a complete stop. Figure 341-6 shows minimum sight/stopping distances for various design speeds and grades based on a total perception and brake reaction time of 2.5 seconds and a coefficient of friction of 0.25, to account for the poor wet-surface braking characteristics of most bicycles.

Figure 341-7 is used to select the minimum length of vertical curve necessary to provide minimum sight/stopping distances at various speeds on crests. The eye height of the average bicyclist is assumed to be 1 350 mm (4-1/2 ft) and the height of the perceived object is assumed to be zero.

Figure 341-8 shows the minimum clearance that should be used for line-of-sight obstructions on horizontal curves. The desired lateral clearance is obtained by entering Figure 341-8 with the sight/stopping distance from Figure 341-6 and the proposed horizontal radius of curvature.

NOTE: To avoid head-on bicycle accidents, lateral clearances on horizontal curves should be calculated based on the sum of the sight/stopping distances for bicyclists traveling in opposite direction around the curve. Where this is not possible, consideration should be given to widening the path through the curve, installing a yellow center stripe, and installing a CURVE AHEAD warning sign.

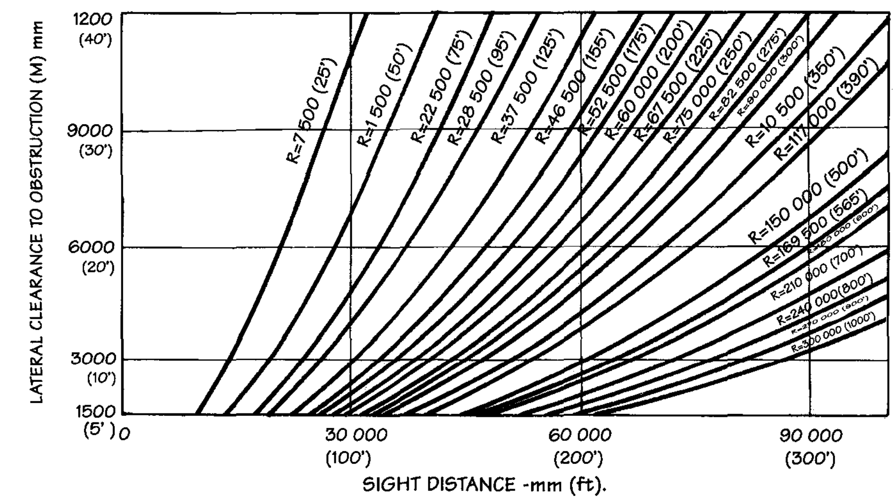

Figure 341-8. Lateral clearances on horizontal curves.

5.3 Curve Radii

General:

The design speed chosen determines the appropriate curve radii. If bikeways are part of a motor vehicle roadway, then no changes in radii are needed. If separate facilities are planned, then the curves should be designed to allow unbraked turns at a prescribed design speed.

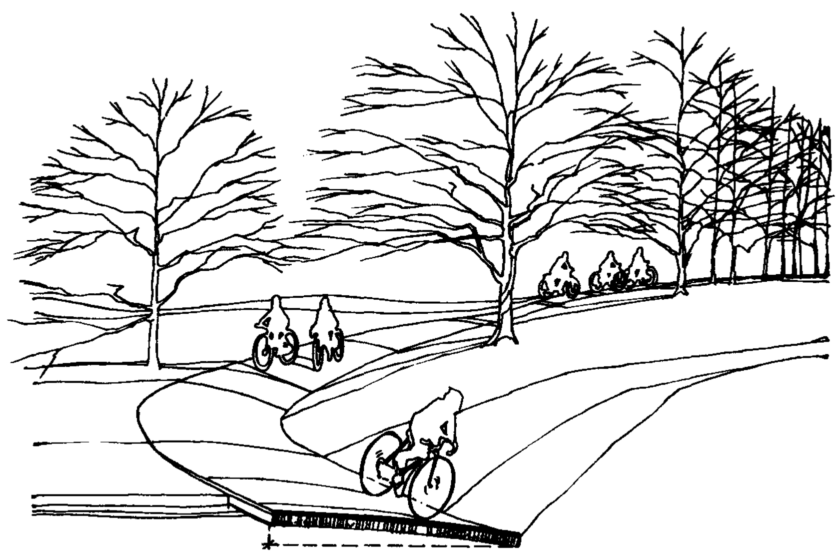

Figure 341-9.Superelevation and curve widening. *These two devices help bicycles negotiate small-radii curves.*

Minimum Curve Radii for Unbraked Turns:

Minimum curve radii for unbraked turns are based on the bicycle speed, the rate of superelevation, and the coefficient of friction between bicycle tire and pavement.

Minimum curve radii for bikeways can be derived from the following formula. A superelevation rate of 2% should be used to provide adequate drainage of the surface and accommodate handicap accessibility. Greater rates of superelevation may be used in unique circumstances where tighter radii are required. However, superelevation rates should not exceed a maximum of 0.05 m/m (0.05 ft/ft).

$$R = \frac{V^2}{15(e + f)}$$ where,

R = minimum radius of curvature, mm (ft)

V = design speed, km/h (mph)

e = superelevation, 2% max.

f = coefficient of friction (varies from 0.17 to 0.27)

NOTE: This formula is for paved surfaces only. Friction factors for unpaved surfaces would be less than half of those for paved surfaces.

Avoid short-radius curves at the bottom of a long grade. Widening the bikeway at short-radius curves is recommended to compensate for the increased operating space required by a bicyclist leaning through a curve (Figure 341-9).

5.4 Intersections

Conflicts at Intersections:

A large share of bicycle-related accidents occur at intersections of streets and bikeways because of the confused comingling of bicycles, motor vehicles, and pedestrians. Major problems occur from the following conditions:

1. Bicyclists turning left across traffic
2. Bicyclists crossing an intersection when vehicular traffic is entering from or turning to the right
3. Failure to yield by both bicyclists and motorists

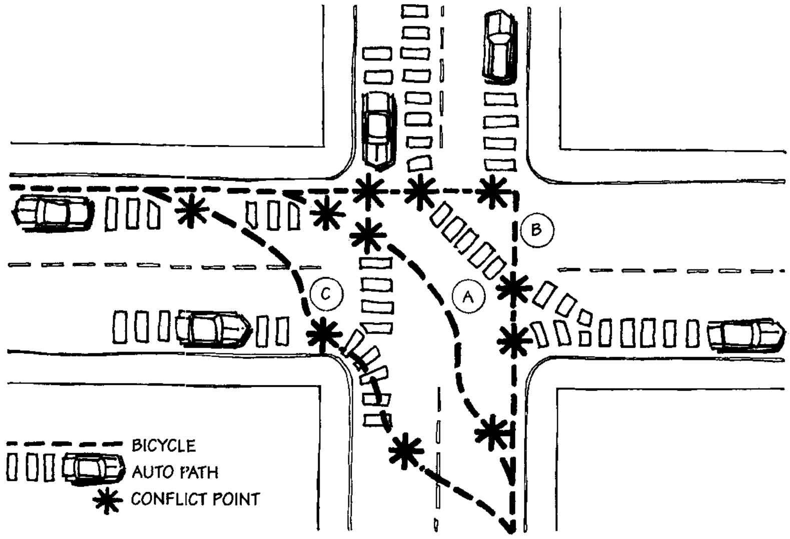

Figure 341-10. Intersection conflict points for left turning bicyclists.

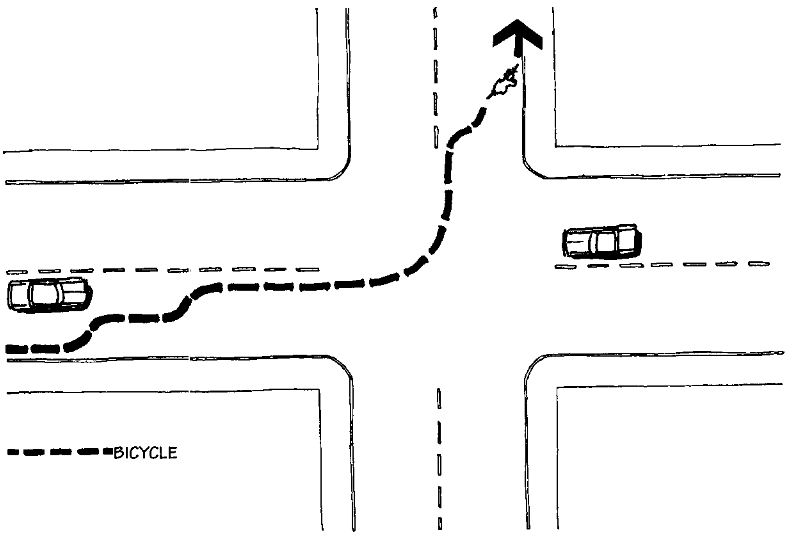

Figure 341-11. Problem of left turning bicyclists. *If auto traffic is moderate to heavy, bicyclists can turn left, flowing with the traffic.*

KEY POINTS: Design Criteria

Bikeway design is based upon the following safety issues:

1. Designated design speed, typically 32 km/h (20 mph), up to 48 km/h (30 mph) for sustained down hill runs.

2. Sight/stopping distance and related clearances may require path widening at horizontal curves, and markings at intersections and some vertical curve crests.

3. Curve radii range from 28 500-165 500 mm (95-565 ft) depending on design speed, and superelevation rates range from 1.0-2.0%, depending on speed, radius, and climate.

4. Potential conflicts at intersections/crossings due to turns across traffic by both cyclists and motorists.

The types of problems encountered in these three situations vary with the type of bikeway. Intersection problems are nonexistent with bicycle paths by virtue of their complete separation from vehicular traffic. The intersection problems of a bicycle lane and of a wide outside lane or a shared roadway are similar. Bicycle lanes represent the most complex set of intersection problems because all three of the above-listed problems are involved and solutions to conflicts between motorists and bicyclists are expected, given the obvious demarcation of their separate domains.

Conflict points and solutions for each problem are described below.

Bicyclists Turning Left across Traffic:

There are several ways for bicyclists to turn left across vehicular traffic, each one posing serious hazards to the rider. Figure 341-10 illustrates the many intersection conflict points that exist when a bicyclist turns left across traffic.

Path A in Figure 341-10 shows the bicyclist leaving the bikeway lane on the far right and, like a motor vehicle, moving to the center lane position to execute a left turn. This alternative accepts the established desires of bicyclists to be treated as vehicle operators rather than as pedestrians, but it exposes the bicyclists to sideswipes and to the failure of automobiles going in either direction to yield the right-of-way. Many bicyclists nevertheless choose this alternative unless a different route is mandated.

Path B in Figure 341-10 shows the bicyclist crossing the intersection in the right lane and, when traffic allows, executing a 90-degree left turn across the street. This alternative is considered contrary to the established desires of bicyclists to be treated as vehicle operators rather than as pedestrians, and it may be slightly confusing to motorists because the bicyclist is behaving neither like a motorist nor like a pedestrian. This solution presents several hazards from through-traveling vehicles as well as from vehicles turning in front of the bicyclist. A less confusing system is one that calls for the bicyclist to walk the bike across both streets, precisely like a pedestrian, but some bicyclists may object to such an inconvenience.

Path C in Figure 341-10 shows the bicyclist weaving across the approach street and, at the first gap in the traffic, proceeding wrong-way through the intersection. This approach is considered very danger-

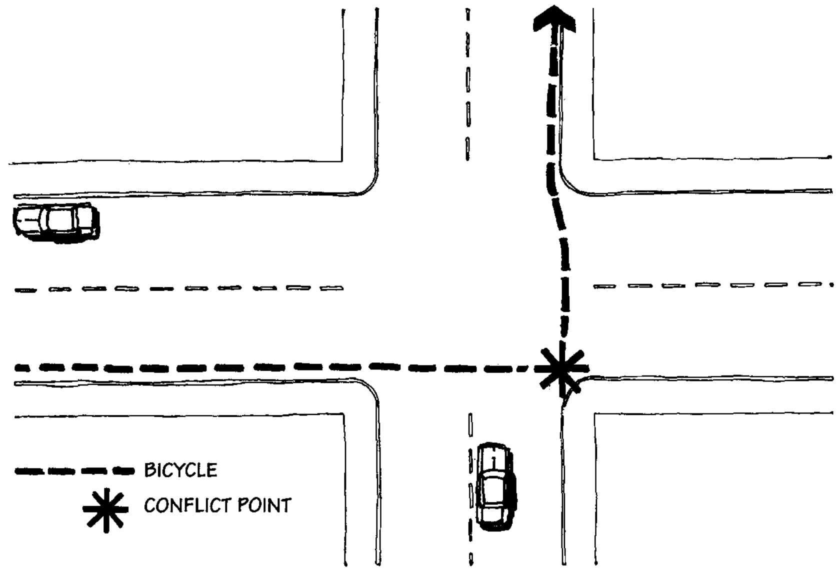

Figure 341-12. Problem of left-turning bicyclists. *When auto traffic is moderate to heavy, bicyclists often stop at far corner and wait for a break in traffic.*

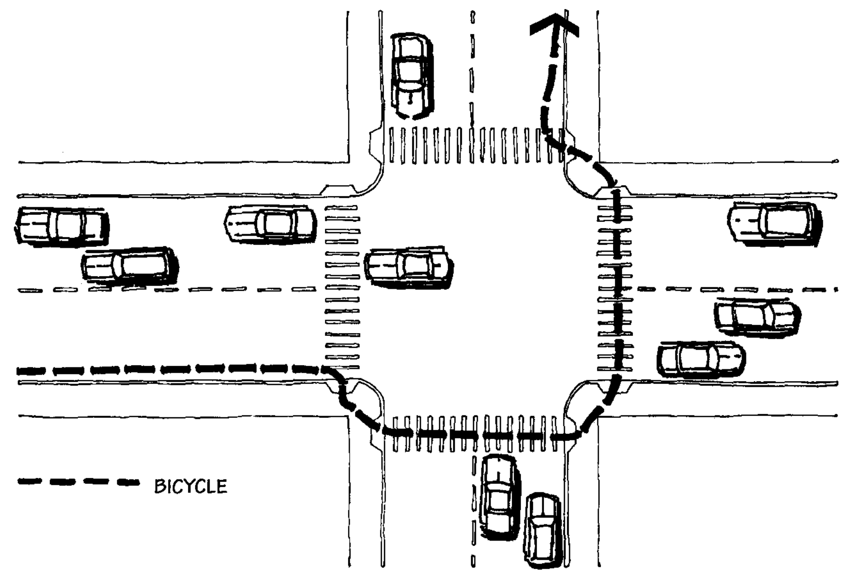

Figure 341-13. Problem of left-turning bicyclists. *If auto traffic is very heavy, some bicyclists may choose to walk their bicycles with pedestrians.*

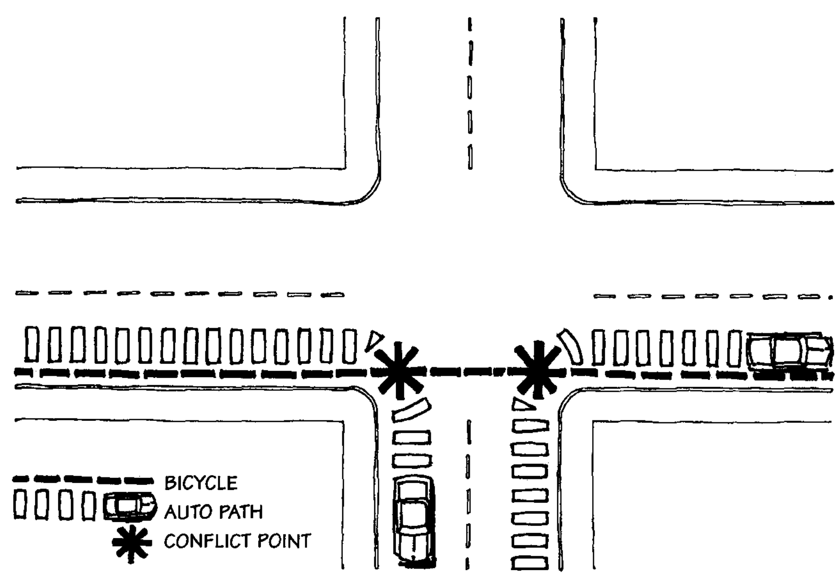

Figure 341-14. Intersection conflict points. *When vehicular traffic is entering from or turning right.*

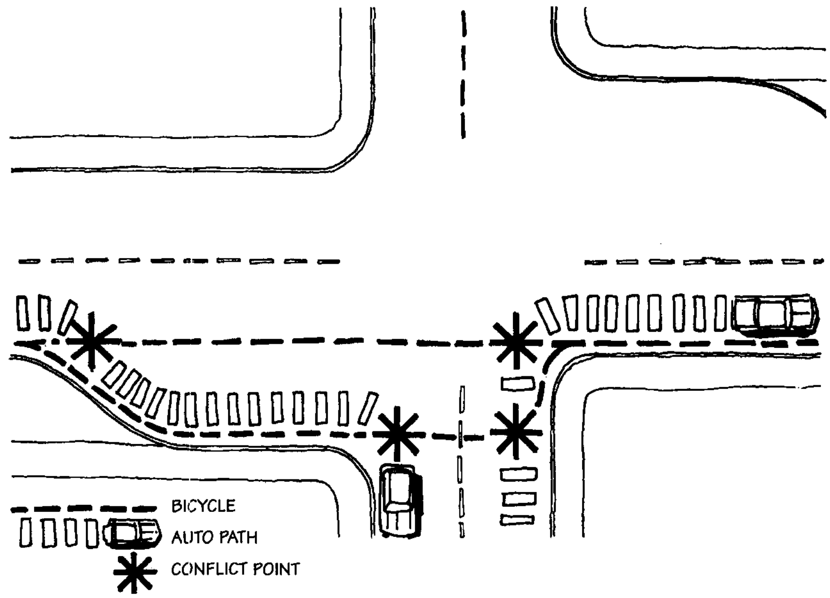

Figure 341-15. Intersection conflict points. *When vehicular traffic is entering from or turning right (indented right-turn lanes).*

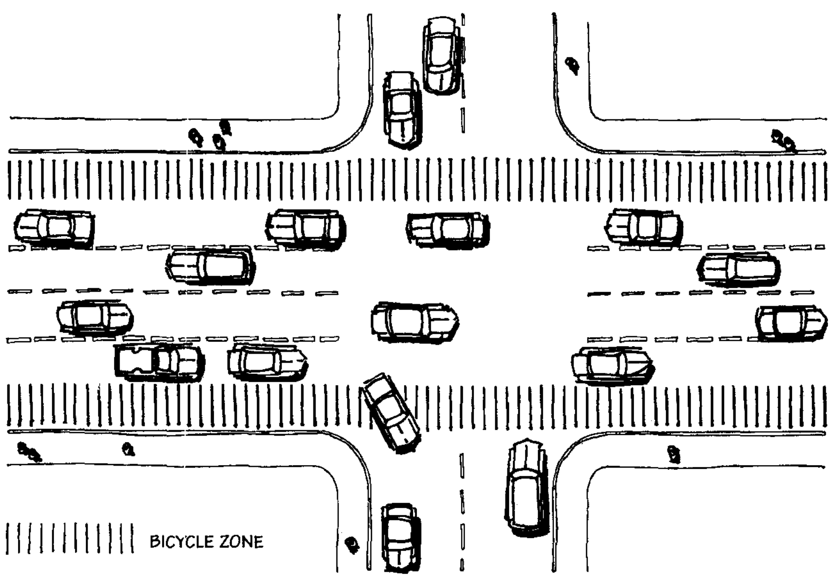

Figure 341-16. Problem of entering or right turning auto traffic. *One alternative is to widen the right lane to give bicyclists the opportunity to maneuver around right-turning auto traffic.*

ous and it should be discouraged or prevented whenever possible.

Figures 341-11, 341-12, and 341-13 illustrate three common solutions to the problem of left-turning bicyclists.

Vehicular Traffic Entering from or Turning to the Right:

A serious problem exists where there are designated vehicular right-turn lanes which force motor vehicles into the bikeway in bike lane and shared roadway conditions. Many motorists do not see bicyclists coming from the rear either because they are preoccupied with other motor vehicles or because of the blind spot to the right rear of most automobiles. Also, most motorists are not accustomed to looking for bicyclists on roadways, and some are simply reluctant to grant the right-of-way to bicyclists. Figures 341-14 and 341-15 show intersection conflict points for this situation.

If auto traffic on cross-streets is moderate to heavy, a possible solution to the problem is to make the right-turn lanes extra wide to give bicyclists the opportunity to maneuver around the turning vehicles (Figure 341-16). This kind of open-field approach is replete with user uncertainty and inherent danger. Signs should always be used to alert right-turning motorists to bicyclists on their right. Figures 341-17 and 341-18 show possible solutions to the problem for roadways with indented right-turn lanes.

If the auto traffic on cross-streets is light, the bikeway lanes might better continue straight through the intersection, as shown in Figure 341-19.

Midblock Crossings:

An at-grade crossing could be used when bike paths or bike lanes must cross a roadway with relatively light traffic at midblock. It should be made to intersect the roadway as close to a right angle as possible so that the bicyclists will be able to see the oncoming traffic in both directions (Figure 341-20). It is also usually appropriate to STOP the bicycle traffic in deference to the motor traffic. Overpasses or underpasses should be considered if these bikeways have to cross more heavily traveled roadways.

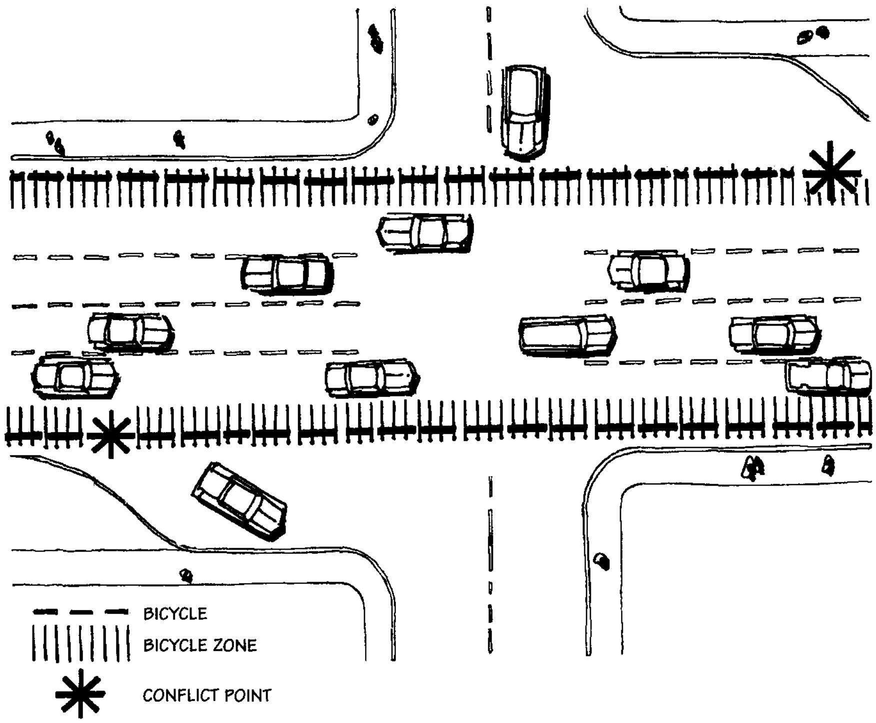

Figure 341-17. Problem of entering or right turning auto traffic. *In this instance, it is primarily the responsibility of the bicyclist to understand the inherent danger at the major conflict point.*

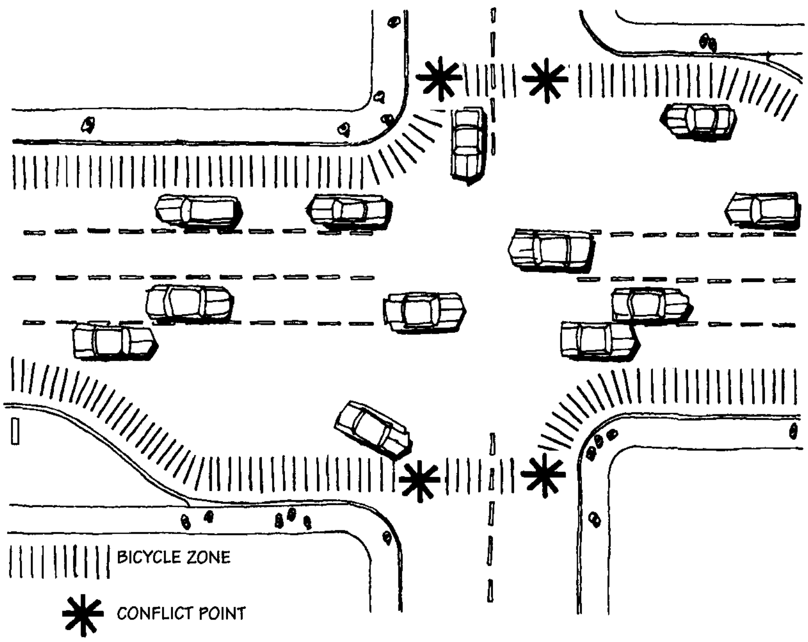

Figure 341-18. Problem of entering or right turning auto traffic. *This alternative usually requires that the bicyclist stop at the major conflict point and wait for a break in right-turning traffic, and should be avoided.*

Freeway Ramp Crossings:

Bicyclists should be encouraged to cross intersections early enough to be easily seen by exiting vehicles where bikeways follow highways or freeways with off ramps (Figure 341-21).

Underpasses and Overpasses:

Ramp grades for either underpasses or overpasses should preferably be no steeper than 5 percent. The approach to the underpass or overpass should be visually obvious and should provide the easiest and safest alternative to crossing the roadway (Figure 341-22).

Curb Ramps:

A ramped curb should be provided when a bikeway encounters a roadway curb (Figure 341-23). These structures also permit crossings by wheelchairs, baby carriages, etc. The maximum running grade should not be greater than 1:12, or about 8 percent. (Refer to Section 240: Access and Egress: Outdoor Standards, and Section 241: Access and Egress: Architectural and Transportation Guidelines, for more information.)

6.0 DESIGN ELEMENTS

Design elements may be grouped into three categories: 1. Pavement materials

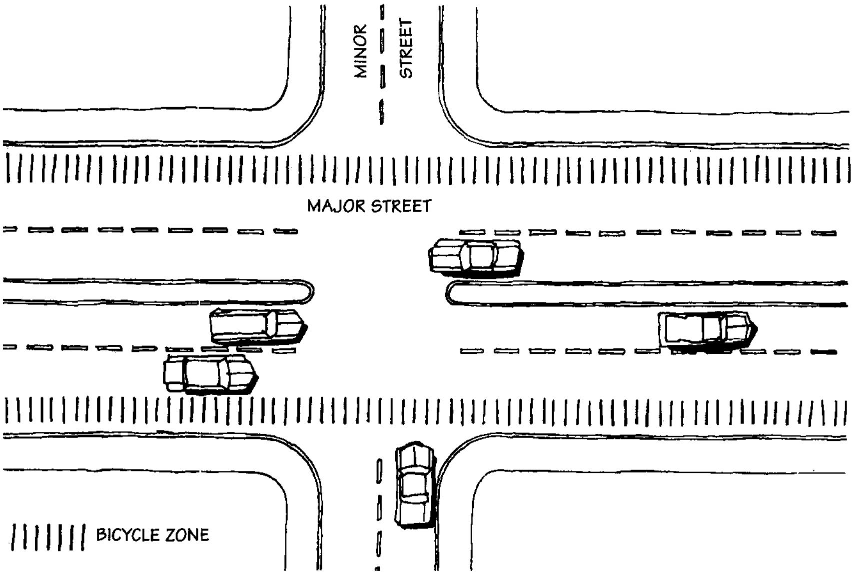

Figure 341-19. Problem of entering or right turning auto traffic. *If auto traffic is light, bicycle traffic can continue straight through the intersection and should be treated as a vehicle.*

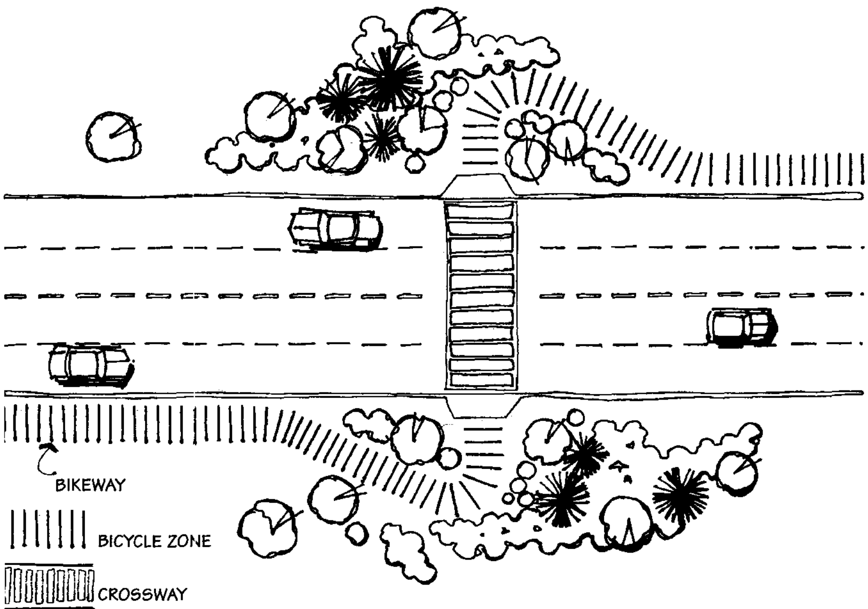

Figure 341-20. Midblock intersection. *The bikeway should cross the roadway as close to right angles as possible.*

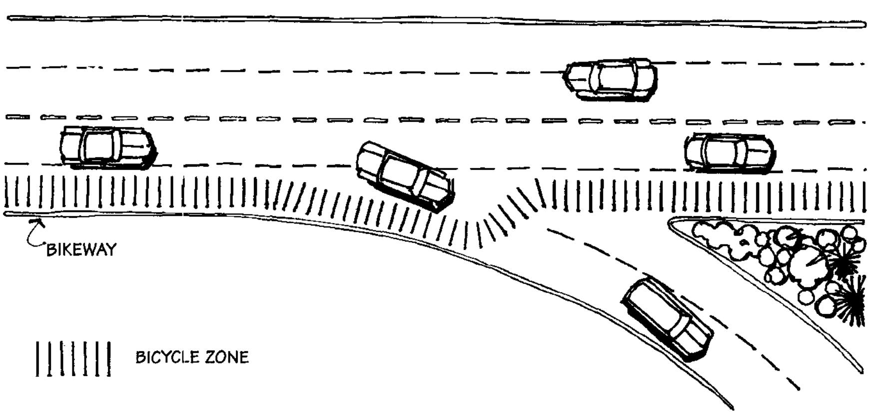

Figure 341-21. Freeway ramp crossings. *Bikeways should cross freeway ramps early enough to be seen by right-turning traffic.*

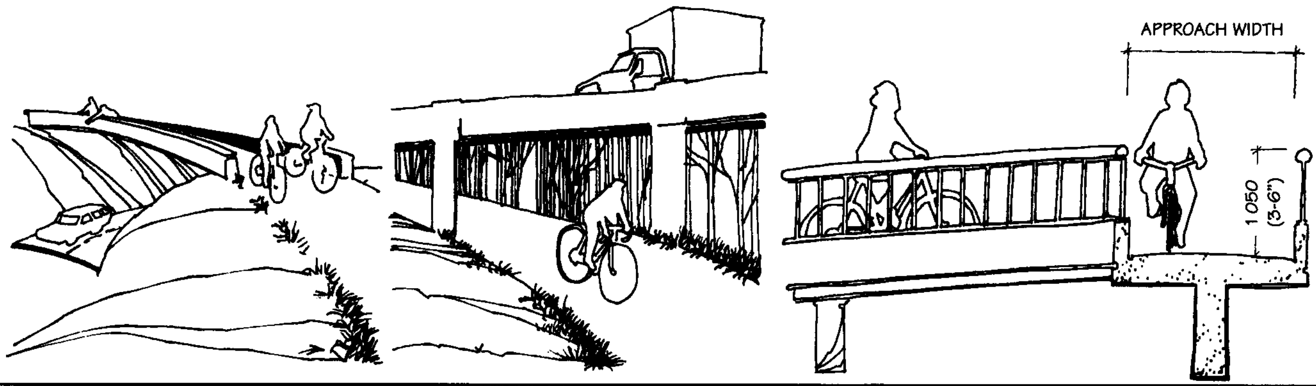

Figure 341-22. Underpass and overpass.

and associated requirements, 2. Path support structures for safety, comfort, and utility, and 3. Path defining elements for general aesthetic and cultural appropriateness.

6.1 Paving and Surfacing

Some types of bikeways share the pavement of an existing roadway, and construction considerations are specific to vehicular traffic. However, if a street or shoulder is widened or a separate bikeway is constructed, the pavement should be a smooth, nonslick surface and have a thickness capable of supporting normal-size maintenance vehicles.

This section does not include detailed information about the construction of pavements for bicycle routes. However, the following notes on various pavement materials are offered as a general overview, and references to other appropriate sections are given

Asphalt:

Hot-mix asphalt is the most popular paving material used for bikeways. (Refer to Section 820: Asphalt, for more information.)

Concrete:

Concrete is the second most frequently used paving material for bikeways. The finish should be lightly textured to prevent slipperiness when wet. Unless sawed joints are used, conventional contraction and construction joints in the pavement cause rhythmic bumps which are annoying to some riders. (Refer to Section 830: Concrete, for more information.)

Soil Cement:

Soil cement is occasionally used for bikeways, although it will deteriorate much sooner than either asphalt or concrete. If deterioration occurs, a seal coat of bituminous asphalt or asphaltic concrete can be applied. (Refer to Sections 810: Soils and Aggregates, 820: Asphalt, and 830: Concrete, for more information.)

Stone Chip Aggregate:

Stone chip aggregate is most useful when the bikeway is to be used primarily for recreational purposes. This material creates fewer drainage problems than the other types of paving, although it requires structural edging (e.g., wood, metal, or plastic) to contain the aggregate. (Refer to Section 810: Soils and Aggregates, for more information.)

Stabilized Earth:

Stabilized earth is perhaps the least expensive way to create a paved surface for a bikeway. However, it is also the least durable and requires the most maintenance to keep it in good condition. (Refer to Sections 810: Soils and Aggregates, and 440: Surfacing and Paving, for more information.)

6.2 Drainage of Bikeway Surfaces

Bikeway surfaces should be pitched at least 2 percent (depending on the texture and composition of the surfacing material) to provide positive drainage. (Refer to Sections 320: Grading Techniques, and 330: Site Drainage, for more information.)

Continuous curbing should be interrupted intermittently to allow for drainage of the bikeway and any adjacent hard surfaces. Surface drain inlets should be provided if the curbs are not interrupted. Drainage grates with slots running parallel to the line of bicycle travel can catch bicycle wheels, damaging rims and causing accidents (Figure 341-24). Some communities solve the problem by temporarily welding transverse bars over existing grates, but snowplows may destroy these. Transverse (or angled) bar or honeycomb grates are preferred. Most bicyclists will avoid riding over almost any type of grate. Drainage grates narrow the effective width of a bikeway and may cause riders to swerve into traffic or other bicyclists. They should be designed and located to minimize danger to bicyclists and avoided where possible.

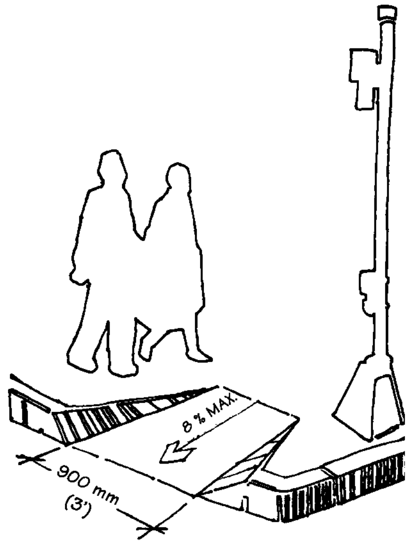

Figure 341-23. Curb ramp.

6.3 Information Systems

Nearly all signs and markings placed on public streets and highways for the benefit of the motorist also apply to the bicyclist.

Traffic Control Devices:

Basic principles governing the design and use of traffic control devices are set forth in the 1988 Manual on Uniform Traffic Control Devices (MUTCD) (pt. 9: Bicycle Facilities), produced by the U.S.

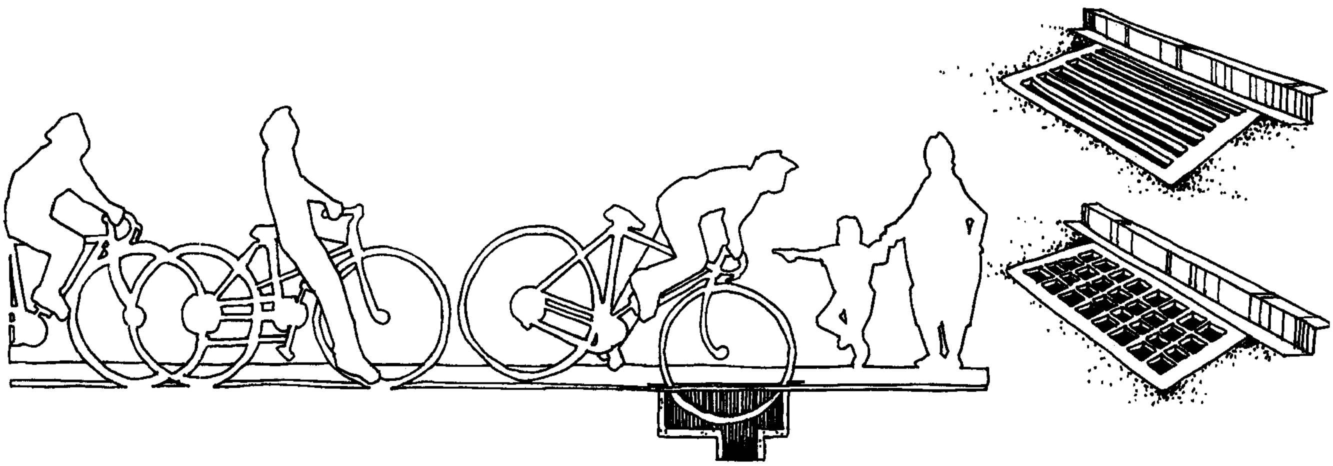

Figure 341-24. Hazards of drainage grates.

Department of Transportation. This source identifies five basic requirements that a traffic control device should meet to be effective; it should:

1. Fulfill a need
2. Command attention
3. Convey a clear, simple meaning
4. Command respect of road users
5. Provide adequate time for response

Standards of design, placement, operation maintenance, and uniformity have been carefully developed to meet these requirements. Care should be taken not to employ a special treatment when a standard treatment will serve the purpose.

NOTE: In the United States, the MUTCD can often be found in local and state highway engineering offices.

Types of Signage:

Signs are categorized into three basic types: (1) regulatory, (2) warning, and (3) guide.

Regulatory signs inform users of traffic laws and regulations governing movements, parking, speeds, etc., and indicate rules that would otherwise not be apparent, such as MOTOR VEHICLES PROHIBITED, NO PARKING, or BICYCLES ONLY.

Warning signs call the user's attention to potentially hazardous conditions and should be placed sufficiently in advance of the hazard to allow for responsive action. The BIKE-X-ING warning, for example, is used to alert motorists to places where a bikeway crosses a street or roadway. Other examples include BUMP, PAVEMENT ENDS, DIP, ROAD NARROWS, and NARROW BRIDGE.

Guide signs provide roadside information to orient and assist users geographically. Typically, guide signs are of most use to bicyclists who are unfamiliar with the layout of an area or facility. Standard guide signs include the BIKE ROUTE sign, supplementary plates such as BEGIN or END, and directional plates with a variety of arrow designations.

Placement of Signs:

Guide signs, such as BIKE ROUTE and supplemental plates, should be placed where a route begins, ends, changes direction, or intersects with other bikeways. Intermediate guide signs should be provided to reassure bicyclists of their position if distances are great between major decision points. Signs warning motorists that bicyclists may be encountered, and vice versa, should be provided where a bikeway intersects a road or sidewalk, at the beginning and end of a bikeway, and at points where large numbers of bicyclists may be expected (e.g., schools and parks).

Signs erected at the roadside should be mounted with the lower edge of the sign no less than 1 500 mm (5 ft) above the pavement on rural roadways, and 2 100 mm (7 ft) above the pavement in residential, business, and commercial districts and on expressways. However, these heights respond to the motorist's field of vision. Signs on roadways which include bicycle lanes should be placed at a lower level corresponding to the bicyclist's field of vision. Signs on isolated bicycle routes can be mounted 1 200 to 1 500 mm (4 to 5 ft) above the pavement, and signs along roadways that are intended specifically for bicyclists may be mounted at a lower height.

Care should be taken to place signs–particularly those at the lower heights–where they will not be obscured by other common elements such as parked cars or vegetation. Bicycle-oriented warning signs should be positioned far enough in advance of the condition to allow time for perception and response, based upon design speeds and sight/stopping distances (Figure 341-6). Placement should be such that a safe horizontal distance of 1 000 mm (3 ft) is maintained between the edge of the bikeway surface and the nearest projection of the sign.

Pavement Markings:

Pavement markings are used to reinforce signage by providing additional information. They are particularly useful for bikeways since they, more than signs, are directly in the bicyclist's normal zone of vision. Striping and message stencils are the most common forms of pavement markings.

Bicycle lanes are normally delineated by a solid, painted line 100 or 150 mm (4 or 6 in) wide between the bicycle lane and the roadway. White is the standard color for bicycle lane-related pavement markings. Some experimentation has been done with other colors in attempts to increase recognition, but the National Advisory Committee on Uniform Traffic Control Devices concluded that other colors had poor visibility characteristics and were unacceptable for bicycle lane markings. Additional cross-striping (zebra striping) is often used to increase visibility at intersections.

Stenciled message markings are normally white, with a minimum letter and arrow height of 1 200 mm (4 ft), and include such

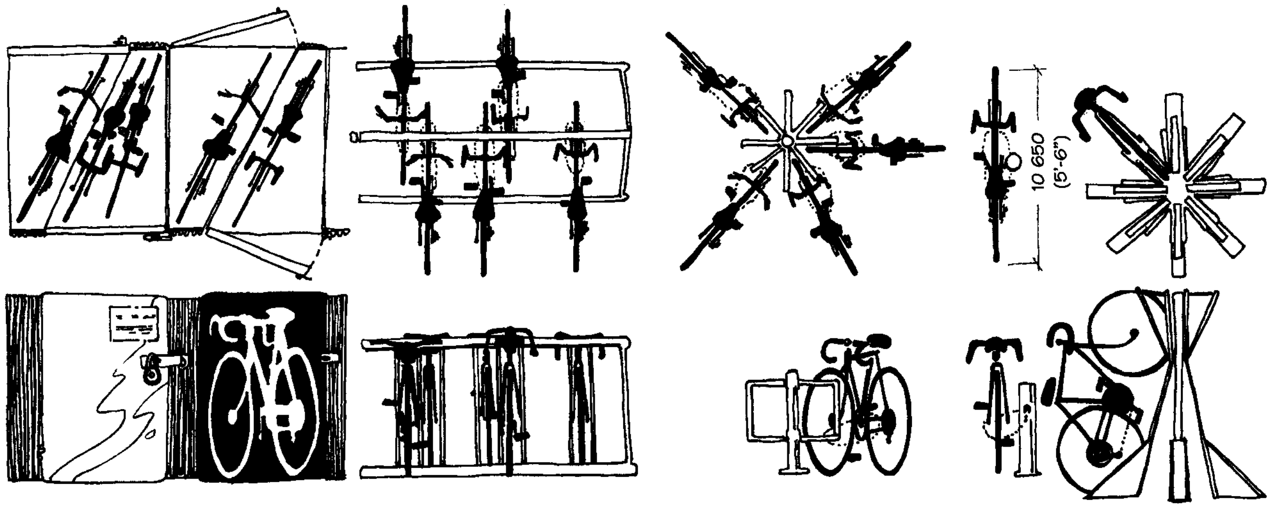

Figure 341-25. Storage lockers and racks.

messages as STOP, YIELD, PED-X-ING, SLOW, RR X-ING, and BIKE LANE, supplemented with an arrow indicating the direction of travel. BIKE LANE or BIKE ONLY messages should be placed at the beginning of a bikeway, at intersections with roadways and other facilities, at midpoints on long blocks, and downstream of major driveways. Care should be taken to avoid placing painted pavement markings at critical stopping points and to limit their occurence. Painted pavements can reduce friction, making stopping more difficult and increasing the dangers of sideslip. Pavement markings are sometimes less visible in areas where snow is a problem, thereby reducing their effectiveness.

KEY POINTS: Design Elements

1. Surfacing materials vary in terms of suitability, cost and durability. Durable easily maintained pavements which conform to accessibility regulations are recommended.

2. Positive drainage should accommodate the pavement and bikeway type to minimize hazards. A 2% minimum cross-slope is desirable. Locate drain structures off of the path to minimize accidents due to settlement or heaving of structure at paving surface.

3. Traffic control/informational systems such as signage and pavement markings facilitate use.
   a. Sign post should be set-back at least 900 mm (3 ft) from path edge, and bottom sign edge should be set 1 500-2 100 mm (5-7 ft) above grade for proper visibility.
   b. Limit number of signs to minimize confusion.
   c. Use signs primarily to mark route, regulate use, and provide safety warnings as required.

4. Lighting at intersections and along path are essential for safety and utility, and typically range from 6-10 lx (0.6-1.0 fc).
   a. Placement of lights and other path furnishings require design coordination to prevent a cluttered appearance along the path.
   b. Benches, racks, and other furnishings require significant setbacks from path to prevent conflicts

5. Barriers and separators such as fencing, plantings, and painted lines, are used to delineate facilities and uses.
   a. Raised or textured surface barriers may pose a hazard in left-turn or in high speed conditions. Choose barrier type appropriate to facility use.
   b. Plantings require proper set-backs to allow for safety clearances and adult plant growth. Select species for safety and maintenance considerations.

6.4 Site Furnishings

Racks and Locking Devices for Bicycles:

Three primary methods for parking bicycles and protecting them from theft are:

1. Enclosing the bicycle in a locker, cabinet, or other lockable space
2. Rendering the bicycle inoperable by weaving a chain and lock through the frame and wheels
3. Locking the bicycle to a rack, post, or other stationary object

The first and third methods are most effective (Figure 341-25). Lockers effectively prevent thefts and relieve the bicyclist of the need to carry heavy chains and locks, but they are space consuming and expensive to install. Devices which provide lateral support only at one wheel leave the bicycle vulnerable to damage.

Bicycle racks and parking facilities should be located as close to destinations as possible without interfering with pedestrian traffic. Storage facilities too far away [more than 15 000 mm (50 ft)] encourage the bicyclist to attach the bicycle to the nearest tree, lightpole, or parking meter. Locate storage facilities where there is visual supervision, lighting, and shelter from inclement weather.

Fixtures for Bicycle Routes:

Depending upon the character, scale, and anticipated use of a bikeway, such elements as shelters, benches, tables, grills, rest rooms, trash receptacles, bulletin boards, telephones, and drinking fountains may be provided.

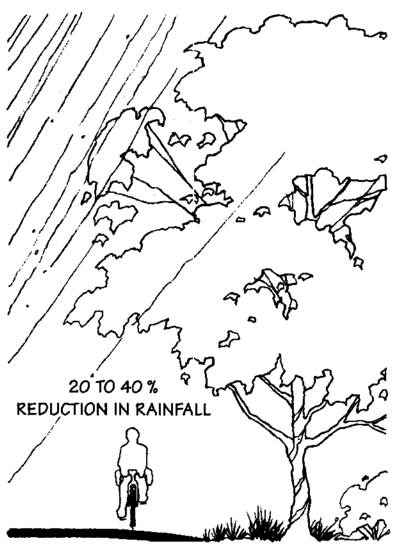

Figure 341-26. Convenience to bicyclists. *Tree canopies can reduce the amount of rainfall reaching the bicyclist.*

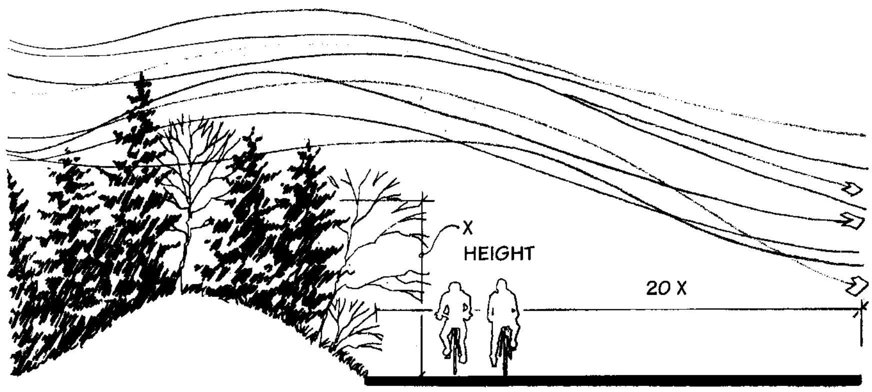

Figure 341-27. Convenience to bicyclists. *Trees can reduce windspeeds by up to 50 percent for a distance downwind 20 times the height of the windbreak.*

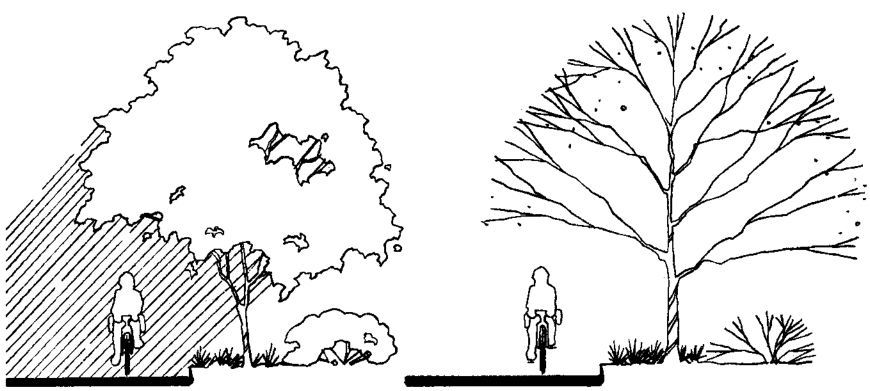

Figure 341-28. Convenience to bicyclists. *Deciduous trees provide shade in summer and allow light through in winter.*

Installation and maintenance costs are a major determining factor, especially with water and toilet facilities. Simple rest stops where bicyclists can pull off the bikeway and rest or enjoy a view are obviously much less expensive, and they can add much to the attractiveness of a recreational facility.

Bikeway Lighting:

Bikeway lighting requirements vary from 6 lux (lx) [0.6 footcandles (fc)] in parks and similar areas, to 10 lx (1.0 fc) in commercial areas, to 20 lx (2.0 fc) at intersections with heavily trafficked streets. Commercial areas with existing illumination may require no additional lighting. The positioning of new luminaires should be such that bicyclists are backlighted against approaching traffic. (Refer to Section 540: Outdoor Lighting, for more information.)

6.5 Barriers and Separators

Bikeways which share or are immediately adjacent to a roadway may be delineated as described below.

Fencing and Plantings:

Fencing provides the least space consumptive physical barrier to contain the path for either screening or safety reasons. Fencing should be deeply setback from the path for safety reasons. Many fencing options are available and may be combined with vine cover to soften less expensive open wire or simple rail fencing (Refer to Section 450: Fences, Screens, and Walls). Shrub planting is an effective screening option, but requires more space than does fencing. Care should be taken to specify plants with appropriate growth habits to meet clearance requirements, and to avoid thorns or excessive fruit droppings. Single standard trees may afford a better multi-purpose option due to a potential for canopy effects (Refer to Section 550: Plants and Planting, and Section 240: Outdoor Accessibility).

Painted Lines:

The simplest and least expensive bikeway delineation is the painted line. It can continue through intersections, allow bicyclists to leave the lane to make left turns, and permit automobiles to enter driveways. A disadvantage of painted lines is the lack of a physical barrier or tactile warning to prevent the encroachment of motor vehicles. Paint that will not become slippery when wet should be specified.

Traffic Buttons:

Raised and reflectorized traffic buttons are sometimes used to delineate bike lanes, either alone or in combination with painted lines. This method provides a visual and tactile warning to the motorists while still allowing lane changes and access to driveways. However, the raised buttons, or other raised elements, are dangerous to cyclists and may make left turns difficult.

6.6 Bikeway Plantings

Plants can reduce headlight glare and traffic dust and can prevent accidental crossovers when used to provide a visual and physical barrier between bicycle and motor vehicle traffic. Plant materials can also mitigate the discomforts of weather. A canopy of deciduous and coniferous trees over a bikeway, for instance, can reduce the amount of rainfall reaching bicyclists by as much as 20 to 40 percent (Figure 341-26). Leaf buildup may require increased maintenance.

Dense planting of trees in a row, perpendicular to prevailing winds and parallel to the bikeway, can reduce wind speeds by

50 percent for a distance downwind of from 10 to 20 times the height of the windbreak (Figure 341-27).

Extremes of heat and cold can also be modified by careful selection and use of plant materials. Deciduous trees can provide shade from the sun in the warm seasons, allow sunlight to penetrate to the ground in the cool seasons, and minimize diurnal temperature changes by trapping heat and reducing its loss through radiation to the atmosphere (Figure 341-28). Plant massings can also alter snow drifting patterns and melting rates through microclimate modification. (Refer to Sections 260: Climate and Energy, and 550: Plants and Planting, for more information on microclimate control.)

The disadvantages of plantings include the consumption of a substantial amount of space and possible confusion at intersections where the planted strip must be broken. Trees planted in a row between the two modes of transportation provide a visual, psychological, and limited physical barrier and take up less space than heavy shrub massings.

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SECTION 342

Vehicular Circulation

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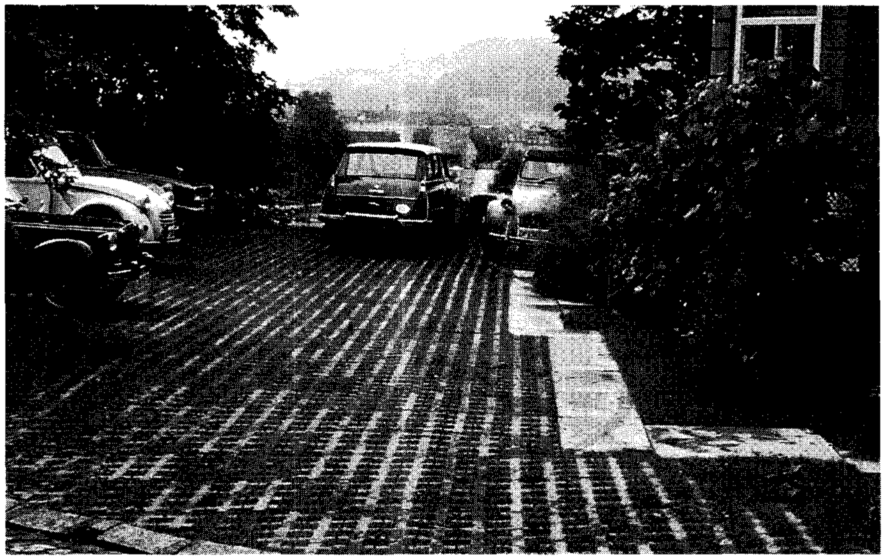

N. Dines

CONTENTS

1.0 INTRODUCTION

1.1 General

The automobile is one of the basic considerations in site planning and design. Often vehicular circulation patterns set the scale and form of future development. As a result, understanding the role of vehicular circulation in the site planning process is critical to satisfying its functions.

1.2 Classification of Vehicular Circulation Systems

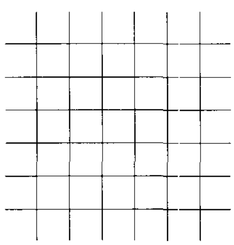
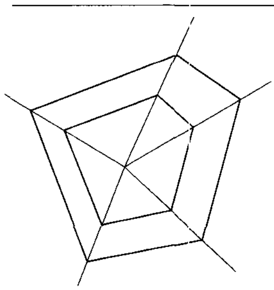
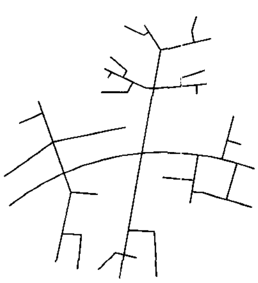
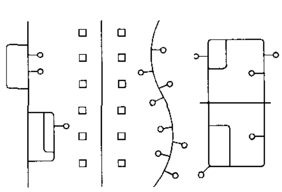
Roadway systems are grouped into a number of different classifications for administrative, planning, and design purposes. Classifications are usually based on traffic volumes, speed, general design requirements, and maintenance requirements.

In the most basic classification system for design work, highways and streets are typically grouped into the following four categories (Figure 342-1).

1. **Freeway systems:** (including expressways and parkways): these systems allow rapid and efficient movement of large volumes of through-traffic between and across urban areas. They have limited access with grade-separated interchanges.
2. **Major arterial systems:** these systems allow through-traffic movement between and across urban areas with direct access to abutting properties. They are subject to control of entrances, exits, and curb use.
3. **Collector street systems:** these systems allow traffic movement between major arterials and local streets, with direct access to abutting properties. Traffic control is usually provided by stop signs on the side streets.
4. **Local street systems:** these systems allow local traffic movement and direct access to abutting properties.

Parkways are an important type of recreational circulation route, facilitating the

Table 342-1. TYPICAL ROADWAY PATTERNS

		Advantages	*Disadvantages*
	*Grid Pattern*	• Simplicity, regularity • Ease of layout (engineering) • Convenient access • Good orientation, easy to follow • Good on level land • Suitable for complex distributed flow	• Visual monotony • Disregard of topography • Vulnerability to through traffic • Lack of difference between heavily and lightly traveled ways
	*Radial Pattern*	• Good direct line of travel	• Not good when neither origin nor destination are related to center • Difficult for service • Causes problems in local flow and creates difficult building sites
	*Classic Pattern*	• Favors the specialization of major vs. minor arteries • Makes the intersection problem manageable by distributing instead of concentrating at center	• Very sensitive to interruptions at single point
	*Linear System*	• Flow primarily between two points • Typically found along railroads, canals, highways	• Lack of focus

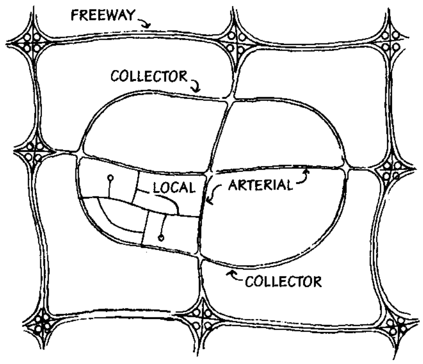


Figure 342-1. Typical vehicular classification system.

efficient movement of large volumes of traffic through areas of high scenic quality. They usually prohibit trucks, buses, and other commercial traffic.

On-site drives and roads refer to vehicular access routes within a site; they represent a category of classification finer than that of the local street system.

Most of this section will focus on the design and construction of on-site roads and parkways, although design standards, techniques of layout, and methods of construction apply to all categories of vehicular circulation. Design and construction measures appropriate to each category will depend upon the local practices and requirements set by controlling public authorities.

1.3 Circulation Patterns

Various roadway patterns are commonly used to lay out a vehicular circulation system (Table 342-1).

1.4 Basic Design Guidelines and Principles

The design of vehicular circulation systems involves both aesthetic judgment and sound engineering practice. A well-designed roadway should harmoniously fit into the surrounding landscape while maintaining the driver's site lines and views. These aesthetic objectives require that the designer visualize the three-dimensional aspects of a roadway, including the various combinations of horizontal and vertical curves, of cuts merging smoothly with fills, and of side slopes blending well with the terrain.

A roadway, however, is primarily a transportation medium. It must be designed and built to facilitate the safe movement of vehicles. To achieve this objective, the design of a roadway must incorporate the criteria of strength, safety, and uniformity common to sound engineering practice.

The following are general design guidelines and principles to consider when designing vehicular circulation systems at any scale:

1. The location of a roadway should be based on a survey of all relevant factors. These include but are not limited to:
   a. Present and proposed land uses and traffic ways
   b. Areas where redevelopment or change is desirable
   c. Existing and planned transportation infrastructure
   d. Traffic "desire lines"
   e. Topographic features
   f. Ecological factors
   g. Cultural and historic factors
   h. Scenic opportunities
   i. Social, economic, and political structures
   j. Safety
   k. Acquisition and development costs
   l. Operation and maintenance costs
2. The location of a roadway must be responsive to natural forces and features.
3. The location and design of a roadway must include consideration of its effect on adjacent properties in terms of noise and fumes. (Refer to Section 660: Sound Control, for more information.)
4. A roadway should be so aligned and constructed as to preserve and accentuate the best qualities of the landscape, providing for a variety of visual experiences.
5. The vertical and horizontal alignment of a roadway should be carefully coordinated to fit into the landscape.

2.0 DESIGN CONTROLS

2.1 General Roadway Standards

Table 342-2 is a comparative summary of design standards for arterial, collector, and

Table 342-2. SUMMARY OF MINIMUM DESIGN STANDARDS FOR URBAN STREETS

	Principal Arterial			Collector Streets		Local Streets	
Design Elements	**Freeways and Expressways**	**Other**	**Minor Arterials**	**Single-Family Residential Areas**	**Other**	**Single-Family Residential Areas**	**Other**
Design Speed, km/h (mph)	95 (60)	65 (40)	50 (30)	50 (30)	50 (30)	30 (20)	50 (30)
Number of Traffic Lanes	4 up	4 up	4-6	2	4	2	2-4
Width of Traffic Lanes, mm (ft)	3 660 (12')	3 660 (12')	3 660 (12')	3 660 (12')	3 660 (12')	3 050 (10')	3 355 (11')
Width of Curb Parking Lane or Shoulder, mm (ft)	3 660 (12')	3 050 (10')	3 050 (10')	3 050 (10')	3 050 (10')	2 440 (8')	3 050 (10')
Width of Right-of-way, mm (ft)	36 575 up (120' up)	36 575 up (120' up)	30 480 - 36 575 (100-120')	18 290 (60')	18 290 (80')	15 240 - 18 290 (50-60')	18 290 - 24 385 (60-80')

local streets. Tables 342-3 and 342-4 give standards for collector and local streets based on terrain and development density.

2.2 Driver Characteristics

Because driver characteristics are a major factor in the design of vehicular circulation systems, human limitations and behavior must be understood and taken into account. The success of the design is dependent upon a thorough understanding of the driver. An understanding not only of average human physical and mental limitations, but also of the range of user performance, is important for sound judgment in the design of traffic controls and operating measures.

Reaction to External Stimuli:

Reacting to external stimuli involves a series of events which are inherently related to human physical factors:

1. Perception: seeing the stimuli for the first time along with other perceived objects.
2. Identification: the identification and understanding of the stimuli.
3. Judgment: the decision-making process.
4. Reaction: the physical execution of the decision.

The total time required to perceive and react to a stimulus is the sum of the above four factors, referred to as PIJR.

Visual Factors in Perception and Identification:

Visual Acuity: Visual acuity refers to the field of clearest vision. The most acute vision is limited to a narrow cone of 3 to 5 degrees; however, sight is fairly clear within a cone of 10 to 12 degrees (Figure 342-2).

Peripheral Vision: Peripheral vision refers to the field of view within which an individual can see objects without clear detail or color. The field of normal peripheral vision in humans varies from 120 to 180 degrees (Figure 342-3).

Depth Perception: Depth perception refers to the ability to estimate distance and speed.

Glare and Recovery: Glare recovery time (i.e., the time required to recover from the effects of glare after a light source has passed), is approximately 6 or more seconds when moving from light to dark areas and about 3 seconds when moving from dark to light areas.

Table 342-3. COLLECTOR STREET DESIGN STANDARDS

	Level Terrain	Rolling Terrain	Hilly Terrain
Right-of-way Width, mm (ft)	21 335 (70')	21 335 (70')	21 335 (70')
Pavement Width, mm (ft)	10 975 - 12 190 (36' to 40')	10 975 - 12 190 (36' to 40')	10 975 - 12 190 (36' to 40')
Type of Curb	Vertical Face	Vertical Face	Vertical Face
Sidewalk Width, mm (ft)	1 525 (5')	1 525 (5')	1 525 (5')
Sidewalk Distance From Curb Face, mm (ft)	3 050 (10')	3 050 (10')	3 050 (10')
Minimum Sight Distance, mm (ft)	76 200 (250')	60 960 (200')	45 720 (150')
Maximum Grade	4%	8%	12%
Minimum Spacing Along Major Traffic Route, mm (ft)	396 240 (1300')	396 240 (1300')	396 240 (1300')
Design Speed, km/h (mph)	55 (35)	50 (30)	40 (25)
Minimum Centerline Radius, mm (ft)	106 680 (350')	70 105 (230')	45 720 (150')

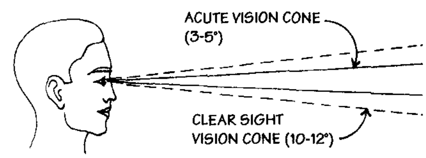


Figure 342-2. Visual acuity cone.

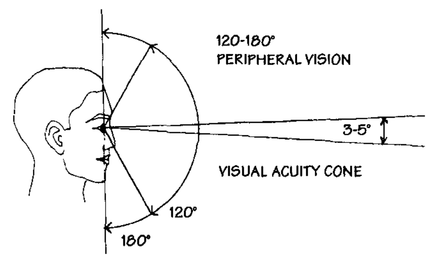


Figure 342-3. Peripheral vision.

Color Vision: Generally, full color vision is not of great importance in driving because most people who are color blind learn to compensate. In general, the eye is most sensitive to black and white or black and yellow combinations.

Total Driver Response Time:

Total driver response time (PIJR) increases with the number of choices and the complexity of the judgment required. PIJR times are used to determine safe stopping distances, safe approach speeds at intersections, and the length of the yellow interval used for traffic signals.

The American Association of State Highway and Transportation Officials (AASHTO) recommends that a minimum PIJR time of no less than 2.5 seconds be used to determine safe stopping distances for all ranges of speed, and that a minimum PIJR time of 2.0 seconds be used for intersection sight distances. Wherever possible, greater PIJR times should be used.

Variability of Drivers:

The variability of drivers and their attitudes with respect to age, sex, attentiveness, knowledge, skill of driving, nervousness, and impatience are important factors and must be taken into account when establishing design criteria. Design values are normally based on satisfying the needs of the 85th percentile drivers, with minor consideration given to the variability of the 15th percentile who represent poorer drivers.

Behavior of Drivers:

A sense of reason will govern the behavior of most drivers, but neither drivers nor pedestrians will react consistently to controls and regulations that seem unreason-

Table 342-4. LOCAL STREET DESIGN STANDARDS

	Level Terrain	Rolling Terrain	Hilly Terrain
Right-of-way Width, mm (ft)	18 290 (60')	18 290 (60')	15 240 - 18 290 (50' to 60')
Pavement Width, mm (ft)	6 705 - 10 975 (22' to 36')	6 705 - 10 975 (22' to 36')	8 230 - 10 975 (27' to 36')
Type of Curb	Vertical Face	Vertical Face	Vertical Face
Sidewalk Width, mm (ft)	0 - 1 525 (0' to 5')	0 - 1 525 (0' to 5')	0 - 1 525 (0' to 5')
Sidewalk Distance From Curb Face, mm (ft)	0 - 1 830 (0' to 6')	0 - 1 830 (0' to 6')	0 - 1 830 (0' to 6')
Minimum Sight Distance, mm (ft)	60 960 (200')	45 720 (150')	33 530 (110')
Maximum Grade	4%	8%	15%
Minimum Spacing Along Major Traffic Route, mm (ft)	152 400 - 304 800 (500' to 1000')	152 400 - 304 800 (500' to 1000')	152 400 - 304 800 (500' to 1000')
Design Speed, km/h (mph)	50 (30)	40 (25)	30 (20)
Minimum Centerline Radius, mm (ft)	76 200 (250')	53 340 (175')	33 530 (110')

Table 342-5. SAFE COEFFICIENTS OF FRICTION (F)

Design Speed, km/hr (mph)	Assumed Speed for Conditions, km/h (mph)	Safe Coefficient of Friction (F)
50 (30)	45 (28)	0.36
65 (40)	60 (36)	0.33
80 (50)	70 (44)	0.31
95 (60)	85 (52)	0.30
105 (65)	90 (55)	0.30
115 (70)	95 (58)	0.29

able. This phenomenon must be taken into consideration when establishing regulations and controls.

Effect of Climate on Drivers:

Various climatic factors such as patterns of wind movement, temperature, precipitation, and sun angle can affect the driver's perception of the road and the driver's consequent behavior.

Visual information increases in direct proportion to the amount of light reflected on the object. Consequently, climatic conditions can obscure the driver's perception. Rain, fog, and mist at night create the greatest visual problems. Such climatic effects create difficulty in determining the size of the object in front of the vehicle, its distance ahead, and the speed at which that object is moving.

Low sun angles in morning or late afternoon can cause nearly total dissolution of the driver's visual field. The result is momentary blindness and an inability to discern visual information readily. Whenever possible, roads should be aligned to minimize such problems.

2.3 Vehicular Characteristics

The physical characteristics of vehicles using a roadway will determine the geometric design and construction of the roadway. For general design use, major class groupings should be determined and representative-size vehicles established within each class.

Design Vehicle:

A design vehicle is a representative motor vehicle, the weight, dimensions, and operating characteristics of which are used to establish highway design controls. For purposes of geometric design, the design vehicle should have dimensions and a minimum turning radius larger than that of all vehicles in its class.

Operating Characteristics:

Three operating characteristics that influence roadway design are turning radius, acceleration, and braking distance.

Turning Radii: The turning radii of the design vehicle are used to determine spatial dimensions for maneuvering on roads and in parking areas.

Acceleration: Acceleration data are used to determine:

1. The time required to cross an intersection from a stationary position.
2. The distance required to pass another vehicle.
3. The gap acceptance.

The rate of acceleration of passenger vehicles is from 6.4 to 9.7 km/h per second (4 to 6 mph per second), which is equal to 1.8 to 2.7 m/s (6 to 9 fps). The rate of acceleration for trucks is from 2.4 to 3.2 km/h per second ($1^1/_2$ to 2 mph per second), or 0.6 to 0.9 m/s (2 to 3 fps).

Braking Distance: The braking ability of a motor vehicle and the forward-friction factor between tires and pavement determine the slowing and stopping abilities of the vehicle. Table 342-5 provides safe coefficients of friction to be used in the formulae that follow.

2.4 Design Speed (by Roadway Types)

The value of a road is often judged by the convenience, safety, and economy by which it transports goods and people. The speed adopted by a driver depends upon four general circumstances:

1. The physical characteristics of a road and its surroundings
2. The weather conditions
3. The presence of other vehicles
4. The speed limitations, either legal or by control devices

While any one of these may govern, the effects of these circumstances are almost always combined. An approximately uniform speed is generally the aim of most drivers. Provision should be made for a speed which satisfies most drivers. The speed chosen for design should be that typically used

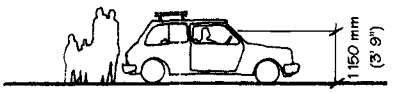


Figure 342-4. Average vehicle eye height.

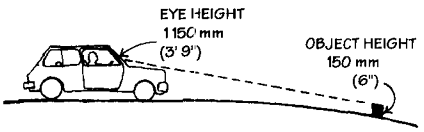


Figure 342-5. Assumed object height for crest vertical curves.

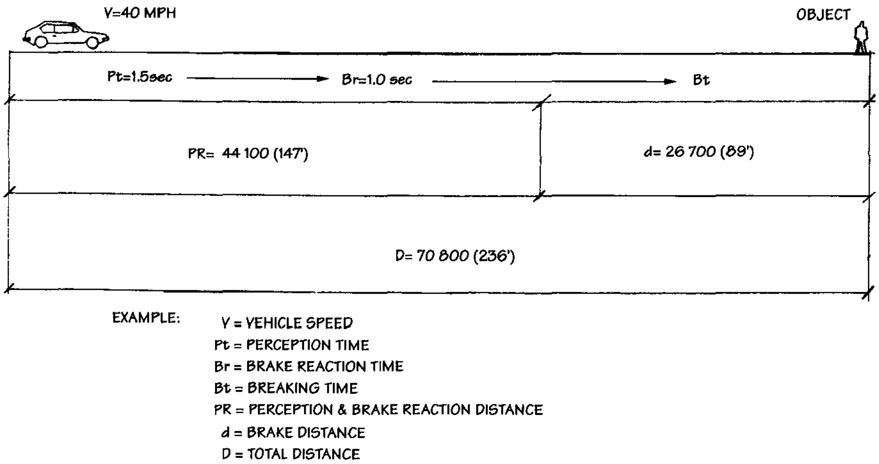


Figure 342-6. Components of sight/stopping distance.

by drivers under favorable weather conditions.

Design speed: Design speed is the maximum safe speed a road is engineered to handle under normal operating conditions. Suggested design speeds for roads of various classifications are given in Table 342-6. The selection of a design speed should be done with great care. Once selected, all pertinent geometric design will be related to the chosen value.

2.5 Sight Distance

The design of a safe and efficient vehicular circulation system depends on the ability of the driver to see a sufficient distance ahead while moving along a roadway.

Criteria for Measuring Sight Distance:

1. **Height of eye:** the eye height of the average driver in a passenger vehicle is 1 150 mm (3 ft 9 in) above the road surface (Figure 342-4).
2. **Height of object:** an object height of 150 mm (6 in) is customarily assumed for measuring stopping distances for crest vertical curves (Figure 342-5).

For passing sight distances, the object height is 1 350 mm ($4^1/_2$ ft), which is generally the current passenger vehicle body height above the pavement.

Sight/Stopping Distance:

Sight distance is the length of road ahead visible to the driver. The minimum sight distance available on any stretch of road should be sufficient to enable a vehicle traveling at or near the design speed to stop before reaching an object in its path.

The minimum sight/stopping distance is a function of two elements. The first is the distance traveled after the obstruction comes into view but before the driver applies the brakes. During this period of perception and reaction, the vehicle travels at its initial velocity. The second distance is traversed while the driver brakes the vehicle to a stop (Figure 342-6).

Perception and Brake Reaction Time: The formula for determining the perception and brake reaction distance is:

$$PR = 1.47(t)(V)$$

where PR = perception and reaction distance, ft

t = perception plus reaction time, seconds (2.5 seconds)

V = initial speed, mph

Example (Figure 342-6): Given that the initial speed = 40 mph,

$$PR = 1.47(t)(V)$$
$$= 1.47(2.50)(40)$$
$$= 147 \text{ ft}$$

Braking Distance: Once the driver has perceived and reacted to an obstruction, the approximate braking distance of a vehicle on a level, dry roadway can be determined by use of the following formula:

$$d = \frac{V^2}{30f}$$

where d = braking distance, ft

V= initial speed, mph

f = coefficient of friction between tires and pavement (Table 342-5)

As in the same example (Figure 342-6), the braking distance for a speed of 40 mph would be as follows:

$$V = 40 \text{ mph}$$
$$f = 0.60$$
$$d = \frac{40^2}{30(0.60)}$$
$$d = \frac{1600}{18}$$
$$= 89 \text{ ft}$$

Total Stopping Distance: The formula for determining the total distance (D) required to stop the vehicle is therefore (Figure 342-6):

$$D = PR + d$$
$$= 1.47(t)(V) + \frac{V^2}{30f}$$
$$= 1.47(2.5)(40) + \frac{40^2}{(30)(0.60)}$$
$$= 147 + 89$$
$$= 236 \text{ ft}$$

Table 342-7 lists for both wet and dry pavements the recommended minimums regarding actual initial speeds, perception and brake reaction times, and coefficients of friction.

Effects of Grades on Stopping: The design values given for minimum

Table 342-6. DESIGN SPEEDS (BY ROADWAY TYPES)

Highway Type	Design Speed, km/h (mph)
Interstate Rural	105 (65)
Rural Highways	90 (55)
Flat Terrain	90 (55)
Rolling Terrain	80 - 90 (50 - 55)
Rough Terrain	50 -80 (30 - 50)
Urban Interstate	
Through Areas of Concentrated Development	80 (50) minimum
Through Areas of Moderate Development	65 - 90 (40 - 55)
Urban Expressways	65 (40) minimum
Through Areas of Concentrated Development	50 (30) minimum
Through Areas of Moderate Development	50 - 80 (30 - 50)
Minor Residential Streets	40 (25)
Access Roads — Recreational Development	25 - 40 (15 - 25)
Drives — Site Access Roads	15 - 30 (10 - 20)

Note: The selection of the design speed should be done with great care on the premise that once selected, all pertinent geometric design should be related to the value selected.

sight/stopping distances in Table 342-7 assume a braking distance on a level roadway. If the vehicle is traveling uphill, the braking distance is decreased. Conversely, if the vehicle is traveling downhill, the braking distance is increased. When a highway is on a grade, the braking distance is expressed by the formula:

$$d = \frac{V^2}{30\,(f \pm G)}$$

where G = grade of the road (uphill grades are +, downhill grades are –)

Example: Given that V = 40 mph and that G = –10%,

$$D = 1.47(t)(V) + \frac{V^2}{30\,(f \pm G)}$$

$$= 1.47(2.5)(40) + \frac{40^2}{30\,(0.60–0.10)}$$

$$= 147 + 107$$

$$= 254 \text{ ft}$$

Variations Due to Vehicle Type: Minimum sight/stopping distances derived from the above formula reflect passenger car operation only. Trucks, especially the larger and heavier units, require a longer stopping distance for a given speed than do passenger vehicles. However, two factors tend to counteract the need for additional braking distance for trucks. First, the truck operator is able to see substantially farther because of a higher position in the vehicle. Second, trucks often travel more slowly than passenger vehicles.

Passing Sight Distance:

It is often necessary on two-lane roads to provide an opportunity to pass slow moving vehicles. Table 342-8 gives the minimum passing sight distance.

3.0 ROADWAY DESIGN ELEMENTS

3.1 Horizontal Alignment

General Design Criteria for Horizontal Alignment:

In addition to the specific design controls described in 2.0 of this section, a number of general design criteria should be considered when developing the horizontal alignment for a roadway:

1. Alignment should be as direct as possible, but respectful of topography and other critical natural or cultural features.
2. Longer curves are preferred to those which satisfy minimum radii.
3. Abrupt changes from straight lines to sharp curves should be avoided.
4. Sharp compound and broken-back curves should be avoided (see Figure 342-7).
5. Abrupt reversal in alignment (i.e., S curves) without transitional tangents should be avoided.

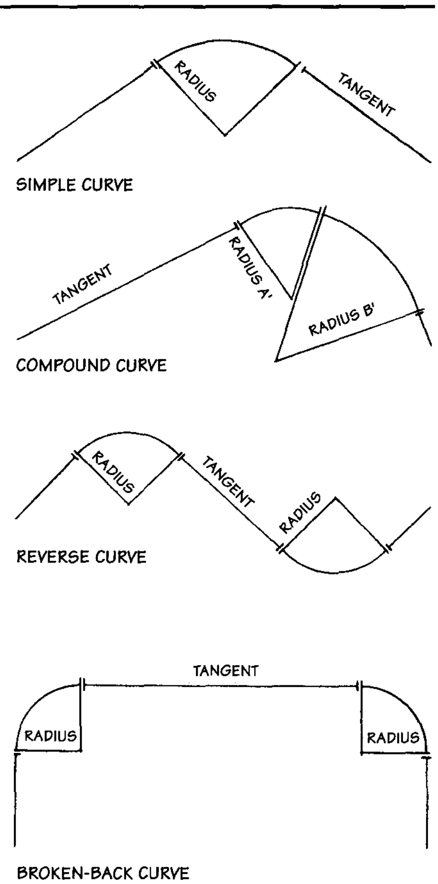


Figure 342-7. Classification of circular curves.

Components of Horizontal Alignment:

Horizontal alignment is generally composed of two geometric components (see Figure 342-7):

1. Straight lines (tangents).
2. Circular curves (arcs).

Tangents: Tangents are the most common element of horizontal alignment. They are the shortest distance between two points and the easiest to lay out. Characteristics of tangents include the following:

1. They can provide clear orientation.
2. They are predictable and tend to encourage excessive speeds.
3. They are justifiable in flat terrain, but in rolling terrain they can be aesthetically uninteresting, monotonous, and fatiguing.

Circular Curves (Arcs): Circular curves are constructed from parts of circles rather than parabolas (as in vertical curves). Several common classifications of circular

Table 342-7. SIGHTING TO STOPPING — MINIMUM DISTANCE

	Perception and Brake Reaction					Sight/Stopping Distance	
Design Speed, km/h (mph)	Assumed Speed for Condition, km/h (mph)	Time, sec	Distance, mm (ft)	Coefficient of Friction	Braking Distance on Level, mm (ft)	Computed, mm (ft)	Rounded for Design, mm (ft)
			Design Criteria — Wet Pavements				
50 (30)	45 (28)	2.5	31 395 (103')	0.36	22 250 (73')	53 645 (176')	60 960 (200')
65 (40)	60 (36)	2.5	40 235 (132')	0.33	39 930 (131')	80 160 (263')	83 820 (275')
80 (50)	70 (44)	2.5	49 075 (161')	0.31	63 400 (208')	112 470 (369')	106 680 (350')
95 (60)	85 (52)	2.5	58 215 (191')	0.30	91 440 (300')	149 655 (491')	144 780 (475')
105 (65)	90 (55)	2.5	61 570 (202')	0.30	102 415 (336')	163 980 (538')	167 640 (550')
			Comparative Values — Dry Pavement				
50 (30)	50 (30)	2.5	33 530 (110')	0.62	14 630 (48')	48 160 (158')	
65 (40)	65 (40)	2.5	44 805 (147')	0.60	27 125 (89')	71 935 (236')	
80 (50)	80 (50)	2.5	55 780 (183')	0.58	43 890 (144')	99 670 (327')	
95 (60)	95 (60)	2.5	67 055 (220')	0.56	65 225 (214')	132 285 (434')	
105 (65)	105 (65)	2.5	72 540 (238')	0.56	76 505 (251')	149 045 (489')	

Table 342-8. RECOMMENDED DESIGN VALUES FOR PASSING SIGHT DISTANCE FOR TWO-LANE HIGHWAYS

	Design Speed				
Assumed Speeds, km/h (mph)	50 (30)	65 (40)	80 (50)	95 (60)	115 (70)
Passed Vehicle	40 (26)	55 (34)	65 (41)	75 (47)	85 (54)
Passing Vehicle	60 (36)	70 (44)	80 (51)	90 (57)	105 (64)
Passing Sight Distance, mm (ft)	335 280 (1100')	457 200 (1500')	548 640 (1800')	640 080 (2100')	762 000 (2500')

curves are illustrated in Figure 342-7. Figure 342-8 illustrates the geometric components of a circular curve.

Calculation of Circular Curves:

Formulas necessary to calculate the components of circular curves (Figure 342-8) are as follows:

$$D = \frac{5729.58}{R} \quad \text{or} \quad D = \frac{100a}{L}$$

$$L = \frac{100a}{D} \quad \text{or} \quad L = \frac{(\pi)(R)a}{180}$$

$$R = \frac{5729.58}{D}$$

$$T = R \tan \frac{a}{2}$$

$$C = 2R \sin \frac{a}{2}$$

$$E = T \tan \frac{a}{4}$$

$$M = R\left(1 - \cos \frac{a}{2}\right)$$

where a = angle

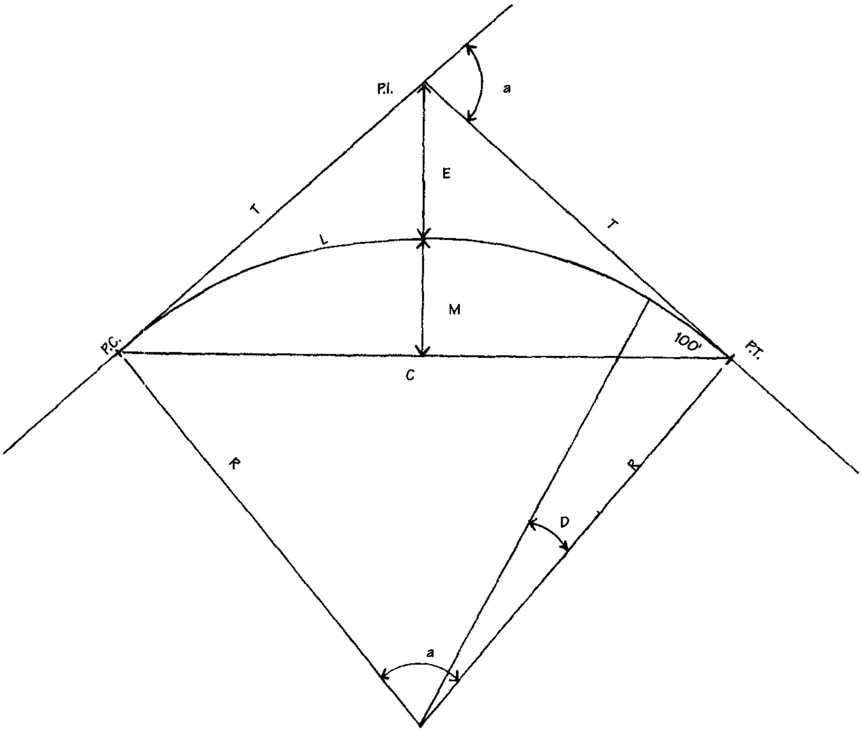
$\pi = 3.14$

Figure 342-9 illustrates a sample circular curve calculation: Given are two tangents with bearings N50E and S30E. A curve with a 1000-ft radius is desired.

Superelevation:

Superelevation refers to the cross slope of a road from the outside edge to the inside edge measured in meters (vertically) per meter (horizontally). Superelevation is necessary on higher-speed curves to counteract centrifugal force and to provide a safe coefficient of friction between tires and roadway surface (Figure 342-10).

Maximum Rates of Superelevation: The maximum rate of superelevation on a road-



P.C.	(point of curvature): the beginning of the curve in the direction of stationing
P.T.	(point of tangency): the end of the curve in the direction of stationing
P.I.	(point of intersection): point where the tangents, if extended, will intersect
a	(delta, intersection angle, central angle): the angle deflection between the tangents, also equal to the angle between radii
T	(tangent distance): horizontal distance between P.C. to P.I. and P.T. to P.I. (They are always equal.)
R	(radius): radius of curve
L	(length of curve): computed (actual) length of curve (arc) from P.C. to P.T.
C	(long chord): distance measured along a straight line (shortest distance) between P.C. and P.T.
E	(external distance): distance from the P.I. to the center of the curve
M	(middle ordinate): distance form the center of the curve to the center of the long chord
D	(degree of curvature): the angle at the center subtended by an arc of 100 ft which corresponds to a radius of 5729.58 ft for a central angle of 1 degree

Figure 342-8. Geometric components of a circular curve (horizontal alignment).

KEY POINTS: Design Controls

1. PIJR is the total time it takes to perceive an external stimuli, identify the stimuli, make a judgment, and react.
2. Three operating characteristics that influence roadway design are turning radius, acceleration, and braking distance.
3. The eye height of the average driver in a passenger vehicle is 1 125 mm (3 ft 9 in) above the road surface (Figure 342-4).
4. The formula for determining the total distance (D) required to stop a vehicle on grade is:

$$D = 1.47(t)(V) + \frac{V^2}{30\,(f \pm G)}$$

Table 342-9. MAXIMUM RATES OF SUPERELEVATION (E)

Surface	Rate of (E)
Urban Streets and Expressways (with snow and ice)	0.06
Rural Roads (with snow and ice)	0.08
Urban Expressways	0.10
Rural Roads	0.12

Table 342-10. MAXIMUM COEFFICIENT OF SIDE FRICTION (F)

Design Speed, km/h (mph)	Coefficient of Side Friction (F)
15 (10)	0.18
25 (15)	0.18
30 (20)	0.17
40 (25)	0.17
50 (30)	0.16
55 (35)	0.16
65 (40)	0.15
70 (45)	0.15
80 (50)	0.14
90 (55)	0.14
95 (60)	0.13
105 (65)	0.13

way is controlled by several factors (Table 342-9):

1. Regional climatic conditions.
2. Terrain conditions.
3. Type of area (e.g., rural versus urban).
4. Frequency and speed of vehicles.

Maximum Degree of Curvature: The maximum degree of curvature, or the minimum radius, is a limiting value for a given design speed. It can be determined from the maximum rate of superelevation and the maximum side-friction factor. The minimum safe radius (R) can be calculated directly by use of the following formula:

$$R = \frac{V^2}{15\,(E + F)} \quad \text{or } R = \frac{85{,}900\,(E + F)}{V^2}$$

where E = rate of roadway superelevation, ft/ft

F = maximum coefficient of side friction (Table 342-10)

V = vehicle speed, mph

Table 342-11. MAXIMUM DEGREE OF CURVATURE AND MINIMUM RADIUS FOR LIMITING VALUES OF E AND F

Design Speed, km/h (mph)	Max, E	Max, F	Total, E and F	Minimum Radius, mm (ft)	Maximum Degree of Curve	Maximum Degree of Curvature*
30 (20)	0.06	0.17	0.23	35 355 (116')	49.39	49.0
40 (25)	0.06	0.17	0.23	39 930 (131')	31.61	31.5
50 (30)	0.06	0.16	0.22	83 210 (273')	20.99	21.0
55 (35)	0.06	0.16	0.22	113 080 (371')	15.43	15.5
65 (40)	0.06	0.15	0.21	154 840 (508')	11.27	11.5
70 (45)	0.06	0.15	0.21	195 985 (643')	8.91	9.0
80 (50)	0.06	0.14	0.20	251 155 (824')	6.95	7.0
90 (55)	0.06	0.14	0.20	306 020 (1004')	5.68	5.5
95 (60)	0.06	0.13	0.19	385 570 (1265')	4.53	4.5
105 (65)	0.06	0.13	0.19	452 325 (1484')	3.86	4.0
30 (20)	0.08	0.17	0.25	32 615 (107')	53.69	53.5
40 (25)	0.08	0.17	0.25	50 900 (167')	34.36	34.5
50 (30)	0.08	0.17	0.24	76 200 (250')	22.91	23.0
55 (35)	0.08	0.16	0.24	103 630 (340')	16.83	17.0
65 (40)	0.08	0.15	0.23	141 425 (464')	12.35	12.5
70 (45)	0.08	0.15	0.23	178 920 (587')	9.76	10.0
80 (50)	0.08	0.14	0.22	230 430 (756')	7.56	7.5
90 (55)	0.08	0.14	0.22	279 500 (917')	6.25	6.5
95 (60)	0.08	0.13	0.21	348 690 (1144')	5.01	5.0
105 (65)	0.08	0.13	0.21	409 040 (1342')	4.27	4.5
30 (20)	0.10	0.17	0.27	30 175 (99')	57.98	58.0
40 (25)	0.10	0.17	0.27	46 940 (154')	37.11	37.0
50 (30)	0.10	0.16	0.26	70 410 (231')	24.82	25.0
55 (35)	0.10	0.16	0.26	95 705 (314')	18.23	18.0
65 (40)	0.10	0.15	0.25	130 150 (427')	13.42	13.5
70 (45)	0.10	0.15	0.25	164 895 (541')	10.60	10.5
80 (50)	0.10	0.14	0.24	211 530 (694')	8.25	8.5
90 (55)	0.10	0.14	0.24	256 030 (840')	6.82	7.0
95 (60)	0.10	0.13	0.23	318 210 (1044')	5.47	5.5
105 (65)	0.10	0.13	0.23	373 075 (1224')	4.68	4.5
30 (20)	0.12	0.17	0.29	28 040 (92')	62.27	62.5
40 (25)	0.12	0.17	0.29	43 890 (144')	39.85	40.0
50 (30)	0.12	0.16	0.28	65 225 (214')	26.72	26.5
55 (35)	0.12	0.16	0.28	89 000 (292')	19.63	19.5
65 (40)	0.12	0.15	0.27	120 395 (395')	14.50	14.5
70 (45)	0.12	0.15	0.27	152 400 (500')	11.45	11.5
80 (50)	0.12	0.14	0.26	195 680 (642')	8.93	9.0
90 (55)	0.12	0.14	0.26	236 525 (776')	7.38	7.5
95 (60)	0.12	0.13	0.25	292 610 (960')	5.97	6.0
105 (65)	0.12	0.13	0.25	343 815 (1128')	5.08	5.0

* Numbers rounded-off.

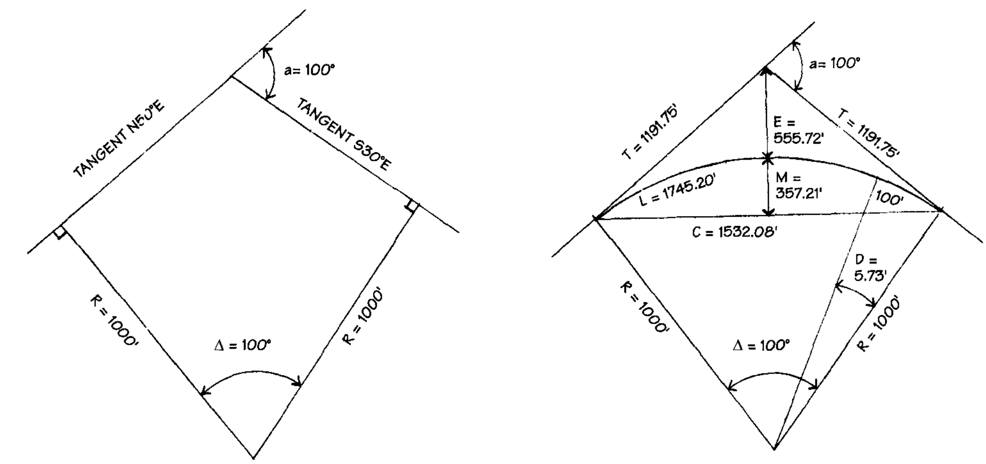


Figure 342-9. Calculation of circular curves.

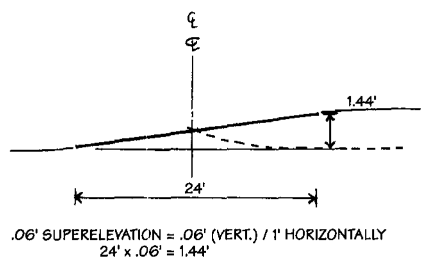


Figure 342-10. Superelevation (example).

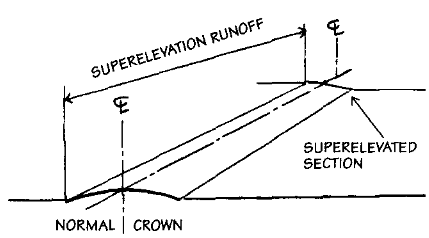


Figure 342-11. Superelevation runoff.

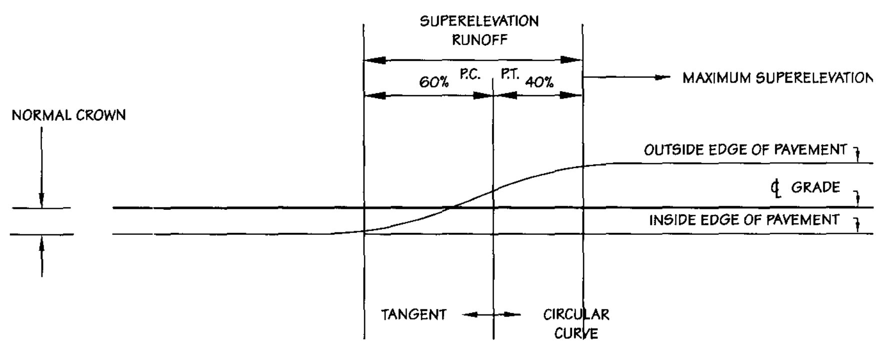


Figure 342-12. Superelevation location and runoff.

R = radius of curve, ft

Table 342-11 lists the maximum degree of curvature and the minimum radius for designated design speeds.

Superelevation Runoff: Superelevation runoff is the length of roadway required to provide a transition from the normal road crown to a fully superelevated section or vice versa (Figure 342-11).

Table 342-12 lists minimum superelevation runoff lengths for various design speeds and superelevation rates.

Superelevation Location and Runoff: In general, superelevation runoff is assumed to run into the tangent. Figure 342-12 shows that from 60 to 80 percent of the length of runoff should be located on the tangent.

Pavement Widening on Curves:

Often, on two-lane roads, pavement widening is desirable on sharp curves for the following reasons (Figure 342-13):

1. Tendency for drivers to shy away from the pavement edge.
2. Increased transverse vehicle width because the front and rear wheels do not track.
3. Added width because of the slanted position of the front of the vehicle relative to the roadway centerline.

Table 342-13 gives pavement widening values for two-lane roadways.

Sight Distance on Curves:

As a vehicle travels around a horizontal curve, any obstruction near the inside edge of the road will block the driver's view ahead (Figure 342-14). Any particular combination of the sharpness of the curve with the position of an obstruction establishes a horizontal sight distance, which is the greatest distance at which a driver can see an object lying in the roadway. To provide safe operation, this horizontal sight distance must equal or exceed the safe stopping distances for each design speed (Table 342-14).

3.2 Vertical Alignment

Components of Vertical Alignment:

The vertical plane, or profile, of a road or drive is essentially made up of two geometric components (Figure 342-15):

1. Inclined straight lines (i.e., tangent grades).
2. Vertical curves.

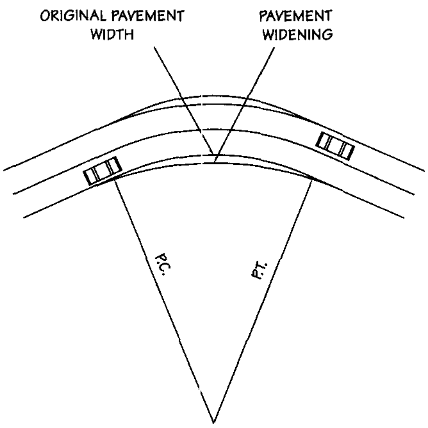


Figure 342-13. Pavement widening on curves.

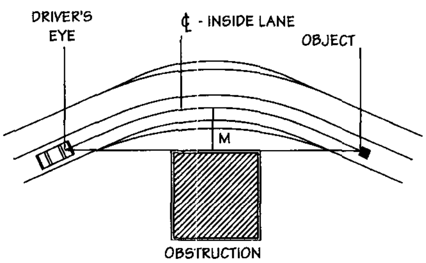


Figure 342-14. Sight distance on horizontal curve.

Grades: Maximum grades for roads vary considerably, depending upon terrain, speed, capacity, and use of the road. Table 342-15 shows the relationship between maximum grades and design speeds for major roadways. Maximum grades for secondary roads may be about 2 percent steeper. In extreme cases, steeper grades for relatively short lengths may be considered.

Vertical Curves: Vertical curves are constructed from parts of parabolas rather than circles, and connect two different grades or tangents. Figure 342-15 shows the various types of vertical curves. Figure 342-16 illustrates the geometry of a vertical curve.

Calculation of Symmetrical Vertical Curves:

Calculations for a symmetrical vertical curve are shown below and basically involve a five-step process.

Step 1 (Figure 342-17):

1. Locate and determine the length of the vertical curve—the stations (lengths) of BVC and EVC (beginning and end of vertical curve). (Refer to information later in this

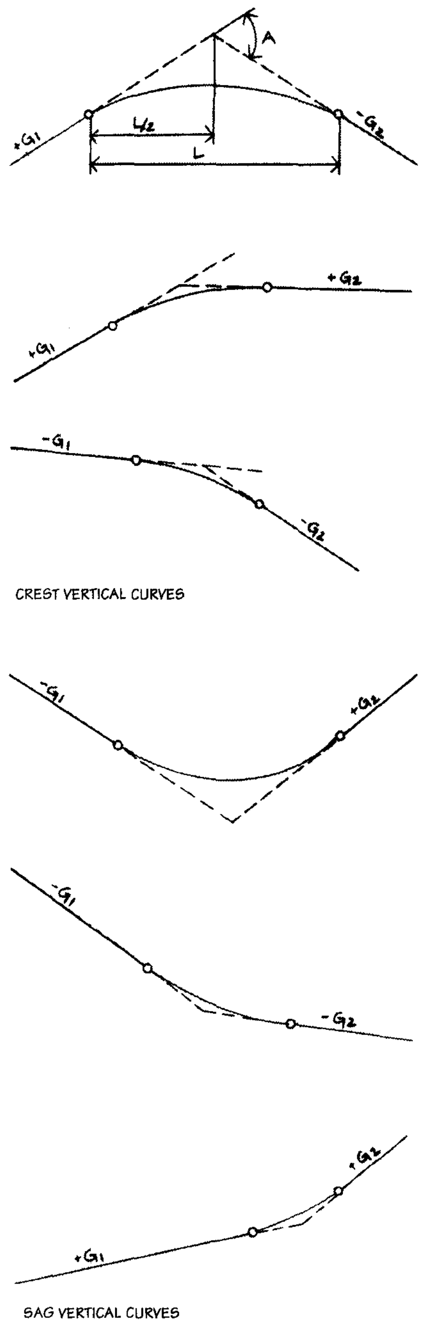


Figure 342-15. Components of vertical curves.

section for determining the minimum lengths of crest or sag vertical curves.)

2. Determine the algebraic difference (A) of the grade tangents:

$$A = g_2 - g_1$$

$$= -7 - (+4)$$

$$= -11\%$$

Step 2 (Figure 342-18): Determine the elevations along the grade tangents at each 50-ft station.

Step 3 (Figure 342-19): Determine the middle ordinate (e) [middle ordinate (e) is equivalent to 1/8 the algebraic difference (A) times the length of the parabola in stations]:

$$e = {}^1/_8\,(g_2 - g_1)L\ /100$$

$$= {}^1/_8\,[-7 - (+4)]\ 300/100$$

$$= 1{}^1/_8 \times 3$$

$$= 4.12 \text{ ft}$$

Step 4: Find the elevations on the curve at intermediate stations. Either of two methods may be employed (see below).

Note: Elevations on the vertical curve (offsets) are always determined at even 50- or 100-ft stations, although the curve may not necessarily begin or end at a 50- or 100-ft station. It is not necessary to adjust the curve to start and end on a station, although it does sometimes simplify the calculations.

First method [middle ordinate (e) method]: The middle ordinate method for determining elevations on the curve involves the use of the middle ordinate (e) as determined in step 3 above. The formula for the middle ordinate (e) method is:

$$0 = e\,[(\text{distance to station from BVC or EVC}) / ({}^L/_2)]^2$$

Example(Figures 342-27 and 342-28):

0_1 (station 8 + 50)

$$= 4.12\ (50/150)^2$$

$$= 4.12\ (0.111)$$

$$= 0.46 \text{ ft}$$

0_2 (station 9 + 00)

$$= 4.12\ (100/150)^2$$

$$= 4.12\ (0.444)$$

$$= 1.83 \text{ ft}$$

0_3 (station 10 + 00)

$$= 4.12\ (100/150)^2$$

$$= 4.12\ (0.444)$$

$$= 1.83 \text{ ft}$$

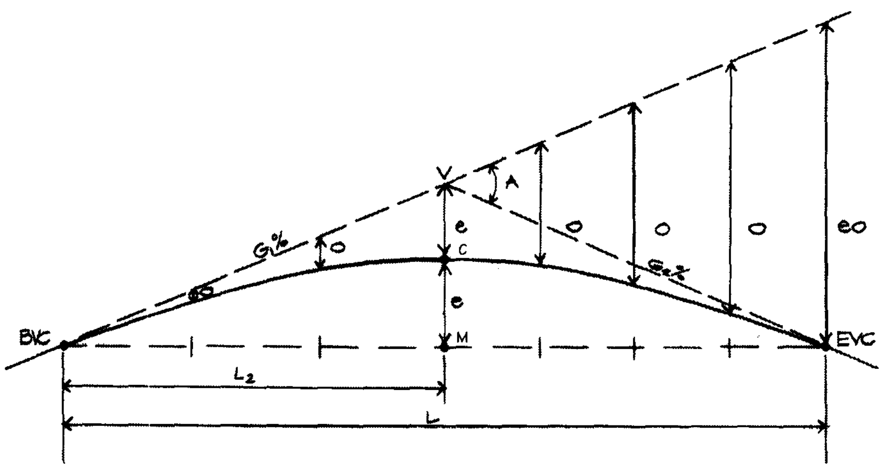
0_4 (station 10 + 50)

$$= 4.12\ (50/150)^2$$

$$= 4.12\ (0.111)$$

$$= 0.46 \text{ ft}$$

Data for the above curve can be recorded using the form shown in Table 342-16.



V = vertex or intersection of two grads
A = algebraic difference in grades (percent) of the grade tangents = $G_2 - G_1$
BVC = beginning of the vertical curve (in relation to stationing)
EVC = end of the vertical curve (in relation to stationing)
C = middle point on the parabolic curve between BVC-EVC and middle point between M-V
G_1% = percentage of slope on the entering grade tangent
G_2% = percentage of slope on the leaving grade tangent
M = middle point or distance halfway on chord between BVC-EVC
e = middle ordinate (offset) between C-V and C-M
L = length (horizontally) of the vertical curve
o = ordinates or station offsets
eo = end ordinate or station offset at EVC

Figure 342-16. Geometry of a vertical curve.

Second method [end ordinate (eo) method]: Alternatively, the end ordinate method can be used to determine elevations on a vertical curve at intermediate stations (Figure 342-22).

1. Determine station grades along g1 grade tangent. [Note that offset (eo) is equal to 4 times the middle ordinate (e) as previously calculated.]
2. Determine offsets at stations from the g_1 grade tangent using the following formula:

$$0 = eo\left(\frac{\text{distance from BVC to station}}{L}\right)^2$$

Example:

$O_1 = 16.5\ (^{50}/_{300})^2$

$= 16.5 \times 0.027$

$= 0.46$ ft

$O_2 = 16.5\ (^{100}/_{300})^2$

$= 16.5 \times 0.111$

$= 1.83$ ft

$O_3(e) = 16.5(150/300)2$

$= 16.5 \times 0.25$

$= 4.12$ ft

$O_4 = 16.5\ (^{200}/_{800})^2$

$= 16.5 \times 0.44$

$= 7.33$ ft

$O_5 = 16.5\ (^{250}/_{300})^2$

$= 16.5 \times 0.69$

$= 11.46$ ft

Data for the above curve can be recorded using the form shown in Table 342-17.

Step 5:

1. Calculate the horizontal distance from the BVC to the high or low point on the profile of a vertical curve:

$$X = \frac{L(g_1)}{A} \quad \text{where:}$$

X = from the BVC to the high or low point

L = length of vertical curve

g_1 = entering grade

A = algebraic difference

Using the previous example's problem, the results are as follows:

$$X = \frac{L(g_1)}{A}$$

$$= \frac{300(4)}{11}$$

$$= 109.09 \text{ ft}$$

Thus, the high point is located 109.09 ft from BVC, or at station 9 + 09.09.

2. Determine the elevation of the high point on the vertical curve by calculating the grade tangent elevation at station 9 + 09.09.

$^4/_{100} \times 109.09 = 4.36$ ft
190.25 (BVC elevation) + 4.36 = 194.61

3. Determine the offset from the grade tangent to the curve at the high-point station (9 + 09.09) by using either of the two previously shown methods:

e Method	eo Method
$O_{hp} = e\left(\frac{109.09}{150}\right)^2$	$O_{hp} = eo\left(\frac{109.09}{300}\right)^2$
= 4.12 (0.53)	= 16.5 (4.13)
= 2.18	= 2.18

Thus, the grade tangent elevation is: (9 + 09.09) – offset (high point) = high-point elevation on vertical curve: 194.61 – 2.18 = 192.43 ft at station 9 + 09.09.

Calculation of Unsymmetrical Vertical Curves:

Sometimes an unsymmetrical vertical curve, rather than a symmetrical (or equal-tangent) curve, may more closely fit certain requirements of the terrain. The terminology applied to the unsymmetrical curve also applies to the symmetrical curve, except that the middle point (M) on the chord and the middle point (C) on the parabolic curve are not located midway between the BVC and EVC (Figure 342-23).

Calculations for determining elevations along an unsymmetrical vertical curve are as follows (Figure 342-24):

Step 1: Determine the algebraic difference (A) of the grade tangents:

$A = g_2 - g_1$

$= -8 - (+4) = -12$

Step 2: Determine the middle ordinate (e):

$$e = \frac{l_1 - l_2}{2(l_1 - l_2)} \times A/100$$

$$= \frac{250 \times 350}{2\ (250 + 350)} \times 12/100$$

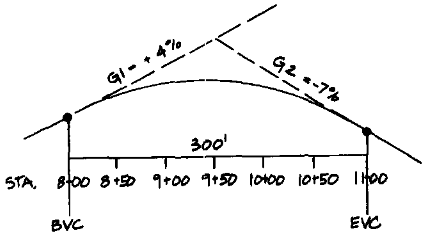
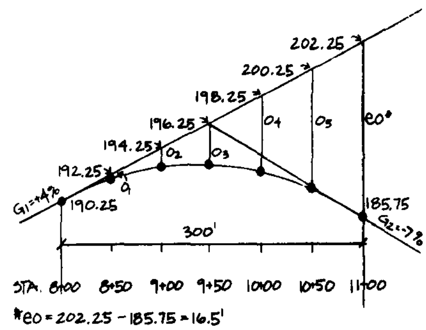


Figure 342-17. Calculation of symmetrical vertical curve (example problem).



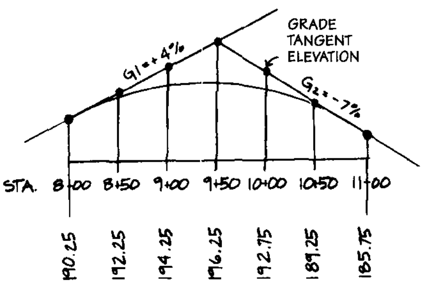


Figure 342-18. Calculation of symmetrical vertical curve (example problem).

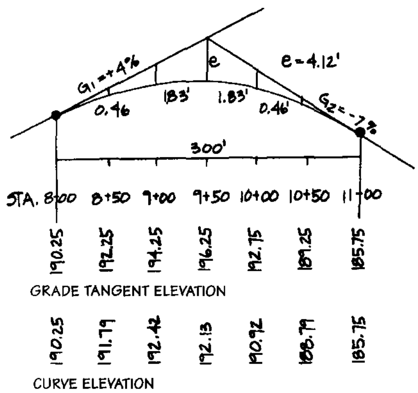


Figure 342-21. Calculation of symmetrical vertical curve: End ordinate (e) method (example problem).

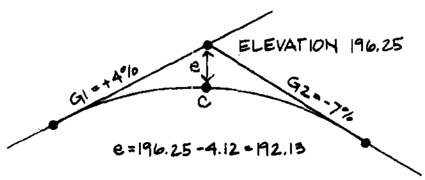


Figure 342-19. Calculation of symmetrical vertical curve (example problem).

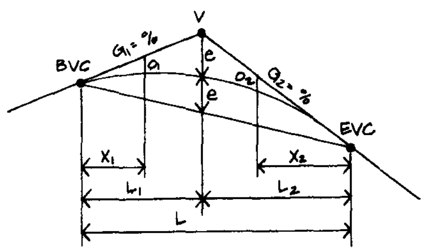


Figure 342-22. Unsymmetrical vertical curve.

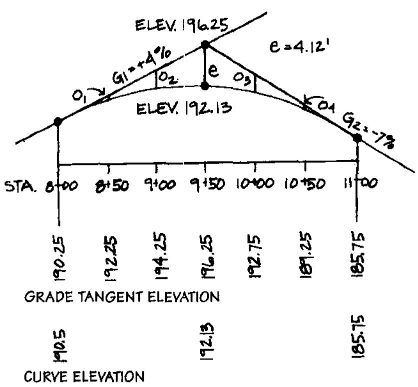


Figure 342-20. Calculation of symmetrical vertical curve: Middle ordinate (e) method (example problem).

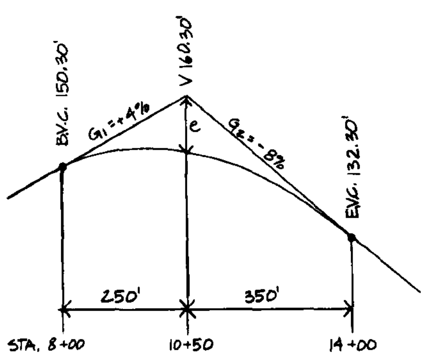


Figure 342-23. Calculation of unsymmetrical vertical curve (example problem).

$$e = \frac{87{,}500}{1200} \times 0.12$$

$$= 72.92 \times 0.12$$

$$= 9.59 \text{ ft}$$

Step 3: Determine the grade tangent elevations at the 50- and 100-ft stations.

Step 4: Calculate the offsets at the 50- and 100-ft stations:

$$0(8 + 50) = 9.59(50/250)^2$$
$$= 9.59(0.04)$$
$$= 0.38 \text{ ft}$$
$$0(9 + 00) = 9.59(100/250)^2$$
$$= 9.59(0.16)$$
$$= 1.53 \text{ ft}$$
$$0(9 + 50) = 9.59(150/250)^2$$
$$= 9.59(0.36)$$
$$= 3.45 \text{ ft}$$
$$0(10 + 00) = 9.59(200/250)^2$$
$$= 9.59(0.64)$$
$$= 6.14 \text{ ft}$$
$$0(11 + 00) = 9.59(300/350)^2$$
$$= 9.59(0.73)$$
$$= 7.00 \text{ ft}$$
$$0(11 + 50) = 9.59(250/350)^2$$
$$= 9.59(0.51)$$
$$= 4.89 \text{ ft}$$
$$0(12 + 00) = 9.59(200/350)^2$$
$$= 9.59(0.33)$$
$$= 3.16 \text{ ft}$$
$$0(12 + 50) = 9.59(150/350)^2$$
$$= 9.59(0.18)$$
$$= 1.73 \text{ ft}$$
$$0(13 + 00) = 9.59(100/350)^2$$
$$= 9.59(0.08)$$
$$= 0.77 \text{ ft}$$
$$0(13 + 50) = 9.59(50/350)^2$$
$$= 9.59(0.02)$$
$$= 0.19 \text{ ft}$$

Data for the above unsymmetrical vertical curve can be recorded using the form shown in Table 342-18.

Table 342-12. LENGTHS REQUIRED FOR SUPERELEVATION RUNOFF (TWO-LANE PAVEMENTS)

Superelevation Rate	Length of Runoff (L), mm (ft) for Design Speed, km/h (mph): 30 (20)	40 (25)	50 (30)	55 (35)	65 (40)	70 (45)	80 (50)	90 (55)	95 (60)	105 (65)
3 660 (12') Lanes										
0.02	22 860 (75')	27 430 (90')	30 480 (100')	35 050 (115')	38 100 (125')	42 670 (140')	45 720 (150')	50 290 (165')	53 340 (175')	57 910 (190')
0.04	22 860 (75')	27 430 (90')	30 480 (100')	35 050 (115')	38 100 (125')	42 670 (140')	45 720 (150')	50 290 (165')	53 340 (175')	57 910 (190')
0.06	25 910 (85')	30 480 (100')	33 530 (110')	36 575 (120')	38 100 (125')	42 670 (140')	45 720 (150')	50 290 (165')	53 340 (175')	57 910 (190')
0.08	36 575 (120')	41 150 (135')	44 195 (145')	48 770 (160')	51 815 (170')	54 865 (180')	57 910 (190')	62 485 (205')	65 530 (215')	70 105 (230')
0.10	45 720 (150')	50 290 (165')	54 865 (180')	59 435 (195')	64 010 (210')	68 580 (225')	73 150 (240')	77 725 (255')	82 295 (270')	88 390 (290')
0.12	54 865 (180')	60 960 (200')	65 530 (215')	71 630 (235')	76 200 (250')	76 200 (250')	88 390 (290')	94 490 (310')	99 060 (325')	105 155 (345')
3 050 (10') Lanes										
0.02	22 860 (75')	27 430 (90')	30 480 (100')	35 050 (115')	38 100 (125')	42 670 (140')	45 720 (150')	50 290 (165')	53 340 (175')	57 910 (190')
0.04	22 860 (75')	27 430 (90')	30 480 (100')	35 050 (115')	38 100 (125')	42 670 (140')	45 720 (150')	50 290 (165')	53 340 (175')	57 910 (190')
0.06	22 860 (75')	27 430 (90')	30 480 (100')	35 050 (115')	38 100 (125')	42 670 (140')	45 720 (150')	50 290 (165')	53 340 (175')	57 910 (190')
0.08	30 480 (100')	33 530 (110')	36 575 (120')	39 625 (130')	42 670 (140')	45 720 (150')	48 770 (160')	51 815 (170')	54 865 (180')	57 910 (190')
0.10	38 100 (125')	42 670 (140')	45 720 (150')	50 290 (165')	53 340 (175')	51 815 (170')	60 960 (200')	65 530 (215')	68 580 (225')	73 150 (240')
0.12	45 720 (150')	50 290 (165')	54 865 (180')	59 435 (195')	64 010 (210')	68 580 (225')	73 150 (240')	77 725 (255')	82 295 (270')	88 390 (290')

Minimum Crest Vertical Curves:

On all crest vertical curves, the length of the curve should permit safe stopping distances (Figure 342-25).

Two basic formulas exist for determining the length of a vertical curve in terms of sight distance(s) and algebraic differences in grade:

When S is less than L:

$$L = \frac{AS^2}{100\,(\sqrt{2h_1} + \sqrt{2h_2})^2}$$

When S is greater than L:

$$L = 2S - \frac{200\,(\sqrt{2h_1} + \sqrt{2h_2})^2}{A}$$

where: L = horizontal length of the vertical curve, ft

S = sight distance, ft

A = algebraic difference in grades, %

h_1 = height of eye above roadway surface, ft

Table 342-13. PAVEMENT WIDENING VALUES (TWO-LANE ROADS), [MM (FT)]

Degree of curve	7.2-m lane design speed, km/h: 48	64	80	96	24-ft. lane design speed, mph: 30	40	50	60
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	150	0.0	0.0	0.0	0.5
3	0.0	0.0	150	150	0.0	0.0	0.5	0.5
4	0.0	150	150	300	0.0	0.5	0.5	1.0
5	150	150	300	300	0.5	0.5	1.0	1.0
6	150	300	300	450	0.5	1.0	1.0	1.5
7	150	300	450		0.5	1.0	1.5	
8	300	300	450		1.0	1.0	1.5	
9	300	450	600		1.0	1.5	2.0	
10-11	300	450			1.0	1.5		
12-14.5	450	600			1.5	2.0		
15-18	600				2.0			
19-21	750				2.5			
22-25	900				3.0			
26-26.5	1 050				3.5			

Source: AASHTO, A Policy on Geometric Design of Rural Highways, 1965.

Table 342-14. SIGHTING TO STOPPING DISTANCE ON HORIZONTAL CURVE M(FT): M-MIDDLE ORDINATE

Design speed km/h (mph)	Sight/ stopping distance m (ft)	Degree of curve 1	2	3	4	5	6	7	8	9	10	11
48	60	-	-	-	-	-	1.5	1.8	2.1	2.4	2.7	3.0
(30)	(200)	-	-	-	-	-	(5)	(6)	(7)	(8)	(9)	(10)
64	90	-	-	1.8	2.4	3.0	3.6	4.2	4.5	5.4	6.0	6.3
(40)	(300)	-	-	(6)	(8)	(10)	(12)	(14)	(15)	(18)	(20)	(21)
80	135	-	2.4	3.9	5.4	6.6	8.1	9.3	10.5	-	-	-
(50)	(450)		-	(8)	(13)	(18)	(22)	(27)	(31)	(35)	-	- -
96	195	2.4	5.7	8.4	-	-	-	-	-	-	-	-
(60)	(650)	(8)	(19)	(28)	-	-	-	-	-	-	-	-

Design speed km/h (mph)	Sight/ distance m (ft)	Degree of curve 12	13	14	15	16	17	18	19	20	21
48	60	3.3	3.3	3.6	3.9	4.2	4.5	4.8	4.8	5.1	5.4
(30)	(200)	(11)	(11)	(12)	(13)	(14)	(15)	(16)	(16)	(17)	(18)
64	90	6.9	7.5	8.1	8.7	9.3	9.9	10.5	-	-	-
(40)	(300)	(23)	(25)	(27)	(29)	(31)	(33)	(35)	-	-	-
80	135	-	-	-	-	-	-	-	-	-	-
(50)	(450)	-	-	-	-	-	-	-	-	-	-
96	195	-	-	-	-	-	-	-	-	-	-
(60)	(650)	-	-	-	-	-	-	-	-	-	-

Table 342-15. RELATION OF MAXIMUM GRADES TO DESIGN SPEED (MAIN HIGHWAYS), (% SLOPE)

Type of topography	Design speed, km/h mph 48 (30)	64 (40)	80 (50)	96 (60)	104 (65)	112 (70)
Flat	6	5	4	3	3	3
Rolling	7	6	5	4	4	4

Source: AASHTO, A Policy on Geometric Design of Rural Highways, 1965.

h_2 = height of object above roadway surface, ft

Solutions to these equations based on criteria of eye height and fixed object height (see Figure 342-25) are given in Table 342-19, from which can be determined the minimum length of vertical curve necessary to match a required stopping sight distance for algebraic differences in grades up to 25 percent.

Passing Sight Distance on Vertical Curves:

Criteria used for determining passing sight distances on crest vertical curves are: a driver eye height of 1 125 mm (45 in) and a height of 1 350 mm (54 in) for an overcoming vehicle (Figure 342-26).

Equations that express the relationship between passing sight distance, algebraic difference in grades, and length of vertical curve are as follows:

When S is less than L:

$$L = \frac{ASp^2}{3290}$$

When S is greater than L:

$$L = 2Sp - \frac{3290}{A}$$

where Sp =passing sight distance, ft

A = algebraic difference in grades, %

L = minimum length of vertical curve, ft

Solutions to these equations based on the above criteria of eye height and vehicle height (Figure 342-26) are given in Table 342-20, from which can be found the minimum length of vertical curve necessary to match a required passing sight distance for algebraic differences in grades up to 10 percent.

Minimum Sag Vertical Curves:

Criteria that are critical for determining the minimum lengths of sag vertical curves include:

1. Headlight illumination.
2. Rider comfort.
3. Drainage control.
4. General appearance.

Headlight sight distance has been used as the major controlling factor. When a vehicle traverses a sag vertical curve at night, the portion of the highway illuminated, and therefore the sight distance, is dependent upon the position of the headlights and the direction of the light beam (Figure 342-27).

The following two formulas show the relationship between light beam distance, length of vertical curve, and algebraic difference:

When S is less than L:

$$L = \frac{AS^2}{400 + 3.55}$$

When S is greater than L:

$$L = 2S - \frac{400 + 3.55}{A}$$

where S =light beam distance, ft

A = algebraic difference in grades, %

L = length of sag vertical curve, ft

Solutions to these equations based on the above criteria are given in Table 342-21.

3.3 Cross-Sectional Elements

Pavement Widths:

The safety and comfort of the driver is influenced by the width and condition of the pavement surface. Because of upward trends in traffic volumes, vehicle speed, and width of trucks, two-lane roads have increased from early widths of 4 800 and 5 400 mm (16 and 18 ft) to present widths of 6 600 to 7 800 mm (22 to 26 ft). Lane widths of 3 000 to 3 900 mm (10 to 13 ft) are now common. The determination of pavement width depends on many factors, including:

Table 342-16. VERTICAL CURVE DATA FORM: MIDDLE ORDINATE (E) METHOD (EXAMPLE PROBLEM DATA)

Intersection station 9 + 50 Elevation 196.25 VC no. 2
Algebraic difference −7 − (+ 4) = −11 Curve length 300 ft
BVC station 8 + 00 Elevation 190.25
EVC station 11 + 00 Elevation 185.75
Middle ordinate (e) $^{1}/_{8}(-11)300/100 = 4.12$ ft

	Station	Distance from BVC or EVC	Tangent grade elevation	vc ordinate	vc elevation
BVC	8 + 00	00.00	190.25	00.00	190.25
	8 + 50	50.00	192.25	00.46	191.79
	9 + 00	100.00	194.25	01.83	192.42
V	9 + 50	150.00	196.25	04.12	192.13
	10 + 00	100.00	192.75	01.83	190.92
	10 + 50	50.00	189.25	00.46	188.79
EVC	11 + 00	00.00	185.75	00.00	185.75

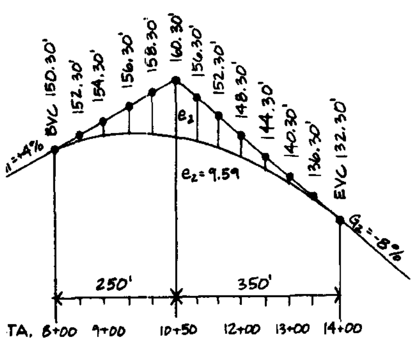


Figure 342-24. Calculation of unsymmetrical vertical curve: *Middle ordinate (e) method (example problem).*

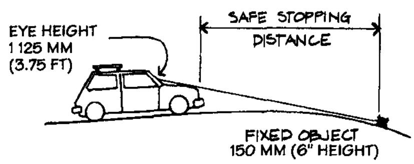


Figure 342-26. Passing sight distance on crest vertical curve.

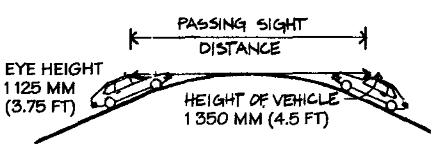


Figure 342-25. Sight/stopping distance on crest vertical curve.

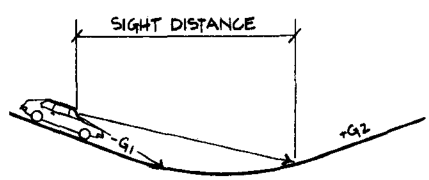


Figure 342-27. Headlight sight distance on sag vertical curve.

1. Density/intensity of land use.
2. Parking (i.e., off-street versus on-street).
3. Whether alignment is smooth and continuous.
4. Speed of traffic.
5. Volume of traffic.
6. Type of traffic (i.e., automobiles, trucks, buses, etc.).
7. Distance between edge of pavement and any obstructions along the roadside.

Table 342-22 gives recommended minimum widths for two-lane roads based on traffic volumes and speed. Table 342-23 gives recommended ranges of pavement width based on use.

Pavement Crowns:

Pavements on tangents and on flat curves are crowned for positive drainage of water off the roadway surface (Figure 342-28). Table 342-24 gives recommended ranges of cross-slope for various types of pavement surfaces.

3.4 Intersection Design Elements

Types of Grade Intersections:

Figure 342-29 shows various types of grade intersections.

Intersection Curves:

Minimum Radii for Sharpest Turns: When turning space is minimal, as at unchanneled intersections, the minimum turning radius of the design vehicle is the controlling factor in the design of the curve.

Minimum Radius for Turning Speed: Table 342-25 give design criteria for curves at various driving speeds.

KEY POINTS: Roadway Design Elements

1. Superelevation, the cross slope of a road from the outside edge to the inside edge, is necessary on higher-speed curves to counteract centrifugal force and to provide a safe coefficient of friction between tires and roadway surface.

2. The minimum safe radius (R) on a horizontal curve can be calculated by use of the following formula:

$$R = \frac{V^2}{15\,(E+F)} \quad \text{or} \quad R = \frac{85{,}900\,(E+F)}{V^2}$$

where E = rate of roadway superelevation, F = maximum coefficient of side friction (Table 342-10), V = vehicle speed, R = radius of curve.

3. Vertical curves are constructed from parts of parabolas rather than circles, and connect two different grades or tangents. Figure 342-15 shows the various types of vertical curves. Figure 342-16 illustrates the geometry of a vertical curve.

4. The algebraic difference (A) between the incoming grade of the parabolic curve and the outgoing grade can be calculated using the formula: $A = g_2 - g_1$.

Alignment and Profile at Intersections:

For safety reasons, horizontal alignment at intersections should be handled as shown in Figure 342-30. Figure 342-31 illustrates preferable grade criteria for intersections.

Sight Distances at Intersections:

It is important that sight lines are unobstructed along both roads of an intersection and across their corners for distances sufficient to allow drivers approaching the intersection simultaneously to see each other in time to prevent collision (Figure 342-32).

Uncontrolled Intersections: At uncontrolled intersections, drivers must be able to recognize a hazard in sufficient time to slow down before reaching the intersection. For two roads of known design speeds, the minimum sight triangle (Figure 342-32) can be determined from Table 342-26.

Controlled Intersections on Minor Roads: At controlled intersections on minor roads, the driver of a stopped vehicle must be able to see enough of the crossroads to cross without danger of collision (Figure 342-33).

Table 342-27 provides the necessary distances needed along the highway from the intersection for various design vehicles.

Table 342-17. VERTICAL CURVE DATA FORM: END ORDINATE (EO) METHOD (EXAMPLE PROBLEM DATA)

Intersection station 9 + 50 Elevation 196.25 VC no. 2
Algebraic difference -7 - (+4) = - 11 Curve length 300 ft
BVC Station 8 + 00 Elevation 190.25
EVC Station 11 + 00 Elevation 185.75
Elevation of entering grade at EVC station 202.25
End ordinate (eo) 16.50

	Station	Distance from BVC	Tangent rise or drop from BVC, ft	Tangent grade elevation	VC ordinate	VC elevation
BVC	8 + 00	00.00	0.0	190.25	00.00	190.25
	8 + 50	50.00	2.0	192.25	00.46	191.79
	9 + 00	100.00	4.0	194.25	01.83	192.4
V	9 + 50	150.00	6.0	196.25	04.12	192.13
	10 + 00	200.00	8.0	198.25	07.33	190.92
	10 + 50	250.00	10.0	200.25	11.46	188.79
EVC	11 + 00	300.00	12.0	202.25	16.50	185.75

Table 342-18. VERTICAL CURVE DATA FORM: UNSYMMETRICAL CURVE (EXAMPLE PROBLEM DATA)

Intersection station 10 + 50 Flevation 160.30 VC no. 4
Algebraic difference -8 - (+4) = 12 Curve length 600 ft
BVC station 8 + 00 Elevation 150.30
EVC station 14 + OO Elevation 132.30
Middle ordinate (e) [(250 X 350)/[2(250 + 350)]] x 12/100 = 9.59 ft

	Station	Distance from BVC or EVC	Tangent grade elevation	VC ordinate	VC elevation
BVC	8 + 00	0	150.30	0.00	150.30
	8 + 50	50	152.30	0.38	151.42
	9 + 00	100	154.30	1.53	152.77
	9 + 50	150	156.30	3.45	152.85
	10 + 00	200	158.30	6.14	152.16
V	10 + 50	250-350	160.30	9.59	150.71
	11 + 00	300	156.30	7.00	149.3
	11 + 50	250	152.30	4.89	147.41
	12 + 00	200	148.30	3.16	145.14
	12 + 50	150	144.30	1.73	142.57
	13 + 00	100	140.30	0.77	139.53
	13 + 50	50	136.30	0.19	136.11
EVC	14 + 00	0	132.30	0.00	132.30

4.0 PARKING

This section does not include detailed information on parking dimensions, lot sizes, handicapped parking standards, or truck loading and docking standards. Such information can be found in Sections 210: Spatial Standards, and 240: Outdoor Accessibility.

This section provides general information on site planning and the layout of parking areas.

4.1 Site Planning Considerations

Thorough consideration should be given to integrating the design of buildings and structures with parking areas and related improvements. Residential, commercial, industrial, institutional, recreational, and other types of projects all have particular parking requirements and should be planned accordingly. When parking layouts are developed simultaneously with building plans, inefficient parking circulation can be avoided.

The parking habits of users have a tremendous influence on standards. Urban drivers will usually accept narrower stalls than will drivers in rural or suburban areas. Activities like picnicking call for wider stalls to make the handling of bulky items in and out of cars easier. In shopping centers where carts are used, wider stalls are more desirable, as compared to all-day parking areas for office workers.

If experienced attendants are to park cars, aisles at least 1 200 mm (4 ft) narrower can be used for 90-degree parking. Designers should also be mindful of the fact that drivers typically will not park precisely in the center of the stall, nor will they always drive in all the way. If stalls are too narrow, drivers will ignore demarcation lines and lap over into adjoining stalls.

In any parking area, handicapped parking spaces or a passenger loading zone should be located as close as possible to the shortest accessible path of travel to buildings.

Table 342-19. VERTICAL CURVE LENGTHS (L) NECESSARY TO OBTAIN A REQUIRED SIGHT/STOPPING DISTANCE, [M (FT)]

Design speed km/h (mph)	Sight/ stopping distance m (ft)	Algebraic difference, % 1	2	3	4	5	6	7	8
32 (20)	**33.0 (110)**	- -	- -	- -	- -	- -	- -	6.0 (20)	13.5 (45)
40 (25)	**45 (150)**	- -	- -	- -	- -	6.0 (20)	20.1 (67)	30.0 (100)	37.5 (125)
48 (30)	**60 (200)**	- -	- -	- -	15.3 (51)	36.0 (120)	50.1 (167)	60.0 (200)	68.7 (229)
96 (35)	**75.0 (250)**	- -	- -	10.2 (34)	45.0 (150)	66.0 (220)	80.4 (268)	93.9 (313)	107.4 (358)
64 (40)	**90.0 (300)**	19.2 (64)	38.7 (129)	57.9 (193)	77.4 (258)	96.3 (321)	115.8 (386)	135.3 (451)	154.5 (515)
72 (45)	**112.5 (375)**	30.3 (101)	60.3 (201)	90.6 (302)	120.6 (402)	150.9 (503)	181.2 (604)	211.2 (704)	241.5 (805)
80 (50)	**135.0 (450)**	43.5 (145)	87.0 (290)	130.5 (435)	173.7 (579)	217.2 (724)	260.7 (869)	304.2 (1014)	347.7 (1159)
80 (50)	**165.0 (550)**	64.8 (216)	129.6 (432)	194.7 (649)	259.8 (866)	325.2 (1084)	389.4 (1298)	454.5 (1515)	519.3 (1731)

		9	10	11	12	13	14	15	16
		19.5 (65)	24.0 (80)	27.9 (93)	31.2 (104)	33.9 (113)	36.3 (121)	39.0 (130)	41.4 (138)
		43.2 (144)	48.3 (161)	5.13 (177)	57.9 (193)	62.7 (209)	67.5 (225)	72.3 (241)	77.1 (257)
		77.1 (257)	85.8 (286)	94.5 (315)	102.9 (343)	111.6 (372)	120.3 (401)	128.7 (429)	137.4 (458)
		120.6 (402)	134.1 (447)	147.6 (536)	160.8 (581)	174.3 (626)	187.8 (671)	201.3 (492)	214.5 (715)
		173.7 (579)	193.2 (644)	231.9 (708)	251.1 (773)	270.3 (837)	289.8 (901)	212.4 (966)	309.0 (1030)
		271.5 (905)	301.8 (1006)	331.8 (1106)	362.1 (1207)	392.4 (1308)	422.4 (1408)	452.7 (1509)	482.7 (1609)
		391.2 (1304)	434.4 (1448)	521.4 (1593)	564.9 (1738)	608.4 (1883)	651.9 (2028)	477.9 (2173)	695.4 (2318)
		584.1 (1947)	649.2 (2164)	714.0 (2380)	779.1 (2597)	843.9 (2813)	908.7 (3029)	973.8 (3246)	1038.6 (3462)

		17	18	19	20	21	22	23	24	25
		44.1 (147)	46.8 (156)	49.2 (164)	51.9 (173)	54.6 (182)	57.0 (190)	59.7 (199)	62.4 (208)	64.8 (216)
		81.9 (273)	87.0 (290)	91.8 (306)	96.6 (322)	101.4 (338)	106.2 (354)	111.0 (370)	115.8 (386)	120.6 (402)
		145.8 (486)	154.5 (515)	163.2 (544)	171.6 (572)	180.3 (601)	188.7 (629)	197.4 (658)	206.1 (687)	214.5 (715)
		228.0 (760)	241.5 (805)	254.7 (849)	268.2 (894)	281.7 (939)	295.2 (984)	308.4 (1028)	321.9 (1073)	335.4 (1118)
		328.2 (1094)	347.7 (1159)	366.9 (1223)	384.0 (1288)	405.6 (1352)	424.8 (1416)	444.3 (1481)	463.5 (1545)	507.0 (1609)
		513.0 (1710)	543.3 (1811)	573.3 (1911)	603.6 (2012)	633.6 (2112)	663.9 (2213)	694.2 (2314)	724.2 (2414)	754.5 (2515)
		738.6 (2462)	782.1 (2607)	825.6 (2752)	869.1 (2897)	912.6 (3042)	956.1 (3187)	999.6 (3332)	1042.8 (3476)	1086.3 (3621)
		1103.4 (3678)	1168.5 (3895)	1233.3 (4111)	1298.4 (4328)	1363.2 (4544)	1428.0 (4760)	1493.1 (4977)	1557.9 (5193)	1622.7 (5409)

Table 342-20. VERTICAL CURVE LENGTHS (L) NECESSARY TO OBTAIN THE FOLLOWING PASSING SIGHT DISTANCES, [M (FT)]

Design speed	Passing sight distance	Algebraic difference, %									
		1	2	3	4	5	6	7	8	9	10
48 (30)	330.0 (1100)	- -	165.0 (550)	330.9 (1103)	441.3 (1471)	551.7 (1839)	662.1 (2207)	772.5 (2575)	882.6 (2942)	993.0.6 (3310)	993.0 (3678)
64 (40)	450.0 (1500)	- -	406.5 (1355)	615.6 (2052)	820.8 (2736)	1025.7 (3419)	1230.9 (4103)	1436.1 (4787)	1641.3 (5471)	1846.5 (6155)	2051.7 (6839)
80 (50)	540.0 (1800)	93.0 (310)	591.0 (1970)	886.2 (2954)	1181.7 (3939)	1477.2 (4924)	1772.7 (5909)	2068.2 (6894)	2363.4 (7878)	2658.9 (8863)	2954.4 (9848)
96 (60)	630.0 (2100)	273.0 (910)	804.3 (2681)	1206.3 (4021)	1608.3 (5361)	2010.6 (6702)	2412.9 (8043)	2814.9 (9383)	- -	- -	- -
104 (65)	690.0 (2300)	393.0 (1310)	964.8 (3216)	1447.2 (4824)	1929.6 (6432)	2412.0 (8040)	2894.1 (9647)	- -	- -	- -	- -

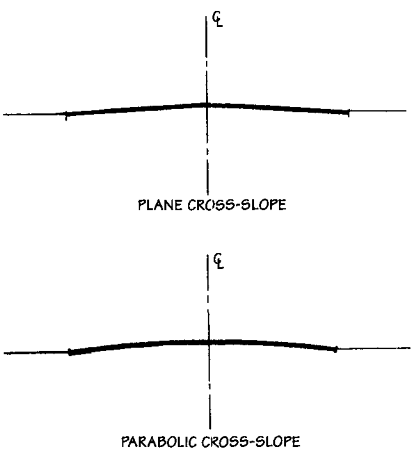


Figure 342-28. Pavement crowns.

4.2 General Layout of Parking Areas

A major consideration in the design of any parking area is simplicity. Parking areas should not be complex or designed in such a manner as to test a driver's patience.

The three basic dimensions of any parking layout are: (1) the length and width of car stalls, (2) the width of aisles, and (3) the angle between car stall and aisle. Aisle width is related to stall width and angle of stalls. With a wider stall, it is possible to use a slightly narrower aisle.

5.0 PAVEMENTS AND CURBS

This section does not include detailed information on the construction of various pavements and curbs. Specific information on the design and construction of these elements is included in Sections 820: Asphalt and 830: Concrete. Division 900: Details and Devices, includes representative detail drawings of various pavements and curbs.

This section includes general information on pavements and curbs, including information on the advantages and disadvantages of various types of pavements.

5.1 Pavements: General Considerations

Pavements for vehicular use are generally divided into two main categories, rigid pavements and flexible pavements. The two vary in terms of construction methods, durability, and cost.

Rigid Pavements:

Rigid (e.g., concrete) pavements have a high compressive strength, which tends to distribute the load over a relatively wide area.

The advantages of properly constructed rigid pavements include:

1. Low maintenance costs.
2. Long life, with extreme durability.
3. High value as a base for future resurfacing with asphalt.
4. Load distribution over a wide area, therefore decreasing base and subgrade requirements.
5. Ability to be placed directly on poor soils.
6. No damage from oils and grease.
7. Strong edges.

The disadvantages of rigid pavements include:

1. High initial costs.
2. Joints required for contraction and expansion.
3. A generally rough riding quality.
4. Expensive to repair.

Rigid Pavement Design Considerations: To arrive at the proper design of rigid concrete pavements, the following factors must be considered:

1. Wheel loads.
2. Subgrade (modulus of subgrade reaction).
3. Protected or unprotected corners.
4. Uniform or thickened edge.
5. Quality of concrete (flexural strength).

Pavement Subgrade: The subgrade soils must be of uniform material and density to provide satisfactory pavement performance. The supporting power of the subgrade is expressed as values of K, the modulus of subgrade reaction.

Protected or Unprotected Corners: Since joints are required for concrete paving because of expansion and contraction, the strength of the pavement will be lost between separate slabs. Protected corners are those at which provision is made for transferring at least 20 percent of the load across the intervening joints by means of aggregate interlock, dowels, or keys. Unprotected corners are those at which there is not adequate provision for load transference.

Pavement Joints: Joints are always necessary in rigid pavements (1) to permit expansion and contraction of the concrete due to temperature and moisture changes, (2) to relieve warping and curling stresses which result from temperature and moisture gradients within the slab, and (3) as a construction expedient to separate areas of concrete placed at different times.

Table 342-21. MINIMUM SAG VERTICAL CURVE LENGTHS (L) NECESSARY TO OBTAIN LIGHT BEAM DISTANCE, [M (FT)]

Design speed km/h (mph)	Sight/ stopping and light-beam distance m (ft)	Algebraic difference, % 1	2	3	4	5	6	7	8	9	10
32 (20)	33.0 (110)	- -	- -	- -	7.2 (24)	18.9 (63)	26.7 (89)	32.4 (108)	36.9 (123)	41.4 (138)	46.2 (154)
40 (25)	45.0 (150)	- -	- -	- -	20.7 (69)	34.5 (115)	43.8 (146)	51.0 (170)	58.5 (195)	65.7 (219)	72.9 (243)
48 (30)	60.0 (200)	- -	- -	9.9 (33)	37.5 (125)	54.0 (180)	65.4 (218)	76.5 (255)	87.3 (291)	98.1 (327)	109.2 (364)
56 (35)	75.0 (250)	- -	- -	22.5 (75)	54.3 (181)	73.5 (245)	88.2 (294)	102.9 (343)	117.6 (392)	132.3 (441)	147.0 (490)
64 (40)	90.0 (300)	- -	- -	35.1 (117)	68.4 (228)	93.0 (310)	111.6 (372)	130.2 (434)	149.1 (497)	167.7 (559)	186.3 (621)
72 (45)	112.5 (375)	- -	- -	53.7 (179)	96.6 (322)	123.3 (411)	147.9 (493)	172.5 (575)	197.1 (657)	221.7 (739)	246.3 (821)
80 (50)	135.0 (450)	- -	- -	72.6 (242)	121.8 (406)	153.9 (513)	184.5 (615)	215.4 (718)	246.0 (820)	276.9 (923)	307.5 (1025)
88 (55)	165.0 (550)	- -	- -	97.5 (325)	155.7 (519)	195.3 (651)	234.3 (781)	273.3 (911)	312.3 (1041)	351.3 (1171)	390.3 (1301)
96 (60)	195.0 (650)	- -	- -	122.4 (408)	189.3 (631)	237.0 (790)	284.4 (948)	331.8 (1106)	379.2 (1264)	426.0 (1421)	473.7 (1579)
		11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
32 (20)	33.0 (110)	51.0 (170)	55.5 (185)	60.0 (200)	64.8 (216)	69.3 (231)	74.1 (247)	78.6 (262)	83.1 (277)	87.9 (293)	92.4 (308)
40 (25)	45.0 (150)	80.4 (268)	87.6 (292)	94.8 (316)	102.3 (341)	109.5 (365)	116.7 (389)	124.2 (414)	131.4 (438)	138.6 (462)	145.8 (486)
48 (30)	60.0 (200)	120.0 (400)	130.8 (436)	141.9 (473)	152.7 (509)	163.5 (545)	174.6 (582)	185.4 (618)	196.5 (655)	207.3 (691)	218.1 (727)
56 (35)	75.0 (250)	161.7 (539)	176.4 (588)	191.1 (637)	205.8 (686)	220.5 (735)	235.2 (784)	249.9 (833)	264.6 (882)	279.3 (931)	294.0 (980)
64 (40)	90.0 (300)	204.9 (683)	223.5 (745)	242.1 (807)	260.7 (869)	279.3 (931)	297.9 (993)	316.5 (1055)	335.1 (1117)	353.7 (1179)	372.3 (1241)
72 (45)	112.5 (375)	270.9 (903)	295.5 (985)	320.4 (1068)	345.0 (1150)	369.6 (1232)	394.2 (1314)	418.8 (1396)	443.4 (1478)	468.0 (1560)	492.6 (1642)
80 (50)	135.0 (450)	338.4 (1128)	369.0 (1230)	399.9 (1333)	430.5 (1435)	461.4 (1538)	492.3 (1641)	522.9 (1743)	553.8 (1846)	584.4 (1948)	615.3 (2051)
88 (55)	165.0 (550)	429.3 (1431)	468.3 (1561)	507.3 (1691)	546.6 (1822)	585.6 (1952)	624.6 (2082)	663.6 (2212)	702.6 (2342)	741.6 (2472)	780.6 (2602)
96 (60)	195.0 (650)	521.1 (1737)	568.5 (1895)	615.9 (2053)	663.3 (2211)	710.7 (2369)	758.1 (2527)	805.5 (2685)	852.9 (2843)	900.0 (3000)	947.7 (3159)

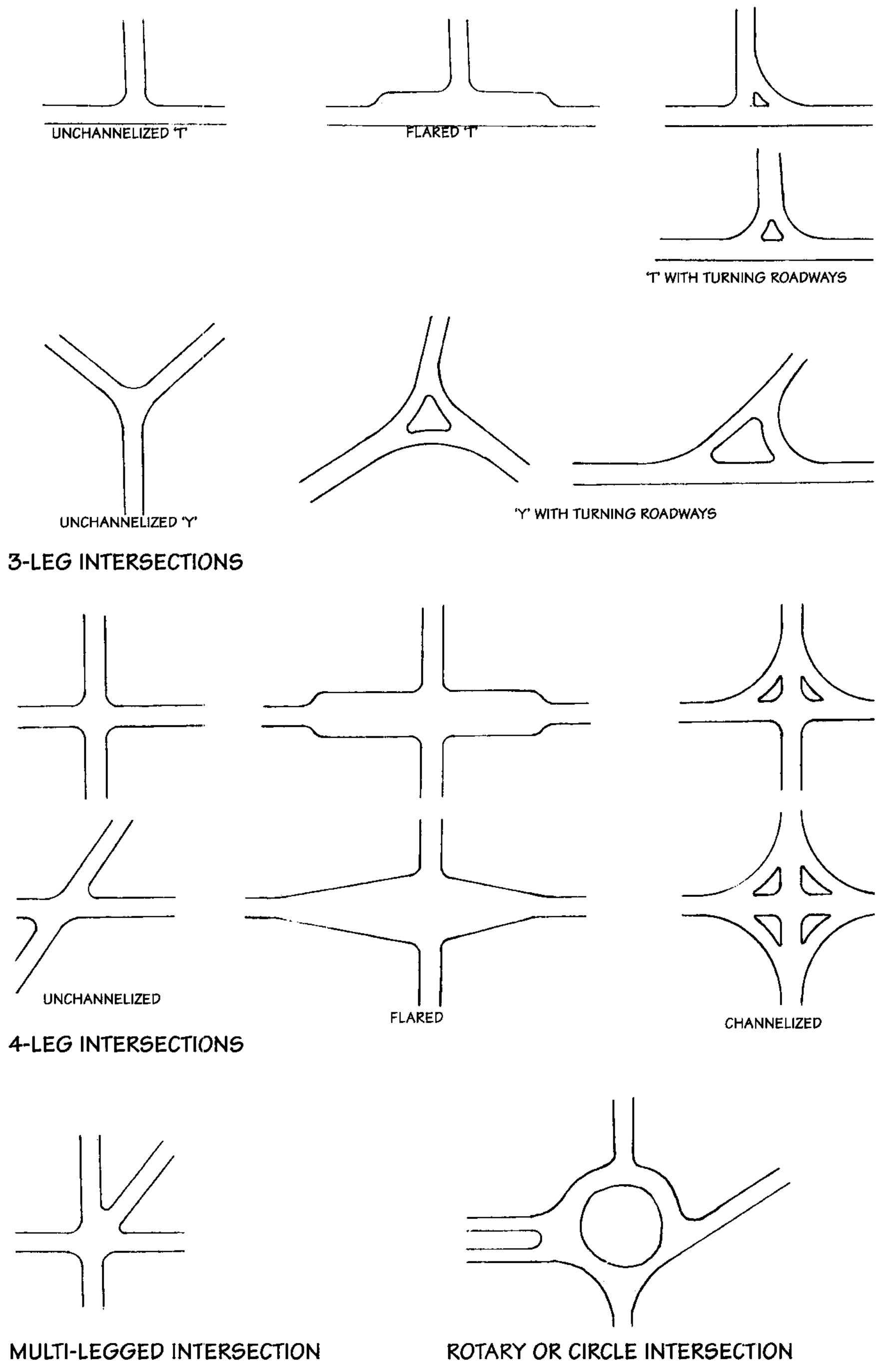


Figure 342-29.

The three basic types of joints used in rigid pavements are (1) contraction joints, which are used to provide controlled contraction cracking; (2) construction joints, which are provided to separate areas of concrete placed at different times; and (3) expansion joints, which are provided for the relief of forces resulting from thermal expansion of the pavement. Expansion joints also permit unrestrained differential horizontal movement of adjoining pavements and/or structures.

Flexible Pavements:

Flexible pavements consist of a series of layers, with the highest-quality materials at or near the surface. The strength of a flexible pavement is a result of building up thick layers and thereby distributing the load over the subgrade, rather than the surface material assuming the structural strengths as with rigid pavements.

The advantages of flexible pavements include:

1. Adaptability to stage construction.
2. Availability of low-cost types which can be easily built.
3. Ability to be easily opened and patched.
4. A generally low initial cost
5. Easy repair of frost heave and settlement
6. Resistance to the formation of ice glaze

The disadvantages include:

1. Higher maintenance costs
2. Shorter life span under heavy use
3. Damage by oils and certain chemicals
4. Weak edges that may require curbs or edge devices

Principles of Flexible Pavement Design: The design of a flexible pavement employs the principle that a load of any magnitude may be dissipated by carrying it deep into the ground through successive layers of granular material. This is because the intensity of a load diminishes in geometrical proportion as it is transmitted downward from the surface, by virtue of spreading over an increasingly larger area. Because of this, materials with a progressively lower bearing value may be employed as the depth increases.

There are various methods employed to determine the thickness required for flexible pavements. Refer to Section 820: Asphalt, for a description of the thickness design procedure.

5.2 Shoulders: General Considerations

A shoulder is the portion of a roadway contiguous with the pavement for (1) accommodation of stopped vehicles in emergencies and (2) lateral support of base and surface courses.

Well-designed and properly maintained shoulders on roads, where appreciable volumes of traffic exist, may serve one or more of the following purposes:

1. Space is provided for stopping free of the traffic lane.
2. Space is provided for the occasional motorist who desires to stop to

consult road maps, to rest, etc.

3. Space is provided to escape potential accidents or to reduce their severity.
4. Horizontal sight distance may be improved in cut sections and may thus reduce hazards.
5. The capacity of the highway may be improved, encouraging uniform speeds.
6. Space is provided for maintenance operations.
7. Stormwater can be discharged farther away from the pavement, and seepage adjacent to the pavement is minimized.
8. Structural support is given to the pavement, which is especially important for flexible pavements.

Shoulder Widths:

Shoulders should be designed wide enough to allow a stopped or disabled vehicle to pull entirely off the road (Table 342-28). Their surface treatment should sustain the weight of vehicles in all seasons. Most frequently, this can be accomplished by the use of well-drained soil mixed with aggregate that has been compacted and, where appropriate, seeded with grass or other types of low-growing ground cover.

Shoulder Cross Slopes:

Table 342-29 gives recommended cross-slopes for roadway shoulders.

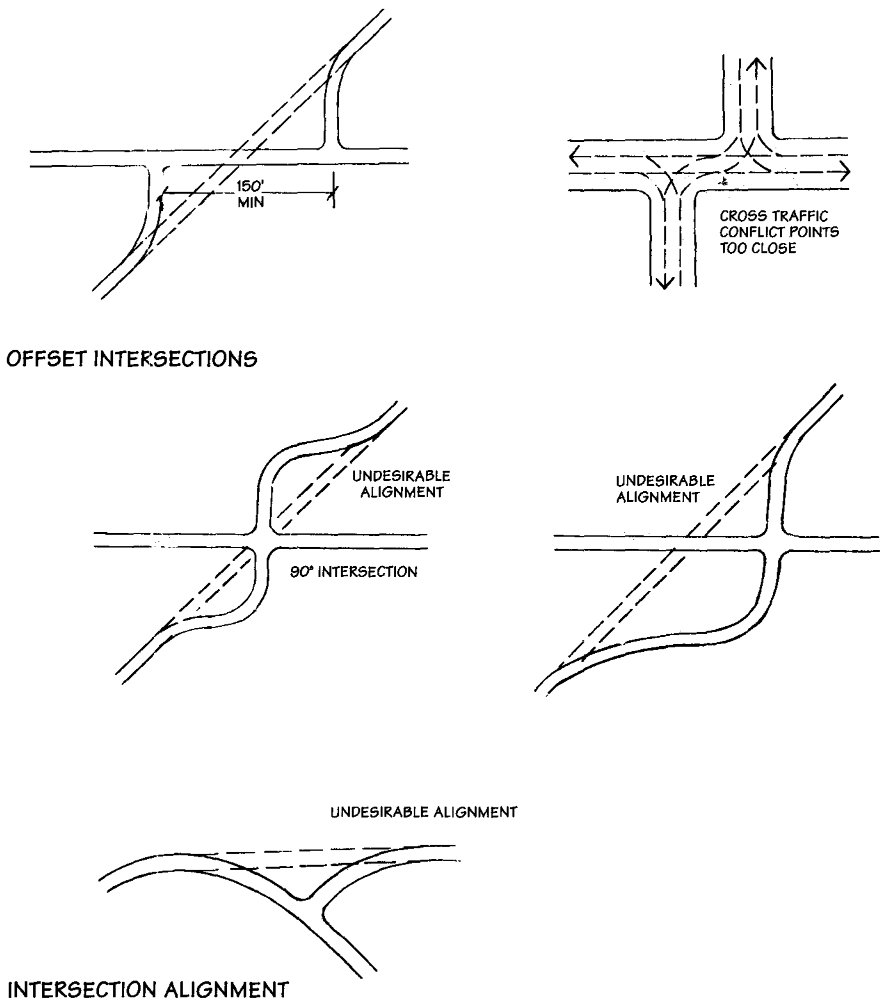


Figure 342-30. Horizontal alignment at intersections.

Table 342-22. MINIMUM WIDTHS FOR TWO-LANE ROADS, MM (FT)

Design speed, km/h (mph)	**ADT*, 50-250**	**ADT, 250-400**	**ADT, 400-750**	**DHV†, 200-400**	**DHV, over 400**
48 (30)	6 000 (20)	6 000 (20)	6 000 (20)	6 600 (22)	7 200 (24)
64 (40)	6 000 (20)	6 000 (20)	6 600 (22)	6 600 (22)	7 200 (24)
80 (50)	6 000 (20)	6 000 (20)	6 600 (22)	7 200 (24)	7 200 (24)
96 (60)	6 000 (20)	6 600 (22)	6 600 (22)	7 200 (24)	7 200 (24)
104 (65)	6 000 (20)	6 600 (22)	7 200 (24)	7 200 (24)	7 200 (24)
112 (70)	6 000 (20)	6 600 (22)	7 200 (24)	7 200 (24)	7 200 (24)

*ADT average daily traffic.
† DHV future design hourly volume.

Table 342-23. RECOMMENDED PAVEMENT WIDTHS (BY TYPE OF USE)

Use type	Widths, mm (ft)
Driveways (residentials)	2 100-3 000 (7-10)
Minor residential streets	
No parking	6 000-7 200 (20-24)
Parking on one side	7 800-8 400 (26-28)
Major residential streets	
No parking	4 800-7 200 (16-24)
Parking on one side	8 400-9 600 (28-32)
Streets with truck traffic	7 200-7 800 (24-26)
Recreational sites	
Heavy vegetation	5 400-6 600 (18-22)
Rough terrain	5 400-6 600 (18-22)
Scenic drives	6 000-7 200 (20-24)
Industrial areas	7 200 (24) minimum (no parking)

Table 342-24. RECOMMENDED CROSS-SLOPES FOR VARIOUS TYPES OF PAVEMENTS

Cross slope, Surface type	mm/m (in/ft)
High • Rigid (concrete) • Asphaltic concrete • Plant mix	10.7-21.3 (1/8-1/4)
Intermediate • Plant mix	16.0-31.7 (3/16-3/8)
Low • Road mix • Macadam • Surface treatment • Untreated surface	21.3-42.3 (1/4-1/2)

Table 342-25. MINIMUM RADII FOR INTERSECTION CURVES

Design (turning) speed V, km/h (mph)*	24 (15)	32 (20)	40 (25)	48 (30)	56 (35)	64 (40)
Side friction factor, F	0.32	0.27	0.23	0.20	0.18	0.16
Assumed minimum superelevation, E	0.00	0.02	0.04	0.06	0.08	0.09
Total, E + F	0.32	0.29	0.27	0.26	0.26	0.25
Calculated minimum radius R, mm (ft)	14 100 (47)	27 600 (92)	46 200 (154)	69 300 (231)	94 200 (314)	127 800 (426)
Suggested curvature for design: Radius maximum, mm (ft)	15 000 (50)	27 000 (90)	45 000 (150)	69 000 (230)	93 000 (310)	129 000 (430)
Degree of curve maximum	-	64	38	25	18	13
Average running speed, km/h (mph)	4 200 (14)	5 400 (18)	6 600 (22)	7 800 (26)	9 000 (30)	10 200 (34)

For design speeds of more than 40 mph, use values for open highway conditions.

Source: Courtesy of AASHTO.

Table 342-26. INTERSECTION SAFE STOPPING DISTANCES

Design speed, km/h (mph)	Safe stopping distance, m (ft)
48 (30)	60.0 (200)
64 (40)	82.5 (275)
80 (50)	105.0 (350)
96 (60)	142.5 (475)
112 (70)	180.0 (600)

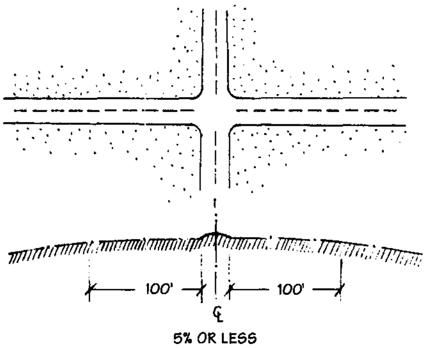


Figure 342-31. Intersection grades.

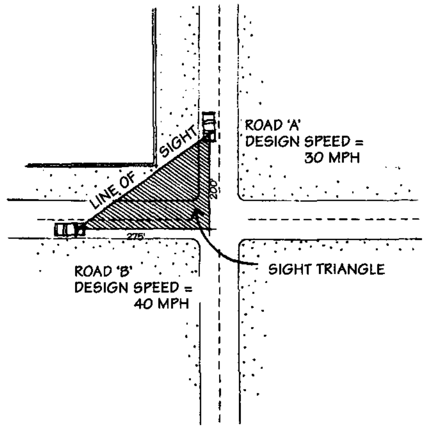


Figure 342-32. Sight triangle at intersections.

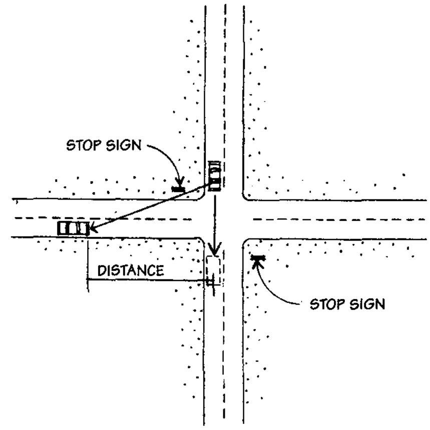


Figure 342-33. Sight distance at controlled intersection.

Table 342-27. MINIMUM SIGHT DISTANCES (IN FEET) NECESSARY ALONG HIGHWAY FROM INTERSECTION

	Major highway design speed, km/h (mph)				
Type of vehicle stopped	48 (30)	64 (40)	80 (50)	96 (60)	1 1 2 (70)
Passenger vehicle					
• Two-lane highway*	90 (300)	120 (400)	150 (500)	180 (600)	210 (700)
• Four-lane highway	105 (350)	143 (475)	180 (600)	210 (700)	248 (825)
Single-unit vehicle					
• Two-lane highway	120 (400)	165 (550)	203 (675)	240 (800)	285 (950)
• Four-lane highway	143 (475)	188 (625)	233 (775)	278 (925)	323 (1075)
50-ft design vehicle					
• Two-lane highway	158 (525)	210 (700)	263 (875)	315 (1050)	368 (1225)
• Four-lane highway	180 (600)	233 (775)	293 (975)	353 (1175)	413 (1375)

* 12-ft lanes with level conditions.

Table 342-28. RECOMMENDED SHOULDER WIDTHS

Type of highway	Width of shoulder, mm (ft)
Heavily traveled	3 000 (10) minimum, 3 600 (12)
High-speed	desirable
Low-type	1 200 (4) minimum, 1 800-2 400 (6-8)
In difficult terrain	desirable

5.3 Curbs: General Considerations

The type and location of curbing will affect driver behavior and, in turn, the safety and utility of a roadway. Curbs are used:

1. To control drainage.
2. To act as a deterrent to vehicles leaving the pavement at hazardous points.
3. To present a more finished appearance
4. To stabilize the road edge in flexible pavements.

Table 342-29. RECOMMENDED SHOULDER CROSS-SLOPES

Type of surface	Shoulder cross-slope mm/m (in/ft)	m/m (ft/ft)
No pavement edge curbs		
• Bituminous	31.7-42.3 (3/8-1/2)	0.03-0.04 (0.03-0.04)
• Gravel or crushed stone	10.6-63.5 (1/8-3/4)	0.04-0.06 (0.04-0.06)
• Turf	84.7 (1)	0.08 (0.08)
With shoulder curbs at pavement edge		
• Bituminous	21.2 (1/4)	0.02 (0.02)
• Gravel or crushed stone	21.2-42.3 (1/4-1/2)	0.02-0.04 (0.02-0.04)
• Turf	31.7-42.3 (3/8-1/2)	0.03-0.04 (0.03-0.04)

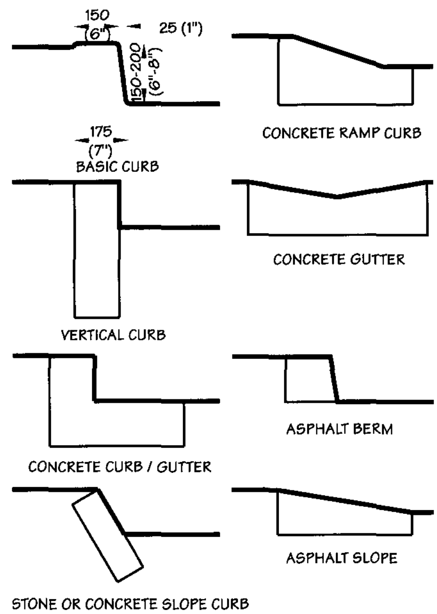


Figure 342-34. Types of curbs.

Types of Curbs:

Two general classes of curbs are barrier and mountable, and each class includes numerous types (Figure 342-34). Each may be designed as a separate unit or integrated with the pavement. Barrier and mountable curbs may be designed with a gutter to form a combination curb-and-gutter section (Figure 342-34).

Barrier Curbs: Barrier curbs are relatively high and steep-faced, designed to restrict or at least to discourage vehicles from leaving the pavement. They are usually 150 mm (6") or more in height, with a sloping face not exceeding 25 mm per 75 mm (1 in per 3 in) of height.

Curbs used for pedestrian islands should be made with heights between 125 and 175 mm (5 and 7 in).

Mountable Curbs: Mountable curbs refer to curbs that can be mounted by automobile tires.

Curb Materials:

Concrete: Concrete is probably the most common material used for both barrier and mountable curbs. Concrete curbs are durable and relatively easy to construct.

Asphalt: Asphalt is frequently used for curbing, especially in parking areas where they can be curved for islands. They are economical, easy to construct, and available in a variety of cross sections.

Granite: Granite curbs are not as frequently used as asphalt or concrete in most parts of the world, but in areas where granite is quarried, it is commonly used and is often no more expensive than concrete. Granite curbs are far more durable than concrete.

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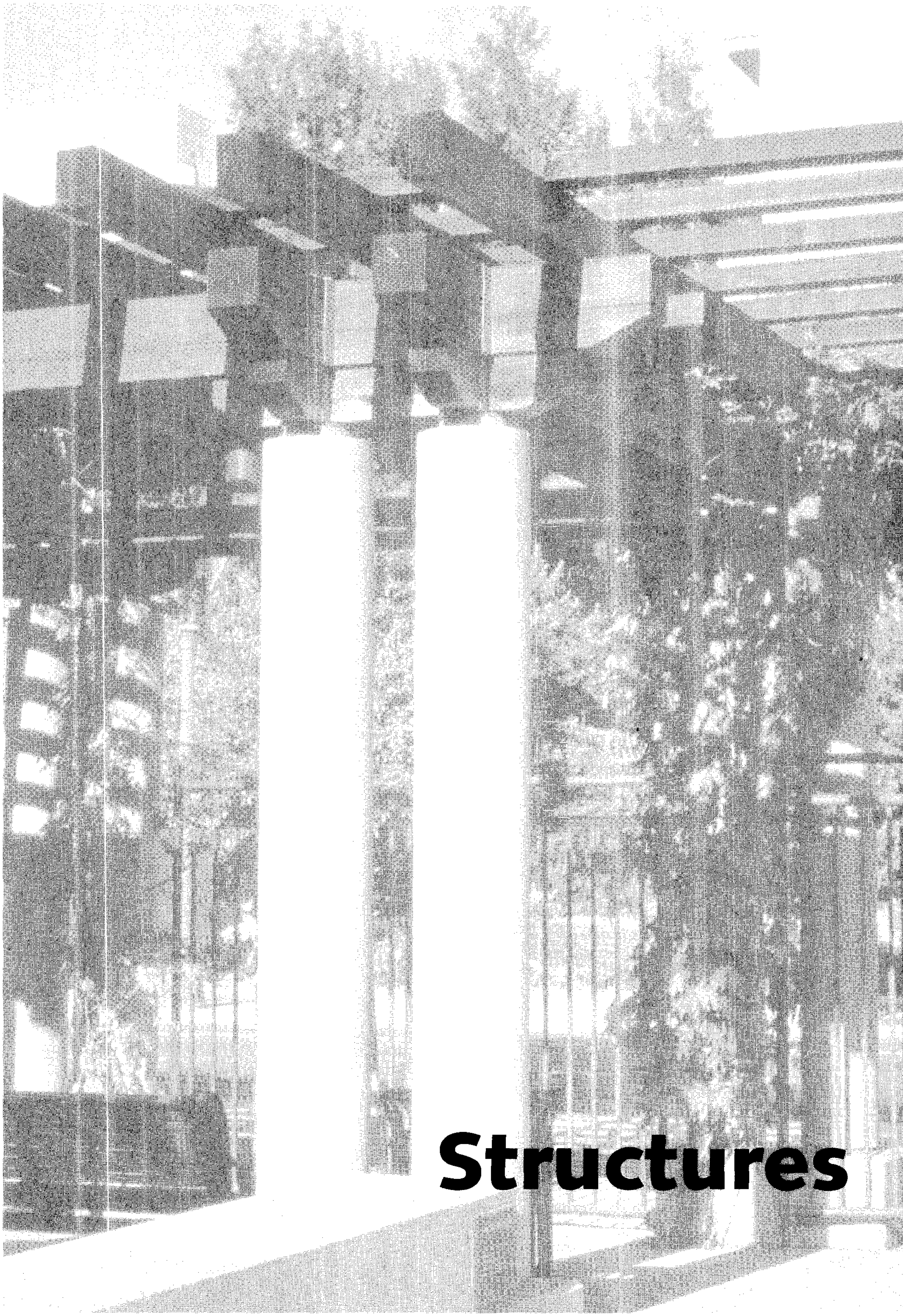
DIVISION 400



Structures

Retaining Walls

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CONTENTS

1.0 INTRODUCTION

An earth retaining structure is a landscape device used to accommodate abrupt grade changes which exceed the natural angle of repose of the existing soil (usually 33 to 37 degrees, or about 1 to 1.5). These devices include not only wall structures, but also embankment reinforcing structures such as rip-rap stone, fiber matting, and highly fibrous rooted plants. All such devices, regardless of their material, or shape, must be able to withstand earth pressures, and other related factors which typically cause structural failure, such as vehicle loading, highway vibration (i.e., live loading), and effects of extreme moisture conditions (e.g., heaving due to swelling and frost/thaw cycles).

1.1 Use of Retaining Structures

Typical structures are designed to accommodate one or more of the following purposes:

1. Protect steep slopes from erosion, either as an existing condition or as a mitigating strategy due to construction alterations (Figure 410-1).
2. Protect specimen tree stands from fill or cut conditions (Figure 410-2).
3. Facilitate vertical circulation at steps or ramp structures (Figure 410-3).
4. Facilitate vehicular access in steeply sloping wooded sites, such as parks, camping areas, or private residences (Figure 410-4).
5. Maximize potential for development and/or building area to accommodate an extensive design program for schools, play fields, outdoor theaters, art galleries, etc. (Figure 410-5).
6. Extend the architecture of a building into the site and to express its functioning levels (Figure 410-6).
7. Accommodate grade changes when limited space prohibits non-structural grading solutions (e.g., at property lines, or existing buildings and specimen trees).
8. Achieve an integrated visual appearance of the proposed development in relation to the existing site and surrounding development or context.

Compared to other forms of earth retaining devices, walls can be five to six times more expensive than engineered earth embankments, rip-rap embankments, or bio-engineered embankments, and

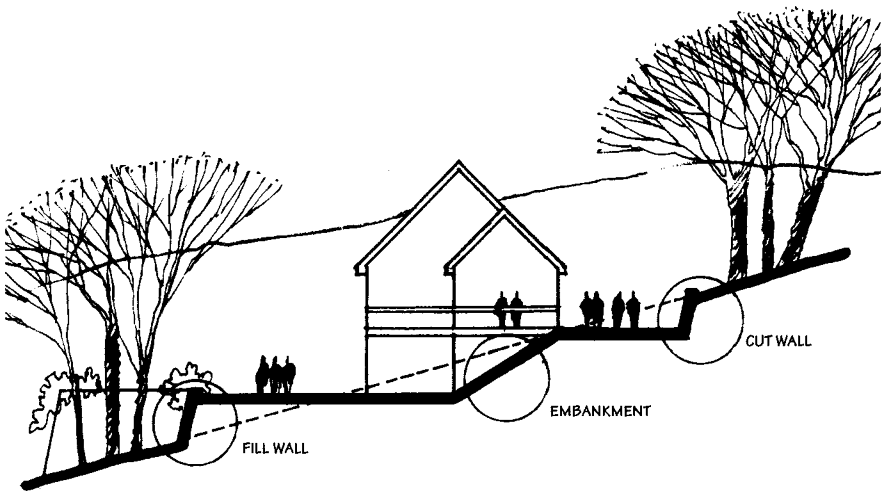


Figure 410-1. Retaining structures for steep slope protection.

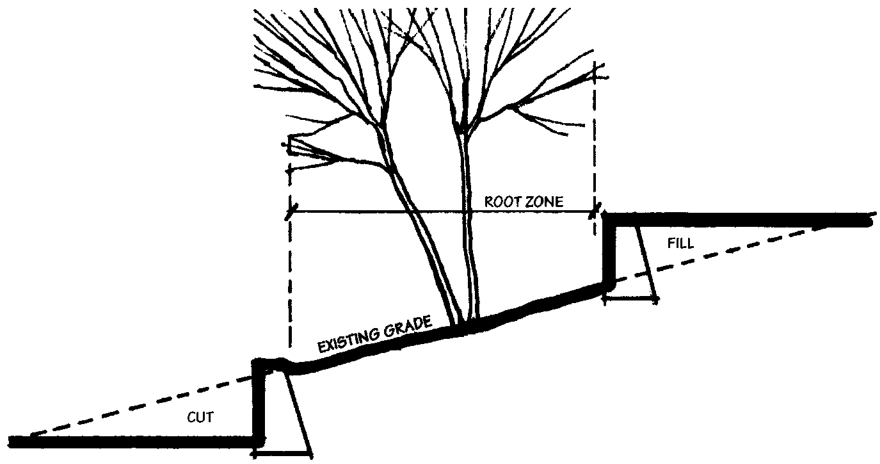


Figure 410-2. Retaining walls for existing tree protection.

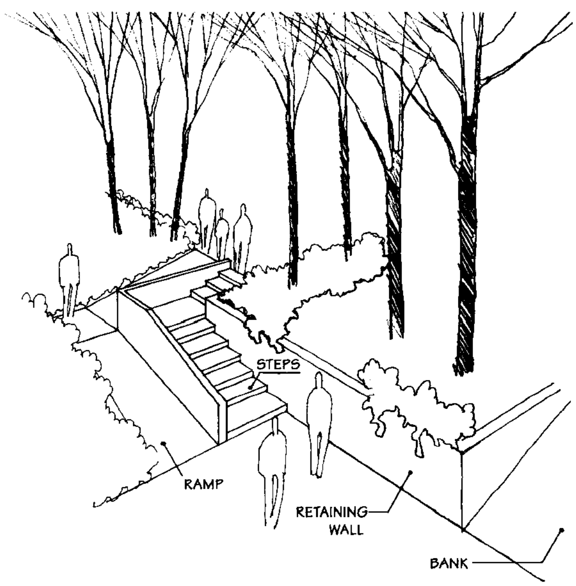


Figure 410-3. Retaining walls to facilitate ramp and step access.

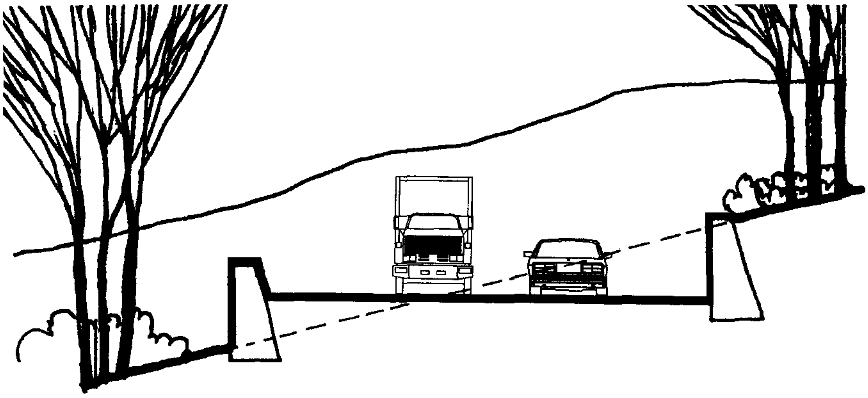


Figure 410-4. **Retaining structures to allow vehicular access on sloping sites.**

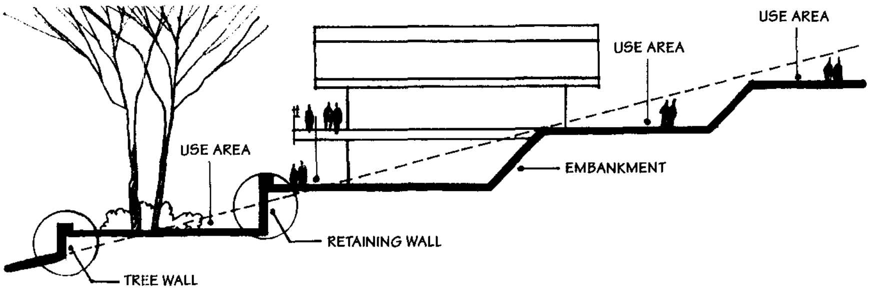


Figure 410-5. **Retaining structures to accommodate extensive building program.**

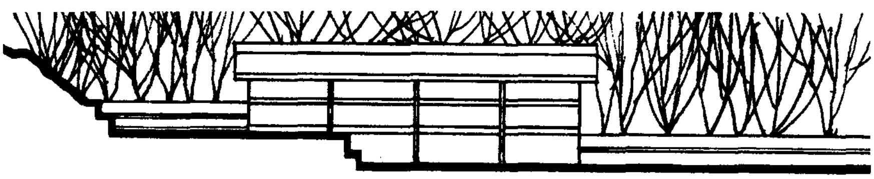


Figure 410-6. **Retaining structures to extend architecture into the site.**

should be considered to be a long-term investment often involving matters or safety and legal liability. Table 410-1 illustrates the continuum of devices suitable for embankment stabilization and retention.

1.2 Design Parameters

This section provides typical designs and standards for retaining walls that may be modified to accommodate specific soil characteristics and the requirements of structural mechanics. The designs and standards provided for retaining walls are limited to a maximum height of 3 000 mm (10 ft), including depth to foundation. Retaining structures above 3 000 mm (10 ft) in height, have numerous variables affecting their design (soils, pressures, foundation, and construction materials) and are assumed to be too complex to be solved with the formulas used in this section. A structural engineer should be consulted, when faced with designing structures of greater size or complexity.

Parameters for retaining walls illustrated in this Section are listed below:

Heights: All retaining walls and devices (unless otherwise noted) are for a maximum height (H) of 3 000 mm (10 ft).

Loading: All walls will permit only a 600 mm (2 ft) surcharge without danger of overturning except for timber crib walls which are at their limits.

Bearing: The maximum soil bearing pressure is assumed to be 16 750 kg/m^2 (1.5 tons/ft^2).

Depth: The foundation depth in rigid construction (D) should extend to 600 mm (2 ft), or in frost conditions should extend below the frost depth according to local practice (typically top of footing is set at frost depth so that base of footing is protected by the footing thickness).

Strength: The compressive strength of all concrete is assumed to be 17 238 kPa (2,500 pounds per square inch [psi]), and the tensile strength of the steel reinforcement is 10 896 kg (24,000 lbs).

Joints: Expansion joints, when needed, should be placed every 9 000 mm (30 ft) or less.

NOTE: When structures have live loads, surcharges higher than 600 mm (2 ft), or poor foundations, a structural engineer experienced with the design of retaining walls should be consulted.

1.3 Design Process

The physical dimensions of a retaining structure are determined by total grade change height, and soil characteristics which affect soil weight, angle of repose, and permeability. Therefore, the design of any retaining structure begins with a careful soil analysis and a clear understanding of appropriate application options with regard to structural types, materials, and local climate variables.

The design process for retaining structures typically includes the following tasks:

1. Study the necessity and feasibility of a structural approach by exploring nonstructural solutions first, and by calculating installation and long-term maintenance costs.

2. Determine the type of structure required for a particular application with regard to:

   a). Magnitude of loads and soil bearing capacity

Table 410-1. RETAINING STRUCTURE CLASSIFICATION AND EVALUATION MATRIX

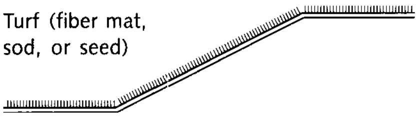
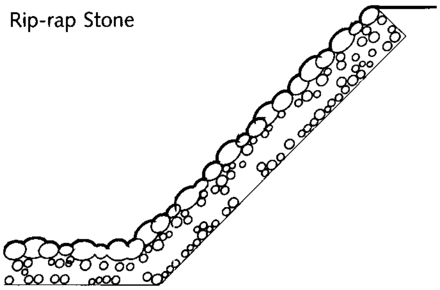
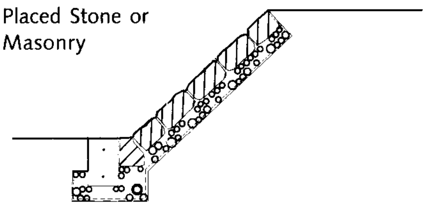
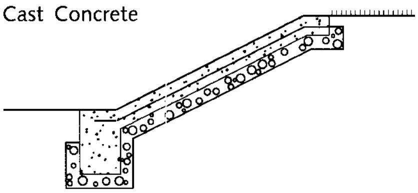
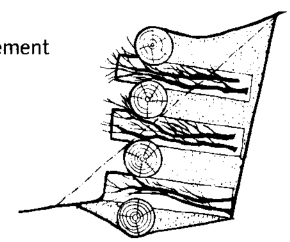
Type	Objective	Cost: Short/Long	Maintenance	Construction	Life Expectancy
Reinforced Embankment (A):					
Turf (fiber mat, sod, or seed) 	Stabilize cut/fill	Low/High	Mowing costs higher with 1:2 or 1:1.5, 1:3 pref.	1:2 max., avoid sheet runoff, use check swale at top	Moderate to Long
Rip-rap Stone 	Stabilize steep erosible soil banks	Low/Low	periodic patching and debris removal	1:1.5 max., Use check swales at top and place on aggregate base and fabric for strength	Moderate to Long
Placed Stone or Masonry 	Stabilize short slopes with higher finish	Mod./Low	periodic weeding and edge repair	1:1.5 max., requires granular subbase on fabric and heavy aggregate at base	Moderate to Long
Cast Concrete 	Clad very steep short slopes (warm climates)	Mod./Low	Very Low	1:1 max., Requires aggregate subbase and footing at base for bearing, sealed expansion joints, weep holes if wet	Moderate to Long
Root Reinforcement 	Stabilize banks in natural settings in high moisture zones	Low/Low	Requires periodic trimming to stimulate roots	1:1.5 max., Short slopes, fibrous rooted shrub stripplings bunched in stacked layers of logs or jute rolls	Short to Moderate

Table 410-1. RETAINING STRUCTURE CLASSIFICATION AND EVALUATION MATRIX (continued)

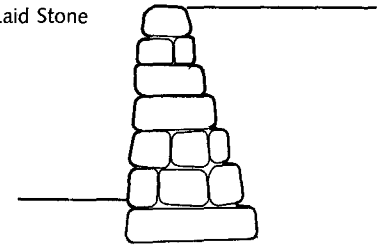
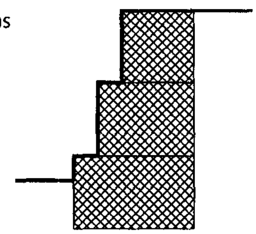
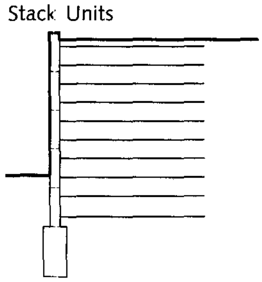
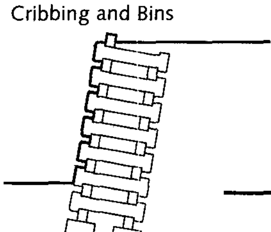
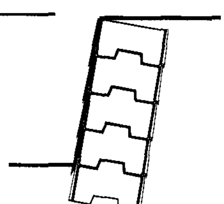
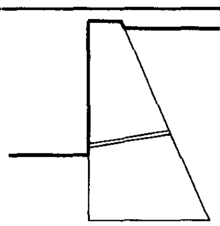
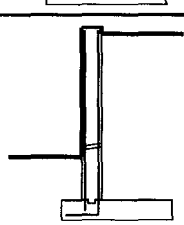
Type	Objective	Cost: Short/Long	Maintenance	Construction	Life Expectancy
Unit and Stack wall Systems (B):					
Dry Laid Stone 	Low walls in garden settings	Mod./Mod.	Periodic resetting of stones at top of wall	Requires batter and shallow aggregate base	Moderate to Long
Gabions 	Utilitarian quickly constructed walls	Mod./Low	Periodic inspection and stapling of wire fabric, repair top dressing	Requires 6° batters for tall walls, or staggered face, requires aggregate leveling base course and fabric separator at back edge of backfill in fine soils	Moderate to Long
Precast Stack Units 	small to high walls for garden to highway	Mod./Low	split face masonry may be susceptible to salt spray and extreme freeze/thaw	3-6° batter for split face masonry, vertical face for heavy precast "T" type, lateral fabric required for walls,	Moderate to Long
Cribbing and Bins  cribbing  bin	high utilitarian walls	Mod./Low	Periodic inspection and top dressing determined by material used	Typically set at 3-6° batter with fabric at base and outer backfill edge, bins may require back drains, wood only for temporary walls	Moderate to Long
Retaining Walls (C):					
Gravity 	Low to moderate walls with high finish	High /Low	Periodic grading at top of wall if required	May require back drainage and separator fabric at backfill edge, rigid requires keyed expansion joints	Long
Cantilever 	Moderate to high walls with many finish options	High /Low	Periodic grading at top of wall and cleaning of face	Requires large excavation and formwork with steel reinforcing, significant back drainage, and expansion joints	Long

Table 410-2. SOIL TYPES AND THEIR PROPERTIES (Unified Soil Classification).

Division	Symbols Letter	Symbols Color	Soil Description	Value as a Foundation Material*	Frost Action	Drainage
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 LL <50†	ML	Green	Inorganic silts, 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 LL >50	MH	Blue	Inorganic silts, micaceous or diatomaceous 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

* Consult soil engineers and local building codes for allowable soil-bearing capacities.
† LL indicates liquid limit.
Source: Douglas S. Way, *Terrain Analysis: A Guide to Site Selection Using Photographic Interpretation*, Douglas S. Way, Columbus, Ohio, 1972.

b). The visual consequences of using various materials for the intended use.

c). Access required for construction

d). Level of maintenance required

3. Select specific materials and design strategies based on:

a). Integration of the proposed structure into the site and/or with other site structures.

b). Site drainage and run-off control

c). Protection of existing vegetation and accommodating proposed plantings

d). Incorporation of safety features such as railings, lights, etc. as required.

4. Calculate the appropriate structural design for the purpose and materials selected based on:

a). The static and dynamic loading requirements

b). Structural analysis at the specific site

c). Construction techniques and specifications.

2.0 SELECTION CRITERIA FOR RETAINING STRUCTURES

The selection of appropriate retaining structures is based on a number of factors, including proposed application, desired materials, long- and short-term costs, maintenance requirements, and service life. Structural types can be broadly categorized as reinforced embankments, unit and stack wall systems, or rigid retaining walls. Although each structure type requires different methods of construction, all are subject to the laws of soil mechanics and the principles of statics in determining their final dimensions and proportions. Selection criteria for each type are described in Table 410-1.

2.1 Reinforced Embankments

Type "A" structures include reinforced embankments of vegetation, geotextile matting, turf grids, stone, or concrete surfacing. These structures are typically less expensive to install, require greater site area, and annual or periodic maintenance to maintain their structural integrity. Ideally, the rise to run ratio of an engineered embankment should not exceed the natural angle of repose of existing site soils, typically assumed to be 33° (degrees). For practical purposes, 1:1.5 is a useful maximum slope for masonry, stone, or other paved embankments. Vegetated or matted embankments typically require a 1:2 maximum slope to accommodate machine or hand maintenance. In all cases, the embankment face must be protected from adjacent storm water run-off through the use of check swales at the top of the embankment. The embankment toe or base typically requires reinforcement to accommodate the resultant surface material weight.

2.2 Unit and Stack Wall Systems

Type "B" structures are essentially flexible interlocking retaining walls that have a vertical face. They include cribbing, precast stack and tie-back units, gabions, dry-laid stone, and timber walls. These structures are typically moderate in both cost and maintenance. The advantage of this type of flexible construction is that it will tolerate a certain amount of differential settlement without being significantly affected. The base, or footing, need not extend below the frost line in temperate climates if the prepared subgrade has sufficient porosity and bearing capacity. Typically, a setting bed of sand or granular material is used to improve drainage and to provide a level subbase. In extreme cold or expansive clay settings, a full depth footing may be required.

With the exception of dry-laid stone or timber walls, unit or stack systems can attain heights exceeding 3 000 mm (10 ft) and have a moderate to long service life. Timber construction should be used as a short-term material for low walls only, especially in cold, temperate, and humid regions. In most cases, these structures are constructed to "lean" into the slope 6° or more to ensure stability. Since the face material is coarse, vines and groundcovers are often applied to provide a more appealing finish in areas adjacent to pedestrian circulation.

2.3 Rigid Retaining Walls

Type "C" structures include concrete and masonry Gravity walls and reinforced concrete Cantilevered walls. These structures are by far the most costly retaining strategy, but have the longest life expectancy, and require minimal maintenance to protect their structural integrity. Rigid construction is used where any movement of the structure cannot be tolerated or when aesthetic considerations require it. All rigid walls require a footing to account for local frost depths, seasonal soil swelling and other factors affecting subgrade movement. Gravity walls are typically constructed of mortared stone or of solid concrete, while cantilevered walls are constructed of reinforced masonry or concrete attached to a continuous reinforced concrete spread footing.

3.0 ELEMENTS OF RETAINING STRUCTURES

3.1 Subgrade

Ideally, the foundation should rest on a prepared subgrade with sufficient bearing capacity to support the estimated pressures of the proposed retaining structure. A prepared granular subbase should be provided if the subgrade requires leveling to achieve uniformity. A prepared granular subbase for drainage is not essential in rigid construction if back drainage is provided, but it is essential for flexible construction to minimize freeze/thaw action.

Properties of Soils:

Table 410-2 shows the Unified System of Soil Classification and the properties of each soil type relevant to the design of retaining structures. More detailed information can typically be obtained in the United States from federal, state, or local government soil and geology maps. Specific data for any site should be obtained through field testing (Refer to Section 810: Soils and Aggregates for more detailed information). Soils can be classified into two broad categories:

Granular (Sands and Gravels): These soils range from fine silty sands [0.05 mm (0.002 in)] to large naturally graded outwash deposits [50–100 mm (2–4 in)], typically found in coastal, riverine, and glacial landscapes. The soil strength is determined by the internal angle of friction between the particles (Typically 33°). The soil strength increases with weight to the point of particle crushing. Its bearing capacity is therefore determined by its granular characteristics and crushing threshold. Granular soils are advantageous for construction purposes due to their high permeability, compactability, and subsequent low incidence of heaving due to moisture infusion, or frost/thaw action. The presence of clays or silts in granular soils tend to negate these latter characteristics. Certain glacial outwash deposits, such as "bank run gravel," are valued because of their characteristically low silt content, and their "natural gradations" from sand to stone.

Colloidal (Silts and Clays): Clays are structurally different from granular soils, and depend on a constant moisture content for strength and stability. The clay particles are microscopic in size [0.001–0.005 mm ($4x10^{-5}$–$2x10^{-4}$ in)], and are ionically bonded by hydroscopic water. The bearing capacity of clays increases with the addition of moisture, up to its plastic limit and liquification point. Unlike granular soils, resistance to loading does not increase with the weight of the load because its bearing capacity is based on chemical bonding and not on mechanical friction. Clays are difficult to work with because of swelling and shrinkage due to moisture fluctuations.

KEY POINTS: Selection Criteria

Retaining structure design begins with a site analysis to determine clear purposes of grade change requirements, the most appropriate retaining strategy for the site and short, as well as long term budget constraints.

1. The three basic retaining structure categories are: reinforced embankments, unit and stack wall systems, and rigid retaining walls. Embankments are least costly, but require the most space and maintenance. Rigid retaining walls are most costly, but provide a long service life (Refer to Table 410-1 for complete summary).

2. With the exception of wood walls and dry-laid stone, most wall systems may achieve a height of 6 000 mm (18-20 ft) with proper engineering [although this section addresses walls only up to 3 000 mm (10 ft) in height].

3. Paved embankments should not exceed a 1:1.5 slope for long-term stability. Reinforced turf embankments should not exceed a 1:2 slope if mowing is required. Although less expensive to construct, these embankments require greater maintenance.

4. Flexible wall structure bases need not extend below frost line, but may require a prepared aggregate base course for drainage and leveling.

5. Rigid wall structures require footings below local frost depths and are typically placed directly on prepared subgrade.

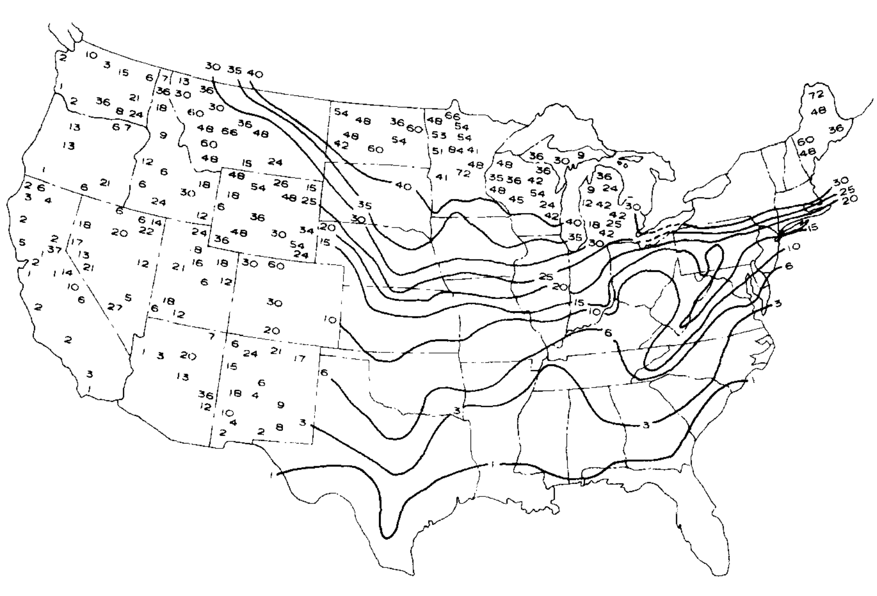


Figure 410-7. Average depth of frost penetration in the United States (inches).

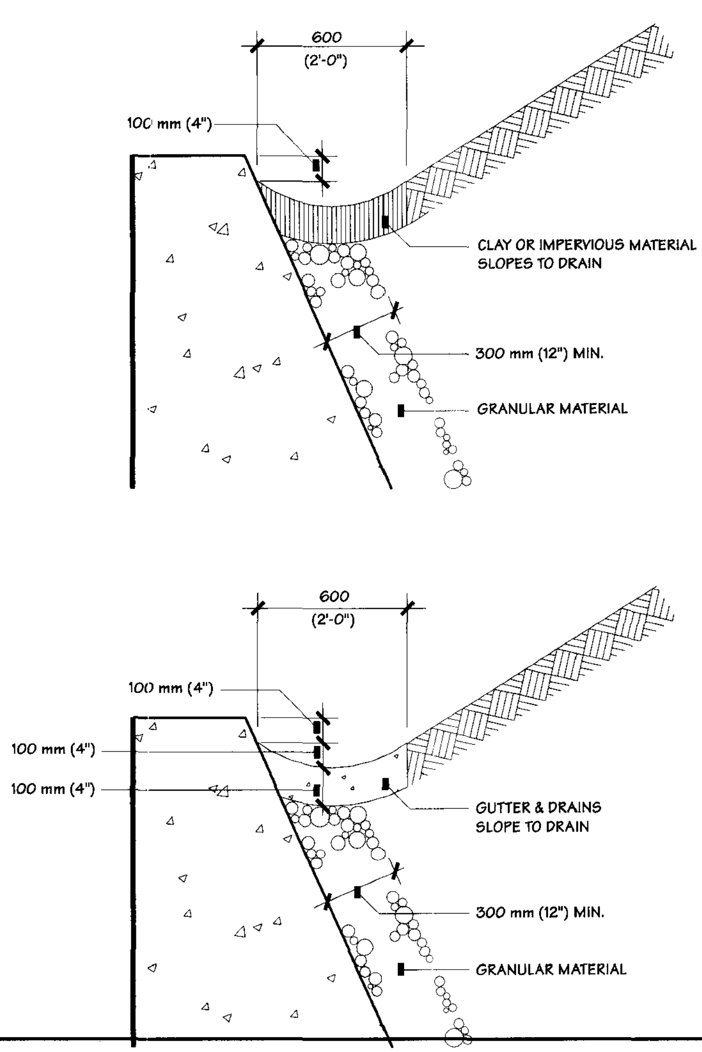


Figure 410-8. Drainage detail at toe of slope.

Design strategies typically focus on stabilizing moisture content. This usually involves heavy-duty graded aggregate sub-bases and backfills, which are drained by perforated pipe and other methods of de-watering.

Soil Testing:

Three methods commonly used in field testing soils are:

1. Probing with a steel bar driven by a hammer to determine the character of the soil and the depth to bedrock or other underground structure.
2. Digging test pits either by hand or mechanically to reveal the nature of the soil and height of the water table.
3. Boring by hand or with a powered rig to obtain samples of the soil. Borings made by powered rigs will provide solid cores, essential for determining the requirements of deep foundations. Normally, these are driven to a point where they will go no farther (i.e., to a point of refusal), meaning that they have hit bedrock or a hard-packed layer of earth.

Soil tests for retaining structures should be made to a depth of at least 1 200 mm (4 ft) below the proposed finish grade at the bottom of the structure. The core boring method of testing is used when the depths are over 4 500 mm (15 ft). Necessary laboratory analysis should be made of the samples to determine the types and characteristics of each sample.

3.2 Foundations

The foundation for any retaining structure is of critical importance, playing a major role in the stability of the structure. Figure 410-7 shows the average depth of frost penetration in the United States. Foundations for rigid retaining structures should be set so that the base rests below the frost line, with top of footing typically being set at the frost line. Flexible retaining structure foundations need not be set below the frost line if they are built on a well-drained subbase with suitable bearing capacities. All foundations should be above the water table. A structural engineer should be consulted to determine what type of foundation is most appropriate. Consult local building codes for minimum requirements for foundations and footings where applicable.

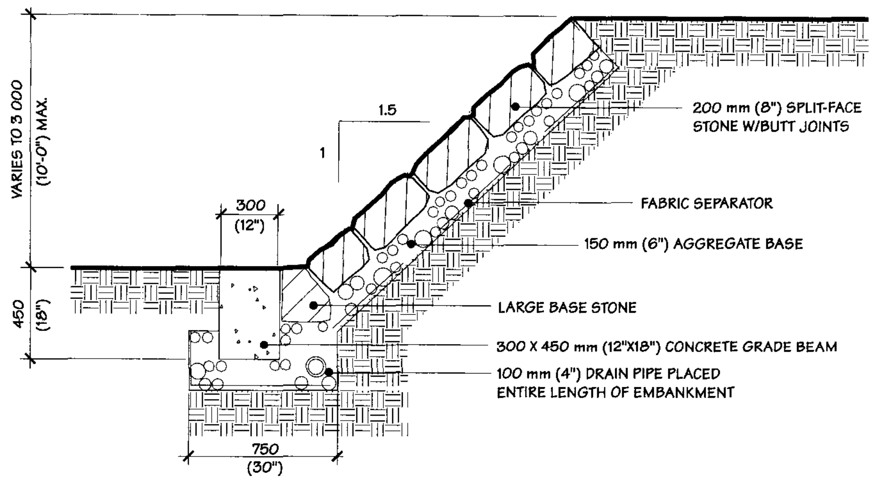


Figure 410-9. Typical reinforced embankment with split-faced stone.

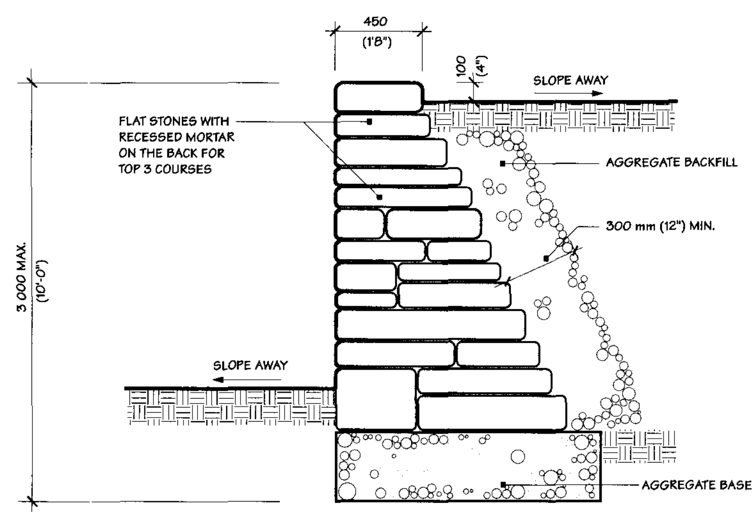


Figure 410-10. Typical dry-laid stone gravity wall

KEY POINTS: Elements of Retaining Structures

1. Soil bearing capacity determines width of footing and method of wall construction.

2. Cast concrete rigid wall footings are typically placed directly onto prepared subgrade to achieve greatest stability and bearing uniformity, while flexible stone walls typically require an aggregate base for drainage and leveling.

3. Top of wall should slope (Typically 2.0%) to drain to the retained side to prevent staining of wall face.

4. Removing infiltrated water from behind the wall structure is a prime objective, especially in clay soils and freeze/thaw conditions. Weep holes and perforated footing drains are typical methods employed.

5. Small walls and those which are extensions of architecture are typically built without a batter. Larger walls commonly have a 12:1 batter for visual reasons.

3.3 Drainage Devices

The leaning, bulging, or misalignment of retaining structures may be the result of improper wall thickness, but is often caused by the buildup of water pressure behind the structure and/or by freeze/thaw action in cold climates. This hydrostatic water pressure can cause problems when surface runoff gets behind the retaining structure via the top or toe of the wall, or when groundwater seeps through the soil behind or under the structure.

Surface runoff should be directed away from both the top and base of the wall. It should also be blocked from penetrating down through the soil either by installing a clay seal under the sod or, where heavy concentrations of runoff exist, by constructing an impervious gutter or drainage channel behind the top of the wall (Figure 410-8). Water filtering down through the soil can be intercepted and taken away from the structure by the use of granular backfills connected to weep holes through the face of the structure or, if possible, by perforated drain pipe connected to outlets directed away from the structure. Clay tile, porous concrete, or perforated plastic, are typically used for this purpose. Alignment of such devices should avoid low points where water could be trapped behind the structure.

3.4 Batter in Wall Faces

Many types of walls have faces that slope slightly off-vertical by various amounts. Such designed slopes are called batters. Both the back and/or the exposed face of a retaining wall can be battered. The face of the wall is sometimes battered when walls are very high to help overcome the optical illusion of the wall leaning forward. A batter may obscure deficiencies in the finishing of the wall's face, minor bulges and other movements for flexible walls. Also, a batter can increase the wall's stability and resistance to overturning.

A typical batter for walls of flexible construction is 6:1, but other ratios are often used. Cribbing, gabions, and masonry unit flexible walls often require a batter of 6 degrees. For rigid walls, particularly those with relatively smooth faces, a batter of 12:1 is recommended. A batter is seldom used when a wall appears to be an extension of a building.

3.5 Face Treatment

Some materials used in retaining structures, such as cast concrete or masonry construction, permit a variety of surface treatments.

Crib, bin, and gabion types of retaining structures are more limited in their variety of surface treatments. (Refer to Division 800: Materials for information on various types of finishes.)

3.6 Expansion and Construction Joints

The placement and spacing of expansion and construction joints should be considered as part of the overall design of the surface treatment of retaining walls. For rigid wall construction, these joints should normally be placed no farther than 9 000 mm (30 ft) apart.

4.0 TYPES OF RETAINING STRUCTURES

4.1 Reinforced Embankment

Reinforced embankments regardless of their degree of slope or material must be protected from sheet flow runoff, typically by check swales or bench terracing, and from capillary infiltration at the slope base by means of aggregate or pipe drainage. Vegetated slopes require natural moisture or irrigation to maintain structural integrity. Stone or concrete faced embankments typically require an aggregate subbase and extra reinforcing at slope base for stability and sustained performance. Figure 410-9 illustrates a typical reinforced embankment.

4.2 Unit and Stack Wall Systems

Dry-Laid Stone Wall:

Dry laid stone walls (without mortar), are useful in many situations where the retained heights are low [less than 3 000 mm (10 ft)], the stone is available on or near the site, and the economy of such construction is desired. Figure 410-10 illustrates a typical stone gravity wall. A stone dike constructed simply by dumping is an inexpensive alternative to a laid-up dry stone wall for fill situations. The top width of these walls is rarely smaller than 450 mm (18 in) and usually varies between 450-600 mm (18-24 in).

Gabion Wall:

Gabions are rectangular baskets made of galvanized steel wire or polyvinyl-coated (PVC) wire hexagonal mesh, filled with stone and tied together to form a wall. The baskets are manufactured in standard sizes usually 900 mm (3 ft) wide in lengths of 1 800, 2 700, and 3 700 mm (6, 9, and 12 ft) and heights of 300, 450, and 900 mm (1, 1½, and 3 ft). Each gabion has a lid and is subdivided by diaphragms into 900 mm (3 ft) cells. After being filled with stone, the lid is closed and laced to the top edges of the gabion. Each gabion is then laced to the adjacent gabions. A gabion wall with a battered face is shown in Figure 410-11. A stepped design may also be used.

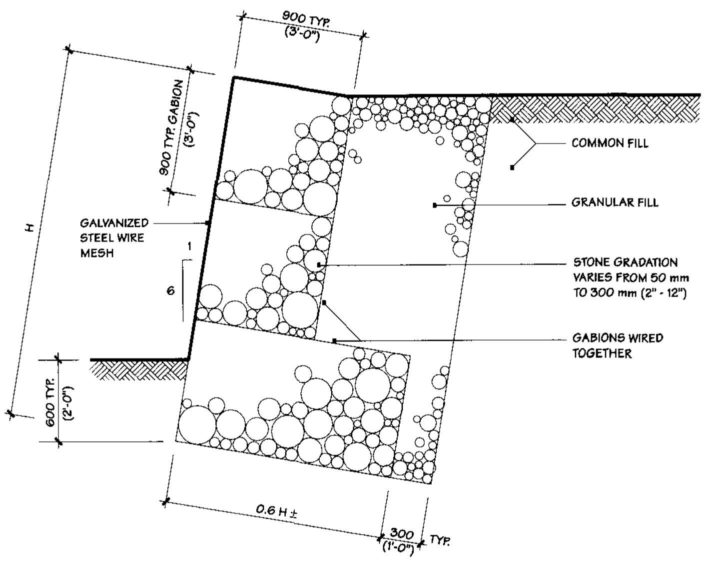


Figure 410-11. Gabion retaining wall. *Face may be battered or stepped. Refer to manufacturer's literature for special details.*

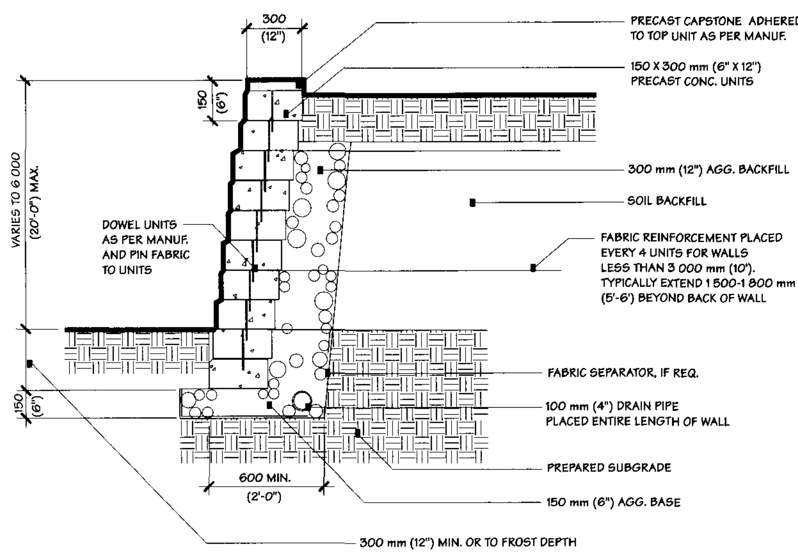


Figure 410-12. Precast concrete masonry unit retaining wall. *Refer to manufacturer's literature for special details.*

Flexible gabion walls can adapt to ground settlement. Their permeability allows water to drain, making gabions especially suitable along stream and river banks where variations in water depths occur between flood and dry weather conditions. Volunteer vegetation establishes itself quickly in gabions, softening the structure's appearance in the landscape while also adding durability. Recent experiments have successfully hydro-seeded gabions lined with separator fabric and filled with an amended soil mix, resulting in a staggered green wall. This application requires a well drained subsoil and sufficient rainfall and is suitable for temperate climates.

Precast Unit Stack Wall:

Modular systems for gravity walls using pre-cast concrete units with various face treatments may be built to a height of

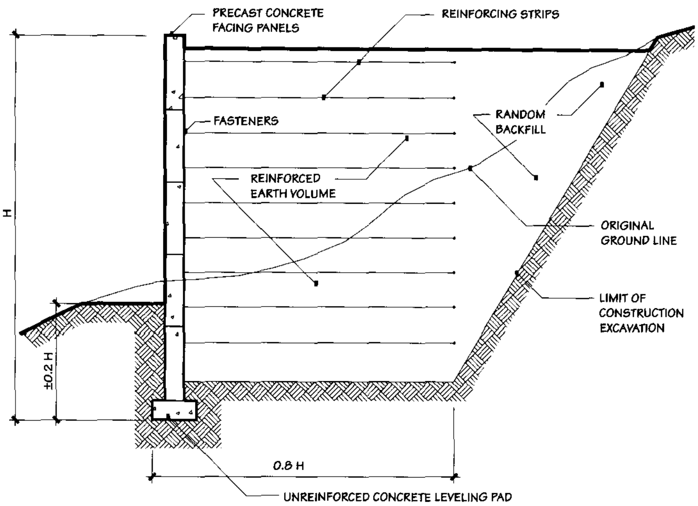


Figure 410-13. Earth tieback retaining wall. *Refer to manufacturer's literature for special details.*

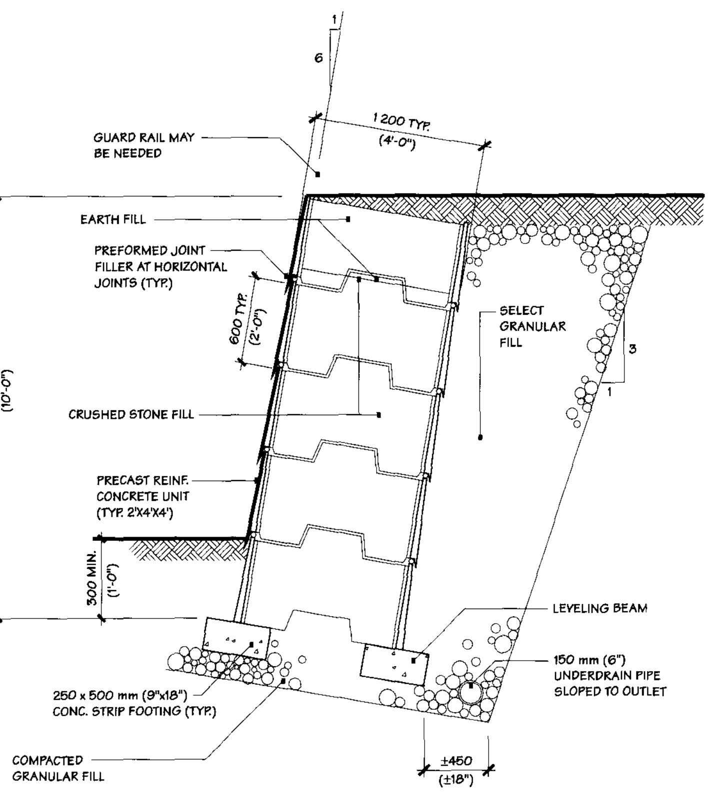


Figure 410-14. Bin wall. Top may be capped. *Refer to manufacturer's literature for special details.*

6 000 mm (20 ft) maximum with the addition of successive fabric tie-back layers as shown in Figure 410-12. A number of proprietary products are available. Such modular systems are easily adaptable to curves and serpentine alignments.

Earth Tieback Retaining Wall:

An earth tieback retaining wall is similar in concept to a precast stack unit wall, but it typically used when larger walls are needed. It consists of interlocking concrete facing panels and prepared cohesionless soil backfill reinforced with thin metallic or polymer strips bolted to the facing panels (Figure 410-13). This type of structure uses the construction principle of sheeting with tiebacks to deadmen, except that multiple strips (i.e., tiebacks) rely on friction for anchorage instead of deadmen. The strips, usually galvanized steel, absorb the tensile stresses within the backfill through friction with the soil and thereby hold the soil together in an integral gravity mass. The facing panels are not structural members; they can be cast in any kind of interlocking geometric design or finish. Typical tieback depth to height ratio is 0.75-0.80H.

Earth tieback construction begins with the casting of an unreinforced concrete leveling pad to support and align the first layer of facing panels (Figure 410-13). The leveling pad is cast on the prepared site at a depth below finished grade, depending on the soil conditions and wall height. The first row of facing panels is set and positioned on the leveling pad, followed by the first backfill lift of cohesionless soil (i.e., silt, sand, broken stone, etc.), which is spread and compacted. The first layer of reinforcing strips is placed on the backfill and bolted to the facing panels. Backfill is spread over the design and compacted. The process is repeated until the finished wall height is reached.

Earth tieback construction is particularly suitable for situations where fill is required or can be placed. Its flexible composition can withstand differential settlement on poor foundation soils. To ensure the strength and stability of the wall, the backfill must be protected from erosion. Polyester foam inserted into panel joints or filter cloth placed behind the joints allows drainage to occur but keeps the soil lines from washing out.

Bin Wall:

Bin walls (also known as cellular walls) are constructed of precast reinforced concrete interlocking modular units which are stacked and then filled with granular fill (Figure 410-14). A flexible form of gravity wall, the bin wall depends on its mass for stability. The modules can be manufactured with a variety of concrete finishes (e.g., smooth, exposed aggregate, bush-hammered, or striated).

Figure 410-14 shows a typical section using 600 x 1 200 x 1 200 mm (2 x 4 x 4 ft) units with earth fill placed to the front of the bin wall. A continuous concrete strip footing along the front serves to align the modular units, and a leveling beam at the back is used to set the batter. While a bat-

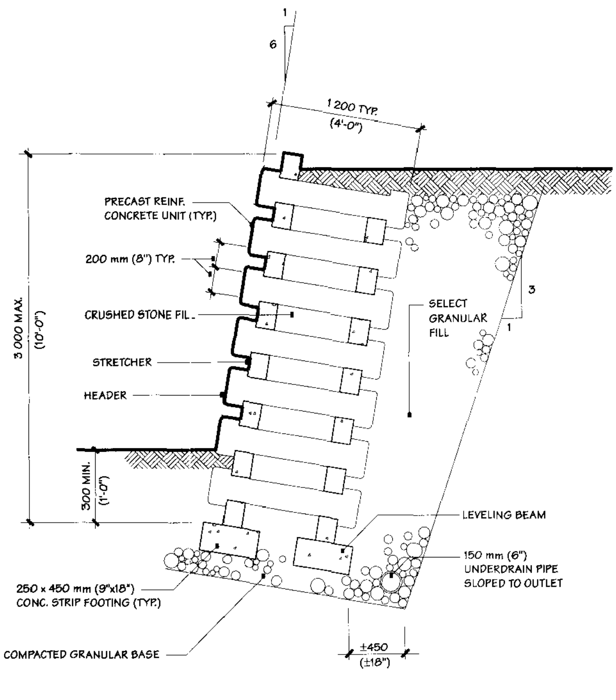


Figure 410-15. Concrete crib wall. *Refer to manufacturer's literature for special details.*

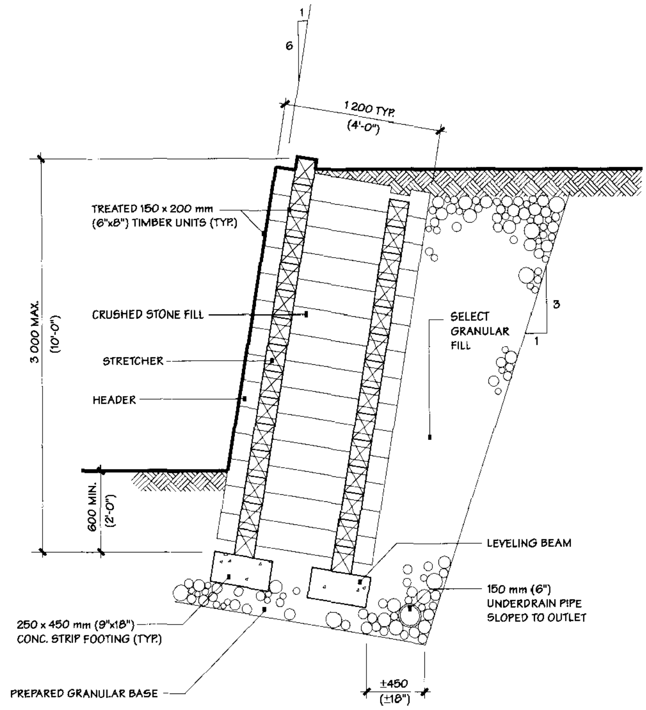


Figure 410-16. Typical timber crib wall.

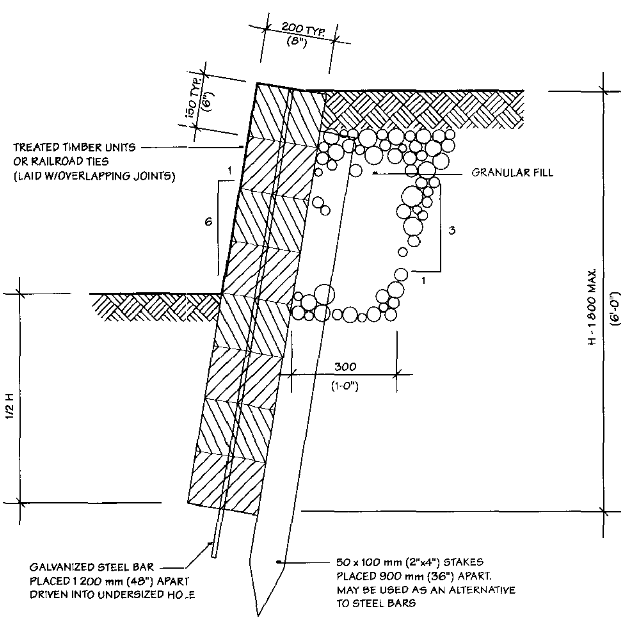


Figure 410-17. Typical horizontal timber wall.

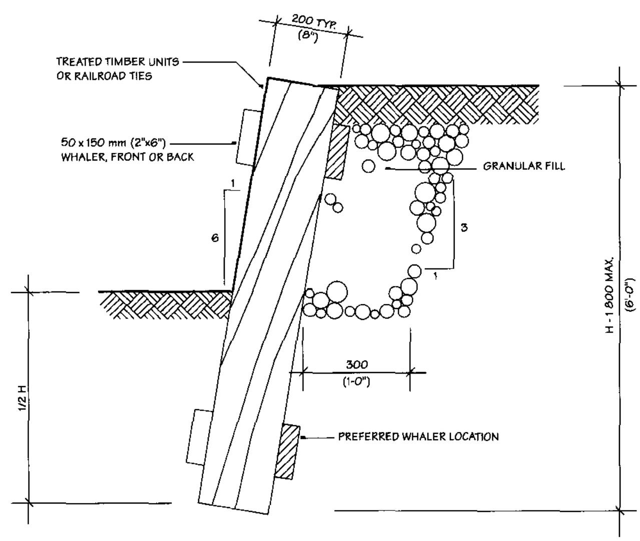


Figure 410-18. Typical vertical timber wall.

Table 410-3. TOP WIDTH OF RIGID GRAVITY WALLS

Wall Height mm (ft)	Min. Top Width mm (in)
under 1 800 (6 ft)	300 (12 in)
1 800-3 000 (6-10 ft)	450 (18 in)
over 3 000 (10 ft)	600 (24 in)

Table 410-5. TYPICAL RATIO OF BASE WIDTH TO HEIGHT IN CANTILEVERED WALLS (AVERAGE SOILS)

Horizontal Loading	0.45 H
Slope Surcharge Loading	0.65 H
Live Load Surcharge	0.65 H

Table 410-4. RECOMMENDED BASE WIDTH TO HEIGHT RATIOS FOR RIGID GRAVITY WALLS

Soil Type	Ratio	Application
Well drained gravel	0.35-0.40 H	Light Duty
Wet sand	0.58-0.60 H	Medium Duty
Water bearing soil	0.65 H	Heavy Duty
Fluid mud	0.75 H	Heavy Duty

ter of 6:1 is indicated in the figures, the bin wall could be built with either more batter or with a vertical face.

Bin walls are especially suitable for projects of heavy construction where special equipment, such as a crane, can be used to lift the units into place. They are also suitable where large scale or massiveness in the design expression is desired, such as at the edge of a vertical cut or toe of a slope that rises for a considerable distance. A bin wall is useful at the edge of a fill, where there is not sufficient space for the slope to meet an existing grade.

Since water can filter through the stone fill and joints of the stacked units, weep holes are not necessary in a bin wall. However, to avoid staining or a buildup of groundwater, an underdrain should be installed in the granular fill at the back of the bin wall. In less stable soils, a concrete footing strip is used to level the initial course and to spread the wall load over a broader subgrade area, effectively increasing the base width.

Crib Wall:

Concrete Crib Wall: A concrete crib wall is constructed of precast reinforced concrete units laid up in interlocking stretchers and headers to form vertical bins, filled with crushed stone or other granular material. They are a particularly utilitarian solution for retaining fills in situations where excavation is not necessary. Figure 410-15 shows a section using a concrete unit 1 200 mm (4 ft) long (the smallest unit typically available). Reinforced projecting lugs on the headers are typically used to lock the headers and stretchers together.

Manufactured standard concrete units are designed for both open-face cribbing and closed-face cribbing. Figure 410-15 shows open-face cribbing. Backfilling should follow closely the erection of units, and the cribbing should not be laid up higher than 900 mm (3 ft) above the backfilled portion.

Metal units made of galvanized steel are also available for crib walls. Weighing less than precast reinforced concrete units, they are easier to handle during construction.

In less stable soils, a concrete footing strip is used to level the initial cribbing course and to spread the wall load over a broader subgrade area, effectively increasing the base width.

Timber Crib Wall: Crib walls may be built of timber when the appearance of wood is desired in the landscape design (Figure 410-16). All timber units should be pressure-treated with a suitable preservative. Timber crib walls are not recommended for wet, damp, or cold climates and are best used in rustic hot-arid settings to prevent the premature leaching of the preservative.

Horizontal and Vertical Timber Wall:

Typical sections for horizontal and vertical timber walls suitable for retained heights up to 900 mm (3 ft) are shown in Figures 410-17 and 410-18. Since the timber wall's resistance to overturning depends upon one-half of its height being below finished grade, it is often not economical or practical to use this timber design for retained heights greater than 900 mm (3 ft). The timber units in the horizontal wall can be of variable length but should be at least 1 500 mm (5 ft) long. Low timber walls are especially useful for raised planting beds and boxes.

A timber wall of posts and planking is illustrated in Figure 410-19. Besides differing in appearance from the heavy timber walls shown in Figures 410-17 and 410-18, the planking in this design provides some economy in materials. Timber walls are not generally recommended and should be confined to small scale residential settings.

Green Retaining Wall:

Techniques have been developed in recent years that combine vegetation and structural elements in retaining sloped embankments and accommodating changes in elevation. A common system that uses precast concrete units interfilled with soil is illustrated in Figure 410-20. Designed as troughs to hold soil and moisture sufficiently for plant growth, the concrete units are set in a staggered arrangement, each course resting on the units beneath and filled with soil. The units can be laid at angles of inclination between 70 and 25 degrees. Interlocking masonry units are available in many configurations.

This type of flexible construction recalls the laying up of stones in the traditional rock garden. It is easily fitted to irregular slopes and accommodates a significant amount of settlement. The interstices in the face can be planted or be allowed to vegetate naturally. As with any flexible wall construction, analysis for sliding, bulging, and rupture should be made. This system is ideal in climates with sufficient rainfall to naturally support the vegetation.

4.3 Rigid Retaining Walls

Gravity Wall:

Gravity walls depend upon their mass (i.e., weight and volume) for stability. The ratio of the base width to height is approximately constant, varying from about 0.40 to 0.45 for a horizontally loaded wall, regardless of their size in most well drained condi-

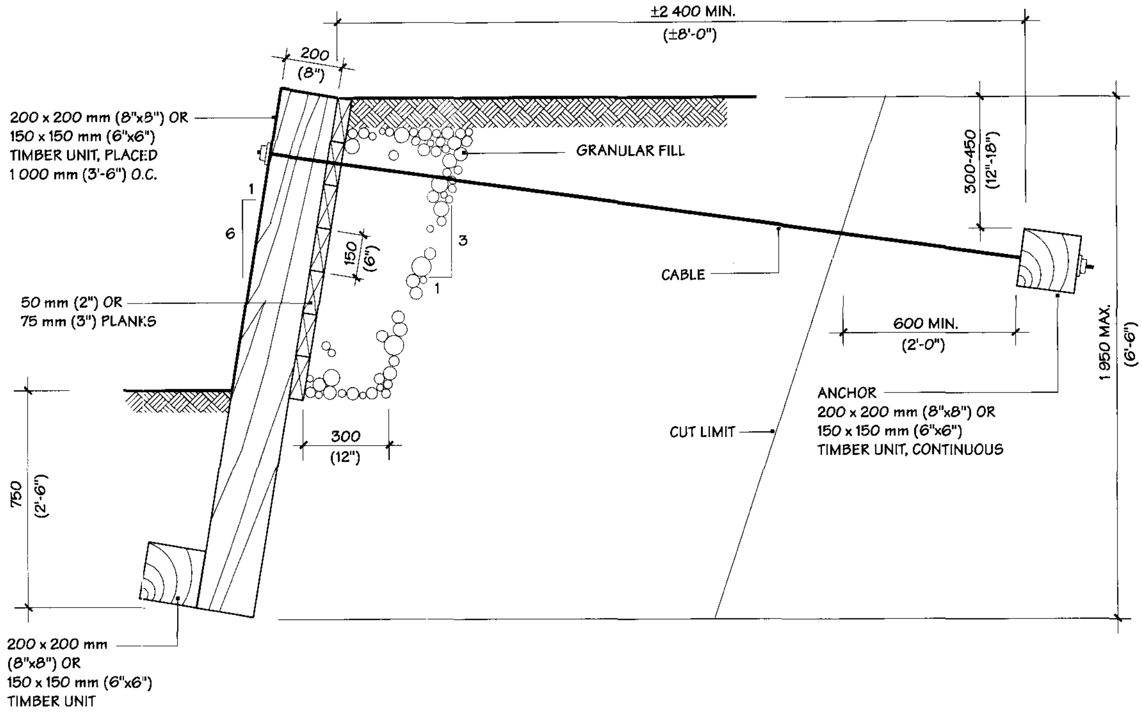


Figure 410-19. Typical timber wall with planking.

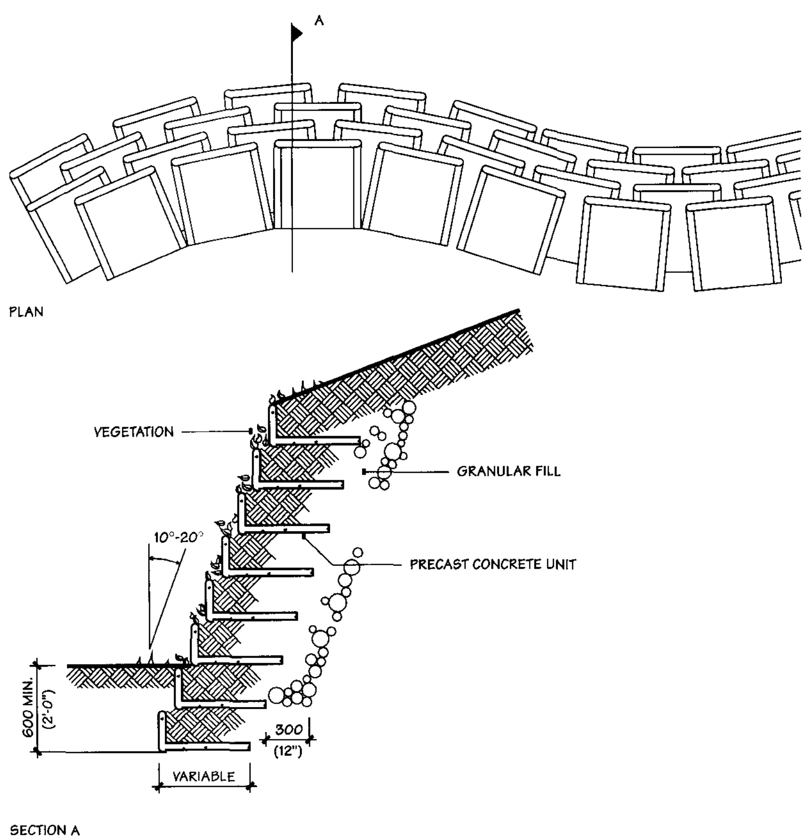


Figure 410-20. Green retaining wall (vegetated). *Refer to manufacturer's literature for special details.*

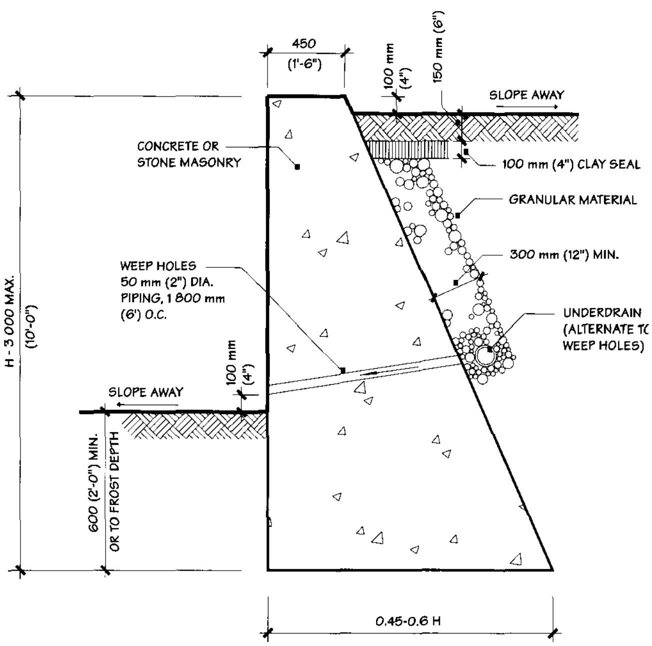


Figure 410-21. Typical concrete or stone masonry gravity wall. *Use expansion joints spaced 30 m (90 ft) apart maximum. Do not use on soils having an allowable bearing pressure less than 0.575 mPa (1.5 tons/ft²).*

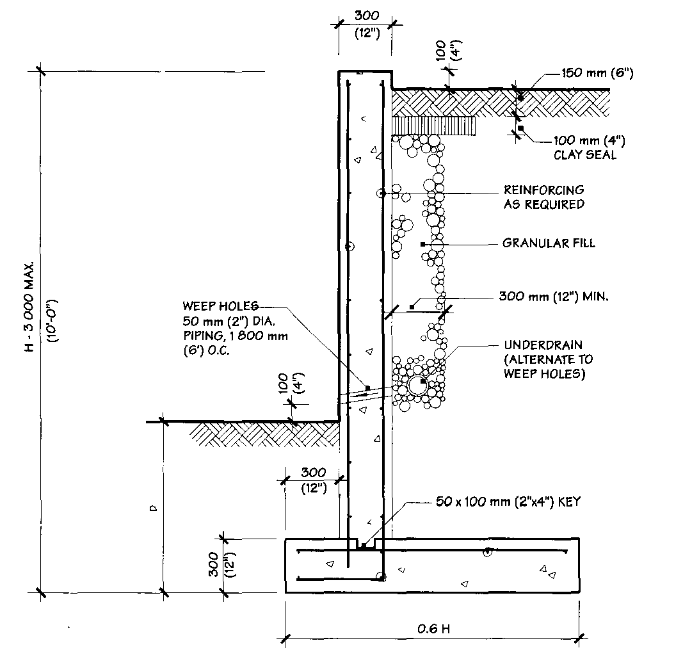


Figure 410-22. Reinforced concrete cantilevered wall. *D = H/3, or 600 mm (2 ft), or depth of frost, whichever is greatest. Use No. 4 reinforcement bars for H less than 1 800 m (6 ft).Use expansion joints spaced 30 m (90 ft) apart maximum. Do not use on soils having an allowable bearing pressure less than 0.575 mPa (1.5 tons/ft²).*

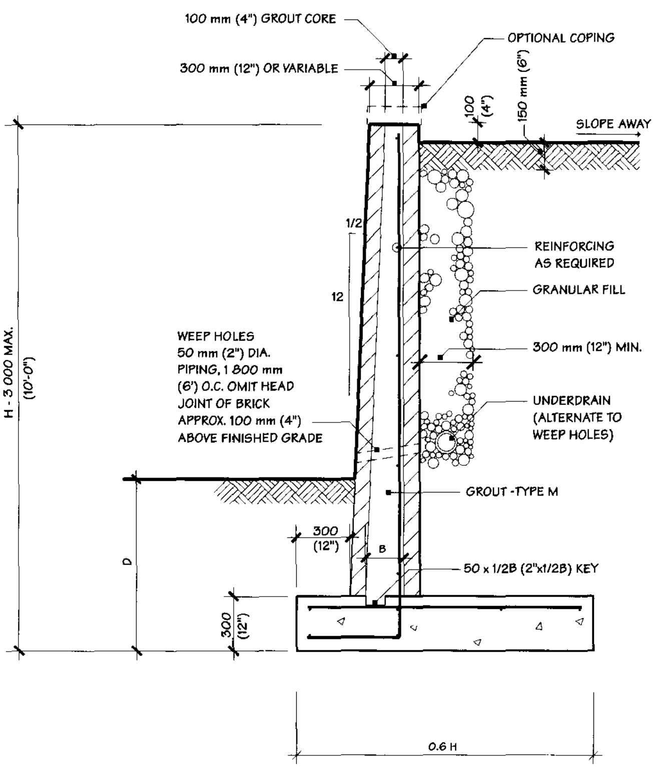


Figure 410-23. Reinforced masonry and concrete cantilevered wall. *D = H/3, or 600 mm (2 ft), or depth of frost, whichever is greatest. Use No. 4 reinforcement bars for H less than 1 800 m (6 ft).Use expansion joints spaced 30 m (90 ft) apart maximum. Do not use on soils having an allowable bearing pressure less than 0.575 mPa (1.5 tons/ft²).*

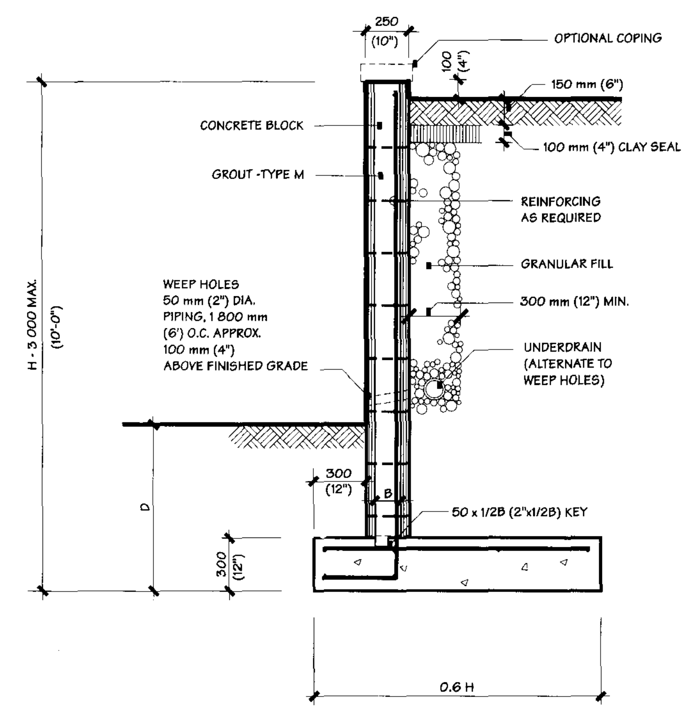


Figure 410-24. Reinforced concrete block cantilevered wall. *D = H/3, or 600 mm (2 ft), or depth of frost, whichever is greatest. Use No. 4 reinforcement bars for H less than 1 800 m (6 ft).Use expansion joints spaced 30 m (90 ft) apart maximum. Do not use on soils having an allowable bearing pressure less than 0.575 mPa (1.5 tons/ft²).*

tions. The actual base width to height ratio should be determined by soil type and moisture content as shown in Table 410-2, and any anticipated adjacent live loads. Gravity walls are constructed of cast-in-place concrete, stone masonry, or concrete faced with stone or brick. Figure 410-21 illustrates a typical concrete wall design. Gravity walls less than 1 500 mm (5 ft) high are usually built vertically at the front and back or with a slight batter. In such cases, the base width should be at least 0.4H.

Tables 410-3 and 410-4 show top widths of rigid gravity walls for various heights, and base to height ratios respectively.

Cantilevered Wall:

A cantilevered wall consists of a base and a stem, which are securely tied together by reinforcing rods extending from the base up through the stem. Table 410-5 shows typical base width to height ratios for cantilevered walls. Reinforcing rods running laterally through the stem provide longitudinal reinforcement in the wall. The weight of the backfill on the base counteracts the forward pressure of the retained height and helps to keep the wall from overturning. Reinforcing steel is typically placed within the soil, or, "tensioned" side of the stem no less than 50 mm (2 in) from the surface to prevent concrete cracking due to differential expansion coefficient factors. Most reinforcing schedules require both vertical and horizontal steel. Wall cross sections can vary widely, but common practice is to locate the stem on the base at a point 1/3 of the base width measured from the toe.

Reinforced concrete: Reinforced concrete cantilevered construction is particularly useful for long lengths of wall where standard metal forms can be reused with great economy in construction. Liners can be used to achieve a variety of finishes and joint patterns in the face of the wall. A veneer of brick or stone can be applied to the wall shown in Figure 410-22 by using standard metal fasteners, and typically rests on an integral concrete sill. Top of wall width is typically 300 mm (12 in) min., but may be 200 mm (8 in) on smaller garden scale walls.

Reinforced Masonry and Concrete Cantilevered Wall: A two-wythe brick retaining wall is especially suitable for low-wall construction (Figure 410-23). It has the finished appearance of brick but the structural stability of a cantilevered wall. It can be laid up without any formwork, using only brick and grout.

The vertical reinforcement bars must be placed within about 15 mm (1/2 in) of the brick on the tension side (i.e., the retained earth side) so that the bars will be bonded to the grout. The vertical bars must extend the full height of the wall. The brick should be laid with full shoved head and bed mortar joints with no headers projecting into the grout (See Section 2413 of the Unified Building Code, Grouted Masonry). Brick should be laid up in successive tiers of about 200 mm (8 in) and the space then filled each time with grout (ASTM C270, Mortar for Unit Masonry, type M), followed by puddling with a grout stick. All joints behind the wall should be fully grouted. The work should be completed in one session, but if it is necessary to delay for more than an hour, the tiers should be brought to the same elevation with the grout 25 mm (1 in) below the top.

Figure 410-23 shows a facing that is one brick wide laid up in running bond, however, the face can be two bricks wide, laid in other patterns. Solid concrete units or stone units may also be used.

Reinforced Concrete Block Cantilevered Wall: A concrete block retaining wall using a cantilever and grout design can be laid up without any formwork (Figure 410-24). The vertical reinforcement bars must be placed within about 10 mm (1/2 in) of the inside face of the blocks on the tension side (i.e., the retained earth side) so that the bars will be bonded to the grout. The cells are filled with grout, which should be thoroughly puddled during pouring. A horizontal construction joint should be formed by stopping the blocks at the same elevation with the grout, 25 mm (1 in) below the top, if the work is stopped for more than an hour.

Various architectural treatments in the face of the retaining wall can be achieved with split-face and split-rub concrete blocks. The blocks can be laid normal, running bond, or laid up with vertical joints the height of the wall.

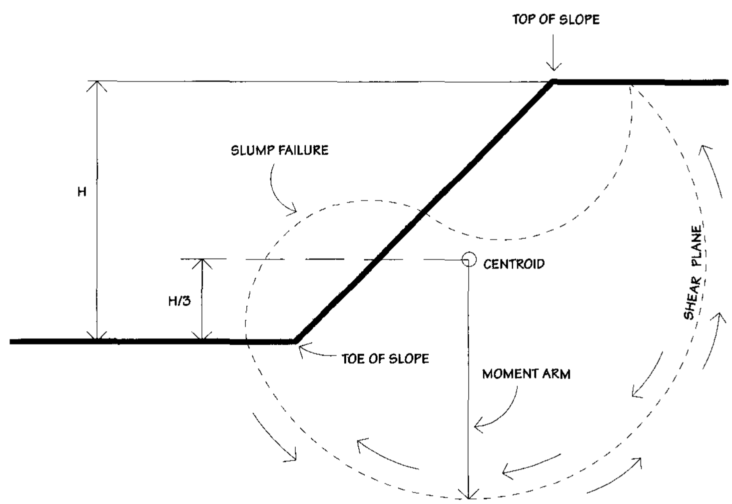


Figure 410-25. Mechanics of an embankment.

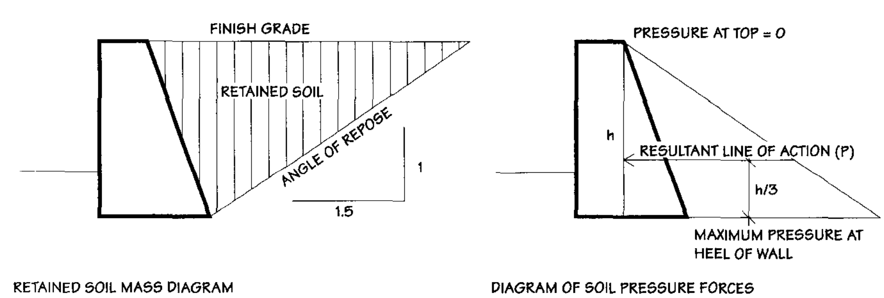


Figure 410-26. Diagrams of retained soil mass and soil pressure forces.

5.0 MECHANICS AND DESIGN CALCULATIONS

A structure designed to retain the weight of soil must maintain a state of static equilibrium at all times. The structure must be proportioned so that its strongest components are located where the soil weight and other hydrostatic pressures are greatest.

In embankment design, the critical factors are the soil's natural angle of repose, its structural properties, its weight by volume, and the design slope ratio. The embankment requires reinforcement when it exceeds its natural gravitational slope or when it is subject to other hydrostatic or vibratory pressures associated with infiltration or vehicular loading. Slope stability mechanics are shown in Figure 410-25. The figure illustrates a typical shear plane, slope centroid, moment arm, and typical soil slump failure profile (dotted line). This slump failure profile is most typical in clay soils, but also reflects the manner in which retaining walls fail by bulging at their lower third.

Figure 410-26 illustrates how the forces may be diagrammed at the back of typical retaining structures. Soil pressure results from the soil above the angle of repose plane. The line of action may be conceived as a horizontal thrust pushing against the wall at the H/3 point as shown.

A wall may fail if the resultant line of action passes through the front third of the base. Most calculations seek to achieve material efficiency by passing the resultant through the front part of the middle third (toward the toe), except in clay soils where the center of the base is sought due to poor bearing and low shearing resistance. The wall may also fail by overturning, settling at the toe, or by sliding.

5.1 Lateral Loading

Lateral loads on retaining structures are a function of the weight of the soil that is being retained. Only soil that exceeds the angle of repose exerts pressure on the structure. The weight of soil is highly variable and is determined by the aggregate density if granular, and particle composition and moisture content if clay. Typically a design force of 16 to 17 kN (100 to 110 pounds per cubic foot) is used for preliminary calculations, although agencies may establish stricter guidelines. The earth pressure exerted on a structure is calculated by one of the following formulas, depending on whether the wall is surcharged with soil embanked above the top of the wall:

Non-surcharged wall:

$$P = 0.286 \times \frac{wh^2}{2}$$

Surcharged wall:

$$P = 0.833 \times \frac{wh + h'}{2}$$

Where:

P = the magnitude of the resultant earth pressure in kilonewtons (kN) or pounds (lbs). Note that the word "resultant" is used to describe the earth pressure because the line of action is a function of gravity working on the earth mass being retained by the wall, and the "resultant" path of least resistance. In non-surcharged walls the line of action is horizontal, intersecting the back of the wall at h/3. In surcharged walls the line of action is parallel to the angle of repose of the surcharged slope and intersects the back of the wall at (h + h')/3.

w = the weight of the retained soil in kN (lb/ft³). Typically a design weight of 16 to 17 kN (100 to 110 pounds per cubic foot) is used for preliminary calculations.

h = the height of the wall in m (ft). Height always equals the distance from the very bottom of the wall base to the top of the wall.

h' = height of the surcharge in m (ft) as measured from the top of wall on a vertical line extended from the heel of the wall

The coefficient that modifies the magnitude of total soil pressure acting on P is 0.286 in non-surcharged walls, and 0.833 in surcharged walls. The additional load on surcharged walls exerts a more eccentric downward weight in a resultant plane equal to the slope of the embankment, typically sloped at 30–33°. Because the pressure has a stronger vertical force acting at P, the magnitude is determined by a higher coefficient of 0.833. In other words, P for the non-surcharged wall is calculated using 28.6% of the total soil pressure, compared with 83.3% of the total soil pressure for a surcharged wall.

Table 410-6 illustrates the calculation of lateral loading for a non-surcharged gravity wall. Table 410-7 provides an example calculation for a surcharged cantilevered wall.

5.2 Resultant of Wall Weight and Earth Pressure

The resultant is a single force that has the same effect as the various forces in the system acting simultaneously. The centroid, or center of gravity, is the point through which all forces act. To find the combined resultant force of the wall and retained earth, the wall's cross section is divided into units of rectangles and triangles. The moments are calculated by multiplying the weight of each unit by the length of its moment arm (horizontal distance of its centroid from the toe) as shown in Tables 410-6 and 410-7. The distance from the toe of the wall to the centroid of the composite cross section is determined by dividing the sum of its moments by the total wall weight.

5.3 Wall Stability Tests

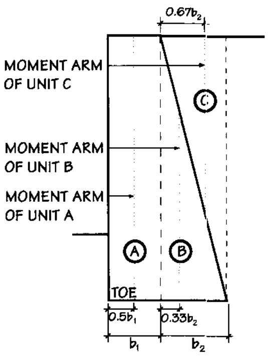
Stability tests are based upon a "test strip" of a proposed wall. It is assumed that if a section of a wall proves to be stable, then the entire wall will be stable. Test strips shown in Tables 410-6 and 410-7 are one meter thick in the metric example, and one foot thick in the U.S. example. All areas measured on cross section drawings therefore have cubic volume that can be converted to weights of different materials.

Overturning:

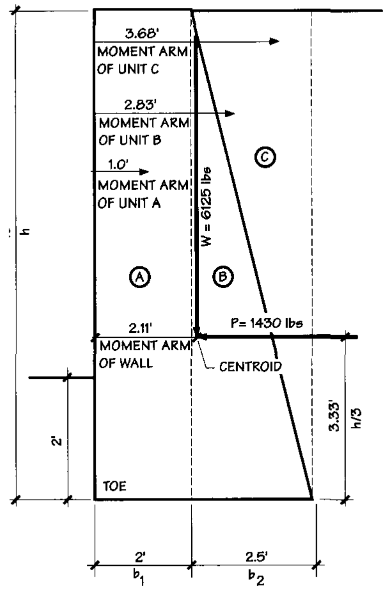
The mass of the wall exerts a downward vertical force due to gravity, known as the resisting moment, which must be greater than the resultant soil pressure tending to overturn the wall (the overturning moment) by a factor of two (2). The resisting moment is found by multiplying the combined weight of the wall by its moment arm, a line perpendicular to the vertical weight force, extending from the toe of the wall to the centroid of the wall. The overturning moment is similarly found by multiplying the resultant soil pressure (P) by the value of h/3, or 1/3 of the height of the wall. Note that this moment arm value is a vertical line running perpendicular to the horizontal line of P.

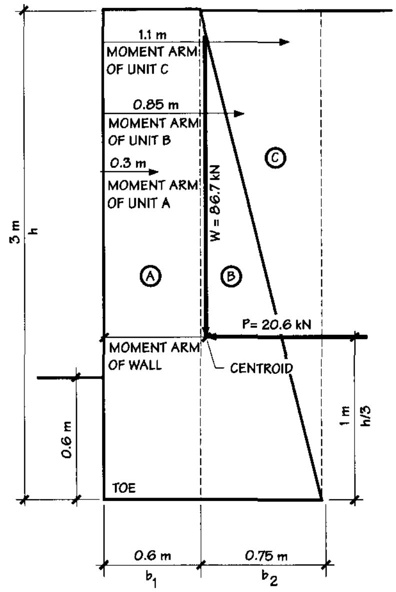
Table 410-6. DESIGN CALCULATIONS FOR NON-SURCHARGED GRAVITY WALL

Concrete gravity wall placed on a sandy-clay foundation



MOMENT ARM CALCULATIONS FROM TOE OF WALL TO RESPECTIVE VERTICAL LINES OF ACTION

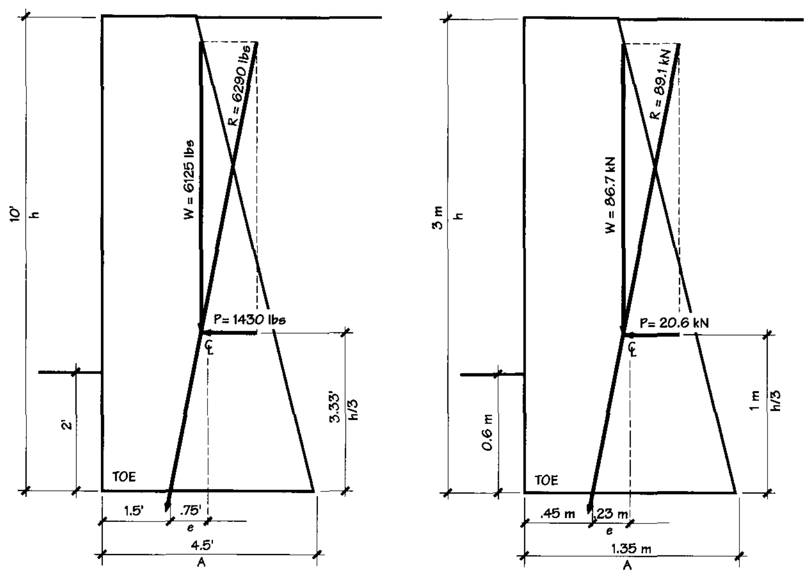




PROCEDURE	U.S. Calculations*	Metric Calculations†
Determining Lateral Force (P)		
1. Calculate pressure of retained soil, acting at h/3 (P): $P = 0.286 \times \frac{wh^2}{2}$	$P = 0.286 \times \frac{(100)10^2}{2}$ P=1,430 lbs	$P = 0.286 \times \frac{(16)3^2}{2}$ P = 20.6 kN
Determining Wall Weight (W)		
2. Calculate weight of section unit A: (b_1 x H x Weight of concrete)	2x10x150=3,000 lbs	0.6x3x23.5=42.3 kN
3. Calculate weight of section unit B: [0.5(b_2 x H) x Weight of concrete]	0.5(2.5x10)x150=1,875 lbs	0.5(0.75x3)x23.5=26.4 kN
4. Calculate weight of section unit C: [0.5(b_2 x H) x Weight of soil]	0.5(2.5x10)x100=1,250 lbs	0.5(0.75x3)x16=18 kN
5. Add weights of units A, B & C. This equals the total weight of the wall's cross section (W).	3000+1875+1250=6,125 lbs	42.3+26.4+18=86.7 kN
Determining the Centroid		
6. Calculate the moment arm of unit A from the toe of the wall. The distance of the vertical line of action from the toe in this rectangular section is found by: (0.5)b_1	(0.5)2=1 ft	(0.5)0.6 = 0.3 m
7. Calculate the moment arm of unit B from the toe of the wall. The distance of the vertical line of action from the toe in this triangular section is found by: (0.33) b_2+b_1	(0.33)2.5+2 = 2.83 ft	(0.33)0.75+.6 = 0.85 m
8. Calculate the moment arm of unit C from the toe of the wall. The distance of the vertical line of action from the toe in this triangular section is found by: (0.67) b_2+b_1	(0.67)2.5+2=3.68 ft	(0.67)0.75+.6 = 1.1 m
9. Calculate the moment of unit A: (Weight x Moment Arm)	3000x1=3,000 ft lbs	42.3x.3=12.7 kN m
10. Calculate the moment of unit B: (Weight x Moment Arm)	1875x2.83=5,306 ft lbs	26.4x0.85=22.44 kN m
11. Calculate the moment of unit C: (Weight x Moment Arm)	1250x3.68=4,600 ft lbs	18x1.1=19.8 kNm

* Assumes a 1 ft thick test strip for calculation
† Assumes a 1 m thick test strip for calculation

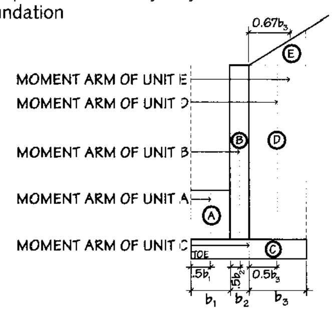
Table 410-6. DESIGN CALCULATIONS FOR NON-SURCHARGED GRAVITY WALL (continued)



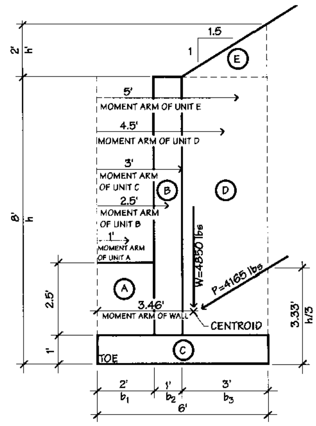
PROCEDURE (continued)	*U.S. Calculations**	*Metric Calculations†*
12. Add moments of units A, B& C to yield the total moment of the wall's cross section.	3000+5306+4600=12,906 ft lbs	12.7+22.44+19.8=54.94 kN m
13. Calculate the moment arm of the wall's entire cross section: $\frac{\text{Sum of Moments}}{\text{Sum of Weights}}$	$\frac{12906}{6125} = 2.11$ ft	$\frac{54.94}{86.7} = 0.63$ m
Determine the Resultant Force (R)		
14. Calculate resultant force of earth pressure and wall weight (R): $R = (W^2 + P^2)^{0.5}$	$(6,125^2 + 1,430^2)^{0.5} = 6,290$ lbs	$(86.7^2 + 20.6^2)^{0.5} = 89.1$ kN
15. Graphically construct a parallelogram of forces and draw in the resultant (R). Extend diagonal until it intersects base of wall. If it passes within the middle 1/3 of the base, it is considered generally stable. The distance from the centerline of the wall base to the point where the resultant force cuts the base is the eccentricity (e)	The wall is generally stable. e=0.75 ft	The wall is generally stable. e=0.23 m
Testing for Overturning		
16. Divide the resisting moment by the overturning moment to check for tendency to overturn. A safety factor of 2 or more is acceptable: $\frac{\text{W x Moment Arm}}{\text{P x Moment Arm}}$	Resisting moment: 6125x2.11=12,924 ft lbs Overturning moment: 1430x3.33=4762 ft lbs $\frac{12924}{4762} = 2.7$ Acceptable	Resisting moment: 86.7x.63=54.6 kN m Overturning moment: 20.6x1=20.6 kN m $\frac{54.6}{20.6} = 2.7$ Acceptable
Testing for Crushing (Settlement at the Toe)		
17. Test for crushing: $f = \frac{W}{A}\left(1 + \frac{6e}{d}\right)$ Compare results with Table 410-8.	$f = \frac{6125}{4.5}\left[1 + \frac{6(0.75)}{4.5}\right]$ $f = 1361\ (2)$ $f = 2,722$ psf Acceptable for sandy-clay foundation	$f = \frac{86.7}{1.35}\left[1 + \frac{6(.23)}{1.35}\right]$ $f = 64.2(2)$ $f = 128.4$ kN or 13 093 kg/m^3 Acceptable for sandy-clay foundation
Testing for Sliding		
18. Calculate the tendency to slide. A safety factor of 1.5 or more is acceptable: $\frac{\text{W x Coefficient of Friction}}{\text{P}}$ Compare results with Table 410-9.	$\frac{6125(0.4)}{1430} = 1.7$ Acceptable for sandy foundation	$\frac{86.7(0.4)}{20.6} = 1.7$ Acceptable for sandy foundation

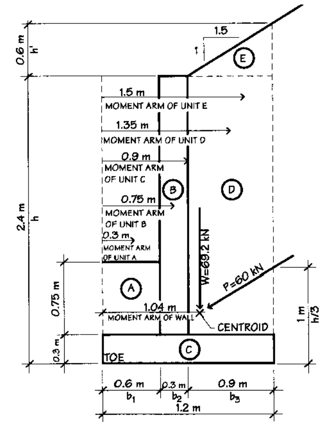
Table 410-7. DESIGN CALCULATIONS FOR SURCHARGED CANTILEVERED WALL

Surcharged concrete cantilevered wall placed on a sandy-clay foundation



MOMENT ARM CALCULATIONS FROM TOE OF WALL TO RESPECTIVE VERTICAL LINES OF ACTION

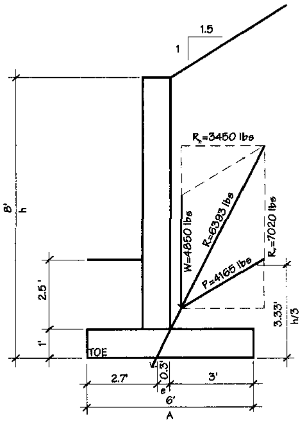


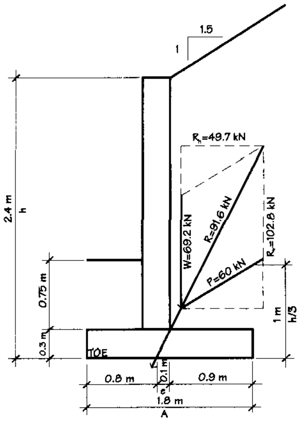


PROCEDURE	*U.S. Calculations**	*Metric Calculations†*
Determining Lateral Force (P)		
1. Calculate pressure (P) of retained soil, acting at (h+h')/3: $P = 0.833 \times \frac{2(h+h')^2}{2}$	$P = 0.833 \times \frac{100(8+2)^2}{2}$ P = 4,165 lbs.	$P = 0.833 \times \frac{16(2.4+0.6)^3}{2}$ P = 60 kN
Determining Wall Weight (W)		
2. Calculate weight of section unit A: (b_1 x H x Weight of soil)	2 x 2.5 x 100 = 500 lbs	0.6 x 0.75 x 16 = 7.2 kN
3. Calculate weight of section unit B: (b_1 x H x Weight of soil)	6 x 1 x 150 = 900 lbs	1.8 x 0.3 x 23.5 = 12.7 kN
4. Calculate weight of section unit C: (b_2 x H x Weight of concrete)	1 x 7 x 150 = 1,050 lbs	0.3 x 2.1 x 23.5 = 14.8 kN
5. Calculate weight of section unit D: (b_3 x H x Weight of soil)	3 x 7 x 100 = 2,100 lbs	0.9 x 2.1 x 16 = 3.2 kN
6. Calculate weight of section unit E: [0.5 (b_3 x H) x Weight of soil]	0.5(3 x 2) x 100 = 300 lbs	0.5 (0.9 x 0.6) x 16 = 4.3 kN
7. Add weights of units. This equals the total weight of the wall's cross section (W).	500 + 900 + 1050 + 2100 + 300 = 4,850 lbs.	7.2 + 12.7 + 14.8 + 30.2 + 4.3 = 69.2 kN
Determining the Centroid		
8. Calculate the moment arm of unit A from the toe ofthe wall. The distance of the vertical line of action from the toe in this rectangular section is found by: (0.5) b_1	(0.5)2 = 1 ft	(0.5)0.6 = 0.3 m
9. Calculate the moment arm of unit B from the toe of the wall. The distance of the vertical line of action from the toe in this rectangular section is found by: (0.5) b_2 + b_1	(0.5)1 + 2 = 2.5 ft	(0.5)0.3+0.6 = 0.75 m
10. Calculate the momentarm of unit C from the toe of the wall. The distance of the vertical line of action from the toe in this rectangular section is found by: (0.5) base of wall	(0.5)6 = 3 ft	(0.5)1.8 = 0.9 m
11. Calculate the moment arm of unit D from the toe of the wall. The distance of the vertical line of action from the toe in this rectangular section is found by: (0.5) b_3 + b_2 + b_1	(0.5) 3 + 1 + 2 = 4.5 ft	(0.5)0.9 + 0.3 + 0.6 = 1.5 m
12. Calculate the moment arm of unit E from the toe of the wall. The distance of the vertical line of action from the toe in this triangular section is found by: (0.67) b_3 + b_2 +b_1	(0.67)3 + 1 + 2 = 5 ft	(0.67)0.9 + 0.3 + 0.6 = 1.5 m
13. Calculate the moment of unit A: (Weight x Moment Arm)	500 x 1 = 500 ft lbs	7.2 x 0.3 = 2.2 kN·m

* Assumes a 1 ft thick test strip for calculation. †Assumes a 1 m thick test strip for calculation.

Table 410-7. DESIGN CALCULATIONS FOR SURCHARGED CANTILEVERED WALL (continued)





PROCEDURE	*U.S. Calculations**	*Metric Calculations†*
14. Calculate the moment of unit B: (Weight x Moment Arm)	1050 x 2.5 = 2,625 ft lbs	14.8 x 0.75 = 11.1 kN·m
15. Calculate the moment of unit C: (Weight x Moment Arm)	900 x 3 = 2,700 ft lbs	12.7 x 0.9 = 11.4 kN·m
16. Calculate the moment of unit D: (Weight x Moment Arm)	2100 x 4.5 = 9,450 ft lbs	30.2 x 1.35 = 40.8 kN·m
17. Calculate the moment of unit E: (Weight x Moment Arm)	300 x 5 = 1,500 ft lbs	4.3 x 1.5 = 11.1 kN·m
18. Add moments of units to yield the total moment of the wall's cross section.	500 + 2700 + 2625 + 9450 + 1500 = 16,775 ft lbs	2.2 + 11.4 + 11.1 + 40.8 + 6.5 = 72 kN·m
19. Calculatethe moment arm of the wall's entire cross section. $\frac{\text{Sum of Moments}}{\text{Sum of Weights}}$	$\frac{16775}{4850} = 3.46$ ft	$\frac{72}{69.2} = 1.04$ m
Determining the Resultant (R)		
20. Calculate resultant force of earth pressure and wall weight (R): $R = (W^2 + P^2)^{0.5}$	$(4850^2 + 4165^2)^{0.5} = 6{,}393$ lbs	$(69.2^2 + 60^2)^{0.5} = 91.6$ kN
21. Graphically construct a parallelogram of forces and draw in the resultant (R). Extend diagonal until it intersects base of wall. If it passes within the middle 1/3 of the base, it is considered generally stable. The distance from the centerline of the wall base to the point where the resultant force cuts the base is the eccentricity (e).	The wall is generally stable. e = 0.3 ft	The wall is generally stable. e = 0.1 m
22. Graphically determine the vertical (R_v) and the horizontal (R_h) components of constructed parallelogram of forces through scaling.	R_v = 7,020 lbs R_h = 3,450 lbs	R_v = 102.8 kN R_h = 49.7 kN
Testing for Overturning		
23. Divide the resisting moment by the overturning moment to check for tendency to overturn. A safety factor of 2 or more is acceptable: $\frac{R_v \times \text{Moment Arm}}{R_h \times \text{Moment Arm}}$	Resisting moment: 7020 x 3.46 = 24,289 ft lbs Overturning moment: 3450 x 3.33 = 11,489 ft lbs $\frac{24289}{11489} = 2.1$ Acceptable	Resisting moment: 102.8 x 1.04 = 106.9 kNm Overturning moment: 49.7 x 1 = 49.7 kNm $\frac{106.9}{49.7} = 2.1$ Acceptable
Testing for Crushing (Settlement at the Toe)		
24. Test for crushing: $f = \frac{R_v}{A}\left(1 + \frac{6e}{D}\right)$ Compare results with Table 410-8.	$f = \frac{7026}{6}\left[1 + \frac{6(0.3)}{6}\right] = 1170\ (1.3)$ = 1,521 psf Acceptable for sandy-clay foundation	$f = \frac{102.8}{1.8}\left[1 + \frac{6(0.1)}{1.8}\right] = 57.1\ (1.3)$ = 74.2 kN or 7 566 kg/m^2 Acceptable for sandy-clay foundation
Testing for Sliding		
25. Calculate the tendency to slide. A safety factor of 1.5 or more is acceptable: $\frac{R_v \times \text{Coefficient of Friction}}{R_h}$ Compare results with Table 410-9.	$\frac{7020\ (0.4)}{3450} = 0.8$ Requires a shear key.	$\frac{102.8\ (0.4)}{49.7} = 0.8$ Requires a shear key.

Table 410-8. APPROXIMATE BEARING CAPACITIES OF VARIOUS SOILS AND ROCK*

Material	t/m2	kg/m2	Ton/ft2	lb/ft2
Alluvial soil	4.5	4,500	1/2	1,000
Soft clay	9.5	9,500	1	2,000
Firm clay	19.5	4,000	2	4,000
Wet sand	19.5	19,000	2	4,000
Sand and clay mixed	19.5	19,000	2	4,000
Fine dry sand	29.0	29,000	3	6,000
Hard clay	39.0	38,500	4	8,000
Coarse dry sand	39.0	38,500	4	8,000
Gravel	58.5	58,000	6	12,000
Gravel and sand (well-cemented)	78.0	77,500	8	16,000
Hard pan or hard shale	97.5	97,000	10	20,000
Medium rock	195.0	194,500	20	40,000
Hard rock	780.0	779,000	80	160,000

* Tons = U.S. short tons (2000 lb), t = metric tons.

Source: Adapted from Albe E. Munson, Construction Design for Landscape Architects, McGraw-Hill, New York, 1975.

Table 410-9. AVERAGE COEFFICIENTS OF FRICTION FOR CONCRETE ON VARIOUS FOUNDATION BEDS

Foundation bed	Coefficient of friction
Rock (moderate)	0.7
Rock (hard angular)	1.0
Gravel	0.6
Dry clay	0.5
Sand	0.4
Wet clay	0.3

Source: Adapted from Albe E. Munson, Construction Design for Landscape Architects, McGraw-Hill New York, 1975.

Altering the geometry of the masses will also alter the magnitude of the forces and their interactions. This is precisely how the design of retaining structures are fine tuned to meet particular site requirements and site conditions. The formula for resistance to overturning is as follows:

$$\frac{W \times \text{Moment Arm}}{P \times \text{Moment Arm}} \geq 2$$

Where:

W = The combined vertical weight of the wall and soil mass which bears on the wall.

P = The total soil pressure acting on a horizontal line of action passing through the wall.

Settlement at the toe:

If the centroid of the wall is too far forward toward the face (due to improper proportioning of the wall design), then the force resulting from the interaction of the horizontal soil pressure and the downward force of the weight of the wall may concentrate too much pressure on the soil just beneath the toe of the wall. This eccentric loading, may exceed the soil's bearing capacity and result in settlement at the toe; a failure of the soil structure. To avoid this possibility, the wall's proportions are designed so that the resultant action line (drawn within a parallelogram of forces) when extended through the centroid, will pass through the middle third of the base width (Tables 410-6 and 410-7). The distance between the exact center of the base, and the point at which the resultant graphically pierces the base is called the factor of eccentricity (e). The pressure at the toe is calculated using a footing formula to determine the actual kilograms per square meter (pounds per square foot) that will be exerted at the toe:

$$f = \frac{P}{A}\left(1 + \frac{6e}{d}\right)$$

f = pressure at the toe in kN (lb/ft^2)

P = the weight of the wall acting vertically at the centroid

A = the area of the base in square meters (square feet).

e = the factor of eccentricity

d = the width of the footing. In the case of a wall test strip, "d" = A.

The calculated toe pressure must not exceed the bearing capacity of the existing soil subgrade. Table 410-8 lists the bearing capacities of various soil types.

Sliding horizontally:

If the friction between the base of the wall and the soil beneath it is inadequate, the wall may creep forward, as often happens in smooth clays, or silty sands and gravel. The force that tends to cause the wall to slide is the horizontal force (P), while the force that tends to resist the sliding is the vertical force of the wall weight (W). Resistance to sliding must be 1.5 times greater than the force causing the wall to slide. To calculate this "factor of safety" (1.5), the wall weight (W) must be multiplied by the soil coefficient of friction (Refer to Table 410-9 for friction coefficients of various soils) and the product must be divided by the value of P [horizontal force in kg (pounds)]. In the event that the sliding resistance is less than 1.5, a concrete key may be placed on the bottom of a concrete footing, or the base of a stone wall may be angled back to create mechanical resistance.

$$\text{Sliding resistance} = \frac{W \times \text{soil coefficient}}{P}$$

Where:

W= Total weight of wall and soil mass bearing on the base

P= Soil pressure measured in kN (lbs) acting on the wall

6.0 DRAINAGE

6.1 Surface Run-off

All surface water should be directed away from embankments and tops of retaining structures to avoid infiltration into the backfill or subgrade. Such infiltration unnecessarily loads granular backfills, weep holes, and footing drains, and in expansive clays or freeze/thaw conditions may create too much hydro-static pressure for the wall to bear.

6.2 Backfill and Footing Drains

A prepared granular drainage medium is typically used to back fill a retaining wall. It is common practice to place a soil separator fabric between the granular backfill and the subsoil to prevent infiltration of fines. In soils subject to lateral infiltration and seasonal water table shifts, a perforated footing drain set in clean stone and wrapped in a fabric separator is recommended.

6.3 Weep Holes

Weep holes are needed in any rigid wall construction to relieve pressure due to infiltration and are typically placed 100-150 mm (4-6 in) above finish grade and are spaced 900-3 000 mm (3-10 ft) apart depending soil porosity (clay soils require close spacing, and granular soils require less frequent spacing).

7.0 MAINTENANCE ISSUES

In addition to the general maintenance factors listed in Table 410-1, routine maintenance of drain pipes, impermeable barriers, and swales is required to prevent run-off and infiltration water from creating seasonal back pressures. Invasive tree roots may also often cause structural failure in walls and reinforced embankments, and may require periodic crown and root pruning of certain species.

Corrosion of materials from salt spray, acid rain, severe oxidation, or excessive freeze/thaw action may compromise the structural integrity of many improperly specified retaining systems. Retaining structures should be considered to be long term investments requiring specification of stable inert materials suitable to local conditions. The cost of replacing short lived materials must be added to the cost of disturbing a finished landscape setting.

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SECTION 420

Small Dams

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CONTENTS

1.0 INTRODUCTION

This section covers the selection and design of small gravity-type dams whose maximum net heads (headwater to tailwater) do not exceed 6 m (20 ft). It does not address the calculation of runoff and other factors related to its retention and management. Refer to Section 330: Stormwater Management for additional information.

Information and expertise gathered from local authorities is essential during the planning and construction of any type of dam, because safety is such an important factor. Even small dams should be carefully located so that failure will not result in serious accidents or damage to property.

2.0 PURPOSES OF DAMS

Dams are used to retain and retard the flow of water for many reasons, including irrigation, fire protection, mechanical or hydroelectric power, flood protection, the establishment of wildlife habitat, recreational opportunities, livestock needs, fish production, drainage structures, aquifer recharge, and the creation of visual landscape amenities. Dams are frequently constructed to serve multiple purposes.

Several sections in this handbook provide specific information on the purposes and construction of small dams and reservoirs. Refer to Section 330: Stormwater Management, Section 710: Water Supply, Section 740: Recreational Waterbodies, and Section 750: Irrigation, for further information.

3.0 SELECTION OF DAM SITE

3.1 Investigation of Potential Sites

It is customary to conduct preliminary studies of several potential locations when siting a dam. In most site evaluations, a geotechnical engineer and a structural engineer should be consulted. Table 420-1 lists the factors typically considered during the investigation of potential dam sites, and possible sources of this information.

3.2 Survey of Proposed Site

Once the location for a dam has been determined, an engineering survey is required to lay out the dam, the spillway, and other features. The survey should include centerline profiles of the dam and spillway, and topographic mapping to determine the extent and capacity of the proposed reservoir.

Table 420-1. IMPORTANT FACTORS FOR THE ANALYSIS OF POTENTIAL DAM SITES

Factors to he investigated	Possible sources of information (U.S.A.)*
RECONNAISSANCE	
Site configuration	U.S. Geological Survey (USGS) air photos
Evidence of good foundation	USGS surficial geology and bedrock maps
Available construction materials	USGS topographic surveys U.S. Department of Agriculture (USDA) soil surveys
Adequate water supply (drainage area)	USGS surficial geology and bedrock maps
DETAILED SITE INVESTIGATIONS	
Available topographic maps	USGS topographic surveys State and county highway maps
Surficial geology	USGS surficial geology and bedrock maps
Subsurface geology	USGS topographic surveys USDA soil surveys USGS surficial geology and bedrock maps
Location of the source of construction materials	USGS topographic surveys USDA soil surveys USGS surficial geology and bedrock maps
Land required for the dam and reservoir	USDA Natural Resource Conservation Service (NRCS) drainage area maps USGS topographic surveys
Flood-producing characteristics of the stream	USDA/NRCS area maps USGS topographic surveys U.S. Weather Bureau rainfall maps (24-hr storm based on 10-, 25-, or 50-yr frequency) USDA/NRCS hydrologic groupings of soils USDA/NRCS runoff curve tables (calculated for land use and soil type) USDA/NRCS runoff depth, in (for a given rainfall and runoff curve number) USDA/NRCS Type I, II storm charts
Previous flood routing studies	Federal Emergency Management Area (FEMA) flood insurance maps and reports
Legal aspects and riparian rights	State laws Department of Public Works (DPW) Departments of conservation State boards of health Federal Emergency Management Administration (FEMA)**
Silt carried by stream	USGS water supply papers USGS river surveys USDA/NRCS reports
Water quality	USGS water supply papers Health Education and Welfare (HEW) reports State board of health reports
Land use and ownership	U.S. Bureau of Land Management (BLM) public land surveys USDA Forest Service national forest maps County survey or engineer maps City or county recorder plats U.S. Bureau of Reclamation federal reclamation project maps
General	Local, State, Dept. of Safety offices

*Possible sources will vary from country to country. Only U.S. sources are shown here.
**Federal Emergency Management Administration (FEMA), National Inventory of Dams (republished periodically).

Table 420-2. SELECTION CRITERIA FOR SMALL DAMS

	Earthfill	Rockfill	Masonry (Stone or Concrete)	Concrete or Timber Crib
		SITE CONSIDERATIONS		
Suitable topography	Low rolling plains	Low rolling plains	Narrow stream; high, rocky walls	Narrow stream; high, rocky walls
Stream diversion	Required during construction	Usually required	Minimal requirements	Minimal requirements
Foundation requirements	Least stringent; solid rock; gravel, sand	Minimal settlement required; same as earth fill	Reasonably sound rock	Suitable for unstable soils
Earthquake resistance	Very good	Excellent	Good	Good
Suitable materials on site	Fill materials may have to be borrowed; variety of materials suitable for zoned embankment	Local stone suitable; rock of all sizes used	Local stone may be suitable; carefully graded aggregate required	Local timber may be suitable; also pre-cast concrete cribbing
Visibility	Slopes are plantable (except with trees)	Highly visible (no planting)	Free, natural forms possible	Beaver type is least visible
		COST CONSIDERATIONS*		
Maintenance	Damaged by animals and woody plants; upstream slope inspection and repair required periodically	Upstream slope inspection and repair required periodically	Concrete spalls and other types of masonry damage may occur; periodic inspection and repair required	Considerable maintenance; periodic replacement is required
		DESIGN CONSIDERATIONS		
Crest width	Table 420-3	Table 420-3	4-ft (1.2-m) minimum	3-ft (1 -m) minimum
Crest height (freeboard)	Table 420-5	Table 420-5	4 ft (1.2 m) above pond at design discharge	Normal maximum pond level
Maximum gradient of side slopes:				
Upstream	1:2.5	1:1.3 hard rock; fill w/concrete slab	Vertical	1:2
Downstream	1:2 Table 420-6	1:1.7 for hard rock fill w/ asphalt; increase for lower quality rock	1:0.7 (min.)	1:1
Seepage control	Clay core required	Face slab required	None required	Timber planking required
Wave protection	Table 420-14	Face slab required	None required	Timber planking required
Spillway	Spillway generally located away from dam as a separate structure	Spillway generally located away from dam as a separate structure	Overflow crest may be incorporated inexpensively in design	All are overflow dams suitable for large drainage areas
Strength and stability	Easily eroded or destroyed if overtopped	Damaged or destroyed if overtopped	Relatively stable if overtopped	Never fails by overturning
Durability	Considered practically permanent	Considered practically permanent	Considered practically permanent	Short-lived unless continuously maintained (permanent if concrete cribbing is used)

*Optimal type of dam depends on relative cost of securing local borrow and/or construction materials.

After establishing the normal full-water and possible high-water elevations of a proposed reservoir, the extent of the reservoir (i.e., surface area) at full capacity can be determined by using one of three methods:

1. Ground topographic survey techniques
2. Aerial survey techniques
3. Measuring the width of the valley at the normal full-water elevation at regular intervals

The capacity of a proposed reservoir is determined by any one of four methods:

1. Contour method
2. Cross-sectional method
3. Average depth method
4. Multiplying the surface area by 0.3 times the maximum water depth

4.0 TYPES OF DAMS AND SELECTION CRITERIA

Table 420-2 lists general selection criteria for small earth, rock, masonry and crib dams.

4.1 Earthfill Embankment Dams

Types of Earthfill Embankment Dams:

Earthfill embankment dams do not rely upon impervious internal cores (or walls) of concrete, timber, steel, or masonry as part of their construction (Figure 420-1). They depend upon carefully rolled and compacted earth fill to ensure retention of water.

Homogeneous Earthfill Embankment Dams: Homogeneous earthfill dams consists of a single kind of material (exclusive of the slope protection) that is sufficiently impervious to function as an adequate water barrier. The side slopes must be relatively flat for stability. Some seepage through the dam typically occurs on the downstream slope if the reservoir level is maintained at or near full at all times. This weakens the downstream slope and may cause erosion of the dam. Consequently, homogeneous earthfill dams are seldom recommended.

Modified Homogeneous Earthfill Embankment Dams: Modified homogeneous earthfill dams have largely replaced the use of homogeneous earthfill dams (Figure 420-1). Small amounts of strategically placed pervious materials can divert seepage to the downstream base of a dam rather than the slope itself. Control is accomplished by using a large filtered-rock toe or by installing a filter drain. Filter drains with supplemental pipes are best used in combination with a rockfill toe because of clogging problems.

Zoned Earthfill Embankment Dams: In zoned earthfill embankment dams, an impervious core is added and flanked on either side by pervious materials which enclose, support, and protect the core (Figure 420-1). Zoned embankment dams are the most reliable and most frequently used type of earthfill embankment dam. The upstream zone provides stability against rapid drawdown and controls seepage.

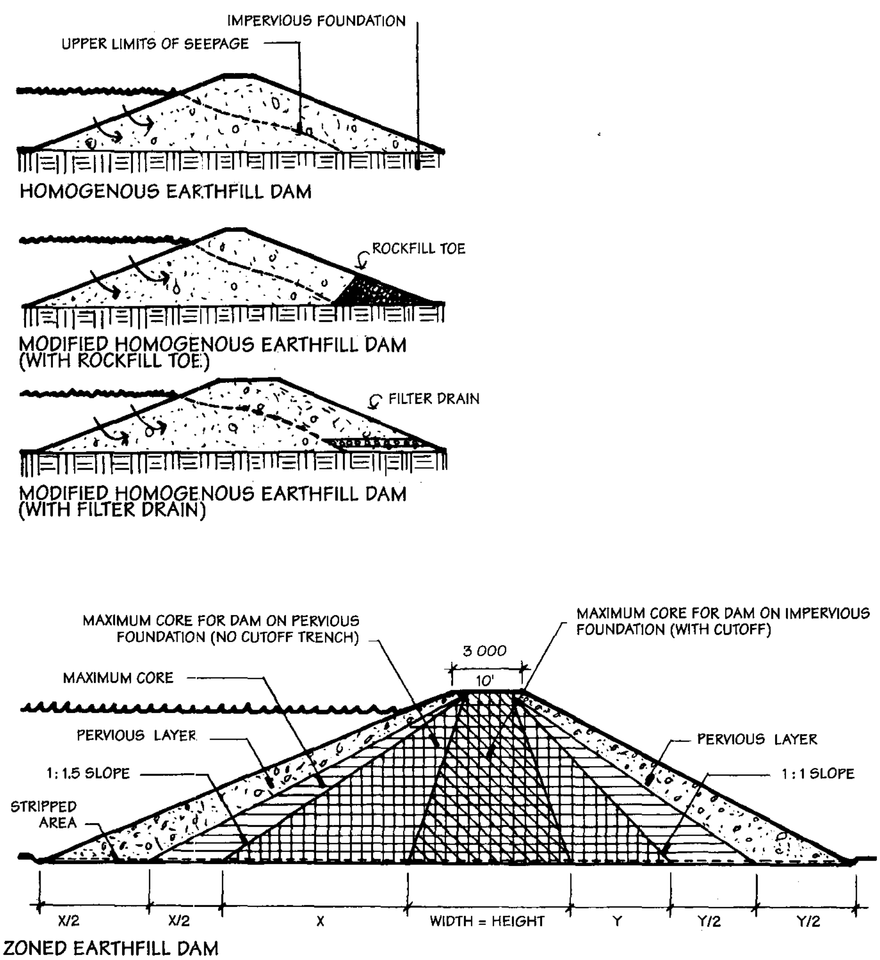


Figure 420-1. Types of earthfill embankment dams.

Foundations for Earthfill Embankment Dams:

The ideal foundation for earthfill embankment dams consists of, or is underlain at a shallow depth by, a thick layer of relatively impervious material. If earthfill dams are constructed on pervious materials, the foundation must be sealed with an impervious cutoff core or blanket (Figure 420-2). If they are constructed on fine-textured or unconsolidated materials, they require careful design to maintain stability. In such instances, an experienced engineer should be consulted. The side slopes of dams on fine-textured foundations must be flattened to reduce the unit load on the foundation.

Figure 420-2 shows how to treat pervious foundations of varying depths. Figure 420-3 shows treatment of stratified pervious foundations, and Figure 420-4 shows how to treat foundations that have an overlying impervious layer. Figure 420-5 shows construction over a saturated fine-textured foundation.

Top Width Dimensions:

Minimum top width dimensions for earthfill embankment dams are listed in Table 420-3. If the top will be used as a roadway, the width dimension should be at least 4 800 mm (16 ft) and include shoulders to prevent raveling of the roadway edge, and provide driver safety.

Settlement Allowance:

Earthfill embankment dams should be built to allow for settlement. Table 420-4 lists expected settlement of earthfill dams based on the composition of the foundation. A minimum camber of 300 mm (12 in) should be specified for well-compacted low dams.

Freeboard:

All earthfill embankment dams must be constructed high enough above the maximum water line to prevent wave action from spilling water over the top of the dam (Table 420-5). Freeboard requirements are dictated by the size of the reservoir, and the resulting fetch.

Side Slopes:

The degree of side slope on an earthfill dam depends on the stability and strength of the fill and foundation material. The more stable the fill, the steeper the slopes allowed (Table 420-6). Side slopes can be contoured to blend in with surrounding landforms as long as good surface drainage is maintained.

4.2 Diaphragm Rockfill Dams

Diaphragm rockfill dams consist of a rockfill core and a waterproof diaphragm on the reservoir side of a dam (Figure 420-6). Rockfill dams have the following advantages:

1. They provide safety against sliding.
2. The rock may be grouted.
3. Fewer problems with uplift pressure.
4. The diaphragm can be placed after the embankment is constructed.
5. The diaphragm is accessible for periodic inspection and repair.

Materials:

The type of rock used for the rockfill zone must not break or crush during hauling and placing, and it must resist disintegration under freeze/thaw and wetting/drying processes.

Most unweathered igneous and metamorphic rock works well. Well-graded rock, from 0.015 to 0.75 m³ (1/2 ft³ to 1 yd³) in size, should be used. Enough fines should be present to fill the voids.

Placement:

Precautions must be taken to prevent the rockfill from settling and causing damage

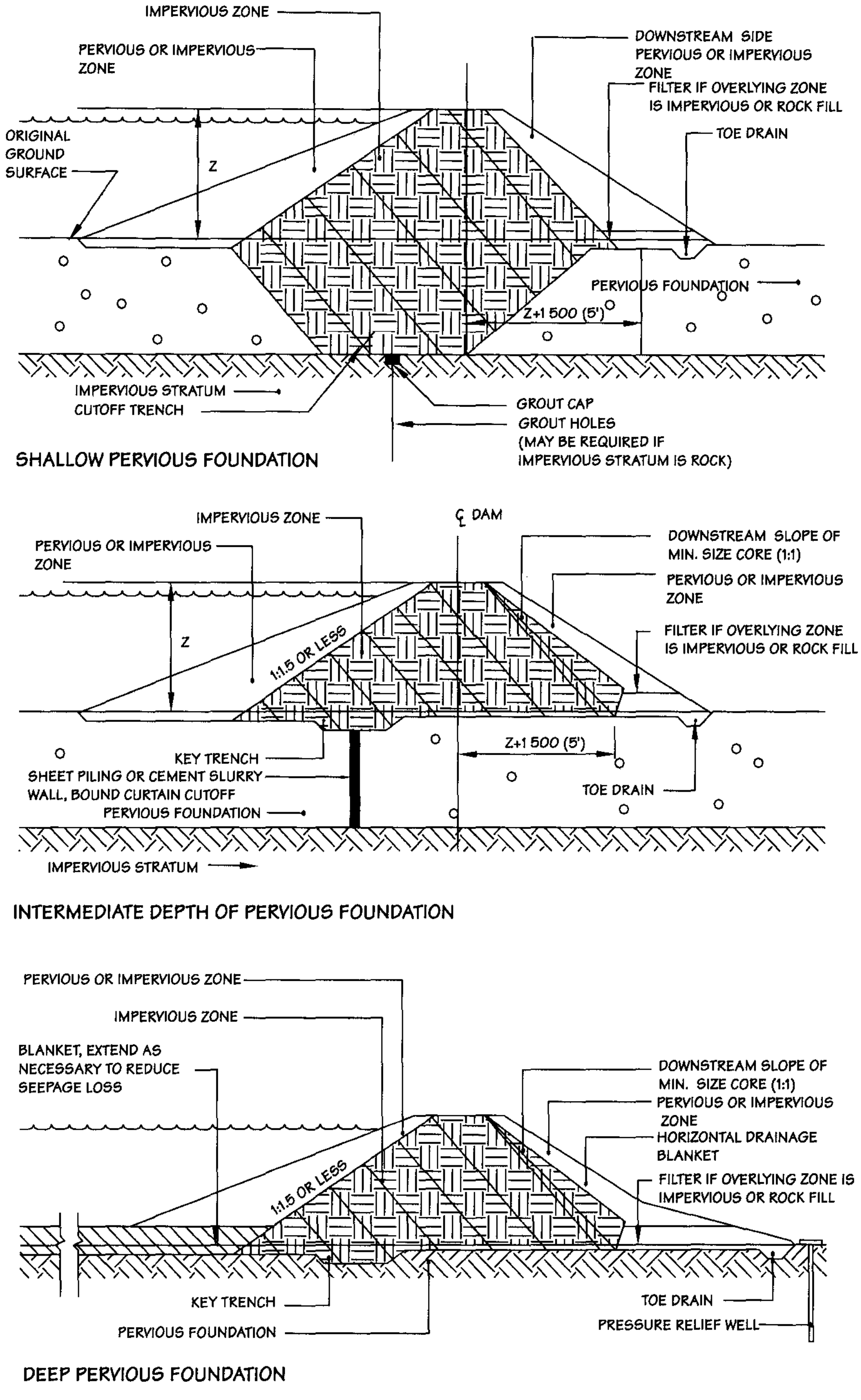


Figure 420-2. Treatment of pervious foundations.

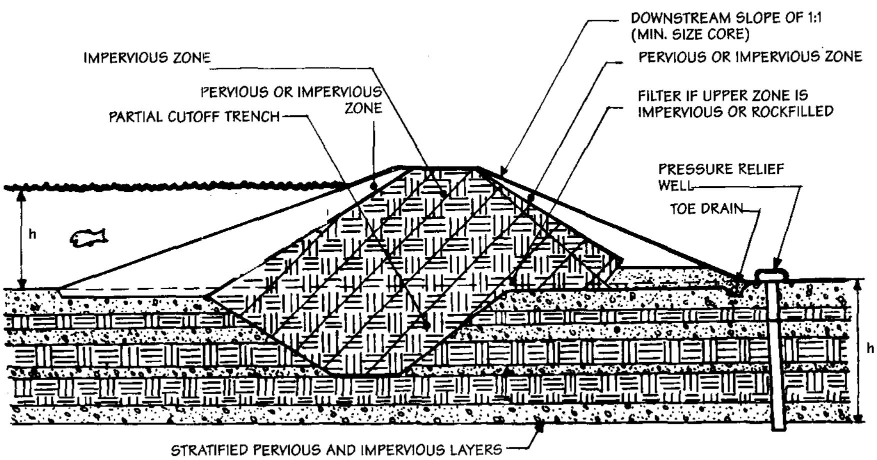


Figure 420-3. Alternative treatment of pervious foundations.

Table 420-3. MINIMUM TOP (CREST) WIDTH DIMENSIONS FOR EARTHFILL EMBANKMENT DAMS

Height of dam, m (ft)	Minimum top width, m (ft)
Under 3.0 (10.0)	1.8 (6.0)
3.4-4.2 (11.0-14.0)	2.4 (8.0)
4.6-5.8 (15.0-19.0)	3.0 (10.0)
6.0-7.4 (20.0-24.0)	3.6 (12.0)
7.6-10.4 (25.0-34.0)	4.2 (14.0)

Source: Soil Conservation Service, "Ponds-Planning, Design, Construction," Agricultural Handbook Number 590, USDA, June 1982.

Table 420-4. SETTLEMENT ALLOWANCES FOR EARTHFILL EMBANKMENT DAMS

Foundation Soil	Settlement Allowance
Coarse Sand or Gravel	1%
Silty or Fine Sand	2%
Clay	5%

Table 420-5. MINIMUM FREEBOARD (CREST HEIGHT) REQUIREMENTS FOR SMALL EARTH-FILL EMBANKMENT DAMS

Fetch, km (mi)	Minimum freeboard, m (ft)	Recommended freeboard, m (ft)
Less than 1.6 (1.0)	3 (0.9)	1.2 (4.0)
1.6 (1.0)	1.2 (4.0)	1.5 (5.0)
4.0 (2.5)	1.5 (5.0)	1.8 (6.0)
8.0 (5.0)	1.8 (6.0)	2.4 (8.0)
16.0 (10.0)	2.1 (7.0)	3.0 (10.0)

Source: U.S. Department of the Interior, Bureau of Reclamation, Design of Small Dams, 2d ed., U.S. Printing Office, Washington, D.C., 1977.

Table 420-6. RECOMMENDED SIDE-SLOPE GRADIENTS FOR COMPACTED EARTHFILL EMBANKMENT DAMS

Fill material	Upstream	Downstream
Clayey sand, clayey gravel, sandy clay, silty sand, silty gravel	1:3	1:2
Silty clay, clayey silt	1:3	1:3

Source: Soil Conservation Service, "Ponds-Planning, Design, Construction," Agriculture Handbook Number 590, USDA, June 1982.

to the impervious membrane. This can happen at two stages:

1. During the construction stage if the rock material is not compacted sufficiently. Rockfill should be placed in layers 600-900 mm (2-3 ft) thick. Each layer should be sluiced, using a volume of water equal to 1/4 to 1 times the volume of rock. Sluicing should take place during compaction with heavy vibratory rollers [e.g., 9-metric ton (10-ton) 1400-rpm rollers].
2. During the first filling stage, owing to the weight of the water. Figure 420-7 illustrates the mathematics of settlement in a diaphragm rockfill dam.

Foundations:

Diaphragm rockfill dams require foundations that exhibit little deformation. Dams should be constructed on:

1. Existing bedrock foundations consisting of hard, durable bedrock resistant to percolating water, free from faults and shear zones, and clear of silt, clay, sand, and organic material.
2. Sand and gravel foundations, with a cutoff and diaphragm constructed to bedrock.

Profile:

The downstream slope of a diaphragm rockfill dam should be flatter than the natural angle of repose of the dumped rockfill. The upstream face should be slightly convex in order to close the contraction joints in the membrane as the dam settles.

The crest width and freeboard requirements are the same as for earthfill embankment dams (Table 420-3, Table 420-5).

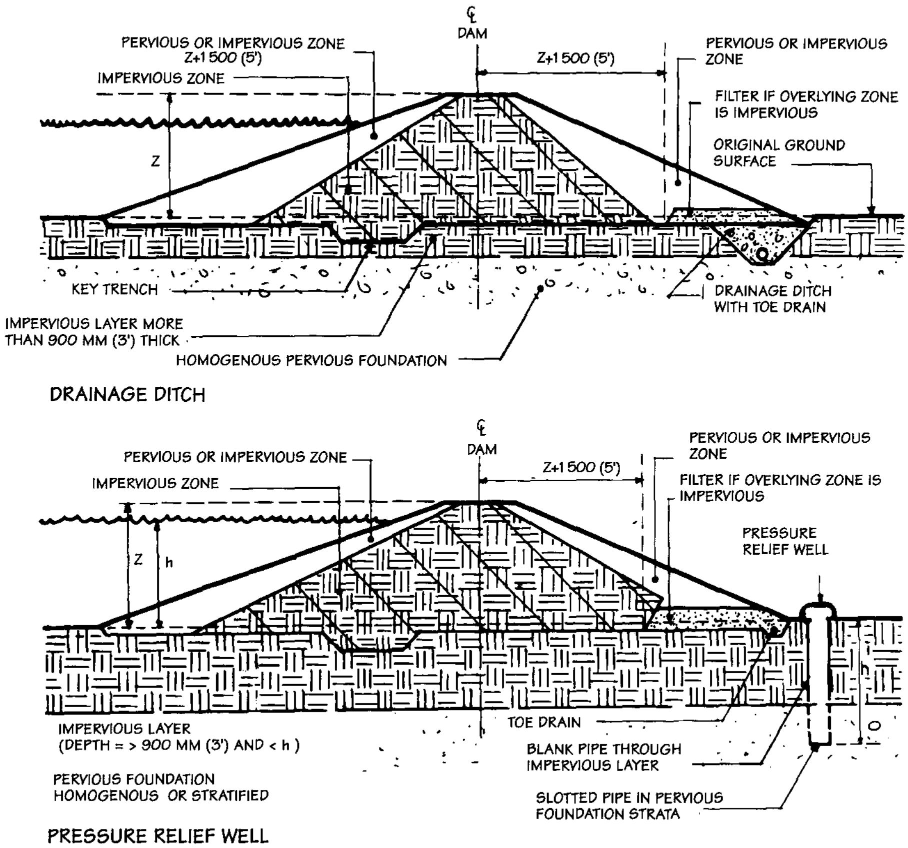


Figure 420-4. Treatment of foundations with overlying impervious layer.

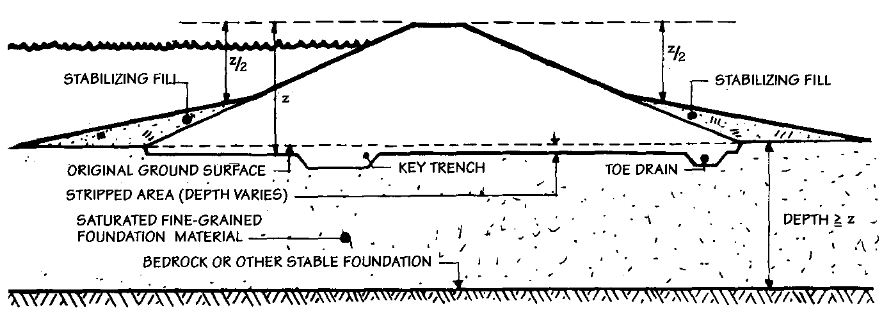


Figure 420-5. Design of Earthfill Dam on Saturated Fine-Grained Foundation. *The outside slope of both the upstream and the downstream stabilizing fills should be the same, but not greater than 3:1.*

Granular Base for Membrane:

A zone of pervious well-graded sand and gravel, quarry fines, or rubble masonry is typically used as a base for the facing of a diaphragm rockfill dam. Material ranges in size from 5 to 75 mm (1/4 to 3 in) with fines.This zone should have a minimum horizontal width of 3 m (10 ft) and should be constructed in 300 mm (12 in) layers, wetted and then compacted by 9- to 18-metric ton (10- to 20-ton) vibrating rollers.

After placement, the zone can be dressed smooth to accept any type of facing. Cutback asphalt [1 liter per m^2 (1 gallon per 40 ft^2)] can be used to seal and stabilize the surface against erosion prior to constructing the facing.

Typical Membranes:

Typical membranes (i.e., facings) for diaphragm rockfill dams include:

1. Concrete (Figure 420-8)
2. Asphalt (Figure 420-9)
3. Timber (Figure 420-10)
4. Steel (Figure 420-11)

4.3 Masonry Dams

Masonry dams can pass large flood flows over their crest without sustaining damage. Their construction costs may be higher than those of earthfill or rockfill dams of comparable height and crest length, but their long-term durability is much greater. Figure 420-12 illustrates stone and concrete masonry dams with overflow spillways.

Foundations:

A solid rock foundation is ideal for masonry dams, but a low dam can be built on a foundation of firm earth as long as the excavation is extended down to an impervious stratum with adequate bearing capacity. If a firm stratum is not present, piles must be used to anchor the dam to a firm foundation. The uplift pressure and buoyancy from tailwater must be considered. Porous strata or earth materials that become plastic when wet are not suitable.

Nonoverflow Design:

To determine the finished elevation at the top of a masonry dam, a minimum freeboard of 1.2 m (4 ft) above the maximum high-water surface in the reservoir is assumed. A profile based on the standards outlined in Table 420-2 is used. The final design width of the base and the downstream slope are determined by stability analysis. Refer to 5.0 Stability Analysis of

KEY POINTS: Types of Dams

Selection of the appropriate dam type is based on site conditions, cost considerations, and desired performance standards. Table 420-2 outlines selection criteria for small dams.

1. Zoned embankment dams (Figure 420-1) are the most common and most reliable type of earthfill dam. Figures 420-2 through 420-5 show designs for various types of foundations.
2. Diaphragm rockfill dams use a rockfill core and a concrete, asphalt, timber, or steel diaphragm on the upstream side of the dam (Figures 420-8 through 420-11). They should be constructed on bedrock or sand and gravel foundations.
3. Masonry dams are more expensive, but offer greater durability and the ability to pass large flows over their crest (Figures 420-12 and 420-13). They should be constructed on sound rock if possible.
4. Beaver-type and timber crib overflow dams are typically used for smaller dams that have short life spans, or where routine maintenance is not a problem. Wood must be kept wet to prevent dry rot. Crib dams may also be constructed out of precast concrete units for greater durability.

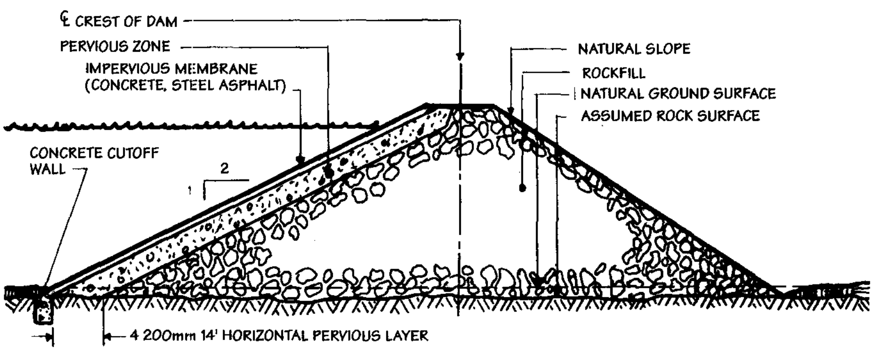


Figure 420-6. Typical diaphragm rockfill embankment dam.

Gravity Dams in this section for information on calculations.

Overflow Design:

The lip of a masonry dam should be sloped in front and designed with a large section to resist ice pressure. Figure 420-13 shows a slight curve at the crest and base to approximate the natural curve of falling water. The stability of an overflow dam is determined by the same method used for nonoverflow dams. In situations where a longitudinal contraction joint at the downstream toe is provided, only that portion of the dam upstream of the joint is used in the stability analysis. If an apron at the upstream face is used to reduce uplift and improve stability, it should be included in the calculations.

Wing Walls:

Wing walls function to join a masonry dam to the side banks of a stream, to prevent erosion of adjacent embankment fills, and to prevent seepage of water around the ends of the dam. The length of the path of percolation along any line beneath or

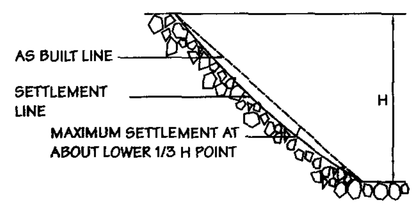


Figure 420-7. Settlement of rockfill material in diaphragm rockfill dams.

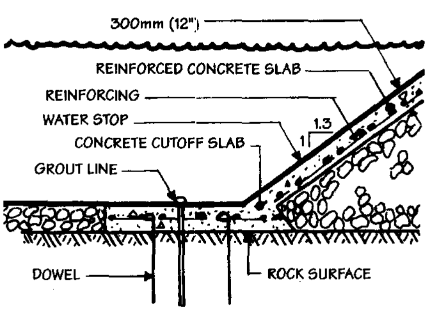


Figure 420-8. Concrete facing and cutoff slab for diaphragm rockfill embankment dam.

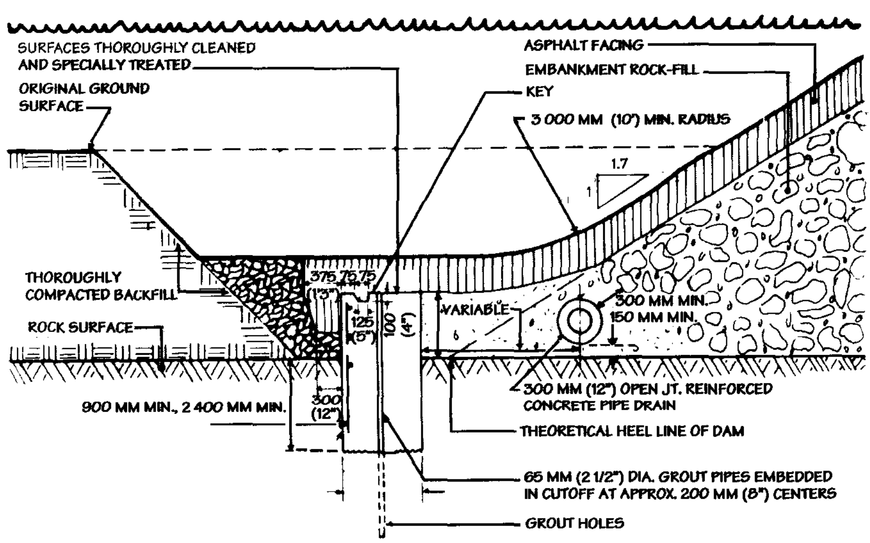


Figure 420-9. Asphalt facing and foundation cutoff for diaphragm rockfill embankment dam.

around the wing walls must not be less than the path of seepage beneath the dam. Wing walls should have a minimum thickness of 600 mm (24 in) and should have properly constructed footings. They should be high enough to confine the maximum flow within the banks of the stream.

Aprons:

The configuration of aprons depends on the topography of the streambed. Erosion must be prevented from occurring around the ends. A minimum thickness of 450 mm (18 in) is recommended for aprons, and they should be backfilled with porous material for drainage.

4.4 Timber or Precast Concrete Cribbing Dams

Two of the most common timber or precast concrete dams are beaver-type dams and crib dams. Most failures are due to leakage underneath the dam, undermining by the overfall, or rotting of the wood members.

Beaver-Type Dams:

Beaver-type dams are typically very low. A profile can be constructed from the criteria

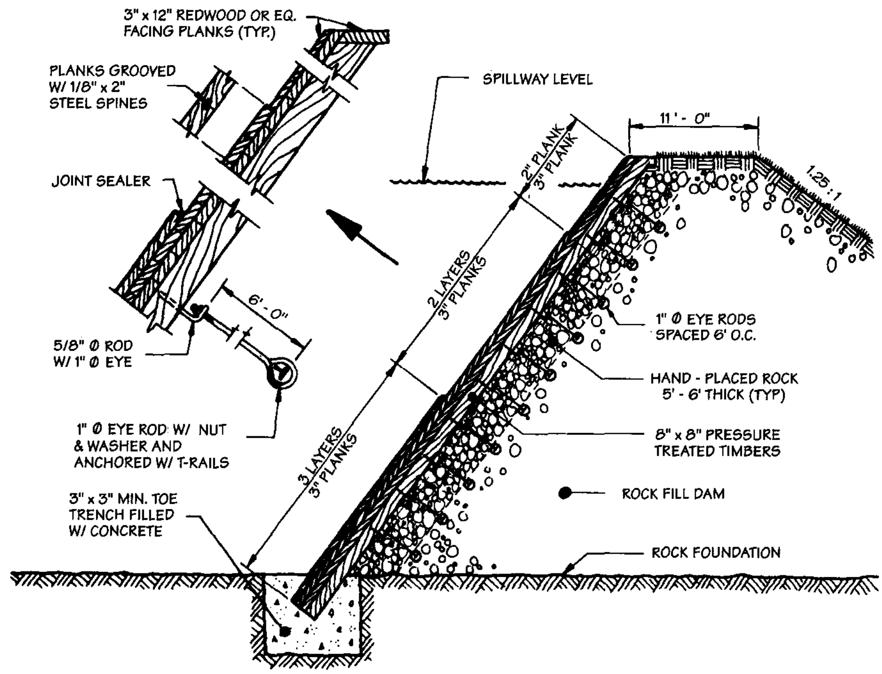


Figure 420-10. Timber facing for diaphragm rockfill embankment dam.

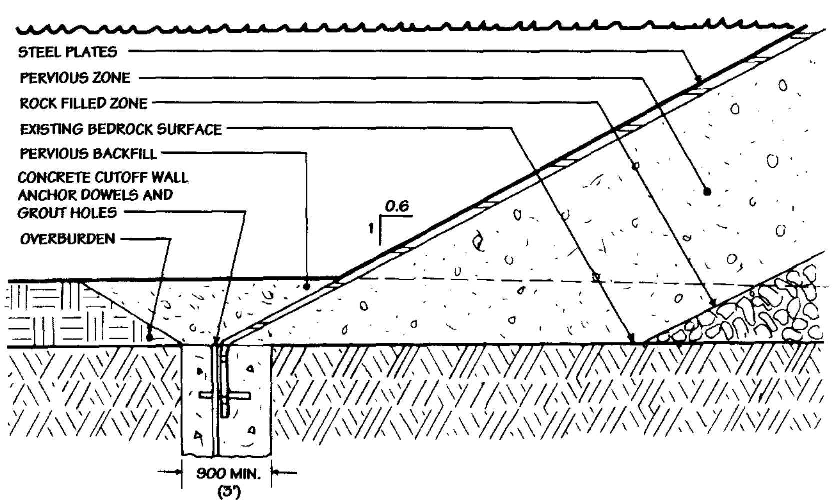


Figure 420-11. Steel facing and cutoff wall for diaphragm rockfill embankment dam.

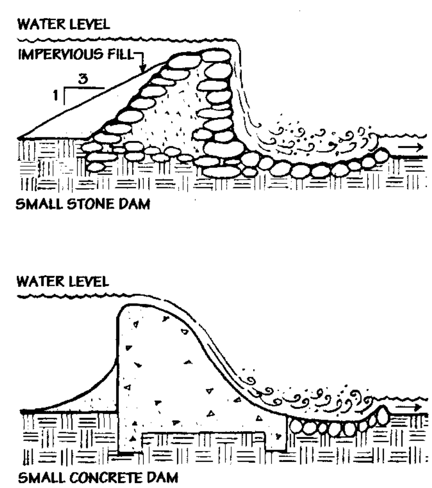


Figure 420-12. Two types of masonry dams.

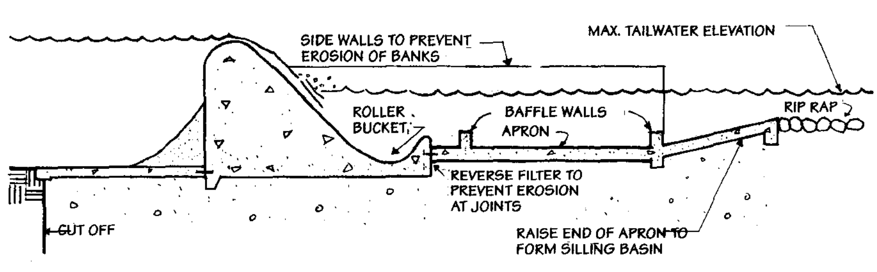


Figure 420-13. Typical overflow section of a concrete dam.

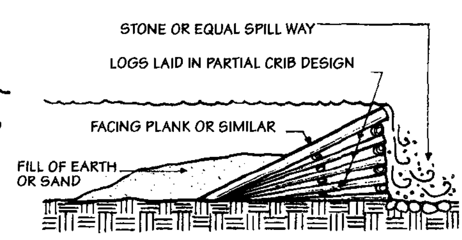


Figure 420-14. Beaver-type dam.

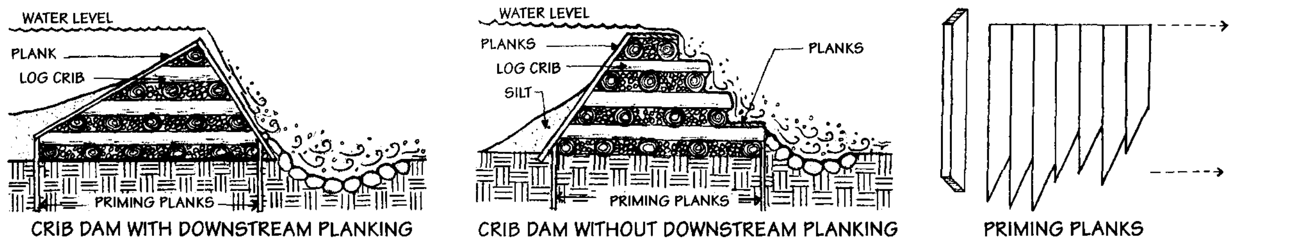


Figure 420-15. Typical crib dams.

outlined in Table 420-2. If logs are used, they should all be drift-pinned. Bottom timbers in the dam are sometimes anchored to bedrock. Longitudinal logs should be laid with their butts downstream. Voids should be filled with gravel for drainage. Plank flooring should be carried from well under the upstream earth fill up to the crest (Figure 420-14). All timber dams must be kept wet to prevent dry rot.

Crib Dams:

Crib dams constructed of timber or precast concrete units have advantages in instances where a drainage area is large, where an overflow dam is necessary, or where it is difficult to drain off the foundation for construction. Crib dams are also a good alternative in locations where rock fill is difficult to obtain or cost prohibitive (Figure 420-15).

Foundations for crib dams should be excavated to a minimum depth of 300 mm (12 in) or, if unstable soils exist, to a deeper, suitable foundation.

Abutments for crib dams should be keyed into the side banks of the streambed to prevent washing around the ends. Rows of sheet piling should be driven to a depth at least the height of the dam below the profile. The rows should be staggered to form a better seal against seepage. The piling at the downstream end of the apron can be of a constant thickness but should reach a minimum depth of 750 mm (30 in) to prevent undermining. A 25 mm (1 in) space should be provided between the planks to drain off accumulated water in the crib on the downstream side when the tailwater falls. Cribs, abutments, and the apron should be filled with gravel or small rocks.

Wood deck planking (upstream and downstream) must be tied to the timber or precast concrete cribbing to prevent floating and bonded ice from plucking at the deck. All timber dams must be kept wet to prevent dry rot. Periodic maintenance and the replacement of rotting timbers is necessary in order to ensure the long-term durability of the dam. In terms of maintenance requirements, precast concrete cribbing and planking have proved to be more economical than timber cribbing.

5.0 STABILITY ANALYSIS OF GRAVITY DAMS

5.1 Forces Acting on Gravity Dams

The forces that act on gravity dams must be accounted for in the design of the dam's cross section. Table 420-7 describes the forces acting on gravity dams.

5.2 Calculation of Stability

The processes that cause a gravity dam to fail are the same as those that act on earth retaining walls: Overturning, Crushing or settlement at the toe, and horizontal sliding.

General Stability:

Prior to checking a cross section for either overturning, crushing, or horizontal sliding, it should be checked for general stability by using the procedure outlined in Table 420-8, testing a 1 m (1 ft) wide strip of the dam.

Overturning:

If a dam were to overturn, it would revolve about its toe. The force resisting overturning must be greater than the force tending to overturn the dam. To check a cross section for its tendency to overturn, divide the resisting moment by the overturning moment. A safety factor (quotient) of 2 or more is considered acceptable. Table 420-8 illustrates the calculation of this test.

Crushing:

To eliminate the possibility of crushing, the toe pressure of the structure (f) [measured in kg/m^2 (psf)] must be less than the bearing capacity of the soil [kg/m^2 (psf)] . Table 420-9 lists approximate bearing capacities of various types of soil and rock. This table can be used for planning on simple projects, however design of complex projects requires test borings and load tests made on-site.

The pressure (f) at the toe of a cross section can be calculated from the following formula:

$$f = \frac{R_v}{A}\left(1 + \frac{6e}{d}\right)$$

where

f = pressure at the toe, kN or kg/m^2 (psf)

R_v = downward force (weight or vertical component of the resultant), kN (lb)

A = area of base in compression, m^2 (ft^2) (meaning a 1 m (1 ft) strip of the dam)

e = eccentricity (distance from centerline of base in compression to point where line of force of resultant cuts base), m (ft)

d = full width of base in compression, m (ft)

Table 420-8 illustrates the calculation of this test.

Horizontal Sliding:

The force tending to cause horizontal sliding of a gravity dam is the horizontal component of the resultant (R_h). The force tending to resist sliding is the vertical component of the resultant (R_v) (the weight of the dam) multiplied by the coefficient of friction between the dam material and the type of soil on which the structure will rest. (Refer to Table 420-10 for average coefficients of friction for concrete on various foundation beds.) A safety factor of 1.5 or more is considered acceptable. Table 420-8 illustrates the calculation of this test.

Other factors that help to resist horizontal sliding are: (1) deep construction into the ground to prevent undermining of the dam, and (2) roughening the rock bottom of the excavation for the dam to increase the coefficient of friction (Table 420-10).

Table 420-7. FORCES ACTING ON GRAVITY DAMS*

*A = area of base, m^2 (ft^2)

a = acceleration due to earthquake, m/s (fps)

d = full width of base from heel to toe, m (ft)

e = eccentricity (distance from centerline of base to point where line of force of resultant cuts base), m (ft)

h = maximum depth of water, m (ft)

h, = maximum depth of silt, m (ft)

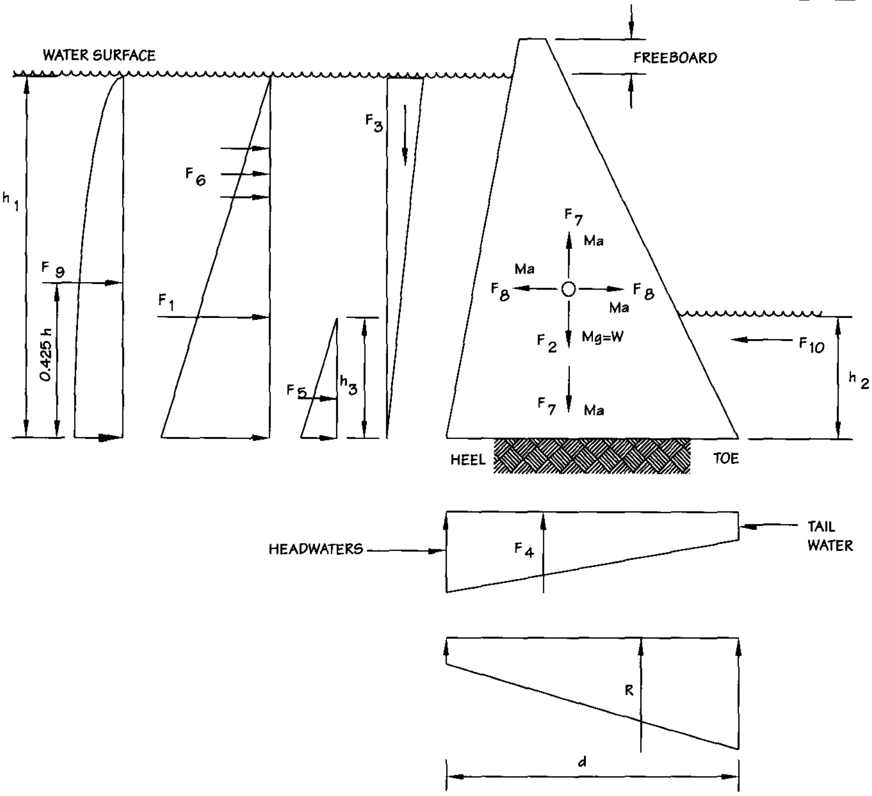
R_v = weight or vertical component of the resultant, kN (lb)

R_h = horizontal component of the resultant, kN (lb)

W = unit weight of water, 9.8 kN (62.4 pcf)

H = height of dam, m (ft)

M = unit weight of dam material, kN (lb)

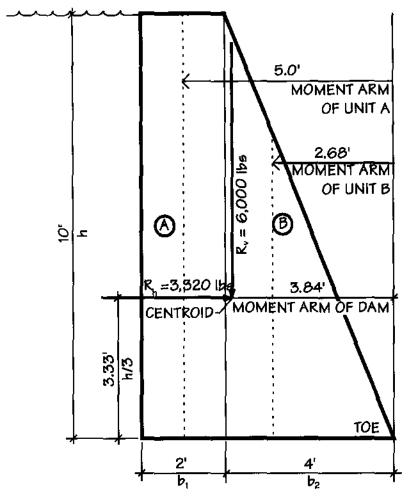


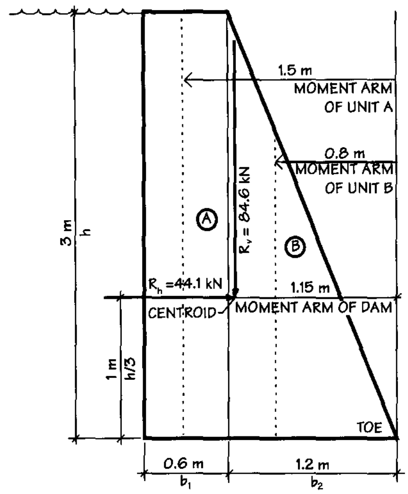
Force	Description	Formula	References
F1	Water pressure: calculated for reservoir pressure (headwater); F1, acts at 1/3 h	$4.9\ h^2$ ($31.2\ h^2$)	Can be calculated by landscape architect for planning purposes
F2	Weight of dam: F2 acts at mass centroid of design section: total moment weight total mass weight	□ = A (H·M) ◺ = A/2 (H·M)	Can be calculated by landscape architect for planning purposes
F3	Weight of water on face of dam: added to weight of dam	◸ = A/2 (H·W)	Can be calculated by landscape architect for planning purposes
F4	Uplift pressure: subtracted from weight of dam	$\frac{d(h_1W+h_2W)}{2}$	Calculated by engineer based on foundation conditions
F5	Silt pressure	Horizontal pressure = 20 psf	Calculated by engineer where siltation is important
F6	Ice pressure: F6 acts 1 ft below the top of the reservoir.	Horizontal force = 10 (h_3) = 1-2000 psf	Calculated by engineer
F7 F8 F9	Vertical earthquake force Horizontal earthquake force (dam) Horizontal earthquake force (water) F9 acts 0.425 h above the base	$0.555\ awh^2$	Calculated by engineer using: "ER 11 10-2-1806, Engineering and Design, Earthquake Projects, May 16, 1983" (or equivalent source of data)
F10	Water pressure: calculated for tailwater pressure For overflow use spillways, F10 acts at 1/3 h	$4.9\ h^2$ ($31.2\ h^2$)	Can be calculated by landscape architect for planning purposes
R	Resultant	Detailed analysis of all forces acting on the base of the dam	A simple analysis, can be done by landscape architect for planning purposes (Table 420-7)
f	Pressure at the toe, psf	$\frac{Rv}{A} = 1 + \frac{6e}{d}$	Calculated by engineer to determine maximum bearing stress of foundation at toe of dam

Source: Adapted from Frederick S. Merritt, (ed.)Standard Handbook for Civil Engineers, McGraw-Hill, New York, 1983.

Table 420-8. STABILITY ANALYSIS FOR A GRAVITY DAM (EXAMPLE CALCULATIONS)

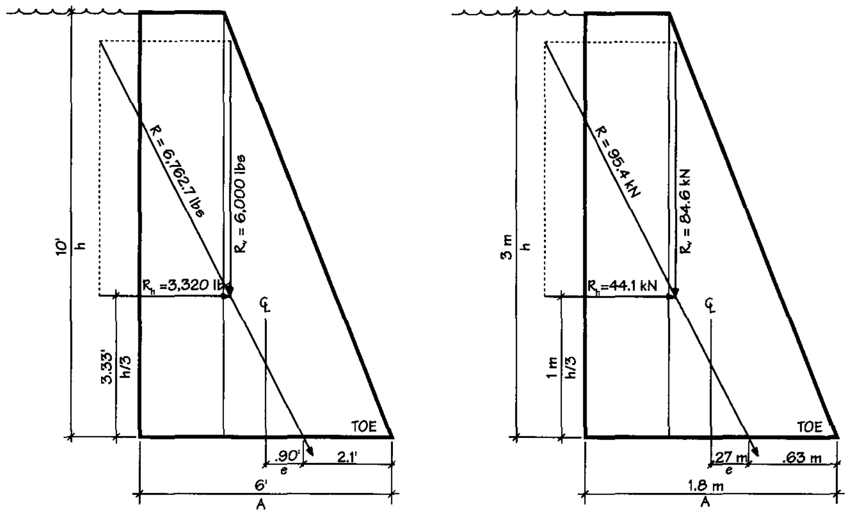
Concrete gravity dam placed on a hard angular rock foundation





Procedure	**U.S. Calculations***	**Metric Calculations†**
Determining Lateral Force (R_h)		
1. Calculate pressure of retained water, acting at h/3 (P): [R_h=0.5(unit weight of water)(height of dam)^2]	R_h=0.5(62.4)(10)^2 R_h=3,320 lbs acting at 3.33 ft from base	R_h=0.5(9.8)(3)^2 R_h=44.1 kN acting at 1 m from base
Determining Dam Weight (R_v)		
2. Calculate weight of section unit A: (b_1 x h x Weight of material)	2x10x150=3,000 lbs	0.6x3x23.5=42.3 kN
3. Calculate weight of section unit B: [0.5(b_2 x h) x Weight of Material]	0.5(4x10)x150=3,000 lbs	0.5(1.2x3)x23.5=42.3 kN
4. Add weights of units A & B. This equals the total weight of the dam's cross section (R_v).	3,000+3,000=6,000 lbs	42.3+42.3=84.6 kN
Determining the Centroid		
5. Calculate the moment arm of unit A from the toe of the dam. The distance of the vertical line of action from the toe in this rectangular section is found by: (0.5)b_1 + b_2	(0.5)2+4=5.0 ft	(0.5)(0.6) + 1.2 = 1.5 m
6. Calculate the moment arm of unit B from the toe of the dam. The distance of the vertical line of action from the toe in this triangular section is found by:: (0.67) b_2	(0.67)4 = 2.68 ft	(.67)(1.2) = 0.8 m
7. Calculate the moment of unit A: (Weight x Moment Arm)	3,000x5.0=15,000 ft lbs	42.3x1.5=63.45 kN m
8. Calculate the moment of unit B: (Weight x Moment Arm)	3,000x2.68=8,010 ft lbs	42.3x0.8=33.84 kN m
9. Add moments of units A & B to yield the total moment of the dam's cross section.	15,000+8,010=23,010 ft lbs	63.45+33.84=97.29 kN m
10. Calculate the moment arm of the dam's entire cross section: $\frac{\text{Sum of Moments}}{\text{Sum of Weights}}$	$\frac{23,010}{6,000}$ = 3.84	$\frac{97.29}{44.1}$ = 1.15 m

Table 420-8. STABILITY ANALYSIS FOR A GRAVITY DAM (EXAMPLE CALCULATIONS) (continued)



Procedure (continued)	U.S. Calculations*	Metric Calculations†
Determining the Resultant Force (R)		
11. Calculate resultant force of water pressure and dam weight (R): $R = (R_v^2 + R_h^2)^{0.5}$	$(6{,}000^2 + 3{,}120^2)^{0.5} = 6{,}762.7$ lbs	$(84.6^2 + 44.1^2)^{0.5} = 95.4$ kN
12. Graphically construct a parallelogram of forces and draw in the resultant (R). Extend diagonal until it intersects base of dam. If it passes within the middle 1/3 of the base, it is considered generally stable. The disance from the centerline of the dam base to the point where the resultant force cuts the base is the eccentricity (e)	The dam is generally stable. e=0.90 ft	The dam is generally stable. e=0.27 m
Testing for Overturning		
13. Divide the resisting moment by the overturning moment to check for tendency to overturn. A safety factor of 2 or more is acceptable:	Resisting moment: 6,000x3.84=23,010 ft lbs Overturning moment: 3,120x3.33=10,390 ft lbs	Resisting moment: 84.6x1.15=97.29 kN m Overturning moment: 44.1x1=44.1 kN m
$\frac{R_v \times \text{Moment Arm}}{R_h \times \text{Moment Arm}}$	$\frac{23{,}010}{10{,}390} = 22$ Acceptable	$\frac{97.29}{44.1} = 22$ Acceptable
Testing for Crushing (Settlement at the Toe)		
14. Test for crushing: $f = \frac{R_v}{A}\left(1 + \frac{6e}{D}\right)$	$f = \frac{6000}{6}\left[1 + \frac{6(0.90)}{6}\right]$ $f = 1{,}000(0.9)$ $f = 1{,}900$ psf	$f = \frac{84.6}{1.8}\left[1 + \frac{6(0.27)}{1.8}\right]$ $f = 47(1.9)$ $f = 89.3$ kN or 9 106 kg/m^2)
Compare results with Table 420-9.	Acceptable for hard rock.	Acceptable for sandy-clay foundation
Testing for Sliding		
15. Calculate the tendency to slide. A safety factor of 1.5 or more is acceptable:		
$\frac{R_v \times \text{Coefficient of Friction}}{R_h}$	$\frac{6{,}000(1)}{3{,}120} = 1.92$	$\frac{84.6(1)}{44.1} = 1.92$
Compare results with Table 420-10.	Acceptable for hard rock.	Acceptable for hard rock.

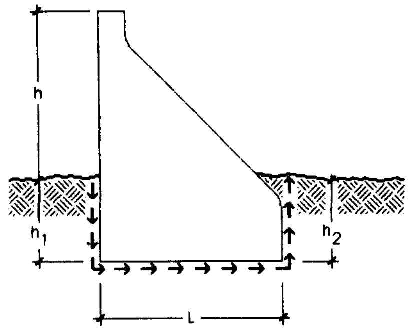
*Assumes a 1 ft thick test strip for calculation
†Assumes a 1 m thick test strip for calculation

Table 420-9. APPROXIMATE BEARING CAPACITIES OF VARIOUS SOILS AND ROCK*

Material	t/m²	kg/m²	Ton/ft²	lb/ft²
Alluvial soil	4.5	4,500	1/2	1,000
Soft clay	9.5	9,500	1	2,000
Firm clay	19.5	4,000	2	4,000
Wet sand	19.5	19,000	2	4,000
Sand and clay mixed	19.5	19,000	2	4,000
Fine dry sand	29.0	29,000	3	6,000
Hard clay	39.0	38,500	4	8,000
Coarse dry sand	39.0	38,500	4	8,000
Gravel	58.5	58,000	6	12,000
Gravel and sand (well-cemented)	78.0	77,500	8	16,000
Hard pan or hard shale	97.5	97,000	10	20,000
Medium rock	195.0	194,500	20	40,000
Hard rock	780.0	779,000	80	160,000

* Tons = U.S. short tons (2000 lb), t = metric tons.

Source: Adapted from Albe E. Munson, *Construction Design for Landscape Architects,* McGraw-Hill, New York, 1975.



$$R = \frac{h_1 + h_2 + 1/3\,L}{h}$$

Table 420-11. LANE FORMULA TO DETERMINE RECOMMENDED CREEP RATIOS (R)

Material	R
Very fine sand and silt	8.5
Fine sand	7.0
Medium sand	6.0
Coarse sand	5.0
Fine gravel	4.0
Medium gravel	3.5
Coarse gravel including some cobbles	3.0
Boulders with some cobbles and gravel	2.5
Soft clay	3.0
Medium clay	2.0
Hard clay	1.8
Very hard clay or hardpan	1.6

Note: If R for a critical section is less than the tabular value, additional flow resistance should be inserted in design section. Limitations: The above R values, determined by the Lane formula, do not take into account (1) the importance of dam shape and (2) the fact that the line of creep may not follow the most direct path of seepage (h1 + L + h2).

Source: Adapted from Elwyn E. Seelye, Design: Data Book for Civil Engineers, vol. 1, Wiley, New York, 1960, (from transactions of ASCE by E. W. Lane, 1935.)

6.0 DESIGN OF MAJOR COMPONENTS

6.1 Foundations

Foundations must be designed to provide adequate bearing strength, and prevent sliding, seepage, piping, scouring, and excessive settlement in earthfill and rockfill dams. Refer to 4.0 Types of Dams and Selection Criteria in this section for design responses to various types of foundations.

Table 420-10. AVERAGE COEFFICIENTS OF FRICTION FOR CONCRETE ON VARIOUS FOUNDATION BEDS

Foundation bed	Coefficient of friction
Rock (moderate)	0.7
Rock (hard angular)	1.0
Gravel	0.6
Dry clay	0.5
Sand	0.4
Wet clay	0.3

Source: Adapted from Albe E. Munson, Construction Design for Landscape Architects, McGraw-Hill New York, 1975.

Types of Foundations:

The existing conditions of earth and rock at the site influence the selection of a dam type. These conditions include the thickness, inclination, permeability, and existing faults and fissures of the load-bearing strata.

Five common types of foundations on which small gravity dams can be built include:

Solid rock foundations: These are suitable for all type of dams described in this section. Disintegrated rock is removed, and fractures are grouted to ensure long-term stability of the foundation.

Gravel foundations: If well-compacted, gravel is suitable for earthfill, rockfill, and concrete gravity dams. Effective water cutoffs or seals are required in order to prevent or minimize water percolation.

Silt or fine-sand foundations: These are suitable only for earthfill embankments. Appropriate steps must be taken to prevent settlement, to prevent piping and percolation losses, and to protect the toe on the downstream side of the foundation from erosion.

Clay foundations: These are suitable for earthfill embankment dams, but special design treatment is required. Field testing is required in order to determine the load-bearing capacity and consolidation characteristics of the foundation.

Nonuniform foundations: Design treatment by experienced engineers is recommended.

Bearing Strength of Foundations:

All weathered material must be removed from the surface of rock foundations. The rock's shear strength should be tested, unless it is of unquestionable durability.

Consolidation and shear strength tests should be made on earth foundations to determine the expected degree of settlement and the required distribution of loading to prevent cracking.

Sliding:

The surfaces of rock foundations must be cleaned to prevent sliding. On horizontally bedded shale foundations with thin beds, the foundation should be designed by an experienced engineer. Where danger of sliding is present, the dam must be anchored by using a weighted upstream blanket or an asphalt or concrete cutoff (see Figures 420-8 and 420-11).

6.2 Drainage Problems

Several techniques are commonly used to minimize seepage and piping, which are pervasive problems in the design of dams.

Masonry or Timber Dams:

The amount of leakage that occurs through foundations depends on the type of foundation on which the dam is built. On rock foundations, masonry dams typically have drilled drainage holes downstream to relieve uplift pressures on the base of the dam.

On earth foundations, masonry and timber dams require:

1. A cutoff of concrete or sheet piling driven to rock or to an impervious stratum
2. An upstream blanket of earth or concrete

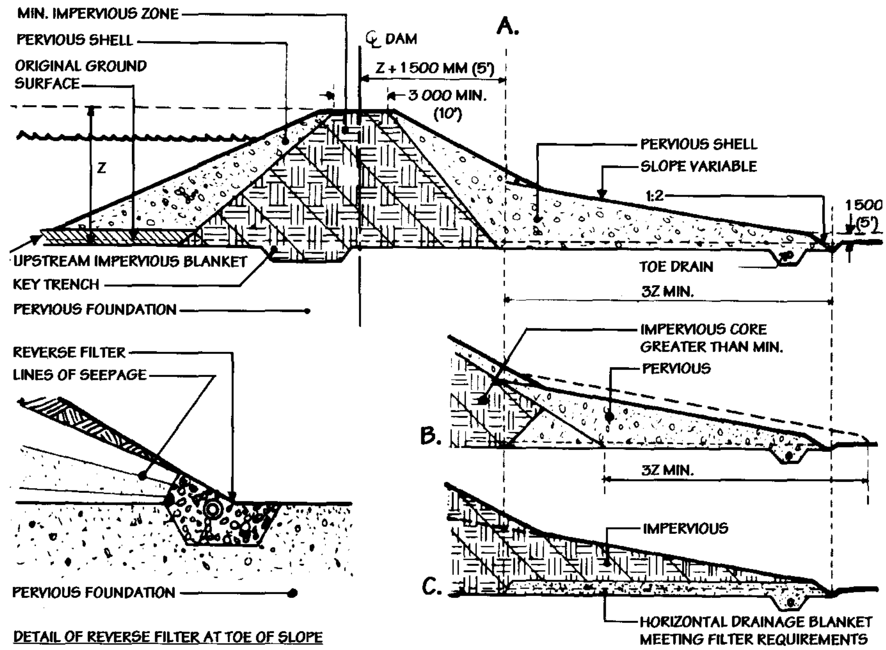


Figure 420-16. Downstream Embankment Sections for Pervious Foundations. *Horizontal drainage blankets meeting filter requirements may be required beneath pervious shells in sections (A) and (B) to prevent foundation piping. The enlarged toe-drain detail illustrates a reversed filter and drain below the ground level to carry off water and thereby stabilize the embankment by lowering the water table, where foundations are pervious.*

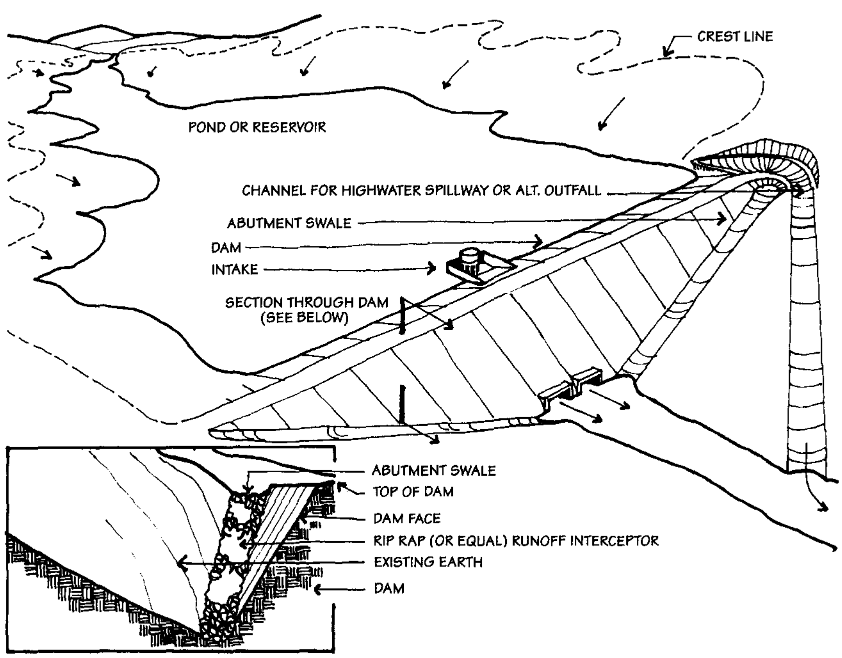


Figure 420-17. Abutment contact protection.

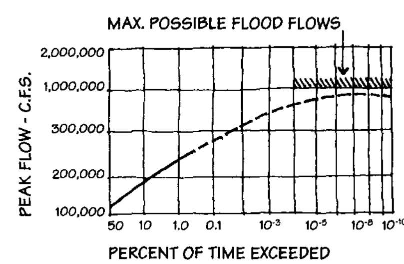


Figure 420-18. Extrapolation of flood frequency curves.

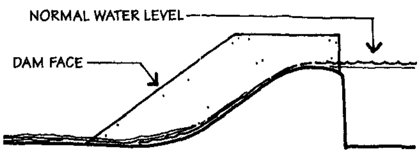


Figure 420-19. Typical overflow spillway.

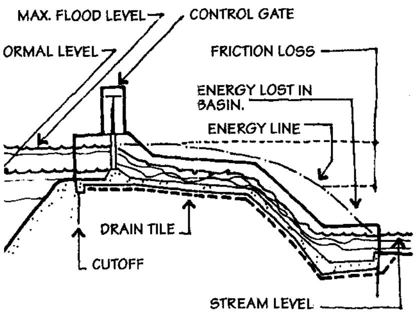


Figure 420-20. Typical chute spillway.

3. A heavy downstream apron to increase the seepage length of the base of the dam

The Lane formula is used to estimate the required length of the path of percolation under masonry dams to prevent piping (Table 420-11). The formula gives the ratio of the weighted creep distance to the net head on the dam. These ratios can be reduced to 80 percent of the values given, if filtered drains are properly used; or 70 percent of the values given, if a flow-net analysis is also conducted. However, the weighted creep ratio should never be less than 1.5.

Earthfill Embankment Dams:

For leakage control, earthfill embankment dams require:

1. A cutoff trench filled with concrete, earth (with bentonite), impervious earth, slurry, or a line of sheet piling (see Figures 420-8 through 420-12)
2. An upstream filter blanket

6.3 Filter Drains

The design of small dams on homogeneous pervious foundations should include the use of pervious shells, horizontal drainage blankets, toe drains, pressure-relief wells (see Figure 420-4), or combinations of these if positive cutoff trenches are not provided (Figure 420-16). Filter drains of gravel or rock prevent piping (loss of core fines) by collecting the seepage and allowing it to flow away. Filter drains are also used on homogeneous pervious foundations overlaid by thin impervious layers (see Figure 420-4).

Pervious Downstream Shells:

The weight of the shell must be adequate to stabilize the foundation. Pressures must be relieved on the impervious layer. Shells must be designed to prevent piping or must be replaced with a horizontal drainage blanket designed to meet filter requirements.

Horizontal Drainage Blankets:

Blankets must have sufficient capacity to conduct the total amount of seepage from the embankment and foundation to the toe drains. A minimum blanket thickness of 300 mm (12 in) is necessary to ensure continuity. The thicker the layer, the greater the permissible deviation from the filter requirements given. Drainage trenches and pressure-relief walls can be used to reduce uplift and control seepage.

Toe Drains:

Toe drains are commonly installed with horizontal drainage blankets. They are progressively increased in size; the smallest drains are laid along the abutment sections, and the largest drains are placed across the valley floor. They collect seepage and lead it to an outfall pipe which discharges into a spillway, outlet works stilling basin, or river channel below the dam where it can be monitored. Vitrified clay pipe, concrete tile, or high density polyethylene pipe is typically used. Minimum depth of trench is 900 to 1 200 mm (3 to 4 ft). The minimum pipe diameter is 150 mm (6 in). Pipes should be surrounded by aggregate that meets filter requirements. Two-layer filters are often required.

Drainage Trenches:

Drainage trenches are used when pervious foundations are overlaid by a thin impervious layer (see Figure 420-4). They relieve uplift pressures in the pervious stratum. Typically, they are installed with toe drains.

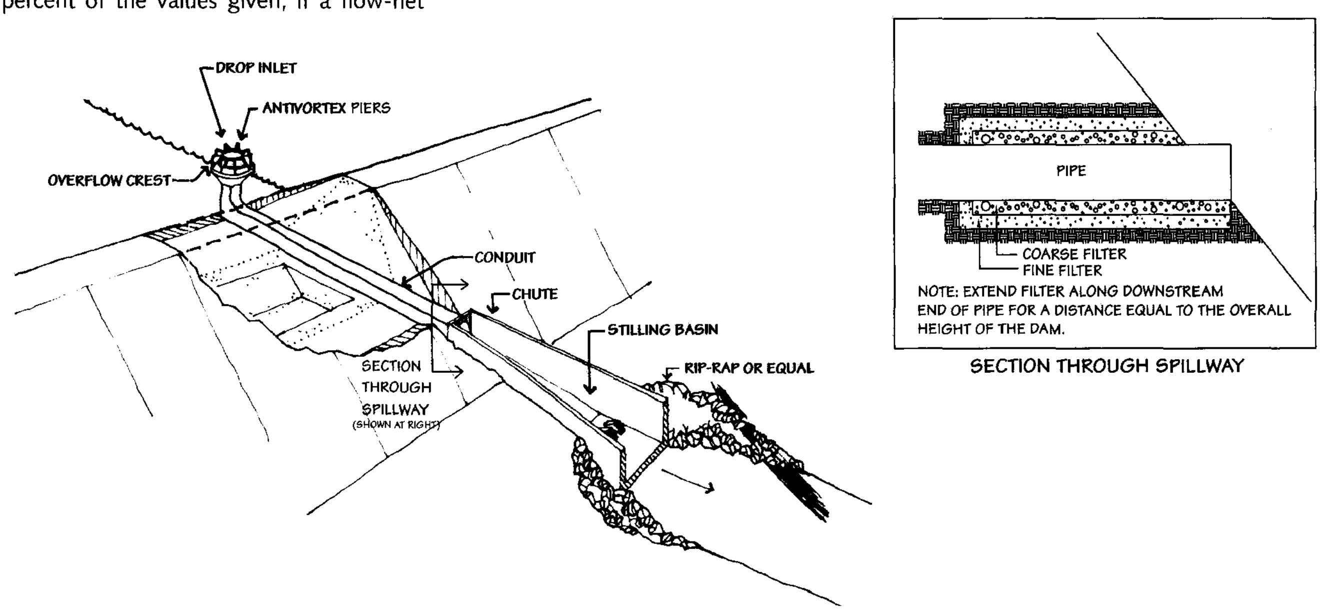


Figure 420-21. Typical drop-inlet spillway for a small dam.

They are not effective if the pervious foundation is stratified. More effective drainage can be accomplished by pressure-relief wells in these instances (see Figure 420-3).

Filter Drain Requirements:

The filter capacity of the drain must be adequate to handle the total seepage flow from the foundation and embankment. it must be permeable to ensure the discharge of seepage water at minimum uplift pressures. The gradation must be sufficient to prevent foundation and embankment soil particles from entering the filter and clogging it. The maximum particle size in the filter material should be 75 mm (3 in).

6.4 Cutoffs

Cutoffs prevent excessive seepage through a dam by joining the impervious stratum in the foundation with the base of the impervious element in the dam. A watertight seal must exist along the upstream contact of the impervious membrane with the foundation and abutments (see Figures 420-8 through 420-11).

Cutoff Trenches:

Cutoff trenches require a minimum bottom width of 2 400 mm (8 ft) and a maximum side slope of 1:1 (see Figures 420-2 and 420-3). They are cut along the centerline of the dam and extend into the impervious layer. The trenches are filled and compacted with thin layers of clay or sandy clay material.

Cutoff Walls:

Cutoff Walls are typically constructed of concrete (see Figures 420-9 and 420-11). They should extend from the upstream toe at least 900 mm (3 ft) into bedrock. They may require a deeper wall and/or grouting, and must provide support for the weight and thrust of the impervious membrane.

6.5 Surface Drainage

Surface erosion from runoff tends to develop along the contact line between the dam abutments and the side slopes of the streambed (Figure 420-17). Runoff can be controlled by constructing a gutter of cobbles, grouted riprap, concrete, asphalt, dry-rock pavement, or half-round pipe.

Earth swales or open drains can be provided to control surface drainage. Discharge should be diverted from the toe drain away from the downstream toe of the embankment by the use of outfall drains or channels.

6.6 Spillways and Fish Ladders

Spillways protect some types of dams from overtopping during flooding, and keep the reservoir's water surface below some predetermined level. The size, type, or location of a spillway will influence the choice of dam type. Runoff and streamflow characteristics determine spillway requirements. On streams with large flood potential, the spillway structure will dominate the dam configuration. The need for a large spillway may suggest the adoption of an overflow dam where the spillway and dam can be combined into one structure, often at less expense.

The probability of a spillway design flood should be determined. Typically, a range of 0.1 to 0.01 chance per year is considered safe. The magnitude of the design flood (in terms of peak flow and volume) that corresponds to the selected probability of occurrence should be determined. Note that there is a ceiling to the flood potential: probable maximum flood (PMF). In most cases, the magnitude of the PMF can be determined for any station on any river. Peak flow can be determined by extrapolating a flood frequency curve toward the ceiling of the PMF (Figure 420-18).

The conventional hydraulic design of the spillway and stilling basin should be based on the maximum reservoir level without wind. This design should be checked for a discharge resulting from maximum reservoir level, including full wind buildup.

Masonry Spillways:

Several types of masonry spillways are commonly used in dam construction, the most important of which are overflow spillways, chute spillways, side-channel spillways, drop-inlet spillways, and siphon spillways.

Overflow spillways refer to the flow of water over the crest of the dam (Figure 420-19). Refer to 4.3 Masonry Dams in this section for information on overflow sections of masonry dams.

Chute spillways are used with both earthfill and rockfill dams where the topography allows the construction of a chute to carry the water away from the toe, thereby eliminating the danger of undermining. The side walls of the chute are designed as gravity, cantilever, or lining walls (Figure 420-20).

Side-channel spillways are used in narrow canyons where it is impossible to obtain sufficient crest length for overflow or chute spillways. The channel normally runs parallel to the river.

Drop-inlet spillways refer to vertical shaft inlets with a horizontal conduit extending through the dam to the base of the downstream face. Figure 420-21 illus-

KEY POINTS: Design Considerations

The calculation of dam stability is similar to earth retaining walls. Table 420-8 outlines a sample calculation for stability analysis in U.S. and metric units. Additional design considerations include:

1. Solid rock or compacted gravel provide the best foundation for all dams. Silt or clay foundations are suitable only for earthfill embankments. Geotechnical engineers should be consulted for construction on non-uniform foundations.

2. Seepage and the loss of core fines (piping) are pervasive problems in the design of dams. Cutoffs, drainage blankets, pervious shells, and filter drains may be used to avoid these problems. Selection of the appropriate method depends on the type of dam, and the foundation.

3. Spillways are designed to prevent nonoverflow dams from overtopping during flooding. Spillways may be constructed out of earth or masonry. Selection of an appropriate design depends on the flood potential and physical characteristics of the dam site.

4. Fish ladders may be required to allow passage of fish over the dam. A variety of designs are used, but typically provide stepped pools with an average slope of 4:1 (Figure 420-24).

5. Drain pipes or drop inlets may be installed to maintain prescribed flow through the dam. Pipes must be properly bedded to prevent failure, and should be designed by a geotechnical engineer.

6. Upstream slopes should be protected with facing materials listed in Table 420-14. Downstream slopes of earthfill dams should be faced with rock or sod.

TABLE 420-12. Permissible Velocities for Vegetated Spillways

	Permissible velocity,* erosion-resistant soil, ** mm/sec		Permissible velocity,* easily eroded soils, ** mm/sec	
	Slope of outlet channel			
	0-5%	5-10%	0-5%	5-10%
Vegetation				
Bermuda grass, bahiagrass	2 400	2 100	1 800	1 500
Buffalograss, Kentucky bluegrass, smooth brome, tall fescue, reed canarygrass	2 100	1 800	1 500	1 200
Sod-forming grass and legume mixtures	1 500	1 200	1 200	900
Lespedeza sericea, weeping lovegrass, yellow bluestem, native grass mixtures	1 050	1 050	750	750

* Increase values 10% when the anticipated average use of the spillway is not more frequent than once in 5 years, or 25% when the anticipated average use is not more frequent than once in 10 years.

** Those with a higher clay content and higher plasticity; typical soil textures are silty clay, sandy clay, and clay.

*** Those with a high content of fine sand or silt and lower plasticity, or nonplastic; typical soil textures are fine sand, silt, sandy loam, and silty loam.

Source: "Ponds-Planning, Design, Construction," Agriculture Handbook No. 590, USDA Soil Conservation Service, June 1982.

trates a typical example of a drop-inlet spillway for a small dam.

Siphon spillways hold the water level of reservoirs within close limits. They are not suitable for handling large variations in flow. They are also relatively expensive because of the cost of the head works (Figure 420-22).

Earth Spillways:

Earth spillways consist of three elements: an inlet channel, a level portion, and an outlet channel (Figure 420-23).

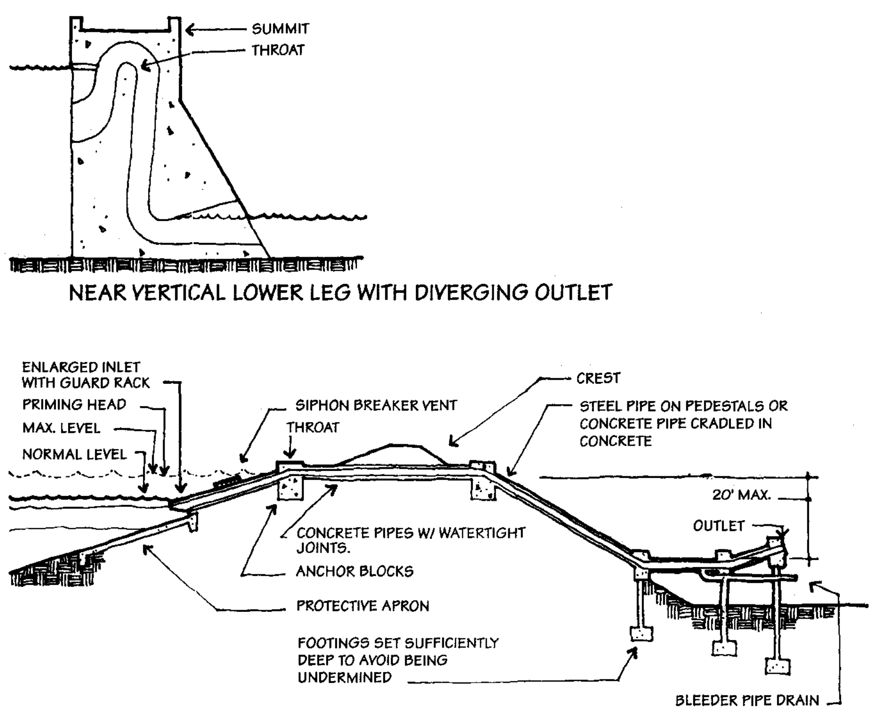


Figure 420-22. Typical siphon spillway for a small dam.

Permissible spillway velocities can be determined from three factors: the vegetation type (degree of retardance), the natural slope of the outlet channel, and the soil erodability factor (Table 420-12).

Earth spillways require regular maintenance, including the repair of erosion channels, the removal of brush and trees, and the clearance of trash from the inlet channel of the spillway.

Fish Ladders:

In the United States most local and state laws require that dams be constructed with a provision of some means for the safe passage of fish. Fish ladders, although built in a variety of configurations, essentially consist of an inclined trough with an average slope of 1:4, baffled to form stepped pools in which the water flows at a velocity against which the fish can easily swim (Figure 420-24). In the United States, specifications for fish ladders are typically furnished by state authorities. The location and design of the entrance to a fish ladder is critical. The entrance to the lower end must be located in an eddy and in the path of migration. The minimum water depth should be approximately 1 m (3-4 ft).

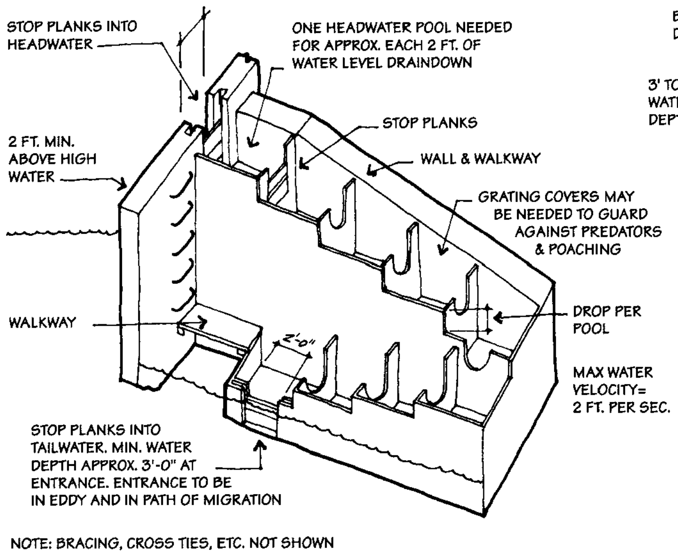
6.7 Outlets

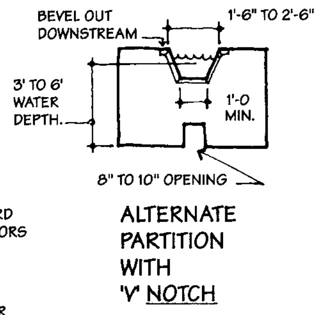
Dam outlets serve to maintain a live stream, preserve downstream uses of water, abate water pollution and allow the emptying of a reservoir for inspection, maintenance, or repair. Dam outlets are also used as service spillways when used in conjuction with bypass overflows or when used as flood control regulators.

The outlet works and their controls are designed to release water at prescribed rates, as determined by downstream requirements, flood control regulations, or storage considerations. Any outlet pipe under a dam on an earth foundation must be properly bedded to prevent failure along the pipe. This design should be approved by an experienced geotechnical engineer.

Drop-inlets consist of a pipe barrel located under the dam, with a riser connected to the upstream end of the barrel (Figure 420-25). The diameter of the riser must be somewhat larger than the diameter of the barrel if the tube is to flow full. Since small-diameter pipe is easily clogged, a minimum pipe size of 150 mm (6 in) in diameter should be used.

Drainpipes provide a means for both partial and complete drainage of reservoirs





POOL DIMENSIONS	
SALMON ETC.	SMALL FISH
DROP - 12" TO 16"	8"
LENGTH- 8'-0'	6'
WIDTH - 6' TO 8'	4' TO 6'
DEPTH - 6' MIN.	4' MIN.
NOTE: ABOVE FOR ORDINARY RUNS. SPECIAL STUDY REQ'D FOR EXTRAORDINARY RUNS.	

NOTE:
CONCRETE PARTITIONS ARE MORE EXPENSIVE THAN WOODEN PARTITIONS BUT REQUIRE LESS MAINTENANCE. PRECAST PARTITIONS ARE CHEAPER THAN WHEN CAST IN PLACE.

CONSTRUCTION MAY BE OF CONCRETE, STEELPLATE, OR TIMBER. ROUND AND SMOOTH ALL EDGES, NOTCHES & PASSAGES.

PROVIDE ADDITIONAL ENTRANCE & EXIT POOLS IF REQUIRED. EXTEND ACCESS WALKWAYS FOR OPERATION & MAINTENANCE.

PROVIDE REST POOL FOR EACH 15 TO 20 FT. OF HEADRISE.

Figure 420-24. Typical pool-type fish ladder.

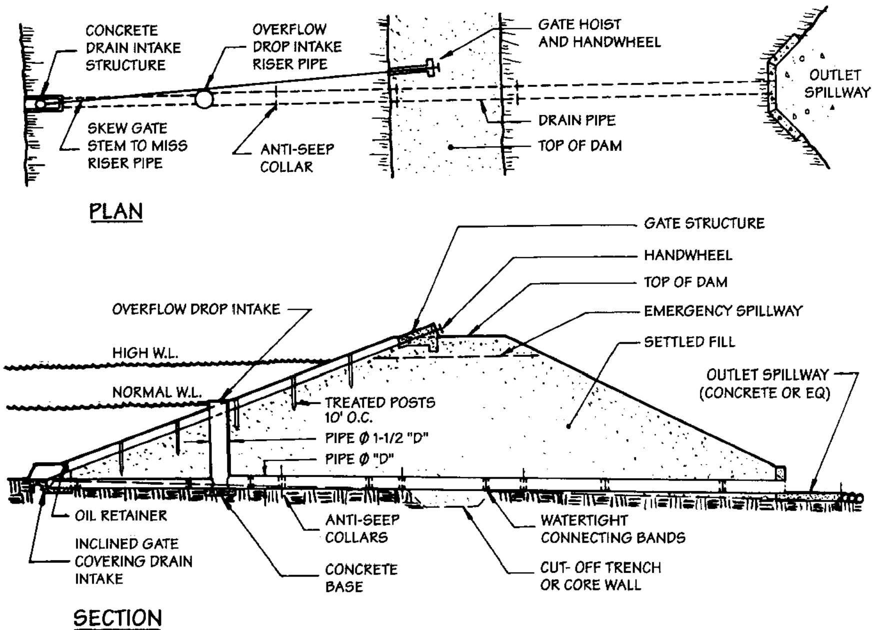


Figure 420-25. Typical drop-inlet trickle tube with drain pipe. *Trash racks and baffles at all intakes are not shown.*

420 Small Dams

Table 420-13. COMMON MATERIALS USED FOR DAM FACE PROTECTION

Type of material	Slope	Depth placed	Considerations
Riprap (dumped)	Upstream Downstream	450-900 mm (18-36 in.)	Placed 100-150 mm (4-6 in.) above elevation reached by normal spring flood Best type of protection for low ultimate cost
Riprap (handplaced)	Upstream Downstream	300 mm (12 in.) minimum	Not suitable for areas with settling Relatively expensive
Concrete	Upstream Downstream	150 mm (6 in.) minimum	Should extend from crest to below minimum water level Expensive Not suitable for areas with settling Laid monolithically or with few sealed joints Precast blocks suitable for less important structures Requires higher freeboard (sometimes wave wall)
Asphalt	Upstream Downstream	100 mm (4 in.) layers minimum	Requires higher freeboard (sometimes wave wall)
Steel	Upstream		Expensive Seldom used
Sod	Downstream		Native grasses suitable Drainage berms required Fertilizer and uniform irrigation required to establish the sod
Reinforced earth	Upstream Downstream		Designed as complete dam structure
Rock cobbles	Downstream	75-300 mm (3-12 in.)	Suitable for arid regions
Soil cement	Upstream	900-3 000 mm (3-10 ft.) horizontal	May be used in lieu of riprap where rock of adequate size is not locally available Rolled compacted concrete
Grouted riprap	Upstream	150-300 mm (6-12 in.)	Stone placed in a mortar bed and filled in with mortar Economical for small dams with cheap source of 150 - 300 mm (6-12 in.) stone
Concrete injection mats	Upstream	150-200 mm (6-8 in.)	Economical Easily installed Useful for small ponds and channels
Gabion mats	Upstream	150-300 mm (6-12 in.)	Economical where only small stone sizes are available Used only for temporary structures

for safety and maintenance reasons. A suitable gate or other control device should be installed, and the drainpipe should be extended to the upstream toe of the dam (Figure 420-25).

6.8 Dam Facing

Upstream Slope Protection:

Upstream slopes of dams should be protected against wave action and burrowing animals. Common materials used for dam facings are listed in Table 420-13. Protective materials should extend from the crest of the dam to 0.6 m (2 ft) below minimum water level. They should be sized for wave action and terminated on a supporting berm (Figure 420-26). Upstream riprap should be protected with suitable filter/transition layers. Refer to Section 880: Geotextiles, for more information on the use of fabrics for slope protection.

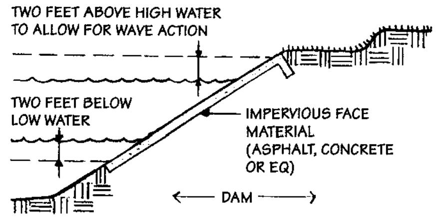


Figure 420-26. Slope protection for small dams. *The required minimum depth may be obtained by trenching.*

Downstream Slope Protection:

No special surface treatment is required for downstream slopes if the downstream zone of an embankment consists of rock or cobble fill. Downstream slopes of dams with outer surfaces of earth, sand, or gravel should be protected against wind and water by a layer of rock, cobbles, or sod (see Table 420-13).

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SECTION 440

Surfacing and Paving

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CONTENTS

440 Surfacing and Paving

1.0 INTRODUCTION

1.1 General

This section covers the structural design of pedestrian and vehicular pavements typically encountered in residential, urban, institutional, and commercial site planning applications. It focuses on construction factors required to accommodate various applications, with regard to loading, subgrade, climate, cost, and maintenance.

This section is supplemented by data contained in other sections of this handbook. Division 800 provides design and construction data on a variety of materials used for paving. Sections 820: Asphalt, and 830: Concrete, refer in considerable detail to the use of these two materials for paving, and provide names of agencies, organizations, and manufacturers of various products. Division 900 includes many examples of paving details for a variety of uses. It also includes examples of related details, such as curbs, dividers, and edges.

1.2 Pavement Contexts

Pavements are generally classified by their intended use within a particular landscape or design context. Pavement types and structural characteristics are modified by application loading (heavy, medium, or light duty), subgrade bearing capacity, climate, installation, and maintenance costs. Table 440-1 illustrates how a decision matrix might be used to help design a particular pavement within the contexts listed and illustrated in Figures 440-1 to 440-9.

2.0 BASIC COMPONENTS

Pavements are layered composite structures designed to bear pedestrian and vehicular circulation loads, while providing an even well-drained surface. The structural layers of pavement commonly consist of a prepared subgrade, an aggregate base, and a wearing or surface layer. Figure 440-10 diagrammatically illustrates the components of a typical light road or heavy path pavement, indicating provisions for clay soil construction, including an additional aggregate subbase, a subgrade fabric separator, and a perforated subdrain pipe system. If a flexible pavement is used, it is common practice to restrain the edge to prevent lateral creep. All subdrains must be placed below the local frost line.

2.1 Subgrade

The subgrade is the soil layer beneath the pavement which bears the design load, receives infiltration water, and is subject to ground water infusion due to seasonal fluctuations or upward capillary migration. It may consist of existing site subsoil at the bottom plane of a grading cut, or a controlled structural fill, placed in compacted lifts. In either event, it is commonly referred to as "prepared subgrade," because a field operation is typically required to prepare the new subsurface to insure proper pitch, elevation or depth, and uniformity. In most circumstances, the subgrade is sloped parallel to the finished pavement surface to insure proper drainage.

Subgrade bearing capacity, uniformity, and permeability are key factors in determining various pavement layer thicknesses. Mitigating devices such as fabric separator, act to prevent fine colloidal soil from migrating upward into the aggregate subbase (Refer to Section 880: Geotextiles for specific references). Uniform subgrade moisture content is essential to reduce general deformation and differential swelling in clay and in frost/thaw conditions. Perforated subdrains aid in stabilizing fluctuating water tables and periodic high infiltration rates (Refer to Section 810: Soils and Aggregates, and Section 130: Site Construction Operations).

2.2 Aggregate Base and Subbase

The base layer consists of a graded aggregate foundation that transfers the pavement load to the subgrade in a controlled radiating manner. The base also prevents upward migration of water through capillary action, and acts to diffuse infiltrated storm water. Light duty pavements typically require a single layer of sand or stone dust to serve both as a setting bed, as well as a structural base.

Heavy-duty pavements or weak subgrades, usually require an additional layer of base material, called a subbase, which also consists of a clean but coarser-graded aggregate layer. Both aggregate base and subbase typically extend beyond the pavement edge to provide lateral support, and to prevent uneven subgrade loading. In heavy clay circumstances, the subbase is often extended well beyond the pavement edge to discourage lateral water migration under the pavement. Care must be taken when fine bases are placed on top of course subbases to prevent fines from

Table 440-1. PAVEMENT CLASSIFICATION BY TYPE, CONTEXT, AND SITE FACTORS (Example Matrix)

Landscape Types:	**Application** (Hv, M, Lt)	**Subsoil** (WD, C, Deck)	**Climate** (HA, HH, T, Cd)	**Cost** (H,M,L)	**Maintenance** (H, M, L)
Public Plaza					
Townscape					
Athletic Facilities					
Highway					
Urban Streets					
Parking Facilities					
Public Garden					
Roof Garden					
Private Garden					

(**Key:** H= High, M= Medium, L= Low; Hv= Heavy, Lt= Light; WD= Well Drained, C= Clay, Deck= Roof Deck; HA= Hot Arid, HH= Hot Humid, T= Temperate, Cd= Cold)

Note: Individual pavement types may be designed to accommodate the typical variables noted in the table above. For example, a Public Plaza pavement supporting heavy duty loads on a clay subgrade in a Hot-Humid climate, within a moderate installation and maintenance budget would require a specific thickness, subbase depth, and limited material and construction options.

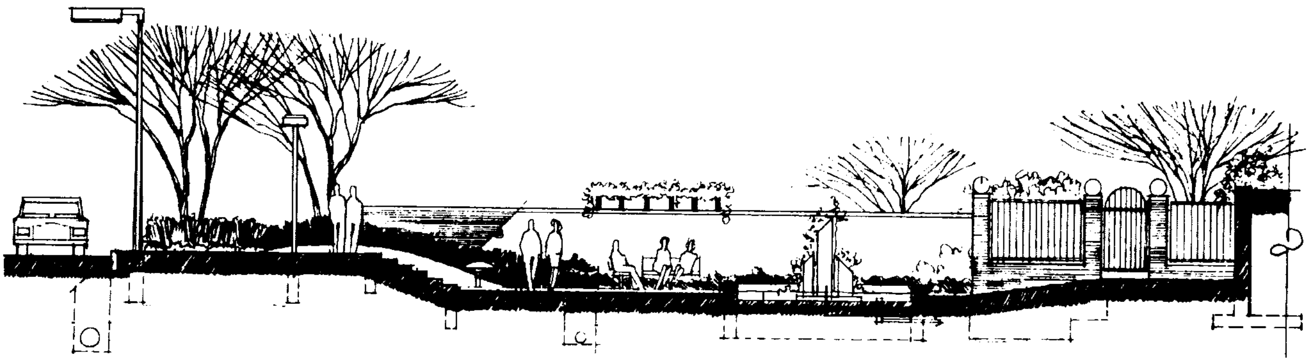


Figure 440-1. Public plaza pavements. *Pavements are typically subjected to medium to heavy duty loads due to dense pedestrian traffic, service and emergency vehicle access, and large-scale mechanical maintenance practices. Cost per square or linear unit is often high due to the need for more durable finishes and stronger materials requiring frequent repair from sustained use and periodic access to buried utilities.*

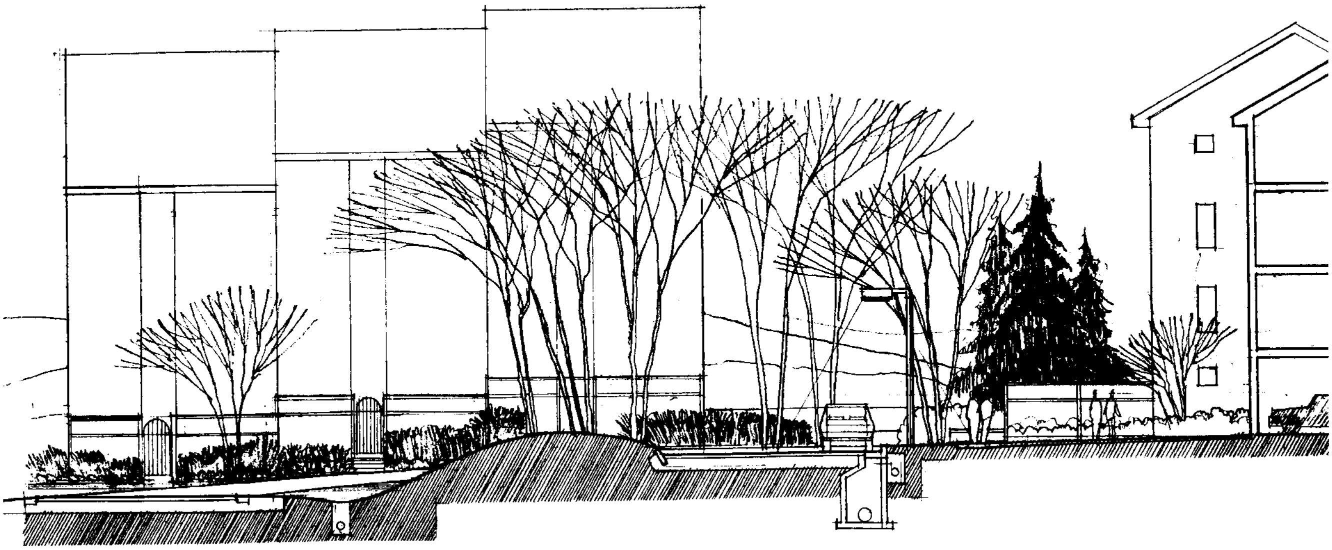


Figure 440-2. Townscape pavements. *Pavements may range from light to heavy duty based upon particular vehicular loading, but are generally rated as light to medium duty. Pedestrian traffic is less dense and materials tend to be moderate in strength, typical of suburban and exurban environments. Costs associated with installation and maintenance tend to be moderate.*

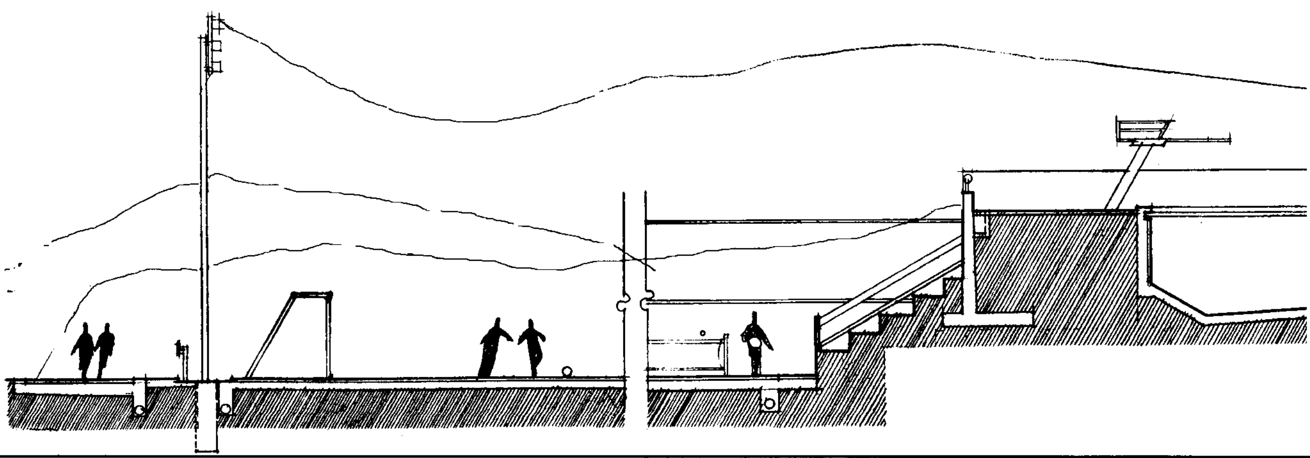


Figure 440-3. Athletic facility pavements. *Pavements typically range from light to medium duty, but occasionally must accommodate heavy duty exposition vehicular loads. This group of pavements are commonly associated with track, field, court, and arena settings. Installation costs are high due to special subgrade preparation and drainage requirements, and long term maintenance is high due to uniformity requirements, specialized equipment, and proprietary surface specifications.*

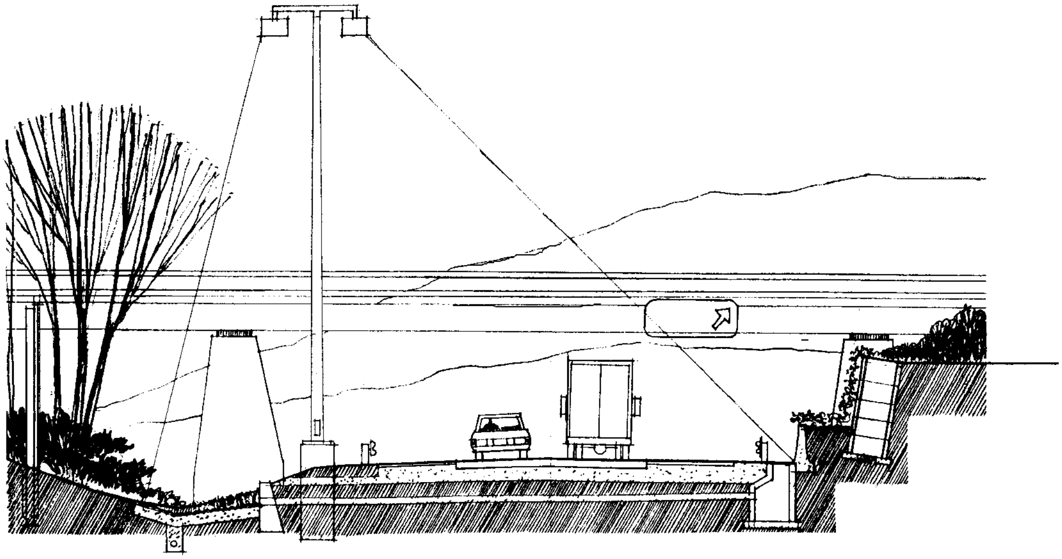


Figure 440-4. Highway pavements. *Pavements range from medium to heavy duty due to heavy traffic loads, speed, and specialized design requirements, typified by multi-layered and reinforced construction, with special emphasis on complex sub-base design. Both installation and maintenance costs are high, but vary by climate zone.*

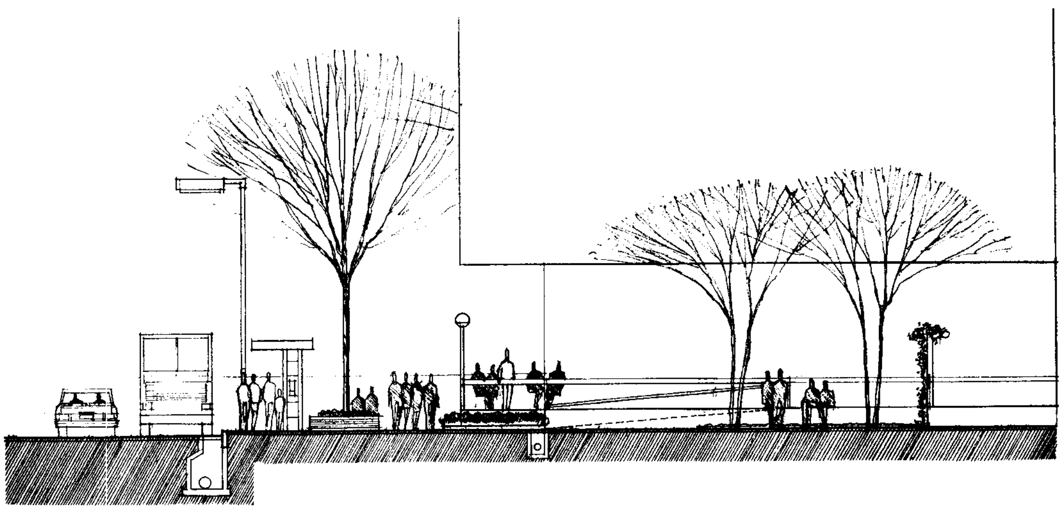


Figure 440-5. Urban street pavements. *Pavements are similar to Highway types, but have potential for greater variety due to lower speeds, and some weight restrictions (no trucking zones). Installation and maintenance costs are typically high.*

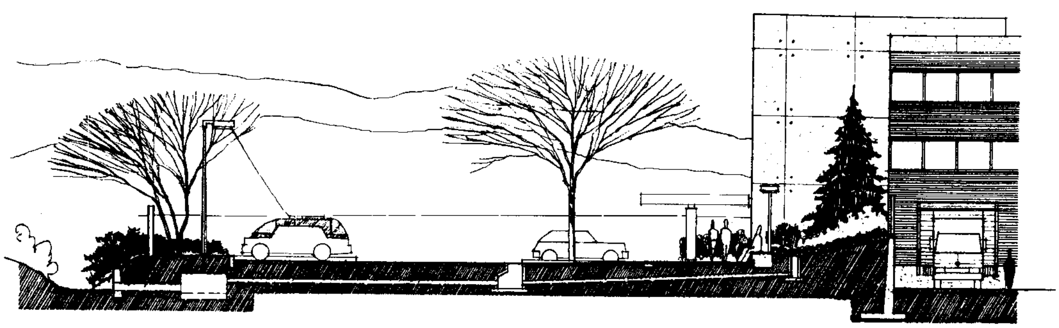


Figure 440-6. Parking facility pavements. *Pavements are commonly light to medium duty due to low velocity and weight requirements, and may include reinforced turf, aggregates, unit pavers, and impervious surfacing. Installation and maintenance costs are typically low to moderate, but may be influenced by extreme climate conditions.*

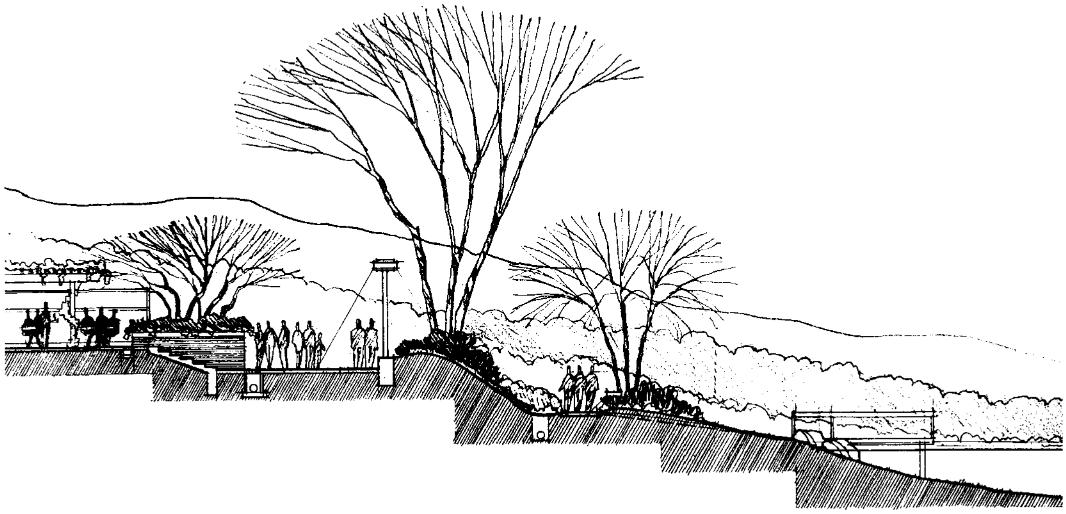


Figure 440-7. Public garden pavements. *Pavements may range from light to heavy duty due to the variety of internal settings typically encountered. Large crowds and special festival or concert events require medium to high installation and maintenance costs.*

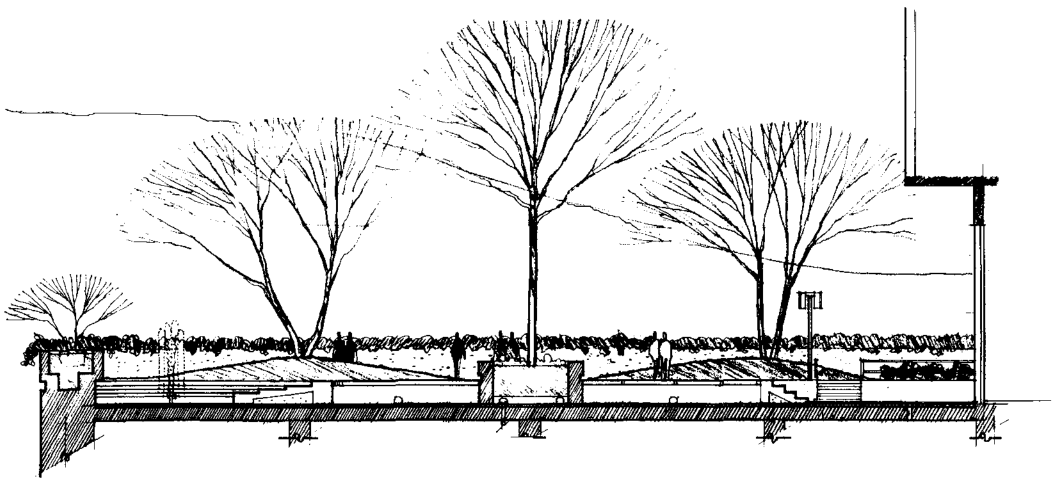


Figure 440-8. Roof garden pavements. *Pavements must be light weight and durable due to extremely variable conditions. Costs are medium to high due to special substrate and drainage requirements, and are greatly influenced by climate variables. Durability is important due to the high cost of repair and replacement in such restricted settings (Refer to Section 610: Rooftop Gardens).*

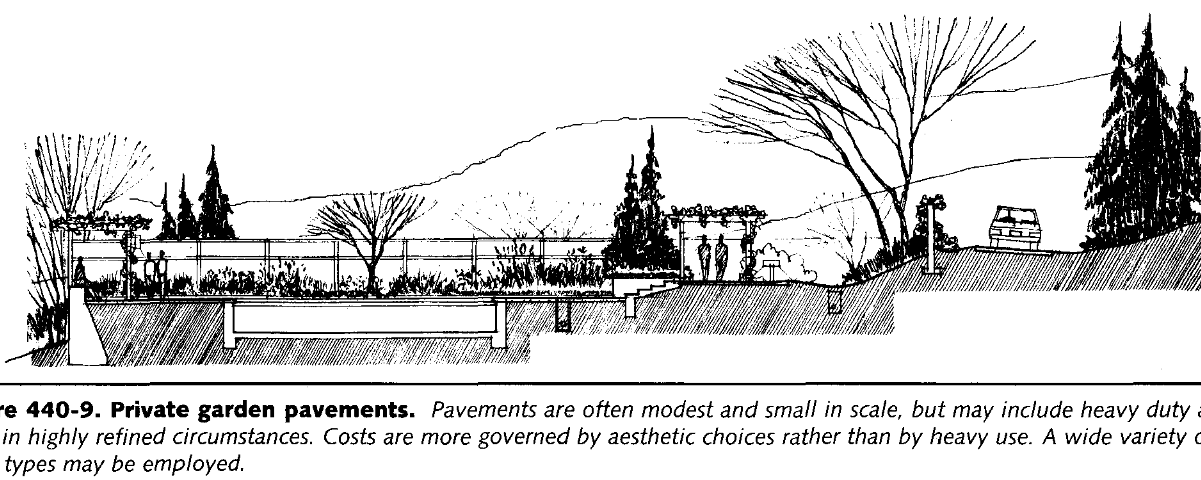


Figure 440-9. Private garden pavements. *Pavements are often modest and small in scale, but may include heavy duty applications in highly refined circumstances. Costs are more governed by aesthetic choices rather than by heavy use. A wide variety of pavement types may be employed.*

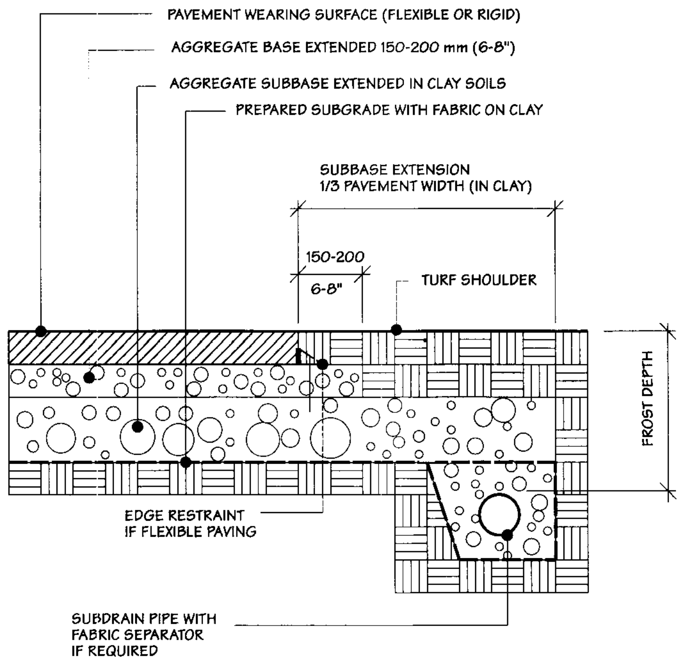


Figure 440-10. Typical pavement components diagram. *The components indicate provisions for clay subgrade conditions. The figure illustrates a variety of paving elements required in severe conditions.*

washing down into the course material. Such downward migration is typically prevented by means of asphalt penetrating sealants, the use of dense graded subbase aggregate, or a fabric separator (Refer to Division 900: Details and Devices, for specific examples of paving details).

2.3 Pavement

The pavement material receives traffic wear and transfers loads to the base and subgrade. Pavements are classified as being either flexible or rigid and as either monolithic or unit. Additionally, they are porous or non-porous. (Refer to Figures 440-11 through 440-13).

Flexible Pavements:

Flexible pavements commonly have thin wearing surfaces and relatively thick aggregate bases and subbases. A thick aggregate base will distribute design loads over a greater subgrade area and will limit subgrade deformation potential. Pavement strength is derived from the aggregate base structure.

Flexible monolithic pavements consist of aggregates, shredded rubber, or polymers which are mixed with an asphalt or proprietary binder and placed on a prepared base to create a seamless monolithic surface. These pavements may be porous or non-porous, and firm or resilient, depending on aggregate and binder composition. Asphalt and resilient athletic surfacing are common examples and are typically 40-100 mm (1$^1/_2$–4 in) thick.

Flexible unit pavements typically consist of dry-laid, sand swept, butt jointed concrete, brick, stone, or synthetic paving units placed on a sand setting bed and a prepared aggregate base. These pavements by virtue of their butt joint construction are porous to semi-porous. Flexible unit pavement applications may range from cobblestone service roads to light-duty flagstone garden patios, and typically require edge restraints to prevent lateral creeping over time. Heavy duty applications require high silica content sand setting beds and dense graded aggregate bases to prevent the pulverizing action evident in stone dust under repeated heavy loads. Unit thickness ranges from a minimum of 40 mm (1$^1/_2$ in) for cut stone or pre-cast concrete, to 200 mm (8 in) for vehicular granite cobbles. Heavy duty brick and masonry pavers are typically 80 mm (3$^1/_4$ in) thick and are increasingly being used as unit pavers for streets and parking areas.

Flexible pavements may require edge repair due to crushing, and periodic sealing to protect surface uniformity. Unit pavers may require periodic re-setting and weeding. These pavements, constructed with properly specified bases, are appropriate in cold climates and in clay subsoil areas due to their capacity to move uniformly during swell and shrink cycles (Refer to Figure 440-11).

Rigid Pavements:

Rigid pavements (i.e. reinforced concrete) are structurally different than flexible pavements (Figure 440-12). Pavement loads are

KEY POINTS: Pavement Contexts

Landuse, climate, substrate condition, level of service, and cost are prime determinants of structural pavement design and on-going maintenance requirements (Refer to Figures 440-1 through 440-9).

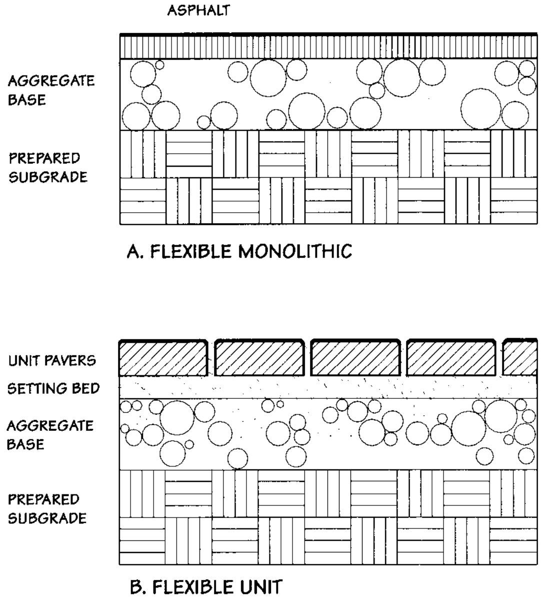
1. Landscape type indicates loading potential and probable use intensity. Prudent design uses aggregate bases and pavement finishes capable of accommodating associated pedestrian and vehicular traffic, including extreme cases for each type.

2. Moisture loading and frost/thaw cycles are critical climate factors. Pavements must be capable of withstanding the climate stresses and the maintenance practices required within each region.

3. Frost/thaw climates and swelling colloidal soils significantly affect pavement design. Both require extra aggregate base material and positive subdrainage.

4. In reduced budget circumstances, it is best to specify a less expensive finish surface, rather than reduce the cost of subgrade preparation or aggregate base placement for better long-term performance.

5. Long term maintenance costs and projected length of service must be considered for cost comparison purposes. Pavement utility will diminish rapidly without periodic maintenance.



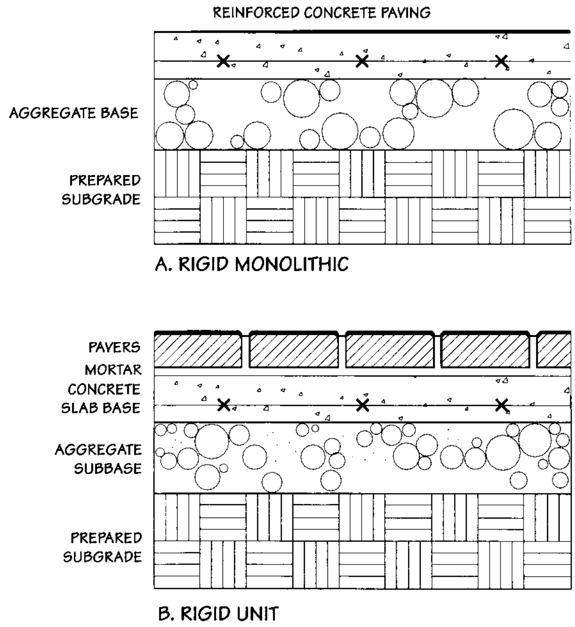


Figure 440-11. Typical flexible pavement section showing monolithic (A) and unit (B) types. *Fabric separator subgrade reinforcing is often used in weaker soils to maintain structural integrity and to guard against deformation. Unit pavers subject to vehicular loading should use high silica content sand, rather than stone dust.*

Figure 440-12. Typical rigid pavement section showing monolithic (A) and unit (B) types. *Although many local practices place rigid pavements directly onto prepared subgrades, especially in warm climates, it is highly recommended to use an aggregate base for best long-term results.*

distributed internally within the rigid pavement and transferred to the subgrade over a broad area, in a manner similar to that found in a concrete spread footing. Generally, given equal soil types, rigid pavements require a thinner aggregate base thickness than flexible pavements designed to carry the same load (Refer to Table 440-2).

Rigid monolithic pavements are typically constructed as cast-in-place reinforced concrete slabs. Rigid unit pavements require unit pavers to be mortared or glued to a reinforced concrete base. Aggregate bases are used to insure subgrade uniformity, an essential condition for rigid pavement

Table 440-2. PAVEMENT DESIGN LOADS AND TYPICAL DIMENSIONS

	Rigid Pavements**		Flexible Pavements	
	Pavement	**Agg. Base**	**Pavement**	**Agg. Base**
Heavy Duty	150-200 mm* (6-8 in)	150-200 mm (6-8 in)	115 mm (4 1/2 in)	300-450 mm (12-18 in)
Medium Duty	125-150 mm (5-6 in)	125-150 mm (5-6 in)	65-75 mm (2 1/2-3 in)	200-300 mm (8-12 in)
Light Duty	100 mm (4 in)	50-100 mm (2-4 in)	50-65 mm (2-2 1/2 in)	150-200 mm (6-8 in)

*Static wheel loads on most municipal service paths, streets, and roads can range from 910 kg-4500 kg (2,000- 10,000 lbs). Although static wheel loads on major highways and freight ways can exceed 6000 kg (14,000 lbs), this table is restricted to the lesser loads of streets and roads more commonly associated with site construction.

**Rigid pavement thickness will vary by cement content, reinforcing, and aggregate specification (Reinforcing is assumed).

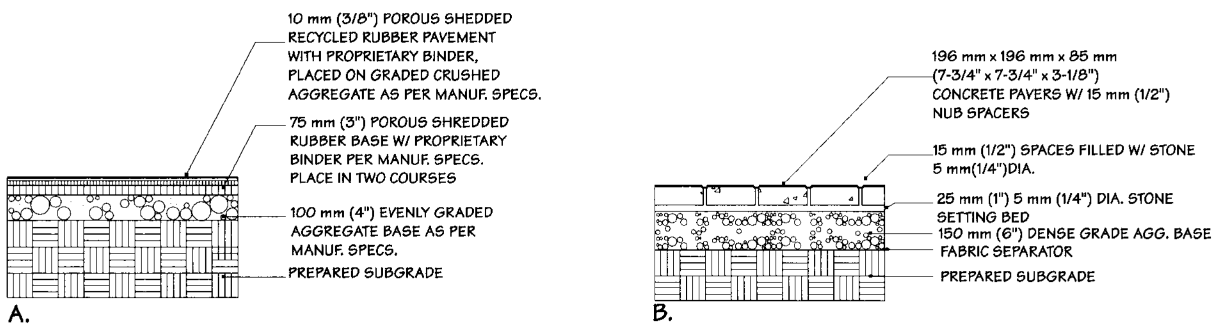


Figure 440-13. Typical porous pavement sections. *(A) Porous pavements employ open structure wearing surfaces and specially designed aggregate bases with limited fines to insure free flow of infiltration water. (B) Unit pavers with spacer nubs allow free drainage. Typically restricted to well drained subgrade conditions.*

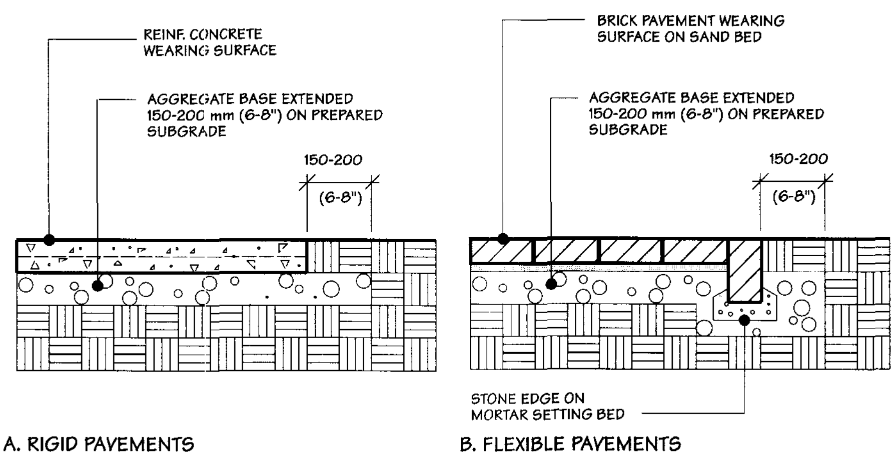


Figure 440-14. Aggregate base extension at pavement edge. *Rigid pavements (A) and flexible pavements (B) employ extended aggregates bases. Edges may also be thickened in both concrete and asphalt applications.*

design. These pavements are suitable in areas that contain uniform subsoils with moderate bearing capacities. Mortared unit pavers are not recommended for cold climates due to high maintenance requirements and chemical and mechanical degradation. Site scale reinforced concrete pavements and bases commonly range in thickness from 100-150 mm (4-6 in).

Table 440-2 indicates the thicknesses required to support various vehicular wheel loads for both flexible and rigid pavements. As the subgrade bearing capacity increases, the pavement thickness decreases. The thickness range is wider in flexible pavements than in rigid pavements due to the manner in which the load is transferred to the subgrade (Refer to Figure 440-12).

Rigid pavements require periodic expansion joint cleaning and repair, and may require re-sealing of proprietary surface coatings.

Porous Pavements:

Porous pavements are a class of pavements structured to allow precipitation runoff to drain freely through the pavement surface and aggregate base. Coarse aggregate containing no fines and bound with asphalt, is a very common type used in warmer climates. Specially designed unit pavers and turf grids over free draining aggregate bases are better alternatives for cold, temperate, and hot-humid climates. The pavement design must allow for periodic cleaning with chemical oxidants or replacement of drainage stone to avoid build-up of toxins from vehicular run-off. Unit pavers and turf grids are highly recommended for this purpose. Thicknesses range from 50 to 100 mm (2 to 4 in), but all have specially designed aggregate bases and subbases (Refer to Figure 440-13, and Division 900 for typical porous pavement details).

Porous pavement may require periodic flushing with oxidants to cleanse granular filter beds and associated perforated drain pipes. Edging may need re-setting (not recommended for use in extremely fine clay soils).

2.4 Pavement Edge

Pavement edges require extra reinforcing to prevent breaking or crumbling due to eccentric loading, invasive plant roots, or wind erosion in coastal sandy soils. Special treatment is also required in clay soil conditions and frost/thaw regions.

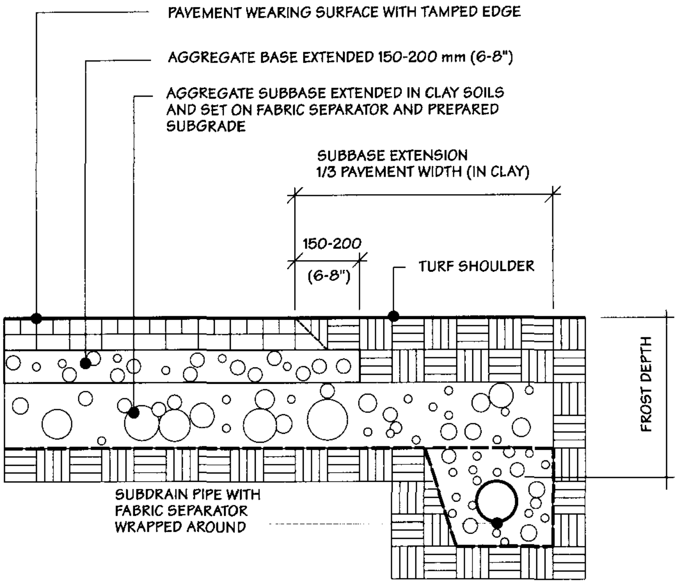
Aggregate Base Extension:

This is accomplished in both rigid and flexible pavements by extending the base beyond the finished pavement edge. Typically the base is extended 150-200 mm (6-8 in), but may extend 900-2 400 mm (3-8 ft) for roads built on clay subsoils (Refer to Figure 440-14).

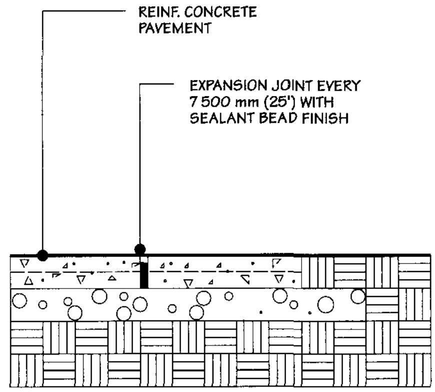
KEY POINTS: Basic Components

Pavement structural layers commonly consist of a prepared subgrade, an aggregate base, and a wearing or surface layer. Heavy loads or weak soils may require an additional aggregate subbase.

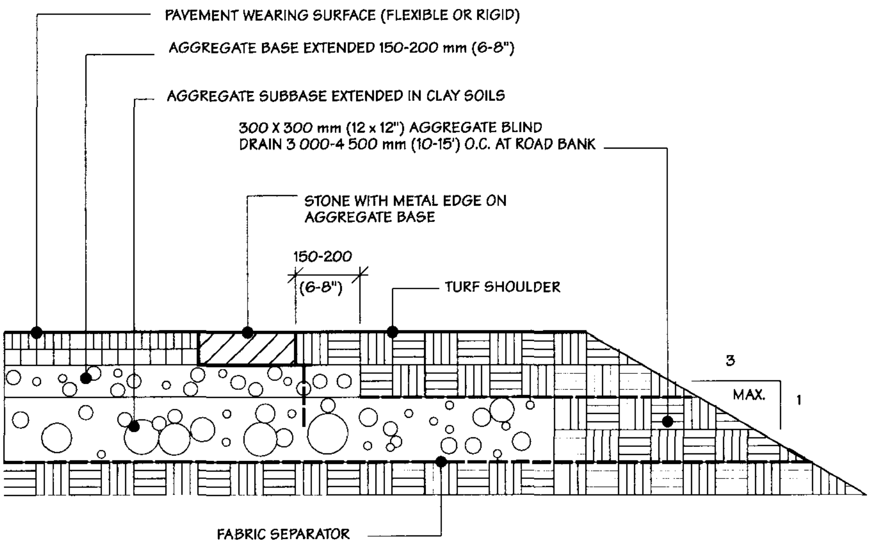
1. The subgrade must be prepared to achieve a smooth uniform surface which typically is graded to slope parallel to the proposed finish grade.
2. Aggregate base material is typically placed in 100-150 mm (4-6 in) lifts for pedestrian pavements, and 150-200 mm (6-8 in) lifts for vehicular pavements. Preparation includes spreading, rolling, and vibrating to create firm consistent bearing density.
3. Flexible paving transfers loads more directly to the subgrade and therefore require thicker aggregate bases than comparably loaded rigid pavements.
4. Flexible pavements perform well in cold climates due to their ability to move uniformly with frost/thaw cycles, and the lower maintenance associated with mortarless unit paver construction.
5. Porous pavements are commonly limited to well-drained subgrades. Porous unit pavers may perform more effectively in cold climates than porous asphalt due to the high potential for clogging from seasonal sanding.
6. Pavement edges are typically reinforced by extending the aggregate base and subbase, thickening the pavement edge, or by the addition of metal, plastic, or stone restraining devices. Unit pavers require restraining edging in all installations to prevent creep, and to provide structural reinforcement (Refer to Figures 440-14 and 440-15).
7. Fabric separator reinforcing is typically applied to the subgrade in wet clay circumstances to help bind the aggregate, prevent upward migration of fines due to pumping, and to add tensile resistance to subgrade deformation (Refer to Figure 440-15).



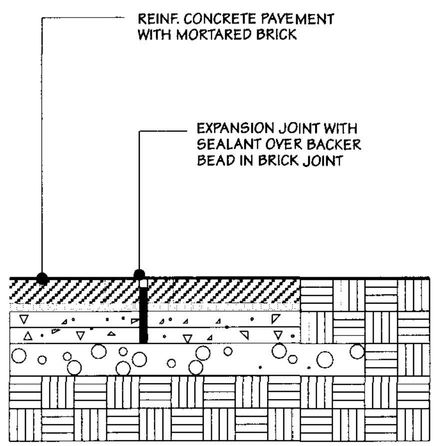
A. TAPERED EDGE



A. CONCRETE EXPANSION JOINT



A. CONTAINED EDGE



A. MORTARED BRICK EXPANSION JOINT

Figure 440-15. Edge treatment in clay soil conditions. *(A) Subdrain is placed at the subbase edge, and fabric reinforcement is placed on the subgrade and around pipe trench. (B) A flat edging stone is used to avoid need for a vertical curb trench, and periodic blind drain stone trenches relieve water pressure from the subbase.*

Figure 440-16. Expansion joint in concrete (A) and mortared brick (B) pavement. *Both details require joint sealant to prevent moisture and debris from entering the filler material, especially in (B).*

Edge Thickening:

In sandy coastal regions subject to wind erosion, pavements may be thickened at the edge to prevent undermining. Concrete slabs may be turned down and asphalt paving may be thickened using an extra base course. Thickened edges may range from 200-300 mm (8-12 in) in width.

Edge Restraint:

Edges of flexible pavements may be reinforced with wood, steel, stone, or masonry curbs (raised or flush) for additional lateral support. Such restraining and containing devices are affected by heaving action of clays and frost/thaw cycles. Heavy wooden stakes should be avoided in these circumstances. Metal "L" channels and polymer triangular profile devices, which are designed to float atop the aggregate base and which are secured with long nails or pins, are a better alternative for restraining pavement edges in all climates.

Clay Soil Strategies:

Figure 440-15 illustrates special edge detailing in moist or expansive soils, where the subgrade is sloped toward subdrains to ensure proper drainage. It is best practice to locate the subdrain outside of the aggregate base load bearing area. Alternatively, the subbase may be drained using aggregate blind drains set at regular 3 000-4 500 mm (10-15 ft) intervals to relieve infiltration water pressure which typically enters the subbase at the pavement edge. All such drains are typically wrapped with fabric separator to prevent silting. In highway applications, the subbase shoulder may be extended to $^1/_3$ of the total road width to prevent edge infiltration. Edge details in clay soils should avoid trenching required of vertical curbs, and should instead use edging which has a flat bottom profile to avoid interrupting the lateral flow of subbase moisture. (Refer to Division 900: Details and Devices, for several examples of paving edges, curbs, joints, and dividers).

2.5 Pavement Joints

Rigid pavements require expansion and control joints to allow for contraction and expansion due to temperature fluctuations. Such joints may be butted, doweled, or keyed using pre-molded expansion joint fillers. All such expansion joints should be sealed with a bonding liquid filler to avoid moisture penetration and deposition of fine sands and silts during contraction periods. Sand accumulation in the joint, may inhibit its expansion capacity, resulting in pavement buckling. Local practices vary (Refer to Section 830: Concrete for details). Expansion joints must be expressed in mortared unit pavers to allow for true base slab isolation. Typically a flexible polymer backer rod is positioned within the unit paver expansion joint cavity and sealed with a liquid waterproof sealant. Figure 440-16 illustrates typical expansion joints in concrete and mortared brick pavements respectively.

Flexible pavements often abut rigid pavements and are subject to differential settlement. A properly prepared aggregate base reinforced with a fabric separator on the subgrade is useful in preventing compression of the flexible pavement support structure at the joint, especially in vehicular loading circumstances. Differential settlement may be minimized when joining two different flexible pavements by maintaining a common pavement thickness so that a common aggregate base may be used to support both finishes. If this is not possible, an intermediate material may be required to serve as an edge for each pavement type.

3.0 PAVEMENT DESIGN CRITERIA

3.1 Application

Load-Bearing Ability:

Heavy, medium, and light duty applications generally refer to the type of vehicular and pedestrian traffic which a pavement must accommodate. Heavy duty pavements are capable of accommodating vehicles, including trucks and buses typically found in city centers, institutions, large parks, and arterial highways. Medium duty pavements are capable of accommodating heavy pedestrian traffic and associated light service vehicles associated with institutions, private drives, parks, and light commercial settings. Light duty pavements are typically associated with residential and restricted public garden paths and plazas.

Table 440-2 illustrates typical loads associated with various uses and design contexts. Typical site scale developments require pavements that accommodate loads from 900 to 2 700 kg (2000 to 6000 lb). Institutional walkways that provide emergency or maintenance vehicle access, require pavements that may accommodate loads from 900 to 1 800 kg (2000 to 4000 lb), with adequate edge reinforcement. Such loads can be supported by 40 to 75 mm ($1^1/_2$ to 3 in) of asphalt concrete on a 100 to 200 mm (4 to 8 in) aggregate base, or by 100 to 125 mm (4 to 5 in) of reinforced concrete on a 100 to 150 mm (4 to 6 in) aggregate base. Soil bearing ratings should fall within a CBR (California Bearing Ratio) of 40-70 (Refer to Section 810: Soils and Aggregates).

Durability:

Pavement design must accommodate sustained pavement loading as well as maintenance methods and natural weathering effects. Cold climates require pavements that are able to withstand the chemical and abrasive maintenance methods used in snow removal. Hot-humid and hot-arid climates require pavements to withstand extreme daily temperature differentials and sustained wetness. Material porosity, density, hardness or flexibility, color, and finish are all characteristics which determine climatic compatibility and long-term durability. Appropriate structural design and detailing may extend a pavement's effectiveness.

Safety:

Both vehicular and pedestrian pavements are required to be universally accessible according to the standards set forth by the Americans with Disabilities Act, and are therefore constrained by texture, joinery, slope, drainage, and associated site furnishings. Pavement color and finish are also constrained by reflectivity, glare, and permeability as they relate to climate setting (Refer to Section 240: Outdoor Accessibility).

Aesthetics:

Proper pavement design aims to achieve structural stability, environmental appropriateness, and cultural utility while at the same time complimenting the overall design in a way that is aesthetically pleasing. Figure 440-17 illustrates several commonly used paving patterns achievable through both flexible and rigid paving systems. Care must be taken to keep patterns and textures in scale with the larger design to avoid inappropriate complexity or blandness. Long term maintenance should be a major factor in determining final finishes and textural treatments to insure that the design intent may be properly maintained. Where limited resources are available, it is best to simplify to achieve a consistent overall appearance.

3.2 Climate

Regional climate factors of daily temperature extremes, precipitation rate and frequency, and frost/thaw cycles heavily influence pavement details and finishes.

Hot Arid: A wide variety of materials are available in this climate zone. Materials are typically light in color to avoid heat absorption, and may include glazed tiles and porous finishes due to low humidity and relatively stable temperature ranges.

Hot Humid: Drainage is critical to prevent build-up of mosses and algae, and to account for intense periods of precipitation. Light colors are often used to avoid heat absorbtion. Stable temperatures provide for a wide variety of materials.

Temperate: Darker colors are typical to absorb radiant solar energy. Frost/thaw cycles require care in aggregate base preparation and subdrainage. Heavy snow regions must account for abrasive clearing practices. Mortared unit pavers require heavy maintenance in extensive applications.

Cold: Cold climate areas require similar treatments as the temperate zone, but with more restrictions. Flexible pavements are preferred over rigid and mortared unit pavers. Reinforcing steel must be placed carefully to avoid damage through chemical assault, or extreme expansion coefficient differentials within concrete slabs and curbs.

3.3 Subgrade

Well drained or clay subsoils, rooftop gardens, or other unique site subgrade features play a significant role in determining a structural pavement design strategy.

Well drained soils: These soils are ideal for construction with regard to permeability and bearing capacity, and typically require only normal site preparation to serve as pavement subgrades.

Clay soils: These colloidal soils are subject to swelling due to moisture infiltration and have a high potential for lateral shearing. Vibration from vehicular loading may produce a pumping action resulting in upward migration of fines into aggregate bases. Freeze/thaw actions create severe construction problems requiring dewatering, extra aggregate and fabric filtration and reinforcement.

Roof structures: Pavement design is highly restricted due to loading and drainage requirements. Special drain mats and insulation are typically required under finish pavement surfaces (Refer to Section 610: Roof and Deck Landscapes for more information).

3.4 Cost and Maintenance

Cost:

Initial installation cost is a function of material cost, labor, business overhead and profit required to install the pavement and associated support structures. Long term cost is a function of length of service, annual maintenance requirements, and replacement value. Generally, costs are lower for simple one or two layer paving systems which require minimal edging, low cost material, and fewer labor and equipment operations. Conversely, multi-layered pavements constructed of durable expensive materials which require multiple operations, cost more than do most simple pavements. Every layer and associated operation carries a discreet cost per m² (ft²). Cost therefore may be considered as equal to the sum of each layer installation cost per m² (ft²). Examples of such layers or operations are:

1. Three sheep foot roller subgrade passes
2. Aggregate subbase per 150 mm (6 in) lift with three passes
3. Dense graded aggregate base per 100 mm (4 in) lift with two passes
4. Sand base per 100 mm (4") of sand vibrated with four passes
5. Mortar setting bed per 25 mm (1") depth, etc.

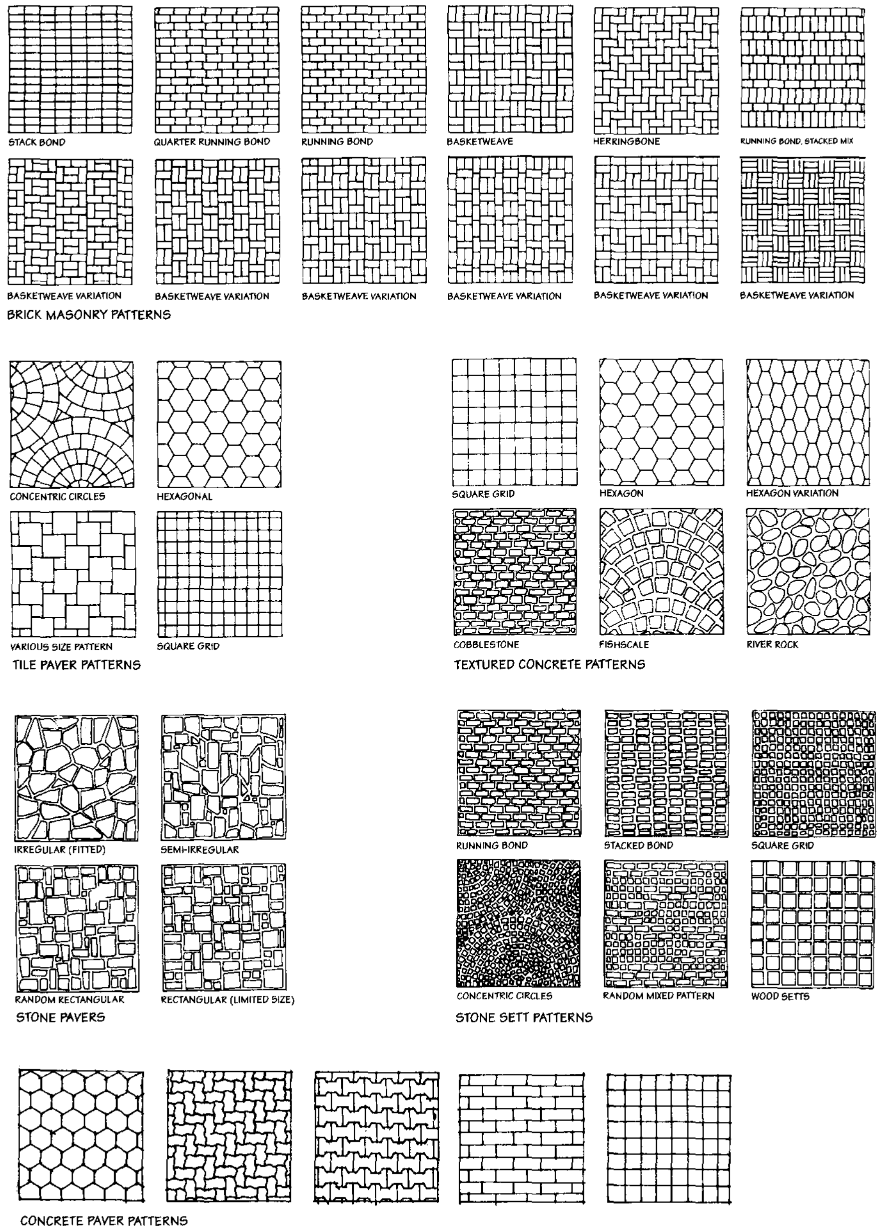


Figure 440-17. Commonly used paving patterns for both flexible and rigid paving systems.

Table 440-3. PAVEMENT CHECKLIST OF ADVANTAGES AND DISADVANTAGES OF VARIOUS PAVEMENT TYPES

TYPE OF PAVING	ADVANTAGES	DISADVANTAGES
In-situ Paving		
Concrete	• Relatively easy to install • Available with several finishes, many colors and various textures • Durable surface • Year-round and multiple usage • Low lifetime maintenance costs • Long-lasting • Low heat absorbency • Hard, nonresilient surface • Adaptable to curvilinear forms	• Joints are required • Some surfaces are aesthetically unappealing • Can disintegrate if not properly installed • Difficult to color evenly and permanently • Light color is reflective and can cause glare • Some types can deteriorate from deicing salts • Relatively low tensile strength: can crack easily • Low resiliency
Asphalt	• Low heat and light reflectivity • Year-round and multiple use • Durable • Low maintenance costs • Dust-free surface • Resiliency can vary depending on mixture • Water repellent surface • Adaptable to curvilinear forms • Can be made porous	• Will fray at edges if not supported • Can soften in warm weather • Soluble by gasoline, kerosene, and other petroleum solvents • Susceptible to freeze damage if water penetrates base
Synthetic Surfacing Systems (proprietary)	• Can be designed for a specific purpose (e.g., court games, track) • Wide color range • More resilient than concrete or asphalt • Sometimes can be applied over old concrete or asphalt	• Specially trained labor may be required for installation or repair • More costly than asphalt or concrete
Unit Paving		
Brick	• Nonglare surface • Nonskid surface • Wide color range • Good scale • Easily repaired	• High installation cost • Difficult to clean • Can disintegrate in freezing weather • Susceptible to differential settlement • Efflorescence
Tiles	• Polished indoor/outdoor appearance	• Suitable only for milder climates • High installation costs
Adobe Bricks	• Fast and easy installation • Can last indefinitely if base contains an adequate amount of asphaltic stabilizer • Rich color and texture	• Tend to crumble at the edges • Store considerable amounts of heat • Fragile; require level foundations (fracture easily) • Dusty • Suitable only for warm and nonhumid areas
Flagstones	• Very durable if properly installed • Natural weathering qualities	• Moderately expensive to install • Might seem cold, hard, or quarry-like in appearance • Color and random pattern sometimes difficult to work with aesthetically • Can become smooth and slippery when wet or worn
Granite	• Hard and dense • Very durable under extreme weathering conditions • Will support heavy traffic • Can be polished to a hard gloss surface that is durable and easily cleaned	• Hard and dense; difficult to work with • Some types are subject to a high rate of chemical weathering • Relatively expensive
Limestone	• Easy to work with • Rich color and texture	• Susceptible to chemical weathering (especially in humid climates and urban environments)
Sandstone	• Easy to work with • Durable	• Susceptible to chemical weathering (especially in humid climates and urban environments)
Slate	• Durable • Slow to weather • Range of colors	• Relatively expensive • Can be slippery when wet
Molded Units (synthetic)	• Can be designed or selected for various purposes (i.e., firm, soft) • Short installation time • Easy installation, removal, and replacement usually without specialized labor • Wide color range	• Subject to vandalism • Higher installation costs than asphalt or concrete
Soft Paving		
Aggregates	• Economical surfacing material • Range of colors	• Requires replenishment every few years depending on amount of use • Potential for weeds • Requires edging
Organic Materials	• Relatively inexpensive • Compatible with natural surroundings • Quiet, comfortable walking surface	• Suitable only for light traffic • requires periodic replenishment or replacement
Turfgrass	• Colorful • Nonabrasive • Dust-free • Good drainage characteristics • Quiet, comfortable walking surface • Ideal for many types of recreation • Relatively low installation costs	• Difficult and expensive to maintain, especially in areas of heavy use
Turf Blocks	• Same as turf alone but has added stability to withstand light vehicular loads	• Requires high levels of maintenance (frequent watering, etc.)
Artificial Turf	• Same as turf surface • Can be used sooner after rains without wet spots • Allows flat grading of playing surface • Available with built-in markings, etc. • No irrigation or maintenance problems as with natural turfgrass	• Results in a higher number of player injuries (regarding field sports) • Results in faster and higher ball roll and bounce • Initial installation costs higher than natural turfgrass

* No one surface will meet the needs of all outdoor activities. Each activity has its own surface requirements.

Table 440-4. BASIC PROPRIETARY PAVEMENT SURFACES AND COATINGS

Category of Use (Generic Names)	Comments on Material and Ranges of Uses	Proprietary Names and Sources
Synthetic Emulsions		
Bonding Agents	Specialized compounds used to bond one material to another, i.e., waterproof membrane to roof slab.	There are too many trade names and manufacturers to attempt to list here
Cushion Coats	Special compounds of rubber granules, acrylic polymer with elastomers, and resin particles or fibers. Manufacturers recommend thickness of number of layers for various purposes.	Plexicushion ® by California Products Corp. Elasta Cushion ® by Julicher Athletic Engineering & Constructors
Wearing or Weathering Surfaces	Special compounds put over cushion coat or other materials to improve resistance to wear and weathering. Typically, several layers are needed and finish color and texture are incorporated into these.	Cushion court ® by Julicher Athletic Engineering & Constructors Flexipave by California Products Corp. Aristrak or Asitex ® by Athletic Surfacing International Acrylo-Kote ® by Koch Asphalt Co.
Striping, Painting, or Resurfacing	Special compounds or paints used by hand or machine to create striping or for adding color for other purposes	Plexicolor, Acrylic Line Paint, or Acrylic Resurfacer ® by California Products Corp. Acrylo-line Paint ® by Koch Asphalt Co.
Synthetic Surfacing Systems	A combination of synthetic materials placed in layers with each layer serving a distinct function to form a final specified surface.	Asitrak ® by Athletic Surfacing International Acrylic Surface by Koch Asphalt Co.
Pre-formed Materials		
Artificial Turf	Developed to provide a substitute for natural turf. It is generally made of nylon or other synthetics.	Astroturf ® by Monsanto Co. All-pro Turf ® by All-Pro Athletic Surfaces Courturf ® by Julicher Athletic Engineering & Constructors
Artificial Ice	A synthetic material used as an alternative to natural or refrigerated ice. For ice or roller skating, certain court games, dancing, etc.	Lenn-ice ® by Julicher Athletic Engineering & Constructors
Synthetic Units or Sheets and Rolls	Molded modular sheet material used to create hard surfaces for court games, track, decks around pools, etc. Can be made porous to permit drainage.	Multideck ® by Julicher Athletic Engineering & Constructors Duragrid ® by Duragrid Inc. Sportan ® by Sportan Surfaces Inc. Cal-trak, Plexicourt, and Plex-tac ® by California Products Corp.

KEY POINTS: Pavement Design Criteria

Landscape design context often determines the types of pavements required for specific applications with regard to loading and wearing requirements (Refer to Figures 440-1 through 440-9).

1. Walkways requiring occasional vehicular access for service should be designed with aggregate bases sufficient to support 900-1800 kg (2000-4000 lb) (Refer to Table 440-2).
2. Special maintenance procedures such as sanding, salting, and plowing in cold climates can rapidly deteriorate some pavement types. Pavement selection should be limited to those types resistant to such stresses.
3. Pavement surfaces, edge transitions, and slopes must conform to local codes and handicapped accessibility regulations.
4. Complex and highly refined pavement installations typically require specialized maintenance equipment and procedures to protect the aesthetic integrity of the design. It is advisable to simplify the design if such resources are unavailable.
5. Short term installation costs and long-term maintenance costs must be balanced to determine the true cost of a pavement per m^2 (ft^2).
6. Each pavement material has advantages and disadvantages for any particular application with regard to climate restrictions, human comfort, reparability, cost, ease of installation and care (Refer to Table 440-3).

Pavement costs must be analyzed on both a short-term and a long-term basis. Cost factors include initial installation, ongoing maintenance, durability, and reparability. For instance, a non-unit or rigid pavement that is difficult to repair is seldom a good choice in areas subject to frequent maintenance damage, or where access to underground utilities, etc., may be required.

Embodied energy, or the total amount of energy required to produce and to transport a particular material is an additional measure to consider in total cost calculation. Ideally, a pavement with a high degree of embodied energy, and a high initial installation cost should also possess a long service life potential.

Maintenance:

The actual cost of a pavement must factor in the annual maintenance cost. Often, a higher initial installation cost may result in a lower annual maintenance expenditure. Additionally, the service life of a less expensive installation may be short, requiring complete replacement within a brief 8 to 10 year period in severe conditions. It is prudent to invest in proper site preparation and aggregate base installation, due to their critical role in maintaining finish surface integrity. It is less prudent to place a high quality finish material over an inadequate, or less expensive aggregate base and subgrade specification.

Annual maintenance for pavements typically requires periodic coatings, pointing, cleaning and sealing of joints, repair of broken segments or settled areas, re-setting of unit pavers, and general sweeping to remove accumulated fines and debris. Unit paving typically requires more attention to maintenance of edges and vegetative invasion, but is easily repaired. Monolithic paving commonly requires less annual maintenance than does flexible unit paving.

Long-term maintenance involves such cost considerations as reparability, specialized equipment requirements (sweepers, washers, etc.), and periodic cleanings, and coatings. Embodied energy and transportation costs represent a broader perspective on long term life-cycle costs. It is recommended that local and recycled materials be given priority over materials imported from other regions (Refer to Section 230: Energy and Resource Conservation).

4.0 MATERIAL SELECTION

Table 440-3 lists the advantages and disadvantages of various types of pavement. Each type has both advantages and disadvantages which vary by climatic region and use intensity. Specific activity requirements and legal regulatory agencies may restrict choices in many public and private circumstances.

Divisions 800: Materials, and 900: Details and Devices, contain technical data on various materials and their application in pavement construction.

A number of key proprietary surfaces are briefly described in Table 440-4, grouped according to categories of use. These materials are normally purchased in ready-mixed or manufactured form and sometimes require installation by licensed contractors.

The variety of proprietary products available and their range of application continues to expand and to change. Trade and technical review journals, and proprietary manufacturers' literature and Internet sites are important information sources .

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SECTION 450

Fences, Screens, and Walls

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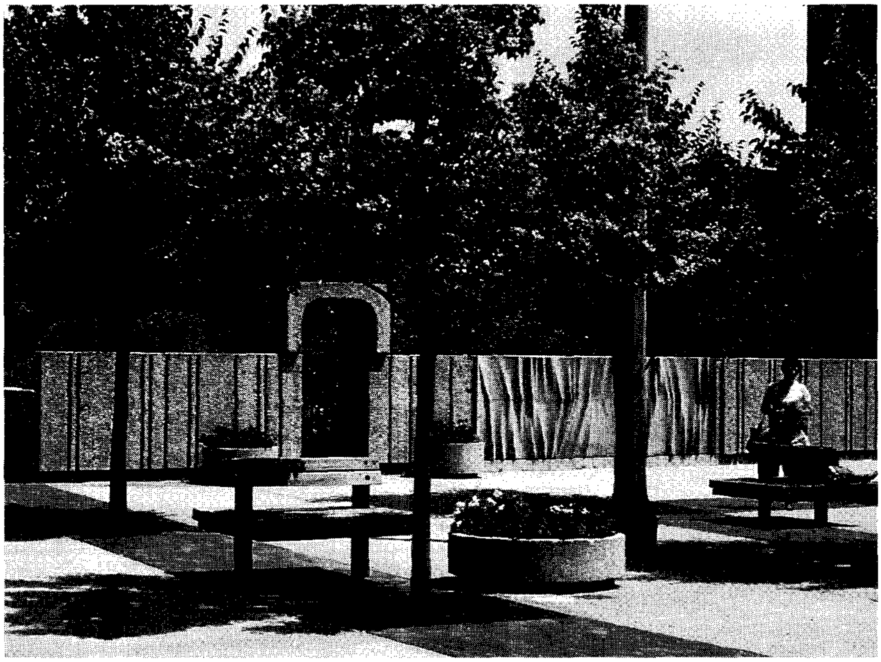

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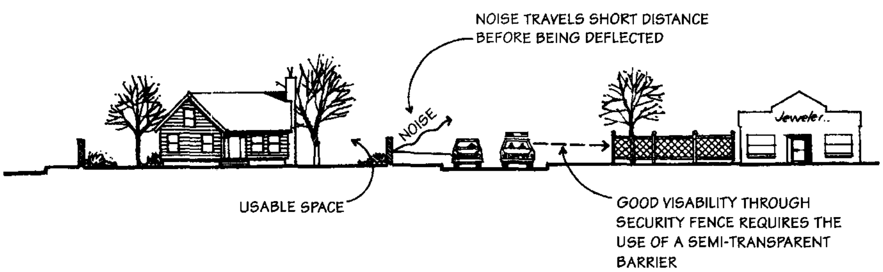

Figure 450-1. Placement of privacy barriers.

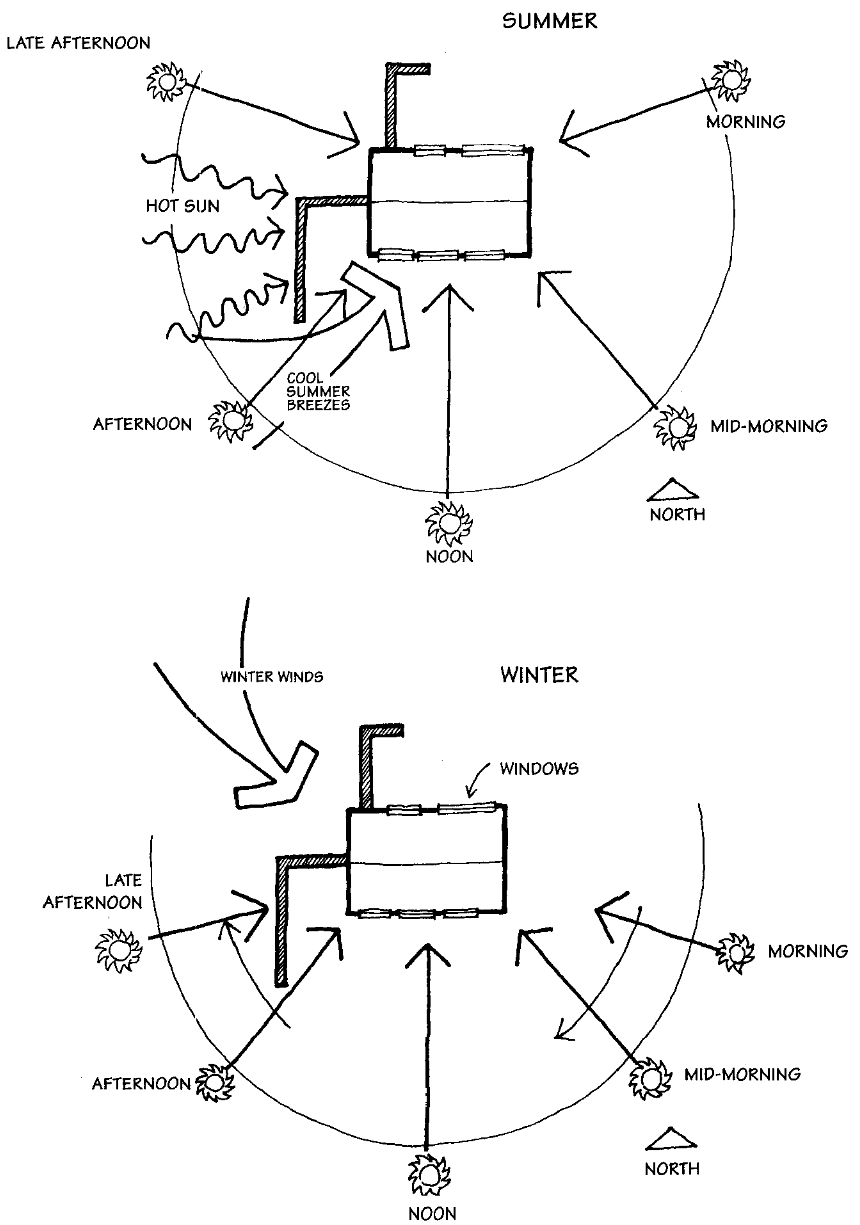

Figure 450-2. Barriers for environmental modification. *Fences, screens, and walls can be used to alter microclimatic qualities of a space in several ways. Example here refers to the northern hemisphere.*

1.0 INTRODUCTION

1.1 General

This section focuses on the basic principles and techniques of selecting, designing and constructing fences, screens, and walls typically found in a variety of site development settings. Major design considerations, structural components, and methods of construction for fences, screens, and walls are provided.

1.2 Design Process

Program requirements: Determine the purpose and use of the proposed barrier, and the degree of exclusion and transparency required, as described in 1.3 Design Considerations.

Schematic Design: a). Determine barrier location, type, size, and style; b). Identify climate modifications and general construction methods; and c). Formulate data to support the design recommendations. Planting and grading should also be considered as an alternative means of providing visual screens and physical barriers where space permits.

Sizing, selection of materials: Walls are often designed from the top down, (i.e., determine wall widths, veneers and cap sizes first, and size footing last based on soil conditions, design loads, and local codes.) Wall and fencing materials may be selected based on availability, and capacity to match the local site and architectural character.

The span between posts or piers determines the size of both wood and metal fencing rails and supports. Plant material should be selected based on existing soil conditions, exposure, hardiness zone, mature height and spread, maintenance requirements, and seasonal interests.

Layout: The layout should be coordinated with utilities, grading and planting plans. Planting and/or grading can accomplish the same purpose as a fence or wall, may be more economical to construct, and require less long-term maintenance. Barriers should disturb drainage patterns only after careful consideration of run-off consequences. Ideally, drainage should be directed away from barrier footings and posts to reduce potential damage to the structural elements.

Details and Refinement of Design: Non-structural features such as fence or wall caps, post tops, wall veneer patterns, and fence picket shapes should be refined and included in the final stage of the design process.

1.3 Design Considerations

The design of barriers should respond to both functional requirements and aesthetic qualities of the site and surrounding development. These factors require careful consideration at the outset of the design process.

Fence and Wall Purposes:

The relationships between typical fence and wall applications, physical design, and visual character are described below.

Privacy: Privacy requires a degree of protection against visual and/or physical intrusion. The extent of privacy desired and its context will greatly influence the design and materials used for privacy barriers. The most effective privacy barrier is often a high, solid barrier as close as possible to the source of intrusion (Figure 450-1).

Safety and Security: Barriers can discourage deliberate trespassing, keep people away from such potentially dangerous items as mechanical equipment, electric transformers, or swimming pools, and keep children and/or animals in safe areas.

Transparent or semi-transparent barriers are sometimes preferable to completely solid barriers because they permit supervision from either side by property owners, police, or security personnel. Solid barriers should be truly impenetrable, to prohibit intruders.

Boundary Definition: Fences and walls are commonly used to define boundaries and to prevent or discourage trespassing.

Circulation Control: Barriers can control and direct the movement of people, animals, or vehicles. Low walls can channel or direct pedestrian traffic, but walls should be designed to discourage unauthorized or unsafe shortcuts. It is often desirable to see over a wall or fence to know what is ahead or what may be approaching. A gate or portal can be designed to be intentionally uninviting, or designed as a symbolic entryway, inviting people into a space.

Environmental Modification: Barriers can reduce or eliminate heavy winds, noise, drifting snow, glare, and strong sunlight. Strategically placed windbreaks and shaded areas can reduce the energy required for heating and cooling (Figure 450-2). Snow fences can control drifting and thus mitigate snow removal problems. (Refer to Section 260: Climate and Energy, for specific information on modification of microclimate, etc.)

Aesthetics: Fences, screens, or walls can often complement their architectural surroundings by extending the lines of a building out into the landscape. They can also be used to dramatize selected views, form backdrops for specific settings, or add interest to an otherwise featureless or monotonous landscape. In most cases, fences or walls should be visually attractive on both sides.

Design Criteria:

Type, size, and material selection will be determined by the purpose of the barrier. The nature of the barrier will be influenced by the following design considerations:

1. Whether the barrier is an aesthetic feature, a practical boundary, or both
2. Whether the barrier provides a strong sense of privacy or security
3. Whether the barrier is solid or allows some degree of visual accessibility
4. Whether the barrier is in harmony or in contrast with other features
5. Whether areas near the barrier are planted
6. Whether planting is heavy or only for accent

Site Context:

Design objectives for fences, screens, and walls need to be interpreted relative to the larger site context. For instance, security for a factory or a retail store would normally require far more elaborate solutions than security for a home. A solution would also be different in a city than it would be on a large suburban or rural site.

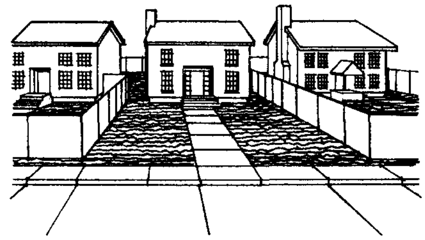

Figure 450-3. Problem of off-site impacts. *In this example, a residence is fenced in, contrary to desires.*

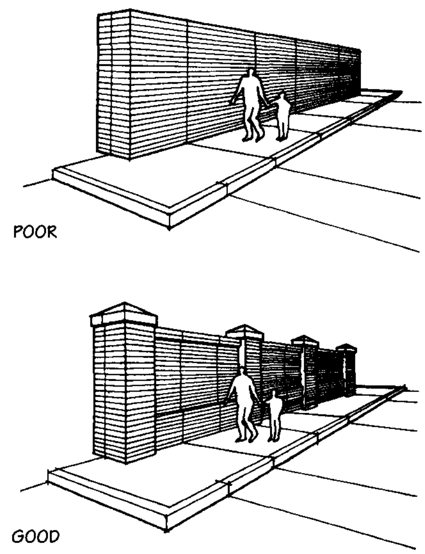

Figure 450-4. Providing human scale with large walls. *Reduction of apparent scale of a wall by use of textures, shadow lines, and articulation of details.*

KEY POINTS: Design Considerations

Design layout requires accurate site survey showing all property lines, easements, contours, significant vegetation, drainage, and buried utilities to insure compliance with all codes and regulations. Seasonal wind patterns and off-site noise requiring attenuation should be plotted.

1. Privacy, safety and security, and environmental modifications typically require barriers to be 1 800-2 100mm (6-7 ft) high, and are often opaque or finely slatted.
2. Circulation control and boundary definition are often low or semi-transparent barriers with well defined gates or portals.
3. Gates should allow some visual penetration if used as a main entrance, often marked by a change in plane, lighting, or other design features.

Off-Site Impacts:

Poorly styled or improperly built fences, screens, or walls can detract from the appearance of adjacent properties, become a nuisance for neighbors by blocking views, cut off desired local breezes, or create unwanted shade (Figure 450-3). Large walls can alter stormwater runoff patterns on neighboring sites and create annoying ponding or saturation problems. All potentially adverse off-site impacts need to be assessed during the design stages, well before any construction begins.

Design Expression:

Choosing a basic fence, wall type, or planting screen is only the first step in developing a successful design solution. Design elements and details which make up the barrier must also be carefully developed and coordinated.

Compatibility: The design of a fence or wall should respond to its landscape context and adjacent architecture. Compatibility can be enhanced by using the same or similar materials, colors, textures, details, and proportions of nearby buildings, streetscape elements, and plant materials.

Scale: Large barriers can be scaled down to relate to human scale by the use of textures and shadow lines, and by the articulation of individual elements, such as posts, panels, rails, and caps (Figure 450-4).

Proportions: The relationship of the height to the width of panels, post sizing, etc., should be carefully scaled to respond to the established design expression of major horizontal or vertical elements nearby. Consider fenestration, doorway proportions, building heights, walls, or other architectural articulations.

Rhythm: The line created by a barrier should be consistent with other lines in the landscape. The rhythmic use of such elements as posts, slats, or panels can affect the perceived size or scale of a barrier through the use of textures, shadow lines, and articulation of details, especially with regard to perception from a moving vehicle.

Color: Lighter colors tend to call attention to the individual elements of a fence or wall, while darker colors appear to unify the appearance. The number of colors used in a barrier should be kept to a minimum.

Texture: The type of materials used and the kind of finish selected will affect the texture of the barrier. The distance between the barrier and the observer, and the speed of the observer (i.e., in a moving vehicle) are major factors to consider.

Legal and Code Requirements:

A proposed barrier or screen must comply with all relevant legal and building code requirements, including:

Boundaries: Property lines should be precisely determined to prevent possible legal disputes. If necessary, a boundary survey should be performed by a registered surveyor. Deed restrictions should also be reviewed for potential design limitations.

Easements: Utility and drainage easements across a site generally preclude using those areas for permanent walls or fences, but non-permanent or moveable features are usually permitted.

Fire Lanes and Police Surveillance: Fire and police departments require readily identifiable, barrier-free access to certain types of sites. For instance, they require easy access to mid- or high-rise buildings and to buildings or areas where potentially hazardous materials are stored.

Permits and Codes: Permits are required for fences and walls beyond a certain height or length in most circumstances. Design minimums or other performance standards for structural integrity, safety, or visual quality may also be included in local building codes. For instance, barriers are mandatory for site facilities such as swimming pool areas, which generally must be enclosed by a fence or wall of a specified height and type.

Design Controls and Covenants: Covenants, local legal, or quasi-legal regulations may exercise control over the choice of materials and colors and even on the design expression and placement of fences, screens, and walls.

Feasibility:

The feasibility of a proposed barrier should be studied based upon the following factors.

Availability of Materials, Labor, and Equipment: If a particular type of barrier is chosen, the necessary materials, labor, and equipment needed for construction should be readily available at the price estimated.

Costs: Budget decisions about fences or walls should be based upon a careful assessment of both short-term and long-term costs. The initial construction cost of building a fence will fall about halfway between the cost of a planted barrier and a masonry wall. However, fences cannot perform all of the tasks that walls can, and their costs may vary greatly according to the type of material used, the amount of detailing involved, and the skill of the labor needed to build and maintain them. Furthermore, the long-term maintenance and replacement costs for brick or concrete are much less than for wooden fencing or screening.

Maintenance Responsibility: The feasibility and ultimate selection of a barrier design should reflect the available maintenance personnel and budget required to maintain the barrier properly over the expected life of the structure or planting.

KEY POINTS: Design Criteria

1. Site Context and off-site impacts are key considerations in determining barrier type, size, and material. Adjacent architectural styles, scale, drainage patterns, topography, and sight lines are key considerations.
2. Lighter colors tend to emphasize the barrier structure while darker colors tend to recede and blend into the landscape.
3. Most sites are highly constrained by legal regulations regarding setbacks, dimensions, and in some cases, materials and colors.
4. Low initial costs should be balanced against annual maintenance costs and eventual replacement. A more permanent screen may require a heavier initial investment.
5. Maintenance access should guide design layout and materials selection to provide ease of routine maintenance on both sides of the barrier.

Time: Some types of barriers require more time to construct than others. This can be an especially important consideration on a large project where the construction deadline is short, or where immediate results are required.

2.0 CONSTRUCTION METHODS AND DETAILS

Typical components for all types of fences and walls, including gates, are presented below. A structural engineer or contractor familiar with local conditions, code requirements and standard practices should be consulted for major structures (such as high masonry walls) in difficult soil conditions.

2.1 Footings and Foundations

Footing Depth:

The depth of a footing or foundation is based upon the following factors:

1. Structural stability (against storm winds, impact, abuse, etc.)
2. Weight of barrier
3. Depth of frostline
4. Local code requirements

The depth of the local frostline and local code requirements are the primary criterion regarding footing or foundation depth, (see Section 410: Retaining Walls, for data on the average depth of frost penetration for the United States). The bottom of footings should be a minimum of 50 mm (2 in) below the frostline to eliminate upward stresses on the structure. Natural stresses such as heavy winds, soil creep on steep slopes, or expansive soils may dictate even deeper footings or foundations.

Soil Conditions:

Extremely sandy, heavy clay, expansive or very wet soil conditions require special considerations. In some cases the existing soil may require replacement. (Refer to Section 410: Retaining Walls, for additional data from the Unified System of Soil Classification and relevant properties of each type of soil).

Drainage:

Freeze/thaw processes in cold climates can cause heaving of posts, footings, and foundations. Periodic or persistent flooding of low spots can accelerate heaving as well as cause decay of wooden posts and damage to footings or foundations. Surface water should not be allowed to collect adjacent

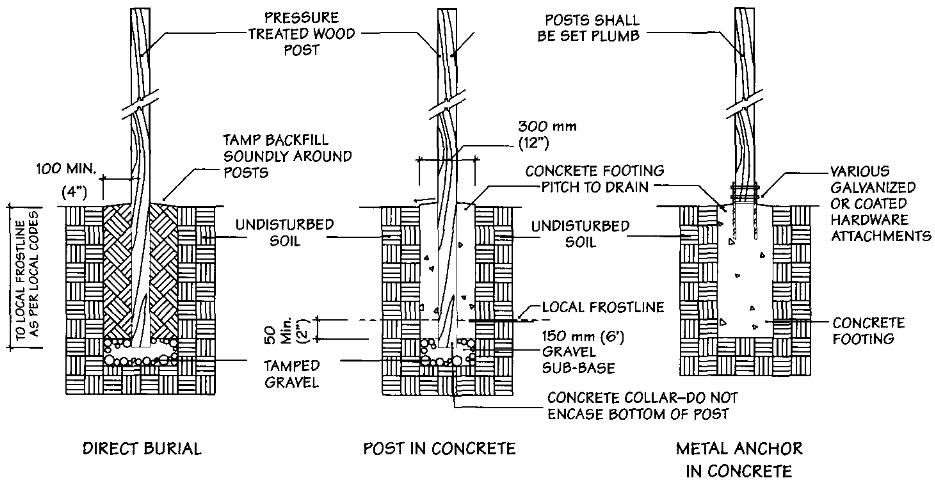

Figure 450-5. Typical post and footing details.

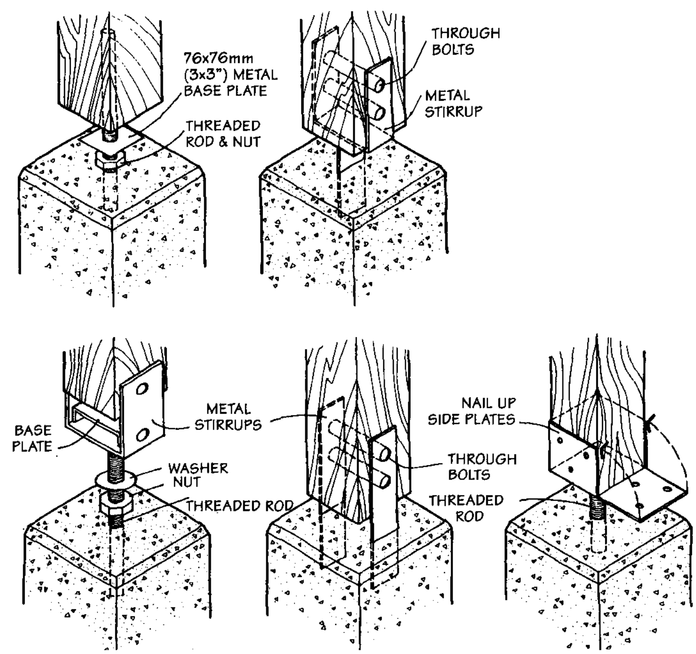

Figure 450-6. Typical post-to-footing connections.

KEY POINTS: Footings and Foundations

1. Top of footing for walls and masonry piers is typically set at 300 mm (1 ft) below finish grade in warm, non-frost areas, and below or at the frostline in cold regions to provide a safety factor equal to the footing thickness. At a minimum, bottom of footing should be set at least 50 mm (2 in) below local frost line (Check local codes).

2. Clay and fine textured subsoils may require deeper and wider footings to insure stability against lateral wind load stresses.

3. Continuous concrete wall foundations typically require steel reinforcing and masonry block walls usually have grouted and reinforced cavities to resist lateral wind loads on the exposed wall and piers above.

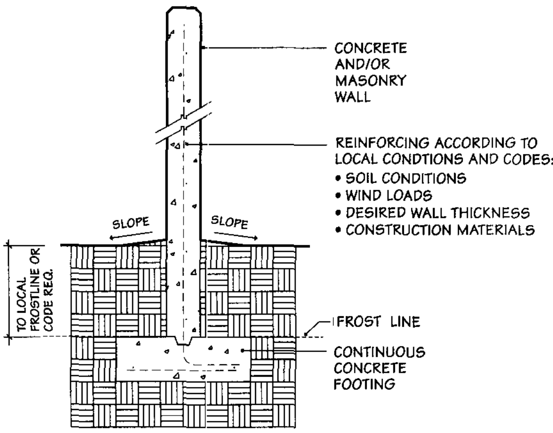

Figure 450-7. Continuous-footing construction.

to, and should be drained away from the base of fences, screens, and walls.

Posts and Footings:

Wooden fence posts are typically 100 x 100 mm (4 x 4 in) with 150 x 150 mm (6 x 6 in) posts at corners for added stability. Various methods are employed to set posts in the ground (Figure 450-5). In some cases it is better to fasten wood or metal posts to concrete footings with standard fastenings (Figure 450-6). Decay-resistant wood or wood preservatives should be used.

Masonry walls require continuous footings which are generally constructed of cast-in-place reinforced concrete. The wall is then built upon these footings (Figure 450-7). Free-standing concrete and masonry walls are examples of rigid construction where any movement of the structure cannot be tolerated.

The exact size of the footing and amount of reinforcing will depend on soil conditions. Many codes require footings for non-loadbearing walls to extend a minimum of 150 mm (6 in) on either side of the wall. Generally, the size of the footing will not be less than 250 mm (10 in) deep by 400 mm (16 in) wide with two continuous reinforcing bars as required by site conditions.

Dry stone walls are an example of flexible construction, which can tolerate a certain amount of differential settlement without being significantly affected. Flexible walls do not typically require a base or footing that extends below the frostline if suitable bearing exists, such as undisturbed sub-soil or a prepared sub-base.

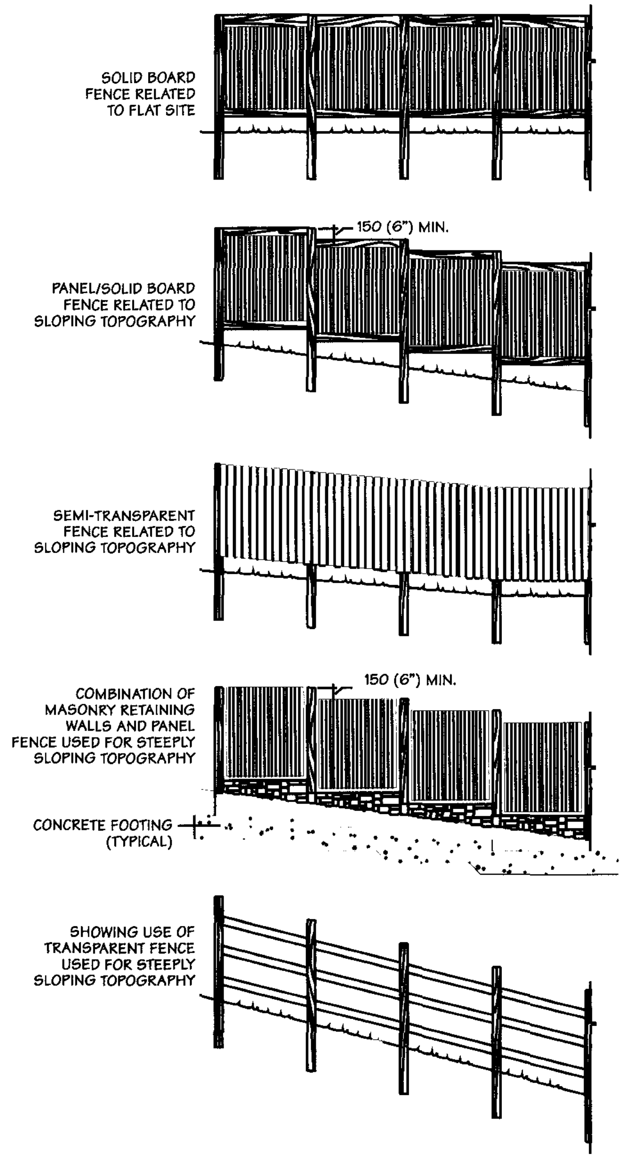

Figure 450-8. Methods for responding to terrain.

KEY POINTS: Post and Footings

1. Posts and piers in clay and fine soils may be subject to seasonal uplift in frost-thaw regions. Granular backfill and smooth concrete forms may prevent uplift (Figure 450-5).

2. Direct burial posts require treated or decay resistant wood. Posts attached to steel flanges and set in concrete piers provide the best long term results with regard to stability and routine maintenance or component replacement (Figures 450-5 and 450-6).

3. Post depth is typically calculated based upon soil type and wind loads. A minimum depth in normal conditions may be determined by adding 10% of fence height to 600 mm (2 ft). A 1 800 mm (6 ft) fence would require a minimum post depth of 750 mm (2 ft-6 in) or to frost depth, whichever is greater.

4. Horizontal post spacing and vertical steps on slopes should be regular for better visual effect in undulating landscapes (Figure 450-8).

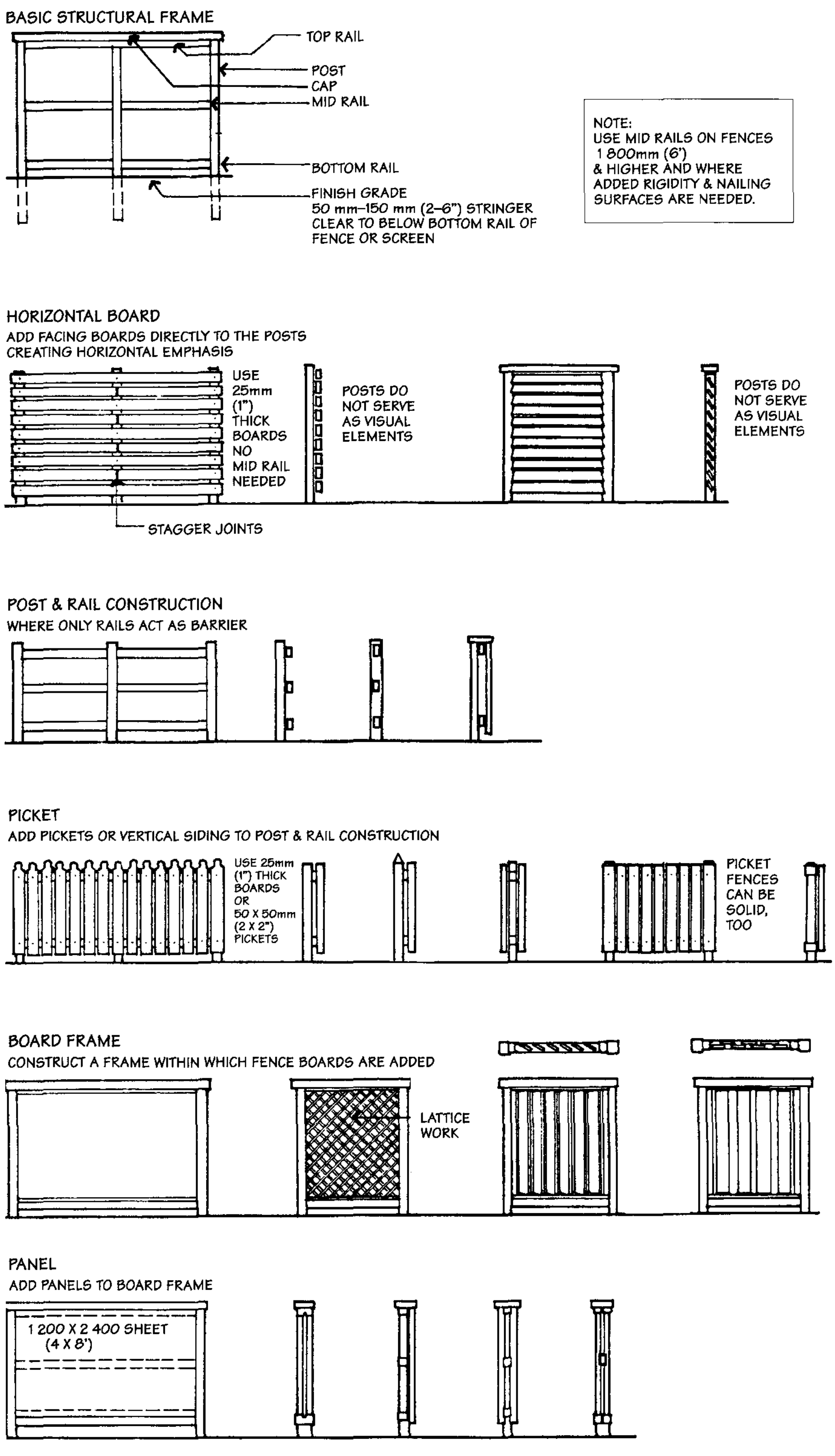

Figure 450-9. Various types of fence construction.

Wind Control:

A slat fence will only reduce wind velocity, whereas a solid fence will give wind protection on the side away from the wind for a distance equal to the height of the fence. A louver fence will reduce the velocity and alter the wind direction. A baffle at the top of the fence angled 45 degrees into the prevailing wind gives the greatest protection closest to the fence. A 45-degree baffle angled away from the wind directs the wind over the fence and creates a wider calm pocket on the leeward side of the fence. (Refer to Section 260: Climate and Energy, for more information.)

The effect of wind loads on fences is a function of how deep the post is set into the ground, and the properties and conditions of the existing soil. Normally, a fence is embedded in the ground at least one third of its height, for wind loads up to 147 kg/m^2 (30 lb/ft^2) or one half the height for loads over 147 kg/m^2 (30 lb/ft^2) for posts placed 2 400 mm (8 ft) on center.

Masonry walls will require additional vertical reinforcement in areas of potential wind damage. The Brick Institute recommends that for 49 kg/m^2 (10 lbs/ft^2) wind pressure, a straight brick wall should not be higher than $^3/_4$ of the wall thickness squared. A 200 mm (8 in) wide wall, for example, would be limited to a maximum 1 200 mm (4 ft) height. Reinforced concrete piers with a masonry veneer and wall offsets can also be used to strengthen walls and compensate for wind pressure. The exact size and spacing should be calculated relative to wind pressures, typical of the site.

Uneven Terrain:

Some types of fences and walls can run parallel to a sloping or rolling landscape, while others require some method of stepping down of panels between posts or piers. It is generally easier to step down a fence than a wall. Simple fences such as split rail or horse fences can easily adapt to the topography of the site. The stringers or rails are run parallel to the grade and the posts and pickets remain vertical. Pier and picket or panel fences are less flexible in structure and in detail. Careful measuring is required to insure that rails remain horizontal when stepping down a slope. Stepped sections are more formal and work best with wide fence members and bays of equal width. If the grade varies greatly, however, the height of the bay width and steps between bays will also vary and must be planned carefully to achieve a regular and orderly appearance (Figure 450-8).

2.2 Wooden Fences and Screens

Selecting Wood Materials:

The type, grade, and species of lumber for fencing will affect its cost, appearance, and short and long-term maintenance. Some wood species can be selected for insect and decay resistance, while others require protection with chemical preservatives. Heartwood typically has greater natural resistance to decay and fewer defects, than

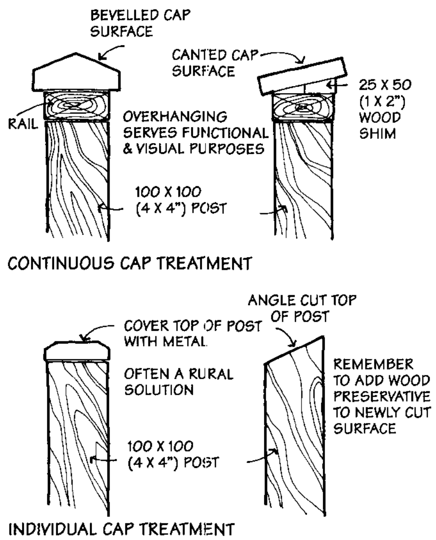

Figure 450-10. Typical cap details.

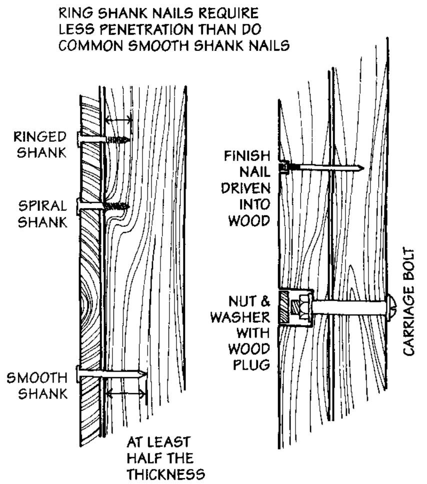

Figure 450-12. Fastening techniques for wood fences and screens.

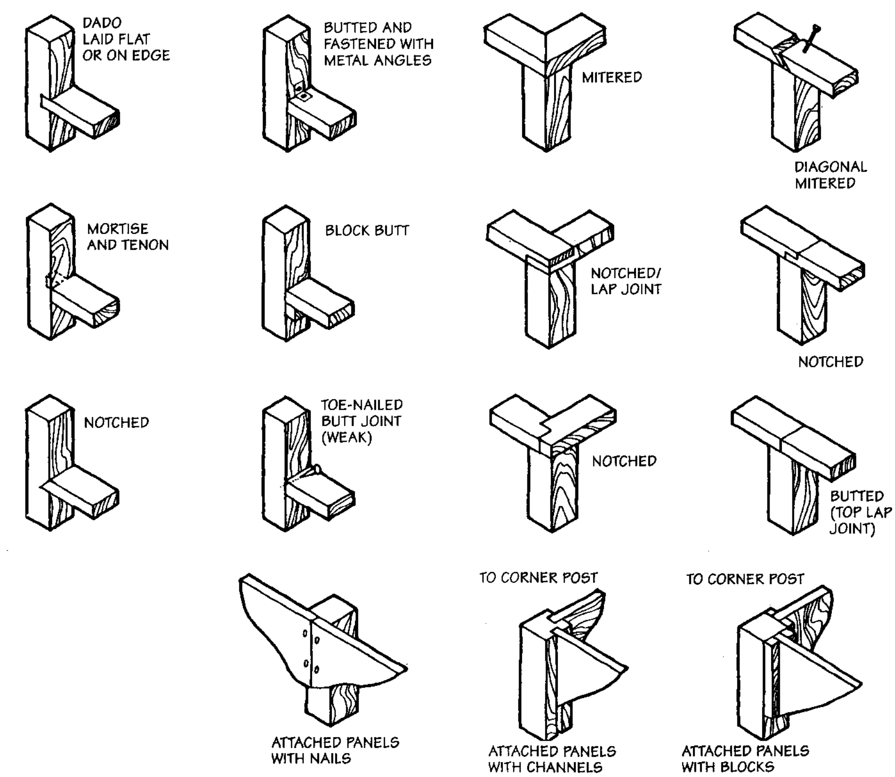

Figure 450-11. Typical joining techniques for wood fences and screens.
Details that trap moisture should not be used in humid climates.

sapwood, but is usually more expensive. Any part of the fence which will be within 150 mm (6 in) of soil or embedded in concrete should be constructed from heartwood of naturally decay resistant woods such as redwood, cedar or cypress, or of pressure treated lumber. (Refer to Section 850: Wood, for a comprehensive explanation of wood and wood products suitable for use outdoors and the regional classification systems used in the United States).

Structural Framework:

Horizontal rails attached to posts make a basic structural frame for supporting pickets, plywood panels, or other wooden fencing (Figure 450-9). Caps can be added for visual appeal and/or to keep water off of the tops of posts or other structural elements (Figure 450-10).

Fencing Materials:

Available standard wood sizes should be considered during the design process. Some of the more common types of wood fencing materials available are listed below, however, due to regional variations, some types may not be available throughout the country.

Board Siding: Available with plain or tongue-and-groove edges. Produces solid fences with no gaps between boards. 25 x 150 mm (1 x 6 in) boards are the most commonly used size.

Plywood-Use exterior grade only in thickness of 10-75 mm (3/8-3/4 in) for fencing, and available in sheets 1 200 mm (4 ft) wide by 2 400-3 600 mm (8, 10, or 12 ft) long.

Precut Pickets and Fencing Lumber and Finials: Pre-sized and cut for posts, rails, boards, pickets, and siding. Fence boards and posts are often available in a variety of simple picket and post top styles. Finials are used as ornaments for topping posts and are usually made of a variety of exterior woods, available in many traditional styles.

Palings and Poles: Wood stakes are available in 50-300 mm (2-12 in) diameter with pointed tops. Pressure-treated poles are often used for stockade-style fencing.

Redwood Grapestakes: Grapestakes are primarily used in the western United States as fence siding. Available in 25 x 50 mm (1 x 2 in) slats, sometimes with one smooth side and usually 900-1 800 mm (3-6 ft) long.

Split Posts and Rails: Used for post and rail fencing and other rustic styles. Sizes vary, but are typically no longer than 3 000 mm (10 ft). Common sizes available measure 125 x 150 x 2 400 mm (5 x 6 in x 8 ft) long.

Garden Lath: Used for woven latticework or inserting into chain-link fencing. Commonly available in 5 x 50 mm (1/4 x 2 in) wide laths.

Wood Preservatives and Finishes:

Chemical preservatives are typically used to prolong the life of a wooden fence or screen, particularly its posts. If pressure-treated, the wood fibers should be saturated with the preservative, (full cell method). Preservatives can also be painted on or soaked into the wood especially where the wood has been cut or in areas where water may become trapped. (Refer to Section: 850-Wood, for further discussion of protective treatments, materials, and methods of application for wood products).

Vertical facing members should never touch the ground. In some cases, drainage holes can be drilled in the supporting rails to prevent them from trapping water.

Joining and Fastening:

Figure 450-11 shows several ways to join together members of wooden fences or screens. The technique chosen and the quality of the hardware specified will affect the visual appeal and the structural integrity of the fence.

Hot-dipped galvanized steel, non-corrosive aluminum alloys, or stainless steel fastenings can be used to prevent the corrosion or discoloring of materials and finishes. Screws and bolts provide the firmest connections and may be needed to guarantee a strong supporting framework. Wood screws can be used to join pieces 25 mm (1 in) thick or less, but lag bolts, which come in a range of sizes, should be used to join more substantial wooden members.

Normally, nails should penetrate at least half the thickness of the receiving member of wood, and shanked nails should be used to prevent eventual loosening of the nail (Figure 450-12).

Countersunk bolt and screw fastenings are less susceptible to corrosion or vandalism when hidden by wooden plugs. Cover countersunk nails with a non-oily filler if the wood is to be stained or left in its natural state. Use oil-base putty if the wood will be painted. Wood fillers may need tinting to match the tone of the wood.

2.3 Metal Fencing

Metal Picket Fences:

Posts can be made of 25–100 mm (1-4 in) square or round tempered steel or aluminum tubing set in concrete footings. Pickets are normally made of 20-25 mm (3/4-1in) square or round tempered steel

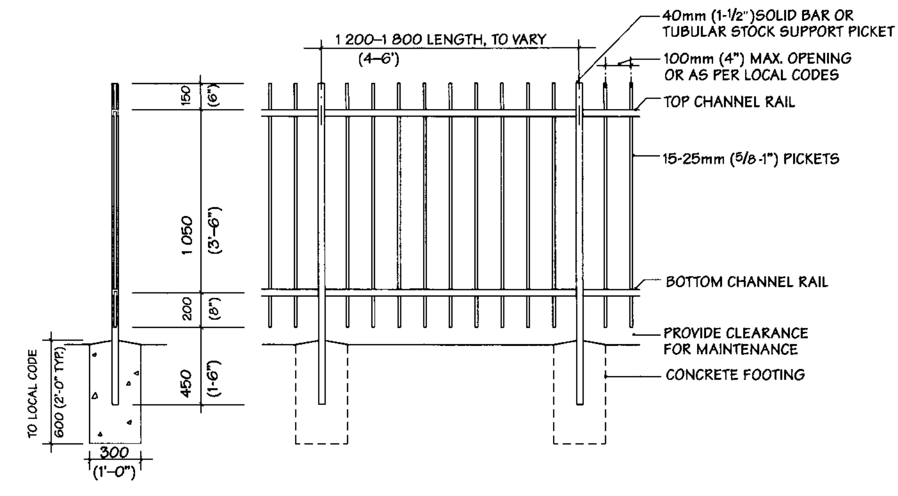

Figure 450-13. Typical metal picket fence construction.

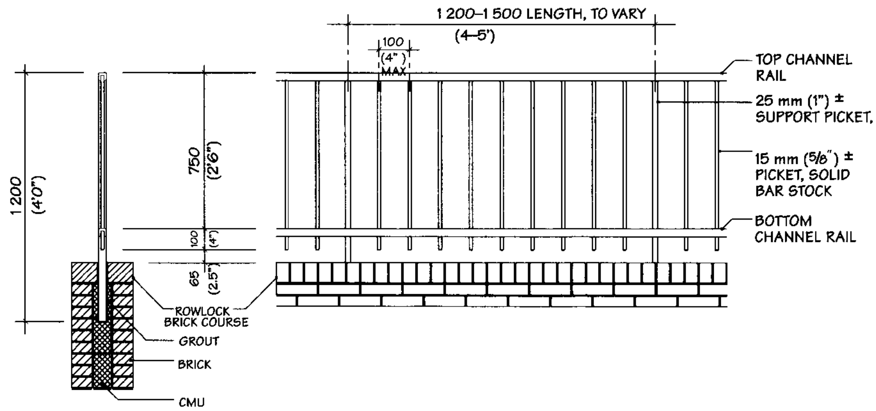

Figure 450-14. Closed-picket metal fencing on masonry wall.

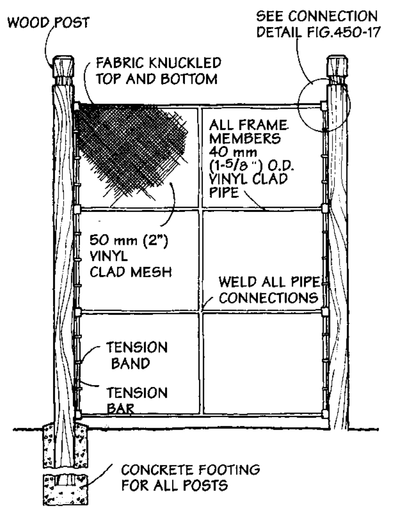

Figure 450-15. Metal fabric fencing with wood post construction.

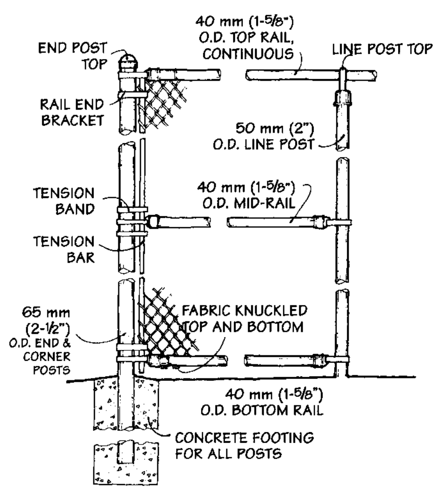

Figure 450-16. Typical chain link fencing.

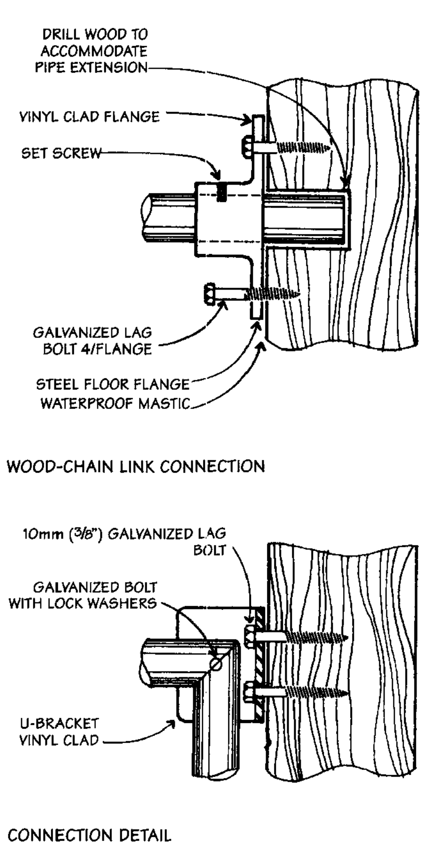

Figure 450-17. Chain link-to-wood frame connection details.

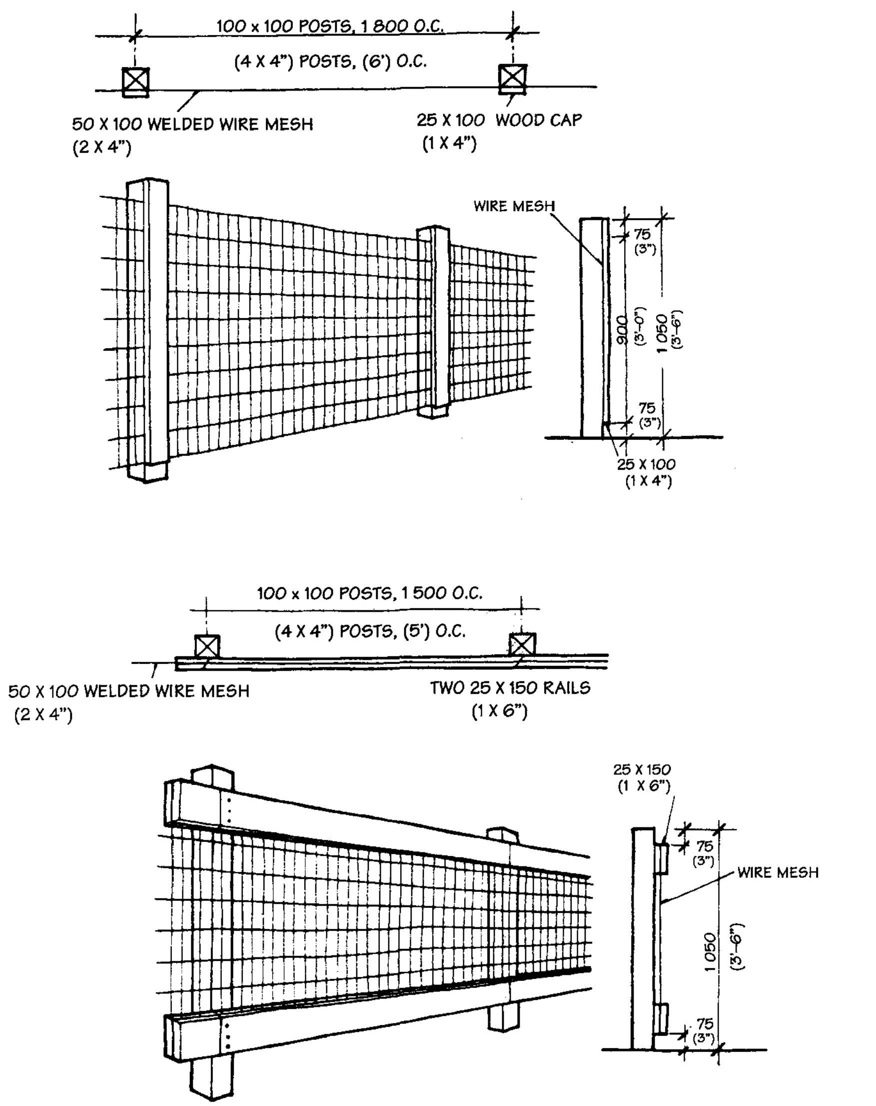

Figure 450-18. Types and application of metal fabrics.

or aluminum tubing or solid bars. (Figures 450-13 and 450-14).

Metal Fabric Fencing:

Metal fabric fencing is typically stretched between posts set in concrete. As with other fences, corner posts are normally larger and set deeper than inner posts. Metal picket and metal fabric fences can be combined with other types of fences and walls. Chain link fabric is usually stretched between metal posts of 50-100 mm (2-4 in) diameter, but it can also be mounted on wooden posts (Figures 450-15 through 450-18).

Metal fabric fencing was originally used for agricultural and security purposes. This material is now available in vinyl coated metal fabrics in a variety of colors and fabric styles that can be used attractively in other applications as well.

KEY POINTS: Joining and Fastening

1. For best results, all horizontal surfaces should slope to prevent water saturation and eventual wood decay or preservative leaching (Figure 450-10).
2. Use corrosion resistant fasteners for all connections. Stainless steel screws provide the highest quality non-staining devices for natural cedar and other decay resistant woods. Screws also provide for easier replacement of key components such as rails, braces, etc.
3. Lag screws and exposed bolts should be countersunk and plugged for best resistance to vandalism and corrosion.

2.4 Brick and Concrete Block Walls

Freestanding masonry walls can be made of brick and/or concrete block (Figure 450-19). These non-load bearing structures carry only their own weight plus any lateral wind loads. Concrete block is normally less expensive than brick, and it is available in standard and special sizes, finishes and shapes. Often, hollow concrete blocks are used to add thickness or to provide a structure that can be faced on one or both sides with brick, tile, stucco, or other materials.

Brickwork Patterns:

Figure 450-20 shows some of the more common bonds used in bricklaying. Because

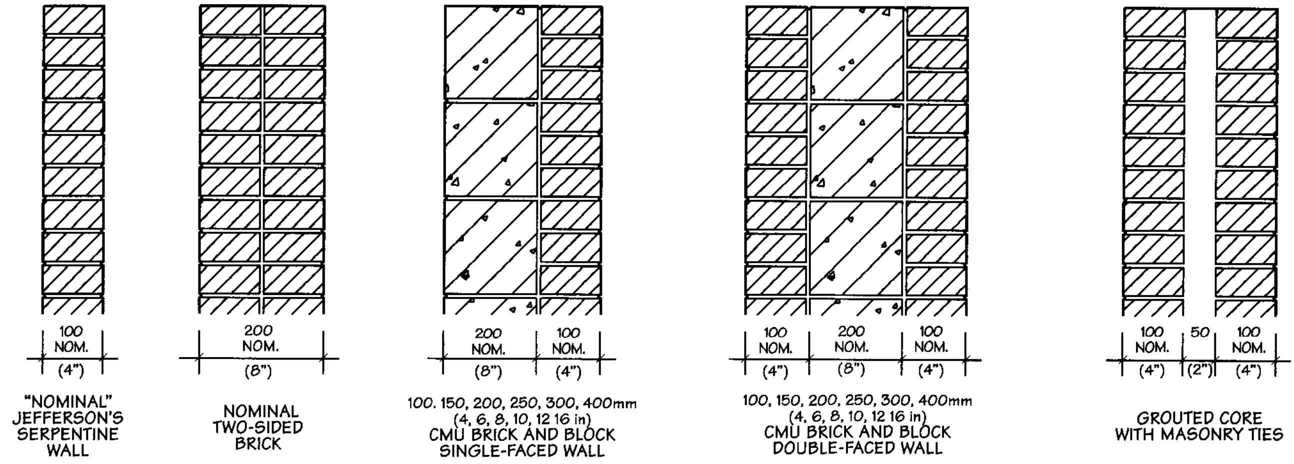

Figure 450-19. Typical brick wall construction.

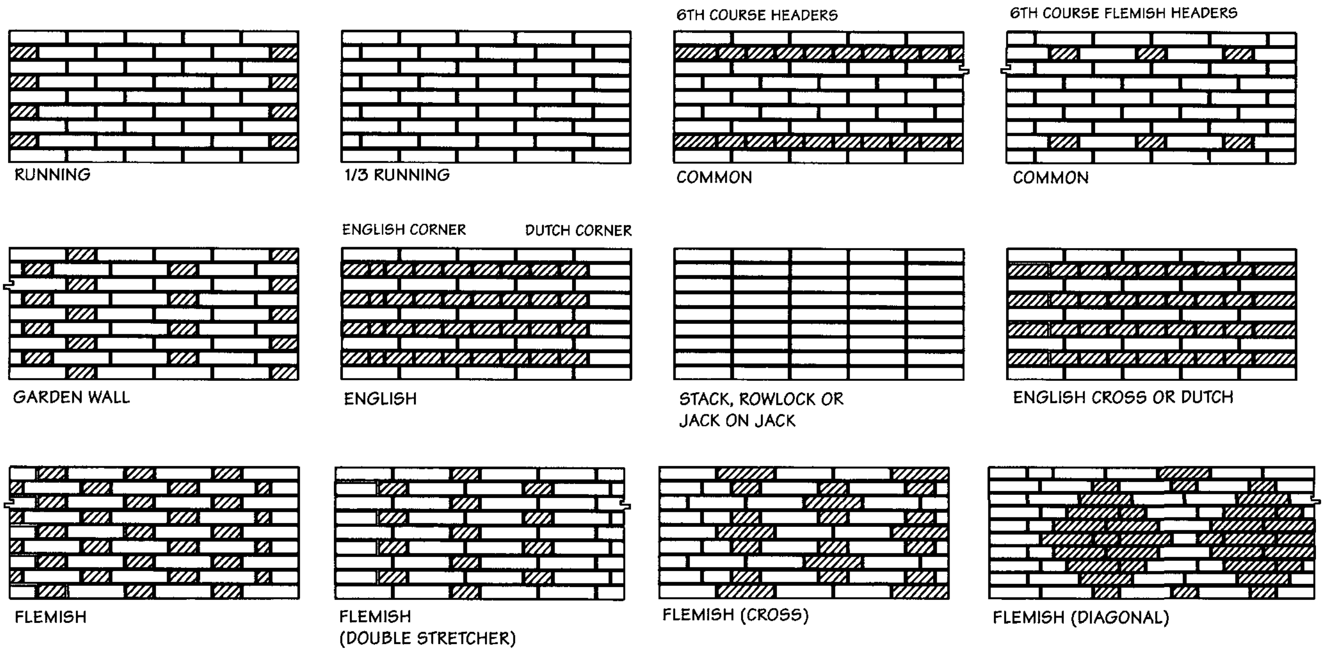

Figure 450-20. Common brickwork patterns.

the ends of walls are often visible, they are usually designed with a running bond pattern or an end-wall pier or column.

Joints:

Expansion and control joints are needed in most types of concrete or mortared brick walls to minimize or control the possible damaging effects of movement due to stresses, expansion and contraction, temperature variation, and the presence of moisture. The spacing and placing of expansion, control, and construction joints should be considered as part of the overall surface design treatment of freestanding walls.

Expansion joints are commonly 10 mm (1/2 in) wide and extend completely through the wall. They should occur at regular intervals as required by the existing conditions, normally no further than 90 000 mm (30 ft) apart. Expansion joints are also recommended at wall offsets, junctions, changes in materials, and corners. (Refer to Section 830: Concrete, for further explanation of joint types). The type of masonry mortar joint should be selected based on the aesthetic appearance and the degree of water tightness required. (Refer to Section 840: Masonry, for types of joints and weatherability).

Moisture Control:

The top surfaces of walls should be pitched to drain, and caps should be extended beyond the wall to shed water away from the wall face. Joints on horizontal surfaces should be sealed to prevent seepage and possible damage to the joint.

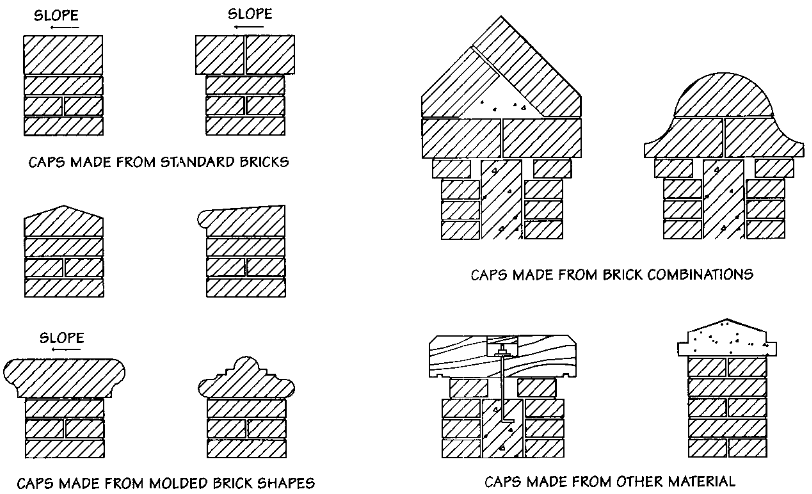

Figure 450-21. Typical caps for masonry walls.

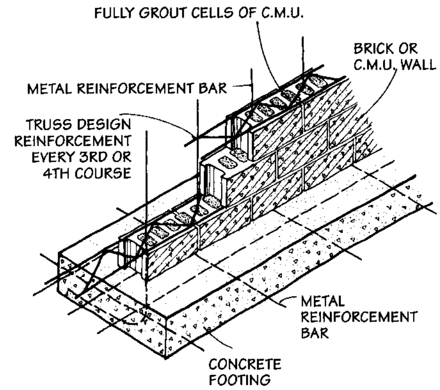

Figure 450-22. Reinforcement for masonry walls.

Brick Cap Units:

Caps can be made from standard bricks or from bricks cut on the site, and they can be set in a pattern different from the wall bond. There are special brick cap units for the wall ends and corners. Prefabricated caps are also available. Alternatively, caps for masonry walls can be of wood, precast concrete, or cut stone (Figure 450-21).

Reinforcement:

The thickness, height and amount of reinforcing for various walls are interrelated. Check local building codes for legal restrictions and building specifications for height, width, and reinforcement requirements before building a wall.

Brick walls can be reinforced with ladder or truss type wire reinforcement or structural brick bonds called header courses. Wire reinforcement is laid horizontally within the mortar bed between every third or fourth course to resist lateral displacement in walls over 600 mm (2 ft) high (Figure 450-22). (Refer to Section 840: Masonry, for further explanation of wire reinforcement types and methods of installation). In single and double wythe walls, the header course consists of a brick laid across the thickness of the wall. In double wythe walls it ties the wall faces together. Freestanding walls above 1 200 mm high (4 ft), should have bar reinforcement running vertically, either in the mortar between the brick or in the open cells of concrete blocks (Figure 450-23). For major structures in difficult soil conditions, a structural engineer or contractor familiar with local conditions and standard practices should be consulted.

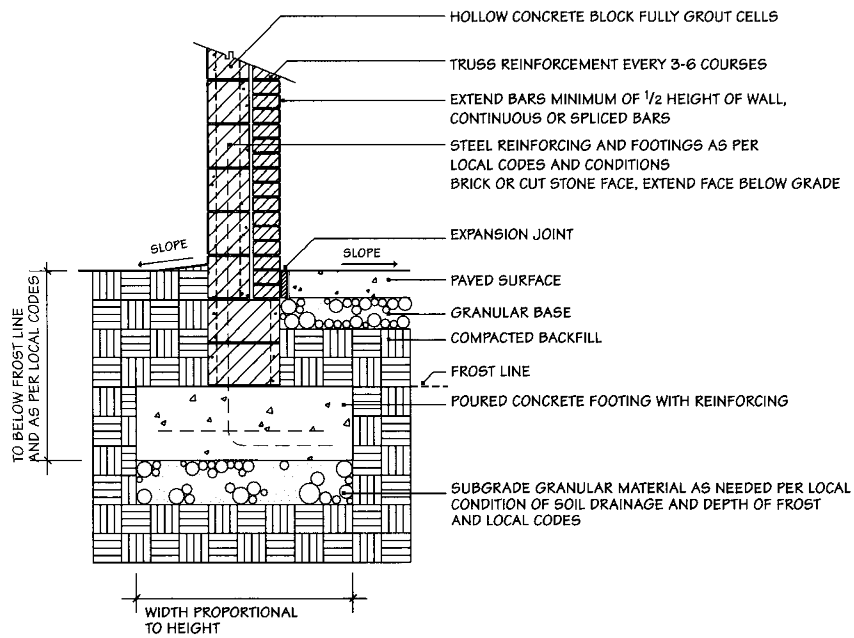

Figure 450-23. Reinforcement for freestanding masonry walls.

2.5 Stone Walls

Two basic methods of stone wall construction are dry and mortar-laid walls. Dry stone walls have no mortar, the stones are irregular in shape, and are laid flat. Mortar-laid stone walls have continuous footings (and therefore are stronger and can be higher) and require fewer stones than dry walls.

Walls can be laid up in two rough wythes with rubble fill or bond stones laid across the wall, tying the wall faces together (Figure 450-25). A good general rule of thumb is to place a minimum of one bond stone for every 1 m^2 (10 ft^2) of wall surface. Overlap of stonework is critical for dry laid and mortared stonewalls. Vertical joints

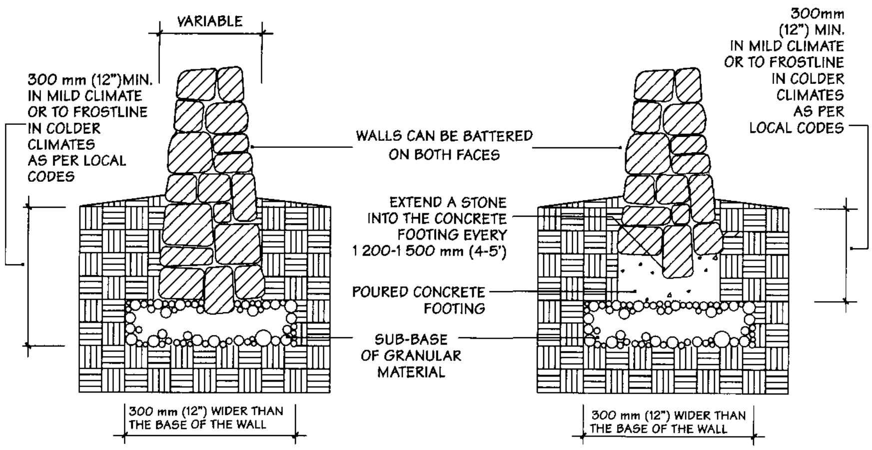

Figure 450-24. Typical stone wall footing construction.

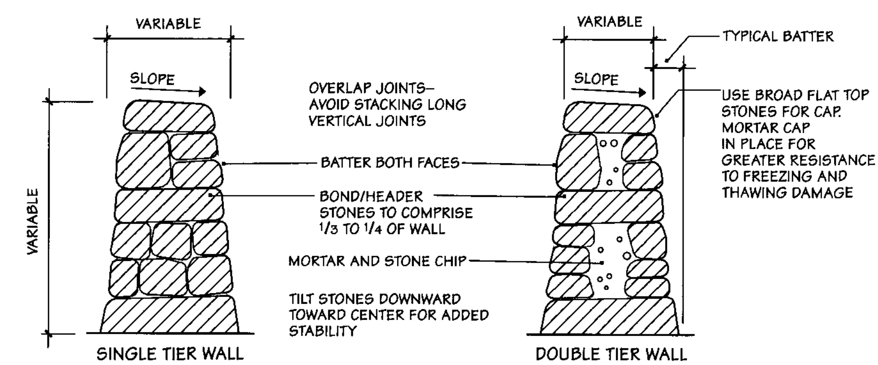

Figure 450-25. Typical stone wall construction.

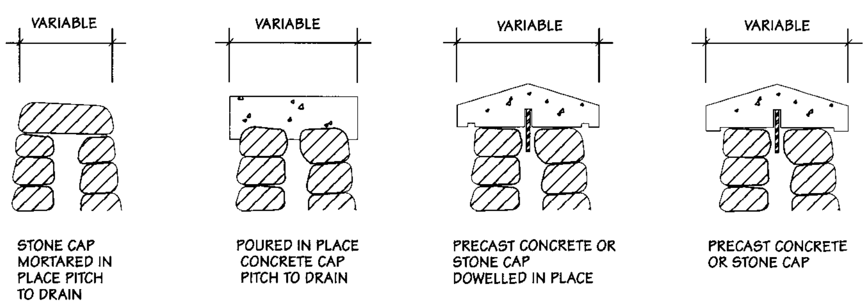

Figure 450-26. Caps for stone walls.

should be staggered, always overlapping the stone above and the one below. Mortared joints are typically recessed and are not flush with stone surfaces.

Walls can be battered to provide increased stability and resistance to overturning. The amount of batter depends on the size and purpose of the wall, the shape of the stones used and whether or not the wall is mortared. Very rounded stones require more batter. A typical batter for dry stone walls is to plan 25-50 mm (1-2 in) of batter for each 300 mm (1 ft) of rise, but other ratios are often used. When a wall appears to be an extension of a building, a battered wall is seldom used (Figures 450-24, 450-25, and 450-26).

Stonework Patterns:

Two basic stonework patterns used in wall construction are random rubble and ashlar (Figures 450-27 and 450-28). Ashlar typically consists of flat surfaces and a limited range of sizes. Fully, trimmed ashlar can be easily laid, makes formal or informal coursing possible and requires less mortar than rubble walls. Rubble is irregular in shape and is difficult to cut, but is an inexpensive material when locally available. Stones should be similar in size, or, if in a variety of shapes and sizes, should be evenly distributed and the largest stones placed near the base to give a balanced appearance to the wall.

Mortar Mix:

(Refer to Section 840: Masonry, for recommended mortar types and properties). Stone must be free of dirt and thoroughly wetted before being set.

2.6 Poured Concrete Walls

Poured concrete walls require the same type of footing as other masonry walls, with key joints to lock the footing to the wall above. Concrete walls also require formwork and vertical and horizontal reinforcing bars to provide stability. A typical reinforcing bar pattern for a poured concrete wall is shown in Figure 450-29. For walls over 1 800 mm (6 ft) in height, a structural engineer should be consulted to determine loads and structural specifications. Control and expansion joints should be used to control locations of cracks, and to relieve wall stresses, as described in 2.4 Joints.

2.7 Miscellaneous Barrier Materials

Panels for fences and screens can be constructed of any number of materials, especially if the fence or screen is going to serve

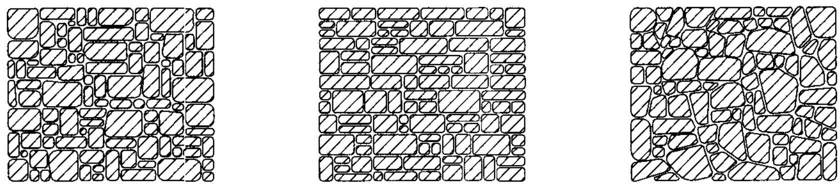

Figure 450-27. Random rubble masonry patterns. *Units are squared and dressed by stone masons in the field.*

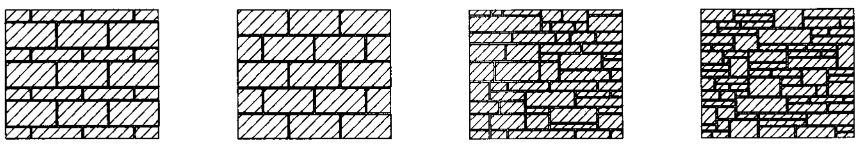

Figure 450-28. Ashlar stone masonry patterns. *Units are precut and dressed before delivery to site.*

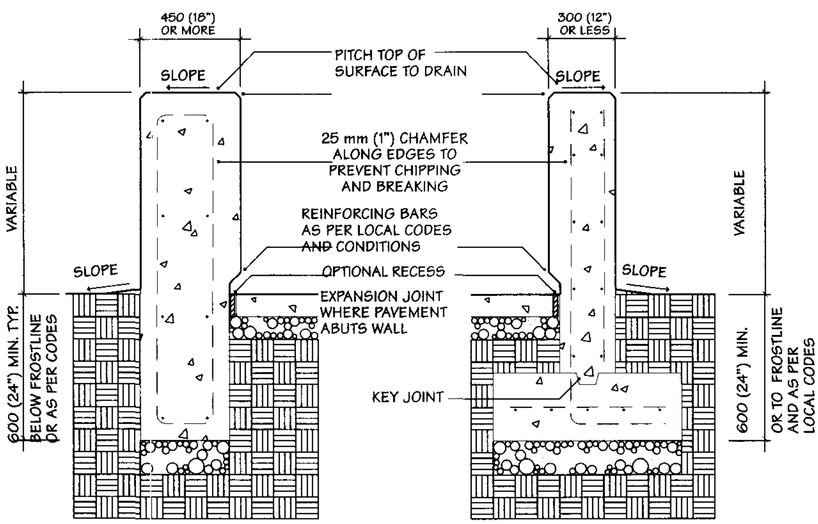

Figure 450-29. Typical poured concrete wall construction.

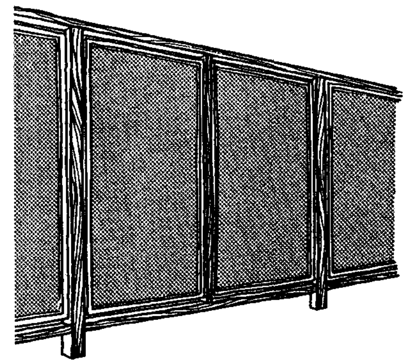

Figure 450-30. Alternative materials for fence or screen panels.

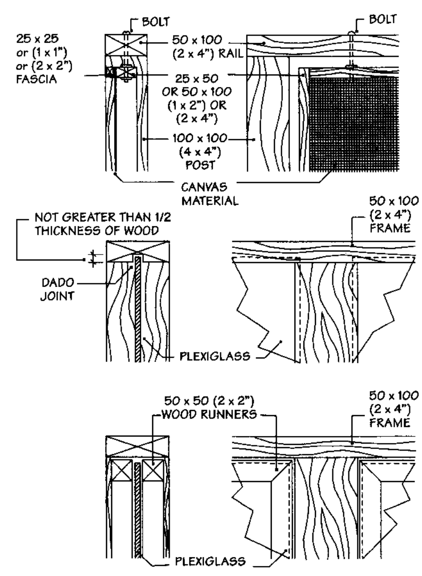

Figure 450-31. Typical screen panel construction.

either a temporary or special need. Figures 450-30 and 450-31 show Plexiglas and canvas applications, but such materials are subject to abuse or vandalism and may therefore require a higher degree of maintenance. The durability of a material is another factor and may imply a shorter useful life.

2.8 Gates

Gate posts are usually larger, [e.g., at least 150 x 150 mm (6 x 6 in)] and taller than the posts used for the remainder of the fence and often the same size as the corner posts. They should always be installed deeper, and often with concrete footings (Figure 450-32).

Sagging is the main structural problem with most gates; therefore, the gate should be as light as possible and have diagonal bracing. A plywood panel is one method to create a sag-free gate (Figure 450-33). Braces should extend from the bottom of the hinge side to the top of the latch side. If a wire and turnbuckle is used, the wire is strung from the upper hinge side to the lower latch side instead. This placement supports the frame and counteracts sagging.

Bolts and wood screws instead of nails should be specified for gate construction. Typical gate hardware is shown in Figure 450-34.

2.9 Connections to Buildings or Other Structures

The point, or juncture, where a barrier joins another structure is a detail crucial to good appearance and structural integrity (Figures 450-35, 450-36, and 450-37). If needed, a gate is often located at this point to solve the problem.

2.10 Maintenance around the Base of Walls and Fences

A fence or wall on a paved surface has few maintenance problems, but if set on mown grass, then a mowing or maintenance strip along the base of the structure might be considered. Alternatively, a low-maintenance ground cover can be substituted for the lawn (Figure 450-38). Curbs, car stops, or other such device should be used to protect barriers from vehicular damage (Figure 450-39).

2.11 Reproducing Historic Styles

Accurate reproductions of earlier barrier styles are sometimes needed in historic landscape restoration. In most cases, however, exact reproductions are unnecessary. Generally, an historic appearance can be suggested by careful detailing of the elements such as the caps, pilasters, pickets, posts, or finials as well as by choosing materials that have strong historical connotations simply because of their past widespread use (e.g., stone, brick, or iron or wooden picket) (Figure 450-40).

GLOSSARY

Ashlar: A type of cut stone typically selected from stratified rock such as limestone, sandstone and shale. Used for building solid walls. Ashlar is also a name for masonry made of squared stone laid in a random or coursed pattern, called coursed ashlar.

Efflorescence: A white powdery substance composed of soluble salts carried to the wall or paving surface by the movement and subsequent evaporation of water.

Frost Line: The lowest level in soil that frosts or freezes.

Galvanized: Process of dipping metal objects in a hot bath of metallic zinc. This process adds a metallic zinc coating which retards rust.

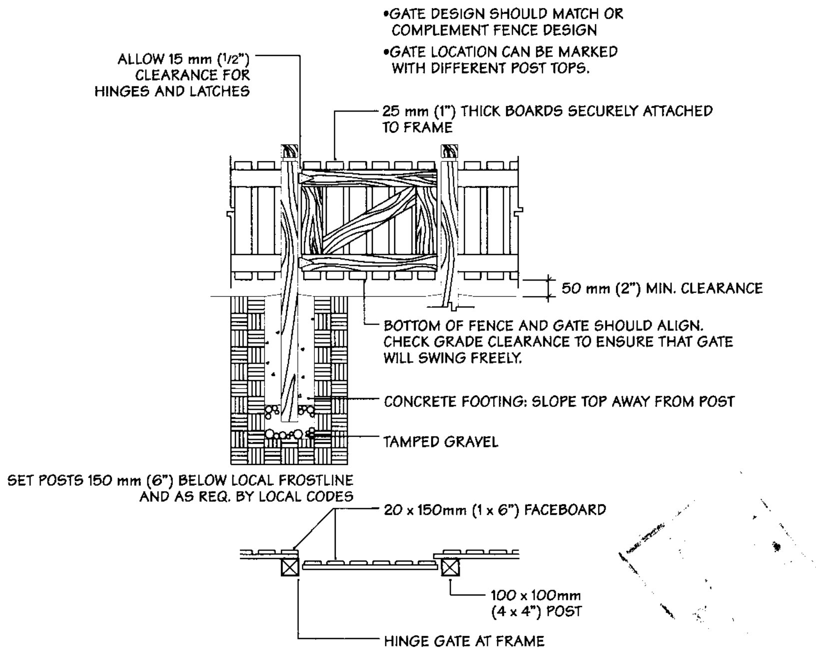

Figure 450-32. Typical gate and gatepost construction.

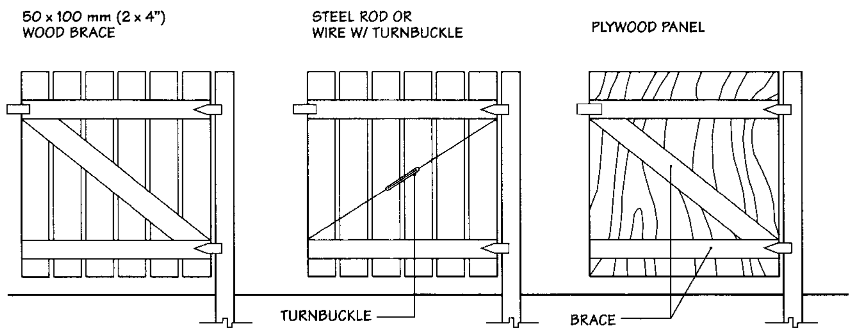

Figure 450-33. Common bracing techniques for wood gates.

KEY POINTS: Brick and Concrete Walls

1. All brick and concrete block walls require continuous concrete footings and vertical reinforcing, extended at least half way up the height of the wall core, especially for walls greater than 1 200 mm (4 ft).

2. Lateral reinforcing may be required in brick and concrete block walls every 3 to 6 courses in heavy wind load applications. Solid brick walls require Flemish or English bond to tie wall faces together.

3. Wall caps should slope to drain. Concrete wall tops may be pitched and beveled, and masonry walls may use specially formed masonry or precast concrete copings (Figure 450-21). Flashing and damp proofing may be required in wet climates.

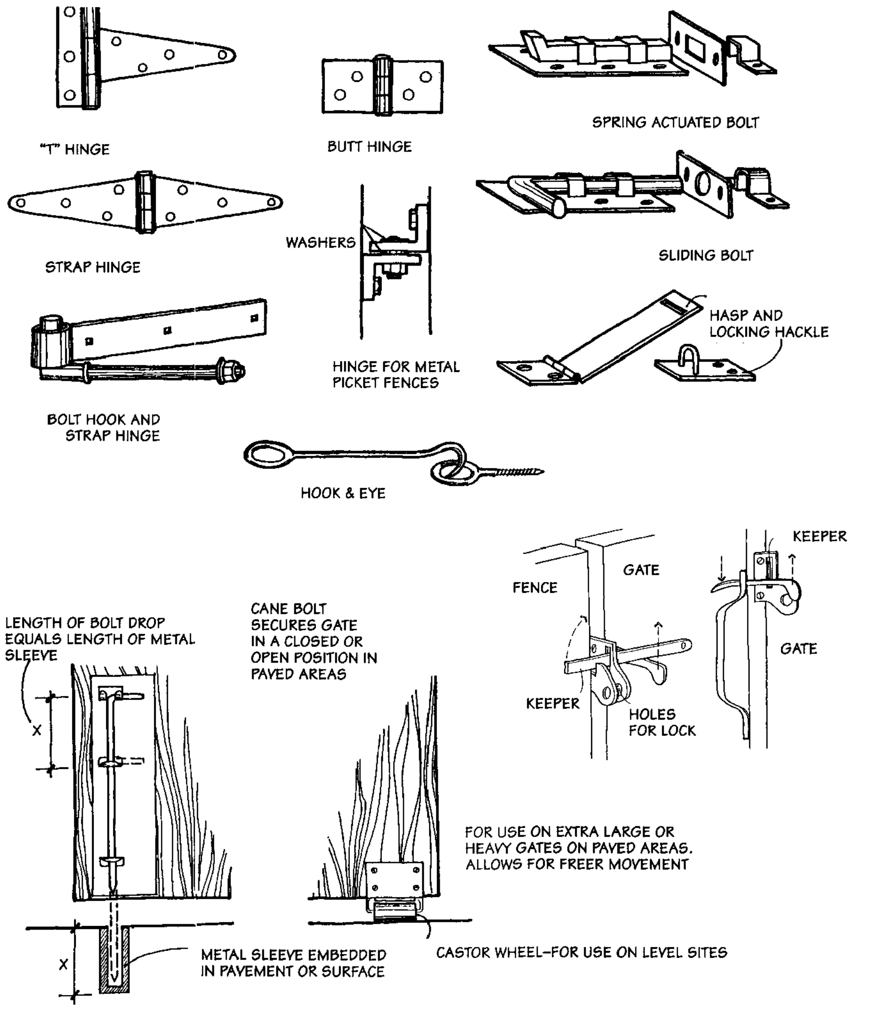

Figure 450-34. Common gate hardware. *Galvanized metal hardware is often used to prevent rusting and consequent staining of wood.*

Masonry Header: A single brick or course of bricks turned to span the width of the wall. Headers tie two side by side tiers of bricks together.

Plywood: Panel made by laminating thin sheets of wood to a wood fibercore.

Random Rubble: Stone wall pattern using uncut stone laid in uneven or irregular courses.

Rebar: Abbreviation for reinforcing bar, sometimes referred to as rods. Round, steel bars placed in concrete and unit masonry walls for reinforcement purposes. Sized in 3 mm (1/8 in) increments. (A No. 4 rebar is 10 mm (1/2 in) diameter).

Rubble: Irregular rough stones such as fieldstone, or broken pieces of brick and concrete, usually with at least one good face used for wall construction.

Wythe: The width of one course of common bricks.

AGENCIES AND ORGANIZATIONS

American Iron and Steel Institute (AISI), Washington, DC

The Aluminum Association, Washington, DC

Western Wood Products Association, Portland, Oregon

National Concrete Masonry Association (NCMA), Herndon, Virginia

Building Stone Institute (BSI), New York, New York

Brick Masonry Institute of America, (BIA) Reston, Virginia

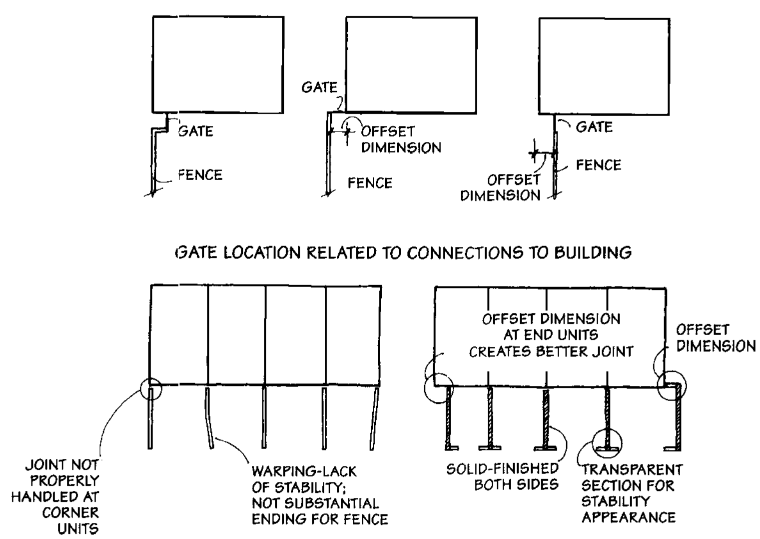

Figure 450-35. Aesthetic considerations for connections between walls or fences and buildings.

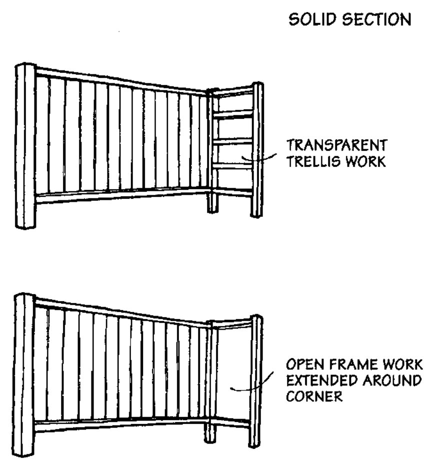

Figure 450-36. Offset details for connections between walls or fences and buildings.

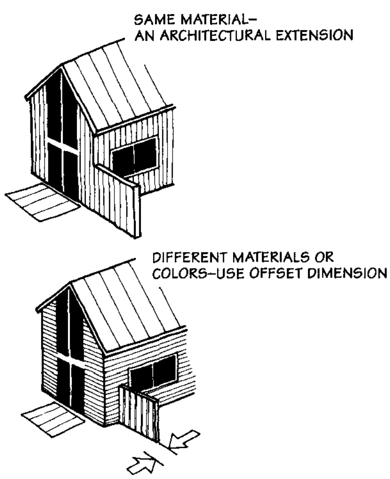

Figure 450-37. Aesthetic considerations for building/wall extension.

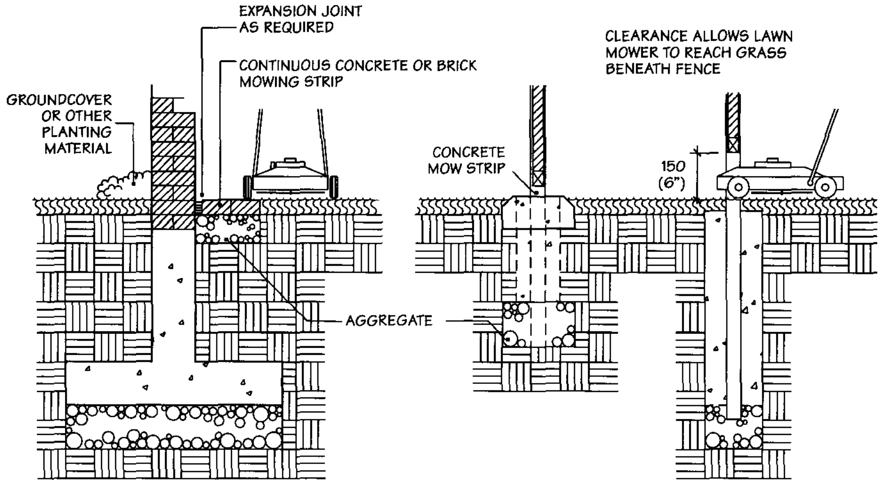

Figure 450-38. Low-maintenance techniques for the bases of walls and fences.

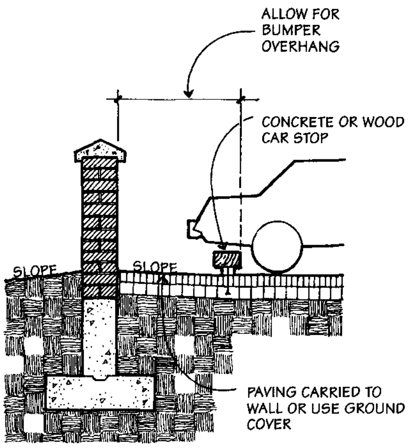

Figure 450-39. Car stop for protection of walls or fences.

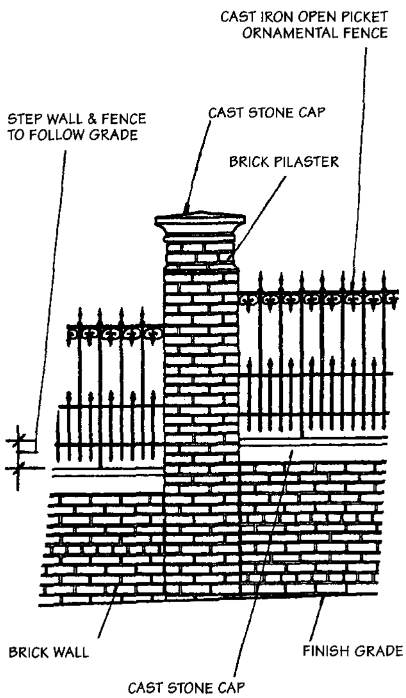

Figure 450-40. Representative example of historic detailing. *(Otterbein Church, Baltimore, Maryland, c.1850.*

KEY POINTS: Stone Walls

1. Dry stone walls typically require an aggregate base to provide a uniform level surface on which to lay the stone. Poorly drained soil may require lateral perforated pipe drainage to prevent swell and shrinkage, and/or frost heaving in cold climates (Figure 450-24).
2. Dry stone may be placed on a concrete or graded aggregate footing set below frost to insure a uniform wall elevation not subject to seasonal fluctuation. Walls greater than 900 mm (3 ft) high, typically require header stone courses to tie wall faces together in wide or cavity wall construction (Figure 540-25).
3. Mortared stone walls require a continuous concrete footing extending below frost in cold climates. Wall may be tied to footing with a key stone set in wet concrete. Mortared walls may have thinner cross sections and require less stone per unit length than dry-laid walls.
4. Cap stones must slope to shed water. Precast or site-cast concrete copings may be used in mortared stone walls (Figure 450-26).

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Wood Decks and Boardwalks

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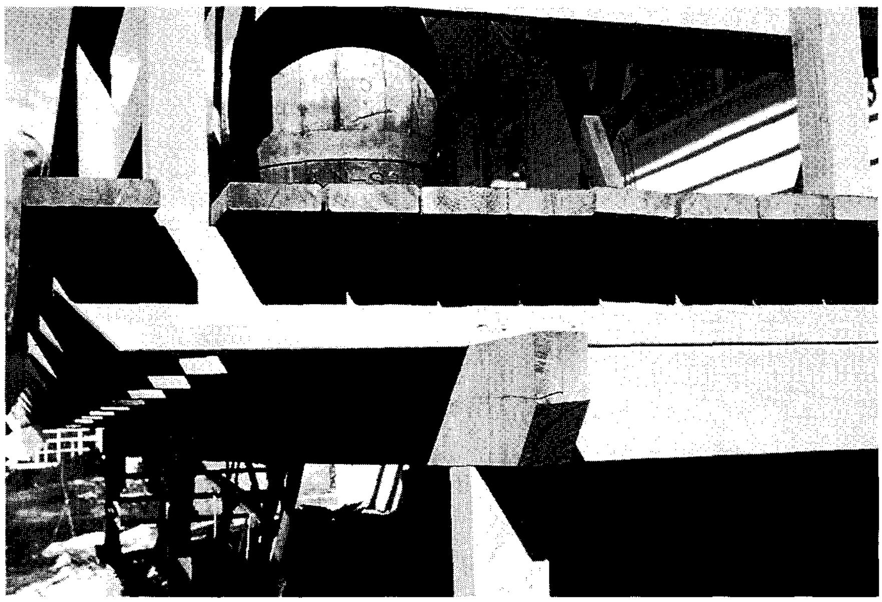
Michael Davidsohn

CONTENTS

1.0 INTRODUCTION

1.1 General

This section focuses on fundamental principles and techniques of wood deck and boardwalk design and construction. Each of the major structural components of a deck and its sizing is described. Construction details for various types of connections, including steps and handrailings, are given at the end of the section.

1.2 Design Process

The design of a deck or boardwalk involves an orderly decision-making process. Basic steps in the process include:

1. **Program requirements:** Create a design program with regard to proposed deck uses and resulting size requirements.
2. **Schematic design:** Develop deck or boardwalk form, spatial organization, and expected circulation patterns.
3. **Rough layout and framing plan:** Develop a rough layout and preliminary framing plan which locates all structural elements required, such as footings, beams, joists, decking pattern, stairs, and rails. Calculations cannot begin until a rough framing plan is prepared.
4. **Sizing wood members and refinement of layout:** Calculate weights and sizes proceeding from wearing surface to pier footings to include decking joists, beams, and finally post calculations. (Refer to 4.0 Sizing Wood Members in this section for an explanation of sizing calculations.)
5. **Details and auxiliary features:** Prepare details for all associated features such as steps, railings, benches, hot tubs, and planters. Such features which bear on the deck structure must be included in weight calculations. Methods of attachment for these details sometimes become part of the structural framing plan (e.g. structural posts as posts for handrailings).
6. **Evaluation:** All structural systems should be reviewed by local permitting agencies and structural consultants.

1.3 Preliminary Design Considerations

The factors that will fundamentally determine the appearance, strength, and relative costs of a deck or boardwalk design are:

1. Framing method and layout
2. Construction materials selection
3. Maintenance considerations

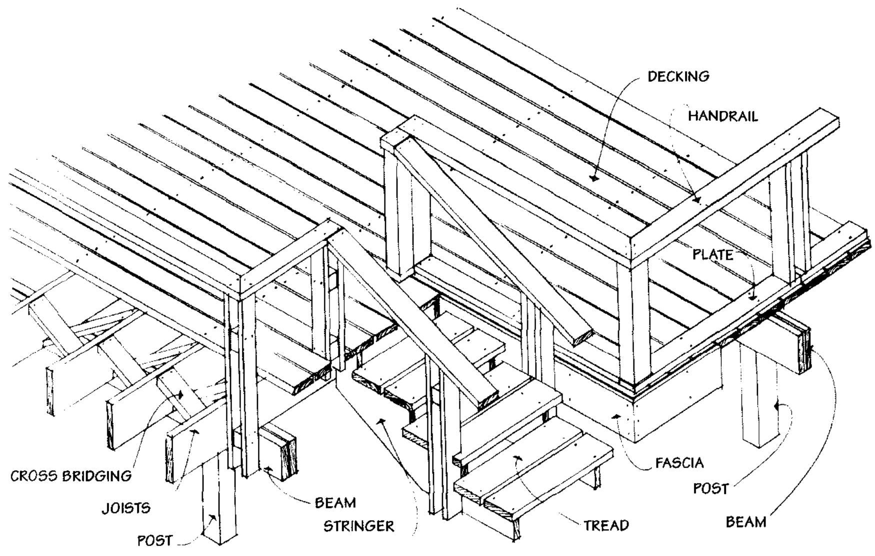

Figure 460-1. Typical platform framing.

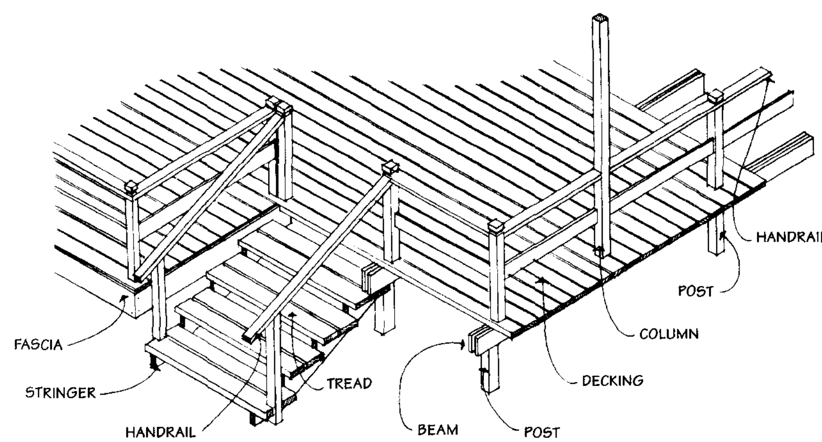

Figure 460-2. Typical plank-and-beam framing.

2.0 PRINCIPLES OF CONSTRUCTION

2.1 Framing Methods

Platform framing and plank-and-beam framing are the two methods commonly employed in deck or boardwalk construction. Both of these methods have advantages and disadvantages, depending on the objectives of the designer. The choice of one method over another is usually based on a combination of cost comparisons, aesthetic preference, and regional practice. The comparative costs between these two framing methods need to be considered on a project-by-project basis due to the many variables involved.

Platform Framing:

Platform framing is a beam-and-joist method of construction (Figure 460-1). Few beams are necessary because joists carry the load over a wide area. Joists typically are of a nominal thickness of 50 mm (2 in) and essentially function as closely spaced beams. The spacing of joists is determined by (1) the load-carrying ability of the joists themselves (a function of their cross-sectional dimension and length of span) and (2) the maximum allowable decking spans, which depend on the cross-sectional dimensions of the decking material and on the species of lumber used. Different species of wood have different inherent strengths.

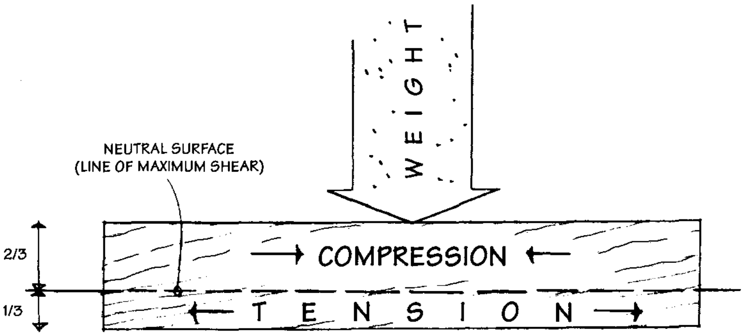

Figure 460-3. Line of maximum shear. *Extensive bolting along the line of maximum shear will weaken the beam.*

Platform framing results in a deeper (thicker) deck profile than plank-and-beam framing because of the inclusion of joists.

Plank-and-Beam Framing:

Plank-and-beam framing refers to a beam-and-decking method of construction (Figure 460-2). No joists are used because the beams are spaced close enough together to function like joists. The spacing of beams is related to the maximum allowable decking spans, the cross-sectional dimension of the beams employed, and the maximum allowable beam spans.

A major advantage of plank-and-beam framing over platform framing is its shallow profile, which gives it a simple and clean appearance. It is commonly employed in boardwalk construction.

2.2 Basic Components

The following descriptions of the various components of wood deck and boardwalk construction apply to both methods of framing:

Decking:

Decking refers to the surface walked upon. It is supported directly by either joists or beams, depending on the framing method. The allowable span of the decking material determines the maximum spacing of the joists—or, in the case of plank-and-beam framing, the maximum spacing of the beams.

Decking is usually laid flat but can also be laid on edge. The appearance and finish of all as decking is usually more important than the appearance of structural members that are out of the view of users. For this reason, the type of wood used for decking is typically of better quality than the type used for the underlying support members. The following design factors should be considered :

1. Decking material should be greater than 25 mm (1 in) (nominal thickness) unless noticeable deflection is acceptable. Pre-molded 30 mm (5/4 in) planking is often used, but 50 mm (2 in) (nominal) material is more common.
2. The spacing between decking planks should be no more than 3 mm (1/8 in) or the equivalent thickness of a 16d nail. In some cases the lumber used is not completely dry and additional shrinkage can be expected causing a hazardous gap; therefore, it may be necessary to place planks without a space to allow for shrinkage.
3. Decking wider than 150 mm (6 in) is not recommended because of its propensity to warp.
4. Decking should be laid with the bark side up to avoid cupping of the decking material and consequent drainage problems.

Joists:

Joists are used only in platform framing and function to support decking material of relatively short spans and to distribute imposed loads over a wider area. They are typically spaced close together [i.e., 400 to 600 mm (16 to 24 in) apart] because of the limited span of decking members. Exceptionally long spans may require a 300 mm (12 in) spacing for added strength. Stress patterns and types of failure are the same in joists as they are in beams. The following design factors should be considered:

1. Dimensioned lumber as classified by the National Forest Products Association (NFPA) should be specified for joists. Joists must be oriented so that the cross section's longitudinal axis is vertical (i.e., narrow dimension up).
2. Ideally, joists should be supported on each end by a beam, a ledger, or metal hangers, but nailing directly to a facer is sometimes adequate for small decks with light loading requirements.
3. Bridging is sometimes used between joists to minimize lateral movement, especially if joist spans are long.
4. When fastening joists or beams, especially with bolts, care must be exercised to prevent weakening of the member along the line of maximum shear (see Figure 460-3).

Beams:

Beams function to support the weight of joists and decking, transferring the load to posts or directly to a foundation. Their spacing is directly related to the allowable span of the members which they are directly supporting, whether they are joists or decking. Typically, beams are spaced 1 800 to 2 400 mm (6 to 8 ft) apart in plank-and-beam framing and 2 400 to 4 800 mm (8 to 16 ft) apart in platform framing. Their required cross-sectional dimension is directly related to the length of their allowable span, given any particular loading requirement.

Common types of beam support systems include:

1. Simple beam: rests on a support at each end.
2. Cantilevered beam: supported at one end only.
3. Overhanging beam: projects beyond one or both supports.
4. Continuous beam: rests on three or more supports.
5. Fixed beam: fixed at both ends

Figure 460-3 illustrates stress patterns and the line of maximum shear in beams. The following design factors should be considered:

1. Graded lumber should be specified for beams and stringers (NFPA).
2. Beams must be so oriented that the cross section's longitudinal axis is vertical (i.e. narrow dimension up).
3. Center-to-center spans rather than effective spans (i.e., the spacing between supporting members) are typically used in sizing calculations for an added measure of support.

TABLE 460-1. RELATIVE COMPARISON OF VARIOUS QUALITIES OF WOOD USED IN DECK CONSTRUCTION

	Douglas Fir-Larch	Southern Pine	Hemlock Fir*	Soft Pines†	Western Red Cedar	Redwood	Spruce	Cypress
Hardness	Fair	Fair	Poor	Poor	Poor	Fair	Poor	Fair
Warp resistance	Fair	Fair	Fair	Good	Good	Good	Fair	Fair
Ease of working	Poor	Fair	Fair	Good	Good	Fair	Fair	Fair
Paint-holding	Poor	Poor	Poor	Good	Good	Good	Fair	Good
Stain acceptance‡	Fair	Fair	Fair	Fair	Good	Good	Fair	Fair
Nail-holding	Good	Good	Poor	Poor	Poor	Fair	Fair	Fair
Heartwood decay resistance	Fair	Fair	Poor	Poor	Good	Good	Poor	Good
Proportion of heartwood	Good	Poor	Poor	Fair	Good	Good	Poor	Good
Bending strength	Good	Good	Fair	Poor	Poor	Fair	Fair	Fair
Stiffness	Good	Good	Good	Poor	Poor	Fair	Fair	Fair
Strength as a post	Good	Good	Fair	Poor	Fair	Good	Fair	Fair
Freedom from pitch	Fair	Poor	Good	Fair	Good	Good	Good	Good

* Includes West Coast and eastern hemlocks.

† Includes western and northeastern pines.

‡ Categories refer to semitransparent oil base stain.

Source: C. G. Ramsey and H. R. Sleeper, *Architectural Graphic Standards*, 9th Ed., John R. Hoke, ed., Wiley, New York, 1994.

4. Steel and concrete beams are less commonly used in deck or boardwalk construction except under unusual loading conditions, in exceptionally long spans, or in very large deck systems.

Posts:

Posts carry the weight of the entire deck structure to the foundation. Posts are commonly used in one way or another to control the finished elevation of a deck or boardwalk. Posts are not a necessary part of the construction if the deck or boardwalk is to lie close to the ground. Beams or joists can rest directly on foundations. Where posts are used, their spacing is directly related to the allowable span of the beams they are supporting. The following design factors should be considered:

1. Lumber classified as post and timbers (NFPA) graded to carry longitudinal load should be specified for posts.
2. Wood posts of approximately square cross-section have the least propensity to twist or warp.
3. Wood posts should be sized to resist buckling and, under unusually heavy loading conditions, to resist crushing. Often posts are sized beyond their recommended dimension, as calculated for the proposed load, in order to add "visual strength" and user confidence.
4. Posts extended up through the deck or boardwalk can also serve as a railing component.
5. Various types of post-to-pier connections are possible. Choices often depend on climate. Avoid wicking or moisture entrapment by specifying a clearance or some sort of barrier between the pier and post.
6. Steel or masonry columns are usually not tested for bearing strength except under extremely heavy loading conditions.
7. Minimize moisture infiltration at the exposed top end of wood posts by angle cutting, capping, or covering.

Footings:

Footings anchor a deck or boardwalk to the ground, supporting its weight and its expected live loading. In cold and temperate climates, footings must extend below the line of maximum frost penetration to prevent movement caused by freeze/thaw processes. Small freestanding decks and light structures can tolerate marginal soil movement and do not necessarily require footings below the frost line. If attached to stabilized structures, however, decks must also be stabilized. (Refer to Section 810: Soils and Aggregates, for information on the properties of various soils, including the bearing capacities of common soil types.) The following design factors should be considered:

1. Expansive clay soils, unstable organic soils, and deep fills require pier-and-beam foundations.
2. The footing size required depends on the weight to be supported and on the load-bearing capacity of the soil. The weight of most decks and light structures rarely exceeds the bearing capacity of most soils, especially if the footing is twice the cross-sectional area of the pier. Avoid using a narrow pier without a footing, as spearing may result.
3. Reinforcing is necessary in larger footings and piers to prevent failure of the concrete, especially in colder climates.
4. Humid climates require different footing types and post connections than arid climates because of moisture trapping problems. In humid climates, avoid the possibility of wicking (i.e., capillary absorption of water), moisture entrapment, and unnecessary contact between wood posts and moisture-bearing materials such as soil, masonry, or concrete.
5. Protect footings from the possibility of soil erosion around the footing.

Bracing and Blocking:

Bracing and blocking help stabilize the deck or boardwalk by limiting lateral movement of the structure. The use of bracing should be considered on all vertical supportive members exceeding 1 500 mm (5 ft) in height, and it is especially important at corners of the structure. Free-standing structures require more support than those supported by adjacent structures. Blocking is more common in platform framing than it is in plank-and-beam framing. The following factors should be considered for bracing and blocking:

1. Methods of fastening are important in bracing details. Moisture trapping should be avoided and connections

should not be weakened by inappropriate or excessive bolting, nailing, etc.

2. For short lengths of bracing [i.e., less than 2 400 mm (8 ft)], 2 x 4's are commonly used, while 2 x 6's are common for longer lengths.

3. Several bracing techniques are commonly used, some stronger than others, but the technique used is largely a matter of aesthetic preference.

Stairs and Railings:

The need for stairs and/or railings on a deck or boardwalk depends on its height above ground level. They become increasingly necessary with greater elevations above ground. Stairs essentially function as a means of level change. Thus, their purpose can sometimes be accomplished by other means, such as regrading, terraced decking, or ramps. Boardwalks can undulate vertically with the ground plane and less often require steps, terracing, or railings. Low-profile decks and boardwalks may not require either steps or railings, but elevated decks usually require both.

Stairs, ramps, railings, and other such features contribute significantly to the overall appearance of the finished deck or boardwalk and therefore require careful attention to design detail. The following factors should be considered for stairs and railings:

1. Local building codes should be checked for safety requirements pertaining to tread/riser ratios, railing heights, rail spacing, etc. (Refer to Section 240: Outdoor Accessibility, and the Americans with Disabilities Act Accessibility Guidelines (ADAAG) for information on handicapped access requirements.)

2. Tread/riser ratios are a function of the difference between the top of stair elevation and the bottom of stair elevation or, if unconstrained conditions exist, are determined according to a particular mood, character, or kinesthetic rhythm that the designer wishes to convey. Normally, outdoor stairs are less steep than indoor stairs, and are generally more pleasant, safer, and easier to negotiate. (Refer to Section 340: Pedestrian Circulation for information on tread/riser ratios.)

3. Level changes can be accomplished in a variety of ways. Investigate alternatives such as regrading, platforms, and ramps.

4. Construction techniques for stair and railing connections vary widely. The design is often determined by the extent of durability and safety necessary. Nails sometimes are not strong enough for railing-to-deck connections. Details that incorporate bolts or lag bolts are preferred.

5. Benches can often serve as safety barriers on low decks.

2.3 Maintenance

Maintenance costs are an important part of wood deck and boardwalk design. The main problem to overcome is wood decay, especially in humid climates. This is largely accomplished by minimizing the incidence of infiltrating moisture, especially at points of connection. Moisture trapping can be avoided, or at least minimized, by the proper use of spacers, flashing, caulking, decktapes, and appropriate joinery. Plank-and-beam framing has an advantage over platform framing in this regard, for it has fewer potential moisture traps and less total area of wood surface requiring protection.

Design details for wood decks and boardwalks should be suitable for outdoor use. Many details that are typical for indoor situations are not suitable for use out-of-doors, including tongue-and-groove decking, tightly mitered corners, etc. The use of such details can result in accelerated deterioration of the wood structure because of their tendency to trap moisture. Some forms of framing hardware (joist hangers, angle irons, plates, etc.) have the disadvantage of trapping moisture unless carefully detailed.

Exposed wood structures should drain freely and should be minimally exposed to contact with plant materials and moist soils.

Special preservative treatments and/or finishes are an important part of maintaining a deck or boardwalk. Most woods require some kind of chemical protection, especially in humid climates. Termites are also a problem in certain regions and may require special flashing and/or chemical treatments (Refer to Section 850: Wood, for more information).

TABLE 460-2. TABLE FOR SELECTION OF DECKING LUMBER

	Weight			
	Moisture Content, 15%		Moisture Content, 8%	
Softwoods	lb/ft^3	kg/m^3	lb/ft^3	kg/m^3
Cedar, Alaska	31.6	506.23	30.4	487.01
Cypress, bald	32.6	522.25	31.4	503.03
Fir, Douglas	30.5–34.3	488.61–549.49	29.2–33.1	467.78–530.26
Fir, true eastern	26.9	430.94	26.4	422.93
Fir, true western	26.7–28.3	427.73–453.37	25.8–27.2	413.32–435.74
Hemlock, eastern	29.0	464.58	28.0	448.56
Hemlock, western	29.6	474.19	28.7	459.77
Cedar, incense	25.5	408.51	24.2	387.68
Larch, western	39.4	613.19	38.2	611.96
Pine, eastern white	25.4	406.91	24.2	387.68
Pine, lodgepole (knotty pine)	29.2	467.78	28.2	451.76
Pine, pitch	34.9	551.09	33.8	541.48
Pine, pond	38.7	619.97	37.5	600.75
Pine, ponderosa	28.6	618.37	27.5	440.55
Pine, red	31.4	503.03	30.4	487.01
Pine, southern yellow	41.6–43.9	666.43–703.28	40.3–42.6	645.61–682.45
	35.7–36.3	571.91–581.53	34.6–25.3	554.29–565.51
Pine, sugar	26.0	416.52	24.0	384.48
Pine, western white	28.0	448.56	27.1	434.14
Cedar, Port Orford	30.1	482.20	28.9	462.98
Cedar, red eastern	33.5	536.67	32.2	515.84
Cedar, red western	23.4	347.87	22.4	358.85
Redwood	28.6	458.17	27.4	438.94
Spruce, eastern	29.4–28.4	470.99–459.97	28.7–27.2	459.77–435.74
Spruce, Engelmann	24.1	386.08	23.2	371.66
Spruce, Sitka	28.1	450.16	27.1	434.14
Tamarack	37.6	602.35	36.3	480.53

Source: Adapted from U.S. Forest Products Laboratory, *Wood Engineering Handbook*, Prentice-Hall, Englewood Cliffs, New Jersey.

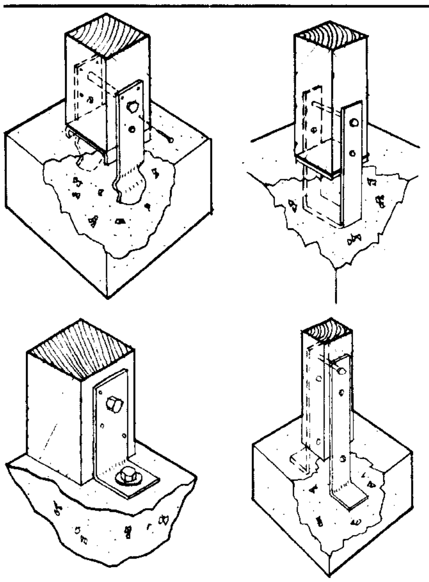

Figure 460-4. Typical post anchors.

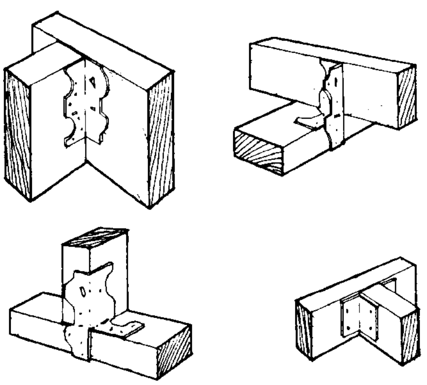

Figure 460-5. Typical framing anchors.

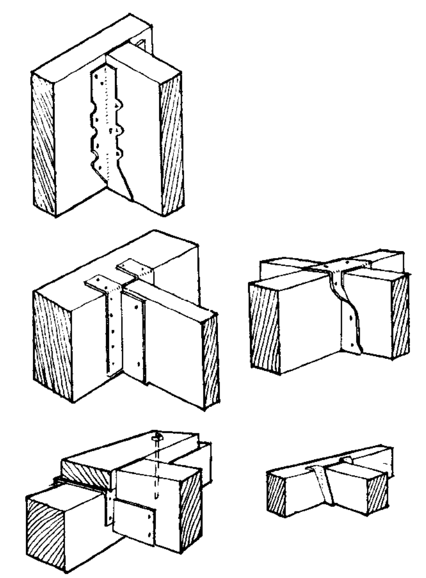

Figure 460-6. Typical joist hangers and girder hangers.

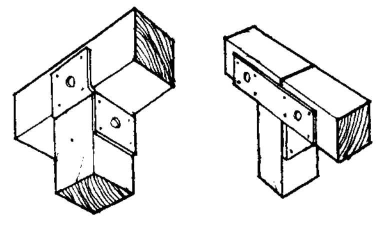

Figure 460-7. Typical post cap and tie plate.

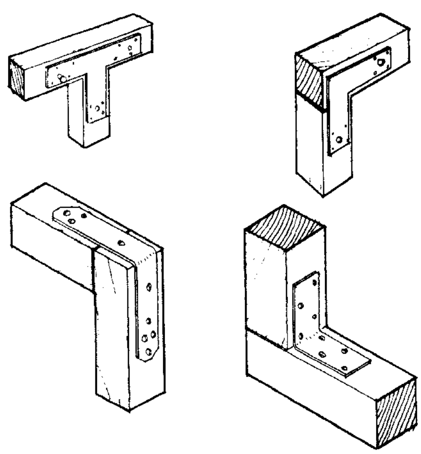

Figure 460-8. Typical metal straps and brackets.

3.0 MATERIALS

3.1 Selection of Materials:

The selection of materials (i.e. lumber and hardware) and their finishing will have an important affect on the final deck or boardwalk. For example, the appearance of the wood is affected by the choice of preservative or finish. Some woods (e.g., cedar and redwood) turn an attractive gray color if left unprotected over time. A sealant can be used to halt the weathering process at any desired point in the color change. Staining lumber will yield various aesthetic characteristics depending on the species and grade of lumber. Corrosion of metals is typically avoided, but the effects of corrosion can be used to aesthetic advantage.

3.2 Wood

Tables 460-1 and 460-2 provide comparative information on various species of wood commonly used for deck construction. Information on decay resistance and the grading of lumber follows (Refer to Section 850: Wood, for a comprehensive explanation of wood and wood products suitable for use out-of-doors.)

Decay Resistance:

Decay resistance is a very important consideration in wood deck and boardwalk design. Not all woods are suitable for use out-of-doors. Some species (e.g., California redwood) are naturally resistant to decay, but no species of wood, regardless of its inherent natural resistance, will last indefinitely without preventative maintenance. Because the effects of climate vary from region to region, the type of treatment necessary will also vary (Refer to Section 850: Wood, for a comprehensive discussion of wood preservatives).

Lumber Grades:

Careful attention to quality and the selection of grade designations are important for many reasons in wood deck construction. Costs, appearances, and relative resistance to decay vary between species and grades, and in some cases between heartwood and sapwood within the same species. Heartwood typically has greater natural resistance to decay than sapwood but is usually more expensive. Appearance is largely a subjective matter, but sapwood may be weak as a result of too many knots. Knots also accept stains and paints poorly.

3.3 Hardware

Various types of metal hardware are typically used in deck and boardwalk construction, primarily as a means of fastening wood members together. Representative examples of each are described below.

Anchors, Hangers, and Plates:

Various types of anchors, hangers, and plates are used to facilitate easy and strong connections between structural members (Figures 460-4 through 460-8).

Nails:

Figure 460-9 illustrates those types of nails commonly used in wood deck and boardwalk construction. (Refer to Section 860: Metals, for a comprehensive description of several other types of nails.) The following factors should be considered for nails:

1. The dimensions, shape, and surface of a nail affect its holding power. Normally, a nail 2-1/2 times as long as the thickness of the board should be used. Hot-dipped galvanized, zinc-coated, cement-coated, ring, and spiral nails also resist withdrawal.
2. Nails with heads (e.g., common) should be used for structural framing. Finish nails are only used in nonstructural situations where appearance is

important. Driving the nail at a slight angle will improve its holding power.

3. Nails may tend to pull out under heavy loading conditions. Bolts or lag bolts should be used in such instances.

4. Aluminum, stainless-steel, and hot-dipped galvanized nails resist rusting and consequent staining of wood.

5. Nails are available in zinc, brass, monel, copper, aluminum, iron, steel, stainless steel, copper bearing steel, and muntz metal. Coatings include tin, copper, cement, brass-plated, zinc, nickel, chrome, cadmium, etched acid, and parkerized.

Wood Screws:

Figure 460-10 illustrates those types of screws that are commonly used in wood deck and boardwalk construction. (Refer to Section 860: Metals, for a comprehensive description of several other types of screws.) The following factors should be considered for wood screws:

1. A screw should be long enough to embed more than one-half of its length into the base.

2. Clearance and pilot holes facilitate the installation of screws and will prevent splitting of the wood member.

3. Flathead screws may be flush or countersunk. Washers under the head are recommended for roundheaded screws, especially with softer woods. These can also be countersunk.

Bolts:

Figure 460-11 illustrates those types of bolts that are commonly used in wood deck and boardwalk construction. (Refer to Section 860: Metals, for a comprehensive description of several other types of bolts.) The following factors should be considered for bolts:

1. Bolts should be long enough to permit a washer under both the head and the nut and allow at least 5 mm (3/16 in) to protrude beyond the nut. Carriage bolts are used with metal plates with a square hole to prevent the bolt from turning while being tightened.

2. A hole 1 mm (1/16") greater than the diameter of the bolt should be drilled for a snug fit. Washers at both ends of bolts are recommended.

3. Lag bolts require a washer under the head. The threaded end of a lag bolt should never be exposed. Pilot holes facilitate the installation of the lag bolt and will prevent splitting of the wood member.

3.4 Masonry

Although this section focuses on the use of wood as a material, it should be noted that in many instances other materials offer advantages. For instance, concrete and masonry materials (such as brick and stone) can be used to build the support system or be used for other components of a deck or boardwalk. Some of these non-wood materials are much stronger and more durable than wood in certain climates, and can offer many aesthetic advantages.

3.5 Other Materials

Plant Materials:

Plant materials can be used with low decks and boardwalks to define edges and to help prevent users from accidentally walking or falling off the structure. Plant materials can also provide screening and windbreaks.

Metals:

In addition to hardware, metal products such as tubing can be used for railings, foot rests, arbors, overhead canopies, and planters. Members such as I-beams and metal columns can be substituted for wooden beams and posts, respectively.

Plastics:

The wide variety of plastics available make this material ideal for many situations. Used for railings, arbors, overhead canopies, tubs, and planters, plastics offer durability, light weight, and a wide variety of colors.

Fabrics:

Fabrics are ideal for such structures as screens, overhead canopies, and miscellaneous decorative elements. The many colors available, especially in the lightweight synthetic fabrics, are advantageous for use as overhead canopies, or roofs of gazebos. Fabrics can also be used as screens on railings for added privacy.

4.0 SIZING WOOD MEMBERS

4.1 Using Span Tables

For the purpose of preliminary design and laying out a rough framing plan, span tables are provided for quick reference. Most span tables for wood deck and boardwalk sizing are calculated for lumber grades of No. 2 or better. Table 460-3 classifies various species of wood according to

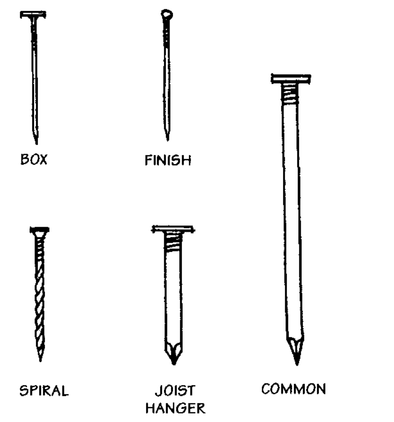

Figure 460-9. Nails commonly used in wood deck construction.

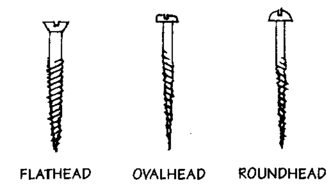

Figure 460-10. Wood screws commonly used in wood deck construction.

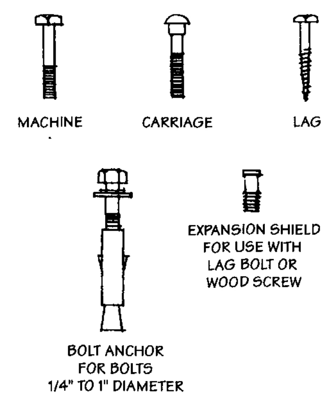

Figure 460-11. Bolts commonly used in wood deck construction.

their inherent strength characteristics and should be used in conjunction with the span tables. It is recommended that local code enforcing agencies and a structural engineer be consulted when finalizing any deck or boardwalk design.

Recommended live-loads for different decking uses:

Type of Deck	Load: kg/m²	(lb/ft²)
Residential decks	195-290	(40-60)
Public decks	390-490	(80-100)
Foot bridges	490	(100)
Light vehicular bridge	980-1 470	(200-300)

The average dead load allowance (weight of decking plus fasteners, etc. per m^2 (ft^2) is 49 kg/m^2 (10 lb/ft^2).

Figure 460-12 shows the interrelationships between decking spans, joist spans, and beam spans. Tables 460-4 through 460-8 provide a quick means for determining maximum allowable spans for decking, joists, and beams based on their cross-sectional dimensions, the species of lumber used, and in the case of joists and beams, their spacing. Table 460-9 shows post sizes and corresponding maximum allowable heights based on the cross-sectional dimensions and the species of lumber used.

4.2 Sizing Example

Figure 460-13 shows the general layout of a simple 4 800 x 7 200 mm (16 x 24 ft) platform-framed residential deck attached to a house sill along one edge. The joists are supported by a ledger connected to the house sill and a continuous beam which in turn is supported by three 1 200 mm (4 ft) long piers. Although the effective span is the distance from the face of beam to the face of the sill ledger, a margin of safety is achieved by using the centerline span value in calculations. Basic wood deck and boardwalk member sizing involves the following steps:

1. **Preliminary Framing Plan:** Develop a preliminary framing plan to locate the position of bearing beams, associated posts and piers, joists, and decking systems with the aim of creating a simple, uncluttered structural design.
2. **Estimate the Design Loads:** Estimate the loads to be carried by each structural element of the deck and the accumulated loads bearing down on each post or pier. Local codes require minimum load allowances for live loads (people, snow drifts, etc.) and dead loads (decking and hardware weight), which vary from region to region. (Refer to 4.3 Estimating Design Loads for calculations).
3. **Calculate Lumber Dimensions:** Using the appropriate span tables, determine the dimensions required for each structural element, in this case, the joists, beams, and posts. The design loads exerted by each tributary load area (t) are transferred to their respective posts. Figure 460-13 illustrates the general framing plan of the proposed deck, and the dashed lines outline the center (t_1) and corner (t_2) load areas. The total tributary load area exerted on

TABLE 460-3. STRENGTH GROUPINGS OF COMMON SOFTWOOD SPECIES

Strength Group	Species
High	Douglas fir Hemlock, western Larch, western Pine: Loblolly† Longleaf† Pitch Slash Shortleaf Virginia Spruce: Canadian coastal Coast Sitka
Moderate	Cedar, western red Cypress Douglas fir (south) Fir: Subalpine White Hemlock: Eastern Western Pine: Eastern white Lodgepole Ponderosa Red Sugar Western white Redwood, California Spruce: Eastern Engelmann Sitka Tamarack
Low	Cedar, northern white

* No. 1 or better.

† Also known as southern pine.

Source: Adapted from *U.S. Department of Agriculture Construction Guides for Exposed Wood Decks,* U.S.D.A. Handbook No. 432, 1972.

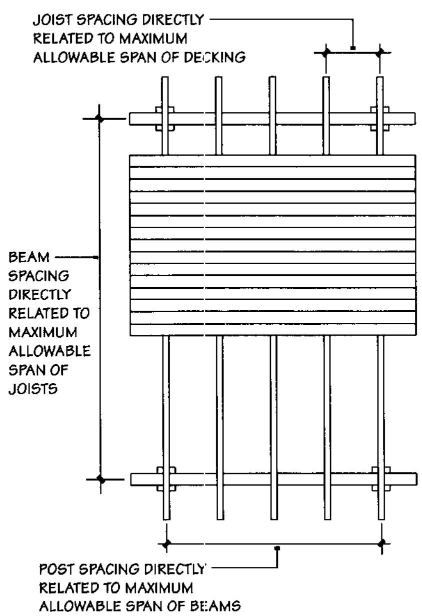

Figure 460-12. Decking, joist, and beam span relationships.

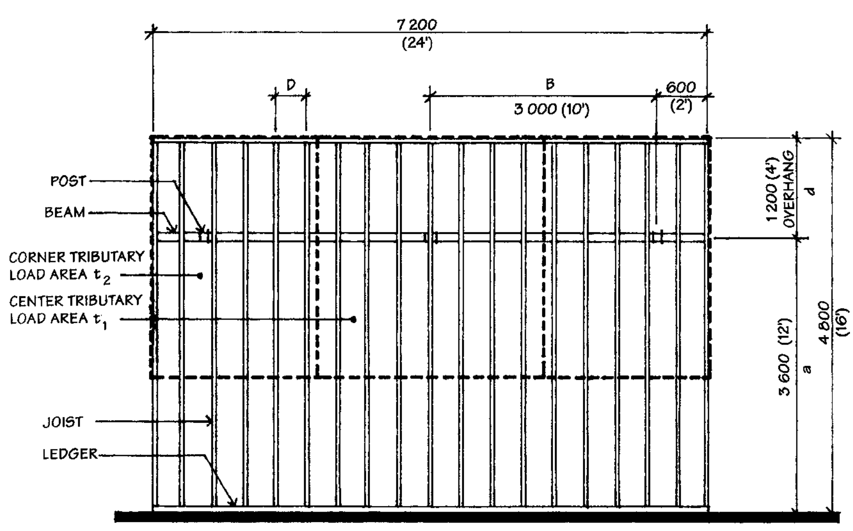

Figure 460-13. Example problem: General layout of platform-framed residential deck.

TABLE 460-4. MAXIMUM DECKING SPANS (JOIST SPACING)

Species	Nominal Decking Size	Recommended Span
Douglas-Fir, Southern Pine,	RED[a]	16"[c]
Hem-Fir, SPF, SPF (south),	2 x 4[b]	24"
Ponderosa Pine, Redwood, Western Cedar	2 x 6[b]	24"

[a]RED is radius edge decking, 4" to 6" widths.
[b]Grade is No. 2 or better.
[c]Southern Pine RED can span 24".
Source: Adapted from McDonald et.al, *Wood Decks: Materials, Construction, and Finishing,* Forest Products Laboratory, Madison, WI, 1996.

TABLE 460-5. MAXIMUM JOIST SPANS (BEAM SPACING)

Species	Joist Size†	Joist Spacing (Inches on Center) 40 lb/ft² Live Load*			60 lb/ft² Live Load*		
		12"	16"	24"	12"	16"	24"
Douglas-Fir, Southern Pine	2 x 6	10'4"	9'5"	7'10"	9'0"	8'2"	6'8"
	2 x 8	13'8"	12'5"	10'2"	11'11"	10'6"	8'7"
	2 x 10	17'5"	15'5"	12'7"	15'0"	13'0"	10'7"
	2 x 12	20'0"	17'10"	14'7"	17'5"	15'1"	12'4"
Hem-Fir, SPF, SPF (south)	2 x 6	9'2"	8'4"	7'3"	8'0"	7'3"	6'3"
	2 x 8	12'1"	10'11"	9'6"	10'6"	9'6"	8'0"
	2 x 10	15'4"	14'0"	11'7"	13'5"	12'0"	9'10"
	2 x 12	18'8"	16'6"	13'6"	16'1"	14'0"	10'10"
Ponderosa Pine, Redwood, Western Cedar	2 x 6	8'10"	8'0"	7'0"	7'9"	7'0"	5'11"
	2 x 8	11'8"	10'7"	8'10"	10'2"	9'2"	7'6"
	2 x 10	14'10"	13'3"	10'10"	12'11"	11'2"	9'2"
	2 x 12	17'9"	15'4"	12'7"	15'0"	13'0"	10'7"

*Includes 10 lb/ft² dead load
†Joists are on edge, and Grade is No. 2 or better.
Source: Adapted from McDonald et.al, *Wood Decks: Materials, Construction, and Finishing,* Forest Products Laboratory, Madison, WI, 1996.

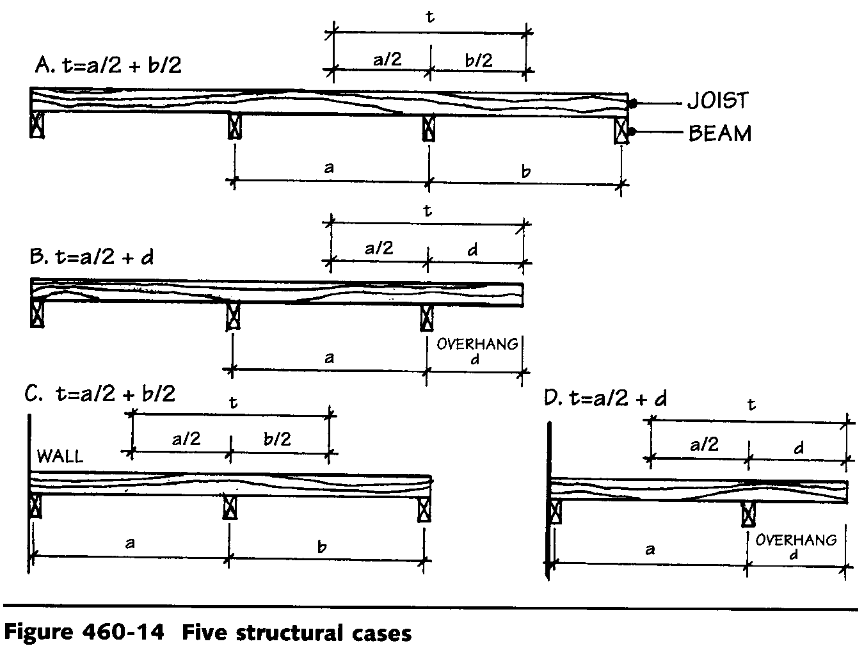

Figure 460-14 Five structural cases

each post can be calculated using the formulae in Figure 460-14, which show five different structural cases, labeled A, B, C, and D.

4. **Refine structural design:** Refine the structural design to reflect the calculations and complete the final design.

4.3 Post Sizing

Post height is measured from the top of footing to the bottom of the beam to which it is attached. Post size is a function of wood species, height, cross sectional area, and total weight carried, called the tributary area load. Figure 460-13 illustrates the tributary load areas for the center post (t_1) and corner posts (t_2). The center tributary area is greatest and therefore exerts the largest post load. The sizing of the post carrying the most load is typically used to determine the post size for all other deck posts. The post spacing distance is multiplied by the beam spacing distance to determine the center tributary area in a symmetrically loaded deck. However, the example deck in Figure 460-13 shows a cantilever or overhang condition, which requires a different method of calculation. This deck is best represented by case "D" in Figure 460-14, which requires the beam spacing to be divided by two and added to the overhang value. The resultant value "t" is then multiplied by the post spacing to determine the center post tributary area:

From Figure 460-13:

Beam spacing (a) = 3 600 mm
Overhang (d) = 1 200 mm
Post spacing (B) = 3 000 mm

t = a/2 + d
t = 3 600/2 + 1 200
t = 1 800 + 1 200
t = 3 000
Tributary load area = t x B

Tributary load area = 3 000 x 3 000
area equals = 9 000 000 mm² or 9 m²

Tables 460-9 indicates that a 4x4 post will support a 195 kg/m² (40 lb/ft²) live load to a maximum 2 400 mm (8 ft) height and a 293 kg/m² (60 lb/ft²) live load to a maximum 1 800 mm (6 ft) height using a Southern pine species for a tributary load area of 9 m² (100 ft²). Greater post heights require a thicker cross section or a shorter post height (Note: use the next lowest area value in the table to determine the maximum post height if calculated tributary load area falls between table area values.

TABLE 460-6. MAXIMUM BEAM SPANS (POST SPACING) FOR DOUGLAS-FIR AND SOUTHERN PINE

Beam Size†	Tributary Load Width, ft												
	4'	5'	6'	7	8'	9'	10'	11'	12'	13'	14'	15'	16'
40 lb/ft² Live Load Deck Design*													
(2) 2 x 6	7'	6'											
(2) 2 x 8	9'	8'	7'	7'	6'	6'							
(2) 2 x 10	11'	10'	9'	8'	8'	7'	7'	6'	6'	6'	6'		
(3) 2 x 8	12'	11'	10'	9'	8'	8'	7'	7'	7'	6'	6'	6'	
(2) 2 x 12	13'	12'	10'	10'	9'	8'	8'	7'	7'	7'	6'	6'	6'
(3) 2 x 10	15'	13'	12'	11'	10'	10'	9'	9'	8'	8'	8'	7'	7'
(3) 2 x 12	16'	15'	14'	13'	12'	11'	11'	10'	10'	9'	9'	8'	8'
4 x 6	7'	7'	6'										
4 x 8	10'	9'	8'	7'	7'	6'	6'	6'					
6 x 8	12'	10'	9'	9'	8'	8'	7'	7'	6'	6'	6'	6'	
4 x 10	12'	11'	10'	9'	8'	8'	7'	7'	7'	6'	6'	6'	6'
4 x 12	14'	13'	11'	10	10'	9'	9'	8'	8'	7'	7'	7'	7'
6 x 10	15'	13'	12'	11'	10'	10'	9'	9'	8'	8'	7'	7'	7'
6 x 12	16'	16'	15'	13'	12'	12'	11'	10'	10'	10'	9'	9'	8'
60 lb/ft² Live Load Deck Design*													
(2) 2 x 6	6'												
(2) 2 x 8	7'	7'	6'										
(2) 2 x 10	9'	8'	7'	7'	6'								
(3) 2 x 8	10'	9'	8'	7'	7'	6'	6'						
(2) 2 x 12	11'	10'	9'	8'	7'	7'	6'	6'	6'				
(3) 2 x 10	12'	11'	10'	9'	9'	8'	8'	7'	7'	6'	6'	6'	6'
(3) 2 x 12	14'	13'	12'	11'	10'	9'	9'	8'	8'	8'	7'	7'	6'
4 x 6	6'												
4 x 8	8'	7'	6'	6'									
6 x 8	10'	9'	8'	7'	7'	6'	6'						
4 x 10	10'	9'	8'	7'	7'	6'	6'	6'					
4 x 12	12'	10'	9'	9'	8'	8'	7'	7'	6'	6'	6'		
6 x 10	12'	11'	10'	9'	9'	8'	8'	7'	7'	6'	6'	6'	6'
6 x 12	15'	13'	12'	11'	10'	10'	9'	9'	8'	8'	8'	7'	7'

*Includes 10 lb/ft² dead load

†Number in parentheses is number of full-length nailed laminations.

Source: Adapted from McDonald et.al, *Wood Decks: Materials, Construction, and Finishing,* Forest Products Laboratory, Madison, WI, 1996.

TABLE 460-7. MAXIMUM BEAM SPANS (POST SPACING) FOR HEM-FIR, SPF, AND SPF (SOUTH)

Beam Size†	Tributary Load Width, ft												
	4'	5'	6'	7	8'	9'	10'	11'	12'	13'	14'	15'	16'
40 lb/ft² Live Load Deck Design*													
(2) 2 x 6	6'	6'											
(2) 2 x 8	8'	7'	6'	6'									
(2) 2 x 10	10'	9'	8'	7'	7'	6'	6'						
(3) 2 x 8	11'	10'	9'	8'	7'	7'	6'	6'	6'				
(2) 2 x 12	11'	10'	9'	8'	8'	7'	7'	6'	6'	6'			
(3) 2 x 10	13'	12'	11'	10'	9'	8'	8'	8'	7'	7'	6'	6'	
(3) 2 x 12	15'	14'	12'	11'	11'	10'	9'	9'	8'	8'	8'	7'	7'
4 x 6	7'	6'	6'										
4 x 8	9'	8'	7'	6'	6'	6'							
6 x 8	9'	8'	8'	7'	7'	6'	6'	6'					
4 x 10	11'	10'	9'	8'	7'	7'	6'	6'	6'				
4 x 12	13'	11'	10	9'	9'	8'	7'	7'	7'	6'	6'	6'	
6 x 10	12'	11'	10	9'	8'	8'	7'	7'	7'	6'	6'	6'	6'
6 x 12	15'	13'	12'	11'	10'	10'	9'	9'	8'	8'	7'	7'	7'
60 lb/ft² Live Load Deck Design*													
(2) 2 x 6	5'												
(2) 2 x 8	7'	6'											
(2) 2 x 10	8'	7'	7'	6'									
(3) 2 x 8	9'	8'	7'	7'	6'								
(2) 2 x 12	10'	9'	8'	7'	6'	6'							
(3) 2 x 10	11'	10'	9'	8'	8'	7'	6'	6'					
(3) 2 x 12	13'	11'	10'	9'	9'	8'	8'	7'	6'	6'	6'		
4 x 6	5'												
4 x 8	7'	6'											
6 x 8	8'	7'	7'	6'									
4 x 10	9'	8'	7'	7'	6'								
4 x 12	10'	9'	8'	8'	7'	7'	6'	6'					
6 x 10	10'	9'	8'	8'	7'	7'	6'	6'	6'				
6 x 12	12'	11'	10'	9'	9'	8'	8'	7'	6'	6'	6'	6'	6'

*Includes 10 lb/ft² dead load

†Number in parentheses is number of full-length nailed laminations.

Source: Adapted from McDonald et.al., *Wood Decks: Materials, Construction, and Finishing,* Forest Products Laboratory, Madison, WI 1996.

TABLE 460-8. MAXIMUM BEAM SPANS (POST SPACING) FOR PONDEROSA PINE, REDWOOD, AND WESTERN CEDAR

Beam Size†	Tributary Load Width, ft												
	4'	5'	6'	7	8'	9'	10'	11'	12'	13'	14'	15'	16'
40 lb/ft² Live Load Deck Design*													
(2) 2 x 6	6'												
(2) 2 x 8	8'	7'	6'	6'									
(2) 2 x 10	9'	8'	8'	7'	6'	6'	6'						
(3) 2 x 8	10'	9'	8'	8'	7'	7'	6'	6'					
(2) 2 x 12	11'	10'	9'	8'	7'	7'	7'	6'	6'				
(3) 2 x 10	13'	11'	10'	9'	8'	8'	7'	7'	7'				
(3) 2 x 12	15'	13'	12'	11'	10'	9'	9'	8'	8'	8'	7'	7'	7'
4 x 6	7'	6'											
4 x 8	9'	8'	8'	7'	6'	6'	6'						
6 x 8	9'	8'	8'	7'	7'	6'	6'	6'					
4 x 10	10'	9'	8'	8'	7'	7'	6'	6'	6'				
4 x 12	12'	11'	10	9'	8'	8'	7'	7'	6'	6'	6'	6'	
6 x 10	12'	11'	10	9'	8'	8'	7'	7'	7'	6'	6'	6'	
6 x 12	15'	13'	12'	11'	10'	9'	9'	8'	8'	8'	7'	7'	7'
60 lb/ft² Live Load Deck Design*													
(2) 2 x 8	6'	6'											
(2) 2 x 10	8'	7'	6'	6'									
(3) 2 x 8	9'	8'	7'	6'	6'								
(2) 2 x 12	9'	8'	7'	7'	6'	6'							
(3) 2 x 10	11'	9'	8'	8'	7'	7'	6'	6'					
(3) 2 x 12	12'	11'	10'	9'	8'	8'	7'	7'	6'	6'			
4 x 8	7'	6'	6'										
6 x 8	8'	7'	6'	6'									
4 x 10	9'	8'	7'	6'									
4 x 12	10'	9'	8'	7'	7'	6'	6'						
6 x 10	10'	9'	8'	7'	7'	6'	6'	6'					
6 x 12	12'	11'	10'	9'	8'	8'	7'	7'	7'	6'	6'	6'	

*Includes 10 lb/ft² dead load

†Number in parentheses is number of full-length nailed laminations.

Adapted from McDonald et.al., *Wood Decks: Materials, Construction, and Finishing,* Forest Products Laboratory, Madison, WI 1996.

TABLE 460-9. MAXIMUM POST HEIGHTS

Species	Post Size	Tributary Load Area to Post, ft^2																		
		36	48	60	72	84	96	108	120	132	144	156	168	180	192	204	216	228	240	256
40 lb/ft^2 Live Load Deck Design*																				
Southern Pine, Douglas-Fir	4x4	10'	10'	10'	9'	9'	8'	8'	7'	7'	6'	6'	6'	6'	5'	5'	5'	4'	4'	4'
	4x6	14'	14'	13'	12'	11'	10'	10'	9'	9'	8'	8'	8'	7'	7'	7'	7'	6'	6'	6'
	6x6 (No.1)	17'	17'	17'	17'	17'	17'	17'	17'	17'	17'	17'	17'	16'	16'	15'	15'	14'	14'	13'
	6x6 (No.2)	17'	17'	17'	17'	17'	17'	17'	17'	16'	16'	15'	14'	13'	13'	12'	11'	10'	8'	
Hem-Fir, SPF	4x4	10'	10'	10'	9'	9'	8'	8'	7'	7'	6'	6'	6'	6'	5'	5'	5'	4'	4'	4'
	4x6	14'	14'	13'	12'	11'	11'	10'	9'	9'	9'	8'	8'	8'	7'	7'	7'	7'	6'	6'
	6x6 (No.1)	17'	17'	17'	17'	17'	17'	17'	17'	17'	17'	17'	16'	16'	15'	15'	14'	13'	13'	12'
	6x6 (No.2)	17'	17'	17'	17'	17'	17'	17'	17'	16'	15'	13'	12'	10'	8'					
Ponderosa Pine, Redwood, Western cedar, SPF (south)	4x4	10'	10'	9'	8'	7'	7'	6'	6'	5'	4'									
	4x6	14'	13'	12'	11'	10'	9'	8'	8'	7'	7'	7'	6'	6'	5'	5'	4'	4'		
	6x6 (No.1)	17'	17'	17'	17'	17'	17'	17'	17'	16'	15'	15'	14'	14'	13'	13'	12'	12'	11'	11'
	6x6 (No.2)	17'	17'	17'	17'	17'	16'	13'	7'											
60 lb/ft^2 Live Load Deck Design*																				
Southern Pine, Douglas-Fir	4x4	10'	10'	9'	8'	7'	7'	6'	6'	5'	5'	5'								
	4x6	14'	12'	11'	10'	9'	9'	8'	8'	7'	7'	7'	6'	6'	6'	5'	5'	5'	5'	
	6x6 (No.1)	17'	17'	17'	17'	17'	17'	17'	17'	16'	15'	14'	14'	13'	13'	12'	12'	11'	11'	10'
	6x6 (No.2)	17'	17'	17'	17'	17'	16'	15'	14'	13'	12'	11'	9'	6'						
Hem-Fir, SPF	4x4	10'	10'	9'	8'	7'	7'	6'	6'	6'	5'	5'								
	4x6	14'	13'	11'	10'	9'	9'	8'	8'	7'	7'	7'	6'	6'	6'	5'	5'			
	6x6 (No.1)	17'	17'	17'	17'	17'	17'	17'	16'	16'	15'	14'	13'	12'	12'	11'	10'	9'	8'	7'
	6x6 (No.2)	17'	17'	17'	17'	17'	16'	14'	12'	10'										
Ponderosa Pine, Redwood, Western cedar, SPF (south)	4x4	10'	9'	7'	7'	6'	5'													
	4x6	13'	11'	10'	9'	8'	7'	7'	6'	5'	5'									
	6x6 (No.1)	17'	17'	17'	17'	17'	16'	15'	14'	13'	13'	12'	11'	11'	10'	10'	9'	9'	8'	6'
	6x6 (No.2)	17'	17'	17'	15'	9'														

*Includes 10 lb/ft^2 dead load
Source: Adapted from McDonald et.al., *Wood Decks: Materials, Construction, and Finishing,* Forest Products Laboratory, Madison, WI 1996.

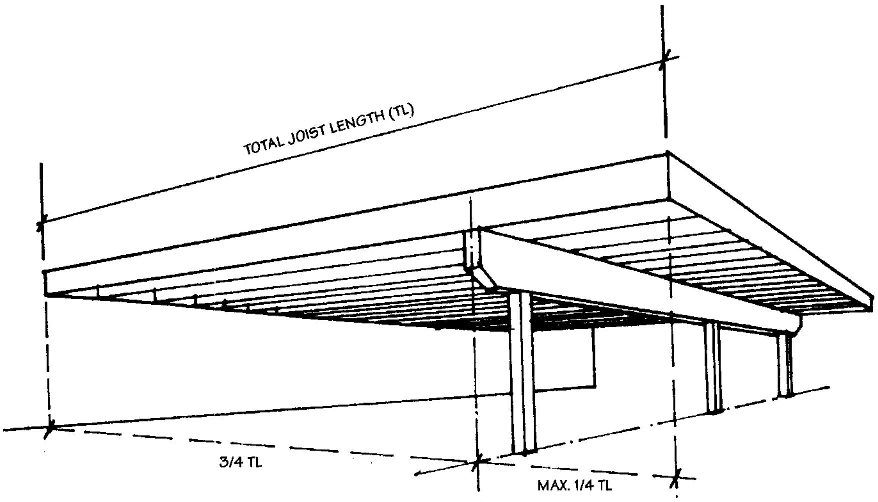

Figure 460-15. Joist cantilever principal.

4.4 Beam Sizing

Figure 460-13 illustrates the beam span to be dimension "B" [3 000 mm (10 ft)], or the distance between supporting posts. The tributary load width for deck beams is calculated by using Case "D" in Figure 460-14 as before, yielding t = 3 000 mm.

Tables 460-6 through 460-8 [195 and 293 kg/m^2 (40 and 60 lb/ft^2) design loads] show that a beam with a 3 000 mm (10 ft) tributary load, and a 3 000 mm (10 ft) post spacing, will require a 150 x 300 mm (6 x 12 in) Douglas fir or Southern pine beam for a 195 kg/m^2 (40 lb/ft^2) load. However, a 293 kg/m^2 (60 lb/ft^2) live load will require closer post spacing to safely carry the tributary load. If the posts are spaced 2 400 mm (8 ft) apart, then a Douglas-fir, or Southern pine beam measuring 150 x 250

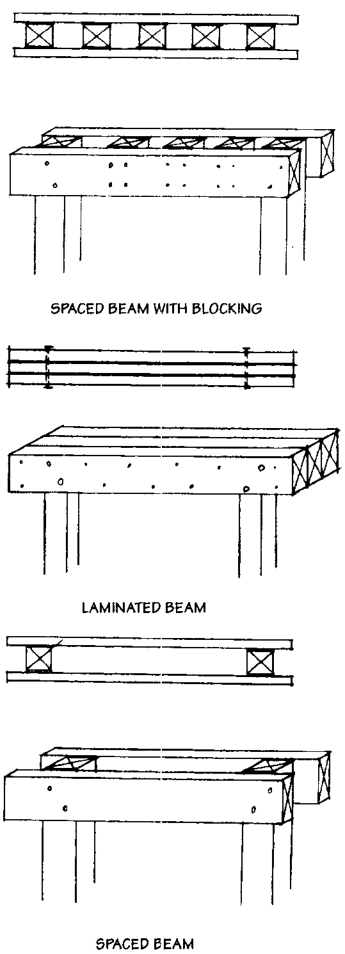

Figure 460-16. Built-up beam assemblies.

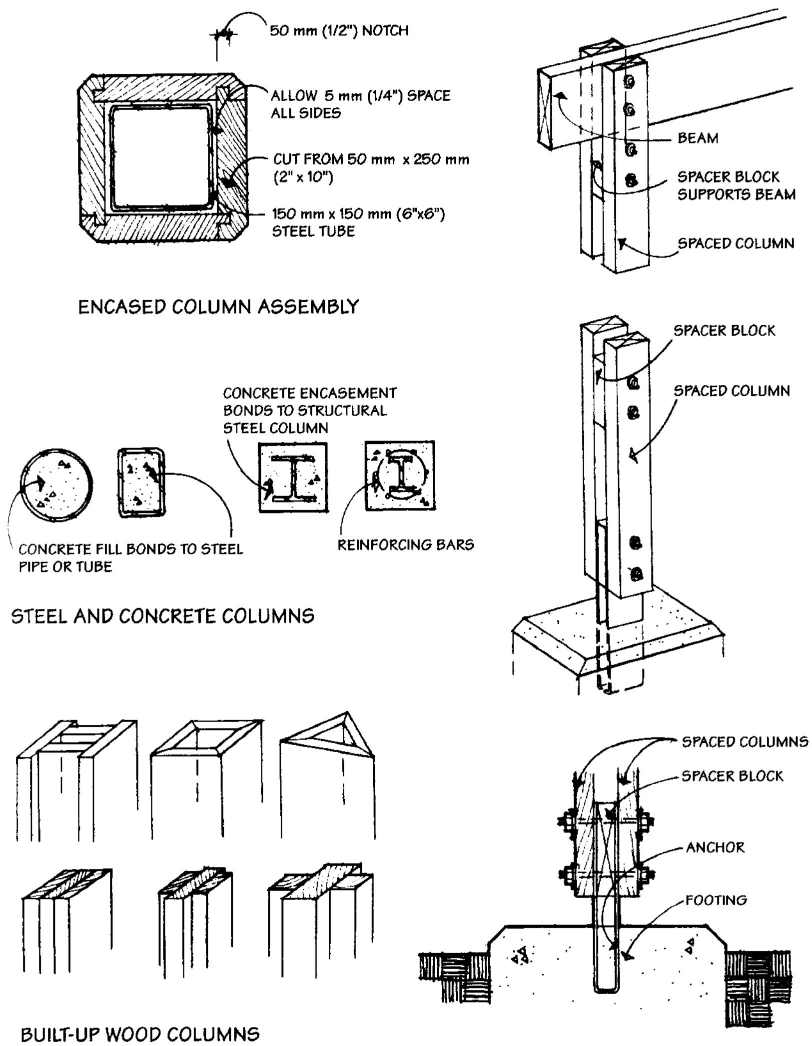

Figure 460-17. Built-up posts and columns.

mm (6 x 10 in) would safely carry the tributary load. It should be noted that solid wood beams are rated for greater spans than are composite beams fashioned from double or triple 50 mm x (2 x) stock.

4.5 Joist Sizing

Figure 460-13 illustrates a total deck width of 4 800 mm (16 ft) using joists which cantilever over the main beam for a distance of 1 200 mm (4 ft). Figure 460-15 illustrates the principle that the cantilever of a simple joist should not exceed 1/4 of the total joist length. The central joist span from sill to beam is 3 600 mm (12 ft). The joist spacing ("D" in Figure 460-13) is limited by the decking material maximum span. This deck uses 25 mm (1 in) radius edged cedar decking which has a maximum span of 400 mm (16 in). However, it should be noted that Southern pine radius edged decking may span 600 mm (24 in).

Table 460-5 provides joist span data for various wood species, joist sizes and spacing values (D). A 195 kg/m^2 (40 lb/ ft^2) load would require 50 x 200 mm (2 x 8 in) Douglas fir/Southern pine joists spaced 400 mm (16 in) on center to effectively span 3 600 mm (12 ft). However, if required to support a 293 kg/m^2 (60 lb/ ft^2) live load using 400 mm (16 in) on center spacing, then the joists would need to be at least 50 x 250 mm (2 x 10 in) to achieve at least a 3 600 mm (12 ft) span.

4.6 Decking Sizing

Table 460-4 shows maximum decking spans as modified by species and decking size.

5.0 CONSTRUCTION DETAILS

In addition to the various details shown earlier in this section, Figures 460-16 through 460-33 of this section illustrate several other details and principles commonly used in wood deck and boardwalk construction.

KEY POINTS: Structural Design

Wood decks and boardwalks must be constructed to withstand the combined weight of both structural materials and the intended users, and must be detailed to withstand the decaying effects of the exterior environment.

1. Design weights range from 195-290 kg/m^2 (40-60 lb/ft^2) for residential decks, to 980-1 465 kg/m^2 (200-300 lb/ft^2) for light vehicular bridges.
2. Graded lumber must possess the structural properties required for designated spans and loading (Refer to Tables 460-4 through 460-9), and must be suitable for exterior exposure.
3. Span tables or span formulas should be used conservatively to account for unforeseen events or loading circumstances. Avoid working at the outer limits of each structural calculation.
4. Local building codes should be studied prior to design to insure compliance within the typical permitting process.
5. Both pressure treated and untreated decks should slope at least 2%, and rails, caps, and other horizontal surfaces should be milled to drain to protect structural integrity.
6. It is recommended that beams bear directly onto posts or notched sills, rather than be attached to post faces with lag screws or bolts to guard against splitting.
7. Plated or stainless steel fasteners are required for all exterior connections.
8. Wood should be sealed with appropriate penetrating coatings to prevent wood grain from exposure to the elements.
9. Ledgers and sills should be properly flashed and spaced to allow for air circulation to avoid moisture penetration.
10. Posts should be attached to concrete pier footings using coated metal fasteners designed to allow air circulation around the post bottom.
11. Grading around footings should prevent erosion in sloping conditions from washing soil cover away from piers, especially in frost/thaw regions, or clay regions.

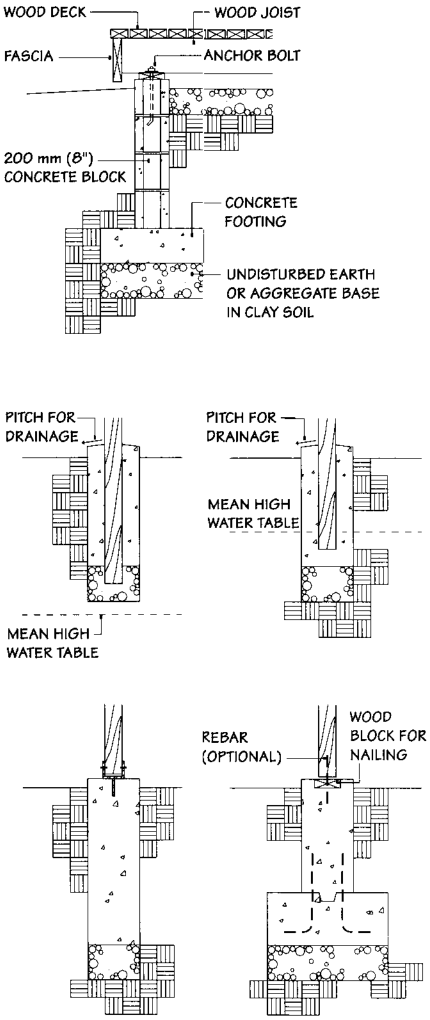

Figure 460-18. Footings and piers.

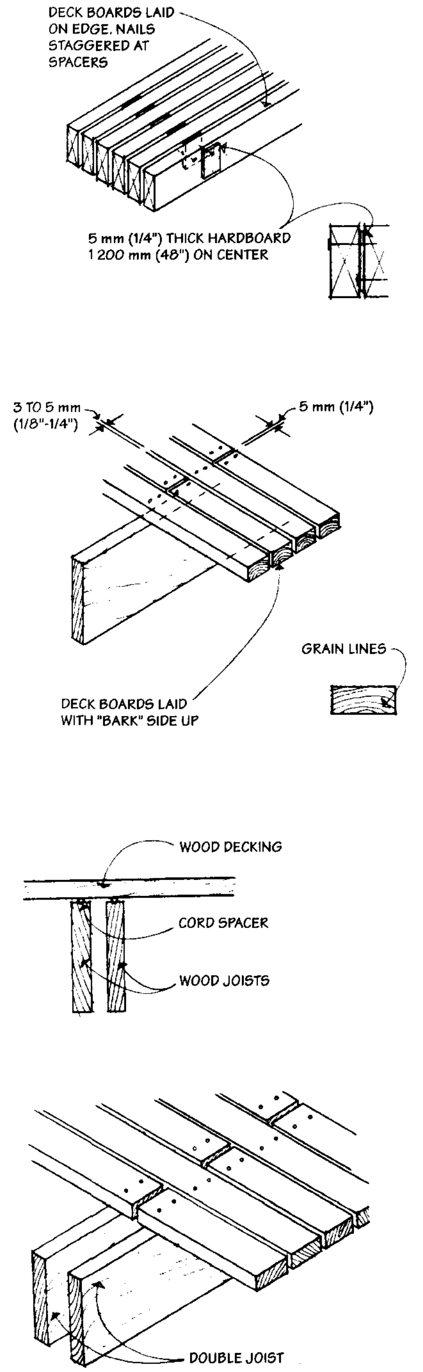

Figure 460-19. Decking details.

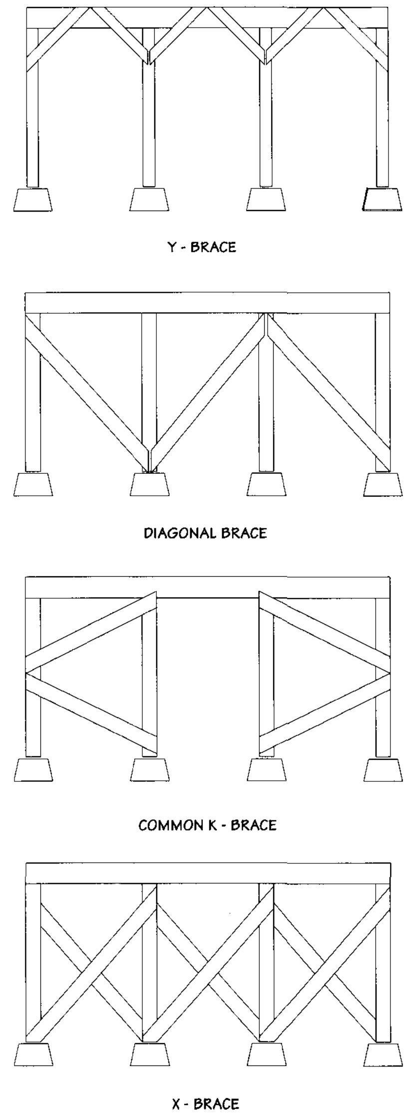

Figure 460-20. Typical bracing systems.

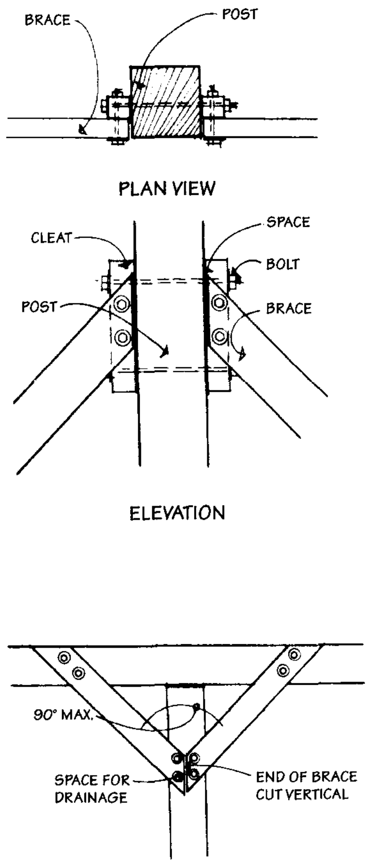

Figure 460-21. Bracing details.

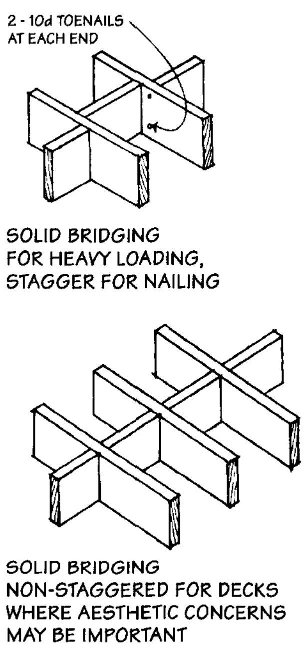

Figure 460-22. Bridging details.

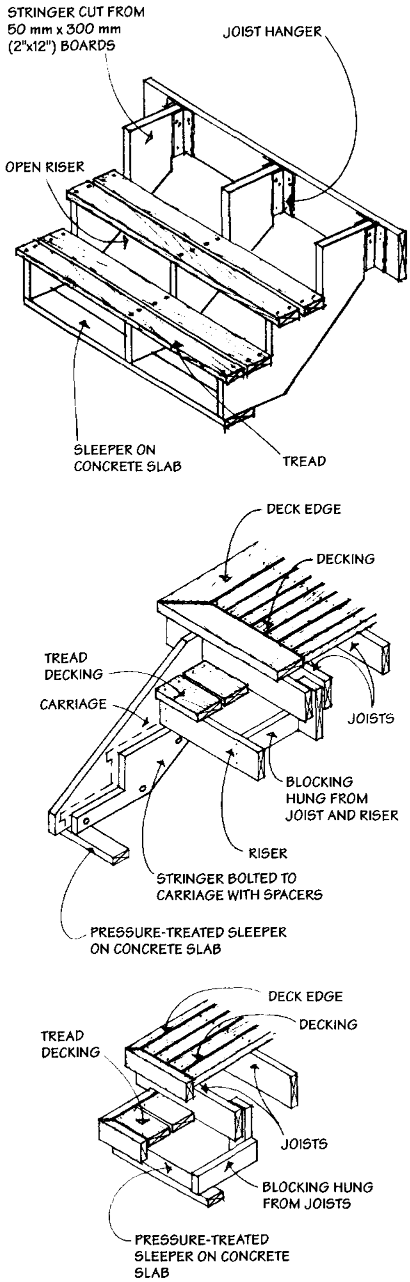

Figure 460-23. Typical stair details.

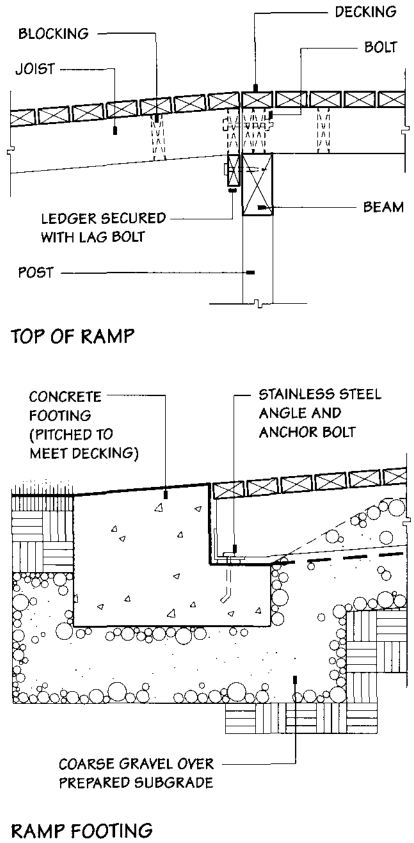

Figure 460-24. Typical ramp assemblies.

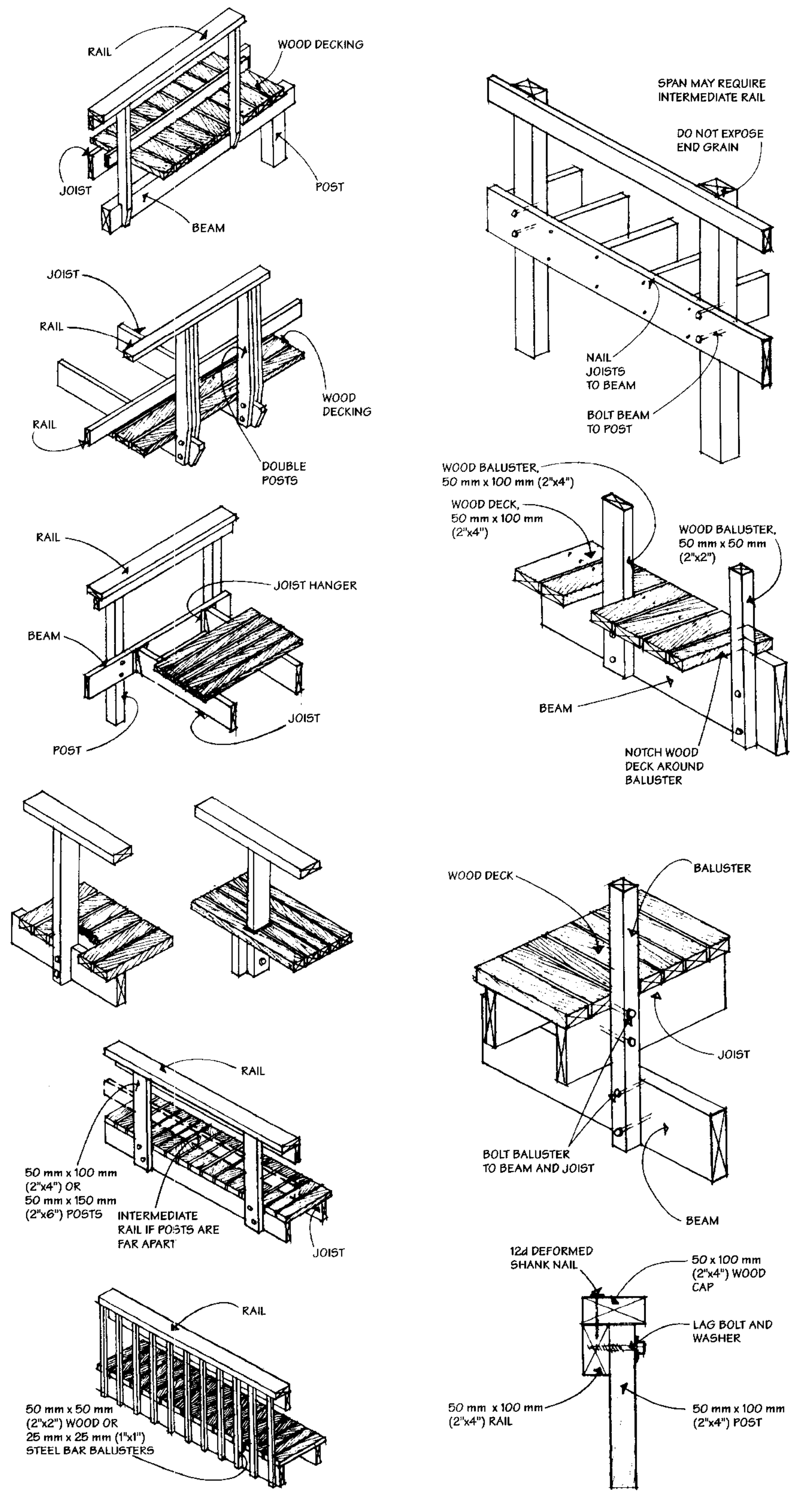

Figure 460-25. Typical railing assemblies.

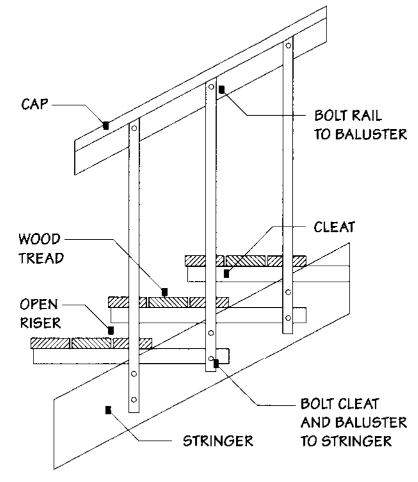

Figure 460-26. Stair to railing details.

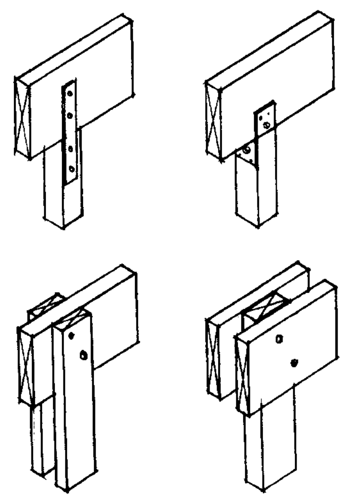

Figure 460-27. Beam to post connections.

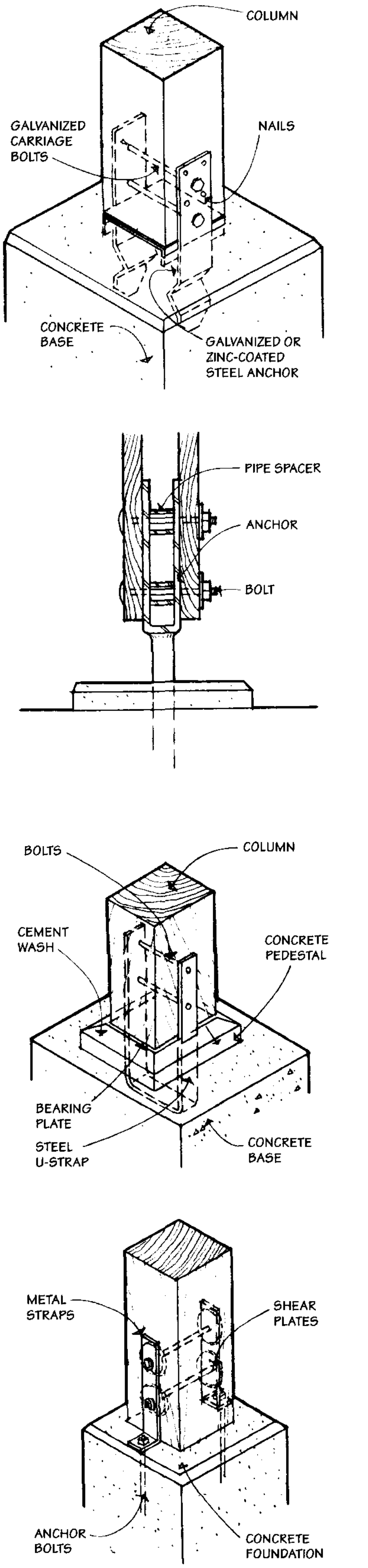

Figure 460-28. Post to pier connections.

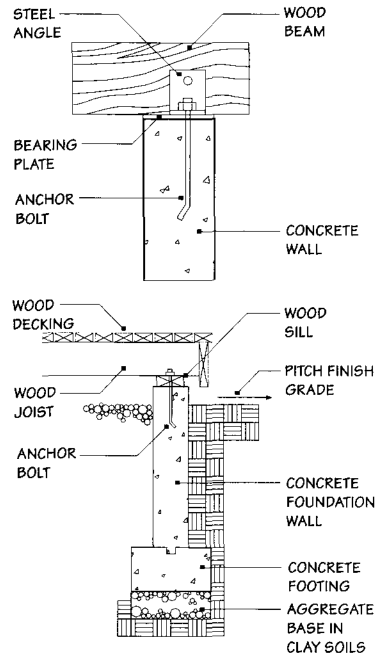

Figure 460-29. Beam to pier connections.

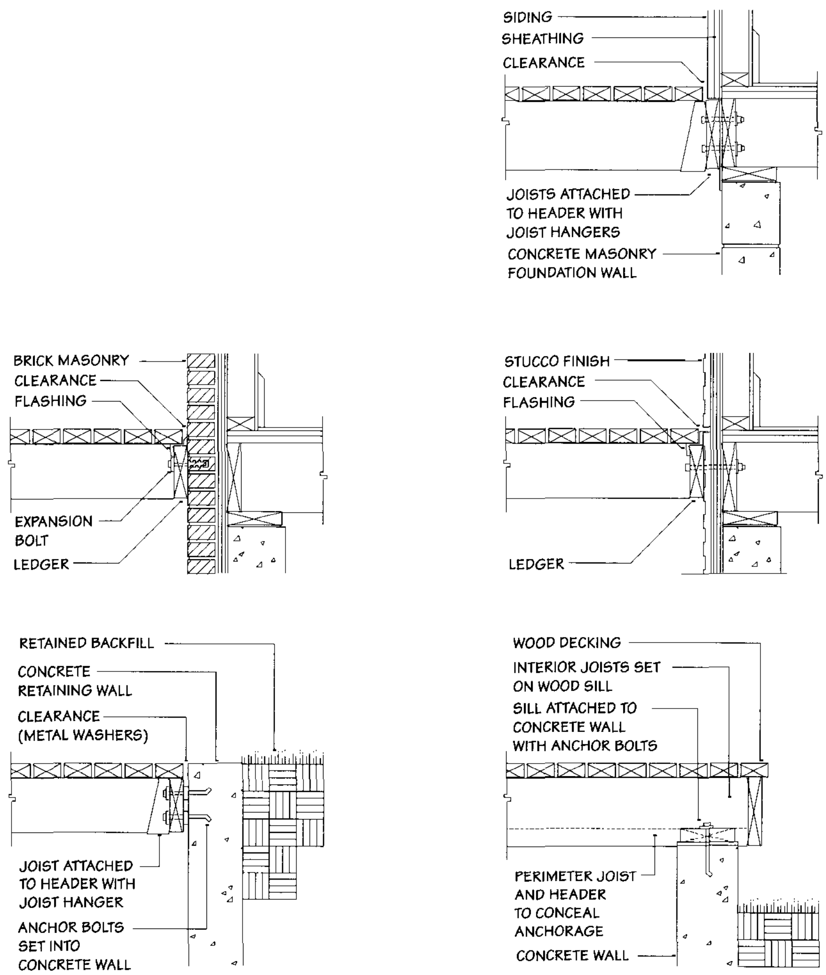

Figure 460-30 . Anchorage to fixed structures.

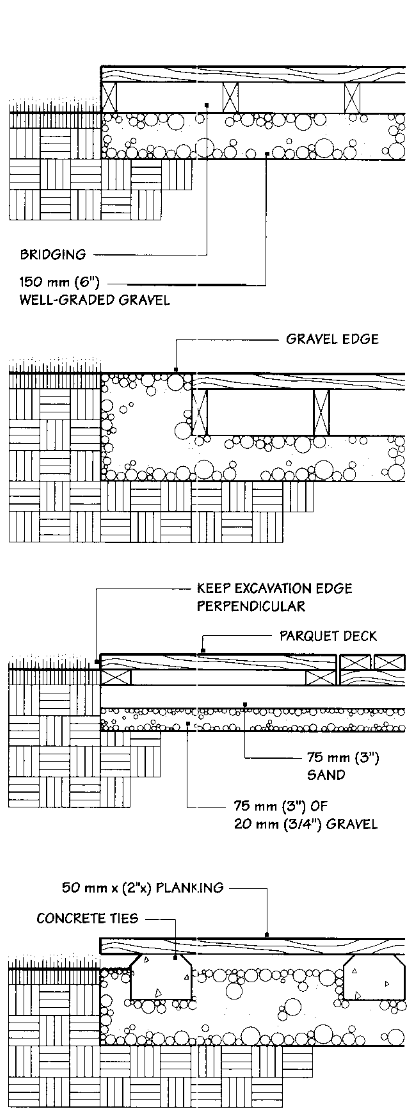

Figure 460-31. Low profile decks on grade.

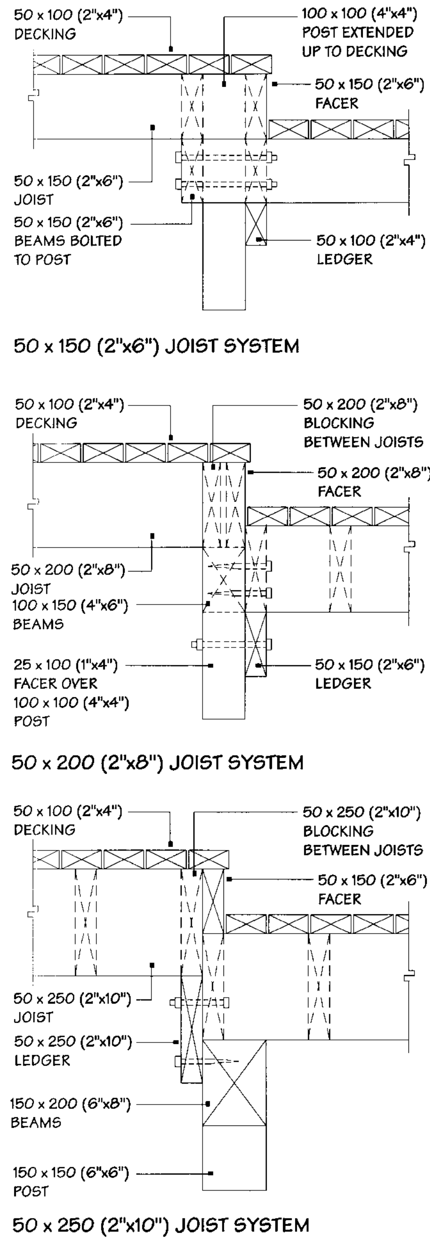

Figure 460-32. Level change in decking.

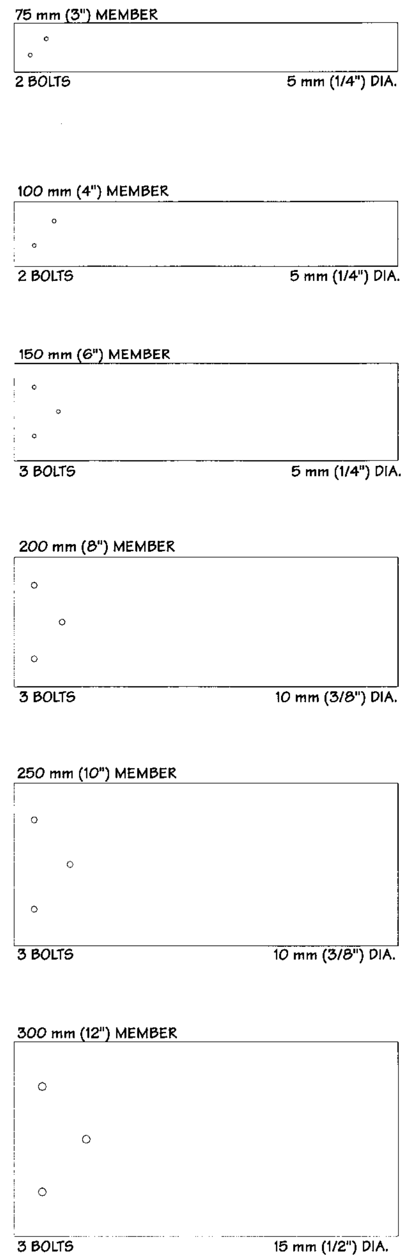

Figure 460-33. Guide to bolt/lag spacing.

GLOSSARY

Bending moment (M): The stress result ing from the forces acting on the beam and the reaction of the supports. The bending moment at any section in the beam is the sum of the moments on either side of the section. Expressed in inch-pounds (in-lb).

Deflection (D): The tendency of a member to deform when placed under a load; present in all structures regardless of the material or magnitude of the load. Common acceptable limits of deflection range from 1/200th to 1/360th the effective span of the member in question. Expressed in inches (in).

Extreme fiber stress in bending (fb): A measure of inherent strength in a species and grade of lumber. Expressed in pounds per square inch (psi).

Loading (P): Dead load is the weight of the materials in the structure, including permanently attached fixtures and equipment. Live load is the weight of the people using the structure, the moveable furniture and equipment, snow, water, ice, and wind. Expressed in pounds per square foot (psf).

Modulus of elasticity (E): A measure of how much a material deforms in relation to the load applied.

Moment: The tendency of a force to cause rotation about an axis. Moment is the product of a force and a distance.

Moment arm: The perpendicular distance from the line of action of a force to the point being acted on.

Moment of inertia (I): An abstract measure described as the sum of all the products of all infinitely small areas times the square of their distance from the neutral surface of the beam.

Section modulus (S): The ratio of the moment of inertia to the distance of the most remote fiber in the beam. Expressed in cubic inches (in3).

Span versus effective span (L): Span refers to center-to-center measurement. Effective span refers to the distance measured between supports.

AGENCIES AND ORGANIZATIONS

California Redwood Association (CRA)
San Francisco, California

National Building Code (NBC)
c/o American Insurance Association
New York, New York

National Fire Protection
Association (NFPA)
Boston, Massachusetts

National Forest Products
Association (NFPA)
Washington, D.C.

Southern Building Code
Congress International
Birmingham, Alabama

Uniform Building Code
c/o International Conference
of Building Officials
Whittier, California

Western Wood Products Association
Portland, Oregon

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Walker, Theodore D. Site Design and Construction Detailing, 3rd ed., *PDA Publishers, Mesa, Arizona, 1992.*

SECTION 470

Pedestrian Bridges

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CONTENTS

1.0 INTRODUCTION

Pedestrian bridges are structures built in the landscape to allow movement across areas that would otherwise be difficult or dangerous to traverse. Bridges become a necessary means for connecting two points in the presence of such obstacles as water, steep topography, or major roadways. Though bridges can enhance the scenic character of a site, they must be seriously considered in the context of cost and liability.

In almost all cases, the design of bridges requires the assistance of structural and/or civil engineers. All dimensions included in this section are for guidance only and for indicating the scale of parts.

2.0 DESIGN CONSIDERATIONS

2.1 Defining the User

Design determinants for bridges are based on both user and site characteristics. Types of users may include:

1. People as individuals or in small or large groups (the latter related to spectators or tourists, etc.).
2. People using wheelchairs, bicycles, or other nonmotorized vehicles.
3. People on horseback and using a range of motorized vehicles (motor bikes, motorcycles, power mowers, and in some instances single cars or lightweight trucks, cattle, etc.).

Any of the above types of users may use a bridge in accordance to or contrary to the designer's intention. In general, pedestrian bridges must conform to the standards of universal accessibility and in the United States must meet the Americans with Disabilities Act Accessibility Guidelines (ADAAG). Refer to Section 240: Outdoor Accessibility for more information.

2.2 Spatial Standards

Spatial standards for bridges to serve bicyclists, pedestrians, and those who are handicapped are given in Table 470-1. Bridges to serve riders on horseback should be at least 1 200 mm (4 ft) wide for single passage crossing.

If a bridge is to be built, then consideration must be given to what may pass underneath. Statutory considerations involving clearances and safety measures apply to roads, rails, and water courses used by canoeists, people fishing or sailing boats, or commercial traffic. Where streams are involved in cold climatic zones, ice floes can create serious problems if not accounted for in the design.

2.3 User Safety

General:

The principal hazard to users of bridges is falling from the bridge or its approach paths. Depending upon the expected users and types of dangers, provisions could range from no handrails over shallow streams to shoulder-high rails with infills of mesh over deep gorges.

Considerations for handicapped users should include appropriate design of the approaches to the bridge. Landings and platforms, rest areas, handrailings, and walking surfaces are all elements that should be checked for compliance with national and local codes. (Refer to Section 240: Outdoor Accessibility, for more information.)

Landings, Rest Areas, and Handrailings:

Level landings or platforms should be provided at the top and bottom of ramp runs. Where pedestrian ramp grades exceed the maximum 1:12 or 8.33 percent, intermediate landings should occur no more than 9 000 mm (30 ft) apart. The landing should have a clear width at least equal to the width of the largest ramp leading to it. The minimum landing depth should be 1 500 mm (5 ft).

Places to sit or rest are particularly beneficial on very long bridges. They can also function as vantage points for scenic views.

Handrailings that are easily grasped should extend continuously along the entire length of the bridge, on both sides, including approach ramps.

Decking and Surface Treatments:

The choice of decking and surface treatments for bridges is very important. Nonslip surfaces are crucial. Wood decking is acceptable if the joints are less than 12 mm (1/2 in) wide. Slip-resistant metal checkerplates, walkway gratings, or traction strips are often used.

3.0 BRIDGE CONSTRUCTION

3.1 Site Selection and Survey

Selection Criteria:

Site factors to consider when deciding on the precise location for a bridge include the following:

1. Which area requires the shortest span?
2. Which area has the best foundation conditions? (In most cases a geological engineer should be consulted)
3. Which area is closest to the line of the existing footpath?
4. Which area has the fewest obstacles in the way of the bridge and/or its approaches?
5. Which area allows the most clearance from flooding?

KEY POINTS: Design Considerations

Design determinants for bridges are based on both user and site characteristics. The potential users of pedestrian bridges must be understood in determining spatial dimensions and design loading for an appropriate bridge type (Table 470-2). Understanding site conditions will help create a bridge that takes advantage of landscape amenities while avoiding negative environmental impacts or safety hazards.

1. In general, pedestrian bridges must conform to the standards of universal accessibility and in the United States meet the Americans with Disabilities Act Accessibility Guidelines (ADAAG).
2. Considerations for handicapped users, including landings and platforms, rest areas, handrailings, and walking surfaces should be checked for compliance with national and local codes. (Refer to Section 240: Outdoor Accessibility, for more information.)
3. Where pedestrian ramp grades exceed the maximum 1:12 or 8.33 percent, intermediate landings should occur no more than 9 000 mm (30 ft) apart. The minimum landing depth should be 1 500 mm (5 ft).
4. The choice of decking and surface treatments for bridges is very important. Slip-resistant metal checkerplates, walkway gratings, or traction strips are often used for safety.

6. Which area is easiest to reach with equipment, labor, and materials?
7. Which area has the fewest hazards? (e.g. precipices, steep paths, or exposure to strong winds)
8. Which location would users prefer and enjoy the most? For instance, are there pools beneath for looking at fish, white-water rapids in sight, or exceptional views from each side of the bridge and approaches?

Site Survey:

Once the location for a bridge is determined, the site must be surveyed to obtain necessary information for the bridge design, its foundations, and approaches. A plan of the area with spot elevations and lateral and longitudinal cross sections are essential for laying out the design.

3.2 Selection of Footbridge Type

Basic Components:

Figure 470-1 illustrates the basic components of simple footbridges.

Selection Chart:

There are many factors that require consideration when selecting a bridge type. Table 470-2 illustrates 16 structural forms and describes the materials, foundation conditions, and spans for which they are suitable.

Additional Considerations:

In addition to the design considerations given in Table 470-2, the following points should be kept in mind when selecting a bridge type.

Clearance: The clearance required will determine the construction depth available between the deck and the underside of the bridge. The bridge can be raised by using approach ramps but usually at increased costs. Table 470-3 lists some typical requirements for clearance and the resulting lengths of ramps based upon 8 and 10 percent gradients.

Accessibility: The difficulty of transporting the main structural members to the site may eliminate certain types of bridges which require long, heavy members. The difficulty of getting earthmoving equipment to both sides of the site may limit the amount of foundation and approach path work which can be done and thus influence the type of bridge.

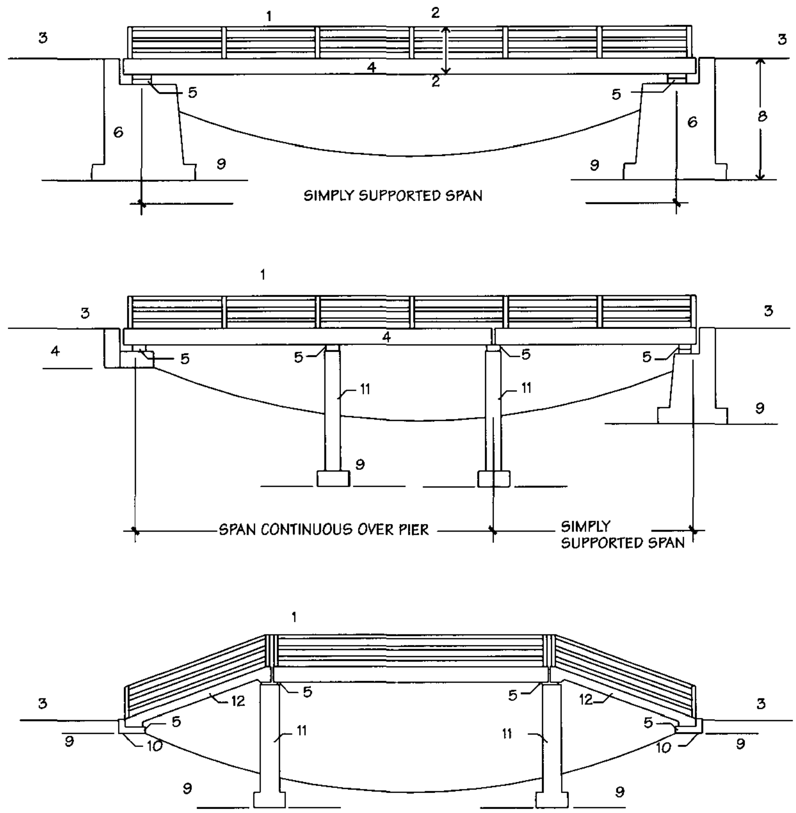


Figure 470-1. Basic Components of a Bridge. *(1) Handrail, (2) superstructure, (3) approach path, (4) main beam, (5) bridge bearing, (6) abutment, (7) end dam, (8) substructure, (9) bearing strata, (10) end sear, (11) pier, (12) approach ramp.*

Vandalism: In areas of risk from vandalism, certain types of bridges that have parts which can be easily detached or broken should be avoided.

Resources Available: Bridges in rural or remote areas may have to be constructed with low-skilled labor and locally available materials.

Planning, Design, and Engineering Knowledge: Local codes or ordinances usually require the use of a registered engineer for detailed bridge design. In the absence of such professional assistance, it may be necessary to restrict the choice of bridge types to familiar designs with minor spans of 9 000 mm (30 ft) or less.

Fitting the Bridge to a Site: A bridge is essentially a continuation of a path. Therefore, it should tie in well with the overall design of the landscape. When a bridge has to be set higher than the original ground level on either side, then access ramps will be necessary. Table 470-3 shows typical lengths of ramps for pedestrian bridges.

Because people tend to slow down, linger, and sometimes congregate at a footbridge, approach paths should be widened to facilitate easy pedestrian flow.

3.3 Selection of Main Structural Members

When a bridge type has been selected, the size and form of the main structural members may be determined for one of the following three categories:

1. *Typical bridge designs:* for spans under 9 000 mm (30 ft) where no site difficulties exist, a typical footbridge may be built. (Refer to 4.0 Typical Designs for Short-Span Footbridges in this section for information on member selection.)
2. *Prefabricated bridge designs:* specialist suppliers offer a range of standard bridge types, either in kit form or completed and ready to place in position. Commonly available bridge types in the United States include:

a. Laminated timber beams

Table 470-1. SPATIAL STANDARDS FOR BRIDGES FOR USE BY BICYCLISTS, PEDESTRIANS, AND HANDICAPPED INDIVIDUALS

	Bicycle		Universal Pedestrian Design	
Geometric element	Maximum or minimum	Desirable	Maximum or minimum	Desirable
Clear width				
One-lane	1 050 mm min. (3.5 ft)	1 200 mm or more (4.0 ft)	900 mm minimum (3.0 ft)	1 200 mm or more (4.0 ft)
Two-lanes	2 100 mm min. (7.0 ft)	2 400 mm or more (8.0 ft)	1 200 mm minimum (4.0 ft)	1 650 mm or more (5.5 ft (to pass two wheelchairs)
More than two lanes*				
Clearance				
Vertical unobstructed height	2 490 mm min. (8.3 ft)	2 850 mm (9.5 ft)	Same as pedestrian	Same as pedestrian
Lateral clearance to obstructions	300 mm min. (1.0 ft)	600 mm (2.0 ft)	Same as pedestrian	Same as pedestrian
Grades				
	10% for maximum for distances of 1 500 mm (50 ft) or less	5% for maximum distances of 90 000 mm (300 ft) or less	8.33%maximum length run is 9 000 mm (30 ft)	5% or less
Cross slope				
	2% minimum on curves	Calculated from superelevation formulas	2% maximum	1% or less
Design speed (bicycles)				
	16.09 km/h minimum (10 mph)	24.14 km/h (15 mph) 32.19 km/h on long down grades (20 mph)	Not applicable	Not applicable
Radius of curvature (bicycles)				
	4 500 mm minimum (15 ft)	Calculate from appropriate formulas (see Table 470-3)	Not applicable	Not applicable
Sight distance				
	Varies with grade and speed. Calculate from appropriate formulas (see Table 470-4).		Provide significant sight distance at curves and turns to avoid collision	Provide significant sight distance at curves and turns to avoid collision

*Where volumes of all types of user groups are heavy, widths should be calculated by using level of service concepts.
Source: DeLeuw, Cather & Company, Inc., Boston, Massachusetts.

b. Hardwood beams and made-up girders

c. Steel lattice girders

d. Aluminum lattice girders

e. Precast concrete beams

(Refer to 5.0 Typical Designs for Prefabricated Bridges in this section for more information.)

3. *Special designs:* custom-made bridge structures may be designed by experienced engineers, especially for spans exceeding 9 000 mm (30 ft).

NOTE: The conceptual design of substructures (foundations, etc.) should be done in parallel with the design of the bridge deck and approaches. Decisions related to span arrangement affect: (1) the number, loading, and size of foundations; (2) the zones of soil providing support; and (3) the relative difficulties of constructing different types of foundations.

Design loads on a particular foundation might be adjusted by a change in the length of spans or the form of deck construction.

3.4 Loadings on the Bridge's Superstructure

Types of Loading:

Various loads which a bridge's superstructure must support include (Figure 470-2):

1. *Dead load:* the weight of the bridge materials themselves

2. *Live load:*

   a. The weight of people, together with any dynamic effect from their movement

   b. Wind pressure on the bridge structure, or suction or pressure on the bridge deck

   c. Accumulation of snow and ice

   d. Water pressure via flooding acting on the bridge structure or transmitted to the bridge structure from floating debris and ice

Design Loading:

The design loading should be determined based on anticipated use (pedestrians and small vehicles, emergency vehicles, etc.).

When estimating loadings, consideration must be given to exceptional conditions which may cause extreme stresses on the structure. For example, if a bridge spans a stream on which boat races may occur, spectator crowding on the bridge (first on the upstream side, and then shifting to the downstream side) could cause twisting and extreme load conditions. If the bridge is on a ceremonial route, where large numbers of people walk in step, concentrated rhythmic impacts could cause excessive vibration and consequent failure. Extreme conditions may result when the bridge is opened or dedicated and is subjected to heavy crowd loadings.

User Loads for Narrow Footbridges:

Most narrow footbridges will rarely be wider than 900-1 500 mm (3-5 ft) and will rarely be subjected to large crowds or other extraordinary loads. Narrow bridges which provide access to popular tourist attractions like gorges or waterfalls should be designed to handle the weight of larger groups of people. Table 470-4 shows loadings for narrow bridges based upon likely uses.

Pedestrian Loading:

1. Main beams and girders: a uniformly distributed live load (UDLL) over the whole span is equivalent to that shown for normal and crowd loading (Figure 470-3).
2. Deck members: where the deck is made of small individual units, such as deck boards, the entire weight concentrated on one foot should be assumed: e.g., total weight 112 kg (246 lbs) on a 75 mm (3 in) square, including an impact factor of 1.250, or a line of people each weighing 90 kg (200 lbs) at 600 mm (2 ft) centers along the member with an impact factor of 1.000 (Figure 470-3).

Horse and Rider Loading:

1. Main beams and girders: horses and riders in single file at spacings of $1\frac{1}{2}$ horse lengths with an impact factor of 1.300.
2. Deck members: where the deck is of small individual units, such as deck boards, the full weight of a trotting animal resting on one hoof should be assumed. For a horse, this load will be on a 175 mm (7 in) square with an impact factor of 1.250.

Deflections:

The deflection of the individual structural members and the main beams and girders under full loading should be limited to $^1/_{240}$th of the span. Where possible, structures should be built with a precamber at least equal to the dead load deflection (Figure 470-4). The aesthetic appearance of a footbridge is improved by making this precamber substantial. Use 10 mm/m ($^1/_8$ in/ft) of total span to 35 mm/m ($^7/_{16}$ in/ft). The top end of this range results in a deck gradient of about 1:15, which is reasonable for pedestrian traffic.

Dynamic Deflection: Long-span footbridges [over 19 500 mm (65 ft)] should be checked for their response to dynamic loading and to excitation by wind. The design should avoid the use of structures whose primary natural frequency coincides with the pace frequency of pedestrians (i.e., approximately 2.0 cycles per second). The calculation of the vibration frequency of a structure is complex and requires consultation with an experienced engineer.

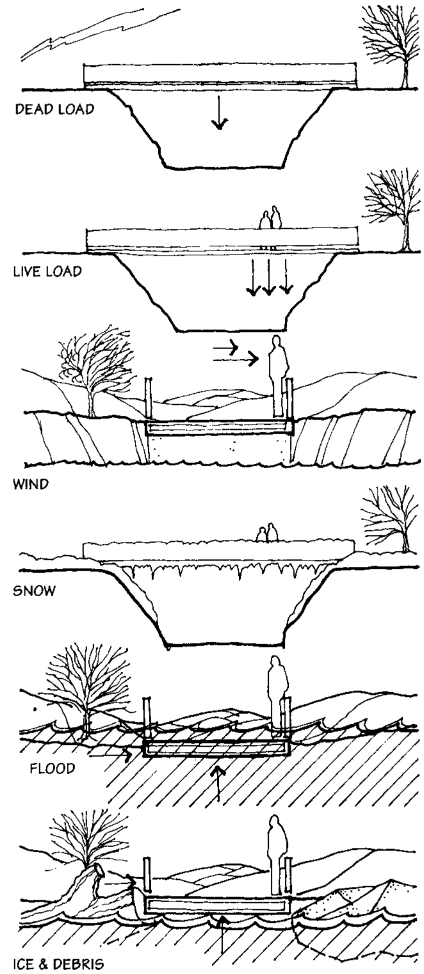


Figure 470-2. Types of bridge loading.

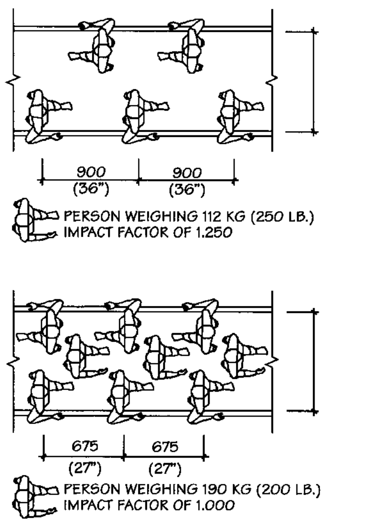


Figure 470-3. Pedestrian loading.

KEY POINTS: Bridge Construction

In almost all cases, the design and construction of bridges requires the assistance of structural and/or civil engineers and must meet the requirements of universal accessibility.

1. For spans under 9 000 mm (30 ft) where no site difficulties exist, a typical footbridge may be built. Custom-made bridge structures may be designed by experienced engineers, especially for spans exceeding 9 000 mm (30 ft).
2. The conceptual design of substructures (foundations, abutments, piers etc.) should be done in parallel with the design of the bridge deck and approaches. Decisions related to span arrangement affect: (1) the number, loading, and size of foundations; (2) the zones of soil providing support; and (3) the relative difficulties of construction of different types of foundations.
3. The design loading should be determined based on anticipated use. Table 470-4 shows loads for narrow footbridges.

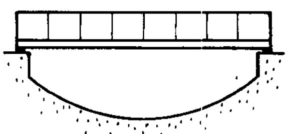
Table 470-2. BRIDGE SELECTION CHART

KEY TO CLASSIFICATIONS

Key #	Comparative costs (CC)	Maintenance classification (MC)	Life classification (LC)	Design and erection classification (DEC)
1	Lowest cost	Every five years	Over 30 years	S-Standard design may be used
2	Low costs`	Paint/preservative every three years	20-30 years	C-Design by structural engineer
3	Medium costs	Repair decking and handrailing every two years	10-20 years	V-Can be erected by voluntary unskilled labor with skilled supervisor
4	High costs	Repairs required every year	5-1 0 years	F-Can be erected by voluntary unskilled labor with skilled supervisor using prefabricated parts made by a subcontractor
5	Highest costs	Regular attention throughout year	Up to five years	P-Must be erected by a contractor

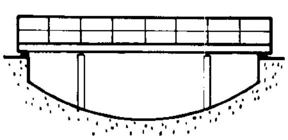
Notes: The classification is based upon typical comparative costs, assuming built by a contractor, site with easy access, and simple foundations.
It is assumed all footbridges are well built using sound materials.
Annual inspection and good regular maintenance is required for all structures.
In all cases the construction of the footbridge should be carried out in accordance with the construction plans and specifications.

SIMPLY SUPPORTED BEAM OR SLAB



Bridge diagram	Material	Span range	CC	MC	LC	DEC	Notes
	Timber:						—This is the simplest footbridge for short spans. Where there are poor foundation conditions, some settlement at abutments can be tolerated. —Beams can be shaped and cambered. Transport problems due to length.
	Log beams	Up to 10	2	4	5	SV	
	Sawn beams	Up to 10	2	3	4	SV	
	Laminated timber beams	8 to 25	5	3	3	CF	
	Steel beams:						—Steel requires good paint specifications.
	Timber deck	5 to 15	3	3	3	SF	
	Concrete deck	5 to 15	4	2	2	CP	
	Concrete:						—Can be shaped for aesthetic effect. Centering required.
	In situ reinforced slab	Up to 10	5	1	1	CP	—Heavy sections for transport and erection. Factory made.
	Precast reinforced or pretensioned beams	Up to 20	5	1	1	CP	

CONTINUOUS BEAM OR SLAB



Bridge diagram	Material	Span range	CC	MC	LC	DEC	Notes
							—Economical with regard to main structuralmembers; requires sound foundations because settlement can overstress the super-structure. The span range is given for the center span. Side spans can be up to approximately two-thirds of the center span.
	Laminated timber beams	8 to 25	5	3	3	CP	—Beams can be shaped and cambered. Transport of long lengths difficult. Site splices required.
	Steel beams:						
	Timber deck	8 to 19	3	3	3	CF	—Steel beams can be transported in short lengths and spliced at site.
	Concrete deck	8 to 19	4	2	2	CP	—Steel beams can be transported in short lengths and spliced at site.
	Concrete:						
	In situ reinforced slab or beam	6 to 20	5	1	1	CP	—Can be shaped; centering required.
	In situ or precast sections pretensioned	10 to 25	5	1	1	CP	—Heavy sections for transport and erection.

Table 470-2. BRIDGE SELECTION CHART (continued)

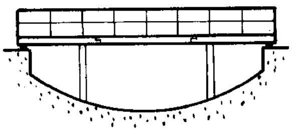
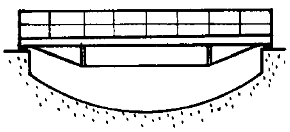
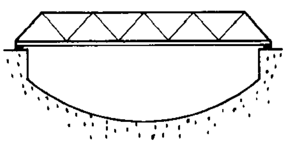
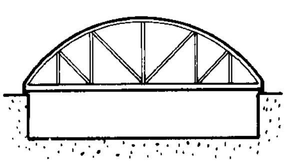
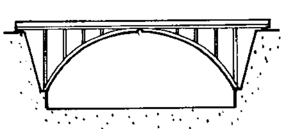
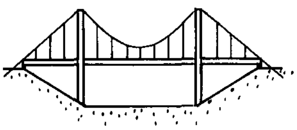
Bridge diagram	Material	Span range	CC	MC	LC	DEC	Notes
CANTILEVER AND SUSPENDED SPAN (BEAM OR SLAB)							
							—Has the same advantages as a continuous spanbut can tolerate some settlement of the supports; may cause uplift problems at the abutments, espcially with short side spans. The span lengths are given for the pier to pier distances. The length of the suspended span should be approximately 0.6 of this. Side spans can be up to the length of the suspended span. —Beams can be shaped and cambered. Transport of long lengths difficult. Site splices required.
	Steel beams:						
	Timber deck	8 to 19	3	3	3	CF	—Steel beams can be transported in short lengths and spliced at site.
	Concrete deck	8 to 19	4	2	2	CP	—Steel beams can be transported in short lengths and spliced at site.
	Concrete:						
	In situ beam and slab	6 to 20	5	1	1	CP	—Can be shaped; centering required.
	Precast beam and slab	10 to 25	5	1	1	CP	—Heavy sections for transport and erection.
TRUSSED BEAM							
							—Requires ample clearance below the tension member to prevent damage. By forming a truss, it allows use of a slender main member.
	Steel beams and rod or wire rope tension member; timber or precast concrete deck	10 to 20	3	3	1	CP	—Requires skilled fabrication of struts and anchorage points.
LATTICE GIRDER (through-type or Warren truss)							
							—Allows minimum construction depth below deck level. The structural girder members act as handrailing. Top flanges of the girders should be braced with raking supports or overhead frames. Horizontal bracing for wind may be required. The small structural members are more susceptible to accidental damage than beam-type footbridges. Girders can be transported to the site in smallsections and assembled.
	Timber: sawn sections	5 to 15	5	4	3	CF/P	—Skill required in fabrication and erection.
	Steel:						
	Angles	10 to 25	1	3	2	CF/P	—"F" for smaller spans.
	Rectangular hollow sections	10 to 25	1	3	2	CF/P	
	Tubes	10 to 25	1	3	2	CF/P	
	Aluminum (standard design by British Aluminum Co., Ltd.)	8.75 to 30	5	3	1	CP	—These require good paint specifications
BOW STRING GIRDER							
							—An economical solution for longer spans where the top cords can be braced together above head height of the user. Horizontal wind bracing may be required. Girders can be transported to the site in small sections.
	Timber: sawn sections	15 to 30	5	4	3	CP	
	Steel (all sections, including RHS and tubes	15 to 30	2	3	2	CP	
THREE-PINNED ARCH							
							—Requires good foundation conditions with little settlement. Preformed arch members can be transported to site in half-span lengths. Best suited for longer spans where appearance is important. Complex erection procedure.
	Laminated timber	15 to 30	5	3	2	CP	—Arch ribs can be transported in half-spa lengths.
	Steel	15 to 30	5	3	1	CP	—Arch ribs can be transported in short sections.
	Concrete: In situ and precast	15 to 30	1	1	1	CP	—Requires in situ centering. Precast units are long, heavy, and difficult to transport.

Table 470-2. BRIDGE SELECTION CHART (continued)

Bridge diagram	Material	Span range	CC	MC	LC	DEC	Notes
SUSPENSION							
							—The span range shown refers to the main span only. This type is good for long spans over water or deep ravines where intermediate piers are not possible. Sometimes used for shorter spans for aesthetic reasons. Wind bracing is sometimes required and the width of the walkway may be determined by structural stability considerations. Cable anchorage points should be firm and safe from accidents or vandalism. The design and erection is complex and requires a trained structural engineer and expert construction supervision.
	Cables						—High risk of corrosion at cable and suspender anchorage points, which requires good construction detailing and regular inspection.
	Galvanized high-tensile steel wire ropes						
	Suspenders						
	Galvanized high-tensile wire ropes or steel rods						
	Deck structure and towers:						
	Timber: sawn structure	15 to 35	3	4	3	CF/P	—"F" for shorter spans.
	Steel: timber deck	20 to 60	3	3	2	CP	—Lattice girders can also act as handrails.

Footbridges found to be susceptible to vibration can be dampened in a variety of ways, including the use of rubber bearings, or of side guys for suspension bridges. (Refer to Section 460: Wood Decks and Boardwalks for more information.)

3.5 Substructures (Foundations)

Substructures are the parts of the bridge which transmit loads from the bridge span to the ground. Substructures include abutments, end seats, and piers.

Loading on Substructures:

Table 470-5 lists various design loadings for bridge substructures.

Foundations and Soil Bearing Capacity:

The applied load from the substructure must be resisted by the ground to prevent failure and excessive settlement (Table 470-6). In almost all cases, engineering advice is required when estimating soil bearing capacity.

Soft clay and materials of low bearing capacity and high water content are likely to compress under load and result in rapid short-term or slower long-term settlement. Within limits, such settlement may not be serious for a footbridge of a short to medium span. For longer continuous beam bridges, such settlement could cause high stresses within the bridge beams.

The bearing capacity of poor soils, such as peat and soft clay, can be improved by spreading the imposed load. High-tensile plastic fiber sheets which allow the passage of moisture but not of soil material are now commonly used. (Refer to Section 880: Geotextiles, for more information on these materials.)

The overall stability of the foundation should be considered. For example, abutments sited on steeply sloping ground may fail when an entire section of the bank begins slipping (Figure 470-5).

The management of water in excavations is difficult and carries considerable risk. Many materials, especially sand, become unstable when subjected to porewater flow, which is the direct result of pumping water from a hole. These operations should only be undertaken by experienced contractors under the direction of an experienced geotechnical engineer.

Choice of Foundation (Footings or Piles):

Engineering advice is important for all but the simplest of structures when selecting an appropriate foundation design. Spread footings are usually preferable to piles because they are less expensive and generally pose less risk in terms of encountering unforeseen and expensive technical and contractual problems during construction.

Table 470-7 lists some of the ground conditions and construction considerations for which footings or piles have been found to be advantageous. For sites with strata of variable bearing qualities, designers may

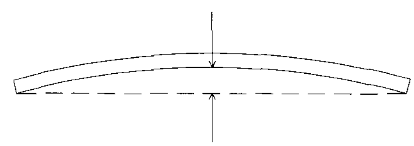


Figure 470-4. Camber. *Where possible, structures should be built with a precamber at least equal to the dead load deflection.*

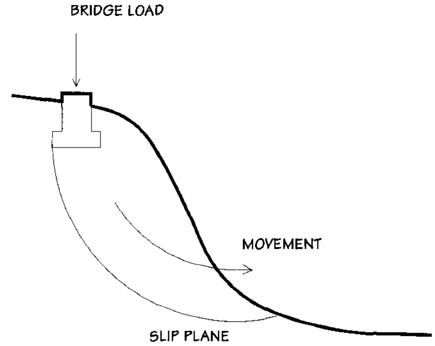


Figure 470-5 Ground Failure at Bridge Foundation. *Abutments sited on steeply sloping ground may fail when an entire section of the bank slips.*

Table 470-3. TYPICAL RAMP LENGTHS FOR PEDESTRIAN BRIDGES

Description of structure	Required vertical clearance, mm (ft)	Elevation change, mm (ft)	Approximate length of one approach ramp: 8% grade, mm (ft)	Approximate length of one approach ramp: 10% grade, mm (ft)
Bridge over highway	5 100 (17)	5 700-6 300 (19-21) ascent	75 000 (250)	60 000 (200)
Bridge over road or street	4 500 (15)	5 100-5 700 (17-19) ascent	67 500 (225)	54 000 (180)
Bridge over railroad	6 900 (23)	8 100-9 000 (27-30) ascent	108 000 (360)	85 500 (285)
Bridge over electrified railroad	7 800 (26)	9 000-9 900 (30-33) ascent	120 000 (400)	94 500 (315)

* Landings are not considered, but if they are used, the approach ramp should be lengthened. *Source:* DeLeuw, Cather & Company, Inc., Boston, MA.

Table 470-4. LOADS FOR NARROW FOOTBRIDGES*

Member	Load type	Loading: Uniformly distributed	Loading: Point load	Remarks
Main beams	Pedestrian/normal crowd Horse and rider	2.3 KN/m^2 (48 lbs/ft^2) 3.2 KN/m^2 (67 lbs/ft^2) 2.3 KN/m^2 (48 lbs/ft^2)		For wider footbridges and urban sites, use appropriate loading standards.
Short-span members	Pedestrian normal crowd	The greater: either 3.2 KN/m^2 (67 lbs/ft^2) or 1.6 KN (364 lbs) on a 75 mm (3") square up to a 1 900 mm (6'-4") span. Thereafter 1.69 KN/m (116 lbs/ft) run of member.		All short-span members may carry crowd loading. Individual timber deck boards may carry point or line load.
	Horse and rider	3.2 KN/m2 (67 lbs/ft^2) or 8.12 KN (1 826 lbs) on a 75 mm (3") square		
Handrail (horizontal load)	Pedestrian/normal crowd Horse and rider	0.74 KN/m (50 lbs/ft), 1 000 mm (3'-4") above deck 1.4 KN/m (lbs./ft), 1 100 mm above deck 1.3 KN/m (89 lbs/ft), 1 250 mm (4'-2") above deck		
All members	Snow	0.4 KN/m^2 (8.3 lbs/ft^2)		
Unloaded footbridge	Wind: 40 000 mm/sec (133 ft/sec) (horizontal load)	1.4 KN/m^2 (29.3 lbs/ft^2)		Permissible stresses increased by 25%.
Loaded footbridge	Wind: 28 000 mm/sec (93 ft/sec) (horizontal load)	0.7 KN/m^2 (14.6 lbs/ft^2)		

* Width of footbridge is 800-1 700 mm.

Source: Adapted from Reiach Hall Blyth Partnership, preparers, *Footbridges in the Countryside*, the Countryside Commission for Scotland, Perth, 1981.

have to work through a range of types, depths, and sizes of foundation to identify the most acceptable economic solution.

Types of Abutments:

Open Abutments: Open abutments, with the end spans of the deck bearing on seatings at the tops of embankments, are often preferable to, and can look better than, a retaining wall type of abutment (Table 470-8). The cost of the end span, pier, and end support of a narrow bridge is likely to be less than that of a closed abutment with wing walls and a retained fill. For a wide bridge, the cost of wing walls is relatively less significant, and the closed abutment is then likely to be more economical.

Open abutments are particularly suitable where the ground is not firm enough to support the heavy weight of a closed abutment, or where horizontal forces must be kept to a minimum. Since the bank seat settles with the embankment, the problems of settlement of backfill behind the abutment are minimal.

Wall Abutments: Various types of wall abutments are described in Table 470-9.

Strutted, Portal, and Box Structures: Strutted, portal, and box structures are described in Table 470-10.

Wing Walls:

The cost of wing walls can be a significant part of the total cost of a substructure, particularly for narrow bridges (Table 470-11). They can also have a negative effect on the aesthetic appearance of the bridge and result in only a marginal cost saving. The choice of geometry is usually controlled by the topography of the site, construction restrictions, and the construction sequence. If possible, it is advantageous to design the wing walls so that a contractor can construct them before constructing the deck. Wing walls often can be structurally independent of the abutment, in which case the joints between them need to be designed to permit significant movement, with provisions made to hide minor tilts. Differences in settlement between the abutment and the wing walls can be due largely to the greater pressure on the abutment.

Simple Abutments for Footbridges:

Sophisticated abutments are not necessary for narrow footbridges. All abutments should provide adequate air space and

Table 470-5. LOADING ON SUBSTRUCTURES AND FOUNDATIONS*

Loading	Comment
Dead load	a. Self weight of substructure b. Weight of fill supported by foundation c. Dead load and superimposed load of superstructure
Earth pressure	Continuously acting on completed substructure but likely to fluctuate in intensity with substructure movement, vibration, water table, etc.
Differential settlement	Differential settlement of embankment relative to substructure transfers load to substructure and foundations. Differential movements of supports of indeterminate bridge change reactions.
Hydraulic	Piers in rivers are subjected to lateral forces from change of direction of waterflow. Forces increase in times of flood.
Flood	Drawdown condition following flooding of embankment. Also, flooding of retaining wall drainage membrane from behind or above.
Creep and shrinkage	Creep and shrinkage movements of superstructure can affect reactions and thrusts on substructure.
Temperature	Temperature changes in superstructure can alter reactions and thrusts or apply displacement to supports (which can in turn alter earth pressures). Temperature changes in parts of substructures and ground affect the forces and differential movement between them.
Traffic on bridge	Detailed information is included in various bridge-design standards for loading from: a. Vertical gravitational load incorporating impact allowance b. Centrifugal load acting radially c. Longitudinal loads, which can act toward or away from substructure
Traffic on abutment	Live load surcharges to represent vertical traffic loading are given in standards for bridge design. Horizontal loads due to braking and traction can act on substructure through fill and pavement.
Wind	Detailed information on wind loads on superstructure and piers is included in the standards listed above.
Impact	Piers may be vulnerable to impact from vehicles, trains, and river craft. Standards provide guidance for piers alongside highways. Massive abutments and foundations are much less vulnerable and not likely to fail, although some displacement can occur from severe impact.
Exceptional Construction	Snow, ice packs, earthquake, etc. Combinations of any of the above loads can be critical for incomplete substructures during stages of construction together with loads due to temporary works, stored materials, moving loads, and possibly also accompanied by reduction of support.

* This table lists various design loadings for substructures. The loadings are not considered to act all at the same time, and various combinations are identified during design.

Source: Building Research Establishment.

Table 470-6. PERMISSIBLE BEARING PRESSURE

Material	Permissible bearing pressure on ground, KN/m²	Tons/ft²
Hard rock	2 150	21
Shale and soft rock	1 075	11
Compact sand or gravel and hard compact clay	430	4
Firm sand, sandy clay, and ordinary fairly dry boulder clay	215	2
Wet or loose sand and soft clay	105	1
Unconsolidated fill, alluvial soil peat	Varies up to 25	Up to 0.25

Note: This table should be used for preliminary estimations only.

Source: Adapted from Reiach Hall Blyth Partnership, preparers, Footbridges in the Countryside, the Countryside Commission for Scotland, Perth, 1981.

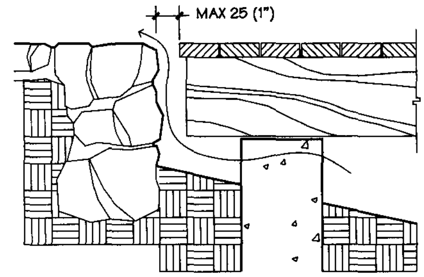


Figure 470-6.
Air space at beam end.

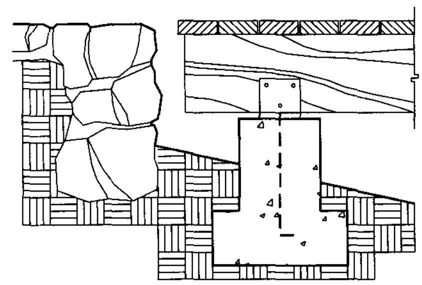


Figure 470-7.
Beam bolted to abutment.

drainage at the bearing area (Figure 470-6).

Footbridges may have to be bolted or clamped to the abutments to hold them in place during flooding or while vibrating under live loads (Figure 470-7).

The simplest abutment is a bank seat, where the bridge superstructure meets the ground at its natural level on a stable area of suitable bearing capacity. In such cases, a concrete strip foundation is adequate (Figure 470-8).

Timber bank seats can be used but will have a limited life. Timber must be treated with some type of wood preservative, and a tile drain is necessary (Figure 470-9).

Where the bridge deck level is above the natural ground level, a mass abutment can be constructed. The fill used to ramp the footpath can be allowed to spill naturally around it. Where abutments are set on steep slopes, it may be necessary to retain the fill for the footpath by widening the abutment or providing wingwalls (Figures 470-10 and 470-11).

Figures 470-12 and 470-13 show typical small abutments suitable for narrow footbridges. If high abutments [over 3 000 mm (10 ft)] are required or if the soil has poor bearing capacity, then more sophisticated solutions, using reinforced concrete or piled foundations, can be adopted. In all these

Table 470-7. GENERAL GUIDE TO CHOICE OF FOUNDATION

Ground	Footings preferred	Piles preferred
Stiff clay, medium-dense dry sand, or gravel	Footings are most often appropriate for footbridges for reasons of cost, reliability, and ease of construction.	Piles may have to be used where very heavy concentrated loads have to be transmitted to ground.
Firm clays, loose dry gravels, or sand and gravel	Some designers prefer to use footings with bearing pressures as low as 100-150 kN/m² if significant settlement is expected during or soon after construction.	Piles are often the preferred solution because settlement of a pile group is often as much as one-half or one-third of that of a footing and takes place rapidly.
Stiff stratum at moderate depth with deep water table	Shallow spread footings supported on mass concrete or granular fill which forms a firm stratum are sometimes less expensive than deep footings.	
High water table in permeable ground		Driven or cased bored piles are typically used, but installation can be difficult.
Stiff ground overlying soft ground, e. g., gravel over clay	Shallow footings can be designed to make use of load-spreading quality of the stiff ground.	Use of piles can create driving or boring problems and by concentrating the load above or in the clay can cause larger settlements.
Soft silty clays, peat, and uncompacted fills	Spread footings can be used on fill if the ground can be consolidated in advance by use of a surcharge.	Piles are usually preferred. Measures sometimes have to be taken to prevent damage from lateral loading due to adjacent embankment.
Interbedded sand and silt layers	Excavation can be hindered by water in layers, but installation of bored piles has also given many problems.	
Loose sands increasing in strength with depth	Improving the strength of existing sand often is cheaper than using piles, but it is difficult to predict and monitor these special techniques. Therefore, piles are sometimes preferred.	Driven piles compact the sand and provide high load capacity with minimum settlement. (Note: single size sands can be impossible to compact.)
Chalk	Use footings unless chalk is deeper than the spread footings. Even soft chalk consolidates quickly under a load (usually during construction). Unpredictable and impenetrable ground, such as boulders or rock with clay matrix can be very difficult, with predictions of movement unreliable. Shallow footings can be the more economical.	If upper surface is at unpredictable depths due to swallow holes, piles may be better because they can be driven to different depths without delays in the contract. Chalk softens during driving or boring but recovers some strength during following weeks; therefore delay testing test piles at different depths to determine the optimum.Excavation for footings or installation of piles
Compacted fill	Well-compacted, suitable, or selected fill is generally as good as, if not better than, natural deposits of the same material.	Steel H piles have been driven either to deep firm stratum or to sufficient depths to mobilize adequate friction.
Steeply dipping rock substratum	Mass concrete fill can grip stepped interfaces where piles might glance off.	If stratum is very deep, then precast concrete piles with rock shoes or use steel piles.

cases, an experienced engineer should be consulted.

Piers:

Piers are used to break up long spans. They should be adopted only where they can be located easily on sound foundations. Piers in waterways are difficult to construct and are subject to abnormal conditions from flooding. Expert advice should be sought before such a solution is adopted.

When foundations must be prepared underwater, a cofferdam is necessary to keep out the water while the footing is being placed. When the water is deep or the current swift, these cofferdams are very expensive, and the construction of each one is a separate problem which should not be attempted except under the direction of an experienced engineer.

Piers can be used to limit the size of abutments and to avoid forming embankments for footpaths by using them to sup-

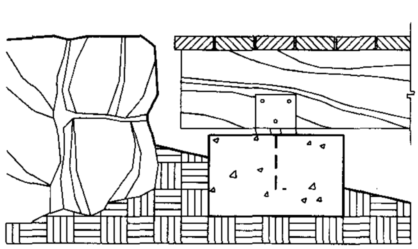


Figure 470-8. Typical bank seat.

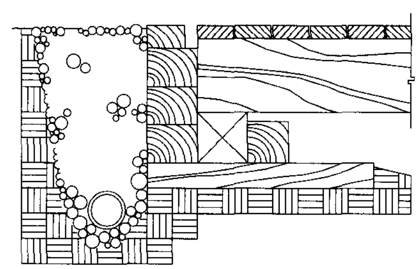
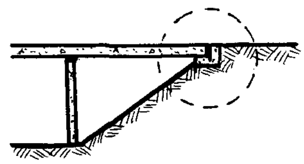
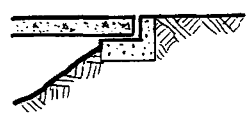
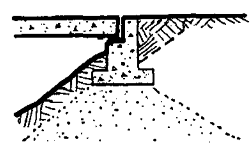
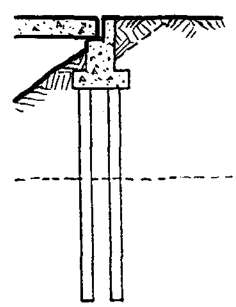


Figure 470-9. Typical timber bank seat.

Table 470-8. OPEN ABUTMENTS

Type, use, and comment	Sketch
Bank seats: Often used in cut areas and less common in fill areas. Bank seats are simple economic structures of semimass or reinforced concrete. Ideal for bridges where there is firm undisturbed ground. The exposed bearing shelf is more economical than the buried type because of the reduced length of deck, but the front edge of the footing should be kept back from the slope face because of erosion, frost action, and because the fill on a slope is not well compacted. Wing walls are constructed as cantilevers or on footings.	  
Bank seats on piles: Used occasionally. Bank seats are placed on piles when the ground or fill is not strong enough.	

Source: Modified from *Building Research Establishment.*

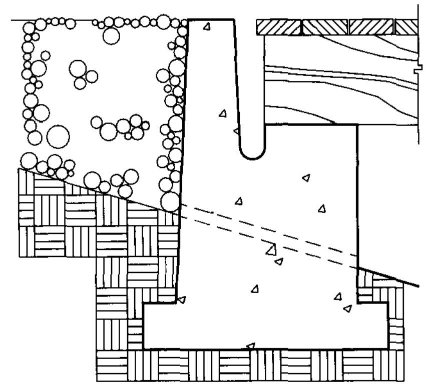


Figure 470-10. Typical mass abutment.

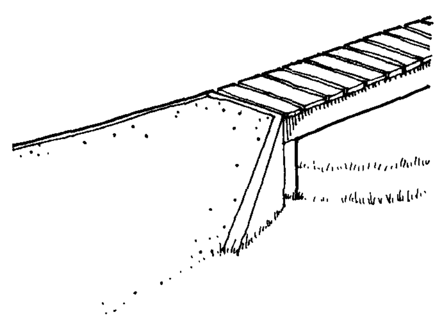


Figure 470-11. Typical mass abutment with wing walls.

port the main span and an approach ramp (Figure 470-14).

The top of a pier must be wide enough to accommodate bearings and beam ends. If the spans are simply supported, two bearings will be necessary, but for a continuous beam only one bearing need be specified (Figure 470-15).

Bridge superstructures exert longitudinal forces from expansion, wind, and traction, which have an overturning effect on piers (Figure 470-16).

The simplest piers to construct, and the most economical, are those that are vertical with a uniform rectangular or circular cross section. Typical pier details are shown in Figures 470-17 and 470-18.

Excavation Shape and Shear Keys:

The foundation for an abutment should be level. Sliding must be resisted by friction under the base or by passive resistance in front of the toe. Often a wider base is needed to prevent sliding than for bearing or to prevent overturning. For this reason, some designers dimension the base for bearing and provide additional resistance to sliding by using a shear key or by inclining the footing (Figures 470-19 and 470-20). To minimize ground softening, some designers give the footing a small cross fall to improve drainage.

The process of constructing a shear key frequently loosens the subbase. Also, rainwater can cause a softening of the soil. Therefore, when shear keys are used, they should be excavated and concreted in one continuous process.

Three typical locations for shear keys are (Figure 470-19):

1. Front shear keys: have to be far enough below ground level to avoid softening due to frost action and to reduce the risk of later scouring or excavations in front of the toe.
2. Middle shear keys: are usually easier to excavate and do not cause complications in the formation of the abutment.
3. Rear or back shear keys: gain additional lateral resistance from the ground because of the increased vertical compression of the abutment and toe. The excavation for a rear shear key normally causes less disturbance of the supporting soil but causes more excavation on the retained side.

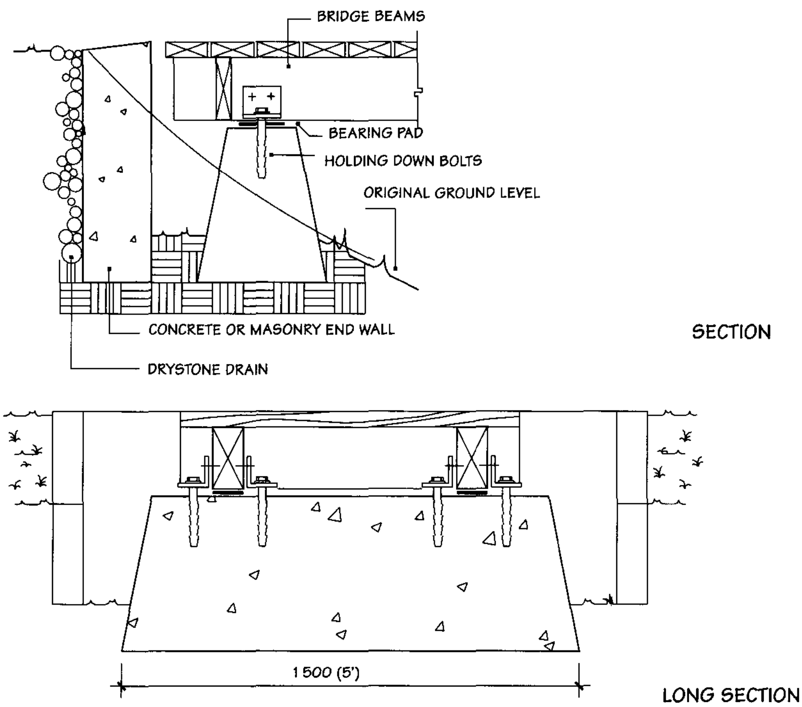


Figure 470-12. Typical small-abutment (end-seat) detail. *Backfilling should be well compacted and water should be led away from the abutment.*

Inclined Footing:

A footing with an inclined bottom has a simpler cross section than one with a shear key, but the excavation and construction of this inclined footing can be more expensive than a shear key (Figure 470-20).

Drainage:

In climates with considerable rainfall, adequate drainage is necessary behind the abutment to prevent the buildup of water pressure and the saturation of the soil behind the abutment.

The drainage system requires an outlet, must be testable, and has to be easily maintainable. Figure 470-21 shows uses of a porous block or equivalent porous material through which the water can drain to a pipe that can be cleared by rods. Weep holes are often specified to allow drainage in case of pipe blockage.

NOTE: A dry stone wall 450 mm (18 in) wide or wider may be equally as good as or better than a concrete abutment in regions where local rock and skilled labor are available.

Bearing Shelves:

If bearing shelves are used, then they require drainage (Figure 470-22). A channel along the top of the bearing shelf should be accessible for cleaning. Placing the channel in front of the bearings makes it simpler to clean.

Protective Coatings:

The back faces of concrete abutments can be given some form of protective coating to inhibit corrosion of the reinforcing in the concrete.

Groundwater:

Groundwater affects the performance of bridge substructures by:

1. Reducing the bearing capacity of substrata.
2. Increasing lateral pressures caused by flooding or a perched water table.

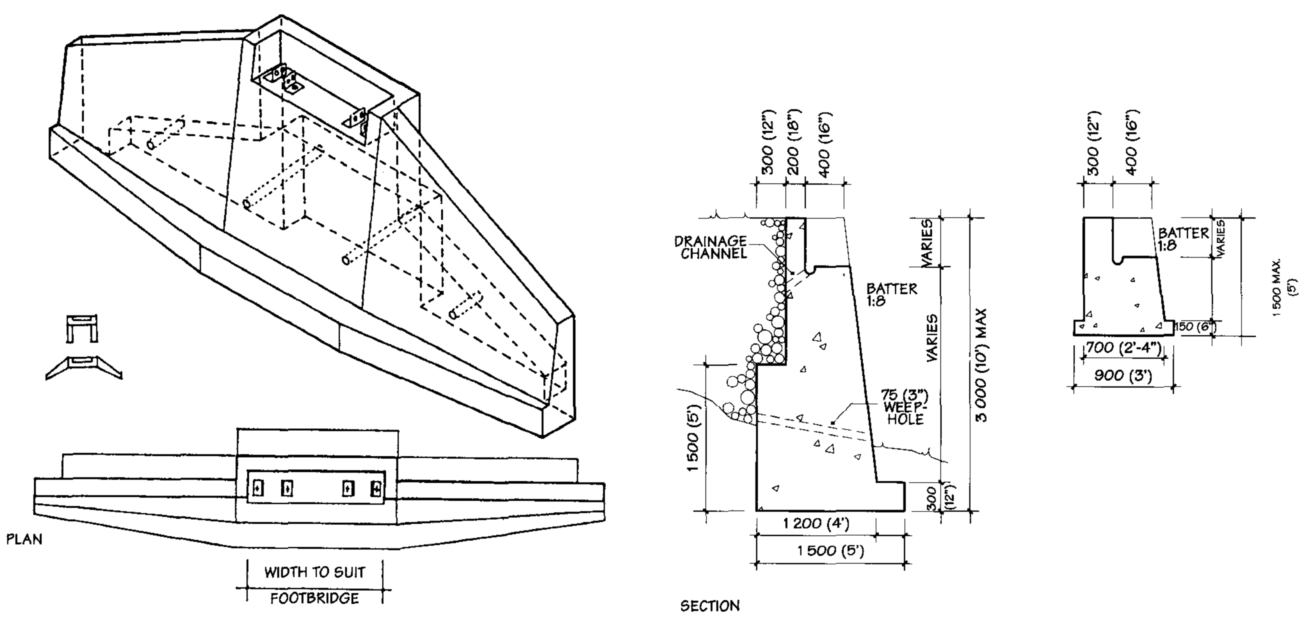


Figure 470-13. Typical mass-concrete abutment and wing walls.

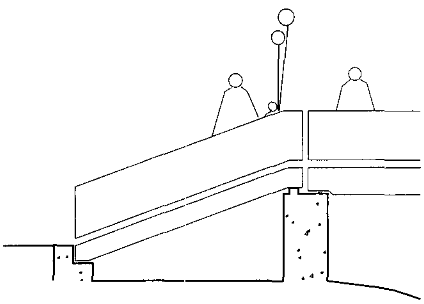


Figure 470-14. Pier supporting access ramp.

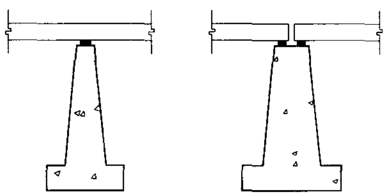


Figure 470-15. Single and double bearing piers. *The top of a pier must be wide enough to accommodate bearings and beam ends.*

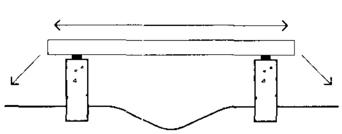


Figure 470-16. Effect of superstructure expansion on piers. *Piers must be constructed to counteract overturning effects due to longitudinal forces such as bridge expansion, wind, and traction.*

3. Leading to frost heaving of light structures.
4. Reducing the stability of earth slopes supporting bank seats or abutments (horizontal and vertical boreholes for drainage can help stabilize a bankslope in shales, mudstones, etc.).

Levels of groundwater in test boreholes should be recorded at the time of construction. Permanent standpipes or piezometers are necessary if groundwater is, or is thought to be, a serious problem.

In regions where there are very large seasonal and yearly variations in the groundwater level, it is important to record

Table 470-9. WALL ABUTMENTS

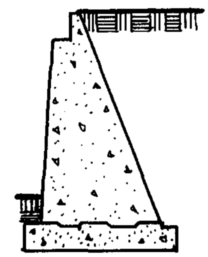
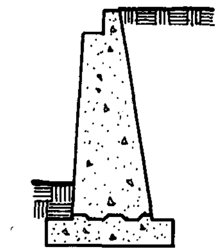
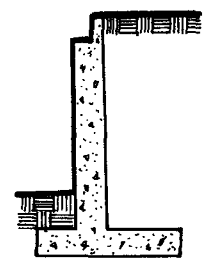
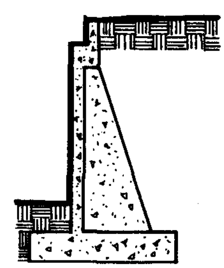
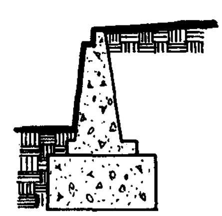
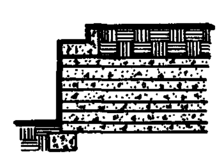
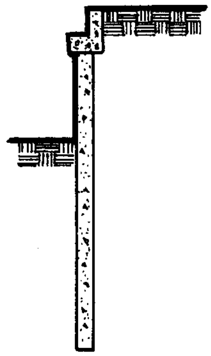
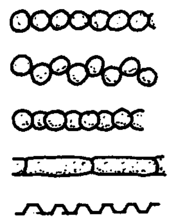
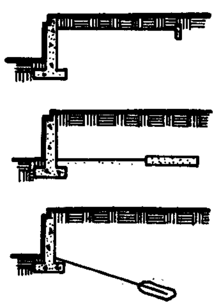
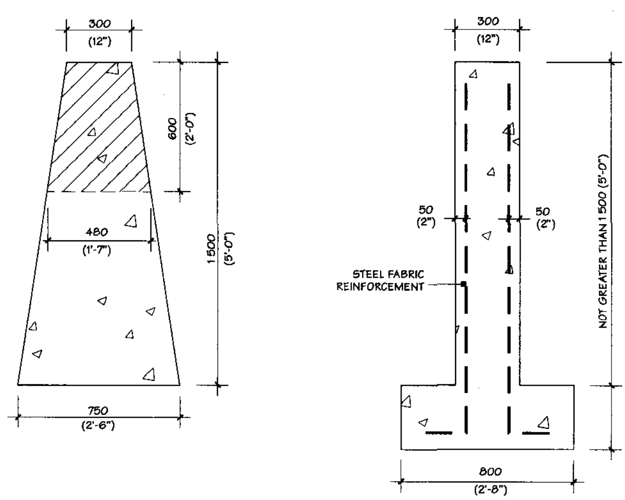
Type, use, and comment	Sketch
Mass or gravity type: Common usage for walls up to 1 800-2 700 mm (6-9 ft). Rare above 5 400 mm (18 ft). Mass concrete without reinforcement provides a simple form of construction but the large quantity of concrete is relatively expensive. Lack of reinforcement may make it ideal for a small contract with little or no other steel used in the construction. Low strength concrete can be used with less heat due to hydration and less cracking problems.	
Semimass: Common usage. A combination of mass concrete and minimum reinforcement.	
Reinforced T: Most common form of construction. Minimum width of base can be achieved if heel is larger than the toe. Complicated reinforcement details make construction slower than semimass.	
Counterfort: Seldom used except for very tall walls. The complicated construction of counterforts and much formwork make this uneconomic for walls less than 9 000-10 500 mm (30-35 ft) in height. Compaction of fill between counterforts is difficult and not always satisfactory.	
Abutment on fill: Used only when appropriate. A deep foundation can often be achieved more economically by placing a small abutment on fill than by constructing a large abutment. In difficult ground conditions fill can be selfcompacting, such as by mass concrete, and placed without workmen entering the excavations. Speed and simplicity of construction more than compensate for the cost of large quantities of material.	
Reinforced earth: Reinforced earth may be appropriate where filled embankments are behind the abutments, but are not appropriate in cut areas. These types of structures have a large tolerance for movement and are ideal for sites with poor ground near the surface (but not if poor stratum is deep because circular slip is not resisted by ties). A batter to the front face is desirable. Be sure to assess the corrosion life of ties and fittings and the possibility of erosion through gaps in some types of facing.	

TABLE 470-9 (Continued)

Type, use, and comment	Sketch
Diaphragm (contiguous bored pile or sheet pile) wall: Used for special situations only. These forms of structure are convenient for construction from ground level, when their high cost is compensated for by the speed of construction and lack of temporary works. They usually require some form of facing after excavation. The piles can be in line or staggered to increase the wall thickness and provide a tolerance for variation in pile size. Diaphragm walling may be economic for large or repetitive works. It can be constructed with precast elements with adequate drainage behind it. Steel sheet piling may not be suitable for permanent works with a long design life. Economy is particularly evident when they are good for temporary cofferdams.	 
Anchors and ties: Ground anchors are practical for abutments if the existing soil is not cohesive or where there is a low water table. When ties are used for deadman anchors, provision should be made for settlement of wall and fill. Allow the movement needed to mobilize the anchor resistance. Anchors and ties, like ground struts used for reinforced earth, can be damaged during excavation when services are performed at a later date.	

Source: Modified from *Building Research Establishment.*



the standpipe levels regularly and for as long a time as possible.

Flood Damage and Scour:

Floods and flood debris can sometimes pose a greater threat during bridge construction than afterwards. During the design stage, it is important to obtain information on flood frequencies and to make this information available to bidders and contractors.

Floods may cause damage to a bridge in the following manner:

1. Insufficient waterway at the bridge site causing flooding and/or high water velocities resulting in scour of the streambed and banks, which may undermine the abutments
2. Insufficient waterway downstream of the bridge causing back-up, or insufficient waterway upstream of the bridge causing high flows, can result in the structure floating off its bearings and being carried away
3. Floating debris and ice wedging against the bridge structure, creating stress and possible structural failures

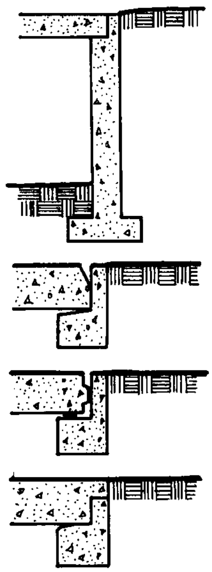
Avoiding Flood Damage: Flood damage can be avoided by (1) setting the bridge high enough to allow passage of the highest flows and to provide clearance for floating branches and other debris, and (2) placing abutments where flow will not be blocked or restricted. Areas upstream of the bridge should be inspected to determine what can be carried downstream during a flood.

Scour: Scour is one of the most frequent causes of failure in bridges over streams. The dangers of scour around abutments and piers can be minimized when:

1. The abutments are kept behind the natural bank line so they do not become an obstruction.
2. The foundations are set well below the lowest level of the scour.

Figure 470-17. Typical support piers for timber beam bridges *(span under 10 meters fixed at both ends.) Smaller piers use top of section (as shown with cross-hatching).*

Table 470-10. STRUTTED, PORTAL, AND BOX STRUCTURES.

Type, use, and comment	Sketch
Strutted or vertical beam abutments: Often used for small bridges, but seldom used or spans exceeding 18 000 mm (60 ft). Many small bridges of spans up to 13 500 mm (45 ft) use the deck and structure of the bridge as a strut to the top of abutments. This allows the foundations to be narrower and simpler than for freestanding cantilever walls. Usually the walls are monolithic with the footings. Strutting of abutments is not recommended for skews greater than 6 000 mm (20 ft), although the effect of the skew depends on the length-width ratio.	
Portal frames: This type is occasionally used. Portal frames are used for the same advantage as strutted abutments, but for much longer spans. It is possible to use a more slender deck than for a simple supported span. The portal frames are generally more expensive, and their foundations have to resist horizontal movement to prevent overstressing the top corners of the portal.	

Source: Modified from *Building Research Establishment.*

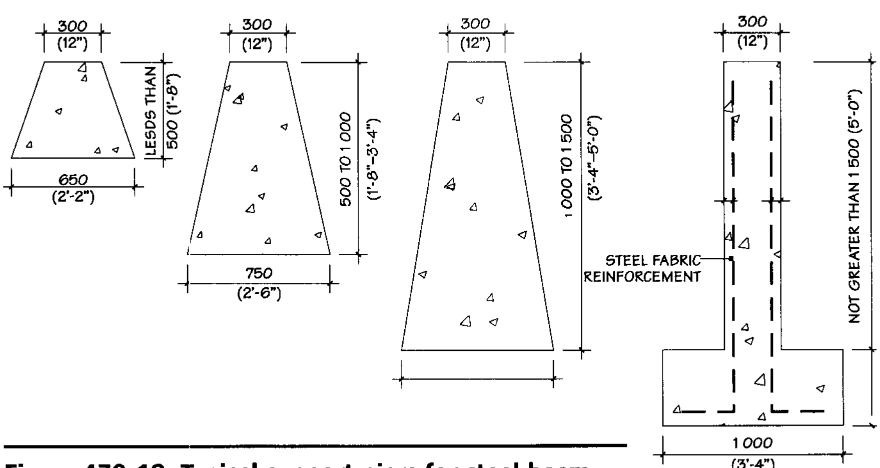


Figure 470-18. Typical support piers for steel beam bridges. *(Span under 10 meters fixed at one end).*

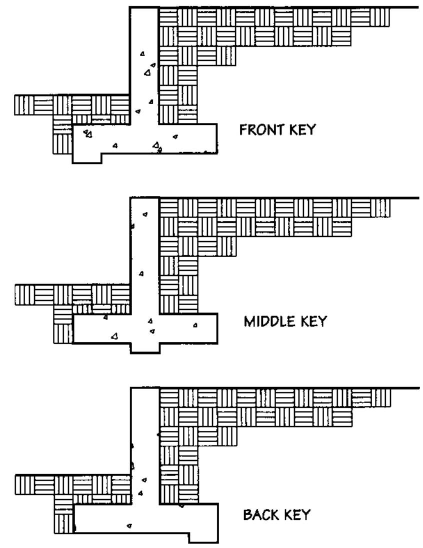


Figure 470-19. Position of shear keys.

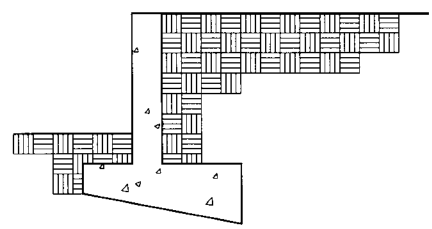


Figure 470-20. Footing with inclined base.

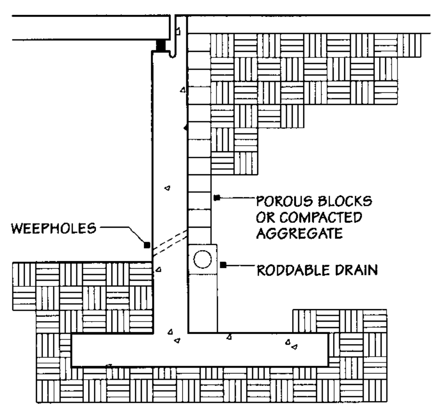
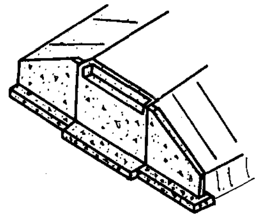
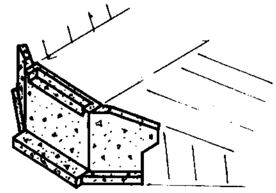
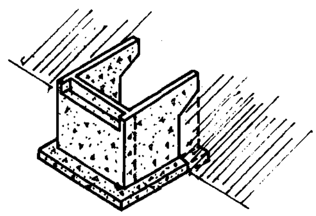
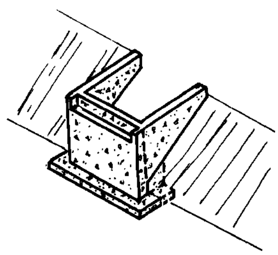
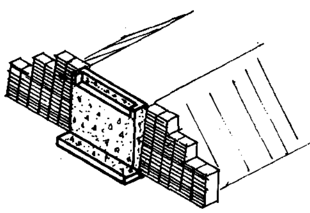


Figure 470-21. Typical drainage system behind wall abutment (for wet climates.

Table 470-11. WING WALLS

Type, use, and comment	Sketch
Wing walls parallel to abutment: Wing walls parallel to the abutment face are not as economic as angled walls but are usually simpler to build. They are often designed monolithic with abutment. For bridges constructed on existing embankments, they cause less disturbance.	
Wing walls at angle to abutment face: These are generally the most economic as far as materials used.	
Wing walls parallel to the bridge: Less economic than angled walls, but continue line of deck and provide support for parapets. Such wing walls may not be appropriate when they or their excavations impinge on adjacent structures, services, or traffic diversion. Proper compaction of backfill in the corners is seldom achieved, and forming of exposed edges of abutments requires special care.	
Cantilever wing walls parallel to over road: Commonly used with sloping abutments. An abutment with large cantilever wing walls looks similar, when complete, to the abutment with wing walls on footings parallel to the bridge. It. has the advantage of having the whole structure supported on a single footing, which can settle as a single body, but it also has the same problems during construction as the one above. Reinforced earth or sheet piling can sometimes be used for wing walls to a concrete abutment.	
Crib walls: Crib walling is suitable for wing wall construction. (It is not considered suitable for abutments.) Its appearance makes it more acceptable in rural than in urban situations.	

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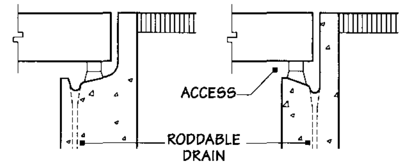


Figure 470-22. Drainage of bearing shelves. *The channel along the top of the bearing shelp should be accessible for cleaning.*

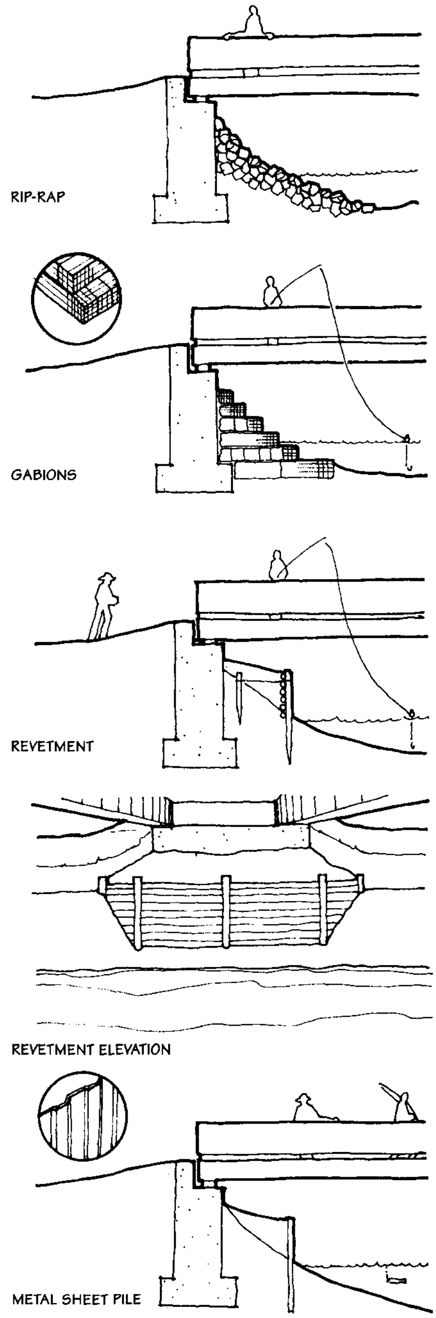


Figure 470-23. Scour protection devises for narrow footbridges.

3. The face of the abutment is made rough, to reduce the speed of the water flow.
4. The piers, if used, are streamlined to cause fewer eddies.
5. The sheet piling, if used for cofferdams, is left in place for scour protection.
6. Scour protection techniques (gabions, riprap, etc.) are used to slow down the flow.

If scour protection devices and techniques are necessary, they should extend far enough upstream and downstream that the stream cannot erode behind them. Often the scour protection device is turned back into the stream bank in order to protect the ends from scouring.

Common techniques of scour protection include (Figure 470-23):

1. Riprapping: stones or precast concrete units are laid on a bed of smaller stone or gravel. The profile of the riprapping should divert the water flow smoothly around the abutment without any obstruction. If the riprapping becomes damaged, the damaged area can enlarge very quickly and cause a complete breakdown.
2. Stone-filled wire gabions: gabions are galvanized wire cages filled with cobbles. They must be installed strictly in accordance with the manufacturer's instructions. Since a large amount of stone filling is required, gabions are best suited for areas where this can be obtained locally. (Refer to Section 410: Retaining Walls, for more information on gabions.)
3. Revetments: wood or precast concrete can be used to create a wall (revetment), which is then filled with stone and/or gravel. Various techniques are employed in the construction of revetments. Figure 470-23 shows one technique using wood. Concrete cribbing is also used and generally has a longer life, although it may be more expensive to construct. (Concrete cribbing is described briefly in Section 410: Retaining Walls.)
4. Interlocking steel sheet piling: steel sheet piling may be advantageous in particularly difficult situations where ground conditions are very poor. This technique usually requires installation by an experienced contractor.

Table 470-12. SIZE RANGES OF PREFABRICATED BRIDGES

Type	Span, mm (ft)	Inside width, mm (ft)	Truss height, mm (ft)
Low-profile bridge (steel)	3 000-31 500 (10-105)	1 200-3 000 (4-10)	1 200 (4)
High-profile bridge (steel)	3 000-31 500 (10-105)	1 200-3 000 (4-10)	2 400 (8)
Aluminum box truss pedestrian bridge	18 000-33 900 (60-113)	—	—
Steel arch bridge	3 000-30 000 (10-100) in 1 500 mm (5 ft) increments	1 200 (4) 1 800 (6) 2 400 (8) 3 000 (10)	
Steel through truss	21 600-50 400 (72-168) in 2 400 mm (8 ft) increments	1 800 (6) 2 400 (8)	2 400 (8)

Bearings:

When superstructures rest on abutments and piers, the load is transferred through some form of bearing device which allows the bridge to expand and contract under temperature or moisture changes. Bearings also let the ends of the beam flex slightly as they are loaded and unloaded (see Figure 470-12).

Timber Footbridges: Timber structures expand in relatively small amounts and do not need special expansion bearings unless the spans are over 30 000 mm (100 ft). Glass-fiber-reinforced bituminous felt, lead, or rubber pads can be used as bearings. Because timber bridges are relatively lightweight, vibration from heavy use may move the bridge off its bearings, or flooding may float it away. Therefore, most wood bridges should be held down by bolts or stainless-steel straps. (See Figures 470-25 and 470-26.)

Steel and Concrete Footbridges: Structures made of steel or concrete may be mounted on glass-fiber-reinforced bituminous felt, lead, or rubber pads for spans up to about 9 000 mm (30 ft). Because a steel footbridge is relatively lightweight, a positive method of holding it down should be incorporated in the bearings. Recent experience shows that prefabricated bearings with stainless steel sliding on a pad of fluorocarbon provides very low friction forces for both steel and concrete bridges.

4.0 TYPICAL DESIGNS FOR SHORT-SPAN FOOTBRIDGES

This subsection includes drawings and information on seven types of footbridges.

Figures 470-24 to 470-30 show representative designs for footbridges for spans under 9 000 mm (30 ft) where the loading is limited to Pedestrian—normal (see Table 470-4). Where the spans are greater than 9 000 mm (30 ft), an experienced bridge designer should be consulted.

4.1 Log Footbridge

For a log footbridge (Figure 470-24), natural logs are often used when timber can be cut at or near the footbridge site. Natural log footbridges may have a relatively short (8 to 10 year) lifespan, depending on the durability of the logs and the wetness of the local climate. The most decay-resistant species of timber should be selected.

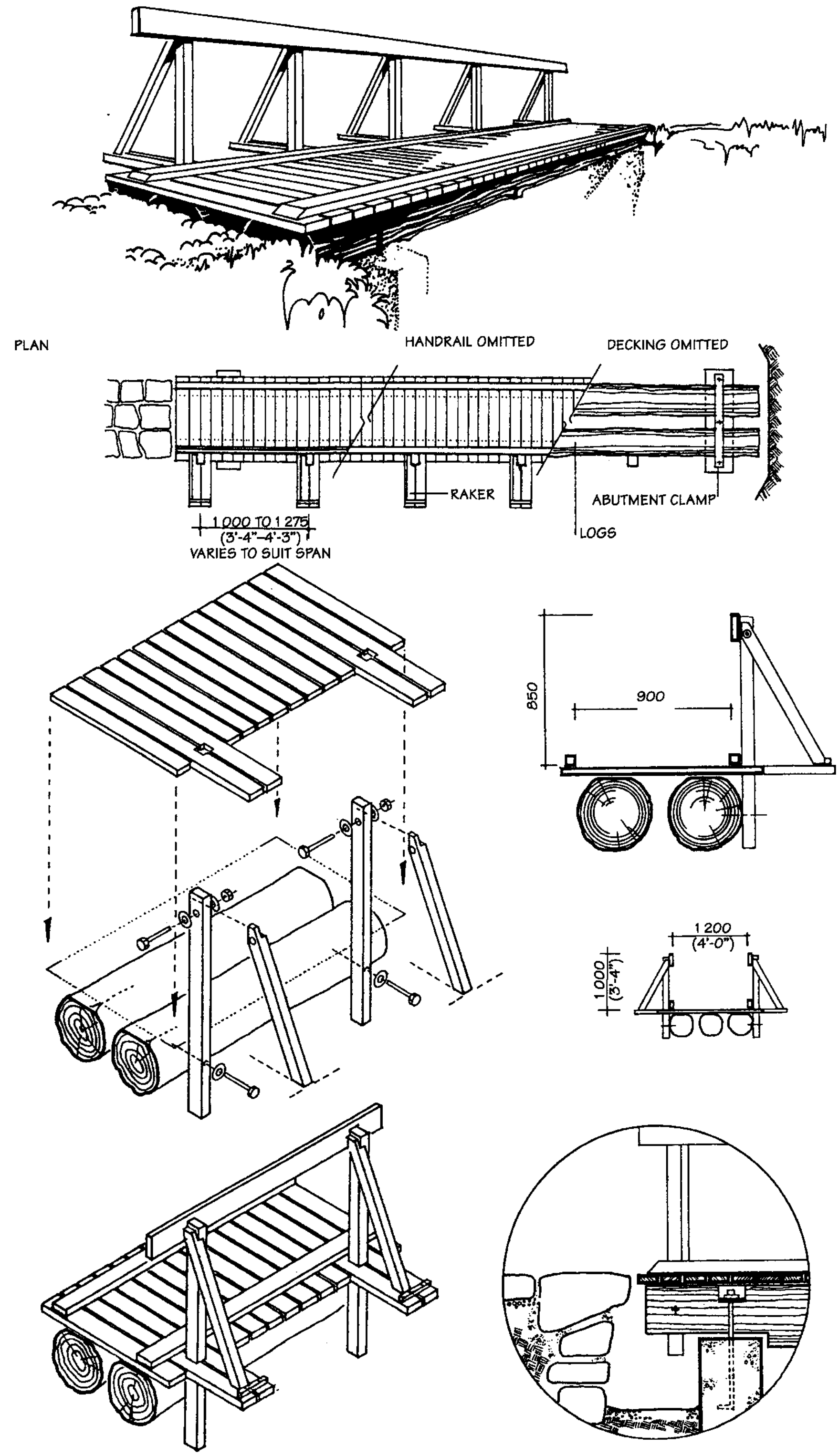
4.2 Sawn Timber Footbridge

The main beams of a sawn timber footbridge (Figure 470-25) should be of high-quality wood and should be pressure-treated with an appropriate wood preservative to provide long life. Sawn timber is lighter and easier to handle than natural logs, and such bridges have a better life than log bridges, typically ranging from 15 to 20 years. (See Section 850: Wood, for more information on the use of wood in outdoor construction.)

4.3 Galloway Timber Footbridge

This design (Figure 470-26) was developed with the following aims:

1. The main beams would not be penetrated by bolt holes or other fasteners after preservative treatment.
2. The bridge would be demountable to permit periodic maintenance and easy replacement of damaged sections.
3. Skilled site work would not be required.



Log Size Average Diameter	Span C/C Bearing 2-log, 900 mm (3 ft) wide deck	3-log, 200 mm (4 ft) wide deck
250 mm (10 in)	5 000 mm (16'-8")	5 500 mm (18'-4")
300 mm (12 in)	6 700 mm (22'-4")	7 000 mm (23'-4")
350 mm (14 in)	8 000 mm (26'-8")	8 500 mm (28'-4")
400 mm (16 in)	9 750 mm (32'-6")	1 000 mm (3'-4")

Figure 470-24. Log Footbridge

These aims have been achieved by using bent bolts to bind the bridge parts together so that friction between the faces replaces bolted connections. The bent bolts could be loosened to allow parts to be removed for maintenance or repair. The problem of fastening handrail posts has been solved by using a prefabricated H frame which is made off-site. The bridge is assembled by unskilled laborers on-site from a kit of parts.

4.4 Galloway Steel Footbridge

The British Army developed this design (Figure 470-27) from the Galloway timber footbridge. The steel beams extend the useful span and are lighter than timber. Horizontal bracing is required between the steel beams because they are less stiff in this direction than timber. A good paint specification and regular maintenance are required to extend the life of the steelwork. The longer spans should not be attempted without engineering advice.

4.5 Steel Beam Footbridge

Two suggested cross sections for steel beam structures are shown in Figure 470-28. The life of the structure will depend on the quality of the maintenance protecting it from corrosion.

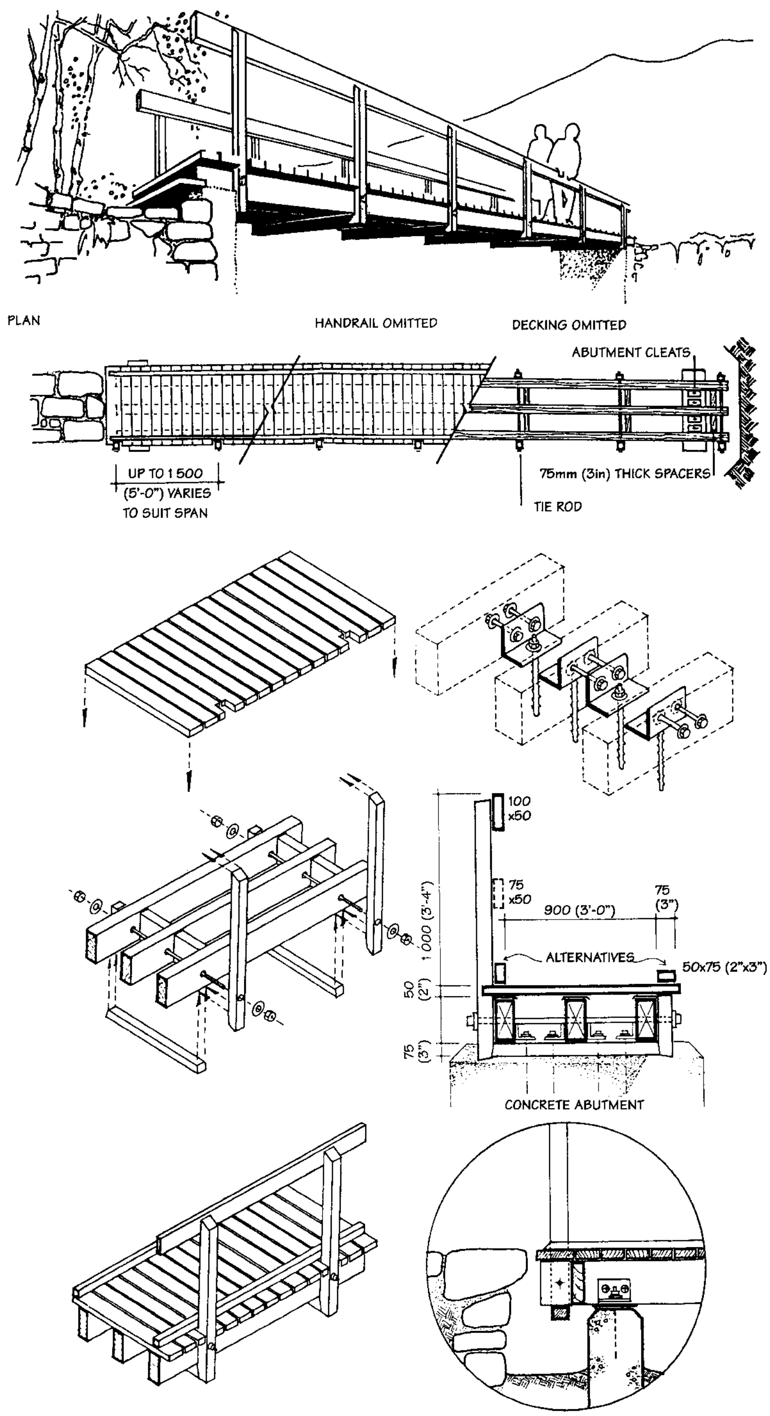
4.6 Suspension Bridge

Suspension bridges (Figure 470-29) are used when (a) streams have fluctuating water levels, (b) the currents are very rapid, (c) conditions for foundations, particularly intermediate piers, are impractical, and (d) sites are remote so that small pieces needed for a suspension bridge can be carried in. Where large crowds are not expected low technology solutions are possible for footbridges of 14 700 to 19 800 mm (49 to 66 ft).

The sizes of all members of a suspension bridge must be determined by an experienced designer or engineer who will also check the method of erection. This should be done under the guidance of a competent construction supervisor. Erection of a suspension bridge is hazardous. Safe working procedures must be formulated and used by experienced personnel using correct equipment.

4.7 Concrete or Masonry Arch Footbridges

In addition to the six types of wood and metal bridges, there are several bridge types that could be constructed from poured-in-place concrete or various kinds



Beam Size	900-mm-wide deck No. of Beams	Span	1 200-mm-wide deck No. of Beams	Span
75x150 (3x6)	3	3 000 (10)	3	2 750 (9.7)
100x200 (4x8)	3	4 500 (15)	3	4 000 (13.3)
150x250 (6x10)	3	6 500 (22.6)	3	5750 (19.2)
200x250 (8x10)	3	6 250 (20.8)	3	7 500 (25)
225x300 (9x12)	2		3	
250x350 (10x14)	2		3	

Figure 470-25. Sawn timber footbridge.

of masonry construction. Figure 470-30 shows two variations, one using concrete and one using stone. In the latter example, other types of masonry (such as brick or precast concrete) could be used as the structural material or as a facing material for a poured concrete footbridge.

As with other types of footbridges, concrete or masonry arch bridges require solid foundations. Most concrete or masonry arch bridges require the advice of a structural engineer to ensure compliance with safe design and construction standards.

If rough stone or rubble masonry is used to construct the arch, then the stones should be roughly squared and laid in portland cement mortar. The stones must be hard, durable, and reasonably flat. Not more than one-third of the stone should be less than 300 mm (1 ft) thick, and no stone should be less than 150 mm (6 in) thick and have a bed area of less than 300 mm (1 ft) square. Walls must be laid using large, flat, selected stone in the bottom and having at least one-fifth of the wall surface made of face headers. All of the spaces in the heart of the wall should be filled with suitable stones or spalls which are thoroughly bedded in cement mortar. The outer arch ring should be made of full-size stones that have been rough-dressed to create smoother abutting inner surfaces. They should be laid simultaneously from both ends, with mortar joints not exceeding 25 mm (1 in) in thickness.

Arch centers should not be struck until directed by the designer. The tops of the face walls should be finished with cope-stones no less than 150 mm (6 in) thick and 450 mm (18 in) wide, with a length of at least 1 1/2 times the breadth.

Dry rubble masonry can be used, but it should meet all of the other requirements for rough-stone or rubble masonry. Only flat stones at least twice as wide as thick should be used. Generally, the larger stones should be placed in the lower part of the wall, although different sizes can be more evenly distributed over the wall face.

If the wall is sloped, then the stones should be placed at right angles to the slope and every stone must extend the full depth of the wall.

5.0 TYPICAL DESIGNS FOR PREFABRICATED BRIDGES

Manufactured prefabricated bridges can offer advantages in sites where access is easy, where long spans are necessary, where minimal costs are required, or where skilled labor is unavailable.

Flat-span and arch-span types of bridges are available in the United States for spans ranging from 3 000 to 48 000 (10 to 160 ft). Lengths over 19 500 (65 ft) are fabricated in sections to be bolted together in the field. Carbon-steel or self-weathering-steel bridge structures finished with wooden decking and handrailings are also available. Loadings are designed in accordance with AASHTO specifications. Optional handrailings 1 350 (54 in) high are available when use by bicyclists is anticipated.

The same careful consideration of foundation and abutment design is required for prefabricated bridges as for site-built bridges because manufacturers provide only bridge superstructures.

Table 470-12 gives the sizes of prefabricated bridges currently available in the United States.

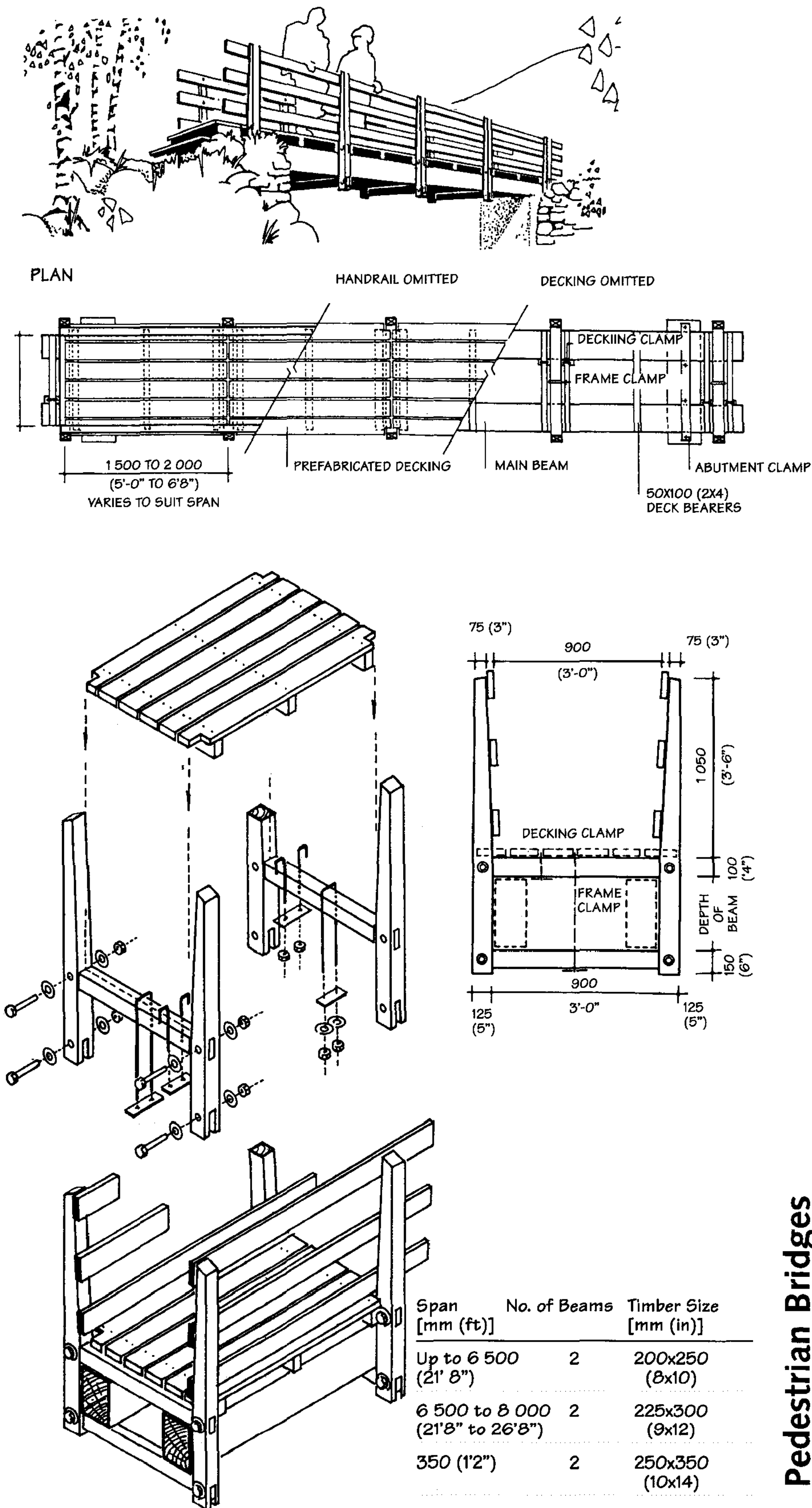
6.0 PROBLEMS OF ERECTING BRIDGES

Every site will present its own distinctive problems in the erection of a bridge. Four of the most common areas of difficulty are:

1. Access to the site: where access is particularly difficult, it may be necessary to design main structural members with small pieces that can be assembled at the bridge site.
2. Amount of clear, level area for assembly of bridge elements: if structural elements have to be assembled at the site before being placed across a gap, a suitable level area is required.
3. Lifting main structural members into position: the method used to place these members will depend on their length, weight, stability, and the nature of the equipment which can be brought to the site. This should be anticipated at the beginning of the design process (Figure 470-31).
4. Maintaining safe working conditions: accidents can be avoided only by adopting safe working methods which are carefully supervised.

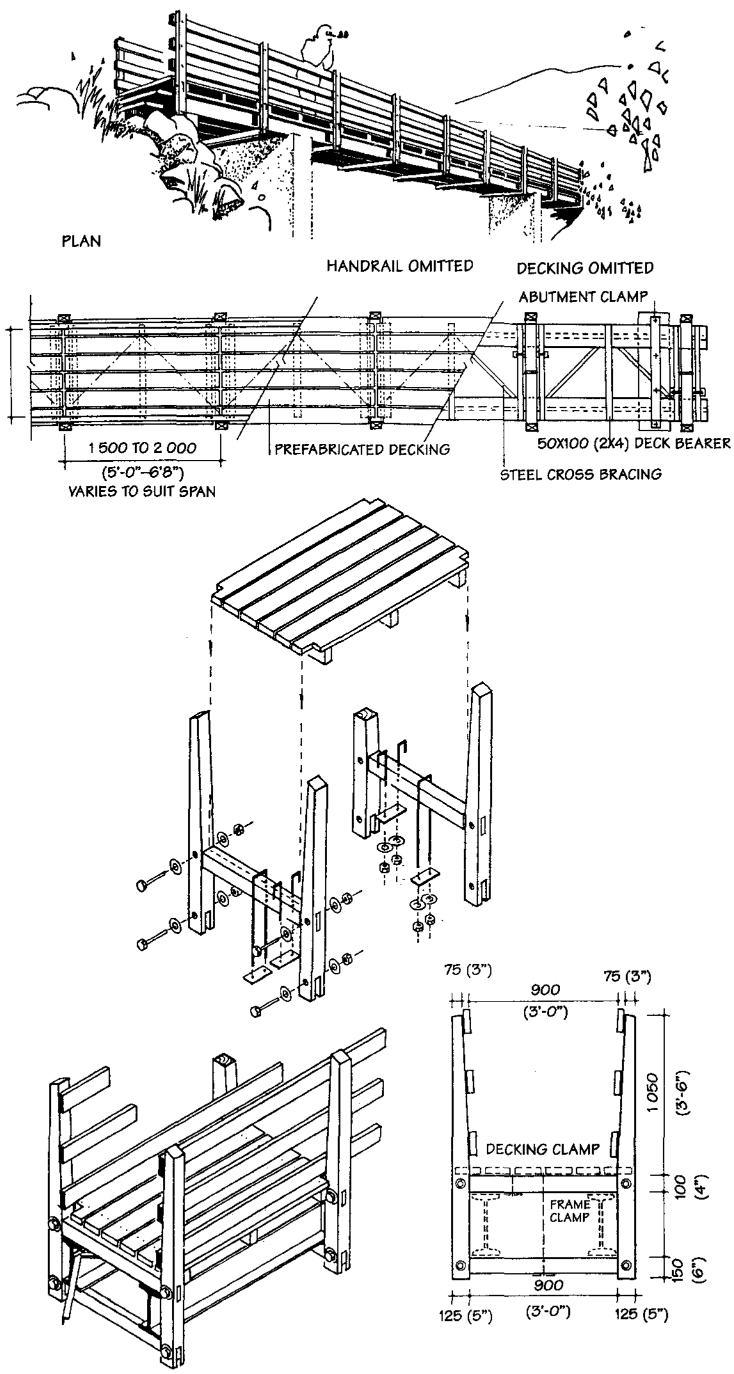
7.0 MAINTENANCE OF BRIDGES

All bridges deteriorate over time as a result of constant use and of decay. Therefore, all bridges need periodic inspections and



Span [mm (ft)]	No. of Beams	Timber Size [mm (in)]
Up to 6 500 (21' 8")	2	200x250 (8x10)
6 500 to 8 000 (21'8" to 26'8")	2	225x300 (9x12)
350 (1'2")	2	250x350 (10x14)

Figure 470-26. Galloway timber footbridge.



Universal Beam Size (dxbxweight)	Simply supported span	Cantilever Length
203x133x25 kg/m	8 750 mm	1 800 mm
254x146x31 kg/m	10 750 mm	2 200 mm
305x171x45 kg/m	13 250 mm	2 700 mm
365x171x45 kg/m	14 750 mm	3 000 mm

Figure 470-27. Galloway steel footbridge.

repair. The following procedures should be adopted to ensure longer life of the bridge.

7.1 Maintenance in Design

Provide for maintenance in design by:

1. Ensuring that the main beams can be inspected along their entire length and especially where they rest on piers and end seats
2. Ensuring that secondary elements (decking, handrailings, etc.) can be removed and replaced without undue difficulty
3. Ensuring that inspections are easy to carry out, including the provision of anchor points for harnesses and/or of platforms for ladders or scaffolds
4. Ensuring that design assumptions are recorded and that design drawings and specifications are kept secure

7.2 Maintenance in Construction

Provide for maintenance in construction by:

1. Ensuring that the bridge is built to design standards and specifications
2. Ensuring that variations are recorded and that an accurate set of as-built drawings is produced, including a simplified plan and elevation for inspection purposes
3. Taking a set of photographs, so that construction work, particularly that which will be hidden, is recorded, and so that progressive deterioration can be assessed by comparison with the original condition.

7.3 Maintenance in Use

Provide for maintenance in use by:

1. Briefing maintenance staff on standards and procedures
2. Maintaining a record file for each bridge
3. Inspecting each bridge and its approaches annually, preparing a bridge inspection report, and ensuring that maintenance recommendations are implemented

Sensible housekeeping measures include cleaning vegetation and soil from timber decking, maintaining free air space around beam ends, and tightening loose fastenings. Wood preservative should be reapplied every 3 years, and metal paint every 5 years. Rust spots should be cleaned every

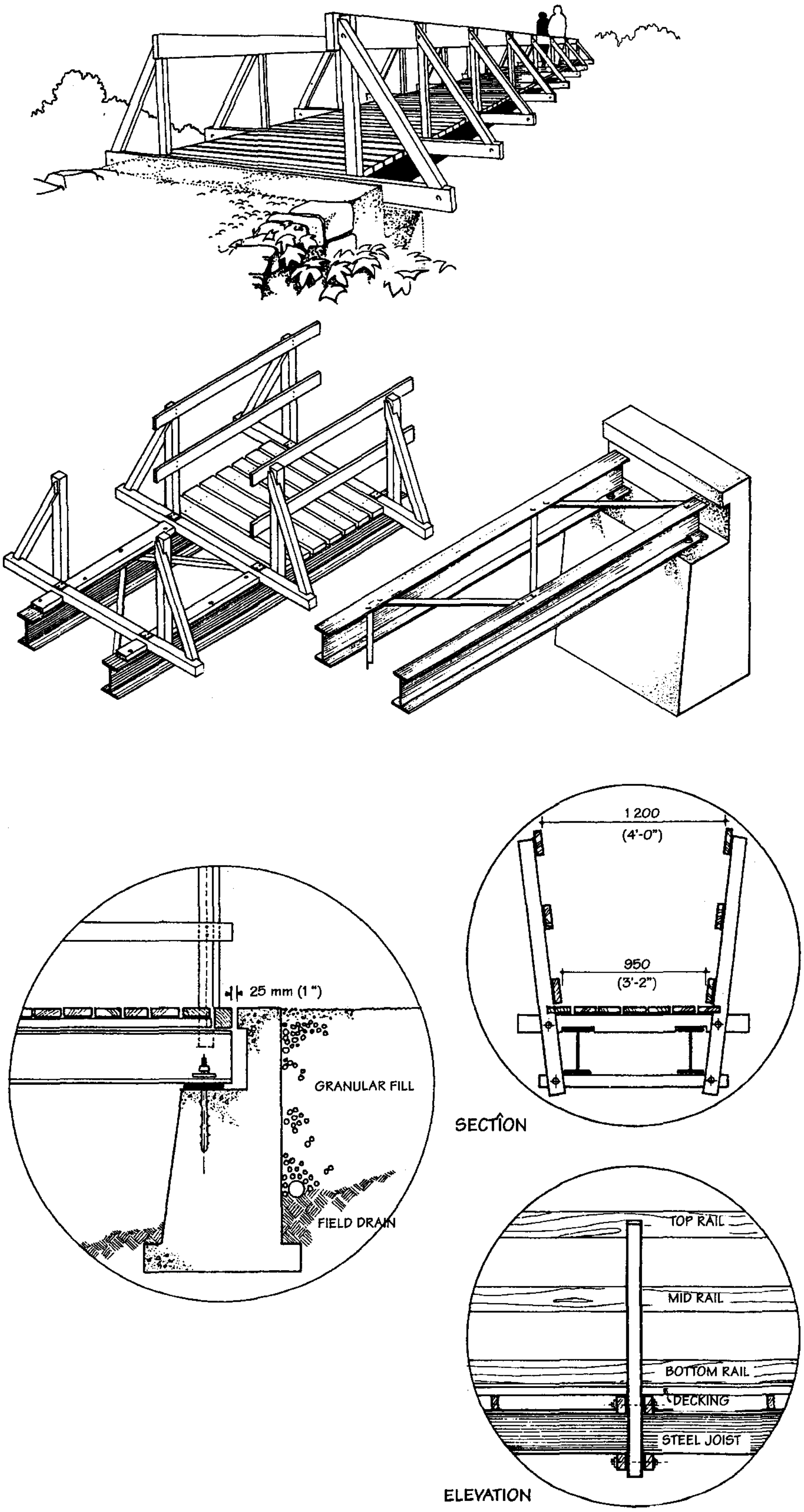


Figure 470-28. Steel beam footbridge.

year, coated with antirust primer, and touched up.

7.4 Inspection

Points to look for during inspection are:

1. Scouring of riverbed and bridge foundations
2. Damage to banks and adjacent land
3. Unsafe trees close to the bridge
4. Muddy or worn footpaths, steps, and ramps
5. Decay of timbers, especially at holes, cracks, and ends
6. Water and moisture traps on horizontal surfaces and joints
7. Loose bolts, screws, nails, posts, and handrailings
8. Metal corrosion

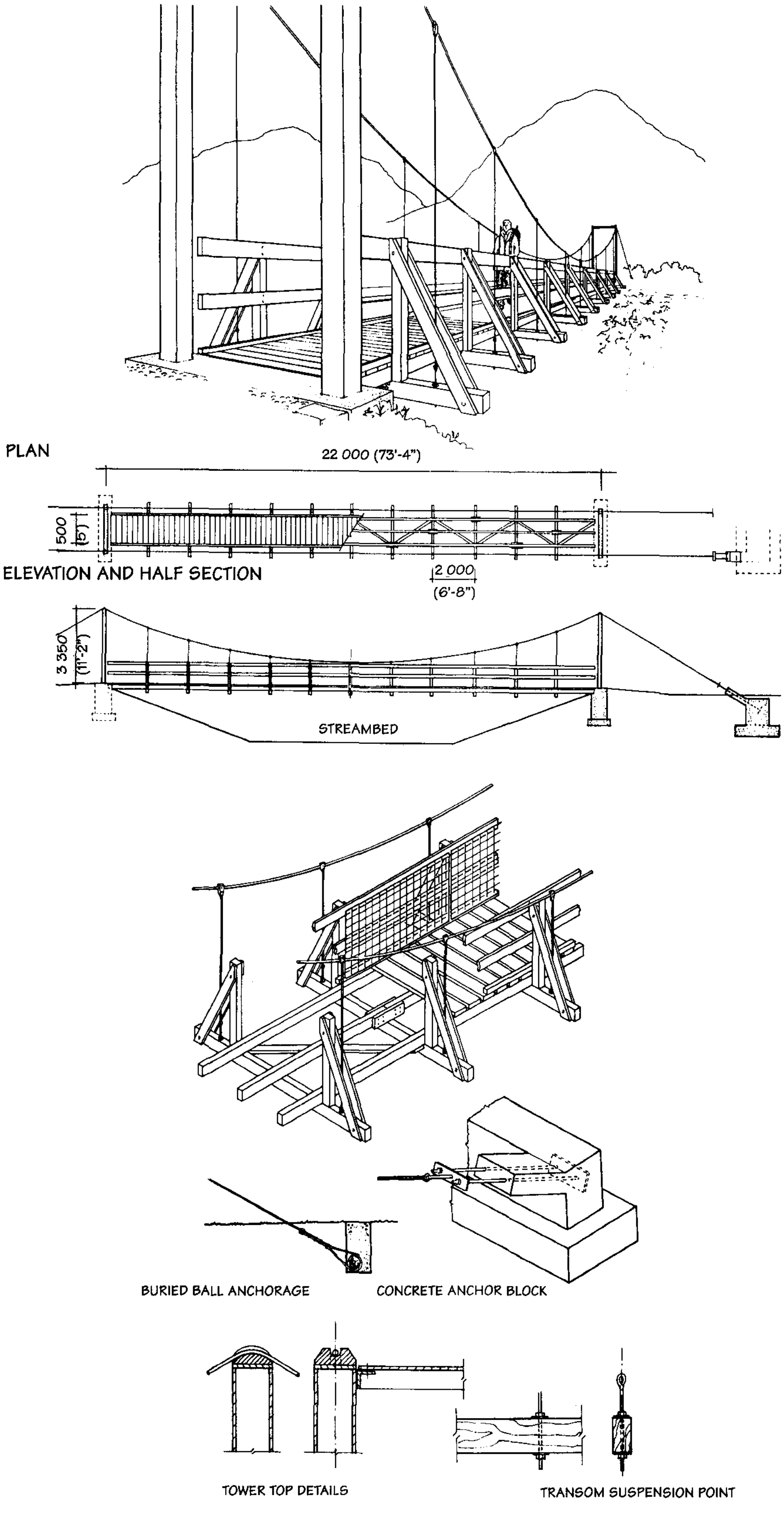


Figure 470-29. Suspension footbridge.

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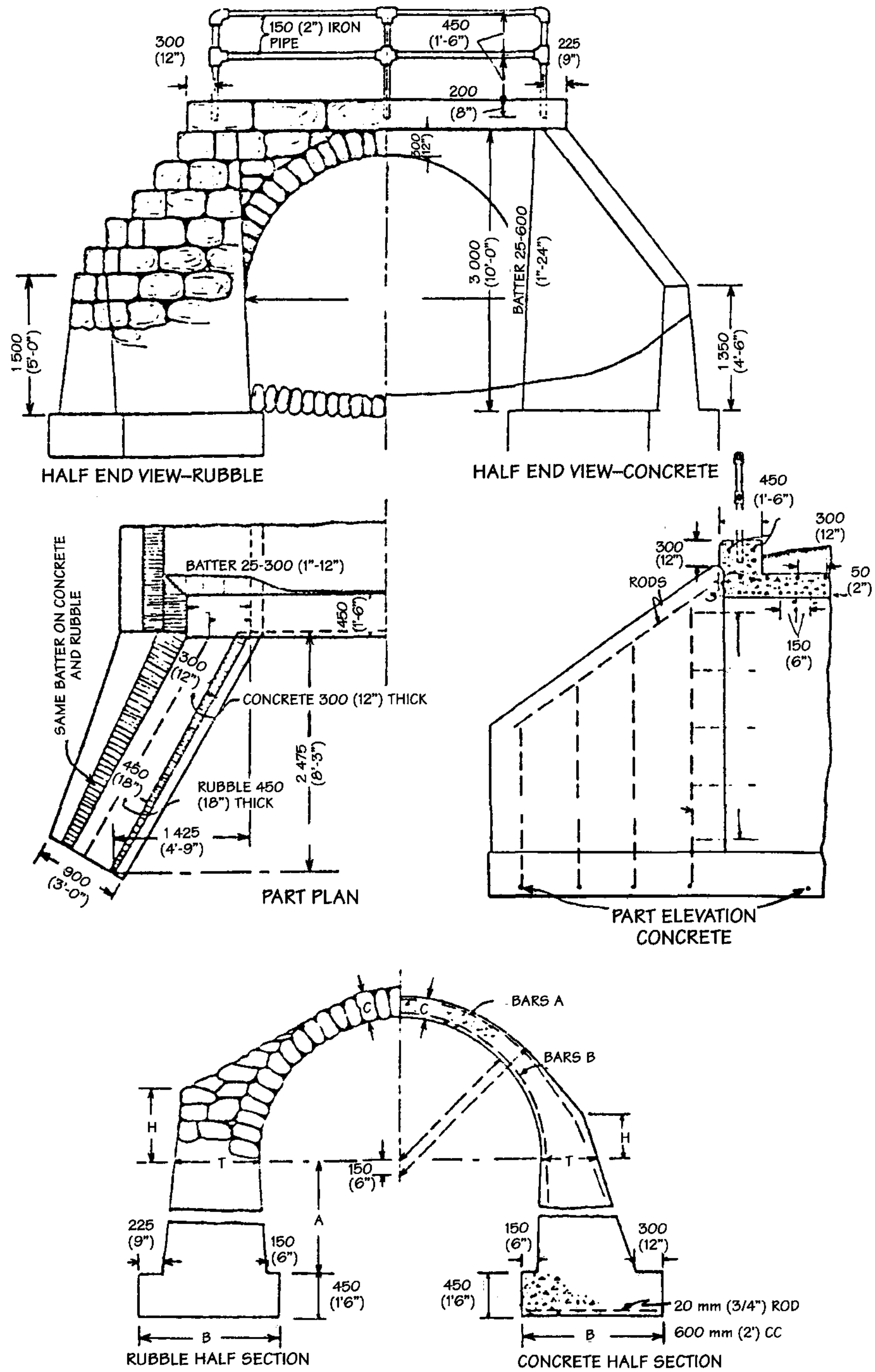

CONCRETE

SPAN	C	H	A & B BARS	T	B	SPAND WALLS & 4 WINGS CONCRETE	STEEL	BARREL/ 300mm (LIN FT) CONCRETE	STEEL
mm (ft.)	mm (in)	mm (ft)	mm (In)	mm (ft)	mm (ft)	m3 (yd3)	kg (lbs)	m3 (yd3)	kg (lbs)
1 800 (6')	150 (6")	300 (1')	15 (1/2")	450 (1'6")	1 425 (4'9")	19.6 (25.6)	84 (185)	.68 (.89)	6 (14)
3 000 (10')	225 (9")	450 (1'6")	17 (5/8")	600 (2')	1 500 (5')	20.3 (26.6)	86 (189)	.84 (1.10)	21 (28)
4 200 (14')	300 (12")	600 (2')	20 (3/4")	900 (3')	1 500 (5')	21.1 (27.6)	88 (193)	1.06 (1.39)	23 (50)

RUBBLE

SPAN	C	H	A	T	B	SPAND WALLS & 4 WINGS	BARREL/ 300 mm (LIN FT)	PIPE RAIL
mm (ft.)	mm (in)	mm (ft)	mm (ft)	mm (ft)	mm (ft)	m3 (yd3)	m3 (yd3)	kg (lbs)
1 800 (6')	250 (10)	600 (2')	1 800 (6')	615 (2'6")	1 425 (4'9")	28.0 (36.6)	.93 (1.21)	94 (208)
3 000 (10')	300 (12)	825 (2'9")	1 200 (4')	1 500 (5')	1 500 (5')	28.7 (37.5)	1.07 (1.40)	121 (266)
4 200 (14')	375 (15)	1 200 (4')	600 (2')	1 725 (5'9")	1 500 (5')	29.4 (38.5)	1.27 (1.66)	147 (324)

Figure 470-30. Concrete or masonry arch footbridge.

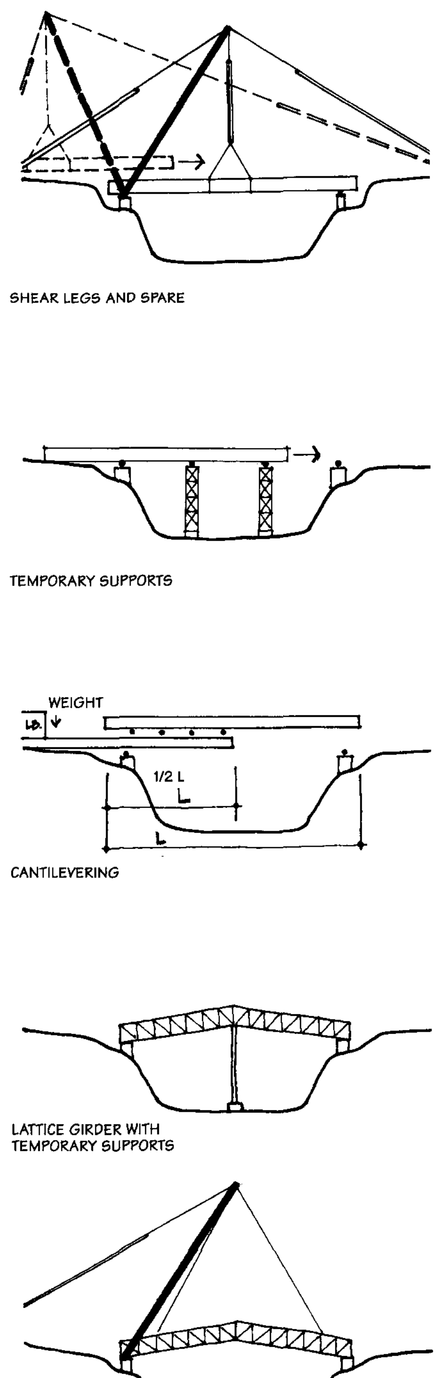

Figure 470-31. Methods of bridge erection. *The method used to place members will depend on their length, weight, and stability and on the nature of the equipment which can be brought to the site.*

DIVISION 500

Improvements

SECTION 510

Site Furniture and Features

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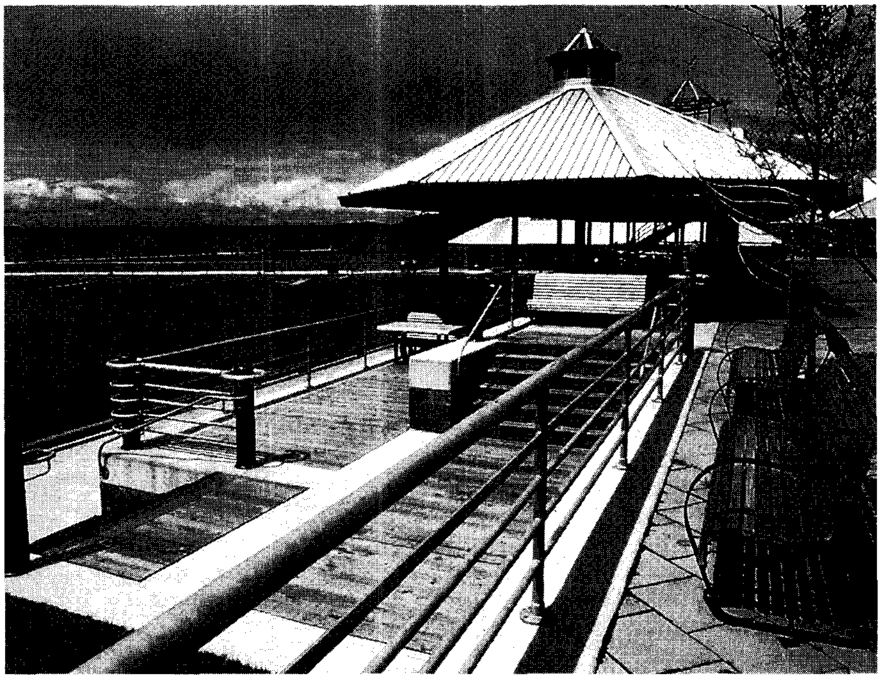

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CONTENTS

510 Site Furniture & Features

1.0 INTRODUCTION

1.1 General

Elements placed in a landscape or streetscape for comfort, convenience, information, circulation control, protection, and user enjoyment are collectively referred to as site furniture (Figure 510-1). Benches, bollards, signage, lighting, tree grates, and utility boxes are but a few examples. Their design and placement require careful consideration, involving several factors, each of which is described in this section.

Many of the same types of furnishings are also used for similar reasons in special landscapes, such as interiors or roof decks. (Refer to Sections 620: Interior Landscapes, and 610: Roof and Deck Landscapes, for more information.)

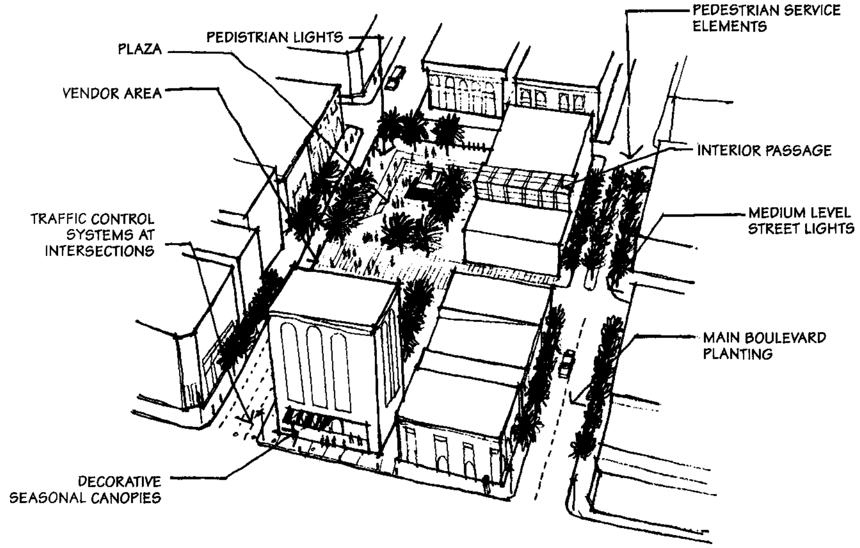

Figure 510-1. The larger setting provides the context of site furniture.

1.2 Design Objectives

Appropriateness:

Appropriateness is a major objective in the design and placement of site furniture elements. It is important to respond to the character of a site as well as its existing and proposed functions (Figures 510-2 and 510-3).

Response to Setting:

Design should respond to the essential identity or inherent character of a place. Successful, lasting design will flow out of its setting, continually responding to the needs of its users, meeting functional requirements, and adapting to the environmental stresses affecting it.

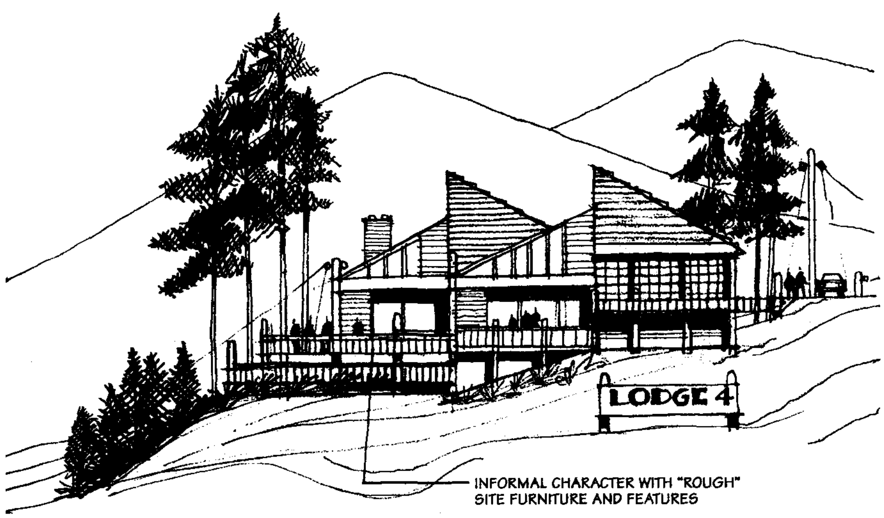

Figure 510-2. Site context: Informal character.

2.0 DESIGN DETERMINANTS

Settings should be analyzed in terms of both cultural and physical factors.

Cultural factors include:

1. Social context
2. Political context

Physical factors include:

1. Climate
2. Natural physiography
3. The existing built environment

Each of these factors is described below.

2.1 Cultural Factors

Social Context:

Attention to both the existing and proposed large-scale social setting will indicate who is currently using the site and who will likely use the site in the future. The manner in which the site is being used requires careful investigation (Figure 510-4).

The traditions and habits of particular user groups provide a basis for unique design departures that can enliven the setting as a whole, while at the same time serving specific needs. This can be reflected both in site organization as a whole and the design of individual elements themselves.

Inattention to the cultural habits and desires of particular groups and the use of improper elements can foster negative reaction in a neighborhood. The use of themes or vernacular forms which have no local cultural root seldom contribute to the evolving identity of a place.

Some ethnic groups, for instance, have need for special types of site furniture appropriate to particular activities. Finding what is needed is not only a basic responsibility of the designer, but often opens up an opportunity to explore new design ideas.

Political Context:

Design ideas will evolve from thoughtful examination of the natural, built, and social setting, but a complex and contradicting array of administrative, operational, regulatory, and legal issues can compromise a design (Figure 510-5). Designing solely to meet these regulations often produces nothing of present or enduring value. This is particularly true regarding the design and placement of furniture in public spaces where a great number of functional, visual, and regulatory factors coincide.

The nature of the setting, whether a public square or a corporate courtyard, implies major differences in the choice of design elements. Public streets and spaces are susceptible to incidences of vandalism, and are also periodically abandoned by revenue-starved local governments. Lastly, issues of long-term maintenance, public safety, and circulation control require careful consideration.

2.2 Physical Factors

Climate:

Different climates and/or dramatic seasonal changes can significantly influence the design of site furniture and the consequent comfort of the users. Figure 510-6 shows typical climate factors. A thorough understanding of the consequences of seasonal variation, including both advantages and disadvantages, is an essential prerequisite for the design of site furnishings.

Physiography:

Particular landforms, vegetation, and other distinctive qualities which give an area its special regional or local character should be responded to in a congruent manner (Figure 510-7). For instance, in the United States the building vernacular of the Rocky Mountains is distinctly different from that of the Appalachian Highlands. Special attention should be given to examining local landscapes and materials before translating program requirements into built elements.

Built Environment:

Site furnishings can strengthen the link between a development and its surroundings, can personalize the setting, and can enhance the positive aspects of the surrounding built landscape.

A careful inventory of the existing built environment should precede decisions of scale, pattern, color, sequence, age, quality, materials, and construction detailing.

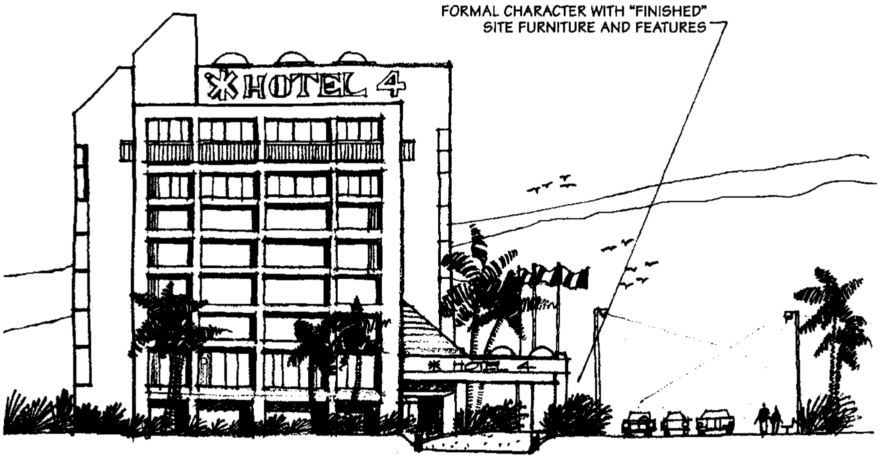

Figure 510-3. Site context: Formal character.

Figure 510-8 illustrates the typical mix of uses and settings to which furnishing systems must relate.

Furniture elements should reflect the character of the built environment, be internally integrated between themselves, and not promote a cluttered appearance. In any streetscape, for instance, effective site furniture design and placement can resolve a chaotic scene of light standards, parking meters, mailboxes, newspaper stands, and trash receptacles. There should be a balance between the visual importance of individual furniture elements and their compatibility within the visual context of the setting. It is important to incorporate the vistas, views, and visual composition of the entire site.

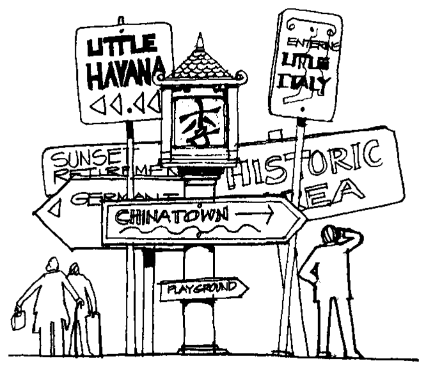

Figure 510-4. Diversity of social settings.

KEY POINTS: Design Determinants

1. The cultural traditions and habits of particular user groups provide a basis for unique design departures that can enliven the setting as a whole. Similarly, inattention to these habits and desires can foster negative reaction in a neighborhood.
2. Design must balance the thoughtful examination of the natural, built, and social setting, with regulatory concerns and politically-charged issues of maintenance and safety.
3. Particular landforms, vegetation, vistas, and other distinctive qualities that give an area its special character should be considered in the selection, design and placement of site furnishings.
4. Furniture elements should reflect the character of the built environment, be internally integrated between themselves, and not promote a cluttered appearance.
5. The physical dimensions and movement characteristics of the human body are essential determinants for the design of site furniture. Sections 210: Spatial Standards, and 340: Pedestrian Circulation, provide information on human dimensions and movement.

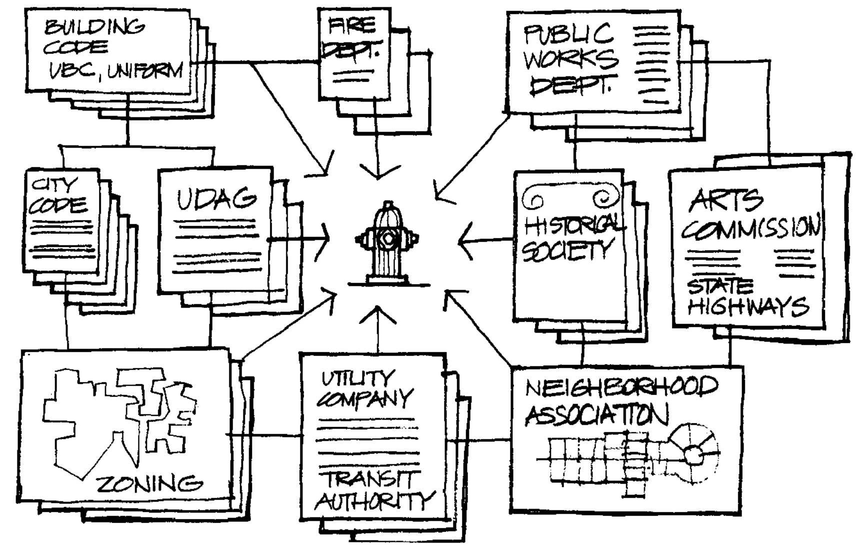

Figure 510-5. Diversity of regulatory standards.

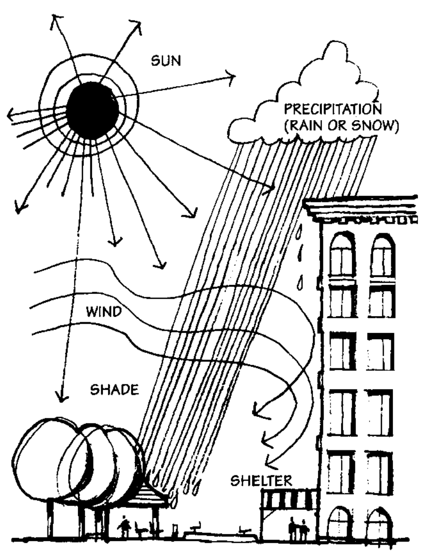

Figure 510-6. Climatic factors.

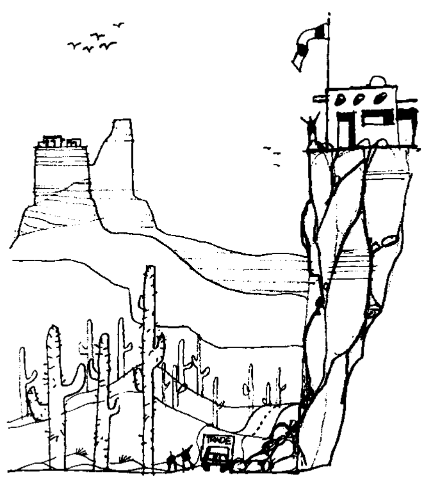

Figure 510-7. Physiographic factors.

2.3 Environmental Factors

Individual site furniture elements should meet the following environmental criteria (Figure 510-9).

Temperature:

Heat: The climate of a particular area is a key consideration when trying to determine whether permanent, partial, or temporary shade and glare reduction measures are needed. Furniture elements, such as permanent benches, should not be placed near extensive areas of paving or wall surfaces which reflect or radiate excessive amounts of heat, unless adequately buffered by shade, etc.

Benches, handles, and handrails exposed to full sunlight should be nonmetallic and/or light in color to remain comfortable to the touch.

Cold: Site furniture should be placed to take advantage of natural sun traps in cool weather regions, thereby extending the usefulness of the site. Materials which absorb and radiate heat are advantageous in cold climates. Darkly colored, smoothly textured materials will inhibit snow and ice accumulation.

Furniture should be designed to minimize water or ice accumulation. For some elements of furniture it may be necessary to periodically shut down service on the site or totally remove the furniture. Such factors should be considered when selecting each item. Consult with manufacturers to determine the all-weather value of various products.

Materials used in cold climates should not become brittle when cold, especially in locations where they may be stressed by normal use. Most cast metals and some kinds of plastics should be carefully analyzed before being used in cold climates. Fasteners and joints should also be able to withstand stresses caused by expansion and contraction of the materials.

Precipitation:

Rain: In regions subject to rain and/or snowfall, some of the site furniture used for sitting should be placed in sheltered locations.

Benches should drain well; they could be constructed of nonabsorptive materials to promote rapid drying. They should also be located to take advantage of the warming effects of sunlight. Materials selected for use in humid climates should be naturally decay and fungus-resistant, or specially treated to minimize mildew, rot, and consequent staining.

Snow: Logical placement of site furniture in areas of high snowfall will depend on the methods to be used for snow removal. Areas where snow is trapped or stockpiled should be identified before locating furniture to avoid damage from snow removal equipment. Maneuvering space and clearances should be provided so that major pedestrian ways can remain open to all essential access points.

Adequate drainage is essential for carrying off snowmelt and preventing ice formation. Furniture should be located where winter sunlight can help to melt the snow.

Wind:

Site furniture (benches, tables, etc.) should be located to minimize any negative gusting impacts upon users in areas subject to strong prevailing winds. Patterns of snow drifting should be studied to minimize its accumulation on furniture.

Furniture can be located to take advantage of natural cooling breezes in warm climates. Trees can provide shade and, to some extent, control the movement of air.

Light:

Site furniture should take advantage of the quality and character of light available on the site.

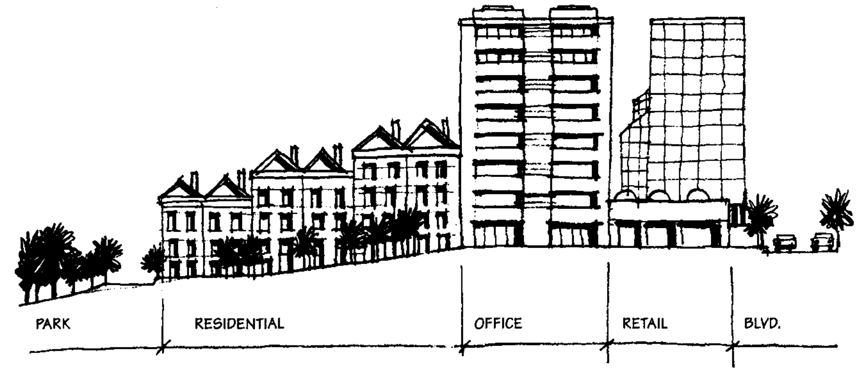

Figure 510-8. Built environment.

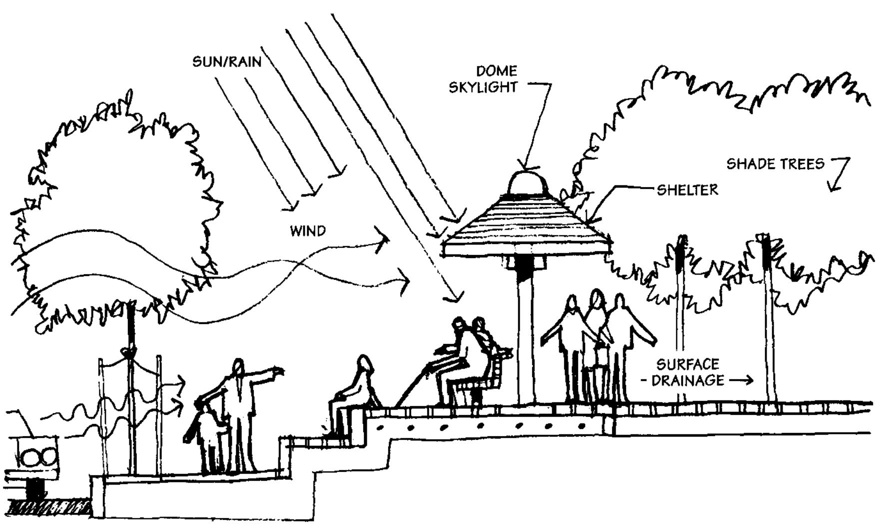

Figure 510-9. Environmental factors.

Wherever possible, minimize the glare from light fixtures and intense sunlight. Recognizing that light conditions change both daily and seasonally, locate furniture and especially outdoor signs in such a way as to minimize the glare caused by low sun angles on wet, frosted, or otherwise reflective surfaces.

Noise:

Site furniture may be focused toward pleasant sources such as the sounds of songbirds, children, street performers, and the like. Reciprocally, undesirable sounds can be blocked. Sound barrier walls, earth mounds, and other techniques of noise control should be considered. (Refer to Section 660: Sound Control, for more information.)

2.4 Operational Factors

Human Body Dimensions and Movement:

The physical dimensions and movement characteristics of the human body are essential determinants for the design of all types of site furniture. These common denominators set all working distances and operational dimensions in the design of furniture components and their aggregate layout. Sections 210: Spatial Standards, and 340: Pedestrian Circulation, provide information on human dimensions and movement.

Regulatory Standards:

Site furniture must also conform to a host of regulatory standards imposed by municipal, state, and federal governments. Nowhere are these more profuse (and contradictory) than in urban public rights-of-way, where the greatest number of jurisdictional domains overlap. For example, typical standards deal with required light intensities for pedestrians and vehicles, light fixture mounting heights, the proximity of trees to utility poles and underground utilities, traffic signalization, signage and control systems, intersection setbacks, wheelchair ramp gradients and placement, the height of mailboxes, the width of vehicular lanes, turning radii, curbside usage, and even the size of garbage cans (Figure 510-10).

These regulations require careful scrutiny rather than slavish adherence in order to achieve a quality result. The designer must understand the purpose and rationale for the regulation, and then be able to interpret its most appropriate application and be prepared to negotiate creatively.

The vast number of off-the-shelf components available are subject to the same regulatory criteria. In some cases, they may be neither adaptable nor appropriate.

KEY POINTS: Climatic Factors

The selection and design of site furniture should take climatic issues of temperature, and precipitation into consideration.

1. In hot climates, furniture elements should be nonmetallic or light in color, and placed away from surfaces that reflect or radiate excessive amounts of heat.
2. In cool climates, furniture should be dark in color, placed to take advantage of natural sun traps and avoid areas where snow is stockpiled.
3. In wet climates, benches should drain well and be constructed of nonabsorptive materials to promote rapid drying.
4. Materials selected for use in humid climates should be be naturally decay and fungus-resistant, or specially treated to minimize mildew, rot, and staining.

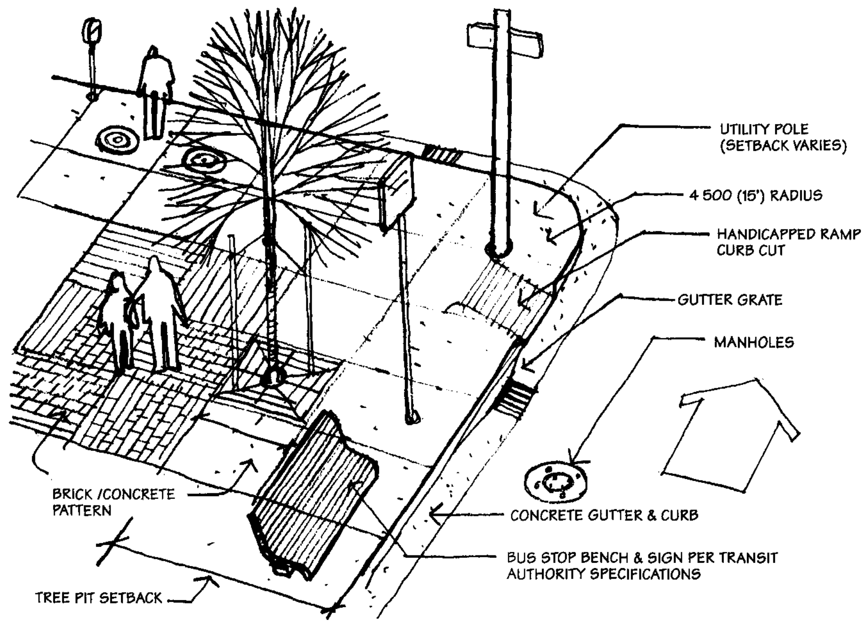

Figure 510-10. Regulatory Standards.

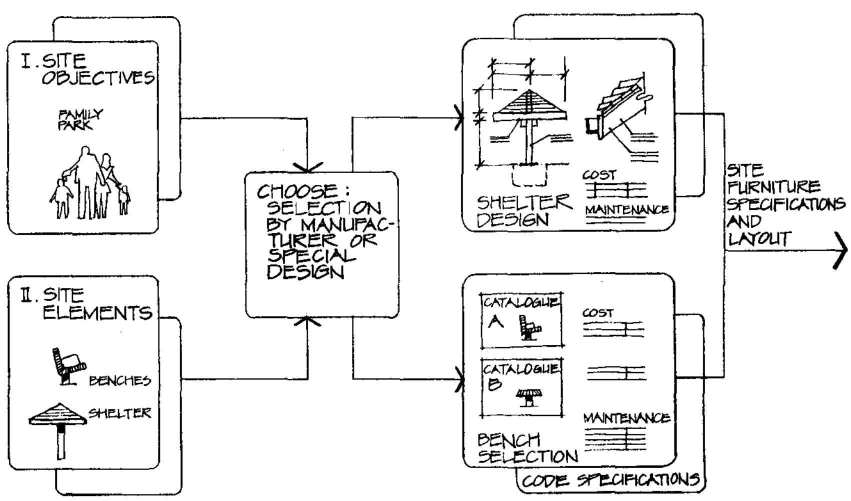

Figure 510-11. Selection process diagram.

3.0 DESIGN CONSIDERATIONS

3.1 Selection Process

Figure 510-11 illustrates how site furniture and features can be selected by careful evaluation of stated site objectives and use criteria.

These objectives and needs are matched with a range of alternatives, such as whether to select the elements from existing ready-made sources, make modifications to such manufactured designs, or develop a new design.

Key factors in the process of either selecting ready-made or custom designing elements are: (1) availability of each unit, (2) maintenance requirements, (3) initial and lifetime costs, and (4) whether the solution will be consistent with the overall design of the project.

3.2 Design Elements

The categories of design elements summarized in Figures 510-12 through 510-20 illustrate a range of designs, materials, and uses of site furniture for various purposes. These figures show basic components of each element, along with generic examples. Diagrams and notes illustrating site concepts are included to further aid the designer.

Appropriateness is the key to the siting and design of these elements. (See 1.2 Design Objectives in this section.) Only after careful inventory and evaluation of these critical design objectives and criteria can proper concepts and solutions for placement and design be made for these elements.

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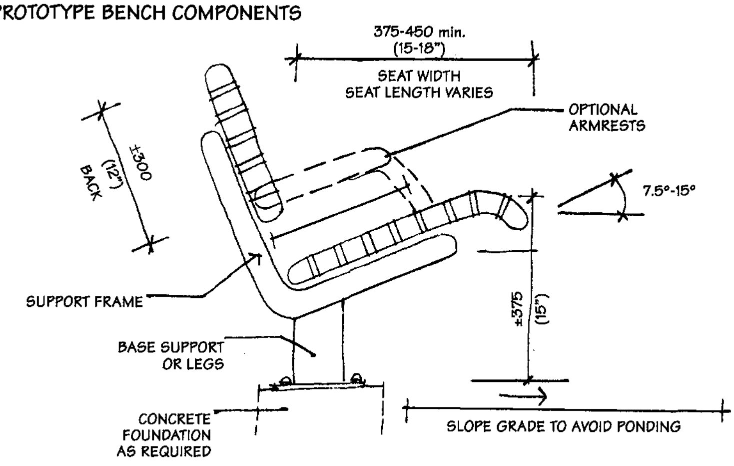
SEATING

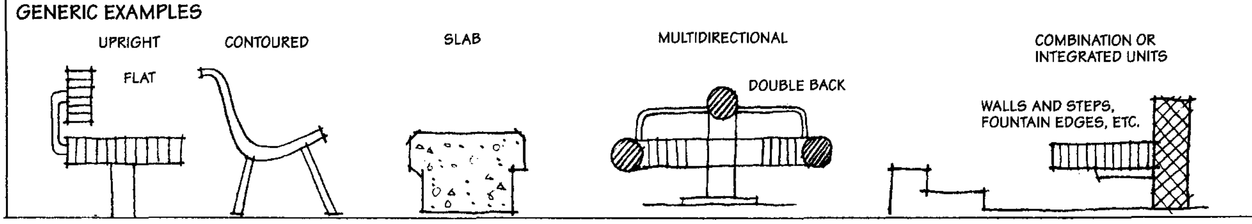
Principles of design should emphasize:

1. Comfort.
2. Simplicity of form.
3. Simplicity of detail.
4. Ease of maintenance.
5. Durability of finish.
6. Resistance to vandalism.

PROTOTYPE BENCH COMPONENTS



GENERIC EXAMPLES

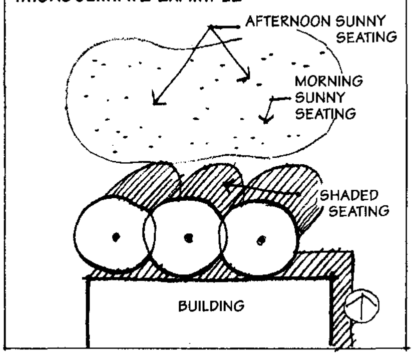


SITE OBJECTIVES

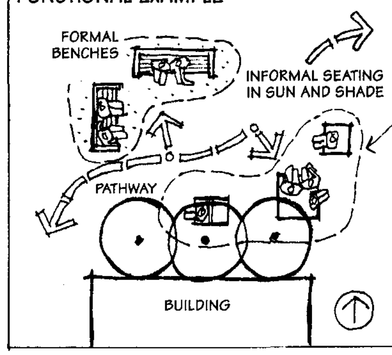
Seating should be sited so as to:

1. Be sheltered from wind.
2. Take advantage of site views.
3. Be situated back of circulation paths.
4. Provide a variety of options for pedestrians, such as:
   - Sunlight/Shade
   - Quietude/Activity
   - Formality/Informality

MICROCLIMATE EXAMPLE



FUNCTIONAL EXAMPLE



CONTEXT

Seating elements are important elements of an environment and should be designed to be compatible with all other elements of the site. Seating elements include:

1. Benches
2. Stoops
3. Ledges
4. Seatwalls
5. Steps

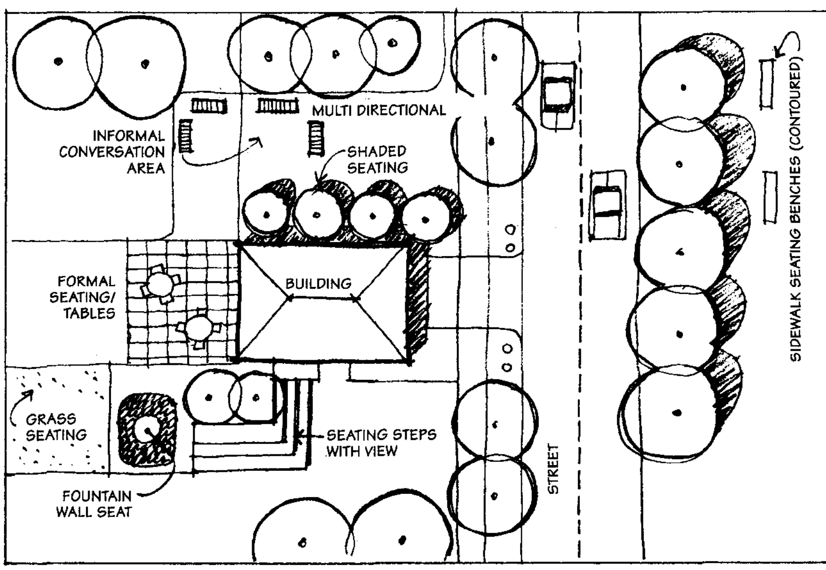


Figure 510-12. Seating.

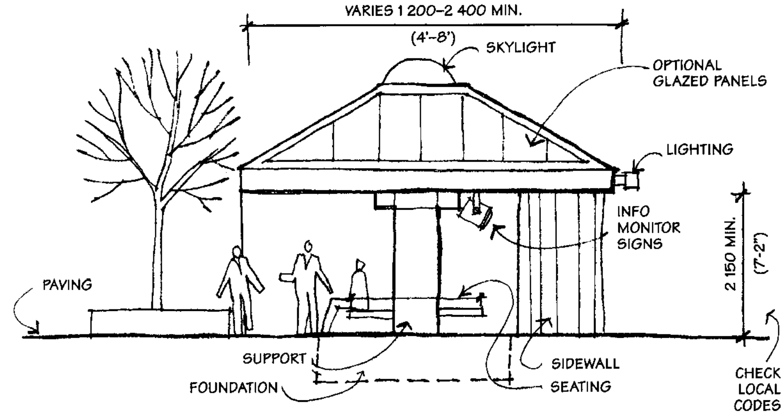
SHELTERS

Shelters diversify the use of a site by accommodating elements that require weather protection, such as:

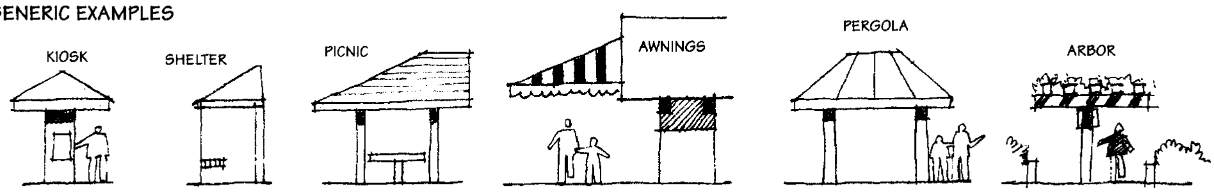
1. Graphic displays
2. TV Monitors

Types of shelters range from very modest structures, such as picnic shelters, to very elaborate structures, such as bandstands.

PROTOTYPE SHELTER COMPONENTS



GENERIC EXAMPLES

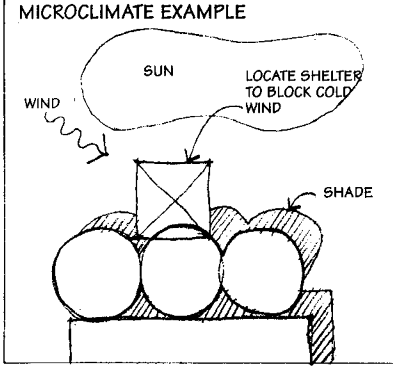


SITE OBJECTIVES

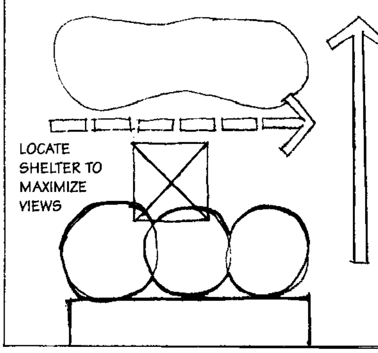
Shelters provide:

1. Protection against inclement weather.
2. A focal point for site activities.
3. Transitional areas between outdoors and indoors.

MICROCLIMATE EXAMPLE



FUNCTIONAL EXAMPLE

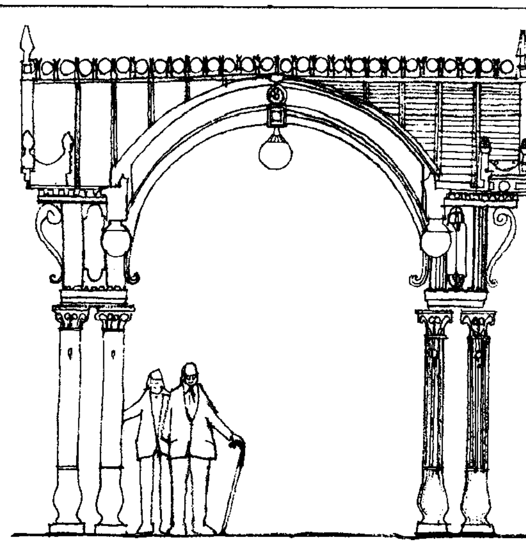


CONTEXT

Shelters are often major elements of a site. They can be used as a visual reference to the historical or cultural character of a place. The choice of an appropriate design idiom should reflect an understanding of the social and cultural forces that have given the place its unique identity.

Because shelters often serve as focal points of a site, they should be:

1. Readily visible
2. Easily accessible
3. Suited to take advantage of views.
4. Sited adjacent to major pedestrian routes



Pioneer Square Park, Seattle, Washington.

Figure 510-13. Shelter.

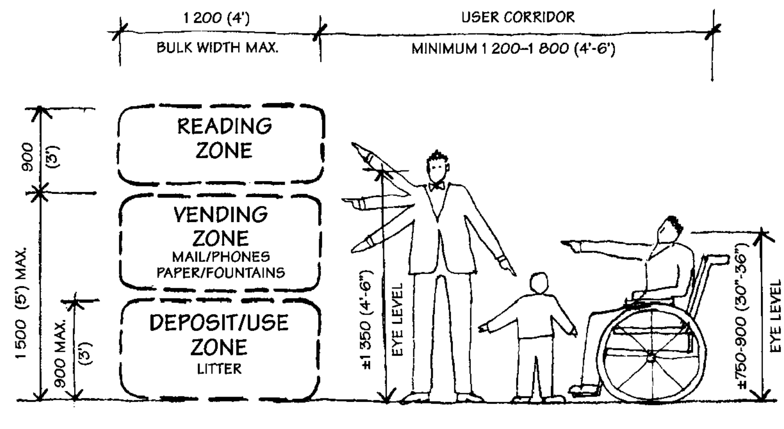
CONVENIENCE ELEMENTS

Convenience elements should be:

1. Easily recognizable.
2. Sited to reduce clutter.
3. Placed to facilitate easy access.

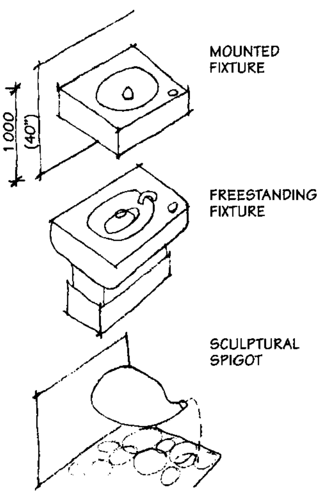
General zones are defined by access requirements.

ZONES

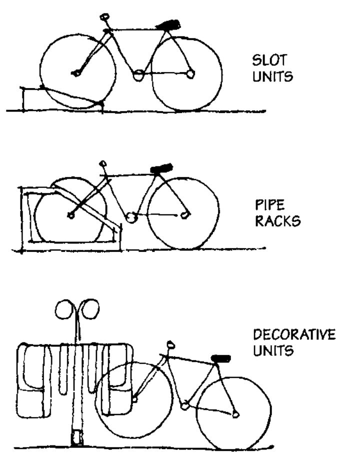


GENERIC EXAMPLES

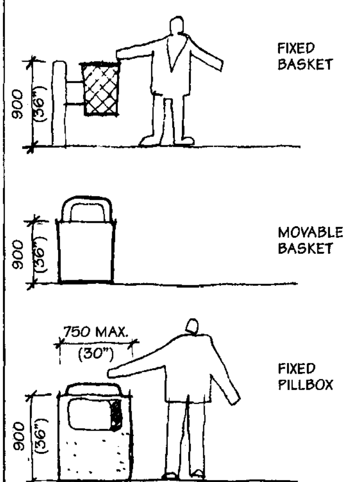
DRINKING FOUNTAINS



BIKE RACKS



TRASH RECEPTACLES



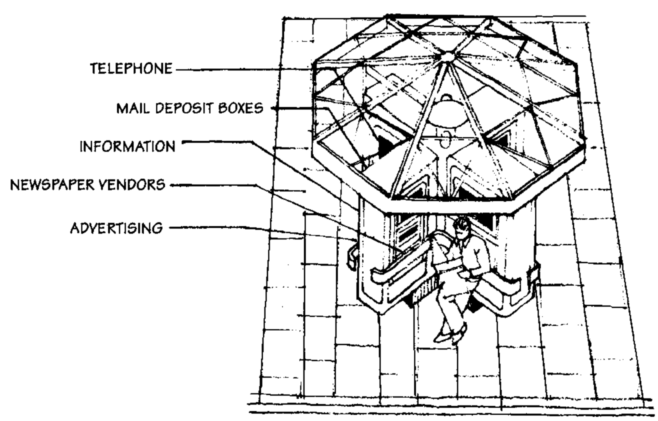
CONTEXT

Consolidation of various convenience elements into a single larger structure can enhance the visual character of a site and provide a readily identifiable feature within a busy streetscape.

Convenience elements include:

1. Newspaper vendors
2. Telephones
3. Information stands
4. Mail deposit boxes

CONVENIENCE ELEMENTS WITHIN KIOSK



5th Ave., Seattle, WA.

Figure 510-14. Convenience elements.

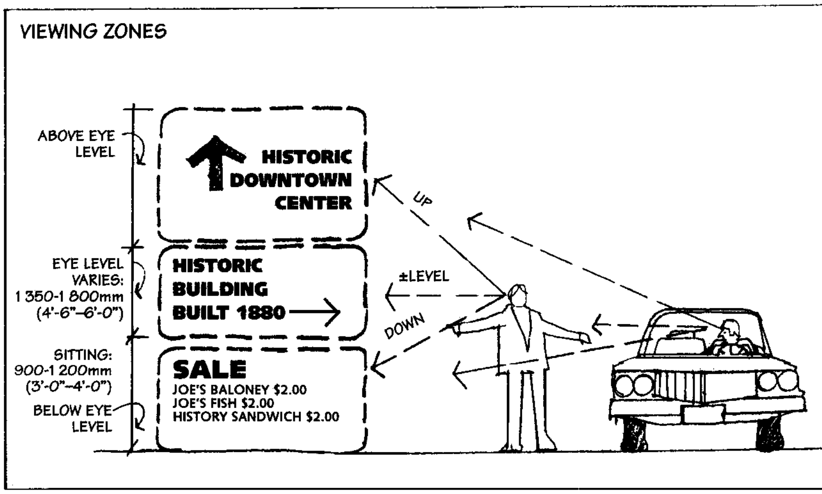
INFORMATION

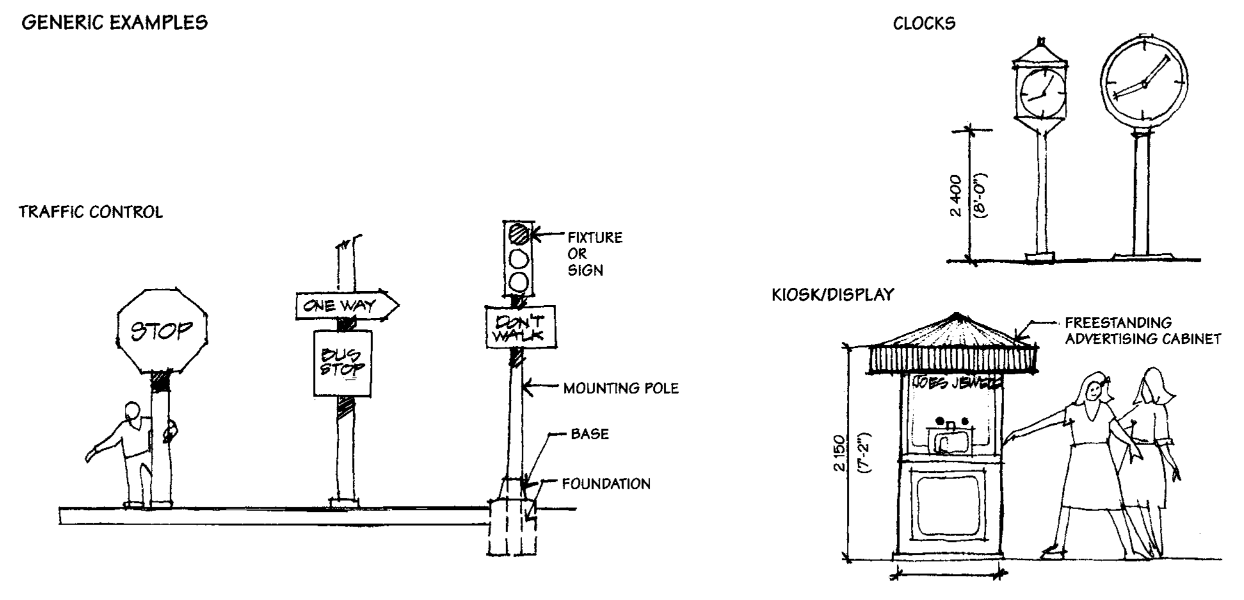
Outdoor information can be grouped into four catagories:

1) Directional; 2) Locational;
3) Identification; 4) Display

The information should be formatted and placed within easy view of either the pedestrian or the motorist.

The primary mode of transportation, whether pedestrian or vehicular, will determine the optimum location and size of signs.





CONTEXT

Because of its brief viewing time, signage aimed at vehicular traffic requires an especially clear hierarchy of lettering.

Sites such as industrial parks and suburban office centers, where circulation is exclusively vehicular, are places that require signage for:

1. Identification of the area
2. Directions within the compound
3. Identification of individual facilities within the compound

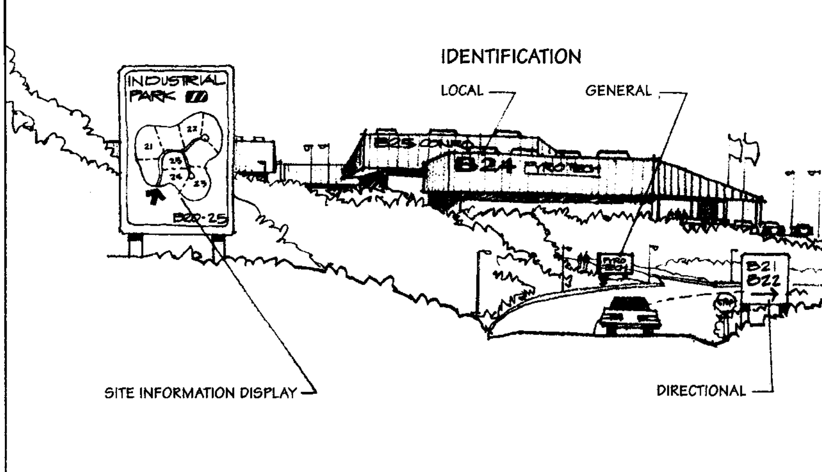
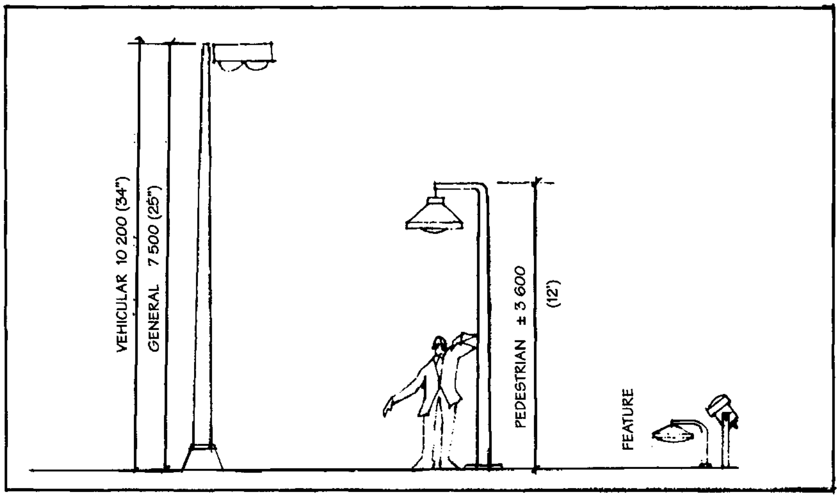


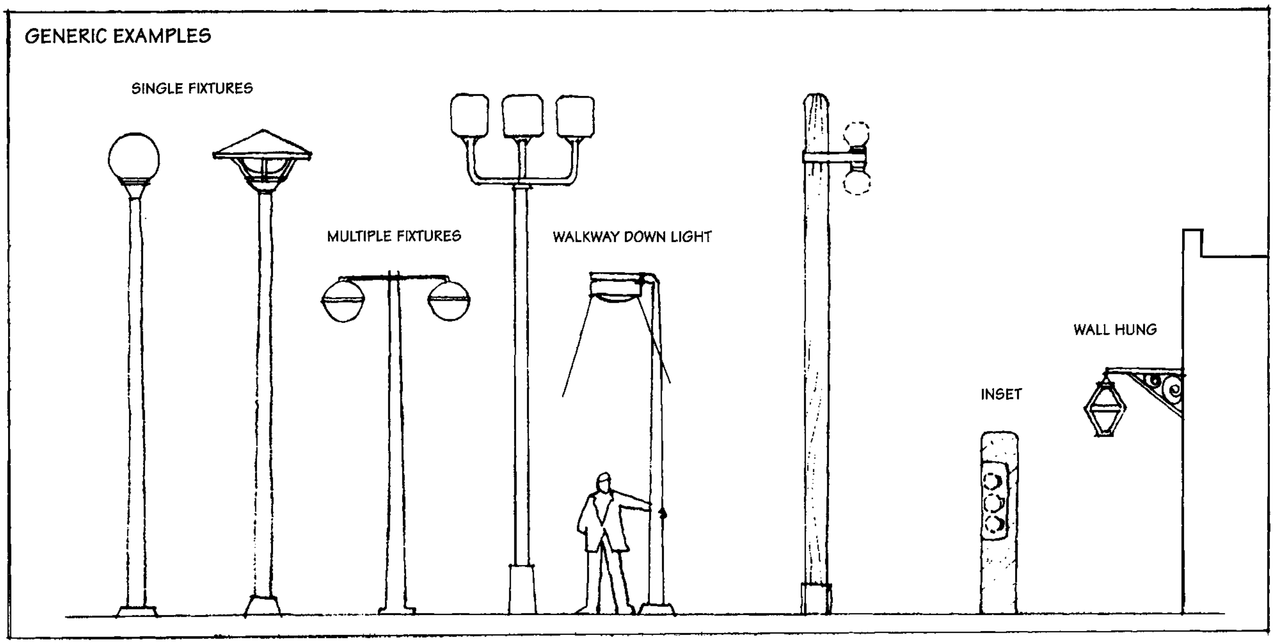
Figure 510-15. Information.

LIGHTING

The height of light standards is the single factor that most directly determines the quality of the light and the consequent ambience of the site. Exterior lighting can be generally categorized as:

1. Decorative lighting
2. Vehicular use lighting
3. General site lighting
4. Pedestrian use lighting
5. Feature lighting





CONTEXT

Lighting must be functionally appropriate and properly scaled to both the pedestrian and the vehicular precincts of the site. For pedestrian area lighting, the light source should be relatively low to the ground in order to remain in scale with the human body and to provide light beneath the canopy of street trees. Uniform area illumination is not always desirable.

Vehicular light standards on roadways must have much greater height than those for pedestrians and must illuminate the road more uniformly.

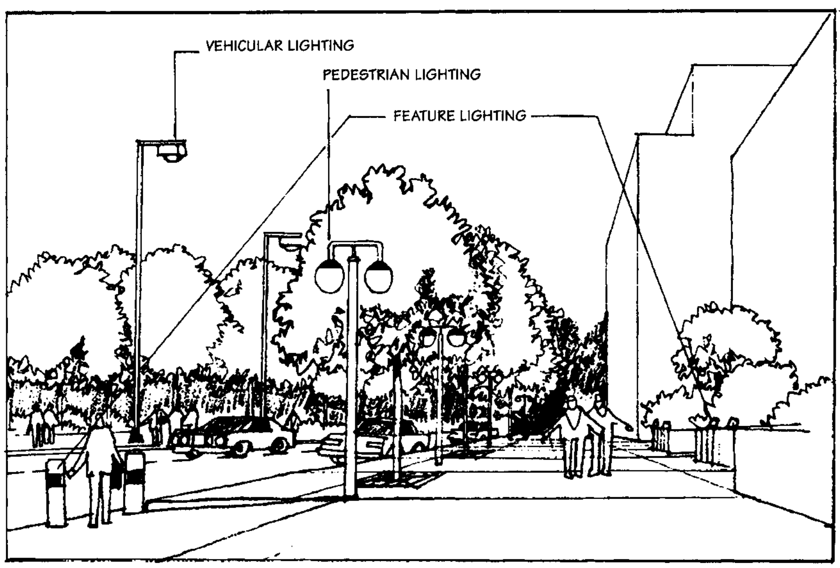
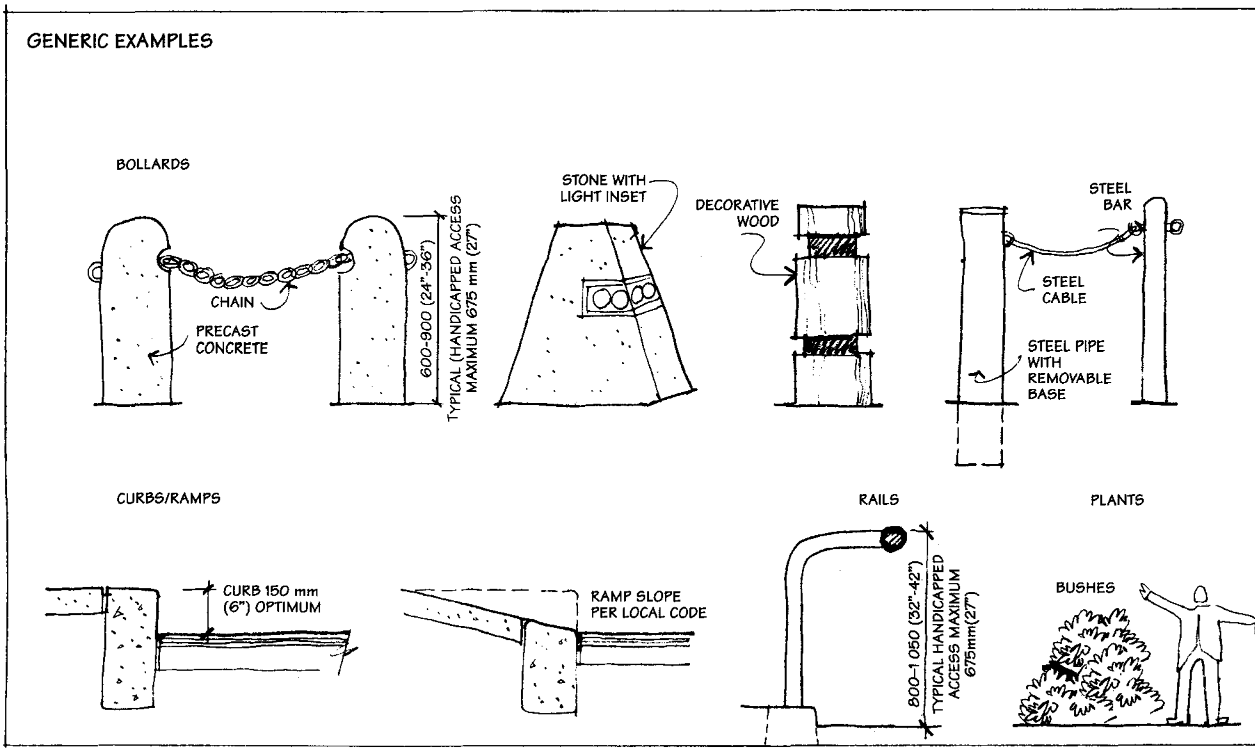


Figure 510-16. Lighting.

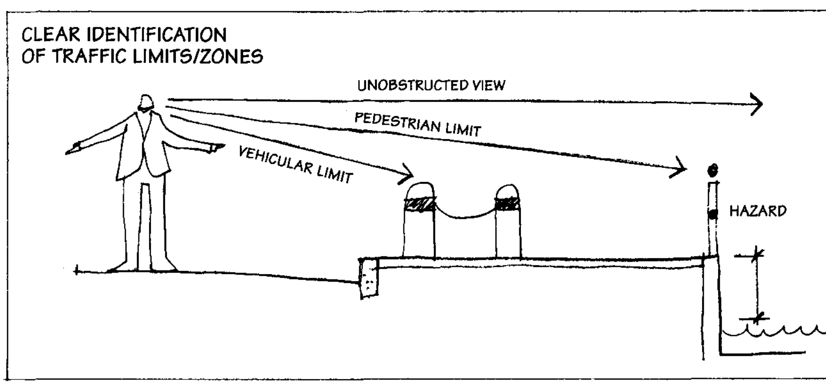


TRAFFIC CONTROL & PROTECTION

Elements to warn both pedestrians and motorists include: paving material changes, bollards, and grade changes.

Elements to restrict pedestrian entry include: railings, kick rails, walls, and hedges.

Elements to restrict vehicular entry include: steep banks, planted areas, steps, and guard railings.



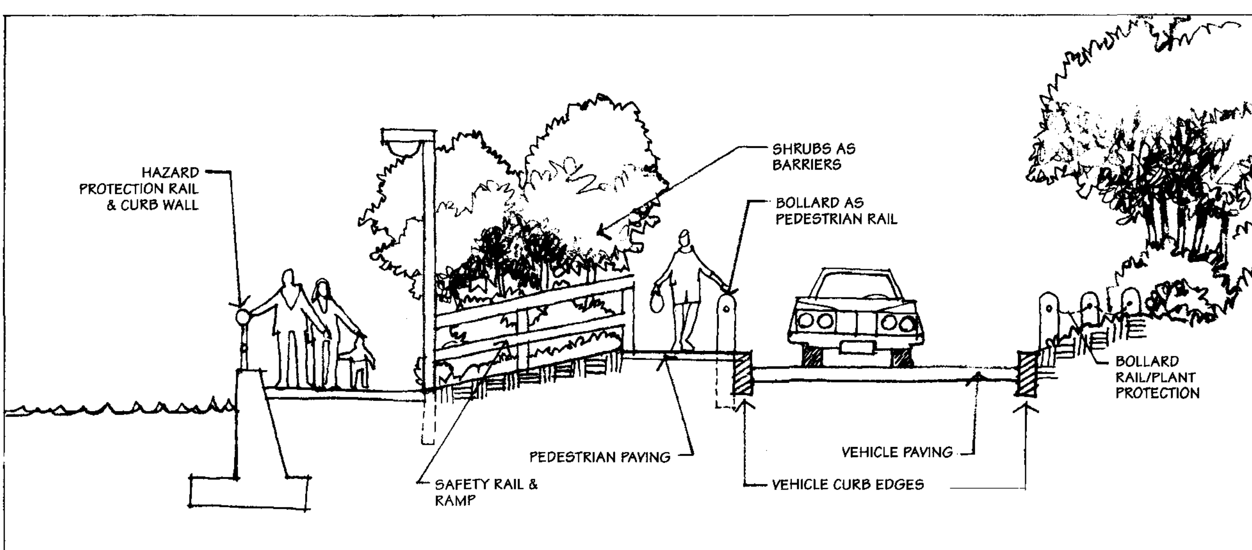


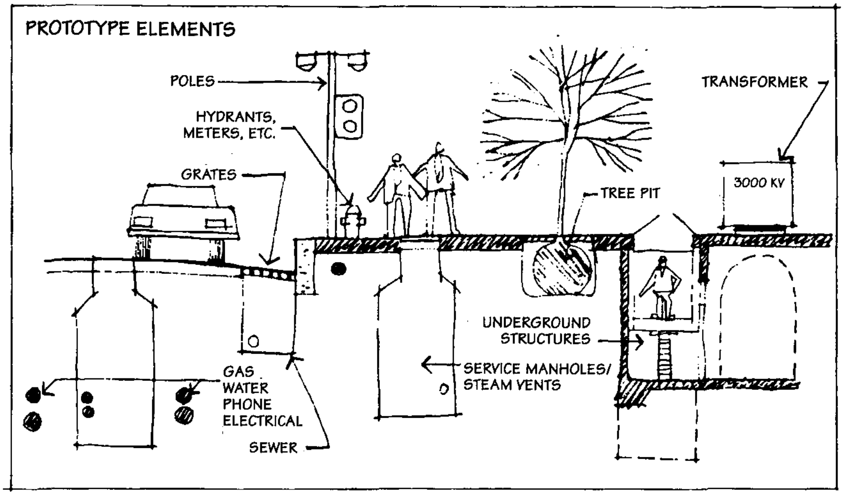
Figure 510-17. Traffic control and protection.

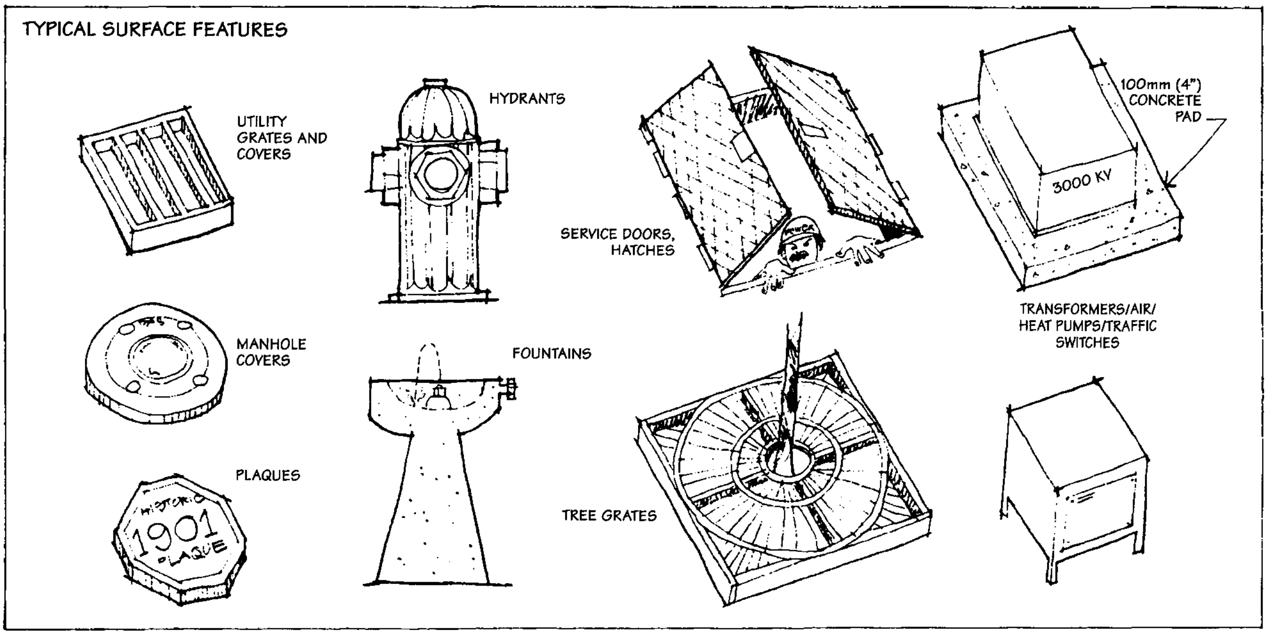
SURFACE UTILITY ELEMENTS

The urban floor contains underground utility systems and vault structures that often restrict the placement of site furniture features.

Access to these utilities and structures is provided by means of metal covers and grates, which in themselves are a feature of the urban floor.

Many utility fixtures, such as fire hydrants and traffic signalization controls, can be spatially constraining.





CONTEXT

Ideally, the heavily used pedestrian core should be kept relatively free from utility covers. Where this is not possible, utility covers can be incorporated as part of the total floor pattern.

Gratings and cover plates are available in many attractive patterns. The custom design of decorative covers can commemorate past events or themes that are of particular local significance.

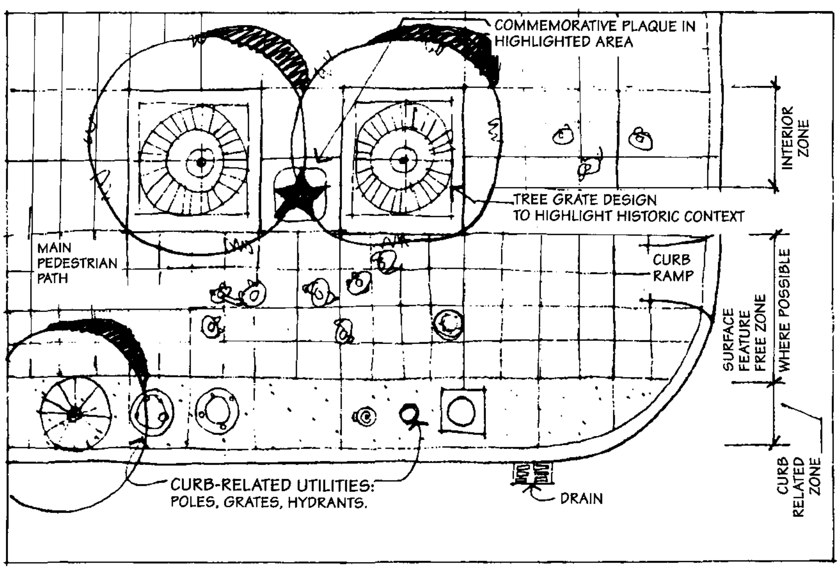
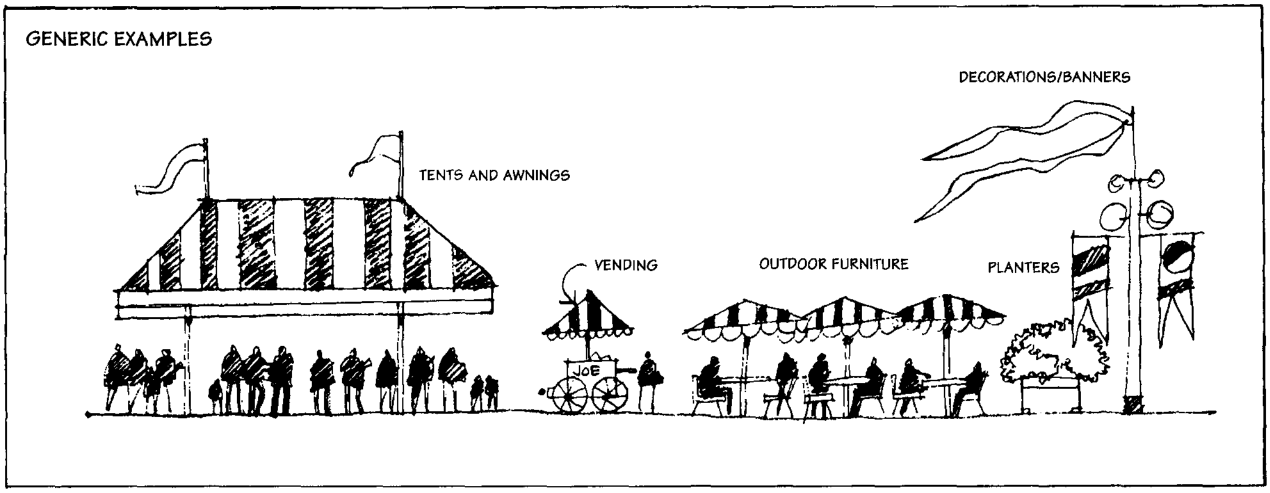


Figure 510-18. Utilities.



SEASONAL ELEMENTS

Seasonal elements can significantly enliven a place. Their appearance signals an event. These elements include:

1. Temporary structures
2. Vending wagons
3. Outdoor furniture
4. Planting tubs

Seasonal elements:

1. Require a flexible site layout
2. Work well when they augment established year-round facilities.
3. Should be sited to conform to the basic circulation structure of the site
4. Should be readily visible and accessible

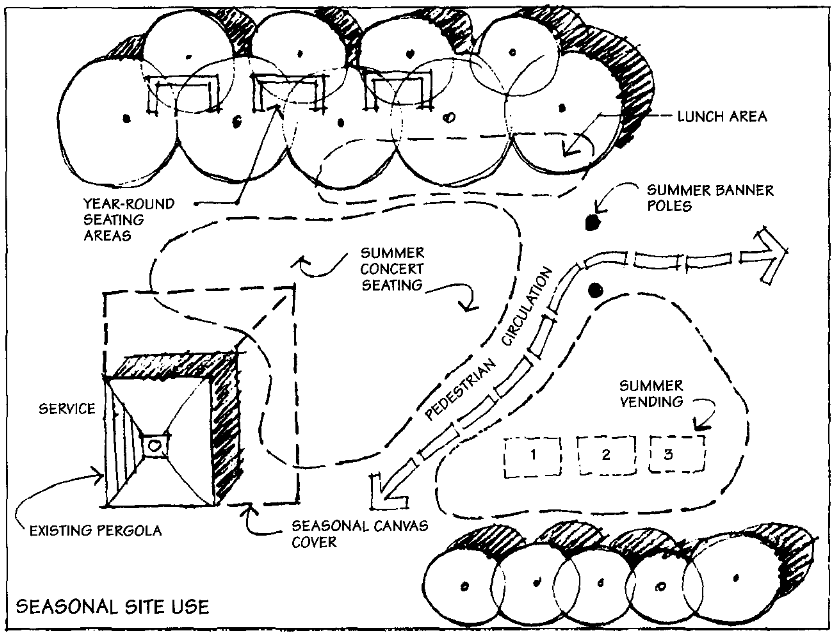


Figure 510-19. Seasonal elements.

SPECIAL FEATURES

Special features are unique site elements that can be used to commemorate significant cultural and social events for the community. They present a unique opportunity for the designer to incorporate:

1. Indigenous materials
2. Local historical resources
3. Local cultural resources

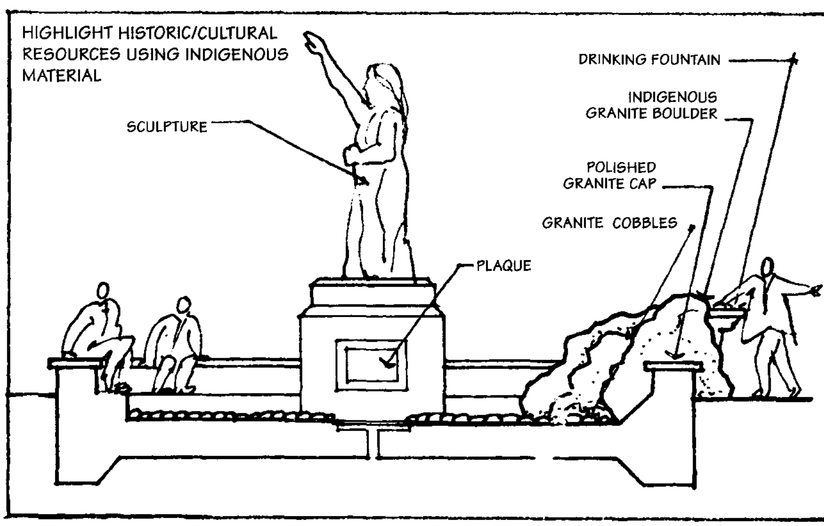


Figure 510-20. Special features.

SECTION 520

Recreational and Athletic Facilities

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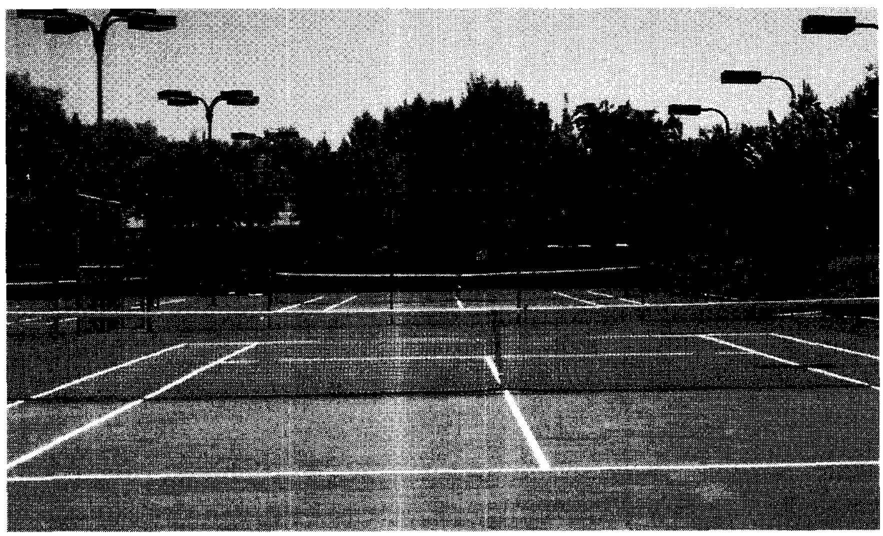
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ACKNOWLEDGMENTS

The authors would like to acknowledge the aid and insight provided by Mr. Ernie Ralston, landscape architect, Marshall, Maklin, Monaghan Limited, Edmonton, Alberta; and Mr. Garrett Gill, Department of Park Administration and Landscape Architecture, Texas Tech University, Lubbock, Texas; and David Gill Corporation (golf course architect), St. Charles, Illinois.

CONTENTS

1.0 INTRODUCTION

The standards for recreational and athletic facilities in this section represent the state of the art as developed by agencies, organizations, manufacturers, and various interest groups.

By definition, recreation represents any rational human activity that results in a pleasurable response, at any time, place or circumstance, with attendant enriching physical, intellectual, or emotional benefits, within the constraints of individual morality and/or social acceptability (Doell and Twardzik, Elements of Park and Recreation Administration). Participation in recreational and athletic activities involves virtually every age group and segment of society from children to senior citizens, including those who are infirm, incarcerated, or physically and/or mentally handicapped. Physical activities go beyond exercise and athletic programs for youth and professional teams to embrace every interest, physical stature, and level of skill. A vast, almost endless array of new activities, equipment, and instructional programs are constantly appearing. The designer now has the Internet as a resource for the most recent information regarding any sport or recreation activity or facility under consideration.

1.1 Trends in Recreational Orientation

In North America, there is an emphasis on development of city, county, state and regional parks. Family-oriented activities within these facilities continue to be of prime importance.

The introduction of new equipment and activities has resulted in a greater popularization of sports activities among all groups and ages. A 1997 study, Outdoor Recreation in the United States reported that in 1994-95, 94.5 percent of Americans participated in at least one of the surveyed forms of outdoor recreation. This represents 189 million participants nationwide. Participation in at least one activity rose 13.4 percent since 1982-83. Table 520-1 shows the percentages of Americans who participated in outdoor recreation activities, common to two surveys, in 1982 and 1994.

1.2 Standards

The standards for recreational and athletic facilities are expressed in many ways. This section describes the design standards established for many activities. These standards are compiled from numerous sources and range from rigid dimensions required for regulation play to suggestions derived from experience. Adherence to standards assures continuity of experience, regardless of location. Conversely, the designer needs to be sensitive to necessary adjustments in standards as demanded by the local conditions, budget, and client.

Table 520-1. POPULARITY OF OUTDOOR RECREATION ACTIVITIES.

Activity	Number 1982-83 (millions)	Number 1994-95 (millions)	Percent Change
Bicycling	56.5	57.4	+1.6
Horseback Riding	15.9	14.3	-10.1
Golf	23.0	29.7	+29.1
Tennis	30.0	21.2	-29.3
Outdoor TeamSports	42.4	53.0	+25.0
Boating	49.5	58.1	+17.4
Sailing	10.6	9.6	-9.4
Motbrboating	33.6	47.0	+39.9
Water Skiing	15.9	17.9	+12.6
Swimming/pool	76.0	88.5	+16.4
Swimming/non-pool	56.5	78.1	+38.2
Fishing	60.1	57.8	-3.8
Hunting	21.2	18.6	-12.3
Hiking	24.7	47.8	+93.5
Walking	93.6	133.7	+42.8
Running/ Jogging	45.9	52.5	+14.4
Bird Watching	21.2	54.1	+155.2
Picnicking	84.8	98.3	+15.9
Sightseeing	81.3	113.4	+39.5
Off-Road Driving	19.4	27.9	+43.8
Ice Skating	10.6	10.5	-0.9
Downhill Skiing	10.6	16.8	+58.5
Cross-Country Skiing	5.3	6.5	+22.6
Snowmobiling	5.3	7.1	+34.0
Sledding	17.7	20.5	+15.8
Camping (overall)	42.4	52.8	+24.5
Developed Area	30.0	41.5	+38.3
Primitive Area	17.7	28.0	+58.2
Backpacking	8.8	15.2	+72.7
Attending a Sports Event	70.7	95.2	+34.7
Attending an Outdoor Concert or Play	44.2	68.4	+54.7

Source: Outdoor Recreation and Wilderness, Outdoor Recreation in the United States: Results from the National Survey on Recreation and the Environment. USDA Forest Service, April 1997.

1.3 General Concepts in Facility Design

The purpose of this section is to provide standards for the development of outdoor recreational facilities. It is important to consider the following factors as they relate to all types of facilities.

Safety and Security:

User safety and security for each activity should be paramount concerns of the designer and administrator. Ultimately, user satisfaction with a facility is related to how safe and secure the users feel. Strategies for discouraging vandalism and increasing security must be incorporated into the planning, design, construction, operation, and maintenance of a facility.

Provision for Elderly and Handicapped Users:

Any persons with temporary or permanent limitations of their motor activity or sense perceptions should be able to gain access to recreational facilities. The primary concerns of the designer with regard to handicapped users are access, mobility, and safety. Information on compliance with the Americans With Disabilities Act is available from the Board of Architecture Compliance, the U.S. Department of Justice and the National Park Service (Refer to Section 240: Outdoor Accessibility for more information.)

The References at the end of this section provide more detailed information on the design of specialized recreational facilities.

Maintenance, Operations and Inspections:

The daily operations and maintenance of facilities are critical to user satisfaction. The maintenance administration can be centralized or decentralized, depending upon the size, character, location, and use level of the facilities.

Maintenance facilities usually include: administrative headquarters, shop and covered storage, open-air or bulk storage, garage and/or service parking, and sometimes greenhouses and nursery space. These areas are best located out of view but should remain easily accessible by motor vehicles. Operations facilities may in some instances have an interpretive and/or educational value, as for example the kitchen and veterinary facilities in a zoo. In this case, controlled public access may be sought or at least permitted.

Inspections may be made on a frequent basis (up to four times a year) depending on the type of facility, nature of use, and local, state, or federal regulatory or insurance carrier requirements. Items such as playground equipment, tennis courts, bicycle trails and paths, or mechanical equipment should be inspected on a frequent basis.

Parking:

Standards for parking vary with each type of activity. In North America it is common practice to provide one parking space for every three users. Parking areas for facilities that sometimes attract large crowds, such as schools, sports complexes, and sports stadiums can also be served by more flexible arrangements. An overflow parking lot can be designed to accommodate other activities, such as basketball or tennis, when parking demand is low. Large parking lots however increase maintenance costs along with increased liability when large expanses of pavement are used as tempo-

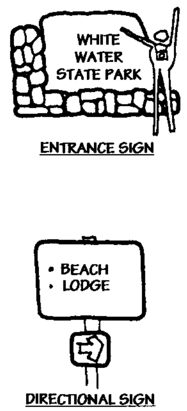


Figure 520-1. Major types of signs.

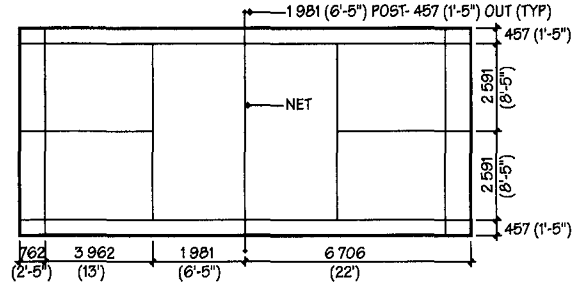


Figure 520-2. Badminton.

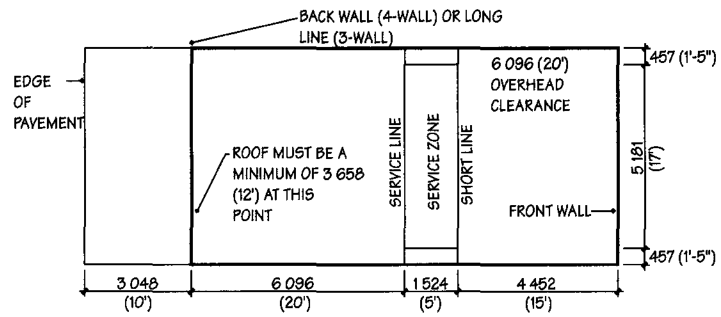


Figure 520-3. Handball/racquetball.

rary multiple use courts. Increasing use of parking lots for roller hockey raises maintenance and liability concerns.

Signage:

Signage should be coordinated to provide essential information within a consistent graphic framework. As illustrated by Figure 520-1, there are four categories of signs:

1. Informational: these signs contain graphic and/or written information intended to enhance the use and enjoyment of a site.
2. Identification: these signs are used for entrances and identifying individual facilities.
3. Directional: these signs channel the flow of visitors/users. They should be simple and should be placed in locations appropriate to the speed of the user.
4. Regulatory: these include speed limits, prohibited behaviors, and other rules as needed. This information should be presented in a positive way.

2.0 COURT GAMES

2.1 General

Court games are sports played primarily on hard surfaces rather than on turf. The standards for courts vary, depending on whether competition is under the auspices of international, national, collegiate, or high school societies. The organizations referred to most extensively in this section are the National Federation of State High School Athletic Associations, the International Amateur Athletic Federation (IAAF) and the National Collegiate Athletic Association (NCAA). For competition-quality court design, contact the organization setting the rules and standards. Major organizations in the United States are listed at the end of this section under Recreation and Sports Organizations.

2.2 Basic Dimensions

Some facilities are provided primarily for popular enjoyment; therefore, their dimensions can be changed to fit the site, client, and/or budget. The standards shown in Figures 520-2 through 520-10 and Table 520-2 should therefore be considered desirable rather than mandatory.

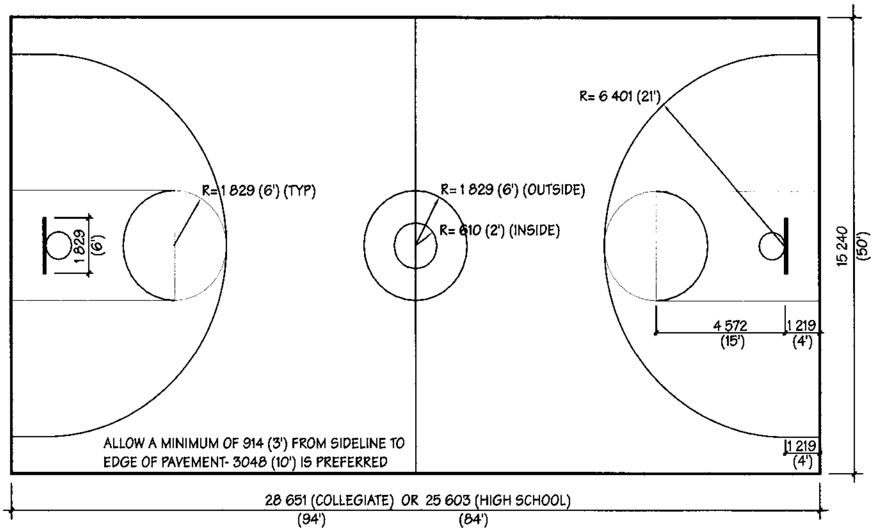
3.0 FIELD SPORTS

Field sports include any activities played, preferably, on soft (turf) surfaces. As discussed for court games, the standards given here for field sports are to be considered desirable. Dimensions for competition quality fields should be verified with the governing organization. In some cases (soccer, for instance, where precise standards have not been established) a range of dimensions is shown. Adequate surface and subsurface drainage is very important. The type of turf used should be sturdy and nonstoloniferous if shoes with cleats are to be used. Where temporary bleachers are to be used, allow a width of 18 000-27 000 mm (60-90 ft) between the sidelines and the playing fields (Figure 520-11 and Table 520-3).

4.0 TRACK AND FIELD

4.1 General

The design of combined track and field facilities depends upon the age group and class of athletes using the facilities. There are few specifics in terms of overall track and field layouts. The dimensions and specifications presented here (Figures 520-12 through 520-32) are only guidelines and



NOTE: UNLESS OTHERWISE SPECIFIED, THE LAYOUT AND DIMENSIONS OF ALL COURTS ARE SYMMETRICAL AROUND THE CENTER LINES.

Figure 520-4. Basketball.

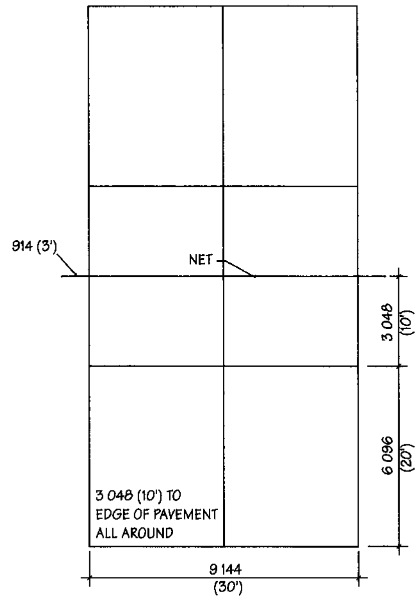
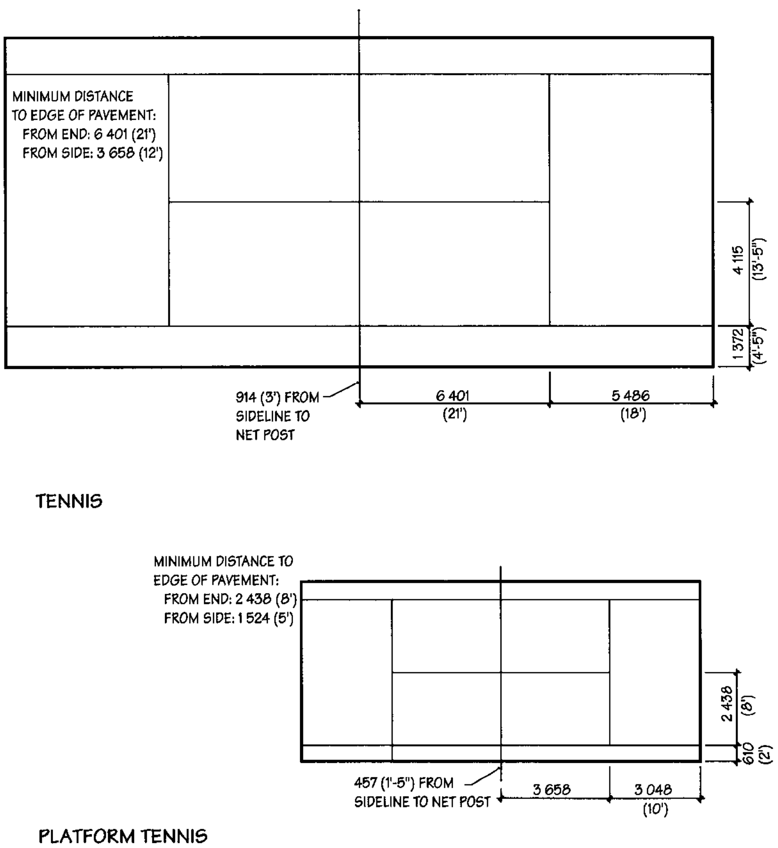


Figure 520-5. Volleyball.



TENNIS NOTES:
TENNIS COURTS ARE OFTEN CONSTRUCTED IN BANKS OF 610mm+ (2ft+). ALLOW 3 048mm (10ft) BETWEEN COURTS.

LIGHTS SHOULD BE LOCATED A MINIMUM OF 3 658mm (12ft) FROM PLAY LINES. IN BATTERIES OF COURTS NOT SEPERATED BY 7 315mm (24ft) POLES, SHOULD BE AT BACK FENCE AND NET LINE. ARRANGEMENT OF POLES DEPENDS ON TYPE AND SIZE OF LIGHT SOURCE.

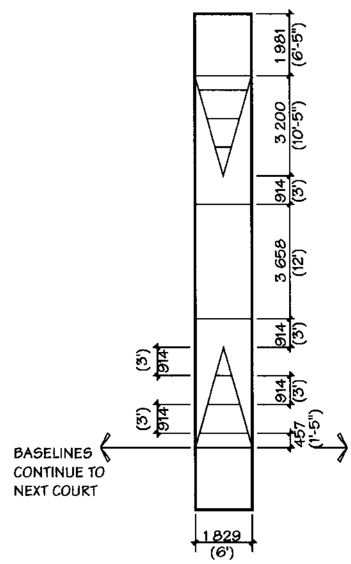


Figure 520-6. Tennis and Platform tennis.

Figure 520-7. Shuffleboard.

520 Recreational & Athletic Facilities

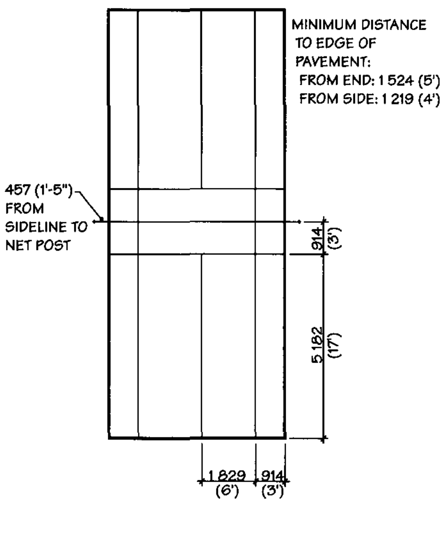


Figure 520-8. Paddle tennis.

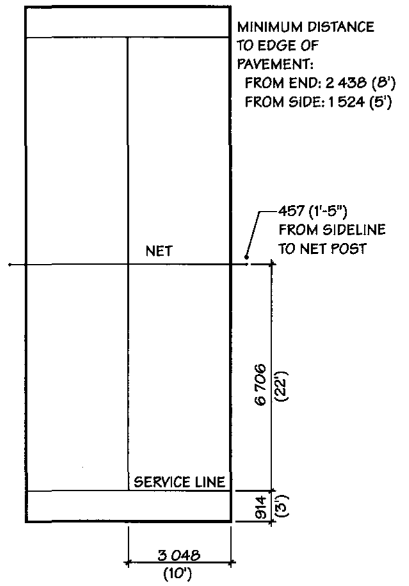


Figure 520-9. Deck tennis.

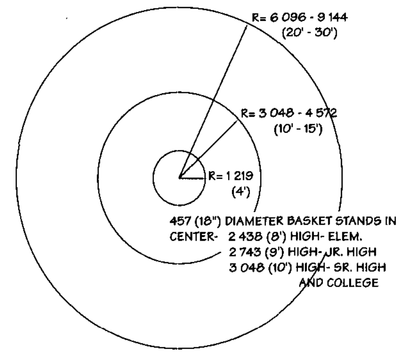


Figure 520-10. Goal-in.

should be checked against the standards established by the appropriate governing organization.

4.2 Basic Dimensions

According to the standards published in the United States by the NCAA, a championship track shall be at least 400 m (440 yds) in length, with uniform straights and curves. The track width should be a minimum of six lanes, although tracks for large meets often have eight lanes, and a few tracks have more. The lane width varies from 900 to 1 200 mm (36 to 48 in). Many high schools have 900 mm (36 in) lanes, especially for practice tracks. On world class tracks, 1 200 mm (48 in) lanes are preferred, but the most common lane width is 1 050 mm (42 in).

4.3 Orientation

Orientation is not as vital a concern in track layout as it is for field events. A north-south orientation along the length of the straightway is preferred. Factors such as space constraints, grading, and prevailing winds often alter the orientation slightly.

4.4 Grading Requirements

Longitudinal slopes for tracks, runways, and landing areas for field events should not exceed a maximum of 0.1 percent (1:1000). Cross slopes should be no more than 1 percent (1:100) or, for high schools, 2 percent (2:100). The slope should be pitched toward the inside of the track.

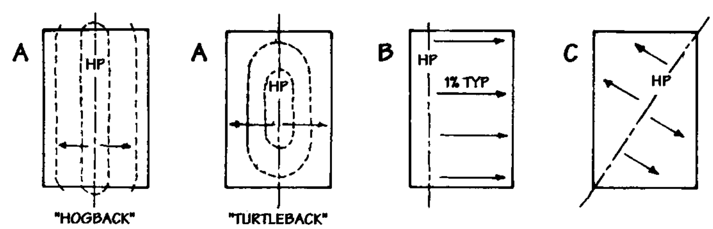


Figure 520-11. Drainage alternatives for fields.

Within the circles for throwing events there should be a slope of no more than 0.1 percent (1:1000) in the throwing direction.

4.5 Construction Materials

Tracks should be constructed of materials that will create a uniform, smooth, safe, and comfortable running surface. Construction methods tend to vary according to local construction practices and in response to specific soil conditions.

4.6 Typical Synthetic Track Construction

Inside Curb:

Both the NCAA and the IAFF require a curb 50 mm (2 in) high along the inner edge of an oval track. The allowable minimum curb width is 50 mm (2 in) for the IAFF and 150 mm (6 in) for the NCAA. Often, a removable aluminum curb is used; American and

KEY POINTS: Track and Field

1. According to the standards published in the United States by the NCAA, a championship track shall be at least 400 m (440 yds) in length with six to eight lanes at 900-1 200 mm (36-48 in) in width.
2. Longitudinal slopes for tracks, runways, and landing areas for field events should not exceed a maximum of 0.1 percent (1:1000). Cross slopes should be no more than 1 percent (1:100) or, for high schools, 2 percent (2:100).
3. Both the NCAA and the IAFF require a curb 50 mm (2 in) high along the inner edge of an oval track. American and world records will not be accepted without this inside curb.

Table 520-2. COURT GAMES

Sport	Use area required including clear zones	Court dimensions*	Orientation	Surface
Badminton				
Doubles	1 500 mm (5 ft) clear zones between courts and at end	6 096 X 13 411.2 mm (20 X 44 ft)	Competition play is usually indoors. Outdoor courts long axis north-south.	Any hard surface or turf; drain as in tennis.
Singles	Same as doubles	5 181.6 X 13 411.2 mm (17 X 44 ft)		(Same).
Basketball				
High school		25 603.2 X 15 240 mm (84 X 50 ft)	North-south	Concrete, drain end to end at 25 mm per 3 m (1 in per 10 ft)
College	34 200 X 21 000 mm (114 X 70 ft)	28 651.2 X 15 240 mm (94 X 50 ft)	(Same)	(Same)
International	18 m X 30 m	14 000 X 26 000 mm	(Same)	(Same)
Goal-hi	18 000 X 18 000 mm to 24 000 X 24 000 mm (60 X 60 ft to 80 X 80 ft)	Circle—12 000 to 18 000 mm (40 to 60 ft) in diameter	Optional	Asphalt or synthetic; drain to edges.
Handball				
One wall	10 200 X 6 000 X 4 800 mm (34 X 20 X 16 ft) high	10 363.2 X 6 096 X4 876.8 (34 X 20 X 16 ft) high	Can be added to exteriors of gym or may be free standing	Any hard surface; drain from front to rear.
Three or four walls	12 000 X 6 000 X 6 000 mm (40 X 20 X 20 ft) high	12 192 X 6 096 X 6 096 mm (40 X 20 X 20 ft) high	Competition play normally indoors	(Same)
Racquetball	Same as handball			
Shuffleboard	15 600 X 3 000 mm (52 X 10 ft), including 1 200 mm (4 ft) between courts	15 849.6 X 1 828.8 mm (52 X 6 ft)	Long axis north-south	Hard/smooth concrete without expansion joints. Alley depressed and drained with catch basins.
Tennis	18 000 X 36 000 mm (60 X 120 ft) for one doubles court. Multiples can be designed with 3 000 to 3 600 mm (10 to 12 ft) between courts.	10 972.8 X 23 774.4 mm (36 X 78 ft)	Long axis north-south is ; OK long axis 22 degrees west of north and east of south is better in southern latitudes.	Many, including concrete, clay, asphalt, and turf. Drain side to side (preferred) or end to end at 0.8 to 1% (nonporous) or 0.003 to 0.004% (porous). Never allow high point at net.
Deck	7 800 X 15 000 mm (26 X 50 ft) (doubles) [needs a 3 000 mm (10 ft) fence]	5 486.4 X 12 192 mm (18 X 40 ft)	Long axis north-south.	Asphalt or concrete; drain side to side at 25 mm per 3 m (1 in per 10 ft)
Paddle	11 100 X 24 000 mm (37 X 80 ft) [needs an 2 400 mm (8 ft) fence]	6 096 X 15 240 mm (20 X 50 ft)	Long axis north-south.	Same as deck tennis
Platform	9 000 X 18 000 mm (30 X 60 ft) [needs a 3 600 mm (12 ft) fence]	6 096 X 13 411.2 mm (20 X 44 ft)	Long axis north-south.	Raised level wood or aluminum platform; 5 mm (1/4 in) spacing between 150 mm (6 in) decking.
Volleyball	15 000 X 24 000 mm (50 X 80 ft) preferred; (42 X 72 ft) OK	9 144 X 18 288 mm (30 X 60 ft)	Long axis north-south.	Asphalt, sand, clay mix, turf (ropes are used for marking sand and turf); drain at 25 mm per 3 m (1 in per 10 ft)

* All conversions to metric are exact.

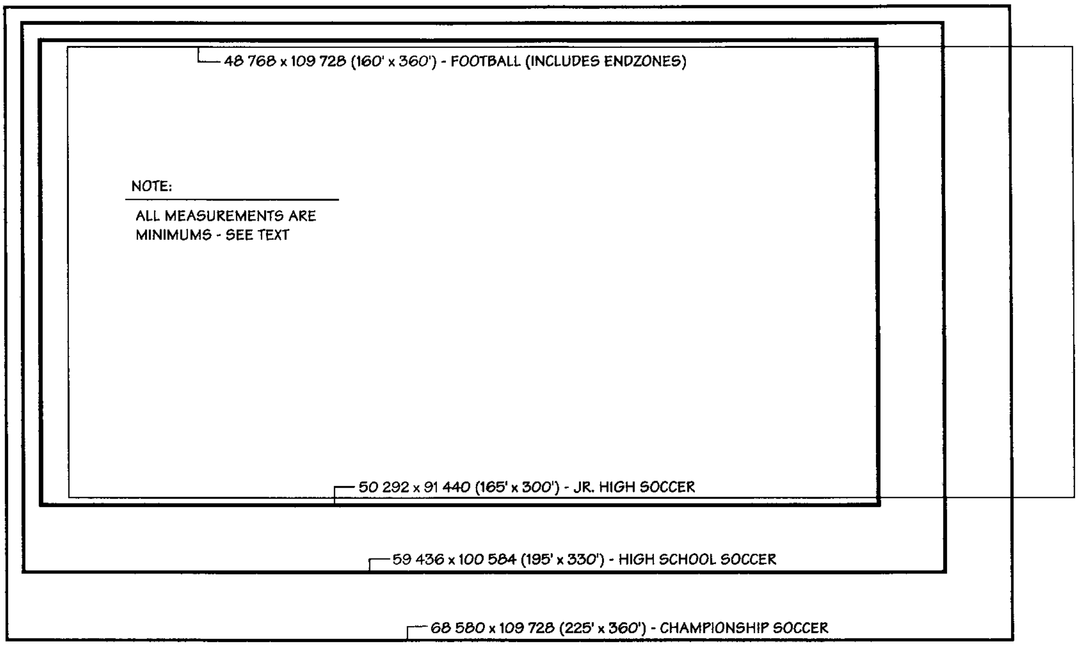


Figure 520-12. Comparative field sizes of common field sports.

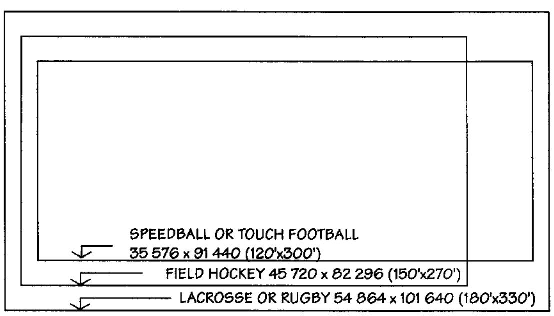


Figure 520-13. Typical field sizes.

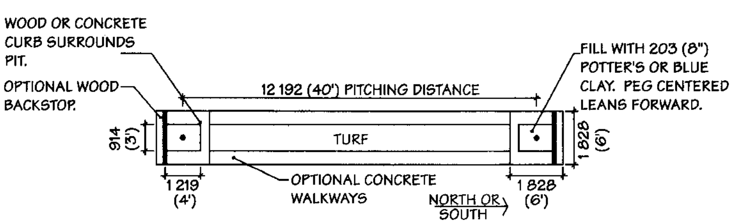


Figure 520-14. Horseshoes.

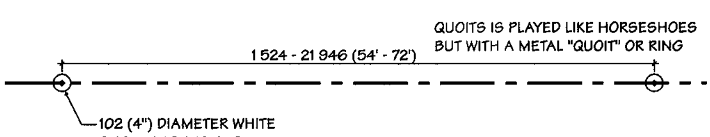


Figure 520-15. Quoits.

world records will not be accepted without this inside curb.

Field Events:

Field events may be located on the interior of the track to conserve space. Throwing events may be moved outside the track to allow for a warm-up area, to accommodate a football field, or to provide for additional safety.

There is no prescribed arrangement for the various facilities. They should be arranged to reflect the opportunities and constraints created by soil conditions, prevailing winds, and safety considerations. Sample arrangements are shown in Figure 520-32.

5.0 MULTIPURPOSE ATHLETIC FIELD COMPLEXES

5.1 General

Athletic complexes can take the form of clover leafs, or fourplexes, where the home plates of the ball diamonds (softball/baseball) are near a central core and football/soccer fields overlap the outfields, as shown in Figure 520-34. Storage, concession stands, locker rooms and restrooms are often located under the bleacher areas.

Advantages of Multipurpose Complexes:

The advantages of multipurpose complexes include common use of the same parking

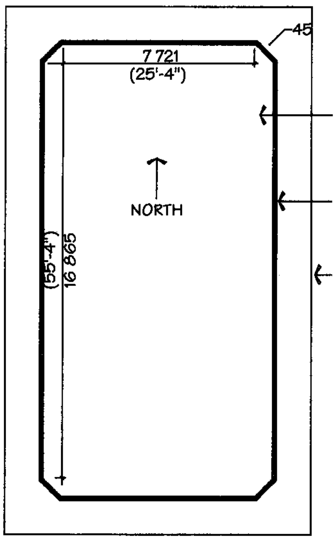


Figure 520-16. Roque/croquet.

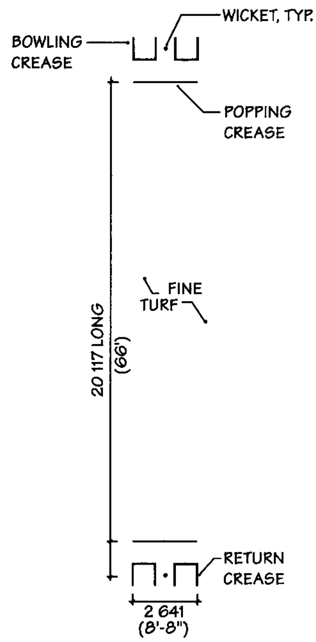


Figure 520-17. Cricket pitch.

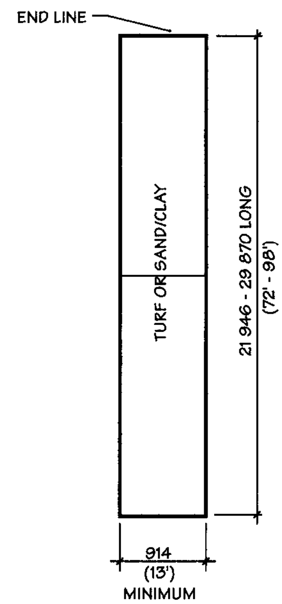


Figure 520-18. Bocce.

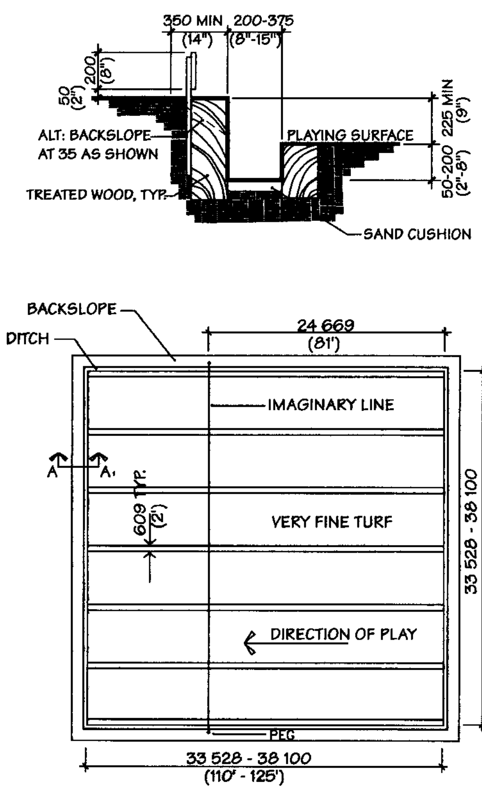


Figure 520-19. Lawn bowling.

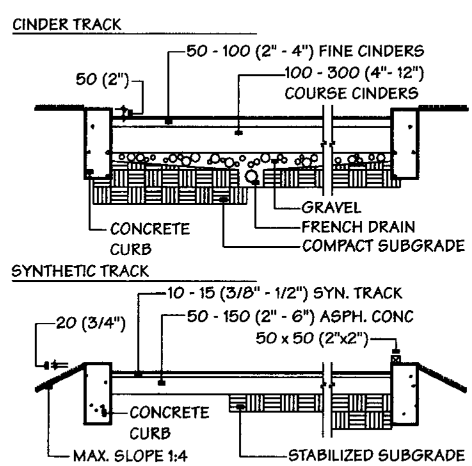


Figure 520-20. Typical track sections.

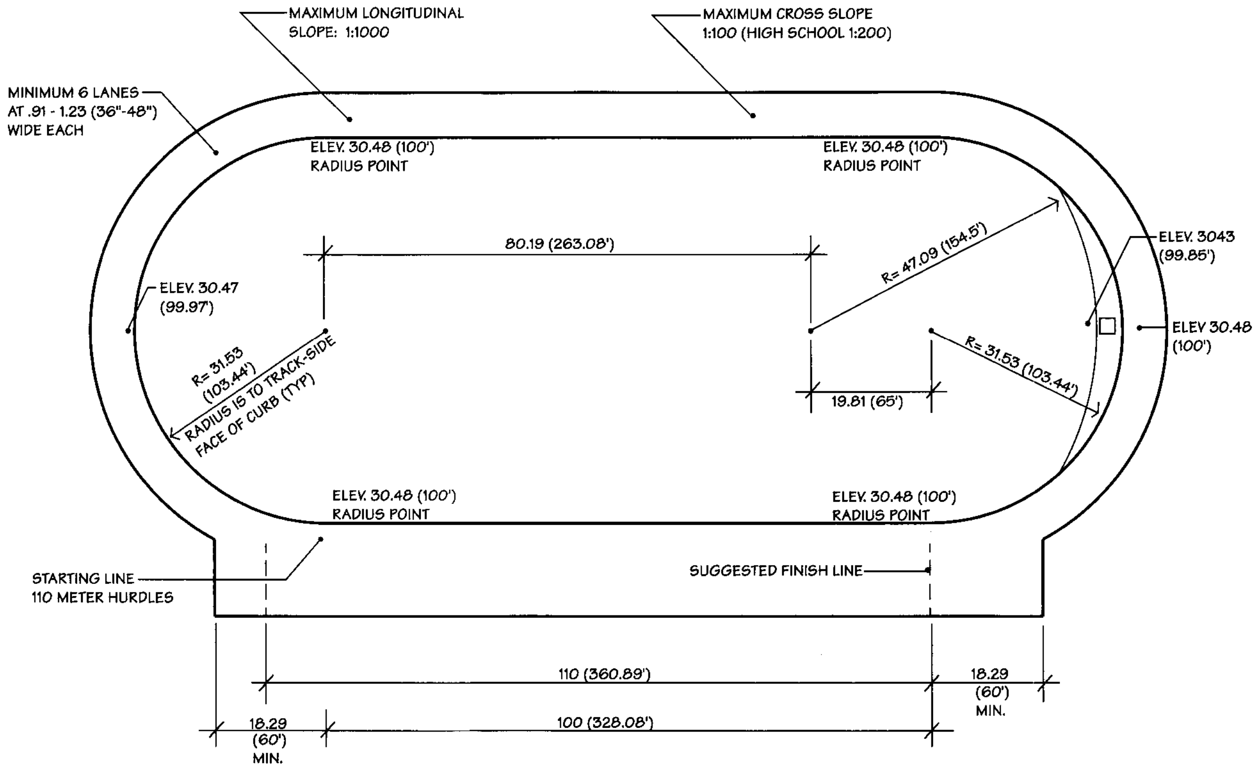


Figure 520-21. Basic layout: 400-meter track.

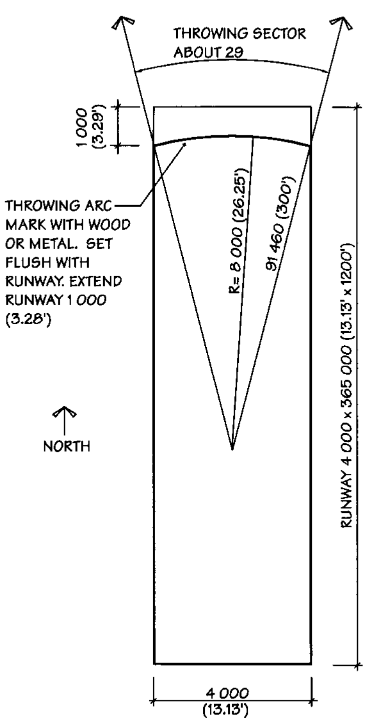


Figure 520-22. Javelin.

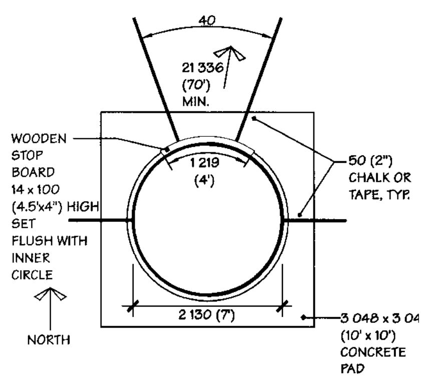


Figure 520-23. Shot put.

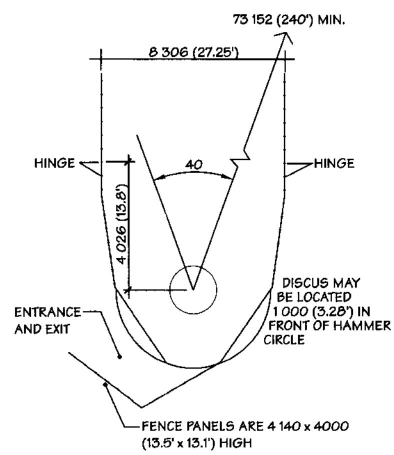


Figure 520-25. Hammer throw.

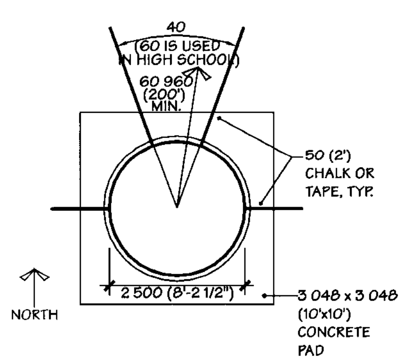


Figure 520-24. Discus.

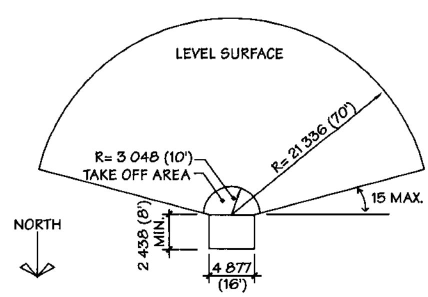


Figure 520-26. High jump.

Table 520-3. FIELD SPORTS

Sport	Use area required	Playing area***	Orientation	Drainage	Comments
Bocce	5.7 to 7.7 m X 24.6-30.3 m (19 to 25 ft 6 in X 82-101 ft)	3 962.4 to 5 791.2 mm X 23 400-27 600 mm (13 to 19 ft 6 in X 78-92 ft)	North-south preferred but not critical	Drain in any direction at 1%	250 to 300 mm wooden boards used at end and side as backstops
Bowling (lawn)	39 X 39 m (130 X 130 ft)	5 791.2 to 6 400.8 mm X 36 576 mm	(19 to 21 ft X 120 ft) alleys	Dead level— use underdrainage	Alleys grouped in banks of six
Cricket	Size varies, but area generally oval with no part of boundary closer than 70 m (75 yds) to pitch	No official size for field, but pitch is 20 116.8 X 3 048 mm (66 X 10 ft)			
Croquet	3.5 X 22.5 m (45 X 75 ft)	12 192 X 21 336 mm (40 X 70 ft) (smaller size is appropriate for nonregulation play)	Orient so that bleachers do not face sun	Drain as in A** at a maximum slope of 2%	
Fieldball	Identical to soccer field	Identical to soccer field	Identical to soccer field	Identical to soccer field	Identical to soccer field
Field hockey Women	*	91 440 X 45 720 mm (300 X 150 ft)	Same as football	Same as football	
Men	*	91 440 X 54 864 mm (300 X 180 ft)	Same as football	Same as football	
Flag or touch football	40 X 95 m (44 X 104 yds)	12 192 X 30 480 mm (40 X 100 yds) [includes two 9 m (10 yd) end zones]	Same as football	Same as football	
Football	Minimum 51.6 X 111.6 m (172 X 372 ft)	48 768 X 109 728 mm (160 X 360 ft) [including two 9 m (10 yd) end zones]	Long axis, northwest to southeast, or north-south for longer season	Drain as in A; B or C** are permitted but not preferred; provide adequate underdrainage	
Horseshoes	6 X 21 m (20 X 70 ft)	3 048 X 15 240 mm (10 X 50 ft)	Long axis, north-south	Drain as in "A"; two end pegs must have identical elevation	
Lacrosse Women		Boundaries set by referee; minimum width 45 720 mm (150 ft), length 109 728-124 968 mm (360-410 ft)	Same as football	Same as football	
Men	60 X 105 m (200 X 350 ft) with fence; 66 X 111 m (220 X 370 ft) without fence	Prefer 54 864 X 100 584 mm (180 X 330 ft), but can be played on football field	Same as football	Same as football	
Polo	Play area includes safety area	91 440 X 48 768 mm (300 X 160 yds) if boarded; 91 440 X 60 960 mm (300 X 200 yds) if not ~3 000 mm			
Quoits	Allow 1 500-3 000 mm (5-10 ft) at side and back boundaries	16 459.2-21 945.6 mm X ~3 000 mm (54-72 ft X ~10 ft)	Same as horseshoes	Same as horseshoes	
Rogue	120 X 210 m (40 X 70 ft)	9 144 X 18 288 mm (30 X 60 ft)	Same as croquet	Dead level; use underground drainage	Surface is packed earth
Rugby (League-professional)	*	100.6 X 54.9 m (110 X 60 yds) plus 5.5-11 m (6-12 yds) at each end for ingoal	Same as football	Same as football	
(union-amateur)		* (110 X 60 yds) plus 22.8 m (25 yds) at each end for ingoal	100.6 X 54.9 m	Same as football	Same as football
Soccer	9 m (10 yds) on all sides free of obstructions	50-70 m X 90-110 m X 100 -120 yds) 68.58 X 109.73 m (75 X 120 yds) for championship	North-south, except south of 38th parallel where long axis may approach 20 degrees west of north	Same as football	There are no official standards for soccer size varies even among Olympic sites
Speedball Women	*	54.86 X 91.44 m (60 X 100 yds)	Same as football	Same as football	
Men	*	48.77 X 109.73 m (53 1/3 X 120 yds)	Same as football Same as football	Same as football	

*When not specified, no standard exists; 9 m (10 yds) is recommended on all sides.
** See Figure 520-11.
*** All conversions to metric are exact.

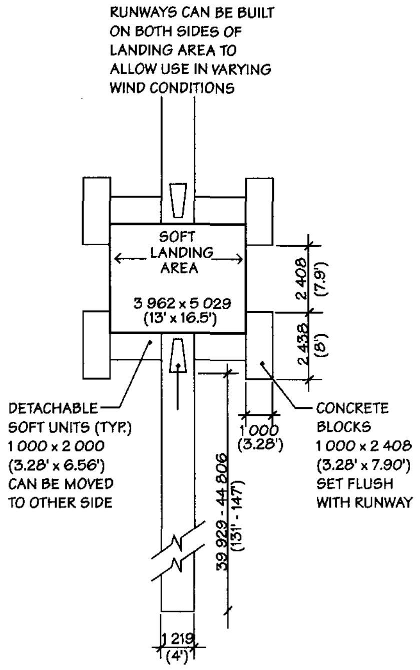


Figure 520-27. Pole vault.

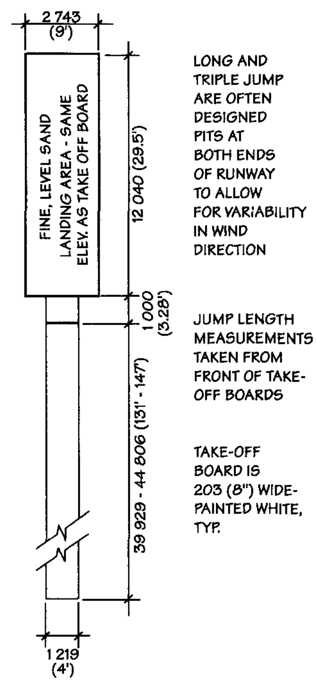


Figure 520-28. Long jump.

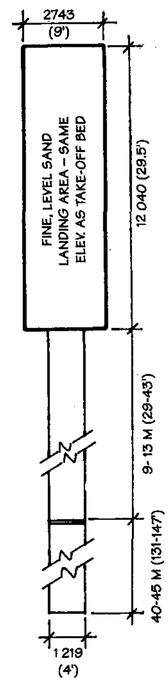


Figure 520-29. Triple jump.

lot for separate sports, the same irrigation and lighting systems, and use of single rather than separate tracts of land. Restrooms, concessions, and other common support facilities are concentrated for more cost-effective maintenance. A centralized administration can help to schedule league and tournament play.

Disadvantages of Multipurpose Complexes:

The disadvantages of multipurpose complexes are the amount of traffic, noise, and glare from night lighting that may disturb nearby residential areas. Other disadvantages include the need for portable outfield fences during championship or tournament ball games and for portable goals during football or soccer play. Also, a greater potential exists for scheduling conflicts when all four sports have demands during overlapping seasons. Furthermore, not all fields will enjoy optimum orientation.

The parking requirements for a fourplex complex (as shown in Figure 520-34) when games are closely scheduled is approximately 250 cars.

5.2 Design Considerations

Ball fields need adequate separation to minimize hazards from foul balls and to reduce noise and confusion. An optimum distance between the foul lines of adjacent ball diamonds is 36 to 42 m (120 to 140 ft). A complex capable of accommodating four diamonds, each with 90 m (300 ft) long foul lines, will occupy a space approximately 240 m X 240 m (800 ft X 800 ft). With the addition of parking and buffer areas, the complex will occupy approximately 7 to 8 hectares (18 to 20 acres) of relatively level land and more if sited on sloping land. Figures 520-33 through 520-35 show two basic grading concepts that can be used in this type of complex. The first concept uses a high spot at the center with water draining off toward all edges, and the other calls for a plane with a uniform slope across the complex. As always, local site conditions will dictate the final solution.

6.0 WATER-BASED FACILITIES

6.1 Docks

Two courtesy docks are needed for each launching facility (Figure 520-36). The minimum width of all docks is 1 800 mm (6 ft). Finger walkways between slips can be as narrow as 750 mm (2 1/2 ft) if they are less than 6 000 mm (20 ft) long. Floating docks are preferred to stationary ones when the water height fluctuates more than 450 mm (18 in). At least one comfort station should be located within 120 m (400 ft) of the dock. Fire codes relating to dock areas should be consulted.

A service dock or float is necessary to supply fuel to outgoing boats. Locate fuel storage tanks underground and above the high-water line as specified by local and National Fire Protection Association (NFPA) codes. Dumps, comfort stations, and other permanent structures should also be constructed above the 100-year flood line or should be flood proofed.

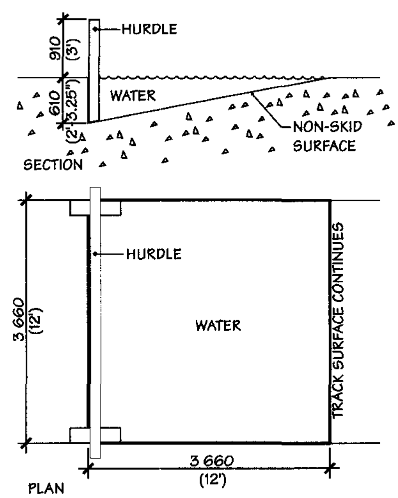


Figure 520-30. Water jump.

6.2 Launch Facilities

Launch lanes should be at least 4 500 mm (15 ft) wide in a multiple-lane facility and 5 400 mm (18 ft) wide in a single-lane facility (See Figure 540-37). The prepared sur-

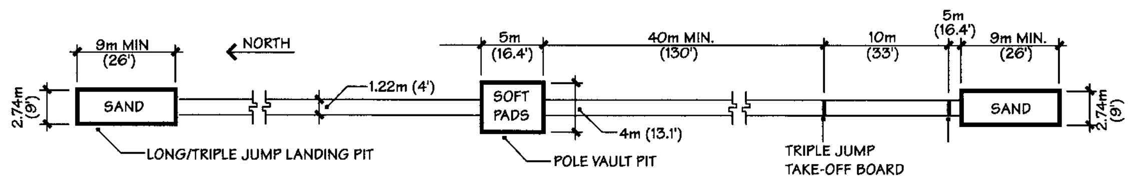


Figure 520-31. Combined long jump, triple jump, and pole vault.

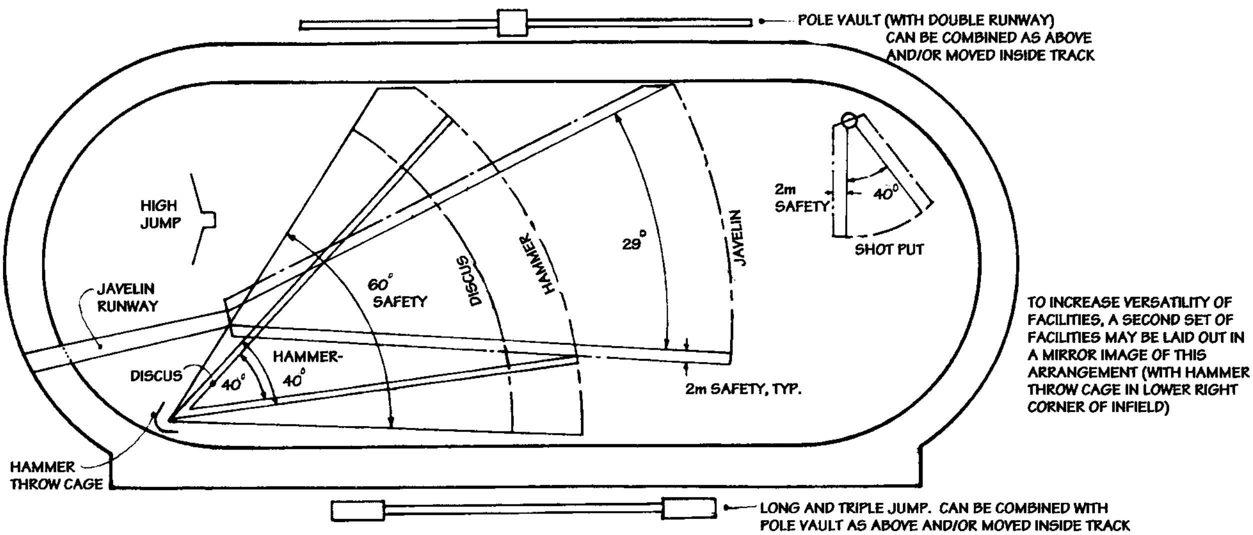


Figure 520-32. Schematic arrangement of infield.

face should be finished with a cross-scored pattern. The ramp grade should be no steeper than 12 to 15 percent. The lowest end of the ramp should extend into the water to a point where it will be at least 1 200 mm (4 ft) below the lowest water elevation in order to protect the base of the ramp from wave action. The backing distance of a vehicle should be limited to 60 m (200 ft). The maneuvering area on land should be at least 24 m (80 ft), and preferably 30 m (100 ft), in diameter. In northern climates, direction of ice flows in the spring of the year should be considered when orienting launch facilities.

6.3 Swimming Beaches

General:

Good swimming beaches should be protected from boats, fuel spillage and organic pollutants, and water should circulate through the area. Ideally, the beach should face the full or at least the afternoon sun. It should have a cross-sectional slope of 4 to 10 percent (based upon local health codes) and consist of sand or a soil mixture having sandy qualities.

Spatial Standards:

Lookout towers should be provided every 90 m (300 ft). A swimming area of 4.6 m^2 (50 ft^2) should be allowed for each bather. Ladders should be provided on all docks within and adjacent to swim areas. Docks should be a minimum of 450 mm (18 in) above water level (Figure 520-38).

The slope of the beach toward the water should be a minimum of 2% and a maximum of 5%. The slope under water should range from 7% to 10%, be free from rocks, and have no sudden changes in elevation or deep holes in the swimming area.

During average periods of use, approximately 70% of beach users will be on the beach, with the remaining 30% in the water (Figure 320-38).

6.4 Swimming Pools

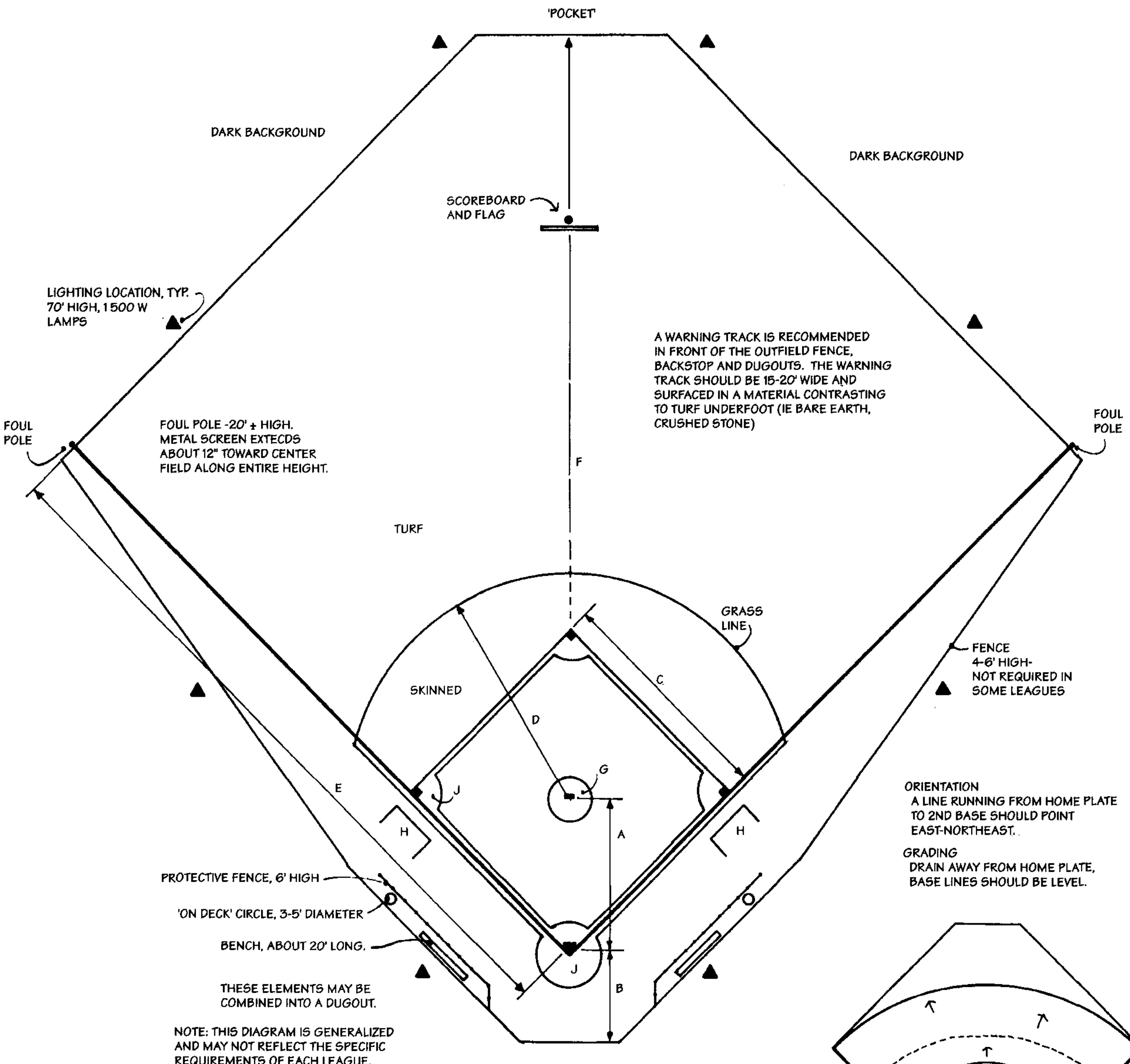
General:

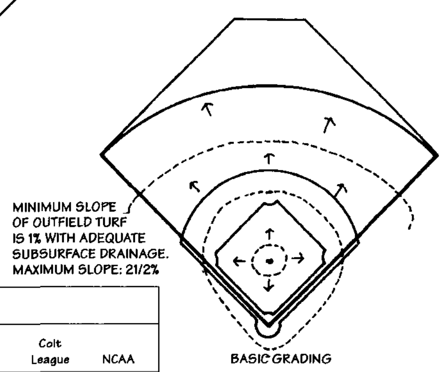
Swimming pools can be made in a variety of shapes, from free-form to T or L shapes, but the basic design of all public and semi-public pools should be checked against local health codes.

Spatial Standards:

The following standards are considered typical for swimming pools:

1. Recreational pools are sized to allow 1 m^2 (10 ft^2) of water surface for every wader or nonswimmer expected, and 2.5 m^2 (27 ft^2) of surface for every swimmer.
2. The area for nonswimmers should be less than 1 500 mm (5 ft) deep.
3. Many public pools have 80 percent of the water area devoted to nonswimmers (Figure 520-39).





	Softball			Baseball					
	16" Slow Pitch	12" Fast Pitch	12" Slow Pitch	Little League	Bronco League	Pony League	Babe Ruth League	Colt League	NCAA
A. Pitching distance[8]	38	46	46 (40)	46	48	54	60.5	60.5	60.5
B. Home plate to backstop	Min. 25	25-30	25-30	25[1]	20	40	60[2]	60	60
C. Baseline	55 (50)	60	60	60	70	80	90	90	90
D. Radius of skinned area[8]	70	60	60	50	65	80	95	95	95
E. Foul line	250 (200)	275 Min.	225 Min.	200	175	250	350[3]	300	330
F. Home plate to 'pocket'	250	275 (250)	225	250[4]	225	300	400	350	400
G. Diameter - pitcher's mound	16	8	8	10[5]	12[5]	15[6]	18[7]	18[7]	10[7]
H. Size of coaches' box	3 X 15	3 X 15	3 X 15	4 X 8	6 X 12	8 X 16	10 X 20	10 X 20	5 X 20
J. Diameter - bases	30	30	30	18	22	24	26	26	26

Notes
1 Optional distance
2 40' satisfactory, 60' preferred
3 320' satisfactory, 350' preferred
4 200' to outfield fence
5 Pitcher's mound raised 6"
6 Pitcher's mound raised 8"
7 Pitcher's mound raised 10"
8 Measured from front center of pitcher's rubber

All measurements are in feet. Women's dimensions, if different, are in parenthesis.

Figure 520-33. Softball/baseball layout.

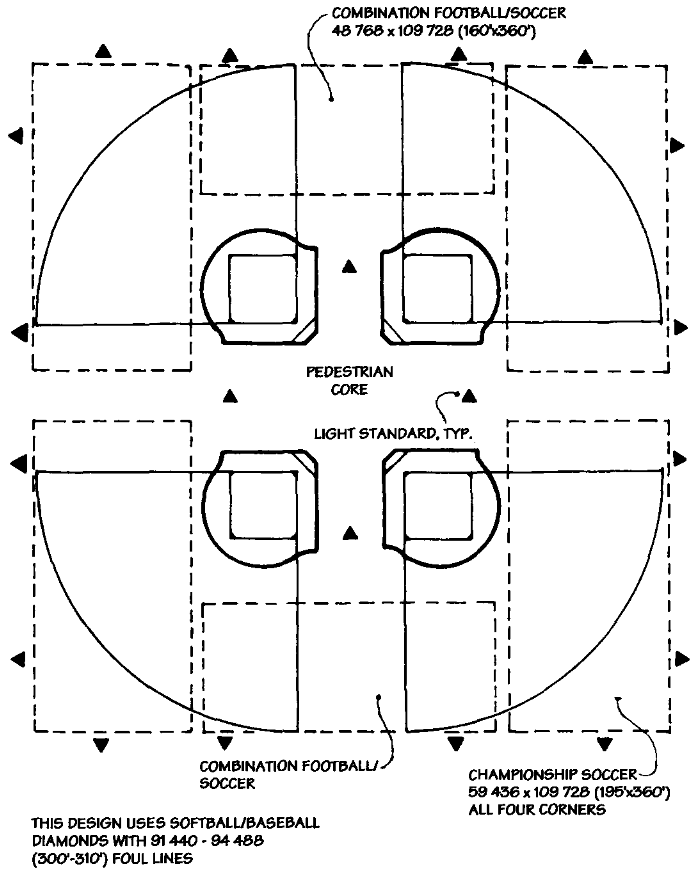


Figure 520-34. Schematic sports complex.

4. An extra 28 m² (300 ft²) should be added for each diving board.

5. Twenty-five yards (75 ft 1-1/2 in to accommodate timing equipment) is the minimum length for interscholastic or intercollegiate competition in the United States. International competition requires a 50-m length pool.

6. Lanes should be 2 100 mm (7 ft) wide between the center lines, marked with lane stripes 250 mm (10 in) wide. Add 450 mm (18 in) to each of the outside lanes.

7. The deck space around recreational pools should be at least equal to the water surface because generally only one-third of the swimmers will be in the pool at any one time. A 3:1 to 4:1 ratio between deck and water surface provides the most functional arrangement.

8. Official standards for water polo depend on the standard-setting agency (Figure 520-40).

Wading Pools:

Wading pools can be placed in the same complex as competition-size pools, but they should be separated and fenced for safety. Fountains or sprays can be added. If facility is outdoors, shaded seating should be provided for parents or other supervisors.

6.5 Fishing

Fishing takes place in ponds, lakes, streams and wetlands. Water depth, temperature, chemistry and biotic composition combine to influence the fisheries within a particular body of water. The following guidelines highlight some key concerns when establishing a natural or constructed fishing pond:

1. A surface area of 0.4 ha (1 acre) is sufficient; a commercial sporting operation can be maintained if the surface area is at least 4 ha (10 acres).

2. 1 800 mm (6 ft) is a good average depth. Areas less than 900 mm (3 ft) deep will encourage the growth of aquatic plants. These plants are considered undesirable because they provide breeding and protection areas for some smaller species of fish, which may lead to overcrowding for the desired species.

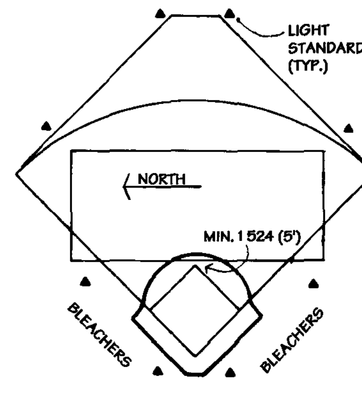


Figure 520-35. Baseball/football complex (baseball primary).

3. Depths should be increased in arid areas where evaporation is a problem or in areas where ice forms.

4. The water supply should have a low amount of silt. If drainpipes are installed, they should be wide enough to allow the fish to pass through unharmed.

5. For casting, allow 1 800 mm (6 ft) between each person fishing. Along some areas of the shoreline, allow at least 1 800 mm (6 ft) of unobstructed space between the water edge and any dense vegetation.

6. A gently sloping shoreline is the least prone to erosion and the safest for those fishing.

7. An access point for a truck is necessary for the stocking and fertilization of a fishing pond.

8. Fishing ponds which attract the greatest number of young children and non-swimmers should include rescue equipment such as throw-rings and reaching poles.

6.6 Accessible Swimming, Fishing, and Boating

More complete and comprehensive information on the design of water-based facilities for accessiblity is found in Section 240: Outdoor Accessibility.

Swimming Pools:

Swimming pools need entry ramps at a slope of 1:12 or less. Two handrails 750 to 900 mm (2 1/2 to 3 ft) high and 900 mm (3 ft) apart should be provided. In a natural setting, provide a paved (or at least a stabilized) surface between the bathhouse and the water.

Beaches:

At beaches, the path should terminate in a 1 800 X 1 800 mm (6 X 6 ft) paved area and should provide a handrail approximately 800 mm (32 in) high that extends into the water to a depth of 750 mm (2 1/2 ft). The beach gradient should be no steeper than 1:12.

Fishing and Boating:

Docks provide access to boating and fishing for those who are handicapped. These docks should be at least 2 400 mm (8 ft) wide, with the boards laid perpendicular to the direction of travel and with the open joints no greater than 10 mm (1/2 in) wide. At least one side of the dock should have a railing that will support a 136 kg (300 lb) individual during loading and unloading. Fishing rails should have a shelf for bait and tackle that is 200 to 300 mm (8 to 12 in) wide and 750 mm (30 in) above the dock surface. The top rail should be 900 mm (36 in) high and slope at 30 degrees toward the user as an arm-and-pole rest. Provide a kick plate to prevent wheelchair foot pedals from going off piers. Segments of the dock or pier should have a roof or shaded area that is fully accessible.

6.7 Water-skiing

The lake size should be 3.25 to 6 ha (8 to 15 acres) per boat. The higher figure should be used where considerable powerboat traffic is anticipated. If many boats are involved, a proportionate number of piers, docks, etc. should be added.

6.8 Crew

International crew races are set at 2 000, 1500, and 1000 m and require at least an additional 250 m (820 ft) distance beyond the finish line. Races require a water body with no moving water, no bridges, and no prevailing crosswinds. A uniform depth of at least 3 000 mm (10 ft) is required. The course consists of six parallel lanes and one return lane, each a minimum of 12.5 m (41 ft) wide. Although natural areas such as rivers have been used, recent Olympic races have been held in artificial ponds.

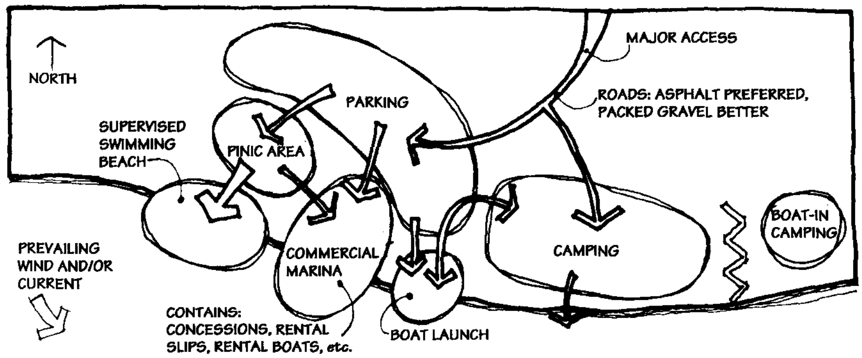


Figure 520-36. Schematic marina layout.

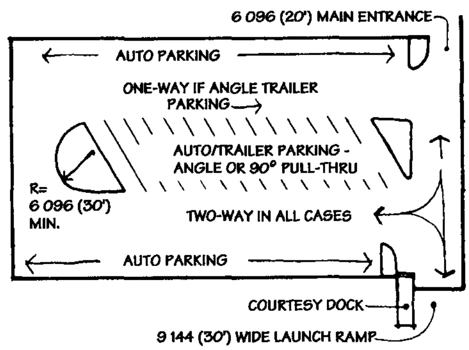


Figure 520-37. Boat launch/parking diagram.

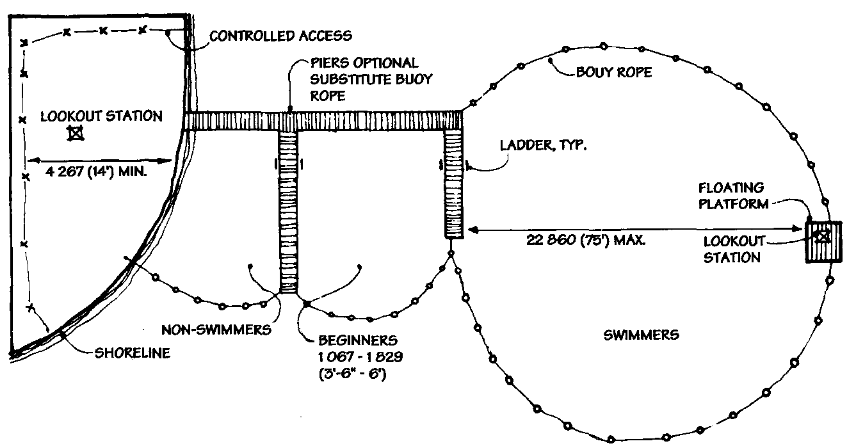


Figure 520-38. Schematic diagram and section for freshwater swimming.

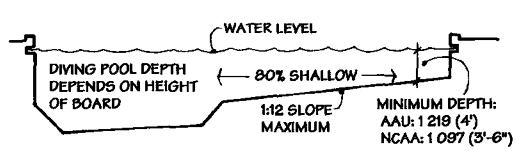


Figure 520-39. Schematic pool section.

7.0 WINTER SPORTS ACTIVITIES

7.1 Snowmobiling

Snowmobiles are often used on terrain and trail systems such as existing snow-covered fire lanes, trails, and rural roads extending out from a central lodge facility (Figure 520-41). Snowmobiles are usually considered incompatible with most forms of nonmotorized winter recreation, such as sking and snow shoeing. Grades in excess of 12 percent, as well as trails cut into steep side slopes, should be avoided. Ice-covered lakes and ponds are often traversed.

Snowmobiling is often a group sport. Groups gather to race and tour. Racing facilities include tracks, generally 1.6 to 3.3 km (1 to 2 mi) in length over wooded terrain, and sprints—45 to 800 m (50 yd to 1/2 mi) strips with a run-out of approximately 100 m (1/16 mi). Cross-country races and tours may involve several hundred participants racing against a clock and are generally 40 to 160 km (25 to 100 mi) in length. Starting areas need to be large enough to accommodate the potentially large number of entrants; an open meadow is often used. Snowmobile trails are often based on a time and distance cycle.

7.2 Cross-Country (Nordic) Skiing

The design of cross-country facilities should reflect the skier's desire to be isolated from other activities, and it should include the following:

1. Adequate separation from such conflicting uses as snowmobiling and downhill (alpine) skiing
2. Passage over a variety of terrains, from flat open meadows to steeper grades
3. Relative safety from risk of avalanche (see Section 253: Natural Hazards: Landslides and Snow Avalanches)

7.3 Downhill (Alpine) Skiing

General:

Precise design criteria and standards for downhill ski areas cannot be established because each development is influenced by the opportunities afforded by (1) the site and its topography and (2) the characteristics of the targeted market area. Ski slopes are usually designated as novice, intermediate and advanced. Computer simulations are often used to model the proposed development of ski areas and to blend the ski trails with the pre-existing visual elements of the terrain.

The following slope percentages are based on difficulty:

Novice	5-20% slope
Intermediate	21-35% slope
Advanced	36 % and above slope

Major Considerations:

Major considerations in the planning and design of downhill skiing facilities include the following:

1. Environmental protection and management should be the major consideration in the planning, design, construction, and operation of the facility. Fragile mountain ecosystems can be impacted adversely by poorly planned ski developments. Because ski areas are often at the headwaters of a watershed, they generally have thin soil layers, short growing seasons, and a high degree of off-site visibility.
2. Facilities such as water tanks (with their distribution lines) and sanitary facilities (with their pipelines) should be located away from the trails and out of view of skiers. If feasible, utilities should be installed during the first phase at the ultimate size and capacity required.
3. Existing and potential wind patterns should be analyzed before locating runs, particularly runs through dense timber. Adverse wind patterns can cause a slowdown or stoppage of lifts, can scour snow from previously well-packed slopes, and can decrease comfort and safety. Timber is best cleared in small increments, with a constant evaluation of changes in wind pattern. Leave the edges of timber lines feathered to appear more natural and to reduce abrupt changes in wind patterns.
4. Avoid areas that are avalanche-prone, since the prediction and prevention of avalanches is not a reliable science.
5. North facing slopes are preferred because they allow a longer skiing season.

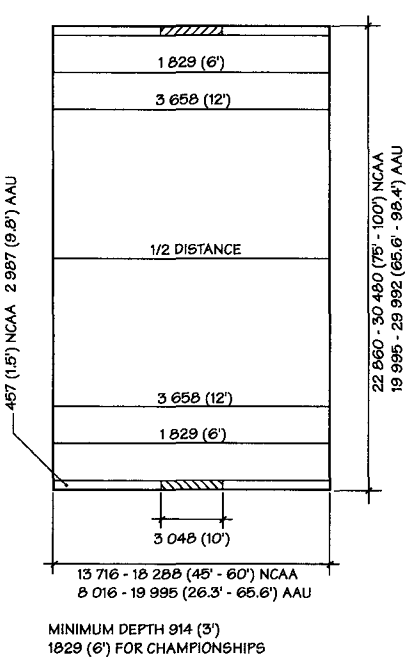


Figure 520-40. Water polo.

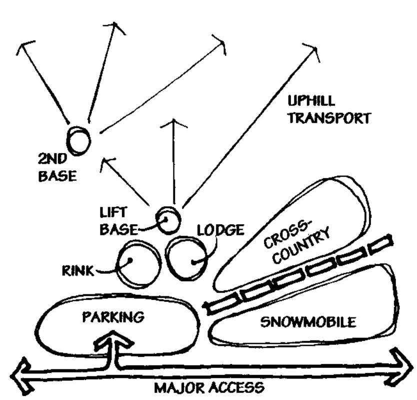


Figure 520-41. Schematic winter sports area.

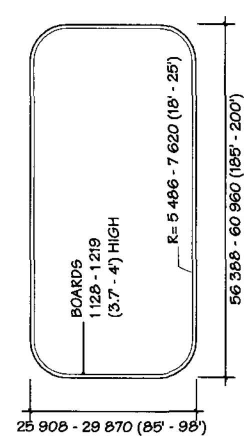


Figure 520-42. Ice hockey.

6. Surface drainage should not be directed across the slopes but into channels away from them in order to avoid the problems of icing and melting snow.
7. If steep slopes separate the base from the more gentle slopes, a second base or staging area may be desired. Also, multiple bases can reduce congestion around the lodge and excessive wear on the snow.
8. Roads should be as narrow as possible. They should switch back only where skiing will not occur, and divert runoff water to buried culverts rather than ditches when control is necessary. If feasible, all roads for the final development should be planned and constructed during the first phase.

7.4 Ice Skating

Competition hockey generally takes place on an indoor rink (Figure 540-42). Free skating can be done indoors or outdoors; it requires a solid ice surface and a space relatively free from obstructions. Natural ice is normally swept regularly to remove leaves and other obstructions. Low walls or railings are optional but do offer support for the beginner and a container for ice made by flooding. The size of the area depends on the type of sport to be played on the surface. Speed skating is done normally on a race track but can be done more informally on a long stretch of frozen river. European-style tracks are 400 m (437 yd) in length and double-laned. Each lane is 5 m (5-1/2 yd) wide. Curling is a sport played on an ice-surfaced court (Figure 540-43).

7.5 Ice Boating

Ice boating takes place on frozen lakes or rivers. Race courses can be 19 km (12 mi) or more long and should meet the requirements for sailing both with and into the wind.

7.6 Toboggan, Sledding and Tubing

Careful thought should be given to the design of winter hills. It is best to separate sledding runs for each of the above uses. Exposure is best facing North to North-East. The shade from the hill will protect the snow later in the season. Slopes on the hill can follow the same slope recommendations as skiing (7.3: Downhill Sking).

Grading of sledding runs should naturally move the participant away from steps, railings, trees, water concentrations and drop-offs. Caution should be used when overlapping the run with other circulation corridors such as paths and seasonal roads.

7.7 Bobsled and Luge

Bobsled and luge courses are highly site-specific and are generally associated with Winter Olympic sites. A course is typically 1000 m in length, and contains both sharp and gentle curves. The average gradient is about 11 percent (a range of 8-1/2 to 15 percent is common). Straight-aways should be 2 m wide and curves should be 3 to 6 m wide; when banked perpendicularly, curves can be as much as 9 m wide. Banked walls are plastered with an ice-snow mixture and may even be finished with a template to meet precise engineering specifications.

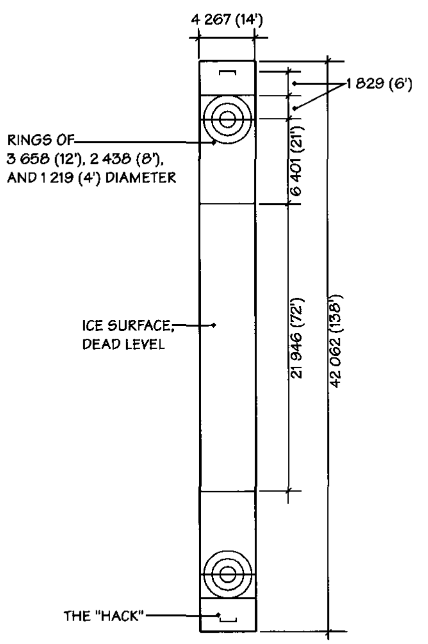


Figure 520-43. Curling.

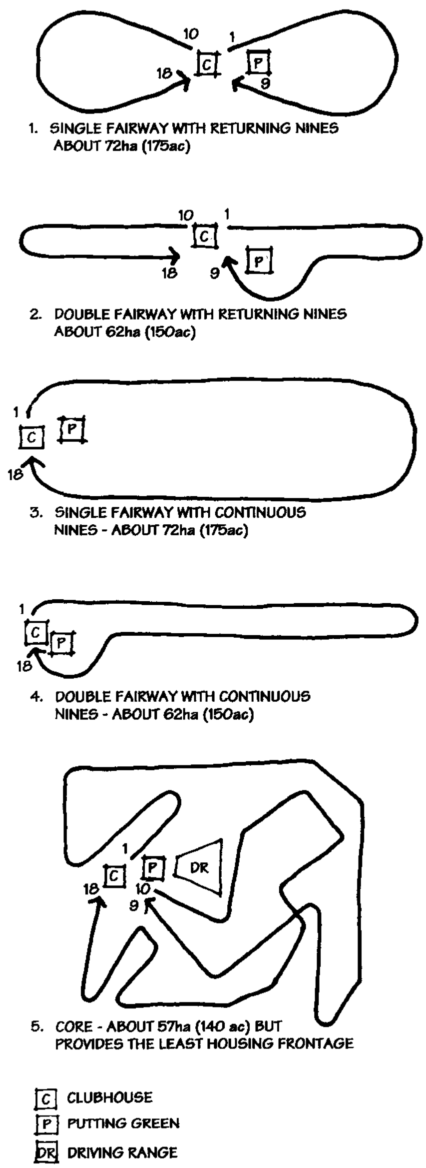


Figure 520-44. Typical golf course arrangements.

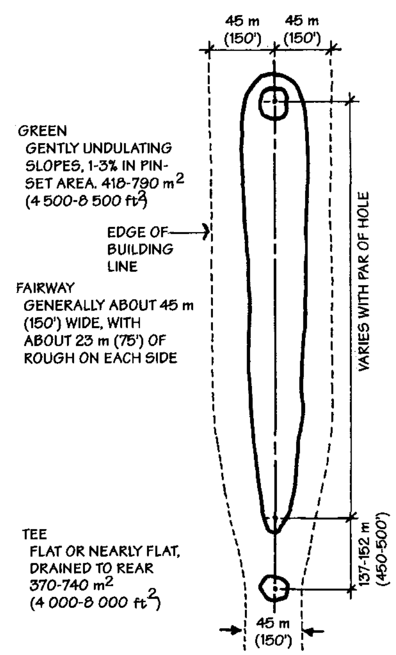


Figure 520-45. Typical golf hole.

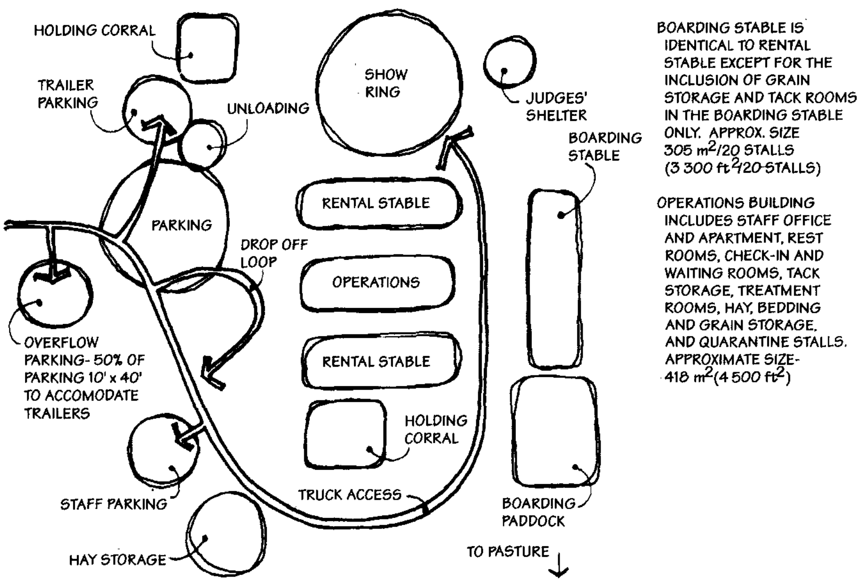


Figure 520-46. Schematic riding stable layout.

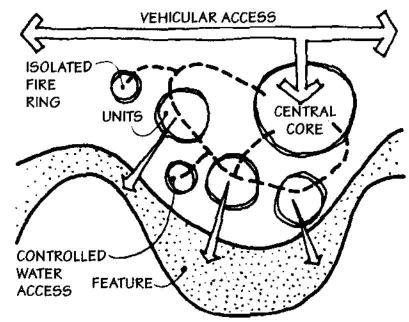


Figure 520-47. Outwardly focused camp.

8.0 SPECIAL COURSES AND AREAS

8.1 Golf

Golf course design is too complex to be fully detailed in this section; however, some of the major considerations and variations are summarized below.

The Site:

Gently rolling terrain provides for a course that is both better for play and more visually interesting. Positive drainage is essential, and therefore sandy soils are preferred. High-quality water is required for irrigation at rates of approximately 50 mm (2 in) per week for greens and tees, and 25 to 38 mm (1 to 1-1/2 in) per week for fairways, the latter depending on the geographic region. Visual connections between tees, landing areas and greens are essential.

Although streams, lakes and ponds are desirable in the development of a golf course, wetlands if present must be protected and mitigated if modified.

The Course:

Regulation 18-hole courses have pars ranging from 68 to 72. Par for a particular course is measured by the length, slope index and ability of a scratch golfer to par the course. Courses can be laid out in one of five basic configurations, their required areas ranging from 57 to 75 ha (140 to 175 acres) (Figure 520-44). The configuration chosen will depend upon the character of the site, the design program and adjacent land use. Figure 520-45 shows the layout of a typical golf hole without hazards.

The Variations:

There are numerous variations of 9 or 18 hole golf courses. A typical course of 9 holes will consist of 2 par 3's, 2 par 5's and 5 par 4's. The 1st and 9th holes are usually par 4's allowing warm up on the first hole and the potential for a good score on the last hole. This principle can be incorporated into any of the following golf course configurations:

1. Thirty-six holes: any combination of the basic configuration.
2. Twenty-seven holes: three returning 9's are preferred; one continuous 18 and one returning 9 is permitted.
3. Nine-hole regulation with multiple tees (2 shots taken to each green for a total of 18 shots).
4. Eighteen-hole executive, nine hole, pitch 'n' putt, par 3, or other short courses. These courses are generally 2 740 to 3 660 m (3000 to 4000 yd) in length with a par of 56 to 60. They require areas of approximately 18 to 24 ha (45 to 60 acres) and use full-size greens to distribute wear.

8.2 Equestrian Facilities

Site Criteria:

Equestrian facilities, which also can include livestock pavilions, should be located where they will be 150 m (500 ft) downwind from other public activity centers. Drainage must be positive and controlled both on- and off-site. Runoff must be retained on-site or properly treated before release into storm sewers or natural drainage. The spacing between buildings will be regulated by local fire codes, but usually at least a 4.5 m (15 ft) fire lane is required. Boarding and rental stables should be separated by at least 30 m (100 ft). Horse trails should be an average of 900 to 1 800 mm (3 to 6 ft) wide,

KEY POINTS: Special Courses and Areas

1. Regulation 18-hole golf courses require areas ranging from 57 to 75 ha (140 to 175 acres) (Figure 520-44).
2. Jogging paths should be a minimum of 0.62 km (1 mi) in length and should be arranged in some variation of a figure eight to allow shorter runs and a greater variety of routes. Paths should be a minimum of 1.2 m (4 ft) in width.
3. Exercise trails are jogging routes with exercise stations located 135 to 180 m (150 to 200 yd) apart.
4. Nature trails are paths along which interpretive stations are often placed to explain the surroundings and should have a minimum width of 2 100 mm (7 ft), a maximum grade of 8 percent, and a firm surface.

3 000 mm (10 ft) wide for passing, and should be clear of overhanging limbs to a height of 3 600 mm (12 ft). Grades should not exceed 5 percent, although 10 percent for short distances is permissible. Washing and grooming areas should be easily accessible, well drained and ventilated and away from the public. (See Figure 520-46.)

Design Criteria:

1. Pasture: 0.8 ha (2 acres) per horse (zoning ordinances vary)
2. Staff office and apartment: 21 m^2 (226 ft^2) per staff member
3. Treatment stalls: 3.5 m X 5 m (12 ft X 17 ft), 1 per 30 horses
4. Quarantine stalls: 3.5 m X 3.5 m (12 ft X 12 ft), 1 per 30 horses
5. Rental or boarding stalls: 3.5 m X 3.5 m X 4 m (12 ft X 12 ft X 14 ft), 1 per horse
6. Hay storage (for 40 horses): 77 m^2 (825 ft^2)
7. Grain storage (for 40 horses): 18.5 m^2 (200 ft^2)
8. Bedding storage (for 40 horses): 37 m^2 (400 ft^2)

8.3 In-line Skating

Inline skating, sometimes referred to as roller blading, has evolved from roller skating and is popular for both roller hockey and fitness.There are no specific design standards for inline skating facilities per se since many inliners use conventional roller skating rinks. The Inline Skatepark Directory provides information on special inline facilities. The International In-line Skating Association (IISA), headquartered in Kennesington, Maryland was formed in 1991 to advance in-line skating as a recreational activity and competitive sport. The association provides technical information for the inline skating community.

8.4 Skateboard Parks

Park designs vary, although they usually range from 0.1 to 2 ha (1/2 to 5 acres) in size. Surfaces should be made of a smooth, fluid, nonjointed material such as shotcrete or fiberglass. Features in a skateboard park include:

1. Freestyle areas: about 24 m X 12 m (80 ft X 40 ft), with slightly banked walls.
2. Slalom run: about 30 m (100 ft) long, dropping 3 to 4.5 m (10 to 15 ft), with slightly banked walls.
3. Snake run: curved channel, with walls 2.4 to 3.5 m (8 to 12 ft) high.
4. Bowls and pools: depths from 2.1 to 3.5 m (7 to 12 ft). Pools should include a slight overhanging lip around the edge.
5. Half pipe: literally a half pipe with no flat area; variable length; diameter usually around 6.7 m (22 ft). Some walls rise beyond vertical.
6. Full pipe: literally a full pipe with no flat spot.

8.5 Jogging Paths

Jogging requires only a path, preferably of crushed stone or a similar resilient material, that is well-drained and has a minimum width of 1.2 m (4 ft). The stone used will depend on local availability but should be smaller than 10 mm (1/2 in) in diameter and angular enough to pack to a firm surface. Paths should be a minimum of 0.62 km (1 mi) in length and should be arranged in some variation of a figure eight to allow shorter runs and a greater variety of routes. Official marathons are 42.19 km (26 mi 385 yd) long and are generally run on existing paved or dirt roads.

8.6 Exercise Courses

Exercise trails are jogging routes with exercise stations located periodically along the path. The stations can be as close together as 46 m (50 yd) or as far apart as 365 m (400 yd), depending on the total length of the track; 135 to 180 m (150 to 200 yd) apart seems to be a good average. Proprietary tracks are available from several companies complete with stations, signs, and installation guidelines. Some offer courses specifically designed for full accessibility.

8.7 Rock Climbing Walls

Rock climbing walls are found either in outdoor settings or in special indoor gym facilities. There are no specific design standards. Local climbing clubs and instructors should be consulted when a climbing wall is being planned.

8.8 Nature Trails

Nature trails are paths along which interpretive stations are often placed to explain the surroundings. These paths can be made accessible to those who are blind by adding Braille strips or raised letters to the interpre-

KEY POINTS: Special Areas

1. Folk or square dancing done outdoors requires a flat and unobstructed area of about 15 m X 30 m (50 ft X 100 ft).
2. A boxing surface should be 5 m X 8 m (16 ft X 24 ft) in size.
3. For international wrestling competition, the mat is 12 m X 12 m (39 ft 3 in X 39 ft 3 in) square with an inner circle of 2 850 mm (9 ft 6 in) in diameter (Figure 520-59).
4. A minimum table size for games like checkers, chess, and backgammon is 0.6 m X 0.6 m (2 ft X 2 ft).
5. A regulation-size table tennis surface is 1 500 mm X 2 700 mm (5 ft X 9 ft) wide and 750 mm (30 in) high.

KEY POINTS: Camping and Picnicking

1. Although camps vary in size and configuration based on terrain, vegetation, etc., a camp for 75 to 100 campers averages approximately 14 to 16.5 ha (35 to 40 acres) in size.
2. Family-size camp sites should be 4.2 m X 4.9 m (14 ft X 16 ft).
3. Picnic areas are generally designed in clusters of 10 to 100 units with 10.7 m (35 ft) between units. 50 units/ha (20 units/acre) is desired.

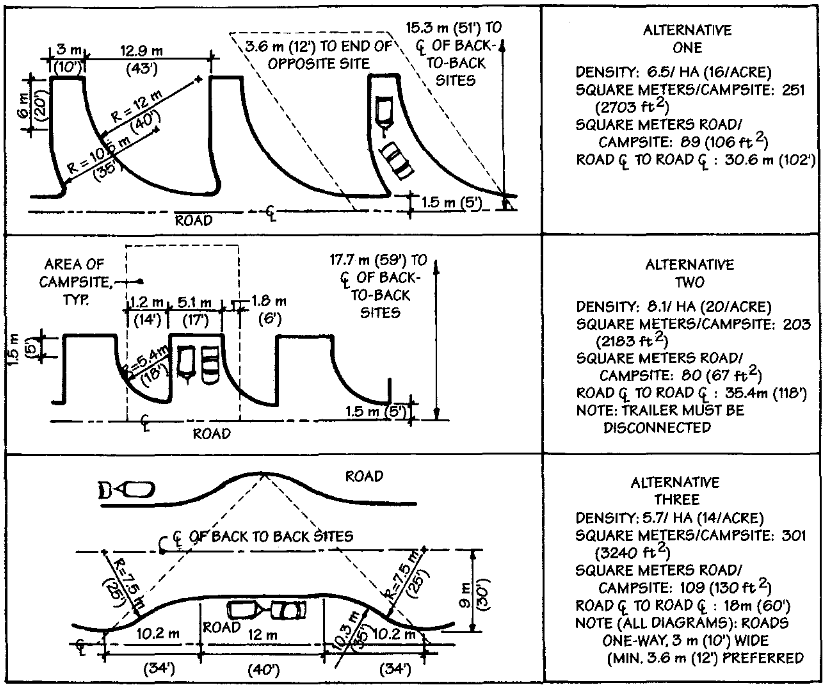


Figure 520-48. Sample motor camping layouts.

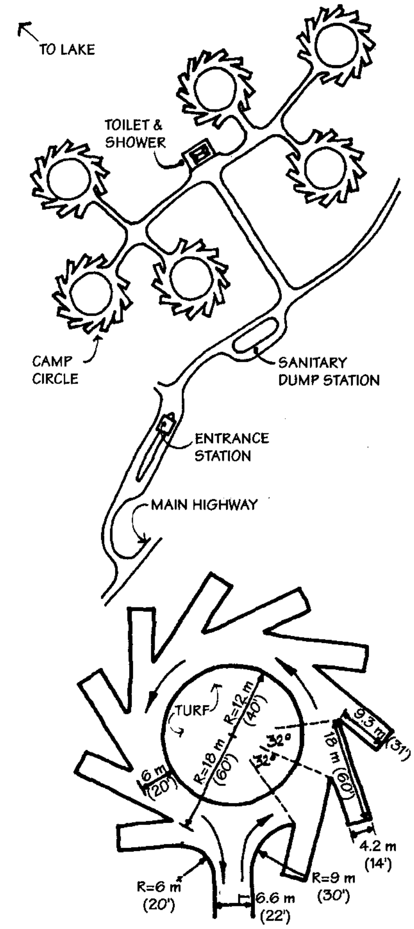


Figure 520-49. Rosette trailer parking layout.

tive plaques, using textured surfaces on the ground plane to identify the interpretive stations, and providing low curbs to help define the pathway. If the path is to accommodate those with mobility handicaps, it should have a minimum width of 2 100 mm (7 ft), a maximum grade of 8 percent, and a firm surface. The adjacent vegetation should not overhang the path at a height less than 2 250 mm (7 1/2 ft). The trail may also be delineated with ropes running through rings on 900 mm (36 in) posts, and knots can be used to call attention to upcoming interpretive stations [U.S. Department of Housing and Urban Development (HUD)]. (Refer to Sections 240: Outdoor Accessibility, for more information.)

9.0 CAMPING AND PICNICKING

9.1 Organized Camping

Definitions:

Organized camping is defined by the American Camping Association (ACA) as "a sustained experience which provides a creative recreational and educational opportunity in group living in the out-of-doors. It utilizes trained leadership and resources of the natural surroundings to contribute to each camper's mental, physical, social and spiritual growth."

Design:

Campgrounds are classified as primitive, semi-primitive or modern depending on the facilities provided. Organized camp design can be inwardly focused toward a campfire ring or some other feature, such as a swimming pool, or outwardly focused toward a lake or river. Most are located in a forested setting, with good breeze orientation and readily available potable water. Camping is feasible for handicapped individuals. The major design adaptation required for those who are handicapped is the provision of paved surfaces between campsites and other features, such as water, comfort stations, and parking. (See Section 240: Outdoor Accessibility for more information.)

Spatial Standards:

Although camps vary in size and configuration based on terrain, vegetation, etc., a camp for 75 to 100 campers averages approximately 14 to 16.5 ha (35 to 40 acres) in size.

1. Central core: service area garage, staff and help quarters, central washhouse, infirmary, dining lodge, administration building, and nature study center.
2. Units: organized in groups of six 4-bed tents or cabins, plus counselor accommodations, a bathroom, and a central core. Units of this size occupy roughly 0.8 ha (2 acres).

American Camping Association (ACA) Standards:

The ACA has established standards by which they evaluate camps seeking accreditation. These standards address camp administration, personnel programs, specific programs for users with special needs, and site conditions (Figure 520-47). Contact the ACA for complete standards.

9.2 RV Camping

The cross section of a RV pad should be level across the width of the trailer. A slight slope along its length is permissible, with a slope toward the rear preferred. RV campers load on the passenger side; utility connections are on the driver's side (Figures 520-48 and 520-49).

9.3 Individual Campsites

Family-size sites should be 4.2 m X 4.9 m (14 ft X 16 ft), with a soft level tent pad within this area. Campfire rings should be raised 600 mm (2 ft) and seating should be provided within 900 mm (3 ft) of the fire. Push lids on trash cans are preferred, and these lids should be 1 m (40 in) from the ground. In some areas, special animal-proof storage lockers and trash facilities are required for the safety of campers. Trails should be designed without obstructions to a height of 2.3 m (7 1/2 ft).

9.4 Picnic Areas

Picnic areas are generally designed in clusters of 10 to 100 units with 10.7 m (35 ft) between units. (A unit consists of a table with benches, a grill, and a trash receptacle.) A maximum density of 50 units/ha (20 units/acre) is desired, with a buffer strip of 60 m (200 ft) between picnicking and other activities. Comfort stations should be provided and placed at least 15 m (50 ft) away, but no further than 122 m (400 ft) away from any unit, and drinking fountains

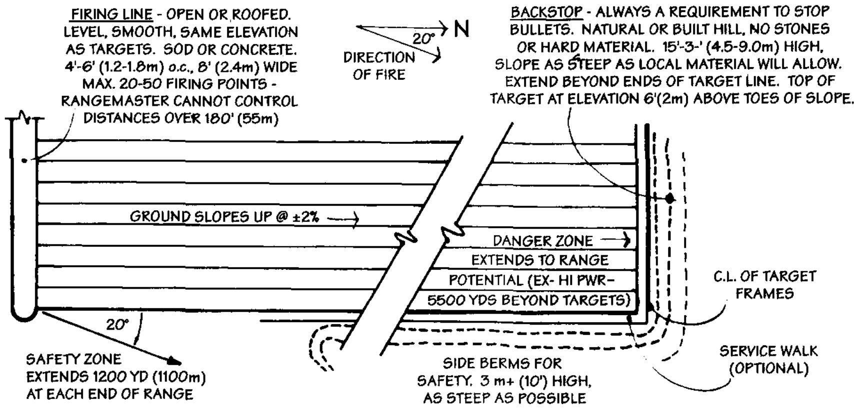


Figure 520-50. Basic rifle/pistol range layout.

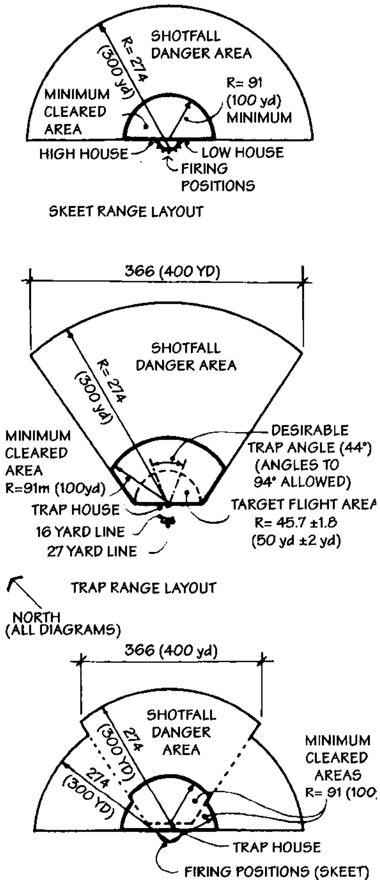
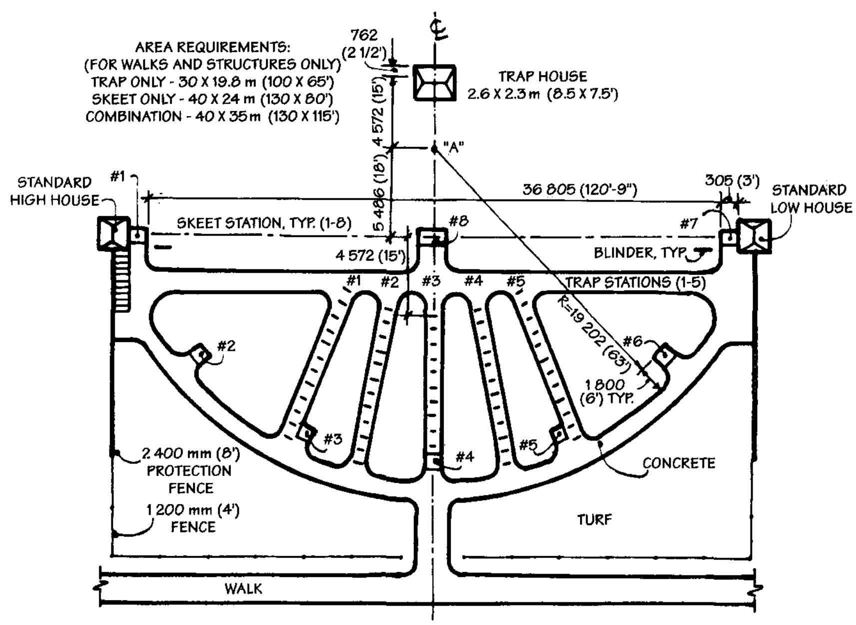


Figure 520-51. Combination skeet and trap range layouts.



THE 14.6 METER (16 YARD) (FRONT) TRAP STATIONS ARE 14.6 METERS (16 YARDS) FROM THE TRAP MACHINE. A 2 743 mm (9 FOOT) CHORD EXISTS BETWEEN EACH STATION. SHOOTING STATIONS CONTINUE AWAY FROM THE TRAP HOUSE AT ONE YARD INTERVALS TO 24.7 METERS (27 YARDS).
SKEET TARGETS ARE FIRED FROM THE HOUSES AND CROSS AT POINT "A". ALL STATIONS ARE 900 X 900 mm (3 X 3 FEET) EXCEPT #8 WHICH IS 900 X 1 800 mm (3 X 6 FEET). A CHORD DRAWN BETWEEN THE CENTERS OF EACH STATION IS 8 137.5 mm (26'-8 3/8" LONG.)

Figure 520-52. Combination skeet and trap range.

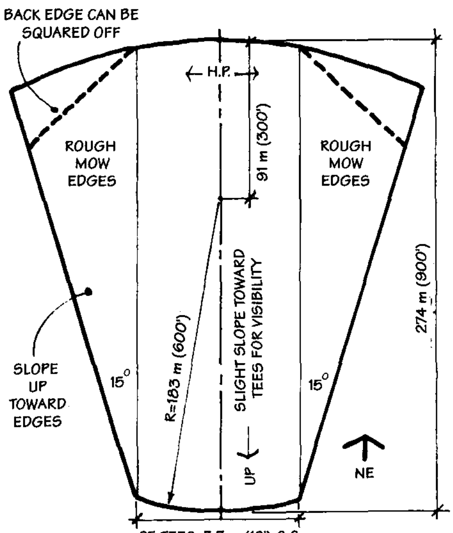


Figure 520-53. Driving range (golf).

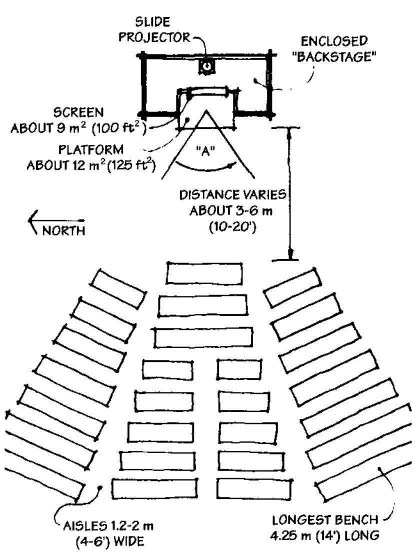


Figure 520-55. Interpretive Amphitheatre.

should be within 30 m (100 ft) of the units. Centralized parking at 1 space per 1.5 tables is required, with several tables within 122 m (400 ft) of the parking area.

Campers in wheelchairs can be easily accommodated by providing paved access to facilities and by making minor modifications to site furnishings. Allow 2.4 m (8 ft) between tables used by wheelchairs and a

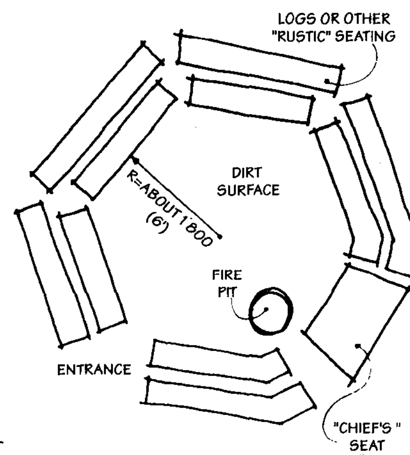


Figure 520-54. Council ring.

clear space 750 mm (30 in) high and 600 mm (24 in) deep under the table to allow a wheelchair to slide under. Grills should be 750 mm (30 in) tall at their top, rotate 360 degrees, and be provided with a utility shelf for cooking tools. Grills on adjustable supports offer flexibility for many user groups. Keep plant material back 900 mm (3 ft) and cleared to a height of 2 250 mm (7 1/2 ft).

10.0 RANGE SPORTS

10.1 Rifle and Pistol Range

General Information:

1. Targets can be placed at varying distances from the firing line (staggered butt range) or can be aligned on a single line with firing positions staggered (butt-in-line range).
2. Consideration should be given to problems that may result from the noise, particularly downwind of a range. Refer to Section 660: Sound Control, for various ways this problem may be treated.
3. Existing hillsides or built-up berms should be used behind and to the sides of the target area for safety reasons (Figures 520-50 through 520-52).
4. Target areas should not be in line with residential or commercial areas to avoid any contact with bullets which may ricochet.

Range Distances:

1. Small-bore rifle: 50 ft, 50 yd, 50 m*, 100 yd
2. High-power rifle: 100 yd, 200 yd, 300 yd,* 300 m(**), 500 to 600 yd, 800 to 900 yd, 1000 yd
3. Metallic silhouette:
   a. mall-bore rifle: 40 m, 60 m, 77 m, 100 m
   b. High-power rifle: 200 m, 300 m, 385 m, 500 m
   c. Pistol: 50 m, 100 m, 150 m, 700 m
   d. Pistol shoot range: 25 m, 50 m, 75 m, 100 m
4. Outdoor pistol: 25 yd, 25 m(**), 50 yd, 50 m(**)
5. Pistol (police combat course): 7 yd, 15 yd, 25 yd, 50 yd
6. International running boar: 50 m

* competition distance.
** international distance.

10.2 Archery

1. The distance to the target should be 91 m (300 ft) for men and 55 m (180 ft) for women.
2. Targets should be 4.9 to 6 m (16 to 20 ft) on-center, with the bulls eye 1.2 to 1.4 m (4 to 4-1/2 ft) off the ground.
3. The archer and the target should be at approximately the same elevation, the range should be free from hard obstructions, and the site should be sheltered from wind.
4. For visual reasons, the archer should face within 45 degrees of north in the northern hemisphere; the preferred background for a target is a natural or built-up dirt embankment or tall, dense vegetation.
5. Existing hillsides or built-up berms should be used both behind and to the sides of the target area for safety resons.

10.3 Driving Ranges

Driving range (golf) design features should include multiple tees, mat and natural grass and tee areas to hit into and across the wind. Figure 520-53 illustrates a typical driving range for golf.

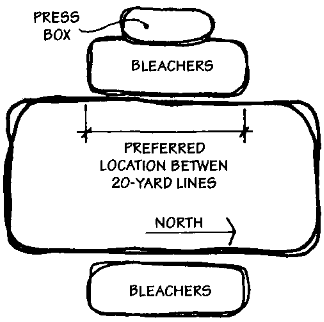


Figure 520-56. Schematic sports stadium.

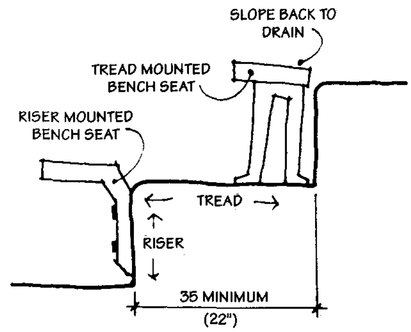


Figure 520-57. Stadium seating.

11.0 SPECTATOR FACILITIES

11.1 Council Rings

The diameter of council rings is normally not very large in order to allow eye contact between participants. Allow at least 500 mm (20 in) of bench space per person. A natural bowl design allows better viewing for more people (Figure 520-54).

A fire ring is optional, but if included it should be at least 1 800 mm (6 ft) in diameter and 1 500 mm (5 ft) from the nearest seated audience. The leader's spot should have a dark background and face the direction of the setting sun.

11.2 Amphitheaters

Small Amphitheaters:

Small amphitheaters, usually designed for campgrounds, consist of seats, a small stage or podium, nighttime lighting, and sometimes a public-address system and provision for showing slides and films (Figure 520-55). There should also be ramps and associated special design facilities for those who are handicapped. Where possible, the amphitheater should be built into a naturally existing or graded bowl and should face away from late afternoon sun. In addition, the following design guidelines can be used:

1. Aisles should be at least 1 500 mm (5 ft) wide, with a maximum space of 9 000 mm (30 ft) between aisles.
2. The backstage area can be enclosed, and where needed it can be used to set up and store slide and film equipment for rear-projection screens.
3. The platform is usually about 450 mm (18 in) off the ground and a minimum of 11.6 m^2 (125 ft^2) in size.
4. Angle A (Figure 520-55) varies to as wide as 120 degrees, but more often ranges between 60 and 90 degrees.

Major Outdoor Theaters:

Major outdoor theaters are usually characterized by professional theater lighting, curtains, orchestra facilities, and elaborate sound systems. Some have wooden or metal seats with backs. The seating area may be concrete, with step lights. Ticket sales areas, restrooms, backstage areas, concession areas, and adequate parking are all necessary.

These facilities pose many more complex design, construction, and operations issues than the basic interpretive or small amphitheaters. Persons interested in facilities of this magnitude should consult the appropriate major reference books and visit and study successful projects. In the United States the following are considered good examples: Wolf Trap Farm Park Amphitheater (Vienna, Virginia), Starlight Theater (Kansas City, Missouri), Concord Pavilion (Concord, California), Hollywood Bowl (Hollywood, California), and Red Rock Amphitheater (Denver, Colorado).

11.3 Sports Stadiums

General:

Spectator sight lines are the principal design consideration in stadium design. The seating capacity can be increased by making the seating either longer or higher. In general, longer, lower seating is less expensive but has fewer seats that are considered prime (Figure 520-56).

Spatial Standards:

Seats can be mounted to either the tread or the riser (Figure 520-57). Treads should never be less than 550 mm (22 in) wide; 650 mm (26 in) is preferred. A tread width of 750 mm (30 in) should be used for benches with backs and 800 mm (32 in) used for chair-type seating.

Provision for those with mobility limitations is important and requires special consideration. Refer to Section 240: Outdoor Accessibility, for more information. Some of the major considerations follow.

Spaces for wheelchairs should be 1 200 mm (48 in) deep and 850 mm (34 in) wide. Seats for persons using crutches or braces should be 600 mm (24 in) wide, with 700 mm (28 in) of clear space in front. Spaces for wheelchairs and persons with crutches should be accessible by a level floor or ramp (such as at the front or rear of the stadium). The handicapped-spectator area should be recessed to allow for free circulation.

There are several important variables that have to be known to determine the amount of parking that is needed for a sports stadium. In the United States the following standards are often used, although each case may have some special feature.

For stadiums near mass transportation, such as New York City's Yankee Stadium, or for stadiums on university campuses where students, faculty, and many guests are within walking distance, there may be very little need for on-site parking. As a rule of thumb, if people do come by car they come at a rate of three passengers per car. For peak crowds, such as at football games, many people will normally come by chartered or special buses. A stadium with a seating capacity of 50,000 people should have spaces for about 100 buses.

There will be a need for special parking spaces for people who are physically handicapped. The parking spaces should be 3 900 mm (13 ft) wide, and there should be about 1 space for every 50 standard parking spaces; this number should be determined based upon local needs. A drop-off zone should be provided within 15 m (50 ft) of an entrance where those who are physically handicapped can gain access to the stadium and viewing area.

12.0 SPECIAL AREAS

The activities listed below are normally accommodated by providing enough open space to set up temporary facilities during special events.

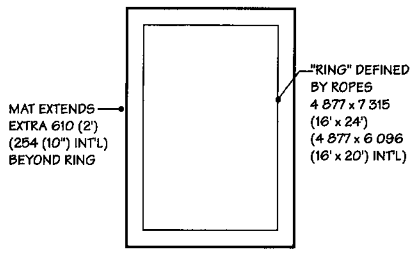


Figure 520-58. Boxing layout.

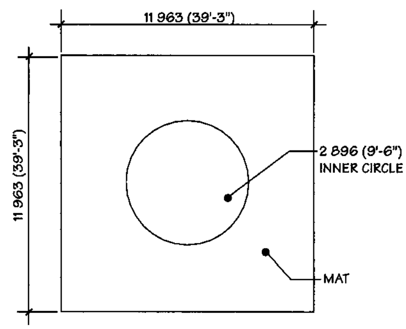


Figure 520-59. Wrestling layout.

12.1 Dancing

When folk or square dancing is done outdoors, it requires a flat and unobstructed area of about 15 m X 30 m (50 ft X 100 ft). Hardwood is the preferred surface for dancing, but smooth concrete or other types of hard paving can be used. In some situations, a covered pavilion with a band platform, special lighting, and amplification equipment is more desirable.

12.2 Boxing

The boxing surface should be no more than 1 200 mm (4 ft) off the ground and 5 m X 8 m (16 ft X 24 ft) in size within the ropes, plus 600 mm (2 ft) around all edges. The surface should be padded with 25 mm (1 in) of a stiff cushioning material covered with canvas and laced outside the apron of the ring (Figure 520-58).

12.3 Wrestling

For international competition, the mat is 12 m X 12 m (39 ft 3 in X 39 ft 3 in) square with an inner circle of 2 850 mm (9 ft 6 in) in diameter (Figure 520-59).

The platform may be raised 1.1 m off the floor in international competition, but under NCAA rules, it must not be raised.

12.4 Table Games

Checkers / Chess:

A minimum table size is 0.6 m X 0.6 m (2 ft X 2 ft). It should have seating for two, plus enough gathering space for spectators.

Table Tennis (Ping-Pong):

A regulation-size table top is 1 500 mm X 2 700 mm (5 ft X 9 ft) wide and 750 mm (30 in) high, and a small table for children (or when used as a picnic table) is 1.2 m X 2.4 m (4 ft X 8 ft) wide and 750 mm (30 in) high. Allow 1 800 mm (6 ft) of unobstructed space between tables or adjacent facilities/structures. This dimension also serves the needs for access by those who are handicapped.

13.0 TOT LOTS AND PLAYGROUNDS

3.1 General

Many experts advocate a play environment for children that provides opportunities for development of motor skills, make-believe, building, competitions, and quiet, solitary activities. Activities that are linked together so that many children can use them simultaneously are generally preferred to isolated apparatus. Safety both within and outside of the playground is important, but an overemphasis on safety measures can sometimes lower the quality of the play environment.

Safety Measures:

The Consumer Product Safety Commission (CPSC) has conducted considerable research on playground design and safety. A recent publication Ten Steps Toward a Safer Playground Fact Sheet #327 provides information planners and designers should consider before undertaking playground design:

1. Protective Surfacing - The surfaces under and around play equipment should be soft enough to cushion falls. For most play equipment, these surfaces should contain a minimum of 300 mm (12 in) of wood chips, mulch, sand or pea gravel.
2. Fall Zones - To cushion a fall, shock absorbing material should extend a minimum of 1 800 mm (6 ft) in all directions from stationary pieces of play equipment. In front of and behind swings, the material should extend a distance equal to twice the height of the suspending bar.
3. Equipment Spacing - Play structures should be spaced at least 3 600 mm (12 ft) apart to allow children space to circulate or fall without striking another structure. Moving pieces of equipment should be located in an area away from other play structures so children have adequate room to pass from one play area to another without being struck by a moving swing or by another child jumping from a slide.
4. Catch Points and Protruding Hardware - There should be no dangerous pieces of hardware, such as protruding bolt ends and narrow gaps in metal connections or open "S" hooks at the top and bottom of swings. Exposed hardware can cut children, puncture skin, or catch clothing drawstrings, which could strangle a child.
5. Openings that can trap - Openings in guardrails, and spaces between platforms and between ladder rungs, should measure less than 87.5 mm (3.5 in) or more than 225 mm (9 in). Children can get trapped and strangle in openings where they can fit their bodies but not their heads through the space.
6. Pinch, Crush, Shearing, and Sharp Hazards - Equipment should not have sharp points or edges that could cut skin. Moving pieces of equipment, such as suspension bridges, track rides, merry-go-rounds, or seesaws, should not have exposed moving parts that might crush or pinch a child's finger.
7. Tripping Hazards - There should be no exposed concrete footings, abrupt changes in surface elevations, tree roots, tree stumps, and rocks, which can trip children or adults.
8. Guardrails - Elevated surfaces such as platforms, ramps, and bridge ways should have guardrails to prevent falls.
9. Routine Maintenance - Provide for a designated official who periodically inspects the play equipment and is responsible for preventive maintenance. This includes: replacing missing, broken, or worn-out components; securing hardware; checking for deterioration in the wood, metal, or plastic materials; maintaining the proper 12-inch depth of surfacing material; and cleaning up debris.

10. Supervision - The play area should be designed so that adults can observe children at play.

The National Recreation and Park Association (NRPA) sponsors the National Playground Safety Institute. The Institute provides numerous playground safety resources and videos and the latest regulations and design guidelines published by the Access Board. The Access Board is charged with providing assistance to the Department of Justice and the National Park Service to implement the Americans With Disabilities Act (ADA) as applicable to parks and playgrounds of all types.

Inspections:

Inspection of playgrounds requires careful examination of the equipment, the surface and any retaining walls or edges to the playground equipment area. Depending upon the nature and use of the equipment the inspection schedule may have to be daily or weekly. Damaged equipment which cannot be repaired on-site should be removed or contained in such a way that it cannot be used.

Dimensions:

Provide seating for play supervisors, and storage for loose apparatus, maintenance equipment, etc. Tot lots generally average about 225 to 465 m^2 (2400 to 5000 ft^2) in size. More complex playgrounds, including areas for paved courts, shelter, a wading pool, etc., average 1 to 4 ha (2-1/2 to 10 acres) in size.

13.2 Adventure Playgrounds

Creative, junk, or adventure playgrounds are generally fenced areas which offer children a variety of junk building supplies with which to assemble forts, play equipment, etc. Concerns about this kind of playground revolve around safety and visual impact. Boundary screening is important, and generally the child will have a safer and more educational experience under the eye of a supervisor/helper who can watch, check out tools, and offer help to young builders.

13.3 Community-Built Playgrounds

This type of playground involves the community in the design, organization and construction of the playground. Volunteers are organized by a professional association to construct the playground according to design specifications.

The main emphasis of this wood-structure type playground is the participation of children in the design process and community volunteers in construction. Creating the play environment is done according to professional plans and specifications. (The Community Built Association, 99 E. Lake Road, Ithica, N.Y. 14850).

RECREATION & SPORTS ORGANIZATIONS

There are many organizations and companies in the United States and throughout the world that provide guidelines for the planning, design, construction, operation, and maintenance of both competition- and non-competition-level athletic facilities. The list shown below includes only U.S.-based organizations. In other parts of the world these guidelines may not apply; they should therefore be checked against local customs and practices.

Badminton
U.S. Badminton Association
P.O. Box 237
Swartz Creek, MI 48473

Baseball, Babe Ruth League
Babe Ruth League, Inc.
P.O. Box 5000
Trenton, NJ 08638

Baseball, Little League
Little League Baseball, Inc.
P.O. Box 3485
Williamsport, PA 17701

Boccie, Croquet, Deck Tennis, Horseshoes
General Sport Craft Co., Ltd.
140 Woodbine Street
Bergenfield, NJ 07621

Camping
American Camping Association
Bradford Woods
Martinsville, IN 46151

Croquet
See Bocce

Exercise Courses
The Gamefield Concept
2088 Union Street, Suite One
San Francisco, CA 94123

Parcourse, Ltd.
3701 Buchanan Street
San Francisco, CA 94123
Football, Junior League

Pop Warner Football
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Philadelphia, PA 19107

Golf
National Golf Foundation
1150 S. U.S. Highway 1
Jupiter, Florida 33477

U.S. Golf Association
Far Hills, NJ 07931

Handball
U.S. Handball Association
4101 Dempster Street
Skokie, IL 60076

Hockey
Amateur Hockey Association of the U.S.
2997 Broadmoor Valley Road
Colorado Springs, CO 80906

USA Hockey
Colorado Springs, Colo.

Inline Skating
International In-line Skating Association
3720 Farragut Ave, Suite 400
Kensington, MD 20895
Phone: (301) 942-9770
Fax: (301) 942-9771

Ice Skating
Ice Skating Institute of America
1000 Skokie Boulevard
Wilmette, IL 60091

Platform Tennis
American Platform Tennis Association, Inc.
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Upper Montclair, NJ 07043

Paddle Tennis
U.S. Paddle Tennis Association, Inc.
189 Seeley Street
Brooklyn, NY 11218

Playgrounds
The Community Build Association
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Ithica, N.Y. 14850

American Society for Testing Materials
1916 Race Street Philadelphia, PA 19103-1187
Phone: (215) 299-5585
FAX: (215) 977-9679.

Consumer Products Safety Commission
Washington, D. C.

Racquetball
U.S. Racquetball Association
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Skokie, IL 60076
Rifle and Pistol Ranges

National Rifle Association of America
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Washington, DC 20036

Roller Skating
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P.O. Box 83067
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Roque
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4205 Briar Creek Lane
Dallas, TX 75214

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210 Paterson Plank Road
Union City NJ 07087

Skeet
National Skeet Shooters Association
P.O. Box 28188
San Antonio, TX 78228

Winchester-Western Recreational Shooting &Marksmanship Department 275
Winchester Avenue
New Haven, CT 06504

Skiing
U.S. Ski Association
P.O. Box 100
Park City, UT 84060

Softball
Amateur Softball Association
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Oklahoma City, OK 73111

Special Olympics
Special Olympics, Inc.
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Suite 203
Washington, DC 20006

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Amateur Skating Union of the U.S.
4423 West Deming Place
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51 East 42nd Street
New York, NY 10017

U.S. Tennis Association
Education & Research Center
739 Alexander Road
Princeton, NJ 08540

International Tennis Federation
Pallister Road, Barons Court London W149EN
Telephone 44 171 381 8060
FAX 44 171 381 3989

Trapshooting
Amateur Trapshooting Association
601 W. National Road
Vandalia, OH 45377

Remington Arms Co., Inc.
Bridgeport, CT 06602

General
International Amateur Athletic Federation (IAAF)
162 Upper Richmond Road
Putney, London SW152SL, England

National Collegiate Athletic Association (NCAA)
NCAA Publishing Department
P.O. Box 1906
Mission, KS 66226

National Federation of State High School Athletic Associations
11724 Plaza Circle
P.O. Box 20626
Kansas City, MO 64195

Amateur Athletic Union of the U.S.
3400 West 86th Street
Indianapolis, IN 46268

American Alliance for Health, Physical Education and Dance
Division of Girls' and Women's Sports
1900 Association Drive
Reston, VA 22091

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SECTION 530

Pools and Fountains

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CONTENTS

1.0 HISTORY

Contemporary water displays rely heavily on historic precedent, with elements usually abstracted to satisfy broader design and environmental constraints. Historical models range from ancient irrigation systems to ornate displays within fountains. Often, modern displays are modeled after free flowing streams and falls within natural settings.

2.0 WATER DISPLAY PURPOSE

2.1 Aesthetic Factors

A designer usually incorporates water into a space as a visual element. The aesthetic qualities of water, however, reach far beyond the visual aspect due to the documented psychological effects of water as a metaphor and as a physical factor providing sound, and climatic modification. The sound of water and the coolness associated with being near or touching water are equally a part of our emotional response to water in the environment.

Visual:

Water can function as a focal point within a space or as a means of creating and maintaining a sense of continuity. A water display can strongly temper the character of a space. A sense of calm and serenity is created by a quiet stream or pool, while excitement and drama can be achieved by swiftly moving, densely massed, or strongly vertical displays. The level of formality will be influenced by the forms of the pools and displays, and the mood further defined or reinforced by appropriate lighting.

Psychological:

It is an essential aspect of human behavior to be drawn toward a riverbank, lake edge, or seashore. We either live near water or convey it to where we live, using canals or pipelines. Our food supply likewise depends upon water for growth and sustenance.

Auditory:

The intensity and frequency of the sound generated by a water display can be used to convey a sense of calm or excitement, and can also mask unpleasant or distracting ambient noise.

Sensory Effects:

Airborne spray and evaporation from water displays cause a cooling effect. Droplets and sprays from active, aerated displays are particularly effective.

2.2 Functional Reasons

Pools also may be introduced or used secondarily for the following functional reasons:

Recreation:

Pools may be designed for wading, swimming, fishing, boating, or just water play, as with participatory water displays.

Circulation Control:

Pools may be used to direct or interrupt traffic patterns for reasons of safety or security or simply to promote an orderly progression through a space.

Utilitarian:

Practical applications for water displays include their use as a fire fighting or irrigation reservoir, as a retention pond for site drainage, or as a means for cooling air and/or mechanical equipment.

3.0 WATER

3.1 Quantification

Three units of measure are used to define water used for a display.

Capacity:

The volume of water in a system is usually expressed in liters (L) or gallons (gal). When designing a water display, it is useful to know that 1 m^3 of water is equal to 304.63 L (1 ft^3 is equal to 7.48 gal).

Flowrate:

The amount of water flowing through or circulating within a system is expressed as a volume per unit time, usually cubic meters per second (m^3/s) or gallons per minute (gpm). Flowrate is perhaps best understood by this comparison: a garden hose discharges about 25 Lpm (7 gpm), a fire hose about 560 Lpm (150 gpm), and a sheared-off fire hydrant about 3 750 Lpm (1000 gpm).

Pressure:

In U.S. units, pressure is usually expressed in terms of pounds per square inch (psi) or feet of water column. This is more commonly called feet of head. The relationship, or the concept, is probably best understood as the weight of a column of water over a unit area. Consider that 1 ft^3 of water weighs (62.4 lb.) If the weight of a column of water 1 ft high is distributed over a base area of 1 ft^2, it will exert a pressure of 62.4 pounds per square foot (psf), or 0.43 psi. Reciprocally, 1 psi is equal to 2.31 feet of head. These are convenient numbers to remember when selecting valves, fittings, and piping, some of which are related in feet of head, others in psi.

3.2 Water Quality

The quality of the water in a pool or fountain is determined by the nature of the supply and the extent of filtration, chemical treatment, and/or biological balance.

Supply:

The most common source of supply is the piped domestic water system. Alternative sources include wells, springs, streams, and other natural bodies of water.

Domestic water is usually filtered and chemically treated and is suitable as delivered. Water from a well, spring, or stream can include excessive minerals and organic nutrients and may require chemical treatment.

Chemical Treatment:

Chlorination levels in the range of 1 to 2 parts per million (ppm) should be maintained as a minimum. Occasional superchlorination or shock treatment with an algacide may be required for algae control. Other chemicals may have to be added to mitigate concentrations of minerals, particularly calcium and iron. The need for any treatment beyond the maintenance of chlorine residual is generally empirically determined and should be administered only after consultation with water treatment specialists and after consideration of its compatibility with pool piping, hardware, and finishes and with governmental standards regulating overflow or effluents from the drain systems.

Biological Balance:

Static water may be kept fresh by promoting biological balance through the use of fish and aquatic plants. Plants need to photosynthesize carbon dioxide in the presence of light in order to grow. This releases oxygen into the water and starves out lower plants such as algae by virtue of competition. The oxygen promotes water clarity and sustains the fish. The fish in turn fertilize the plants, keep down pests, and provide some of the carbon dioxide for photosynthesis.

Table 530-1. WATER EFFECT CLASSIFICATION

CATEGORY	INFLUENCE	TYPE	EFFECT
STILL (CONTAINED)		UNDISTURBED POOL	REFLECTOR
			WINDOW
		DISTURBED POOL	TEXTURE
			ACTIVATOR
MOVING (UNCONTAINED)	GRAVITY (FALLING)	FREEFALL	FULL SHEET
			INTERRUPTED SHEET
			GRAVITY SPOUT
			BROKEN SHEET
		FLOW	SMOOTH WATERWALL
			TEXTURED WATERWALL
			QUIET STREAM
			TURBULENT STREAM
		CASCADE	CASCADING WATERWALL
			STEPPED FORMS
			WATERSTAIRS
			STEPPED POOLS
	APPLIED PRESSURE	SPOUT (JET)	CLEAR COLUMN
			AERATED MASS
			SPRAY
			SHEET

4.0 WATER EFFECTS

4.1 Classification and Description

Table 530-1 provides a framework for discussion of water effects. These effects are typically grouped into two basic categories: (1) still water and (2) moving water (Figures 530-1 through 530-5).

Still Water:

The container defines the form assumed by the water. The finish of the underwater surfaces and the condition of the water at the surface influence the ultimate effect. A dark pool finish with an undisturbed surface will function as a reflector, while a disturbed surface is a texture. A light-colored and/or patterned pool finish with an undisturbed surface will function as a window, while a disturbed surface will act as a modifier, imparting a dynamic quality to the submerged surface. A light, unpatterned finish will emphasize water clarity.

Moving Water:

There are two subcategories within this classification. Falling water refers to water moving solely under the influence of gravity, while spouting water refers to water discharged or displaced under pressure, countering or complementing gravitational movement. This latter category includes waves and spouts (jets) of water. The wave effect, while a viable alternative visually and mechanically, has not been widely applied because of the excessive energy requirements and the considerable bulk of the activating mechanisms. Falling water may be further categorized as free-falling, flowing, or cascading.

Free-Falling Water: Free-falling water moes vertically without contacting any surfaces and is most often expressed as a full sheet (Figure 530-2). Decreasing the flowrate produces a rainlike broken sheet.. Other variations include obstructing the weir periodically to form an interrupted sheet or supplying water behind an orifice to form a gravity spout.

Flowing water is, by contrast, constantly in contact with the container. A vertically oriented flow creates a waterwall (Figure 530-3). A smooth plane or the resultant smooth waterwall will derive only subtle highlights from the moving water. A textured plane will entrain air and generate an aerated waterwall. A horizontally oriented flow creates a stream. A flat container of uniform width will create a quiet stream similar to a body of still

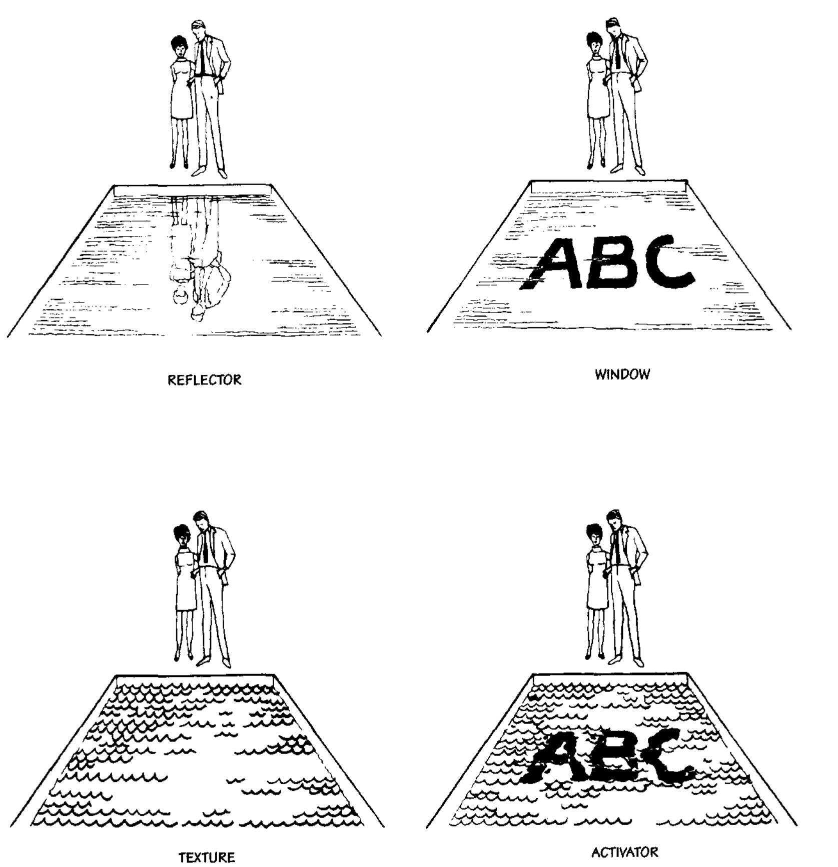


Figure 530-1. Still-water effects.

water. A turbulent stream is derived by increasing the flowrate and/or manipulating the sides of the container.

Cascading water is a combination of flowing and falling water. A cascading waterwall differs from a smooth or aerated waterwall in the sense that water moves over a texture comprised of projecting forms of sufficient dimension to divert the flow laterally or to cause it to spring free of the vertical surface, thereby resulting in a pattern of free-falling water, flowing water, and dry areas. A stepped-form cascade directs water over an irregularly stepped structure which may vary from a random array of natural stone to a precise, geometric, often sculptural element. A stepped-plane cascade, typified by the waterstair, provides a controlled, more architectural display, varying from highly aerated to predominantly clear as the dimensions of the tread increase. Stepped pools provide more control and give a more formal appearance with less aeration than other cascading displays (Figure 530-4).

Spouting Water: Spouting water relies on externally applied force to direct water through an orifice or nozzle and, working with gravity, forms a jet of some configuration. A clear-column effect is a straight, clear, vertical jet complemented by veiling peripheral fallback. An aerated mass is a strong, turbulent, whitewater jet produced by combining air and/or pool water with the primary stream, using a venturi to accomplish the induction. This effect comprises three basic profiles and assumes one of three forms: hemispherical, conical, or columnar. Sprays derive their form using droplets rather than a stream or sheet. They are available in planar forms similar to irrigation heads or in solid form from near planar description to solid cones of 120 degrees overall spread. Sheet effects are generated by forcing the water through a fine, linear orifice to generate such forms as mushrooms, morning glories, fans, and dandelions (Figure 530-5).

4.2 Characteristics of Various Effects

Table 530-2 lists characteristics for each type of display, or effect. It should be realized that these evaluations are both generalized and subjective and that a particular characteristic for any display can be reinforced. For example, an increased flowrate will improve the visibility, sound level, and wind stability but adversely affect the splash pattern and energy efficiency of a display.

Characteristics are subjectively rated on a scale of 1 to 4: poor or nominal, fair or low, good or moderate, and excellent or substantial.

A nominal sound level is barely perceptible against the ambient level at an urban plaza or shopping mall. A moderate sound level is one that ranges up to 75 decibels (dB), or roughly the level of sound within the cabin of a commercial jet plane. At the extreme, large free-falling displays may generate sound levels as high as 90 dB. Obviously, such levels are not appropriate for interior spaces or for areas where people might want to converse.

A nominal splash might affect a 600 mm (2 ft) radius, while the substantial classification ranges to a radius of 3 000 mm (10 ft).

An energy budget must be considered, unless the systems do not require motors to operate them. A small, moderately active system may require a pump of 4.9 to 9.8 horsepower (hp) (5 to 10 empirical hp). At a large scale, with considerable activity, the pumping horsepower might range to 398 hp (400 empirical hp) or more. A larger system may cost 40 times more annually to operate than the small system.

Visibility and wind stability are subject to even more variables; accordingly, the ratings should be considered as relative, understanding that considerable overlap may accrue to combinations of these variables.

4.3 Applications

Still water is a consideration in virtually any pool or fountain design, even in those that are not intended primarily as still or reflective pools. Most designs using moving water incorporate still areas as a complementary element, and attention should be given to the appearance and function of all pools when the display system is not operating. Still water as a primary element may be used in quiet, passive areas to reinforce a sense of tranquility, or in active areas to impart a sense of formality.

Free-falling displays and steep cascades can provide a high level of activity, visibility, and sound in a limited area. For falls of 1 000 mm (3 ft) or less, a free-falling full sheet, an interrupted sheet, or spouts are generally preferable. An interrupted sheet, spouts, a waterwall, or a cascade will provide a display of equal or greater visibility for greater heights, while affording considerable energy savings, less splash, greater wind stability, and a sound quality more appropriate to confined or interior spaces. Free-falls are appropriate for installations at

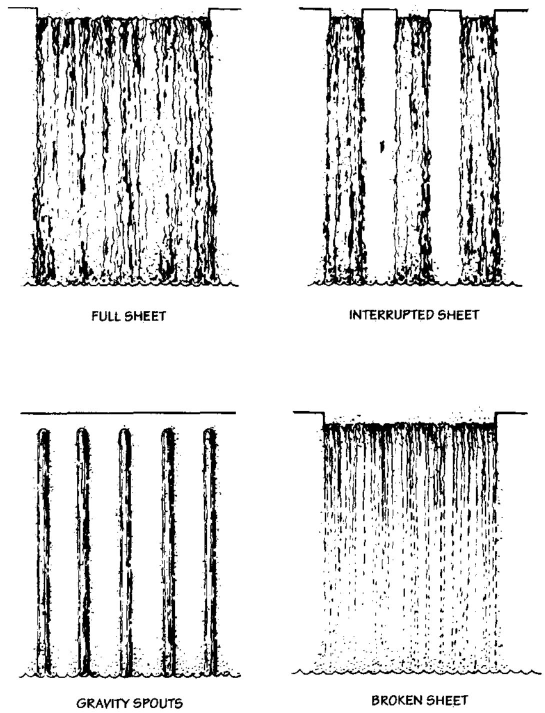


Figure 530-2. Free-falling water effects.

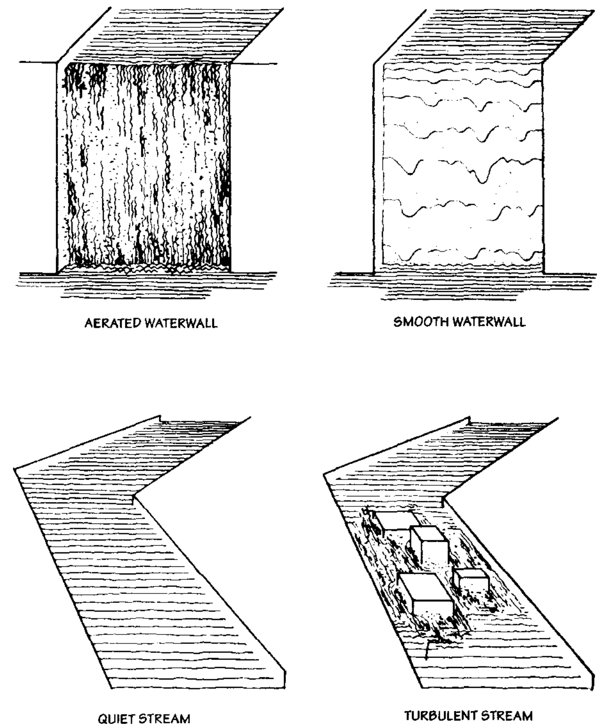


Figure 530-3. Flowing water effects.

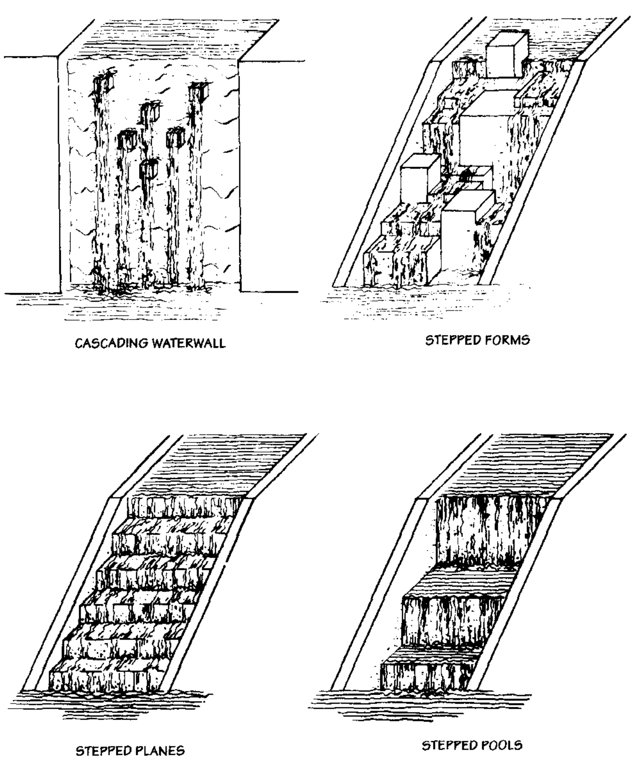


Figure 530-4. Cascading water effects.

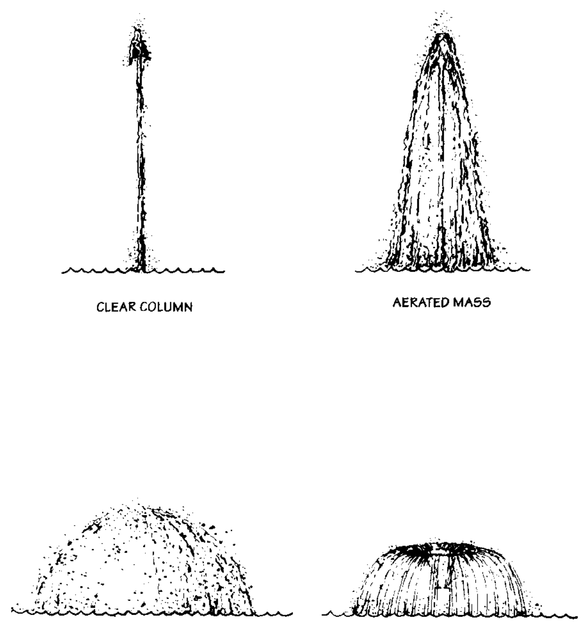


Figure 530-5. Spouting water effects.

Table 530-2. WATER EFFECT CHARACTERISTICS

Effect	Controlling Variables	Visibility	Sound Levels	Splash	Wind Stability	Energy Efficiency
POOL EFFECTS - CHARACTERISTICS						
REFLECTOR	Dark container or . shallow viewing angle	Good	None	None	Excellent	Excellent
WINDOW	Light container. Steep viewing angle	Fair	None	None	Excellent	Excellent
TEXTURE	Dark container or shallow viewing angle. Surface disturbance. (i.e. waves)	Good	Nominal	None unless disturbance is extreme	Excellent	Excellent, unless disturbance is extreme
ACTIVATOR	Light container and steep viewing angle. Moderate surface disturbance.	Fair	Nominal	None unless disturbance is extreme	Excellent	Excellent
FALL EFFECTS - CHARACTERISTICS						
FULL SHEET	Continuous weir. Moderate to high unit flow rate.	Good	Low to high with increasing flow rate and height	Moderate to substantial with increasing flow rate and height	Good	Poor
INTERRUPTED SHEET	Intermittent weir. Moderate to high unit flow rate.	Good	Moderate	Substantial	Good	Good
BROKEN SHEET	Continuous weir. Low unit flow rate.	Fair	Low	Moderate	Fair	Good
SPOUT	Circular discharge opening.	Good	Moderate	Substantial	Good	Good
FLOW EFFECTS - CHARACTERISTICS						
SMOOTH WATERWALL	Polished wall surface. Low unit flow rate.	Fair	Low	None	Excellent	Excellent
AERATED WATERWALL	Textured wall surface. Moderate to high unit flow rate.	Excellent	Moderate	Moderate	Good	Good
QUIET STREAM	Low stream velocity. Shallow shape. Gradual changes in direction.	Fair	Nominal	None	Excellent	Excellent
TURBULENT STREAM	High stream velocity. Steep slope. Abrupt changes in direction	Good	Low	Nominal	Excellent	Excellent
CASCADE EFFECTS - CHARACTERISTICS						
CASCADING WATERFALL	Vertical orientation. Extreme texture.	Good	Moderate	Substantial	Good	Good
STEPPED FORMS	Randomly stepping forms or irregular steps sloping more than 1:1. Moderate to high unit flow rate.	Excellent	Moderate	Moderate	Good	Good
WATER-STAIRS	Regular steps sloping more than 1:1. Moderate unit flow rate.	Excellent	Moderate	Moderate	Good	Good
STEPPED POOLS	Random or regularly stepped pools. Moderate to high unit flow rate.	Good	Moderate	Moderate	Excellent	Good

Table 530-2. WATER EFFECTS CHARACTERISTICS (continued)

Effect	Controlling Variables	Visibility	Sound Levels	Splash	Wind Stability	Energy Efficiency
JET EFFECTS - CHARACTERISTICS						
CLEAR COLUMN	Circular discharge opening. Minimal turbulence in stream.	Good	Moderate	Substantial	Fair to poor with increasing height	Fair
AERATED MASS	Air introduced into stream. Mass broadens with increasing turbulence in stream.	Excellent	Moderate	Moderate	Fair to good with increasing height	Good
SPRAY	Discharge passage breaks stream into droplets	Good	Low	Nominal	Generally poor-varies with droplet size	Excellent
SHEET	Linear discharge opening. Minimum turbulance in stream.	Good	Low	Nominal	Poor to fair with increasing sheet thickness	Good

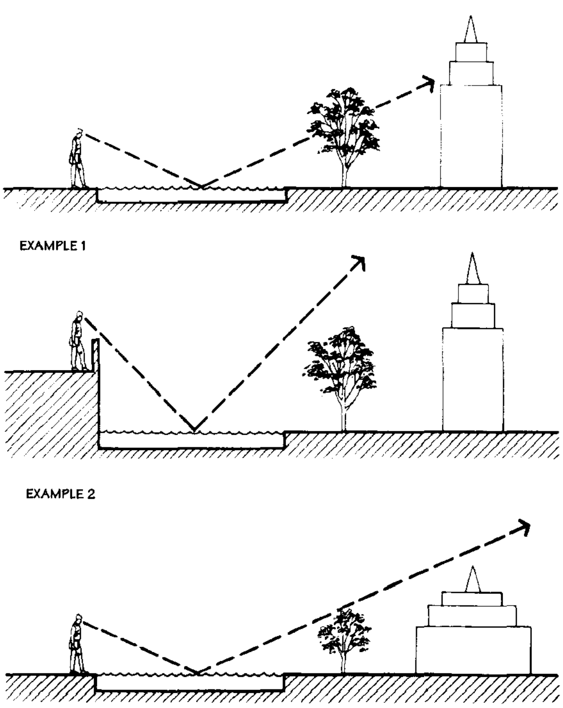


Figure 530-6. Still-water design.

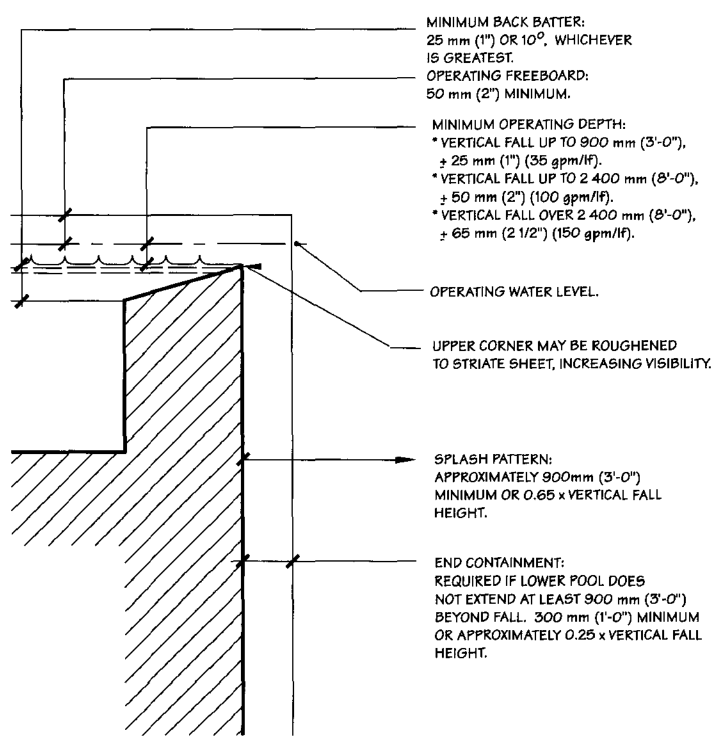


Figure 530-7. Free-falling or cascading sheet design.

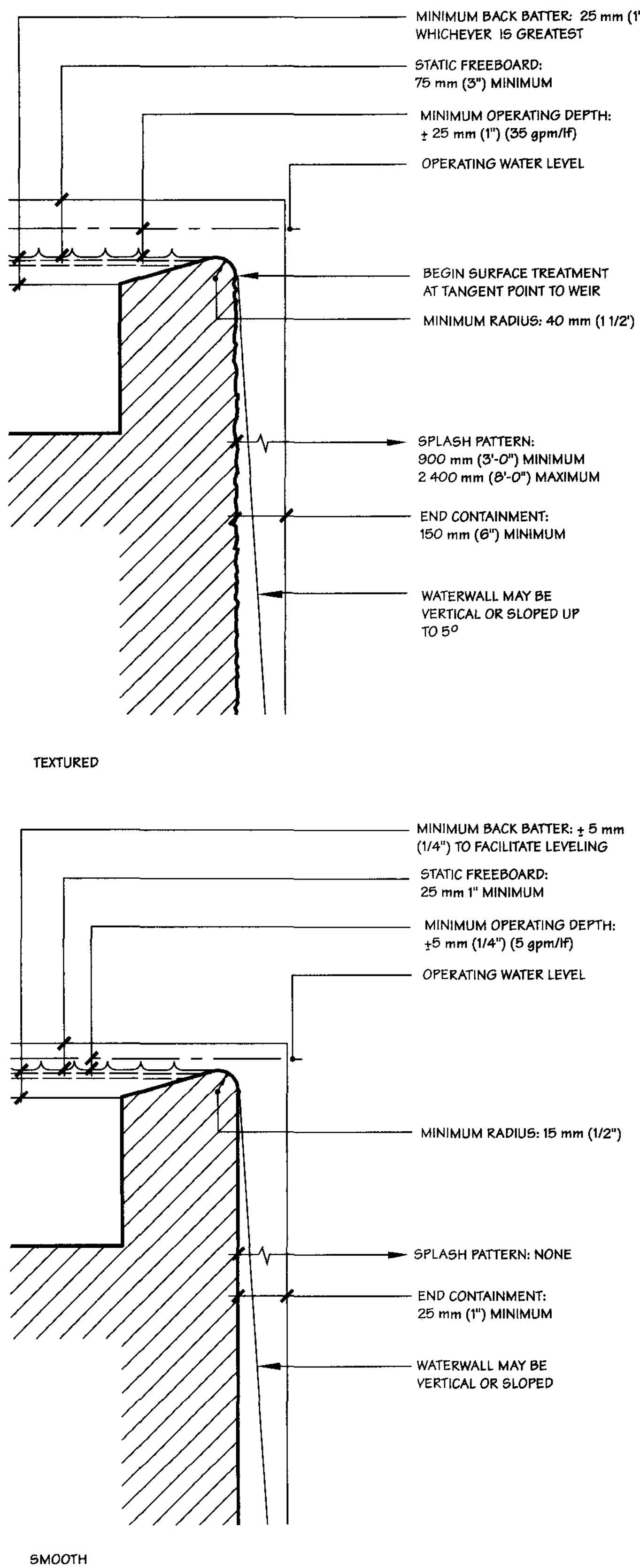


Figure 530-8. Waterwall design (textured and smooth).

even greater heights which are to be seen through or viewed from both sides, or in situations requiring a higher level of sound.

Smooth waterwalls and broken sheets have limited application. A broken sheet is generally a complementary or secondary element. A smooth waterwall is limited to close viewing, except for very large area applications, and does not generate any significant sound. In some installations the sound level can be increased by free-falling a short distance below the smooth waterwall.

Flatter cascades and streams are used to provide a sense of continuity to architectural and/or landscape elements and to direct or interrupt traffic patterns.

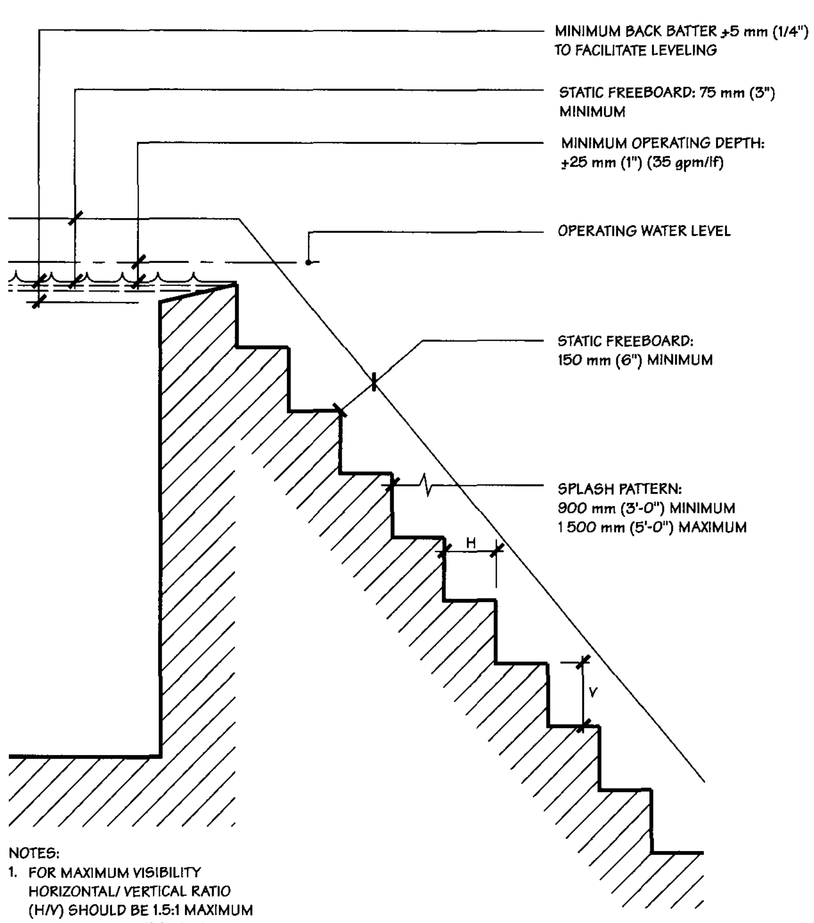
Spouting water provides verticality and sound in a flat pool and a sense of source or beginning to free-falling, flowing, or cascading displays. Groupings of jets can be organized to provide dynamic, sculptural compositions. Jets are also used functionally in lakes and ponds to improve water quality through aeration.

4.4 Design

Still water effects are a function of container configuration, color, material, the influence of wind or mechanically generated activity at the water surface, and of the siting of the pool in relation to vertical elements in the immediate environment.

The container may convey a sense of formality by virtue of a regular geometric configuration or by the use of a cut, polished stone for edge material. Conversely, a free-form container with an edge of plant material or natural stone appears quite informal. If the pool is nonreflective, the bottom materials may be articulated in a sculptural fashion or as a mural with carefully designed patterns of tile, pavers, or cobbles. A finer texture (smaller units) will make better use of surface rippling and reflected sunlight.

Reflectivity is generated by dark container surfaces or opaque water, which absorb rather than reflect light in conjunction with an undisturbed water surface. The pool must be sited to reflect the desired vertical elements at logical observer positions, as illustrated in Figure 530-6. Opaque water can be achieved by using dyes or allowing the controlled growth of algae and plants in a biologically balanced system. A disturbed surface may be generated by prevailing winds or can be introduced mechanically by employing small, closely spaced jets, aimed horizontally, near the surface of the water.



NOTES:

1. FOR MAXIMUM VISIBILITY HORIZONTAL/VERTICAL RATIO (H/V) SHOULD BE 1.5:1 MAXIMUM 1:1 MINIMUM, TREAD WIDTH= 300 mm (1'-0") MAXIMUM, 100 mm (4") MINIMUM. OPTIMUM H/V = 1:1, TREAD WIDTH 150 mm (6")
2. FALL OVER FIRST VERTICAL IS GENERALLY NOTICEABLY CLEARER UNIFORM WHITEWATER EFFECT BEGINS WITH SECOND FALL

Figure 530-9. Waterstair cascade design (stepped planes).

Design Criteria for Various Effects:

Free-Falling Sheet and Waterwall: Figure 530-7 shows design criteria for a free-falling sheet. This detail is appropriate for all free-falling and cascading effects except gravity spouts and cascading waterwalls. Figure 530-8 shows criteria for textured and smooth waterwalls. The back-battered weir is used for a number of reasons. Concrete can be finished to the front (downstream) form, which can be leveled using instruments, generally resulting in an acceptable ± 3 mm (1/8 in) tolerance along the entire weir. High spots can readily be ground level along the ridge created by the sloped configuration if tolerance cannot be maintained. Water occupies the entire horizontal plane when the fountain is off, generally resulting in a more desirable relationship with the container. The slope also moderates the sudden increase in velocity that causes water to draw down sharply at the back edge of a flat weir, interrupting the continuity of the horizontal plane. The color of the weir and vertical surfaces should be as dark as possible to facilitate perception of the water movement by the contrast and reflection from the sheet itself. The knife-edge weir used for free-falling water causes the sheet to break free of the structure and may easily be roughened to cause striations at the back of the sheet to increase visibility. The radius used for the waterwall weir works in conjunction with the back batter to direct the water onto the waterwall.

Waterstair: Figure 530-9 shows specific criteria for a waterstair. These criteria generally apply to all stepped-form or stepped-plane cascades, except that the criteria for splash should be projected for the highest free-fall.

Streams, like still water, assume a form defined by the container whereby the form primarily determines the level of activity. Figure 530-10 shows five ways to increase the level of activity by increasing the velocity and/or introducing turbulence which increases the visibility and sound level in a stream.

The character and flow requirement of a waterwall will be determined by the finish of the material over which the water flows. A very smooth surface such as glass, sheet metal, or polished stone achieves maximum visibility, using the surface tension of the material to create a standing wave effect with a very nominal flow. Too much flow will substantially reduce the visibility. An intermediate texture such as troweled concrete or thermal-finish stone also reduces visibility by moderating the effect of surface tension. The minimum textural articulation required to generate an aerated waterwall is on the order of 5 to 10 mm (1/4 to 3/8 in), and the transitions must be sufficiently abrupt to entrap air. The most common and predictable method to achieve this textural quality is exposed aggregate concrete, using carefully graded aggregate with the matrix retarded 5 to 10 mm (1/4 to 3/8 in). Other methods include bush-hammered concrete or stone, corbelled brick or tile, and horizontal saw cuts with random areas broken out.

Finishes at joints in weirs and waterwall surfaces should be as nearly flush as practical to avoid localized streams breaking free of the wall and to avoid air pockets between the wall and the water.

There are several critical considerations in the design of spouting (jet) displays. The variability in wind velocity and direction for outdoor installations is most readily accommodated by designing the pool/jet combination to provide a clear radius equal to the height of the jet to any point beyond the pool. A wind control system should be employed if the immediate surroundings include a building or heavy pedestrian or vehicular traffic. Splash is usually a secondary consideration with outdoor displays, since the normal pattern is only 1 000 to 1 500 mm (3 to 5 ft) and is more than adequately accommodated by the clearances required for height. The splash pattern is the prime determinant of the jet placement/clearance requirement for interior spaces and low jets.

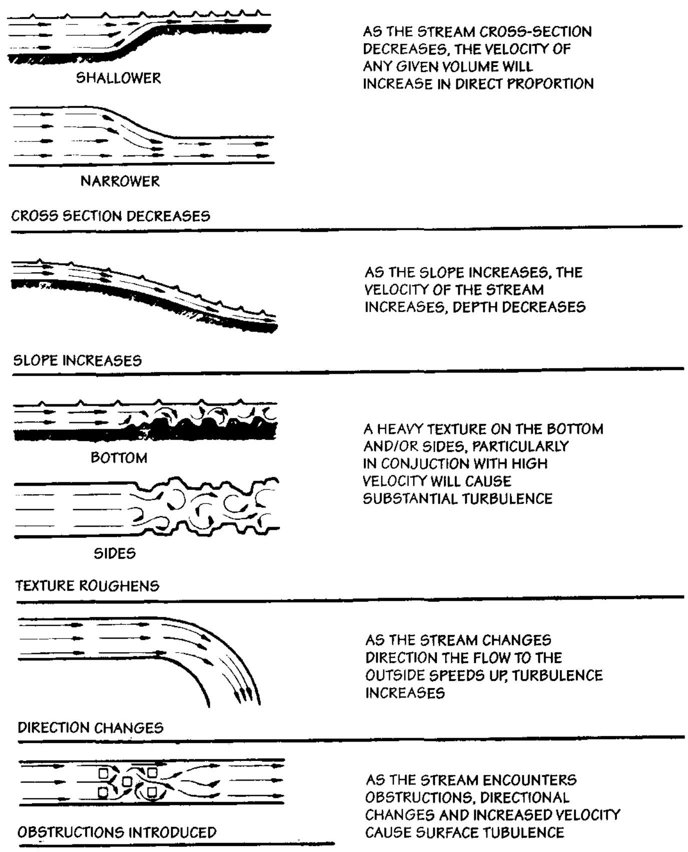


Figure 530-10. Turbulent stream design.

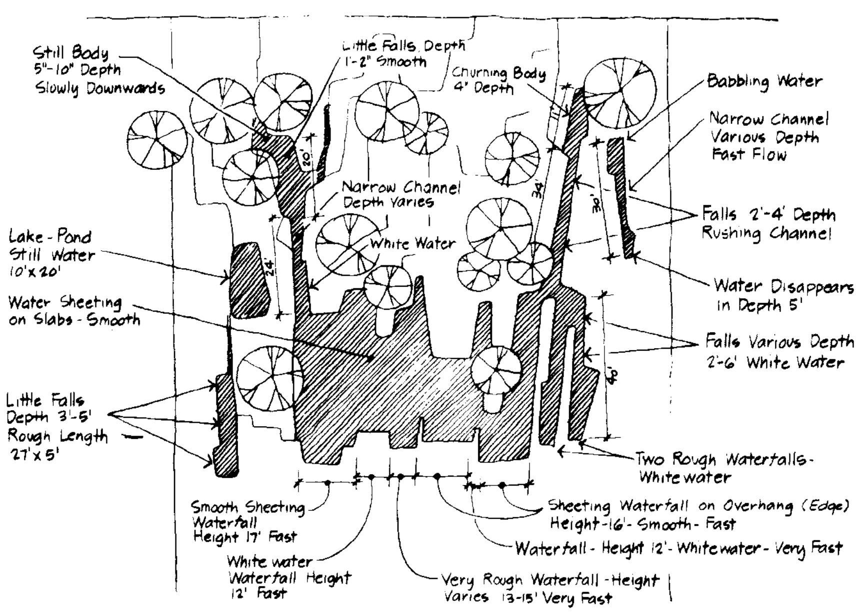


Figure 530-11. Water effects sketch.

Accommodations of Mechanical System:

Accommodations to be considered in the mechanical system include the following.

Adjustability: Most jets are oriented vertically, but arching and horizontal variations are used. Adjustability is generally desirable for either application. Adjustable swivel joints are available with a range of 15 to 20 degrees about the center through a full 360-degree arc. These swivels are available for supply pipe sizes from 3 mm (1/8 in) through 100 mm (4 in).

Multiple-Jet Display: Jets are often employed in groups. A few loosely spaced jets are generally piped individually with a balancing valve for each to allow for varying heights and/or differences in pipe and fitting losses. A plenum arrangement, often called a pod or cluster, may be used for singly massed displays. A spray bar or spray ring may be used for closely massed groupings, depending upon the configuration. The flow is sufficiently balanced with these singly or closely massed groups, and balancing valves are only required if varying heights are desired.

Debris: A jet display is more readily affected by waterborne particulates and debris and variables in the pumping system than are other types of displays. They will require more day-to-day maintenance and more frequent repairs than still or falling water. Important initial design criteria are the selection (1) of a pump strainer with perforations smaller than the smallest jet orifice and (2) of a pump with characteristics that will afford a constant display throughout the normal range of strainer loading.

Surge Collar: Submerged jets, such as a cascade or bubbler, often generate wave patterns that periodically cause flooding. This exposes the submerged jet, thereby generating more waves which could exceed the confines of the pool, or at the very least causing a major change from the intended display. This can be countered by installing a perforated collar (i.e., a surge collar) with a diameter at least twice that of the jet, placing it concentrically around the jet at or slightly below water level.

Straightening Vanes: In situations where a single jet requires flowrates in excess of 3 750 Lpm (1000 gpm), or where the installation of the jet precludes a clear vertical feed equal to 5 times or more the nominal diameter of the supply pipe, straightening vanes may be required. If the situation is marginal, merely provide for a retrofit.

KEY POINTS: Water Effects

Water effects are typically grouped into two basic categories: (1) still water and (2) moving water. Moving water includes free-falling, flowing, cascading, and jet displays. Table 530-2 lists characteristics for each type of effect. Design considerations include the following:

1. Still water effects are a function of container configuration, color, material, the influence of wind or mechanically generated activity at the water surface, and of placement.
2. The character of a waterwall will be determined by the finish of the material over which the water flows. Smooth surfaces achieve maximum visibility. Textural articulation of 5 to 10 mm (1/4 to 3/8 in) may be used for aerated waterwalls.
3. The variability in wind velocity and direction for jet displays is accommodated by designing a pool with a radius equal to the height of the jet.
4. Jet displays are higher maintenance than are other types of displays because they are more readily affected by waterborne particulates, debris and variables in the pumping system.
5. Displays with longer transit time for water, typically require less water volume to maintain desirable flow rates.

4.5 Maximization of Water Effect

The transit time, volume, and readability should all be maximized to optimize the impact of any given flowrate, to minimize the cost, and to conserve energy, if a recirculating system is used.

Transit Time:

Transit time is probably the single most important factor in designing with water. The longer the water is kept in play (transit time), the greater will be the effect achieved at any given flowrate. For example, water is introduced to one end of a cascade 90 000 mm (300 ft) long and 4 500 mm (15 ft) high, then recirculated from the other end. If an average stream velocity of 600 mm/s (2 fps) is assumed, the water will take 2-1/2 minutes to traverse the system. If 1 500 Lpm (400 gpm) is recirculated, there will be 3 750 L (1000 gal) of water in motion. In contrast, consider a sheet or spout of water free-falling 4 500 mm (15 ft); under the influence of gravity this water will reach the lower pool in approximately 1 second. At this extreme, 225 000 Lpm (60,000 gpm) would have to be pumped to maintain the same 3 750 L (1000 gal) in motion.

Air Entrainment:

White water is generated by creating sufficient turbulence in a sheet or stream to entrap air, or by artificially introducing air to the display. The entrained air provides additional volume for any given flowrate and further increases visibility by reflecting a much greater component of natural or artificial light. This technique is employed for most cascades and for aerating jets.

Readability:

Further impact is achieved by maximizing the surface area, optimizing the exposure to natural or artificial light, and using dark, contrasting materials in and around active water.

4.6 Optimization of Water Effect

The effect of a water display may be further optimized by graphic and model studies, observation of similar effects, prototype testing, and field adjustment of the completed system.

Graphic and Model Studies:

Graphic and model studies are an excellent way to study the scale and massing appropriate for the container, the integrated structures, and the immediate environment. These studies can further serve as a basis for quantifying the effects and for communicating with clients and other members of the design team. Figure 530-11 is a copy of an early sketch prepared by Angela Danadjieva for Ira's Fountain (Portland Auditorium Forecourt Fountain, Portland, Oregon), which served as a basis for the development of models and for early structural and hydraulic studies.

Observation of Precedent:

Observation of similar effects to be used will serve to confirm visual characteristics as well as sound levels, splash patterns, and the overall feel of the display.

Prototype Testing:

Hydraulic testing is used to determine the feasibility and design criteria for prototypical effects and/or to fine tune such items as weir configuration, splash containment, and waterwall textures. Tests may be conducted at the designer's office, on the construction site, or at an established testing facility, such as a manufacturer's test pool or a university hydraulics laboratory. The testing program should be witnessed and evaluated by the designer, consultants, and appropriate construction personnel.

Tests must generally be conducted at full scale, since hydraulic factors such as surface tension are constant or vary in a nonlinear fashion. For most testing, a single spout, a short length of weir, or a small area of waterwall surface is adequate for evaluation.

The construction of the test assembly, the variables to be evaluated, and the performance criteria should be carefully specified prior to testing in order that each item such as weir profiles, surface textures, waterwall joints, drip notches, pool depths, splash patterns, and jet heights can be evaluated as fully as possible. Where appropriate, two or three variations of each critical item should be tested.

Field Adjustment:

Field adjustment, including modifications where necessary, is extremely important, since each installation is a prototype and must finally be evaluated in place. This effort should include consultants and construction personnel as well as the designer.

5.0 CONTAINERS AND STRUCTURES

The pool may evolve in a number of ways. It can be a primary landscape form working with space and/or structures, an envelope-sized (or contorted) to contain a preconceived display element, an amenity to derive a density bonus for an expensive Manhattan parcel, or a filler to make use of an odd area on a plaza or mall or of the space under an escalator. It can even be a nonpool, that is, a display integrated into the paving or walls, with no visible reservoir.

Each of these suggests a design direction in addition to imposing constraints. Other factors affecting the design include the environment, construction budget, appropriate materials, and governing codes.

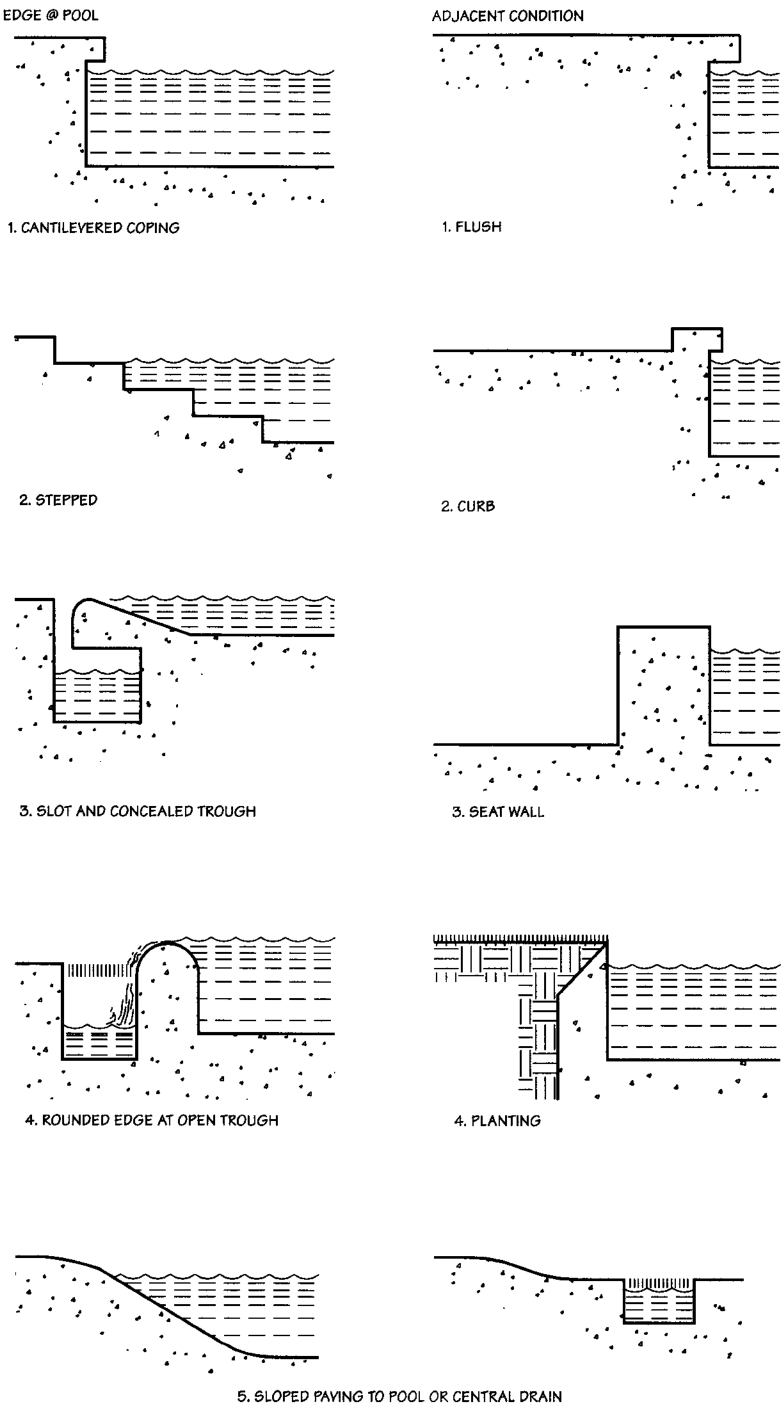


Figure 530-12. Edge conditions.

5.1 Environment

A number of contextual variables within the designed and natural environment dictates further design direction. Among these are scale, setting, climate, location, and surrounding materials.

Scale:

Scale is perhaps the most important of the contextual variables, and an aesthetically viable water display must in some way relate to the scale of its surroundings. This need not be the scale of the entire space, however. The water display often relates to a space that is a component of the larger space, as with a small fountain in a bosque of trees or on a dining terrace. Once this relationship is established, scale and proportion among the parts of the fountain itself are equally important. Displays should relate properly to the pool, and if the display includes structure, the water massing must be adequate and complementary in character.

Setting:

The configuration, edge condition, materials, and display itself will be influenced by the formality of the designed environment. A very formal setting will lead to strongly geometric shapes, hard edges, and more refined materials. Conversely, a naturalistic setting will direct the design toward more organic shapes, soft edges, and nonexpressed construction materials. Most of these matters will likewise be influenced by whether the pool is indoor or outdoor, urban or suburban, commercial, residential, or institutional.

Topography:

It is usually difficult from a design standpoint, and expensive, to install a large reflecting pool on a steeply sloping site or a major fall on a flat site. A more viable solution, accepting the goal of reflectivity on the steep site and verticality on the flat site, might be a series of interconnected ponds or rectilinear trays for the former, and a massive composition of jets for the latter.

Climate:

Climatic variables are quite important considerations for an outdoor installation. Prevailing winds, sunshine frequency and orientation, and temperature extremes can offer direction as well as constraint. Long, hot summers suggest cooling displays, perhaps even a participatory design. Severe winters dictate a 4- to 6-month shutdown, necessitating that configurations, materials, display structures, and particularly hardware be carefully considered both with and without water. In many instances a nonpool, as mentioned earlier, is an excellent answer to protracted winter shutdown. Other wintertime solutions include a pool that doubles as a skating rink, and ice formations which complement display structures.

Support Medium:

A number of potential constraints must be investigated for pools, whether they are built above-structure or on-grade. An above-structure solution is generally the more difficult to work with, as there are usually very definitive limits to depth and weight, and waterproofing must be very

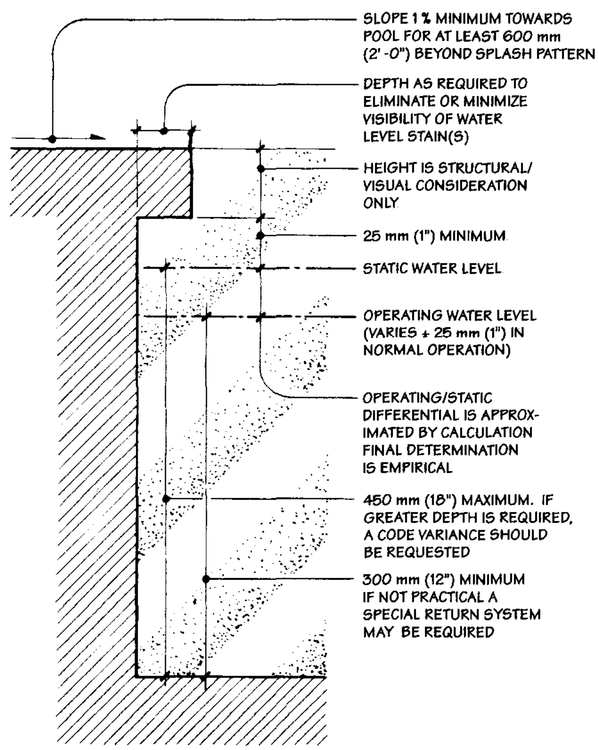


Figure 530-13. Pool design.

carefully addressed. An on-grade installation requires considerably less attention to waterproofing, as minimal leakage does not usually present a problem. Soil stability must be carefully investigated, however, as even nominal differential settlement may have a substantial effect on the pool, particularly if it involves long weirs and waterwalls. If the soil is expansive, an underdrain system should be considered.

Surrounding Materials:

If the water display is used as a primary element rather than as a complement to the pool, it is often desirable to minimize the presence of the container and any support structure for the display by integrating it into the immediate surroundings. Continuity of material is probably the single most important element in accomplishing this end.

5.2 Construction Budget

Construction budget considerations may be beyond the scope of this section however, it should be recognized that a fountain is a very expensive element in the landscape. To proceed with any design without both the designer and the owner recognizing the potential costs may be a waste of time. A few examples are cited below to help broadly bracket these costs:

The mid -1990s cost in the United States for a simple recirculating fountain of 9.3 m^2 (100 ft^2) or less, using a submersible system to generate a display of 375 Lpm (100 gpm) or less, would be on the order of $15,000 (1997 U.S.).

The mid-1990s cost for a fountain of about 93 m^2 (1000 ft^2), with recirculated water and a display flowrate of 1125 to 3750 Lpm (300 to 1000 gpm), would be on the order of $250,000 to $300,000 (1997 U.S.).

At the extreme, a good number of fountains were constructed in the late 1960s, 1970s, and 1980s, at a cost exceeding $1 million each.

5.3 Materials

There are a variety of materials appropriate for the construction of pools and displays. Installations seeking a natural appearance, may use a native soil material, if it is sufficiently impermeable, or a clay or flexible liner with nominal edge treatment. The more formal and primarily urban installations could incorporate choices of concrete, stone, brick, and in the case of smaller installations, wood, metal, or fiberglass (refer to Division 800: Materials, for technical data about these materials).

Native Soil and Clay:

Generally, these are used for large ponds, lakes, and reservoirs, and as such are somewhat beyond the scope of this discussion, offering geotechnical problems that must be expertly addressed on a project-by-project basis. Flexible liners are simply waterproofing membranes (refer to 5.5 Waterproofing in this section and section 880: Geotextiles for further information).

Concrete:

Concrete is probably the most commonly used material for urban installations. It is durable, economical, reasonably waterproof, and amenable to a wide range of configurations, finishes, and construction techniques, including cast-in-place, precast, and sprayed (gunite).

Cast-in-place concrete can be enhanced by the addition of integral color or finished with a variety of textures, including exposed aggregate, bush hammering, or random formboard. It could be coated or veneered, using epoxy paint, tile, or stone.

Precast concrete may be used for display structures or for the pool itself where precise control of the configuration, dimension, or surface is required. The only drawback is that the joints between sections must be waterproofed in pools or bowls. And in the case of a weir or waterwall, where a depressed or raised joint might cause irregular flow, the joint must be both waterproof and flush.

Sprayed concrete, or gunite as it is commonly called, is generally used where a free form or naturalistic form is required, or on structures where the light weight of forms created by spraying gunite over wire mesh or expanded metal lath are an asset because of marginal load-bearing capacity.

Stone:

Widely used, stone imparts a richness and permanence difficult to achieve with concrete. Granite is by far the most common and appropriate stone for fountain use. Where possible, the stone should be dark to enhance the reading of moving water and the reflectivity of still water.

Stone may be expressed as cut, finished material in either monolithic or veneered form, or as naturally occurring boulders, slabs, or smaller stones. With cut material, polished finishes are generally best, since rough or honed finishes, particularly with dark stone, tend to read differently wet and dry, magnifying the presence of overspray

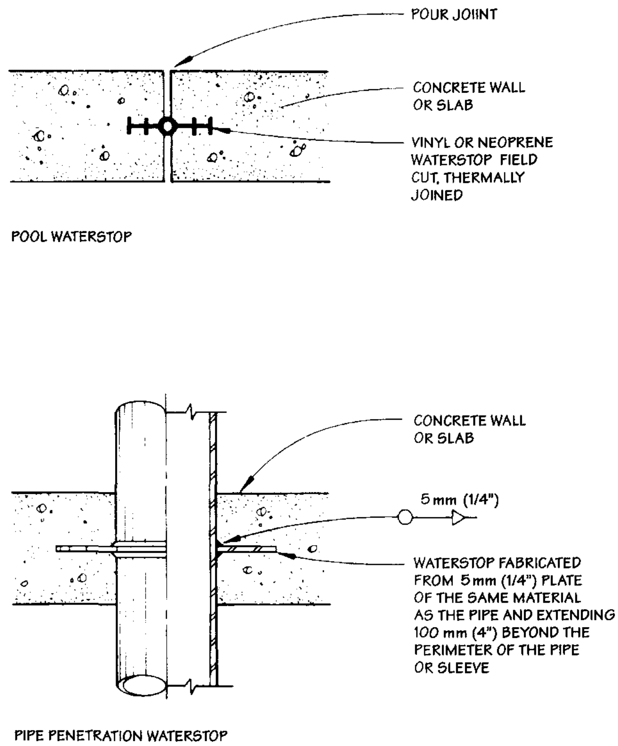


Figure 530-14. Waterproofing.

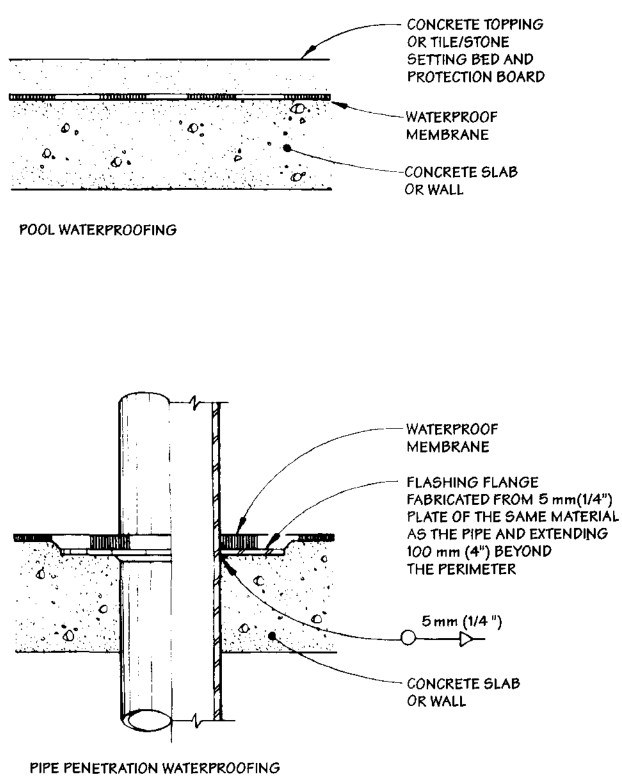


Figure 530-15. Waterproofing.

and other misdirected water—which is virtually unreadable on a polished surface.

Brick:

Brick generally provides a finish intermediate to concrete and stone in terms of both cost and aesthetics. It integrates well with brick paving and structures and can be articulated to generate whitewater waterwalls or cascades. Brick generally requires sealing unless glazed, and, as with precast concrete, joints at weirs and waterwalls must be carefully controlled, generally flush.

Wood, Metal, and Fiberglass:

Each of these materials offers inherent advantages for use in smaller installations and structures within the pool. Wood absorbs water, sealing the joints as it expands, and is inexpensive and simple to construct. Metal, either cast or fabricated from sheets, is waterproof and offers a richness and permanence equivalent to that of stone. Suitable metals include bronze, brass, copper, and stainless steel. Fiberglass is waterproof and may be integrally colored or filled with ground or crushed stone for situations on a structure where, as with gunite, the light weight is required to accommodate a marginal load-bearing capacity. Fiberglass can also be used to resurface or repair existing pools.

5.4 Cross-Sectional Configuration

There are several aspects of cross-sectional configuration that must be considered in addition to the shape of the water feature as seen in plan.These include the relationship to plaza level and the edge conditions, depth, and freeboard.

Relationship to Plaza Level:

Both the rim and water level elevations are very important considerations. For instance, the more a rim is elevated, the more it tends to break up the visual continuity of the surrounding space and focus the viewer's attention on the pool itself. This often reduces the visual impact of the display and/or reflected images. On the positive side, the elevated rim may be used for seating and for keeping out dust and debris blown in from the surrounding plane. It can also serve as a barrier to prevent accidental walking or falling into the pool.

An elevated water level is often appropriate to provide a desired field of reflection. An at-grade water level, particularly with a still pool, will integrate the pool into the surrounding plane. A depressed water level will strengthen the impact of the display, much like the nonpool will.

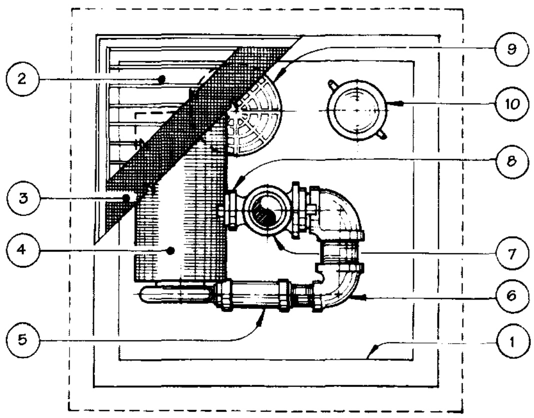


Figure 530-16. Submersible fountain system.

Edge Conditions:

Figure 530-12 shows a number of typical edge conditions. A cantilevered inner edge is probably the detail used most often. It serves to contain the waves generated by the wind or the display and will conceal any stains caused by normal variations in the water level. Critical dimensions are shown in Figure 530-13.

The stepped recess, the wall, and the warped paving tend to integrate the pool with its immediate environment, minimizing its impact on the space and maximizing the impact of the display. The rounded edge and the trough detail allow the water level to be at or above plaza level, expressing the entire body of water as a dynamic display element.

Hard-planted edges (Figure 530-12) are accomplished by back-battering the pool edge in such a fashion that the planted plane can be carried up to the point of intersection with the plane of the pool wall. A soft-planted edge extends the plant material to the waterline and is often used in an earth-bottomed pool or in one having loosely set cobbles or sprayed concrete edges. It is usually employed in the construction of naturalistic streams, ponds, and lakes.

Depth, Freeboard, and Clearance from Displays:

Figure 530-13 shows the primary considerations for a pool with a single level or for the lower pool of a multilevel design. The freeboard for the upper pool's falling or cascading water is discussed for various displays in 4.0 Water Effects in this section.

Depth: The pool depth generally varies between 300 and 450 mm (12 and 18 in). In the United States, 450 mm (18 in) is the maximum recommended depth because interpretation of the Uniform Building Code generally leads to the conclusion that anything of greater depth can be considered a swimming pool, as opposed to a wading pool. 300 mm (12 in) is generally the minimum depth required to provide for a satisfactory return system and to submerse wall-mounted and freestanding pool lights properly. Source pools usually need a minimum depth of 300 mm (12 in) for a jet or nonexpressed source. Algae growth is enhanced by increased heat and ultraviolet light as the depth decreases in outdoor installations. Most jurisdictions will accept a gradual slope or steps to a deepened central area in a large pool or pond or lake.

Freeboard: Freeboard requirements vary as a function of the edge condition. With a cantilevered or stepped edge, the freeboard need only be an inch or so below the cantilever or tread to allow for nominal fluctuations in water level. Adequate freeboard is inherent to the wall edge; the trough water level at the rounded edge should allow at least 150 mm (6 in) of freeboard, the hard-planted edge should have minimum freeboard of 75 mm (3 in), and the soft-planted edge made of loosely set cobbles, and gunite edges should extend to at least 150 mm (6 in) above the highest water level.

When multiple levels are involved, the lower pool will have two different water levels—the static, or nonoperating, level and the operating level, which will be lower. The difference is due to the water that is built up behind the weirs, etc., during operation, which will ultimately reach the lower pool when the fountain is not operating. If the flowrate and weir lengths are known, this amount can be calculated by first determining the area of each pool and then determining the depth over the weir(s), using Table 530-3.

Clearance from Displays: Where possible, all displays (fountains, etc.) should be set back from the pool edge to a distance equal to or greater than the splash pattern or jet clearance, as described above in 4.0 Water Effects. Where pool edges are flush with the paving, an additional margin of safety should be obtained by sloping the pool rim and/or adjacent surfaces from a point at least 600 mm (2 ft) beyond the necessary clearance back toward the pool.

5.5 Waterproofing

Measures needed for waterproofing depend upon whether the pool is on-grade or on-structure above a functional area in a building.

On-Grade:

Unless there is a critical area immediately adjacent, or an unusual soil condition where even nominal leakage might present a problem (such as in areas of expansive soils), waterproofing is usually confined to the proper mixing and vibrating of the concrete in conjunction with waterstops at slab joints and pipe penetrations (Figure 530-

KEY POINTS: Pool and Fountain Design and Construction

Factors affecting the design of water features include its purpose, the environment, construction budget, appropriate materials, and governing codes.

1. Hot climates suggest cooling displays, while cold and temperate climates dictate a 4 to 6 month winter shutdown, which may suggest non-pool design or alternative cold-weather uses.

2. On-structure pool and fountain design may be limited by concerns for weight and waterproofing. On-grade design may require underdrains if soils are expansive, to avoid differential settlement.

3. Native soil or clay materials may be used in pool design to achieve a "natural" appearance. More formal installations may incorporate concrete, stone, brick, wood, metal, or fiberglass.

4. In the United States, 450 mm (18 in) is the maximum recommended pool depth in order to avoid being classified as a swimming pool. A depth of 300 mm (12 in) is generally the minimum depth to provide a satisfactory return system, display jets, and submersible pool lights.

5. Freeboard requirements vary as a function of the edge condition. Cantilevered or stepped edges require only about 25 mm (1 in), whereas soft-planted edges or rounded edges with troughs should allow at least 150 mm (6 in).

6. Where pool edges are flush with the paving, an additional margin of safety should be obtained by sloping the pool rim and/or adjacent surfaces from a point at least 600 mm (2 ft) beyond the necessary clearance back toward the pool.

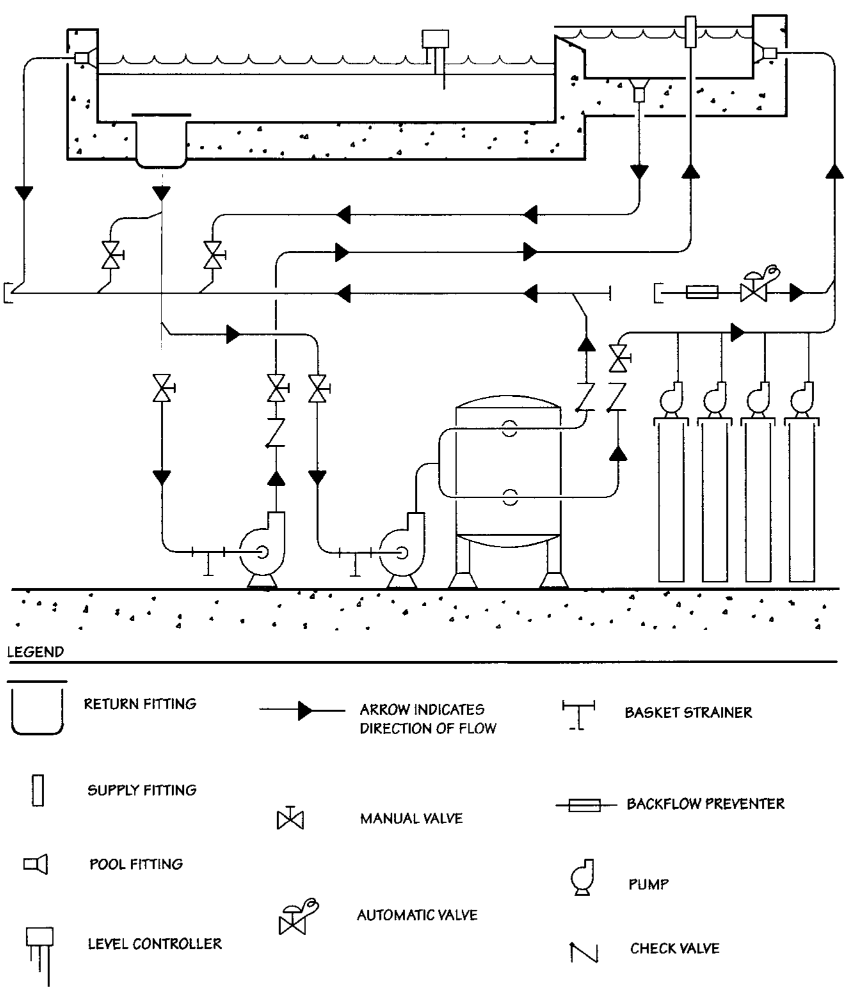


Figure 530-17. Schematic fountain diagram.

14). Additional protection may be provided by plastering or tiling the surface or by coating the pool with an epoxy paint or elastomeric coating.

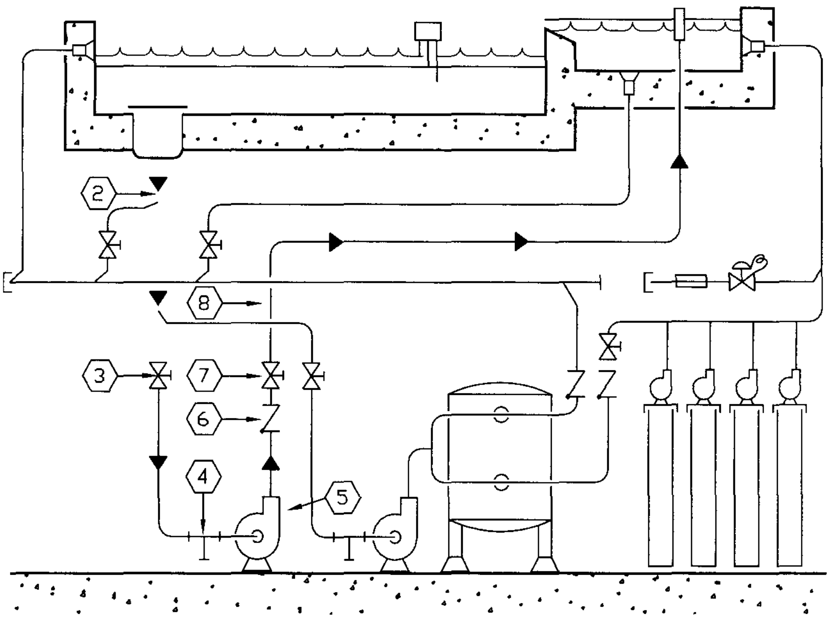
On-Structure:

Waterproofing is accomplished by coating the inside of the basic pool structure with a waterproof membrane, usually the fluid-applied types. Sometimes a hot-mopped felt membrane is used; in rarer instances, lead, copper, or stainless-steel liners with soldered or welded joints are used. Waterproofing should be protected from physical damage, terminated above the static water level, and run continuously behind waterwalls and weirs. Figure 530-15 shows typical pool and pipe penetration waterproofing.

6.0 OPERATING SYSTEMS

There are two basic ways to operate decorative pools and fountains. The oldest and often the most cost-effective and reliable method is to use natural sources of water and let the water flow through rather than be recirculated through the system. This is typically accomplished by the use of water from flowing streams, springs, or artesian wells, from gravity-operated irrigation systems, or from elevated water tanks and impoundments.

The second way is through the use of mechanical motors and pumps and typically involves recirculation of the water. This section covers only this second method of operation and provides data on two types



NOTES (NOTES WITH "*" FOR MULTI-LEVEL POOLS ONLY)

1. RETURN SUMP
2. RETURN PIPING
3. ISOLATING VALVE
4. BASKET STRAINER
5. DISPLAY PUMP
6. CHECK VALVE *
7. ADJUSTING VALVE
8. SUPPLY PIPING
9. SUPPLY FITTING

Figure 530-18. Display system diagram.

of mechanical systems—the submersible pump (located within the pool and below the water) and the remote pump (located outside of the water and pool). Each of these two approaches is described below.

6.1 Submersible Systems

The submersible system is generally limited to installations of 9 m² (100 ft²) or less in areas that are drained, cleaned, and filled every few days in lieu of filtering. Other potential applications include larger, biologically balanced pools with minimal displays or temporary, portable, or seasonal displays. The primary concerns with submersible systems are maintenance and electrical safety. A remote system should be used if the pool requires filtering rather than periodic draining, cleaning, and refilling.

A typical submersible system is shown in Figure 530-16. Located in the floor of the pool, it comprises (1) a sump with a grating and large mesh screen to protect the pump and intercept larger debris and leaves; (2) a submersible pump with noncorrosive piping to the display, along with appropriate electrical connections; (3) a drain, which often has a standpipe extended to the surface to double as an overflow; and (4) a submersible junction box for the electrical connection. The drain can be omitted and the pool simply siphon-drained in the simplest of systems. A niche-mounted float valve can be installed, in a slightly more sophisticated system, eliminating the need to top up the pool periodically. The same niche assembly can be purchased with an adjustable overflow standpipe to stabilize the water level further.

6.2 Remote Systems

Figure 530-17 illustrates the essential elements to consider in the design of a remote fountain system. The system, as shown, may appear complex; however, it comprises several modules, or subsystems, which are only marginally interrelated and which in their most basic form are quite simple and understandable. These subsystems include display (Figure 530-18), filtration (Figure 530-19), fill/makeup and overflow/drain (Figure 530-20).

6.3 Equipment Space

The system design and the equipment selected will depend in great measure on the location and configuration of the equipment space. A number of interrelated considerations are required in order to optimize an equipment space; the most important of these are elevation, location, size, and configuration.

Elevation:

Elevation is the single most important consideration with regard to the equipment space. The floor elevation of the space should be at least 600 mm (2 ft) below the lowest water level in the pool in order to provide a flooded suction for the pump. If no viable space can be found, a vertical pump inserted into a large pipe or sump below the floor should be considered. If a pump is started automatically each day, any location above water level (suction lift) will be an ongoing maintenance headache, since the pump will periodically air-lock and must, at the very least, be protected with a flow switch or similar device.

Location:

If at all possible, the equipment space should be located within a building or a structure that has horizontal access for maintenance personnel and equipment removal. The location should be as close as possible to the pool—or to the lowest pool in a multilevel situation. Distances of 30 to 45 m (100 to 150 ft) are acceptable for an installation with piping of 150 to 200 mm (6 to 8 in) or smaller, but anything over 15 to 30 m (50 to 100 ft) for large piping becomes expensive. Adequate provision for access, equipment removal, waterproofing, draining, and ventilation must be provided if a subterranean vault with a vertical access hatch is used.

Size and Configuration:

The dimensions of the equipment space must be adequate to provide access to all equipment and valves. They must also provide for the code-required clearances around electrical equipment, as established by local building codes. Generally, a minimum size is 2 200 mm² (75 ft²), commonly ranging up to 1 200 m² (400 ft²) for larger installations. The ideal configuration is

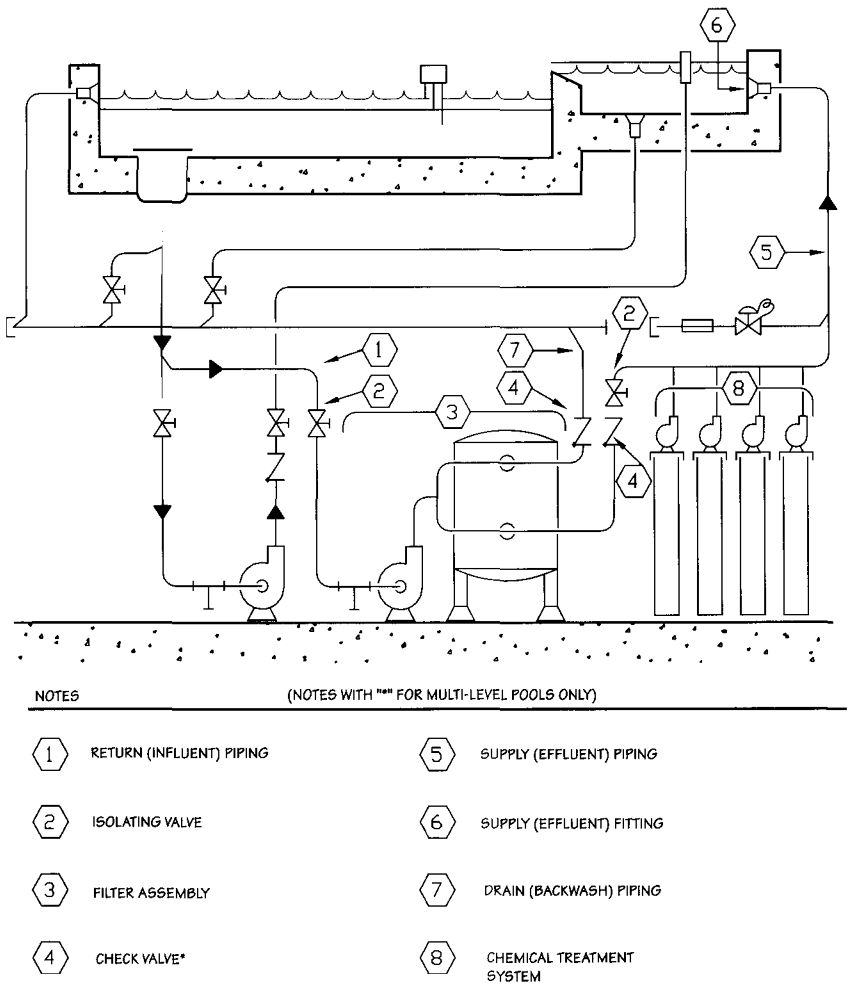


Figure 530-19. Filtration/water treatment system diagram.

KEY POINTS: Operating Systems

Submersible pumps and larger remote systems are the two mechanical methods for recirculation of water in pools and fountains. Selection of an appropriate system depends on the size, application, and budget of the proposed display.

1. Submersible pumps are generally limited to installations of 9 m² (100 ft²) or less in areas that are drained, cleaned, and filled every few days in lieu of filtering. Maintenance and electrical safety are the primary concerns with these systems.
2. In remote systems, the equipment space should be as close as possible to the pool, and the floor elevation should be at least 600 mm (2 ft) below the lowest water level in the pool in order to provide a flooded suction for the pump.
3. Filter systems are used to remove particulates from the water and return it to the pool (Figure 530-19).
4. The fill/makeup system establishes the static water level (in conjunction with the overflow) and maintains the operating water level (Figure 530-20).
5. The overflow/drain system establishes the static water level (in conjunction with the fill system) and provides for draining of the pools, piping, and equipment (Figure 530-20).

broadly rectangular or square with no dimension less than 2 400 mm (8 ft).

Accommodations:

A properly designed equipment space should have a floor drain and/or a sump pump to handle water from strainer cleaning, repairs, etc. It should be ventilated to maintain a reasonable temperature and to control humidity. It should also have minimal heating (if needed to prevent freezing), power outlets for movable lights and small tools, and overall electric lighting of 538 to 807 lx (50 to 75 fc) to facilitate routine maintenance.

6.4 Alternative Water Display System

Alternative water display systems include non-pool fountain schemes (Figure 530-21), and pool fountains with perimeter overflow (Figure 530-22).

6.5 Support Systems

The group of support systems are subsystems used to help maintain the quality and level of the water in the pool and to facilitate cleaning.

Filter System:

The filter and treatment systems are shown on Figure 530-19. The filter system uses a circulating pump, a line strainer, and shut-off, check, and throttling valves, just as the display system does. One of the most common systems returns the water to the pool through a filter medium consisting of fine silica sand supported on a base of heavier sand and gravel. This medium is contained in a steel or fiberglass tank. It is generally considered a permanent installation. Trapped particulates can be removed from the finer sand by reversing the flow through the medium (called backwashing) and discharging the effluent to the sanitary or stormwater drain system. The return water from the pool can be routed through the display return system or through a separate fitting.

Item 3 is the filter package, which includes the strainer, circulating pump, filter tank, and filter media. Item 6 is the supply (effluent) fitting for the filter system and is often used to add fill/makeup water. In a fountain with a nonexpressed source, this water may be returned through a display system supply fitting. Item 7 is the filter backwash line.

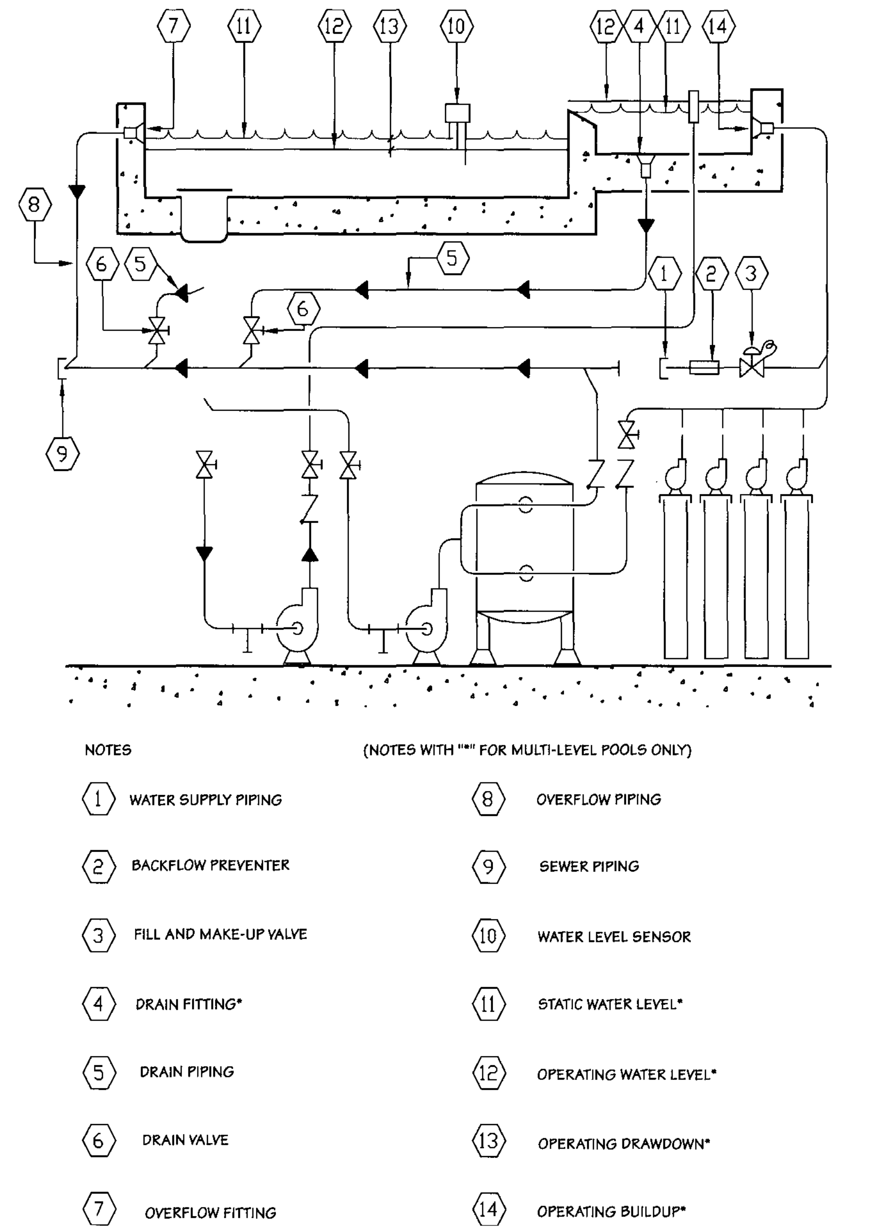


Figure 530-20. Water supply/drain/level control system diagram.

Fill/Makeup and Overflow/Drain Systems:

Fill/makeup and water supply/drain/level control systems are shown on Figure 530-20.

The fill/makeup system establishes the static water level (in conjunction with the overflow) and maintains the operating water level. Item 1 is the water supply, usually connected to the domestic water system. Item 2 is a backflow preventer, required by code when the supply is derived from the domestic water supply (in the absence of an air gap) to prevent back siphoning of potentially contaminated fountain water back into the domestic water supply. Generally installed in the equipment space, below-grade and/or below the pool's water level, it requires a reduced-pressure-type device. Item 3 is a solenoid-actuated valve, used in conjunction with the water level controller to establish or maintain appropriate water levels. Item 10 is the water level controller, which is discussed in subsection 9.6 Water Level Control.

The overflow/drain system establishes the static water level (in conjunction with the fill system) and provides for draining of the pools, piping, and equipment both for cleaning and for shutting down the pool and fountain in climates where the water could freeze and thus cause problems. Item 4 is a drain fitting, used to remove water from the various pools to facilitate cleaning and equipment maintenance. Pools with return or supply fittings may be drained at the equipment room via the piping to these systems; they may be drained either at the primary fitting or through an auxiliary drain fitting installed at the low point in the pool. Each pool level in a multilevel installation requires a drain fitting. Item 7 is the overflow fitting, used to remove excess water resulting from rainfall, irrigation runoff, or a

Table 530-3. VARIOUS FLOWRATES

FLOWRATE FOR SOLID STREAM JETS (GPM)

HEIGHT (FT.)	2	4	6	8	10	15	20	30	50	75	100
HEAD (FT.)	3	5	8	10	14	20	27	41	69	97	150
1/4" ORIFICE	2	2.8	3.4	4	5	6	-	-	-	-	-
3/8" ORIFICE	4	6	7	8	9	12	15	20	-	-	-
1/2" ORIFICE	7	11	12	15	19	22	26	33	-	-	-
3/4" ORIFICE	16	21	26	31	35	50	58	74	93	-	-
1" ORIFICE	37	46	50	56	60	82	106	127	167	199	238
1 1/2" ORIFICE	-	-	-	-	159	199	233	304	368	444	518
2" ORIFICE	-	-	-	-	309	357	410	526	650	780	938
3" ORIFICE	-	-	-	-	-	-	965	1220	1640	1750	1905

FLOWRATE FOR RECTANGULAR WEIRS

DEPTH OVER WEIR	1/4"	1/2"	3/4"	1"	1 1/2"	2"	2 1/2"	3"	4"	5"	6"
GPM PER LINEAR FT.	4.5	13	23	36	65	101	141	185	285	399	524

FLOWRATE FOR CASCADE TYPE AERATED STREAM JET

SIZE	HGT. (FT.)	2	4	6	8	10	12	15	20	25	30
3/4"	GPM	18	21	26	30	-	-	-	-	-	-
	HEAD	30	43	61	77	-	-	-	-	-	-
1 1/2"	GPM	28	32	40	46	50	56	67	-	-	-
	HEAD	15	27	37	50	60	70	83	-	-	-
3"	GPM	71	110	142	157	171	186	210	246	312	330
	HEAD	9	16	26	32	36	44	56	66	108	134

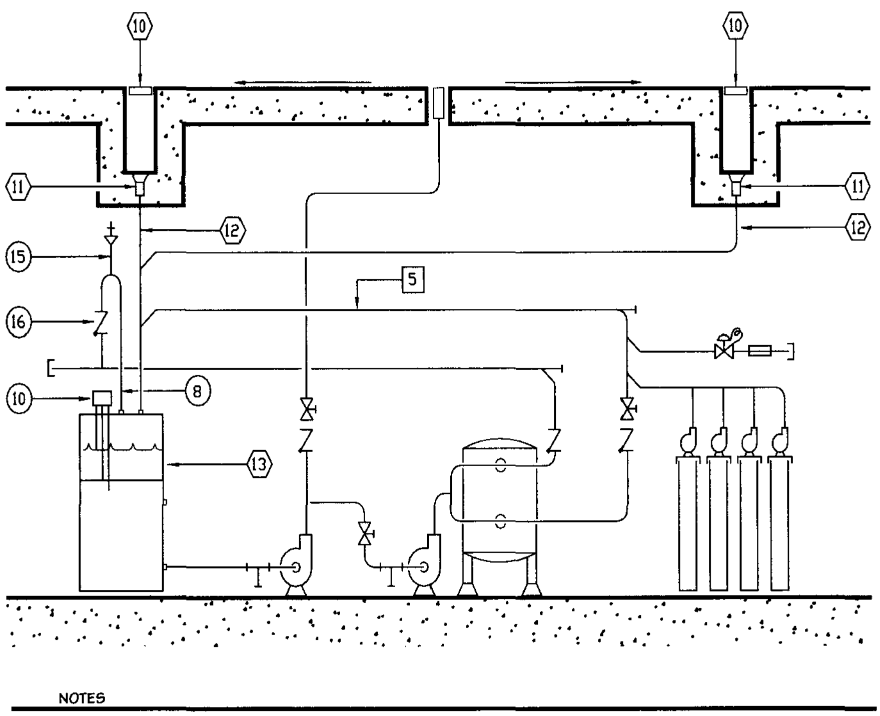


Figure 530-21. Non-pool fountain diagram.

malfunctioning fill/makeup system. Item 9 is the sewer or outlet connection. Most local health codes require that the effluent from a filter should be treated as any other sanitary waste. The overflow drainwater can be treated as any other on-site stormwater runoff.

7.0 EQUIPMENT AND PIPING SELECTION

Tables 530-3 through 530-6 have been included to reduce most required data to chart or nomograph form. Table 530-3 shows flowrates for weirs. Table 530-3 also includes charts showing flowrate and head requirements for solid-stream jets and for jets of the geyser, or cascade, type, which is the most commonly applied of the aerated types. Data for other aerated types and for sculpted jets may be derived from the manufacturer's data. Tables 530-4, 530-5, and 530-6 show data required to determine system head losses. These, in conjunction with other system head data, will enable the designer to select and determine the size of the pump.

7.1 Display Pump

There are three conditions that must be optimized in selecting a pump: (1) flowrate, (2) head, and (3) minimum net positive suction head. A typical pump selection curve is shown in Figure 530-23.

Flowrate:

Using Table 530-3 or the manufacturer's data for display nozzles, all requirements must be totalled. The required flow at any weir may be reduced by the amount that jets or other weirs contribute to the source of that weir.

Head:

The head is the total pressure required to accommodate the difference in elevation between the highest and lowest pools (static level differential), plus discharge head requirements for display jets taken from Table 530-3 or the manufacturer's data, plus total calculated head for entrance, exit, velocity head, pipe, fitting, valve, and strainer losses can be taken from Tables 530-3, 530-4, and 530-5.

Note: The requirements may be reduced if the jets are not located in the upper pool.

Net Positive Suction Head:

The net positive suction head (NPSH) is the resultant pressure available at the pump from atmospheric pressure after adding or deducting (1) the differential between the operating water level and the pump elevation, (2) all losses accruing to entrance conditions, (3) the friction losses through pipes, fittings, valves, and strainers on the suction side of the pump. Atmospheric pressure is 10 200 mm (34 ft) at sea level, decreasing approximately 3 650 mm (1.2 ft) with each 300 000 mm (1000 ft) rise in elevation. If the NPSH is marginal, more definitive calculations should be made, using expanded-pipe sizing charts based on the particular materials used and the manufacturer's data for each component in the return system.

Pump Selection:

Refer to Figure 530-23. After determining the required flowrate and head plus the available NPSH, select the pump to satisfy these parameters and to maximize efficiency. In general, efficiencies of 70 to 90 percent (increasing with the flowrate) should be attainable. Finally, determine the pump manufacturer, the model, the suction and discharge sizes, and the motor horsepower and speed (rpm).

As a general rule, pumps up to 3 750 to 4 500 Lpm (1000 to 1200 gpm) are end-suction centrifugal types. Those ranging from 3 750 to 18 750 Lpm (1000 to 5000 gpm) are more likely to be double-suction split-case types. Beyond 18 750 Lpm (5000 gpm), the pumps used are either the multiple split-case or the mixed-flow and propeller types. These are the same as those used to move large volumes of water in irrigation and wastewater applications. Pumps with low head requirements, i.e., 10 500 to 15 000 mm (35 to 50 ft), will generally be of a lower speed, i.e., 1150 rpm or less, and/or have the smaller impeller diameters. As a final general consideration, if the equipment-space floor elevation is near or

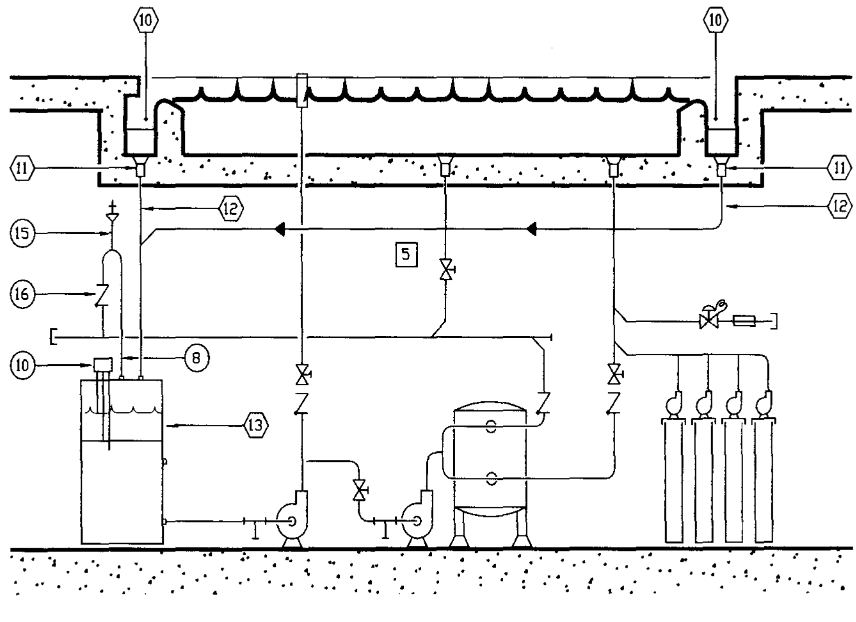


Figure 530-22. Perimeter overflow fountain diagram.

above the return pool's water level, a vertically mounted pump of the turbine, mixed-flow, or propeller type will greatly improve the suction conditions, allowing optimization of NPSH and submergence.

7.2 Fountain Filters

Refer to Table 530-7. Fountain filters are usually a high-rate sand-type unit, sized on the basis of pool area. Use 900 to 1 200 mm² (3 to 4 ft²) of filter area for each 300 000 mm² (1000 ft²) of pool area 900 mm² (3 ft²) is adequate for indoor applications and 1 200 mm² (4 ft²) is appropriate for outdoor installations in an urban area. Diatomaceous earth and cartridge-type filters are sometimes used for fountain installations but are not recommended, given their greater maintenance requirements.

7.3 Filter Pump

For units 750 mm (30 in) or less in diameter, it is usually included as part of a prepiped unit. For larger units, select the pumps as follows.

Flowrate:

Refer to Table 530-7. The 56.2 Lpm (15 gpm) rate should be used unless the extra flow associated with the 75 Lpm (20 gpm) rate is required for display purposes.

Head:

The total head required has to accommodate (a) static level differential; (b) the total calculated for entrance, exit, velocity head, pipe, fitting, valve, and strainer (as taken from Tables 530-4, 530-5, and 530-6); and allowance for losses due to dirt and other particulates building up on the sand bed between backwashings. This allowance should be 10 500 mm (35 ft) for units with manual backwash and 7 500 mm (25 ft) for units with automatic backwash.

Net Positive Suction Head Selection:

The NPSH calculations and pump selection will be the same as for the display pump. (See 7.1 Display Pump in this section.)

7.4 Piping Materials

Piping materials are generally noncorrosive. Each material has particular advantages and limitations, particularly in light of economic considerations.

Polyvinyl Chloride:

Polyvinyl chloride (PVC) is noncorrosive and has low friction losses. Its limitations include its vulnerability to ultraviolet deterioration in exposed outdoor situations and its limited physical strength, leading to a variety of failures, particularly at fittings. Failure may be induced by differential settlement, physical damage, or vibration in the pumping system. Vibration is a particularly common problem for open fountain systems where either entrained air in the return system or operation at more or less than design flow (and hence lower efficiency) will cause the pump(s) to vibrate. PVC is appropriate for low-budget installations, for underground piping in planted areas where repairs can easily be made, or for carefully controlled circumstances where it may be embedded in concrete.

Copper:

Copper, also noncorrosive, has much better physical strength than PVC, particularly at fittings. Costs generally limit its application to sizes 75 mm (3 in) and smaller. Copper must be dielectrically isolated from adjacent steel piping and equipment to prevent galvanic action, which causes deterioration of the steel, particularly galvanized steel.

Red Brass:

Red brass has many of the same characteristics as copper but has greater physical strength, making it particularly useful for exposed piping in the pool. In general, its high cost limits it to this application.

Steel:

Steel is probably the best overall material for any piping that is 75 to 100 mm (3 to 4 in) or larger in diameter. Fountain water has a high oxygen content and the system is not only open but often drained down for cleaning and winterization. Piping should be galvanized or epoxy-lined to prevent rust formation and staining. Note that galvanization may be impractical where the piping is threaded or in close proximity to fittings (or other hardware) made of brass or bronze.

Ductile or Cast Iron:

Ductile or cast iron is used in all sizes for the overflow/drain system. Generally, it is an economic alternative to steel for long runs at diameter sizes of 200 mm (8 in) or larger. It should be specified to be cement-lined, and for pressure systems it should have mechanical joints. Ductile iron may be welded for waterstops, shaped nipples, and other special fabrications, whereas cast iron cannot be.

7.5 Pipe Sizing

Table 530-8 shows maximum pipe sizes and corresponding velocities for any given function. Return piping size must be reviewed in light of NPSH requirements.

Sizing for gravity return, drain, and overflow piping is critical and must be carefully calculated, particularly for long piping runs and minimal slopes. Improper sizing may result in flooding and/or pump damage.

7.6 Fittings, Valves, and Strainers

This hardware is generally of the same material and size as the piping. Gate valves are suitable for shutoff only, while butterfly valves, globe valves, and ball valves and

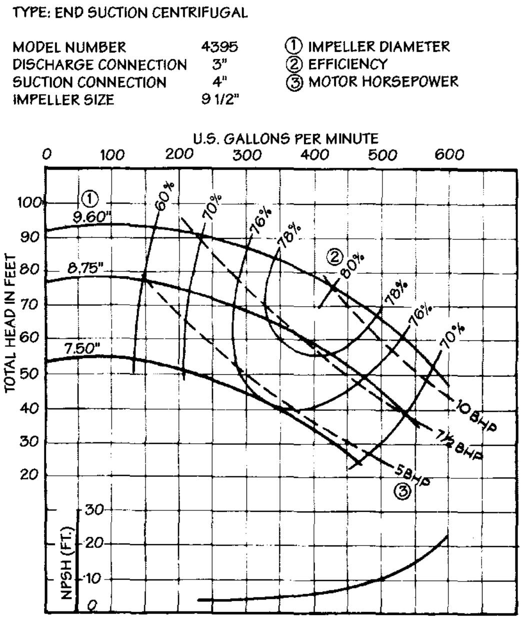


Figure 530-23. Typical pump curve.

Table 530-4.
PIPE SIZING AND HEAD LOSS CHART
(Expressed in feet of water per 100 feet length of pipe)

VELOCITY	2 F.P.S.		5 F.P.S.		7 F.P.S.		10 F.P.S.	
FUNCTION	• GRAVITY RETURN		• RETURN ≤ 3" • GRAVITY DRAIN		• RETURN > 3" • PRESSURE SUPPLY OR DRAIN ≤ 3"		• PRESSURE SUPPLY OR DRAIN > 3"	
SIZE	GPM	HD. LOSS	GPM	HD. LOSS	GPM	HD. LOSS	GPM	HD. LOSS
½"	2	7.4	5	38.3	7	70.5	10	134.8
¾"	3	5.9	8	28.6	12	50.2	17	95.1
1"	5	3.8	13	20.4	19	38.0	27	73.7
1¼"	10	2.9	23	14.6	32	27.1	46	53.1
1½"	13	2.2	32	12.2	44	23.3	63	44.0
2"	19	1.8	49	9.5	68	17.7	98	34.5
2½"	31	1.3	76	7.3	103	13.8	151	26.5
3"	44	1.1	110	6.0	152	11.0	220	21.5
4"	78	0.78	195	4.0	273	8.0	393	15.0
5"	125	0.60	308	3.3	428	6.1	612	11.8
6"	177	0.48	440	2.6	616	4.9	881	9.7
8"	315	0.34	780	1.8	1090	3.5	1560	6.7
10"	490	0.27	1240	1.4	1657	2.7	2450	5.2
12"	725	0.23	1760	1.2	2466	2.2	3550	4.2
14"	950	0.18	2400	0.99	3354	1.8	4761	3.6
16"	1250	0.15	3127	0.98	4387	1.6	6255	3.0
20"	1960	0.12	4900	0.65	6910	1.2	9850	2.3
24"	2830	0.09	7100	0.55	9970	0.97	14400	1.9
30"	4400	0.08	11022	0.40	15400	0.95	21500	1.4
VELOCITY HEAD	0.06		0.39		0.76		1.55	

Table 530-5.
HEAD LOSS NOMOGRAPH FOR FITTINGS AND VALVES
(Expressed in equivalent feet of pipe)

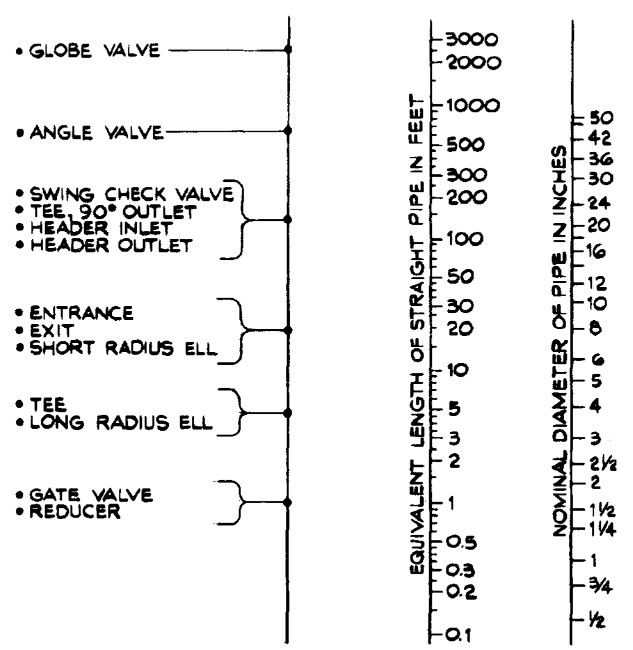


Table 530-6.
HEAD LOSS CHART FOR STRAINERS AND VALVES
(Expressed in feet of water)

BUTTERFLY VALVE

V(fps)	3"	4"	6"	8"	10"	12"	14"	16"	20"	24"	30"	
5	-	-	-	-	-	-	-	-	-	.18	.17	
7	.53	.34	.57	.115	-	-	-	-	-	.35	.37	
10	1.31	1.06	1.38	.78	.69	.46	.57	.6	.5	.75	.70	

BASKET STRAINER

V(fps)	2"	2½"	3"	4"	6"	8"	10"	12"	14"	16"	20"	
5	2.35	1.73	1.5	1.1	.80	.64	.36	.25	.23	.23	-	
7	5.77	4.15	3.0	2.07	1.51	1.03	.64	.55	.46	.46	.46	
10	11.55	6.43	6.46	4.62	2.77	3.01	1.38	1.15	.80	.92	.87	

SILENT CHECK VALVE

V(fps)	2"	2½"	3"	4"	6"	8"	10"	12"	14"	16"	20"	24"
5	4.38	4.15	4.15	4.5	4.62	4.85	4.96	3.9	4.85	3.9	1.73	1.61
7	6.00	6.23	6.69	6.69	7.16	7.85	7.39	5.31	6.0	6.0	6.0	3.11
10	11.08	11.08	11.31	11.31	12.01	13.86	13.16	9.24	10.39	11.55	12.7	23.1+

DIAPHRAM VALVE - GLOBE

V(fps)	1"	1½"	2"	2½"	3"	4"	6"	8"	10"	12"	14"	16"
7	6.2	6.4	4.1	5.7	4.6	1.6	1.6	4.8	2.0	4.6	5.7	5.7
10	11.5	13.4	9.0	11.5	10.4	7.8	4.4	8.0	11.0	9.4	11.5	11.5
12	20.7	20.3	12.7	18.5	15.7	11.8	12.0	13.1	15.9	13.8	16.1	16.1

DIAPHRAM VALVE - ANGLE

V(fps)	1½"	2"	2½"	3"	4"	6"	8"	10"	12"	14"	16"	
7	5.5	3.2	3.2	2.3	2.3	-	2.8	-	2.3	2.8	2.3	
10	11.0	6.5	5.8	5.5	4.6	1.8	4.6	4.6	4.1	4.9	4.8	
12	16.1	8.3	9.5	7.4	6.7	7.2	7.8	6.5	6.2	7.2	7.0	

Table 530-7. HIGH RATE SAND FILTER DATA

FILTER TANK DIAMETER	SAND BED AREA	POOL SIZE		FLOW RATE	
		3/1000	4/1000	15GPM	20GPM
1'-4"	1.4 SQ. FEET	465	350	21	28
1'-8"	2.2 SQ. FEET	730	550	33	44
2'-0"	3.1 SQ. FEET	1030	775	47	62
2'-6"	4.9 SQ. FEET	1630	1225	74	98
3'-0"	7.1 SQ. FEET	2366	1775	107	142
3'-6"	9.6 SQ. FEET	3200	2400	144	192
4'-0"	12.6 SQ. FEET	4200	3150	189	252
4'-6"	15.9 SQ. FEET	5300	3975	239	318
5'-0"	19.6 SQ. FEET	6530	4900	294	392
5'-6"	23.7 SQ. FEET	7900	5925	356	474
6'-0"	28.3 SQ. FEET	9430	7075	425	566
6'-6"	33.2 SQ. FEET	11,065	8300	498	664
7'-0"	38.5 SQ. FEET	12,830	9625	578	770
7'-6"	44.2 SQ. FEET	14,730	11,050	663	884
8'-0"	50.3 SQ. FEET	16,765	12,575	755	1006

cocks may be used for shutoff or throttling. Diaphragm valves are used for sequencing, flow regulation, and other forms of automatic modulation. All strainers should be fitted with brass or stainless-steel baskets. Strainers over 200 mm (8 in) in diameter should be provided with either an integral cover lift or an auxiliary means to lift the cover.

7.7 Pool Hardware

Aside from underwater lighting, several basic items of hardware are required for pool operation, and several more are available to facilitate maintenance.

Return Fitting:

A fabricated fiberglass or metal sump is usually employed, with an antivortex cover plate to prevent any entrainment of air. For large installations, the return fitting may be a concrete sump formed in the pool floor, with a cover grate and leaf screen; a cover plate is not necessary, as the increased depth prevents vortexing or air entrainment.

Figure 530-24 shows a fabricated sump with an infill-type antivortex cover plate. The plate is designed to receive concrete or tile infill to match the pool bottom. Figure 530-25 shows a formed concrete sump in the pool floor. This type of sump is generally employed for flowrates in excess of 3 750 Lpm (1000 gpm) where the fountain is on-grade. In a rectangular configuration, a sump can simply have more return elbows; for instance, 750 mm x 1 500 mm (2-1/2-ft x 5-ft) sump would have two 200 mm (8 in) return ells entering the long wall on quarter points. The sump may assume any irregular shape, which can be accommodated simply by discounting all sump area beyond the basic configuration.

Supply Fitting:

Either a nozzle (as discussed above in 4.0 Water Effects) or a nonexpressed source employing one or more fabricated sumps (as shown in Figure 530-24) is necessary. For larger nonexpressed sources, one or more formed concrete sumps may be used, as shown in Figure 530-26.

Fill/Makeup Fitting:

If the supply is nonexpressed, fill/makeup fittings may be routed via the supply fitting. If jets are used, then a separate fitting should be used (Figure 530-27).

Filter Systems Fittings:

Main-drain (filter return), skimmer, eyeball supply, and vacuum fittings are all carryovers from swimming pool design and should be avoided if possible, as they will clutter the pool with hardware that is of questionable value and nearly impossible to conceal. The filter return may be via the main return sump in lieu of the main drain and skimmers. Supply to the pool may be via the fill/makeup fitting rather than eyeball supply fittings if effective circulation can be promoted via the display system.

Overflow Fitting:

Refer to Figure 530-27. Where possible, a submerged overflow strainer may be used in conjunction with an inverted trap. If the pool is elevated, a conventional sidewall fitting may be used unless the freeboard is inadequate, in which case a standpipe or a specially fabricated slot-type overflow may be used.

Table 530-8. SIZING OF GRAVITY FLOW PIPING

TYPE OF PIPING	SIZING	SIZED FOR MAXIMUM VELOCITY OF:
GRAVITY RETURN PIPING	Sizing is critical & must be carefully calculated for long piping runs & minimal slopes	600 mm/sec. (2 fps)
RETURN PIPING	75 mm (3") & smaller 100 mm (4") & larger	1.5 m/sec (5 fps) 2.1 m/sec (7 fps)
SUPPLY PIPING	75 mm (3") & smaller 100 mm (4") & larger	2.1 m/sec. (7 fps) 3.04 m/sec. (10 fps)
GRAVITY DRAWN AND OVERFLOW PIPING		1.5 m/sec. (5 fps)
PUMPED DRAIN PIPING	75 mm (3") & smaller 100 mm (4") & larger	2.1 m/sec. (7 fps) 3.04 m/sec. (10 fps)
FILL/MAKE-UP PIPING		3.04 m/sec. (10 fps)

Drain Fittings:

Refer to Figure 530-27. In general, each pool should have a drain at its lowest elevation. In the case of return or source pools, this may be via the return or sump, utilizing the fittings or drains shown in Figures 530-24, 530-25, or 530-26. For intermediate pools, a separate valved drain or solid-top drain may be used.

Finishes:

Important compatible finishes should be selected, since the pool fittings may be provided by several suppliers and/or fabricators. Either a brass/bronze or stainless-steel/nickel plate vernacular generally is used. This should include gratings and frames for the return/supply pumps, jets, and fill/makeup, overflow, and drain fittings, as well as for the lighting fixtures.

8.0 FOUNTAIN LIGHTING

Fountain lighting is typically thought of only in terms of underwater lighting; however, the use of daylighting (i.e., optimizing orientation relative to sunlight) as well as floodlighting has great potential and is considerably less costly than underwater lighting. Effective use of each of these alternatives is both an art and a science. Although a thorough discussion is beyond the scope of this section, a brief overview of the applications of each is appropriate. Information on colored lighting is not included here, as ample reference material is available from manufacturers and the applications are limited. (Refer to Section 540: Outdoor Lighting, for more information.)

8.1 Daylighting

Daylighting is a very important aspect of siting and display orientation, particularly with directional displays. Sunlight is especially effective on free-falling or formed jets, as it attractively reflects off the sheet surface, illuminating surface highlights. It also works well with whitewater displays such as textured waterwalls, waterstairs, cascading falls, and aerated jets. In the northern hemisphere, a southerly exposure is optimal. An easterly or westerly orientation affords morning or afternoon light. Northerly exposures generally offer little enhancement to the basic readability of the display; moreover, windborne spray and splash do not dry quickly, and so the cooling potential is minimized.

Table 530-9. LIGHTING

MINIMUM BEAM CANDLEPOWER REQUIREMENTS													
WATER EFFECT HEIGHT (IN FEET)	5	10	15	20	25	30	35	40	45	50			
CANDLEPOWER REQ'D. (IN THOUSANDS)	4	11	21	34	50	69	91	115	144	170			

BEAM CANDLEPOWER AVAILABLE FOR VARIOUS LAMPS													
WATTAGE ENVELOPE BEAM (1)	150 PAR SP (3)	150 PAR FL (3)	250 PAR SP (4)	250 PAR FL (4)	300 PAR NSP (3)	300 PAR MFL (3)	300 PAR WFL (3)	500 PAR NSP (4)	500 PAR MFL (4)	500 PAR WFL (4)	1000 PAR NSP (4)	1000 PAR MFL (4)	1000 PAR WFL (4)
CANDLEPOWER AVAILABLE (2) (IN THOUSANDS)	10.5	3.5	34	6	70	22	10	90	49	18	160	60	27

(1) NSP = NARROW SPOT, SP = SPOT, FL = FLOOD, MFL = MEDIUM FLOOD, WFL = WIDE FLOOD.

(2) CANDLEPOWER SHOWN IS INITIAL AVERAGE IN CENTRAL 5° CONE FOR SPOTS, CENTRAL 10° CONE FOR FLOODS.

(3) INCANDESCENT LAMPS, 2000 HOUR AVERAGE LIFE.

(4) TUNGSTEN HALOGEN LAMPS, 4000 HOUR AVERAGE LIFE.

8.2 Floodlighting

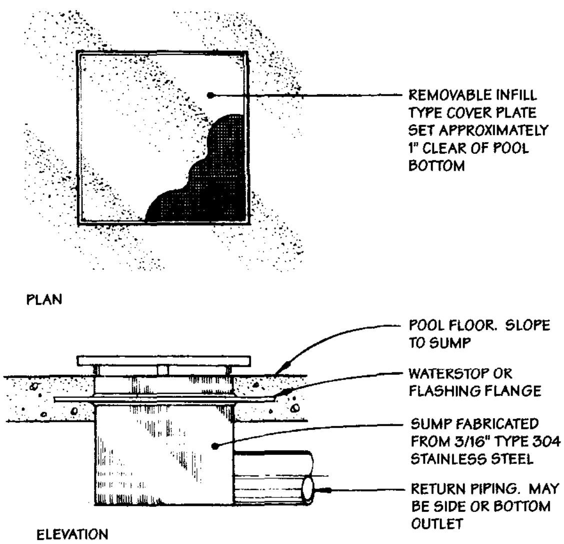
The effects of floodlighting are very similar to those of daylighting, but floodlighting must be used very judiciously, as the distraction of visible sources often offsets the value of the lighting. If sources can be minimized, this can be a very effective and economical means of lighting. Floodlighting may also be used in combination with underwater lighting, affording a broader spectrum of effects with which to achieve the overall composition.

8.3 Underwater Lighting

Underwater lighting is potentially the most dramatic, as it renders a self-illuminated quality to display effects, particularly with regard to free-falling sheets and jets. The water acts like a lens, refracting and diffusing the light. Underwater lighting must, however, be used judiciously, as each fixture in place costs 3 to 5 times as much as a floodlight or typical open-air landscape fixture because of the requirements for submersibility, corrosion resistance, and code-required safety provisions. Furthermore, the maintenance for underwater units is considerably more costly than for landscape units.

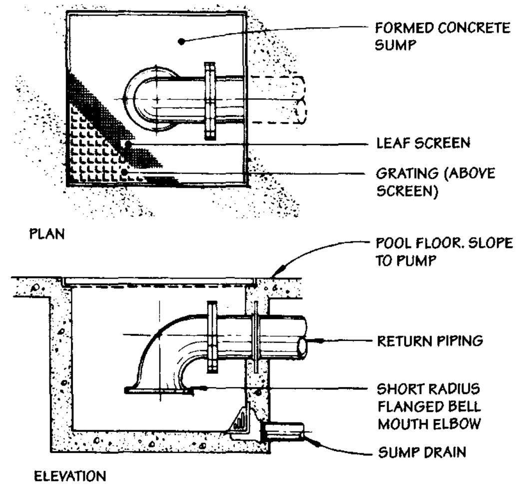
Underwater lighting may be used in two basic ways: uplighting, as used for a sheet or jet, and pool lighting, where the pool itself is lighted to delineate surrounding surfaces or to feature materials and/or textures. Uplighting is generally the more dramatic and practical of the two.

Pool lighting generally requires many more fixtures than uplighting, and because



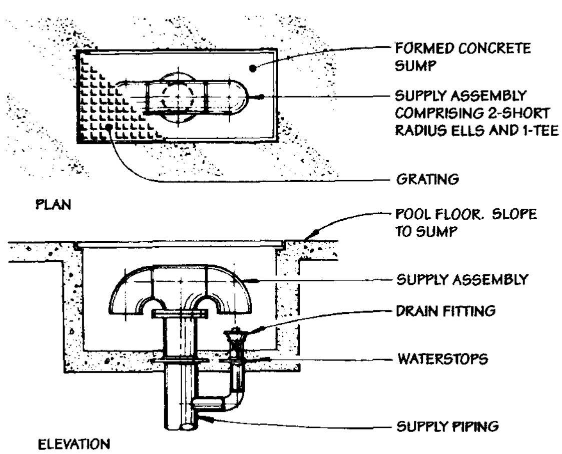
MAXIMUM G.P.M.	SUMP SIZE	COVER PLATE SIZE	RETURN PIPE SIZE
200	8" x 8" x 8" DEEP	1'-0" SQUARE	4" Φ
300	1'-0" x 1'-0" x 1'-0" DEEP	1'-4" SQUARE	6" Φ
500	1'-6" x 1'-6" x 1'-4" DEEP	2'-0" SQUARE	8"Φ

Figure 530-24. Return/supply sump.



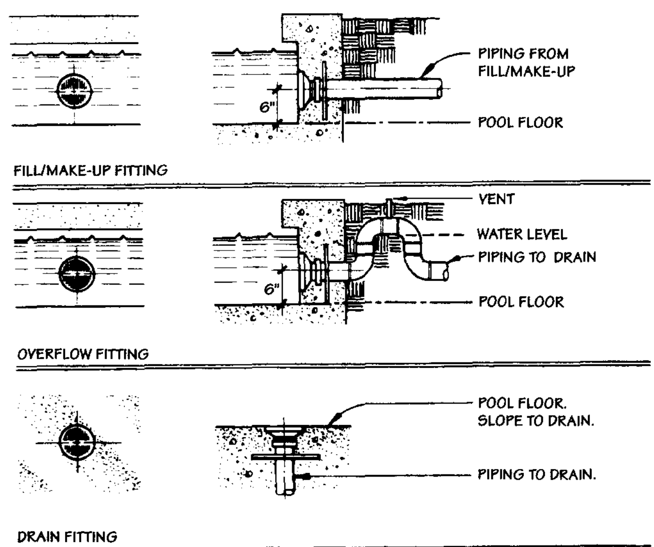
MAXIMUM G.P.M.	MINIMUM SUMP SIZE	RETURN PIPE SIZE
1000	2'6" x 2'-6" x 2'-6" DEEP	8" Φ
1750	3'-0" x 3'-0" x 3'-0" DEEP	10"Φ
2500	3'-6" x 3'-6" x 3'-6" DEEP	12"Φ
3250	4'-0" x 4'-0" x 4'-0" DEEP	14"Φ
4000	4'-6" x 4'-6" x 4'-6" DEEP	16"Φ
5500	5'-0" x 5'-0" x 5'-0" DEEP	18"Φ
7000	5'-6" x 5'-6" x 5'-6" DEEP	20"Φ

Figure 530-25. Return sump.



MAXIMUM G.P.M.	MIINIMUM SUMP SIZE	SUPPLY PIPE SIZE
150	2'-0" x 1'-0" x 1'-3" DEEP	3" Φ
400	2'-6" x 1'-3" x 1'-6" DEEP	4" Φ
900	3'-6" x 1'-6" x 2'-0" DEEP	6"Φ
1600	4'-6" x 2'-0" x 2'-6" DEEP	8" Φ
2500	6'-0" x 2'-6" x 3'-0" DEEP	10" Φ
3500	7'-0" x 3'-0" x 3'-6" DEEP	12" Φ
4750	8'-0" x 3'-6" x 4'-0" DEEP	14" Φ
6250	9'-0" x 4'-0" x 4'-6" DEEP	16"Φ

Figure 530-26. Return sump.



NOTES

1. IF POSSIBLE, ALL STRAINERS SHOULD BE THE SAME CONFIGURATION, DIMENSION AND SHAPE.
2. FOR CONCRETE FINISH POOLS, A ROUND STRAINER WILL ELIMINATE THE POSSIBILITY OF AN OUT-OF-SQUARE FITTING.
3. FOR TILE FINISH POOLS, AN 8" SQUARE STRAINER CAN VISUALLY BE INTEGRATED INTO THE TILE MODULE.
4. FOR STONE FINISH POOLS, A 7" ROUND STRAINER CAN BE FITTED IN A 8" CORE DRILL HOLE.

Figure 530-27. Pool fittings.

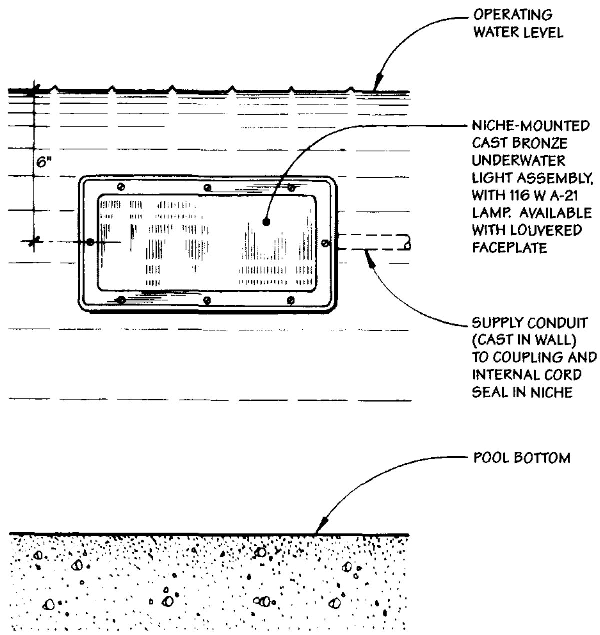


Figure 530-28. Submersible lighting.

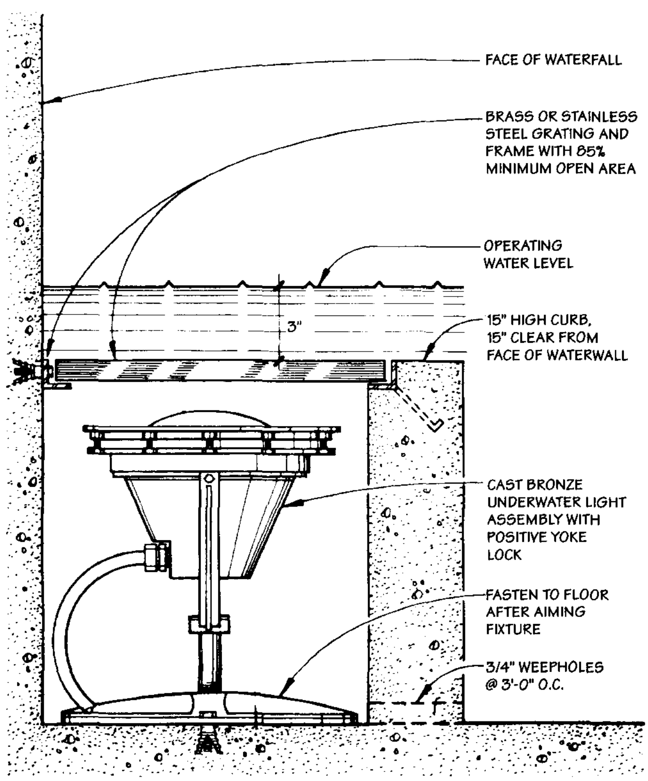


Figure 530-29. Submersible lighting.

the inside surfaces of the pool need to be light-colored to reflect the light, this often compromises the pool's reflective capabilities during the day; it should be mentioned, too, that painting a pool a light color will give it an appearance more like a commercial swimming pool than an ornamental pool or fountain. Pool lighting also makes silt and debris considerably more visible, necessitating more frequent maintenance. Lastly, but perhaps of greatest importance, the lighting must be very well maintained, because the effect of having only one or two lamps burned out may be much worse than having no light at all.

8.4 Design Principles

Although nighttime lighting, whether floodlighting or underwater lighting, is generally used to accentuate only a part of the total fountain composition, it typically intensifies the nighttime presence of the illuminated pools or display elements (as compared to the daylight impact). With larger, more complex fountains, an intermediate lighting level is often introduced, subordinate to the focal elements while still strongly contrasting with the immediate surroundings. This typically requires the use of underwater lighting in lieu of, or in addition to, any floodlighting that may be used.

Once the basic composition is determined, the design criteria are fairly objective. Lighting intensity is based on luminance, i.e., surface brightness, measured in footlamberts rather than footcandles.

Human perception of light intensity is generally logarithmic in nature, requiring 10 times the brightness to double the intensity perceptually. Accordingly, the brightness of a primary display should average at least 10 times the surrounding ambient light level and 3 times the subordinated displays. The uniformity ratio—the maximum to minimum brightness for any display element—ideally should not exceed 3:1.

Since water displays are generally highly reflective and localized, the use of relatively low-level light will achieve the desired brightness. Careful selection of the type of lamp is the key to proper lighting and, as such, should precede the selection of the lighting fixture itself. For example, when lighting a narrow, vertical jet, a very narrow low-voltage 240-W spot lamp affords more light in the critical 5-degree central cone than does a 1000-W spotlight. In general, narrow-beam spotlights are used for lighting jets and wide-beam floodlights for falling water. In the interest of uniformity, a minimum of two fixtures should be used for

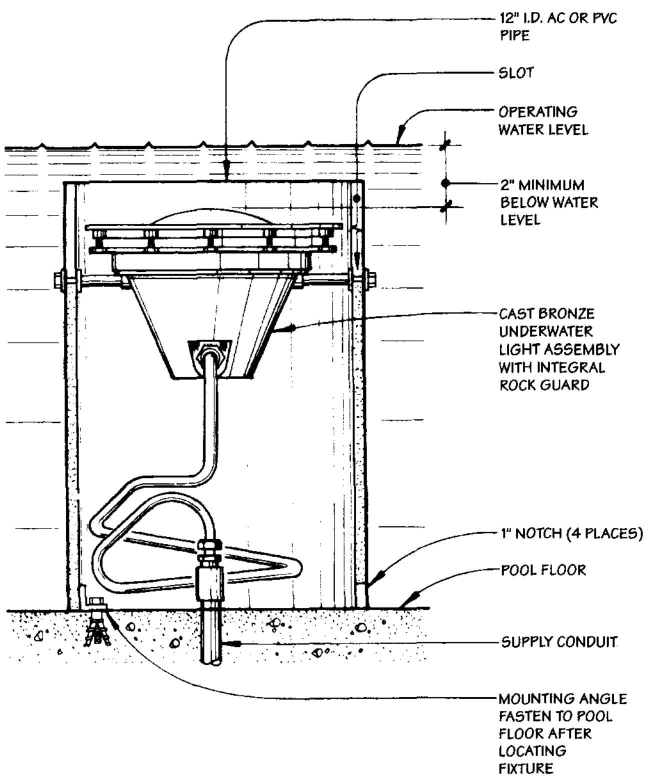


Figure 530-30. Submersible lighting.

KEY POINTS: Pool and Fountain Lighting

Lighting for pools and fountains includes underwater lighting, daylighting and floodlighting.

1. In the northern hemisphere, a southerly exposure is optimal for daylighting water displays. Northerly exposures generally offer little enhancement to the readability of the display; moreover, windborne spray and splash do not dry quickly, so the cooling potential is minimized.

2. The effects of floodlighting are similar to those of daylighting, but floodlighting must be used very judiciously, as the distraction of visible sources often offsets the value of the lighting.

3. While underwater lighting can be dramatic, each fixture costs 3 to 5 times as much as floodlights or typical open-air landscape fixtures because of the requirements for submersibility, corrosion resistance, code-required safety provisions, and maintenance.

4. Generally, the brightness of a primary lighting display should average at least 10 times the surrounding ambient light level and 3 times the subordinated displays.

5. In the interest of uniformity, a minimum of two fixtures should typically be used for jet displays and maximum spacing of 1 000 mm (3 ft) on center used for waterfall uplights.

6. Fixtures should be selected to accommodate (1) the type and orientation of the lamps, (2) the pool configuration and finish, (3) applicable codes, and (4) regular maintenance.

jet displays and maximum spacing of 1 000 mm (3 ft) on center used for waterfall uplights. Fixtures should be selected to accommodate (1) the type and orientation of the lamps, (2) the pool configuration and finish, (3) applicable codes, and (4) regular maintenance.

It should be noted that fountains are rarely overlighted, but the lighting for a single jet or waterfall need not be as complex as described above. Most suppliers of components offer relatively simple tabular data, such as that shown in Table 530-9.

8.5 Installation

There are several critical considerations regarding the physical installation of underwater fixtures, including proper submersion, minimization of hardware, shielding the source from view, and accommodating code-mandated safety requirements.

Submersion:

Most underwater fixtures rely on submersion for cooling to prevent lamp and lens breakage. Minimum submersion is about 25 mm (1 in), with 50 mm (2 in) submersion commonly specified to accommodate wave action and water level variability. Any depth beyond this dimension should be minimized, as the light output is reduced by 10 percent for every 2 in of submergence.

Minimization of Hardware:

Underwater fixtures are inherently bulky, and the need for cords, junction boxes, and other related hardware compounds the problem. Figures 530-28, 530-29, and 530-30 show clear, typical details for the installation of underwater fixtures for the delineation and uplighting of sheets and jets; although these are only representative, they do show methods for concealing cords, conduits, and junction boxes and for minimizing the presence of the fixture itself. Among the several variations on typical fixture construction and installation detailed in these figures, the more important include the following.

Yoke Locks: Yoke locks should be specified for fixtures used to illuminate falling water from jets or waterfalls, particularly when vertical dimensions exceed 6 000 mm (20 ft). Fixtures positioned by friction devices are inadequate for heavy falls or jets.

Bases: Bases should be secured to the pool floor to prevent any movement due to falling water or any dislocation that might occur in the course of normal pool maintenance.

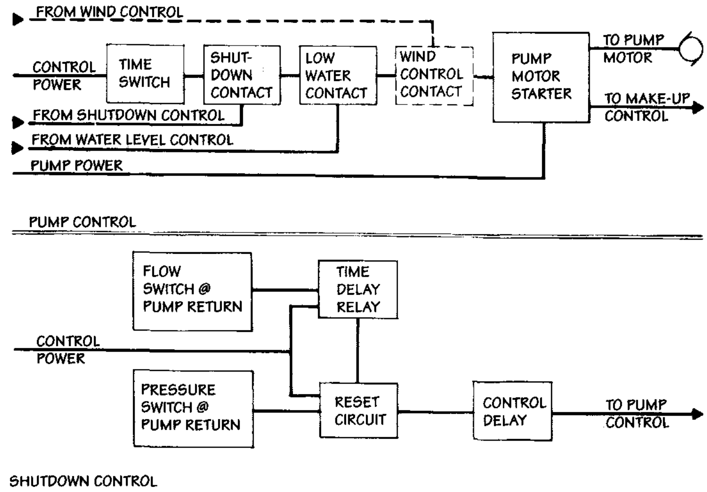


Figure 530-31. Controls (pump control, shutdown control).

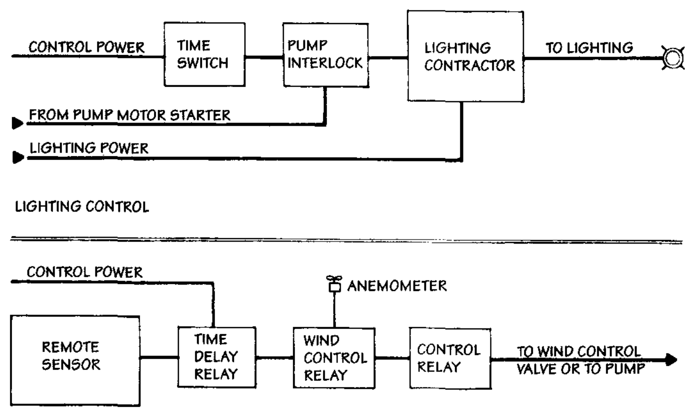


Figure 530-32. Controls (lighting control, wind control).

Rock Guards: Rock guards are required by code for fixtures facing upward. A cast-bronze grid integrated with the lens door is commonly used, but a protective grating (as shown in Figure 530-29) will serve the purpose just as well.

Flush-Mounted Fixtures: A flush-mounted fixture (as shown in Figure 520-28) cannot be embedded directly in concrete, but must be installed in a niche with sufficient length of cord to allow the fixture to be elevated to at least 600 mm (2 ft) above water level for relamping. Since the niche is a wet area, a cord seal, like that used at the fixture for the cord connection, should be used at the conduit entry to the niche to keep water out of the conduit system. This fixture, which employs the standard A-type lamp, should always be provided with the traffic signal version of this lamp, which affords an 8000-hour average lamp life rather than the 750-hour life of the household version.

Shielding the Source:

Figure 530-28 shows a fixture that can be fitted with an optional cast-bronze louver if the fixture falls within the line of sight from normal viewing positions. Figure 530-29 shows a fixture below a linear bar grate that, in itself, functions as a louver. In Figure 530-30, the mounting cylinder itself will afford some shielding. Other underwater fixtures have optional louvers that are integral with the lens door and double as the code-required rock guard.

Safety Requirements:

Article 680 of the U.S. National Electric Code (NEC) mandates several safety provisions, including corrosion-resistant conduits, positive grounding, and ground-fault current-interrupting circuit breakers, which trip instantaneously if current leakage to ground exceeds 5 mA (a fraction of the current level that might pose a lethal shock hazard). These provisions must be carefully studied and applied. Because of the somewhat subjective nature of the wording contained in the codes, it is often wise to review the provisions with the authority who will be responsible for inspection and approval of a particular installation.

9.0 CONTROLS

The fountain control system may be as simple as a single manual switch used to turn on or off a submersible pump, or as complex as a fully automatic system with hundreds of electromechanical devices responding to a controlling computer. The primary functions of an automatic control system are: (1) automating otherwise manual chores which may be aesthetic or practical in nature and (2) protecting equipment against damage or deterioration due to inoperative auxiliary equipment, inadequate maintenance, or variable external circumstances. Interestingly, as complex as these systems can become, variants and combinations of only a handful of control devices and a half-dozen or so basic subsystems are used to moderate, protect, and maintain the subsystems discussed in 6.0 Operating Systems.

9.1 Control Devices

Selector Switch:

Selector switches are used to select, vary, bypass, or deenergize the automatic control devices in each subsystem.

Pilot Light:

Pilot lights are used, where appropriate, to show the status of each subsystem.

Motor Starter, Contactor, Relay:

These are magnetically operated or actuated switches. A motor starter, in addition, integrates a thermally operated switching device to protect the motor against a variety of potential malfunctions. When control power is applied to the coil of the actuating electromagnet, one or more contact pairs are simultaneously opened or closed. Removing the control power will reverse the contacts. A relay may have up to 12 sets of contacts, and each of these may be specified as closed or open in the normal (deenergized coil) mode. Each contact pair is then normally open or normally closed.

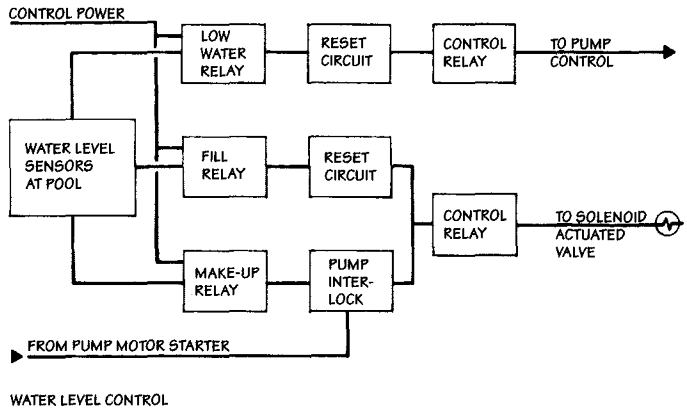


Figure 530-33. Controls (water level control).

Time Delay Relay:

A time delay relay is similar to the relay described above, except that actuation is delayed by an auxiliary timing device. The delay may occur upon energization or deenergization, the length of delay may be adjusted, and instantaneous (nondelayed) contacts may be actuated by the same coil.

Time Switch:

A time switch is a clock-operated switch that may be preset to switch on and off at any desired time of day. If required, the device may be specified to switch several times during each day. Time switches used for lighting may be specified with an astronomic dial which corrects the on time for the time of year and the specific latitude.

Pressure Switch:

A pressure switch opens or closes upon change of pressure. It can be specified to operate on either increasing or decreasing pressure. If the desired actuation is at less than atmospheric pressure, a combination pressure-vacuum or vacuum switch must be specified.

Flow Switch:

A flow switch opens or closes when water is flowing in a pipe, and it reverses mode when the flow ceases.

Level Sensor:

A level sensor is a float- or probe-actuated device used to sense liquid level in a container and to cause a remote low-voltage relay to switch on and off as the level falls and rises. The minimum practical difference between the on and off levels is on the order of 25 mm (1 in).

Wind Sensor:

An anemometer (wind-driven generator) is used to sense wind velocity and to cause a remote relay to switch on or off as the velocity exceeds or falls below a preset velocity.

9.2 Pump Control

Refer to Figure 530-31. Power for the pump is routed through a motor starter. The coil is actuated by a time switch, set to switch the pump motor on and off at the desired times of day. Additional controls in the control circuit will prevent the motor from running if the shutdown system is energized or if the water level in the pool is too low. An auxiliary contact (interlock) in the motor starter is used to keep the make-up system from operating if the pool is drained or a low-water condition exists.

9.3 Shutdown Control

Refer to Figure 530-31. This system is designed to keep the pump(s) from running if the return system is clogged or if the water is not flowing. A third shutdown circuit is included in the water level control. (See 9.6 Water Level Control in this section.)

Clogged Return:

Clogged returns are usually caused by a poorly maintained leaf screen or strainer. As the pump works harder to draw water, a low pressure or vacuum develops between the strainer and the pump. A properly installed pressure or pressure/vacuum switch on the return line will signal this condition.

No Flow:

This condition is caused by a loss of prime (air in the pump), a malfunctioning pump, or a closed valve or other obstruction in the supply piping. A time relay is incorporated in conjunction with the flow switch to allow the flow to become established on start-up.

The control relay is actuated on signal from the pressure/vacuum or flow switch, interrupting power to the pump control circuit. Once the pump is stopped, the system must be reset manually; otherwise, the system would try to restart as the flow diminishes and a full static head is reestablished.

9.4 Lighting Control

Refer to Figure 530-32. This system is virtually identical to the pump control system, utilizing a lighting contactor, or heavy duty type of relay, in lieu of the motor starter. Power is routed through a lighting contactor, which is actuated by an astronomic dial time switch via an auxiliary contact in the display motor starter, ensuring that the lights will not operate if the display is off for any reason.

9.5 Wind Control

This system switches control power through a relay actuated by a wind-driven generator. An integral time delay ensures that the system is not triggered by momentary gusts. Often two relays are used, each with a different set point. When the lower velocity set point is reached, the first-stage control relay is actuated, throttling an automatic valve to reduce jet heights. When the higher velocity is reached, the second-stage control relay interrupts power to the pump and lights. A restart time delay is used to ensure that the pump does not exceed an allowable number of starts per hour or day, which could cause damage to the motor.

9.6 Water Level Control

Refer to Figures 530-20 (Item 10) and 530-33. This system switches control power through relays actuated by water level sensors, either probes or floats, which monitor the water level at the pool. The probe system is most commonly used, each function comprising two probes and a probe relay—although, with proper design, the fill and low-water functions can be combined. The fill and makeup systems utilize a common water level control relay which is used to actuate the solenoid-operated valve. The low-water shutdown system has a separate control relay which is used to interrupt power to the pumps and lights should the water in the pool fall below a preset minimum level.

9.7 Sequencing

The mechanics of controlling a sequenced fountain are sufficiently varied and complex, and the applications infrequent enough, that a detailed discussion here is probably not justified. It is appropriate to note, however, that there are four commonly used methods of controlling sequenced fountains. They are, in order of complexity:

1. A simple cam timer, of the type used to control traffic signals
2. A series of step switches and timing relays
3. Programmable solid-state logic modules
4. Computers of varying capacities

Each of these has a particular useful range. The cam timer, for instance, might control a relatively straightforward group of three or four jets. Intermediate systems could range to the latter methods, which might be used to deliver complex instructions to hundreds of jets and lights—while at the same time responding to environmental variables, such as wind, rain, and temperature—or used to provide a constantly modulated, or fluid, effect rather than a stepped effect.

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Outdoor Lighting

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CONTENTS

1.0 INTRODUCTION

1.1 General

This section includes information useful for solving site lighting problems. Included are definitions of terms associated with lighting, general design principles, characteristics of various lamps, and recommended levels of illumination (industry standards) for various landscape uses. The information included here will aid in the process of specifying fixtures for particular lighting projects.

1.2 Objectives of Outdoor Lighting

The purposes of outdoor lighting include: (1) improving the legibility of critical nodes, landmarks, and circulation and activity zones in the landscape; (2) facilitating the safe movement of pedestrians and vehicles, promoting a more secure environment, and minimizing the potential for personal harm and damage to property; and (3) helping to reveal the salient features of a site at a desired intensity of light in order to encourage nighttime use.

2.0 TERMINOLOGY

Lumen: A quantitative unit of measurement referring to the total amount of light energy emitted by a light source, without regard to the direction of its distribution.

Footcandle (fc): A U.S. unit of measurement referring to incident light. Footcandles can be derived from lumens (1 fc = 1 lumen/sq. ft.) or candelas (fc = candelas/distance^2).

Lux (lx): The International Standard (SI) measure of incident light. It is equal to one lumen uniformly distributed over an area of one square meter (10.7 lx = 1 fc) (Figure 540-1).

Candlepower: The unit of intensity of a light source in a specific direction, often referred to as Candela. One candela directed perpendicularly to a surface one foot away generates one footcandle of light.

Illuminance: Incident light, or light striking a surface (Figure 540-2).

Luminance: Light leaving a surface, whether due to the surface's reflectance, or because it is the surface of a light-emitting object (like a light bulb). Luminance is the measurable form of brightness, which is a subjective sensation.

Efficacy: A measure of how efficiently a lamp converts electric power (watts) into light energy (lumens) without regard to the

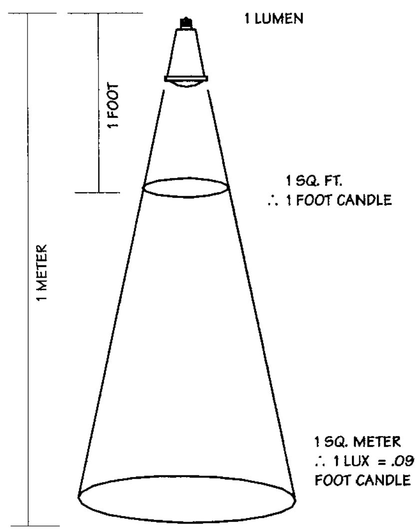


Figure 540-1. Lux and footcandle measurements.

effectiveness of its illumination. It should not be assumed that a lamp which has high efficacy will give better illumination than a less efficient lamp (Figure 540-3).

Light depreciation: Lamp output (lumens) will depreciate over its effective life. Illumination will be reduced further due to an accumulation of dirt and grime on the lamp and fixture. Adjustments should be made to compensate for this depreciation when determining the average values of illumination maintained over time. A maintenance factor of 50 to 70 percent is common for outdoor applications. New installations are routinely designed to deliver 1-1/2 to 2 times as much illumination as needed, to sustain this maintained output over the anticipated life of the lamp.

Color: Two measures used to describe the color characteristics of lamps are (1) the apparent color and (2) the color rendering index.

The apparent color of a light source is given by the color temperature. Figure 540-4 shows various index numbers used to rank sources on a scale that range from warm to cool in appearance. Preference for one or another is a matter of taste and usually varies with the context of the application and with the illumination level. Warm tones tend to be favored when illumination is low and cooler tones are preferred under high lighting levels.

The color rendering index (CRI) is a measurement of the degree to which object colors are faithfully rendered. This scale

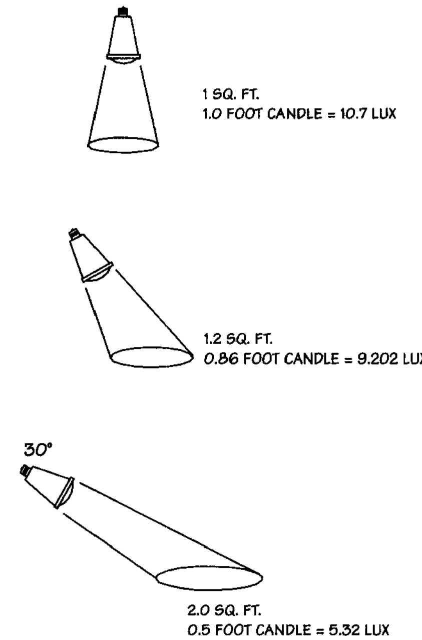


Figure 540-2. Incident illumination.

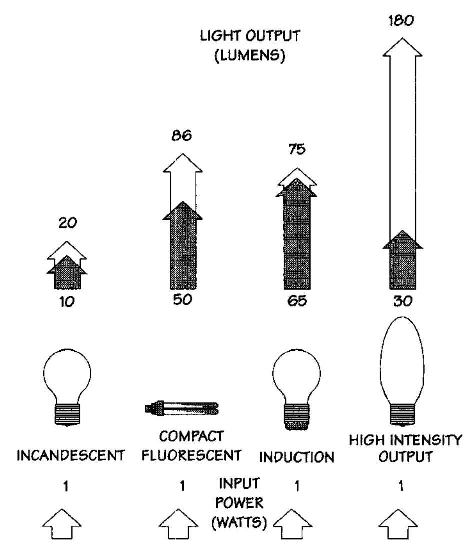


Figure 540-3. Lamp efficacy.

ranges from 0 to 100 and is a reasonable approximation of color rendering accuracy. CRI is completely independent of whether a light source casts the object in a warm or cool tone. The CRI graph shows the ranking of the major outdoor light sources (Figure 540-4). As a general guideline, a minimum CRI of 50 is suggested to attain a reasonably faithful or natural color rendition. Lamps ranked significantly below this are judged to cause visible distortions to appearance.

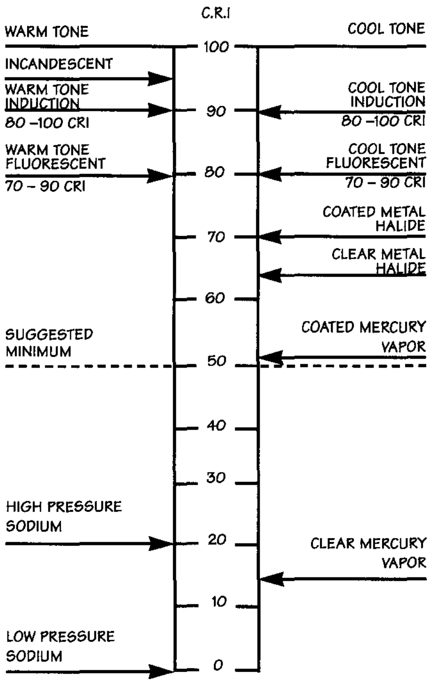
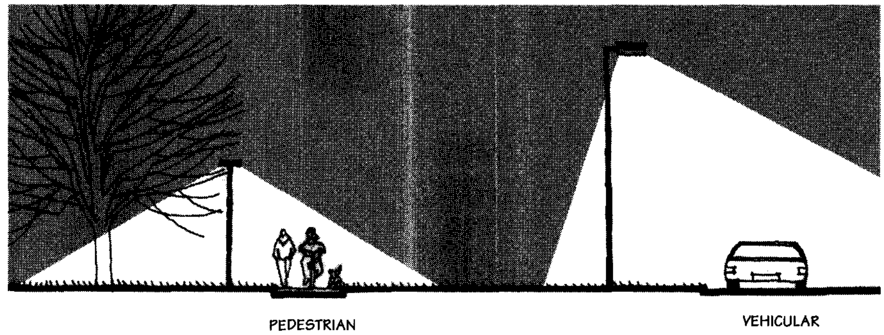
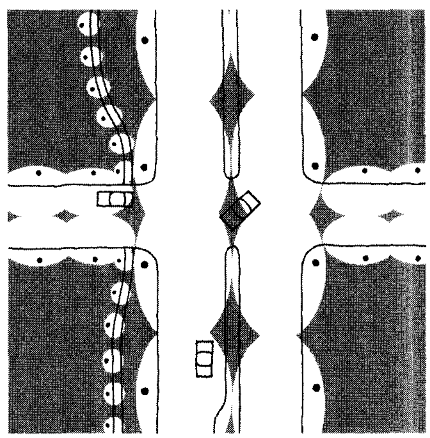


Figure 540-4. Color rendering index.





MAJOR AND MINOR ROADS ARE DISTINCT, AND PEDESTRIAN ROUTES DEFINED.

Figure 540-5. Lighting hierarchy.

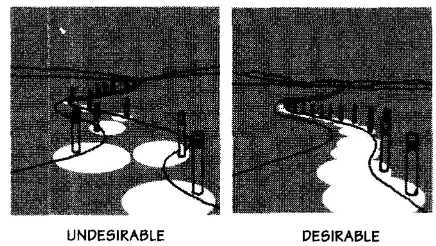


Figure 540-6. Lighting patterns.

Glare: A point or surface of luminance that is above one's current state of adaptation. The human visual system can comfortably see in light levels ranging from starlight to noonday sun, but cannot do so over this entire range at the same time. We adapt to one limited range or another, and perceive glare as any brightness above our current state of adaptation. Disability glare impairs visibility and is primarily a physiological phenomenon; e.g., the nighttime glare from an oncoming vehicle's headlights can momentarily blind a driver's perception of the road ahead. Discomfort glare does not impair visibility but is primarily a psychological phenomenon or an annoyance which may produce fatigue if it continues over an extended period of time.

Cutoff light distribution: A term used in reference to the optical design of some fixture types. Proper placement of lamps and the use of carefully aligned reflectors, can effectively eliminate intense high-angle light. Most cutoff designs severely restrict fixture intensities above 75 degrees from nadir, that is, within 15 degrees of horizontal (Figure 540-16).

3.0 GENERAL DESIGN PRINCIPLES

3.1 Orientation

Lighting Hierarchy:

Driver and pedestrian orientation can be aided by providing a hierarchy of lighting effects that correspond to the different zones and uses of a site. For instance, subtle but recognizable distinctions can be made between major and minor roads, paths, and use areas by varying the distribution and brightness of the light and by varying the height, spacing, and color of lamps (Figure 540-5).

Attaining high levels of illumination along circulation routes does not have to be a prime consideration in outdoor lighting. If a clear and consistent system is provided, low levels may be adequate for safe circulation.

Clear Lighting Patterns:

Clear optical guidance can be provided with the alignment of light fixtures positioned in consistent, recognizable, and unambiguous patterns. A staggered layout of road and pathway lights tends to obscure rather than reinforce the direction of circulation and the location of intersections (Figure 540-6).

3.2 Identification

Intersection Articulation:

Intersections, decision points, crossings, bus stops, steps, arrival points, etc., should be articulated in a manner that signals their presence, shape, and nature. The illumination pattern should serve as a visual cue to what conditions may lie ahead.

Placement of Luminaires:

Spacing, height, and distribution of luminaires should avoid foliage shadows, provide uniformity, and vertical surface illumination. High mounting and wide spacing of fixtures may result in disruptions to the illumination pattern due to tree shadows [Figure 540-7 (top)]. Lower mounting heights and closer spacing between fixtures may create a more uniform distribution of light promoting the pedestrian's sense of security. [Figure 540-7 (bottom)].

Deciding What to Light:

In some circumstances, it may be equally as important to determine what not to light as to determine what to light (Figure 540-8).

3.3 Safety

In addition to poor lighting layout and design, glare and underlighting can create hazardous conditions for pedestrians and vehicles.

Glare:

Glare is a major inhibitor of good visibility and can be produced by any scale of light fixture, including small lens-type step lights (Figure 540-9).

Glare is more of a problem when exposed light sources, such as lamps or lenses, can be seen directly. Luminaire location and mounting height, fixture type, and lamp intensity must be carefully selected to optimize light distribution and minimize glare.

Lower mounting lanterns may or may not have sharp cutoff optics. If high-angle illumination is appropriate in order to illuminate facades, trees, and other streetscape elements, then care must be taken to prevent glare. An outdoor mock-up at night is an excellent technique to use when deciding what light distribution pattern and intensity to use and whether or not there will be any likelihood of glare.

High-angled cobra-head types of lenses are a major source of glare when used along roadways. Luminaires with sharp cutoffs effectively direct the light into a visually useful and comfortable pattern.

Underlighting:

Underlighting is potentially hazardous if insufficient light is provided to protect pedestrians and/or vehicles from potential injury and damage. Sufficient light is especially important in areas where heavy pedestrian traffic is expected, such as near parks, ball fields, and other places that attract crowds of people, or where children cross streets. Parking areas, access and egress points, loading areas, etc., should have adequate lighting to help protect drivers, pedestrians, and vehicles.

Note that overlighting an area can generate high amounts of glare, which can also create hazardous conditions. A careful balance of light intensities must be achieved. Table 540-3 lists recommended levels of illumination as stated in the Illuminating Engineering Society's IES Lighting Handbook. Levels of lighting are related to types of use and other characteristics within use areas.

3.4 Security

Darkness, together with unfamiliar surroundings, can incite strong feelings of insecurity. To provide a sense of security, possible hiding places and dense shadows

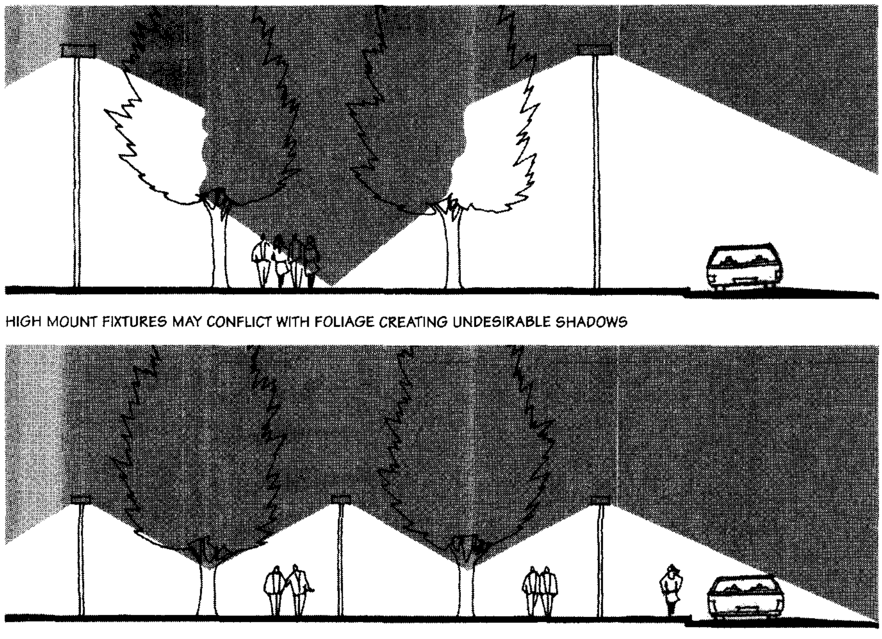


Figure 540-7. Luminaire mounting heights. *Low mount fixtures provide for better uniformity and vertical surface illumination.*

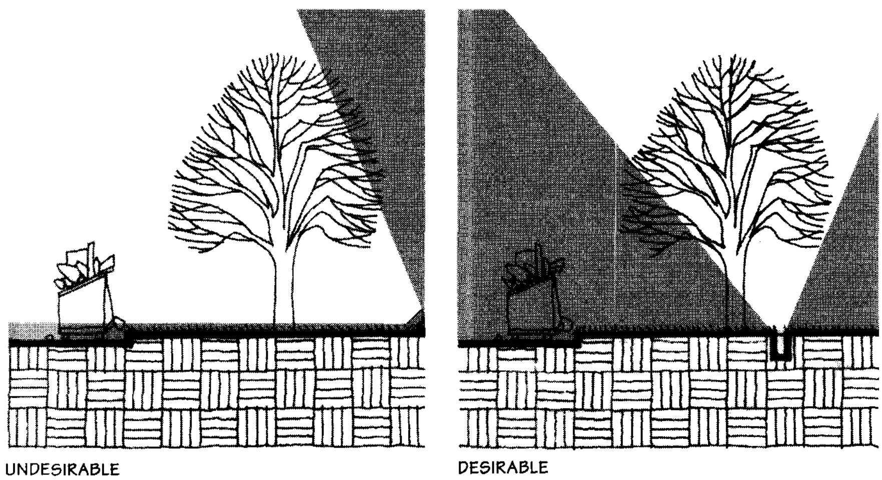


Figure 540-8. What to light and what not to light.

KEY POINTS: General Design Principles

1. Subtle but recognizable distinctions can be made between major and minor roads, paths, and use areas by varying the distribution and brightness of the light and by varying the height, spacing, and color of lamps (Figure 540-5).
2. Clear lighting patterns reinforce the direction of circulation, delineate intersections, and provide a visual cue to what conditions may lie ahead.
3. Glare from exposed light sources and underlighting are major safety concerns (Figure 540-9). Luminaire location and mounting height, fixture type, and lamp intensity must be carefully selected to optimize light distribution and minimize glare.
4. Security is not necessarily enhanced by increasing illuminance levels on the ground; consider peripheral lighting, vertical illuminance levels, and good color-rendering sources as well.
5. Color differentiation, unobtrusive illumination of background spaces, and bright illumination of objects of interest are common approaches for articulating landscape character.

should be minimized by the placement of appropriate light fixtures.

Walkway Lights:

Walkway lights should have enough peripheral distribution to illuminate the immediate surroundings. Vertical light distribution over walkway areas should cover or overlap at a height of 2 100 mm (7 ft) so that visual recognition of other pedestrians is maintained (Figure 540-10). When the pedestrian's sense of security is a primary consideration, low mounting height with close spacing and a vertical illumination pattern may be the most effective approach.

Surveillance:

For surveillance needs, lighting requirements should permit the detection of suspicious movement rather than provide for the recognition of definitive details. For the same expenditure of light energy, it is often more effective to light backgrounds, thereby generating silhouettes, than to light the foreground (e.g., lighting the vertical face of a building instead of its horizontal foreground (Figure 540-11). It is also desirable to highlight entrances and to direct lighting away from points of surveillance.

Vandalism:

The best way to reduce the vandalism of light fixtures is to use fixtures that are durable enough to withstand abuse, or to place them out of reach. An alternative solution may be to use hardware that is less expensive to replace.

3.5 Atmosphere and Character

A consistency of design expression can be achieved by identifying the common elements in a landscape that give it character, and then using similar approaches to their lighting. The clarity with which an object is perceived is influenced by its context.

Background:

Exterior spaces should have a well-defined sense of background. Background spaces should be illuminated as unobtrusively as possible to meet the functional needs of safe circulation and protecting people and property. Whenever possible, these needs should be accommodated with peripheral lighting from the walkways, signage, entrances, and other elements relevant to the definition of the space.

Foreground:

Foreground spaces or objects may be major elements and should be treated according-

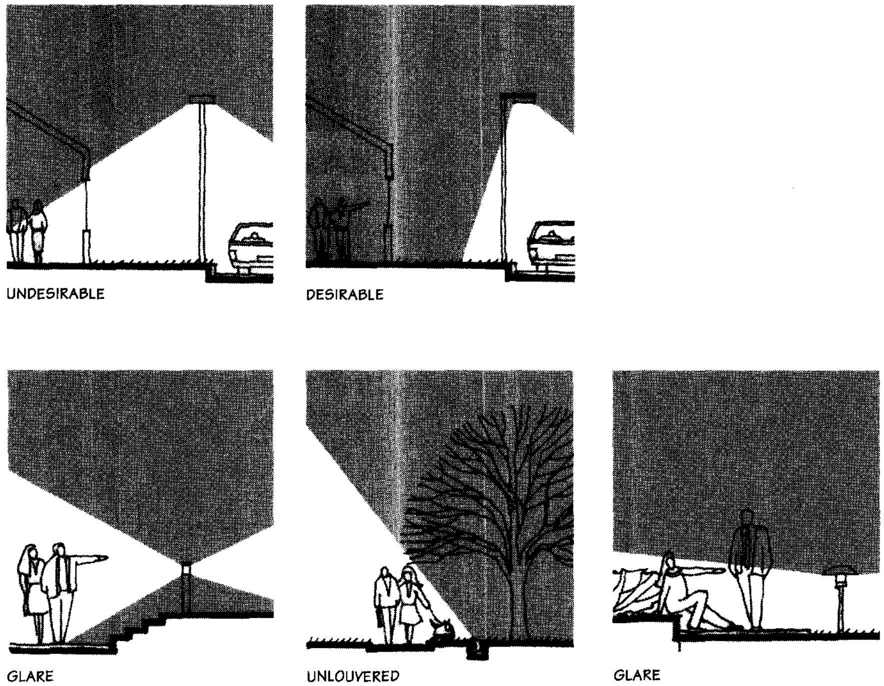


Figure 540-9. Glare.

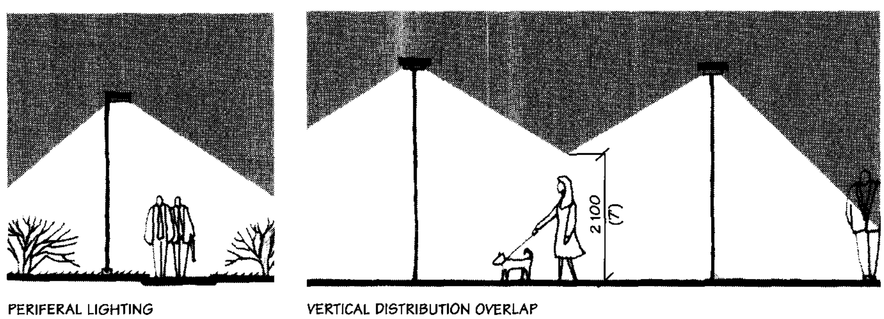


Figure 540-10. Walkway lights.

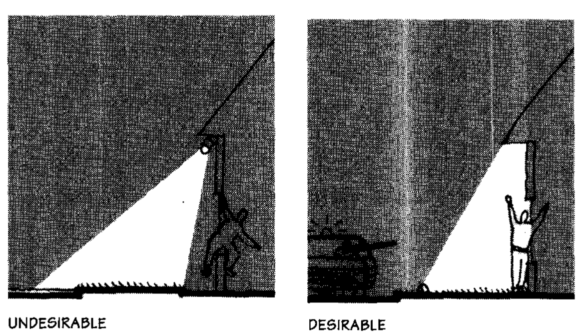


Figure 540-11. Surveillance.

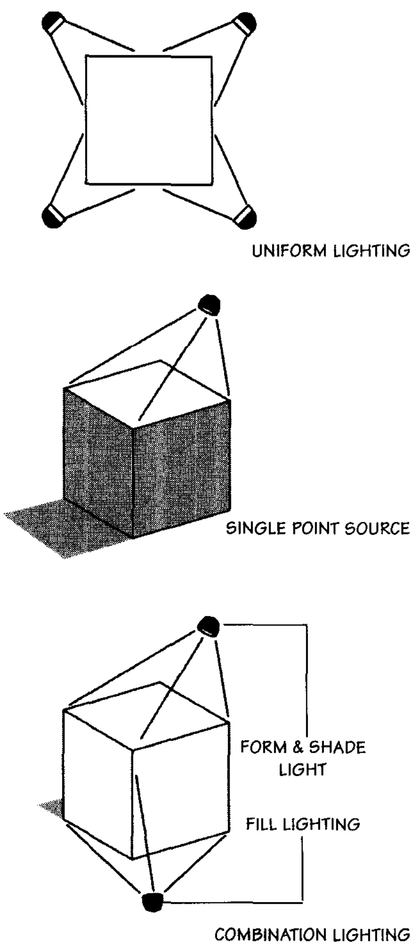


Figure 540-12. Shape accentuation.

ly. Foreground spaces should utilize local lighting which produces maximum focus, minimum distractions, and no glare. Objects of interest and activities can be brightly illuminated while the background produces only minimal distraction.

Illumination of Objects (Shape Accentuation):

The direction of the light source is important for perception of three-dimensional objects. The ability to perceive volumetric form is influenced by the gradient of light and shadow falling on the object. Uniformly distributed, diffused light results in poorly rendered shadows (Figure 540-12); one must then rely upon outline and color in order to perceive the shape and form of the object. Conversely, a single point source will produce maximum shadows but may also minimize the perception of details.

Usually, the best way to illuminate standing objects is with a combination of both types of lighting. One source should accentuate shape and form by contrasting the surface with sharp shadows while the other source provides fill-lighting for details.

Color Perception:

Differences in lamplight color are often used with great effect in public lighting to color code roadways or to clearly delineate one area from another. As the general illumination level rises in a given situation, preference usually shifts away from a warm appearance toward the cool range.

Accurate color rendition will aid recognition and improve the perception of outdoor environments. This is especially important at the pedestrian scale, where the color contrast of paving and landscape materials is often subtle.

4.0 LAMP CHARACTERISTICS AND LIGHT DISTRIBUTION

4.1 Lamp Characteristics

Selection of a lamp involves trade-offs between lamp size, optical control, efficacy, appearance, color temperature, color rendition, lamp life, costs, and maintenance (Table 540-1).

Incandescent Lamps:

Incandescent lamps have superior color rendition and a warm white appearance. The disadvantage of a short lamp life can be overcome by the use of a rugged traffic signal lamp rated at 8000 hours nominal life or by undervoltaging the circuits to extend the life. Incandescent lamps have the lowest efficacy of all the lamps. However, they are inexpensive and the small filament permits good optical control.

Fluorescent Lamps:

Although compact shapes are becoming more widely used, most fluorescent lamps are long and linear, making optical control very difficult. They tend to produce glare unless they are well baffled. They have a good color rendition, whitish appearance, and superior life. Although they have good efficacy, their light output may be severely diminished by very cold weather.

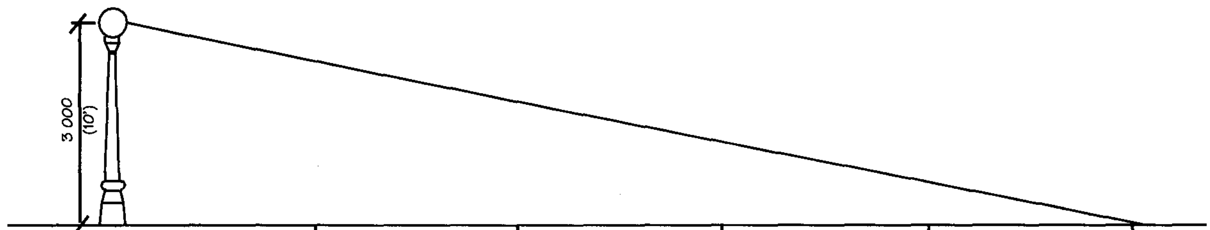
Induction Lamps:

Induction lamps are relatively new, high-frequency sources that have no filaments or electrodes, but rather use the electro-magnetic spectrum to directly energize a phosphor coating on the bulb. These lamps have a light quality similar to fluorescent in a 90-115 mm (3 1/2-4 1/2 in) spherical lamp envelope, but with a significantly longer average rated life (up to 100,000 hours), and with almost no sensitivity to ambient temperature.

Table 540-1. SUMMARY OF LAMP CHARACTERISTICS

Lamp	Wattage range, M (ft)	Efficacy, lumen/watt*	Average life, hrs	Apparent color	Color rendering	Initial cost of equipment
Incandescent	3-300 (10-1000)	10-25	750-2000	Warm white	Best overall	Low
Fluorescent	4.5-64.5 (15-215)	40-80	7500-15,000	Warm to cool white	Good	Medium
Induction	16.5-25.5 (55-85)	63-70	100,000	White	Very Good	High
Mercury vapor (deluxe white)	12-300 (40-1000)	25-60	24,000	Cool white	Good	Medium
Metal halide	52.5-450 (175-1500)	65-105	7500-20,000	Cool white	Very good	Med to High
High-pressure sodium (STP)	10.5-300 (35-1000)	60-120	—	Orange-yellow	Poor	High
'White' high-pressure sodium	45-75 (150-250)	75-80	—	Warm white	Very good	High
Low-pressure sodium	5.4-54 (18-180)	70-150 -	—	Intense yellow	Very poor	High

*Includes ballast losses



MOUNTING HEIGHTS	1	2	3	4	5
150W HPS	19.3 (1.8)	10.7 (1.0)	5.4 (.5)	2.1 (.2)	1.1 (.1)
175W MH	23.5 (2.2)	9.6 (.9)	4.7 (.44)	1.9 (.18)	1.0 (.09)
40 – 50W MV	6.4 (.6)	3.3 (.31)	1.3 (.12)	.7 (.07)	.3 (.03)

MOUNTING HEIGHT MULTIPLIER			
HEIGHT M (FT)	2.4 (8')	3.6 (12')	4.2 (14')
CORRECTION FACTOR	1.5	.69	.51

Figure 540-13. Typical photometric chart for roadway, walkway or area lighting. *Lux (footcandle) levels displayed are for a mounting height of 3 m (10 ft). Other mounting heights must factor in the multiplier listed in the table. Once minimum illumination levels are identified, fixture spacing is determined by multiplying the number of corresponding mounting heights by two.*

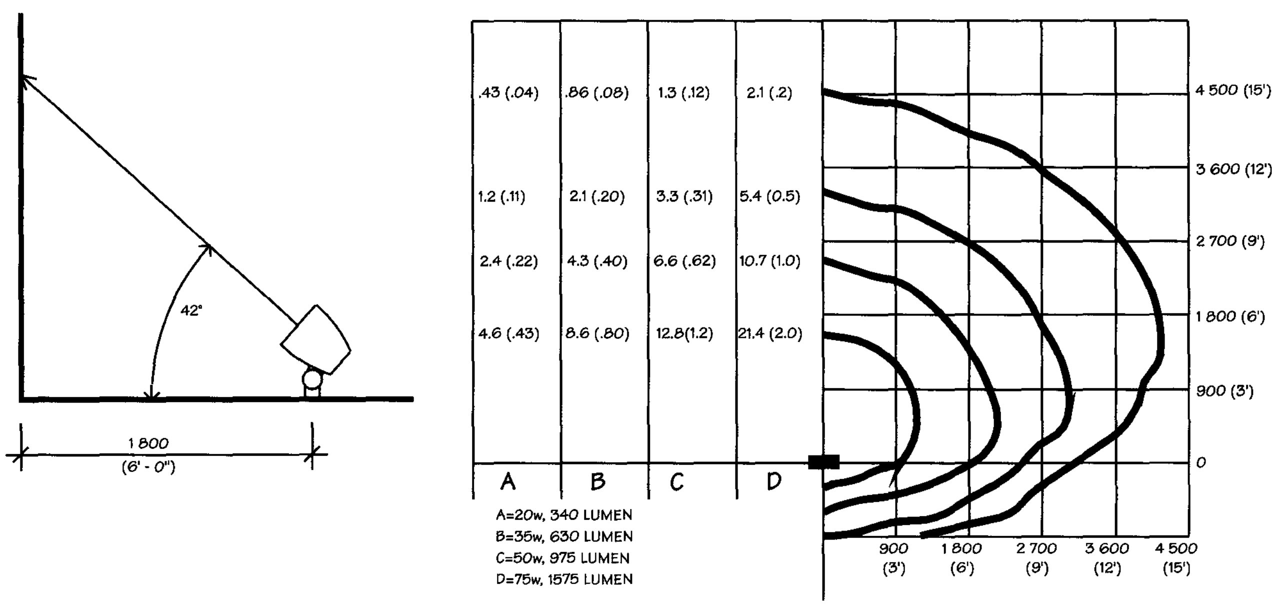


Figure 540-14. Typical photometric chart for directional lighting: *Displayed in lux (footcandles). Illumination levels listed are based on a typical half 42° aiming angle.*

Mercury Vapor Lamps (Deluxe White):

Mercury vapor (MV) lamps have good efficacy, excellent life, and a good cool white color. Strong in the blue-green end of the color spectrum, the lamp is popular for foliage lighting. The cost of the lamp and fixture is the lowest of the high-intensity discharge (HID) lamps. In general, it has a good combination of characteristics when no extremes are required.

Metal Halide Lamps:

Metal halide (MH) lamps offer superior optical control and color rendition. Their efficacy is substantially better than mercury vapor lamps but slightly poorer than high-pressure sodium lamps. The light appears cool white and has a shorter life than the other HIDs. The cost falls between that for mercury vapor and high-pressure sodium lamps.

High-Pressure Sodium Lamps:

High-pressure sodium (HPS) lamps have excellent efficacy, superior optical control, superior life, and very low maintenance, which accounts for their popularity. The light tends to have an orange-yellow appearance and a mediocre color rendition of objects. It rarely enhances foliage colors because of deficiencies at the blue-green end of the color spectrum. If color is not an important consideration, this lamp can have broad application. The initial cost for the lamp and fixture may be higher than

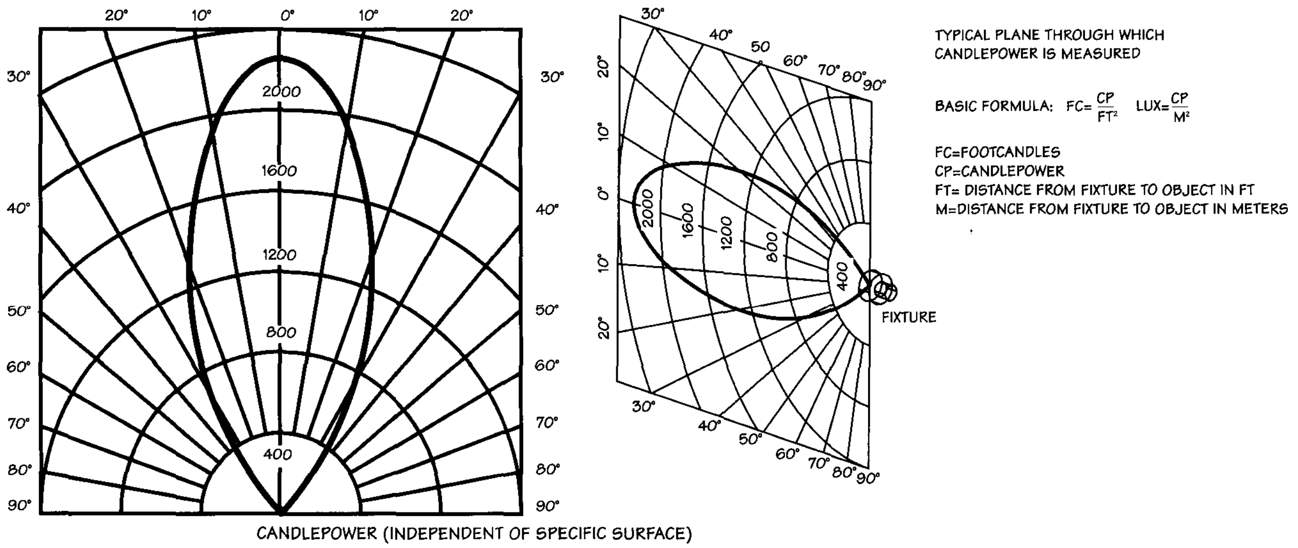


Figure 540-15. Typical photometric chart for directional lighting: *Displayed in candela. Maximum candela in this example is at 0° (2,200 candlepower). Conversion to lux (footcandle) can be calculated by the above formula.*

for metal halide. HPS lamps and fixtures are available in a wide range of sizes.

'White'High-Pressure Sodium Lamps:

These lamps provide excellent color rendition in a warm tone similar to incandescent. Efficacy is sacrificed to obtain improved color. The resulting characteristics are a cross between metal halide and incandescent lamps.

Low-Pressure Sodium Lamps:

Low-pressure sodium (LPS) lamps have the highest operating efficacy but depreciate considerably over their lifetime. A large arc tube results in poor optical control, but the lamp does have superior life. The light itself appears an intense yellow and has very poor color rendition properties. Colors in the landscape appear as shades of gray. The costs are comparable to those of high-pressure sodium lamps.

4.2 Light Distribution

Horizontal and Vertical Distribution:

Horizontal illumination is especially important along the ground plane where changes in grade occur. However, a considerable portion of the night environment is perceived through direct and silhouette lighting of vertical objects and surfaces. Both patterns should be carefully coordinated in developing a successful lighting scheme.

Illumination data for outdoor lighting fixtures are illustrated by the manufacturers' photometric charts. These charts illustrate the actual light patterns and intensity levels on horizontal and vertical planes. Figure 540-13 illustrates basic photometric data for walkway, road or area lighting. Lux (footcandle) measurements are given for horizontal distances based on mounting height and type of fixture. Spacing is determined by identifying minimum desirable lux (footcandle) levels, and doubling the number of mounting height units.

Photometric data for directional lighting, typically used for wall or signage applications, are illustrated by Figure 540-14. The aiming angle is commonly specified, and the fixture type is selected based on distance and illumination requirements.

A third type of photometric chart shows the distribution of candlepower, or intensity, in various directions, independent of any specific surface (Figure 540-15). The maximum value within any given point on the distribution curve can be converted into lux (footcandles) with the formula shown in Figure 540-15. This chart is occasionally used when determining light intensity and the angle of distribution for accent lighting (uplighting of trees, floodlighting, etc.).

Basic Light Distribution Patterns:

Spread and Path Lights: These fixtures produce circular patterns of light that are symmetrical around the light center. Whenever fixtures produce a light pattern

Table 540-2. UNIFORMITY RATIOS

Uniformity ratio Average, lux (fc)	Minimum, lux (fc)	Visual description of illuminated field
21.4 (2)	10.7 (1)	Just a visible difference in light intensities
32.3 (3)*	10.7 (1)*	The high values of the field are twice as bright as the low values
43.0 (4)†	10.7 (1)†	—
107.6 (10)	10.7 (1)	Very distinct focal highlights; spotty

* Average and minimum uniformity ratios usually recommended for roads.
† Average and minimum uniformity ratios usually recommended for walkways.

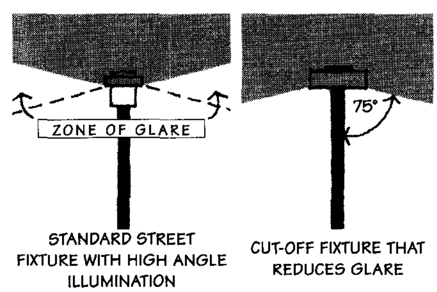


Figure 540-16. Cutoff light distribution.

that is symmetrical, only one half is shown, permitting maximum size and accuracy (see Figure 540-13).

Wall or Sign Lights: These fixtures are nearly always used to light vertical surfaces. Therefore, photometrics are presented on a vertical plane with the fixture set at an optimum distance (which varies per fixture) and backlit from the plane (see Figure 540-14). For a long wall or sign, the spacing from fixture to fixture can be determined by overlapping curves until the minimum acceptable light level between fixtures is established.

Accent Lights: Photometricfor adjustable accent lights, where the aiming angle and distance to lighted objects can vary, must be expressed in terms of the light output from the source rather than of the light falling upon the object. Candlepower is measured on a typical plane through the fixture and is charted in curve form (see Figure 540-15). Conversion to lux (footcandles) can be accomplished by formula.

Uniformity:

The uniformity of an illuminated field can be described with a ratio of light intensity values in lux (footcandles). The uniformity ratio typically compares the average illumination with the minimum footcandle value of a particular field. A low ratio appears more evenly lit and very uniform. The opposite is true for a high ratio where the two values are wide apart, resulting in a field that has distinct and contrasting values. Refer to Table 540-2 for a general description of different uniformity ratios.

Cutoff:

Many kinds of light fixtures greatly reduce glare by restricting high-angle light to not more than 75 degrees above nadir (Figure 540-16). The following criteria are the general industry classifications of degrees of high-angle cutoff:

1. Noncutoff: unrestricted high-angle illumination.
2. Semicutoff: not more than 5 percent of peak intensity radiating above 90 degrees and 20 percent of peak intensity above 80 degrees.
3. Cutoff: not more than 2-1/2 percent of peak intensity radiating above 90 degrees and 10 percent of peak intensity above 80 degrees.

4.3 Categories of Light Fixtures

Various categories of light fixtures commonly used in outdoor lighting situations are described below (Figure 540-17).

Low-Level Landscape Lights:
Typical characteristics include:

1. Heights usually less than 1 800 mm (6 ft) but sometimes up to 3 000 mm (10 ft).
2. Lamps may be incandescent, compact fluorescent, induction, mercury vapor, metal halide, or high-pressure sodium.
3. Low-wattage capabilities, with limited intensities.
4. Substantial variety, with some sizes and shapes fitting within modules of finish materials (brick, etc.).
5. Finite light patterns, with directing capabilities.
6. Light sources are usually below eye level, so glare must be controlled.
7. Low maintenance requirements but high susceptibility to vandalism.

Intermediate-Height Landscape Lights:

Typical characteristics include:
1. Average heights of 3 000 to 45 000 mm (10 to 15 ft).
2. Lamps can be incandescent, compact fluorescent, induction, mercury vapor, metal halide, or high-pressure sodium.
3. Substantial variety of fixtures and respective lighting patterns.
4. Generally used in or around pedestrian pavements, and considered pedestrian in scale.
5. Lower fixture mounting heights are susceptible to vandalism.

Parking Lot and Roadway Lights:

Typical characteristics include:
1. Average heights of 6 000 to 15 000 mm (20 to 50 ft).
2. Lamps can be mercury vapor, metal halide, or high-pressure sodium.
3. Used to light streets, parking lots, and recreational, commercial, and industrial areas.

High-Mast Lights:

Typical characteristics include:
1. Average heights of 18 000 to 30 000 mm (60 to 100 ft).
2. Lamps can be metal halide or high-pressure sodium.
3. Used for large parking lots, highway interchanges, and recreational areas.

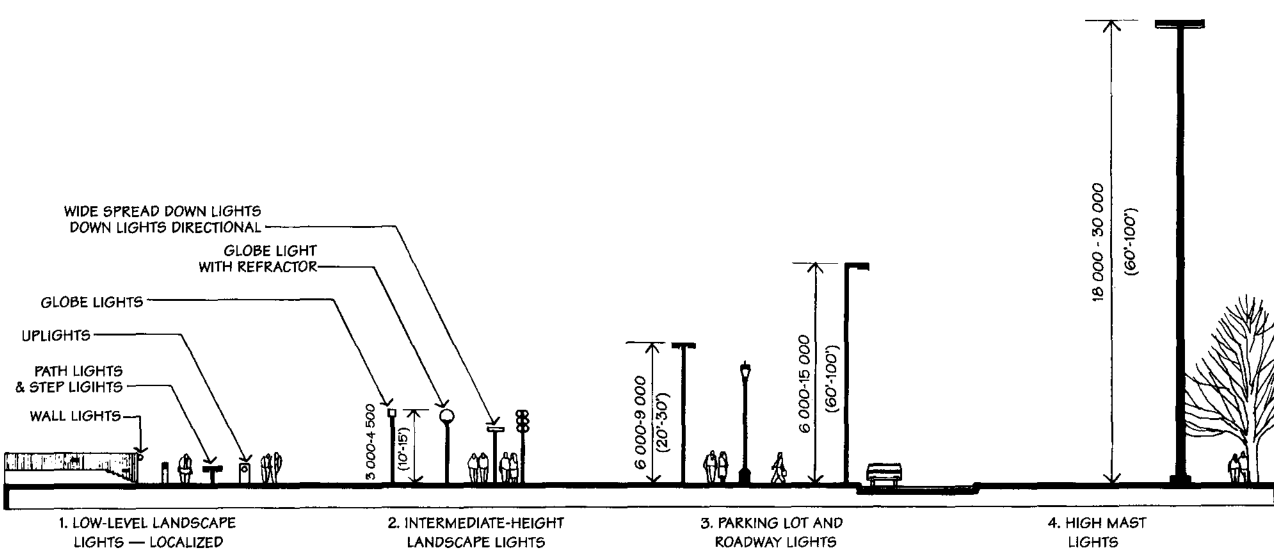
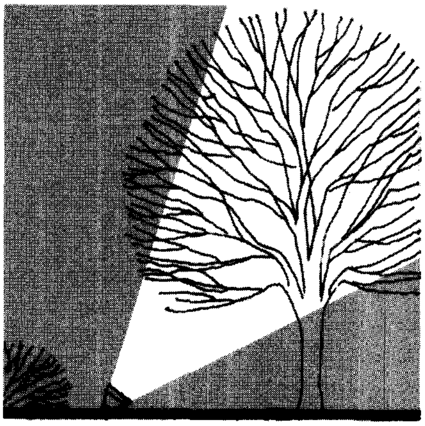
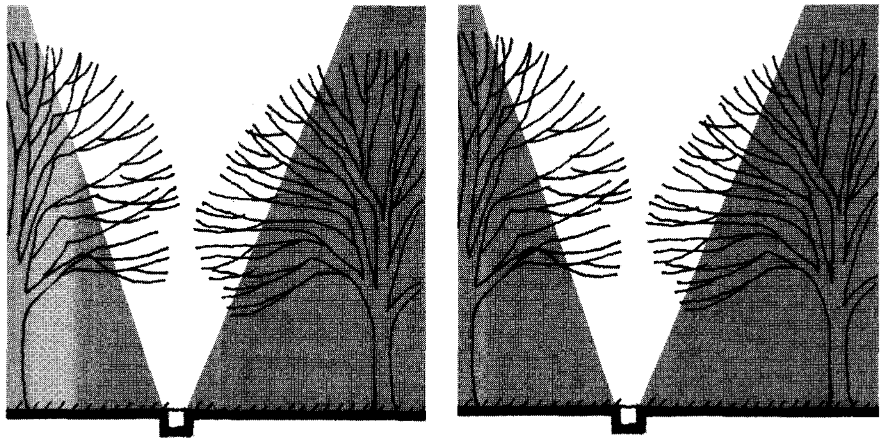


Figure 540-17. Categories of light fixtures.



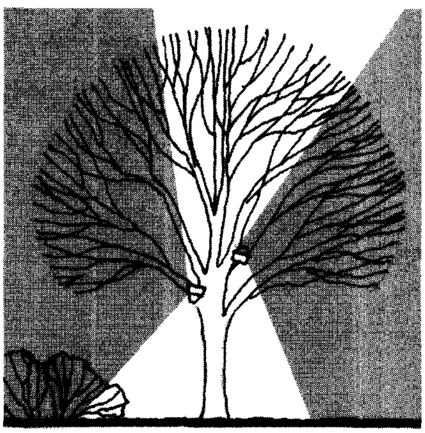
ABOVE GRADE ACCENT LIGHT

Figure 540-18. Uplighting (directional viewing).



WELL LIGHTS WITH LOUVERS

Figure 540-19. Uplighting (all-around viewing).



UP AND DOWN LIGHTS PLACED IN TREES

Figure 540-20. Moonlighting.

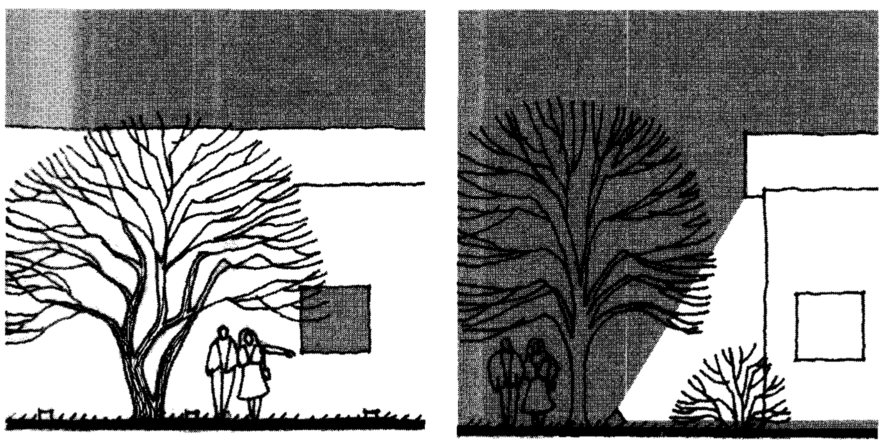


Figure 540-21. Silhouette lighting.

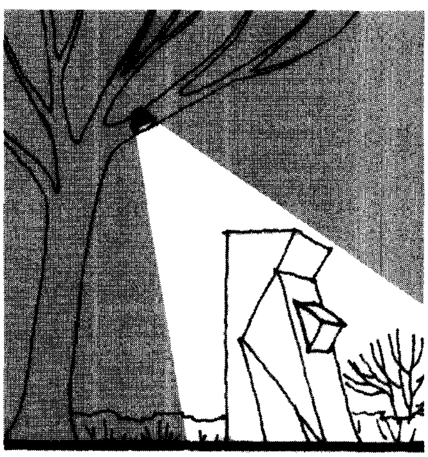


Figure 540-22. Spotlighting.

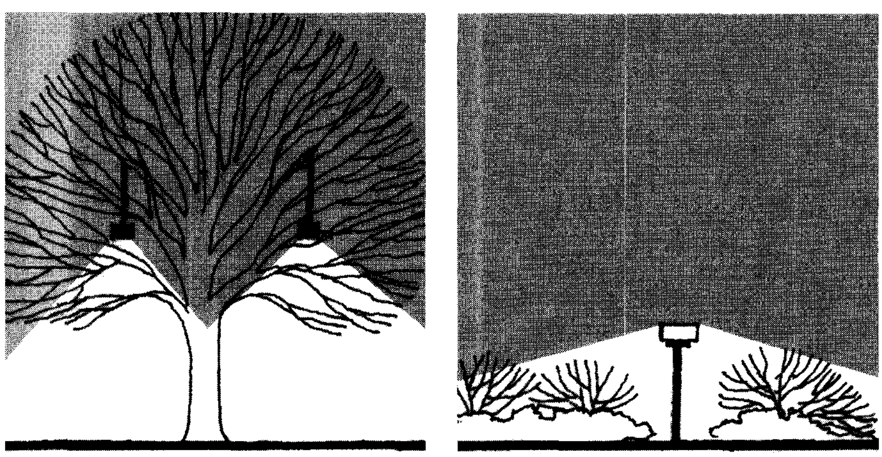


Figure 540-23. Spreadlighting.

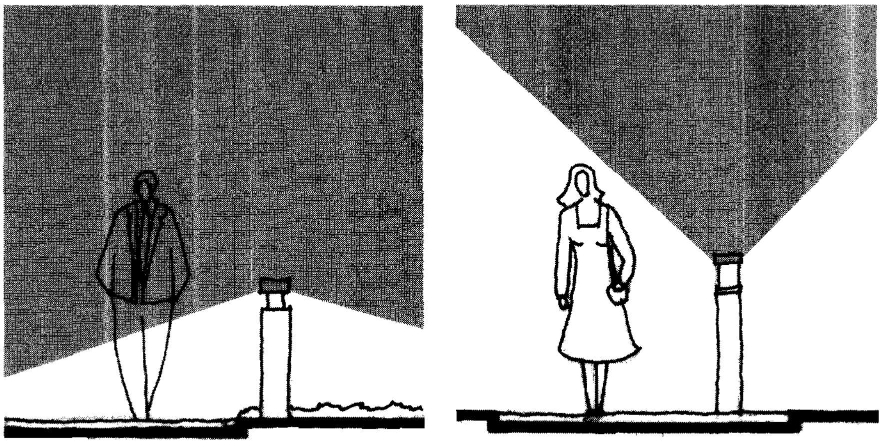


Figure 540-24. Pathlighting.

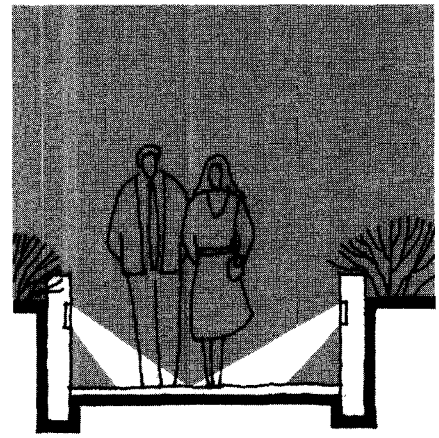


Figure 540-25. Wall lights.

4. Fixtures must be lowered to be maintained.

4.4 Landscape Lighting Effects

Six lighting effects most frequently used in outdoor lighting situations are described below (Figures 540-18 through 540-25).

Uplighting:

Uplighting for Directional Viewing: When a lighted object can be seen from one direction only, above-grade accent lights can be used. To prevent glare, fixtures should be aimed away from observers and, if possible, concealed to keep the landscape uncluttered (Figure 540-18).

Uplighting for All-Around Viewing: If the lighted object can be seen from any direction, then well lights with louvers should be considered (Figure 540-19). With newly planted trees, place uplights as close as possible to the outside of the root ball.

Placing fixtures midway between trees is rarely satisfactory. The light typically misses the trunk and most foliage. It is particularly unsuccessful if trees are deciduous, especially during the winter stage.

Moonlighting:

The effect of moonlight filtering through the trees is another pleasing outdoor lighting technique. Up-and-down lighting is used to create this effect, which requires that fixtures be carefully placed in trees (Figure 540-20). Ground lighting is accented by shadows from leaves and branches.

Silhouette Lighting:

Trees and shrubs with interesting branching structure can be dramatically expressed when silhouetted against a wall or building facade. Such lighting also provides additional security near the building (Figure 540-21).

Spotlighting:

Special objects such as statues, sculpture, or specimen shrubs can be lighted with well-shielded fixtures using spot lamps (Figure 540-22). By mounting lights overhead in trees or nearby structures, glare and fixture distraction can be eliminated. If ground-mounted fixtures are used, they should be concealed with shrubbery.

Spreadlighting:

Spread lights produce circular patterns of illumination for general area lighting (Figure 540-23). They are effective for groundcovers, low shrubs, walks, and steps. However, to take full advantage of the light throw, fixtures should be kept to open areas so that shrubbery does not restrict light distribution. The overhead spread light provides additional height and throw. When used in eating or recreational areas, several fixtures should be used to soften shadows while creating a uniform lighting effect.

Pathlighting:

Path lights are essentially spread lights at a lower height (Figures 540-24 and 540-25). In areas where other landscape lighting is used, a high degree of light shielding is necessary for path lights. This prevents the glare which inhibits a full view of the surrounding landscape.

If no other outdoor lighting is used in the immediate area, less-shielded path lights may be acceptable. These fixtures illuminate the path and some of the surrounding landscape as well, but there remains the possibility that the glare will be disruptive.

KEY POINTS: Lamp Characteristics and Lighting Effects

1. A variety of lamp types are commercially available. Selection of a lamp involves trade-offs between lamp size, optical control, efficacy, appearance, color temperature, color rendition, lamp life, costs, and maintenance (Table 540-1).
2. Illumination data for lighting fixtures are illustrated by photometric charts provided by the manufacturer. These charts illustrate light patterns on horizontal and vertical planes (Figures 540-13 through 540-15).
3. Uniformity of illumination is described by a ratio of light intensity values in lux (footcandles). A low ratio appears more evenly lit and uniform, while a high ratio displays distinct and contrasting values (Table 540-2).
4. Light fixtures can be broadly categorized into four main types based on size and design purpose: Low-level landscape lights, intermediate-height landscape lights, parking lot and roadway lights, and high-mast lights (Figure 540-17).
5. Levels of lighting are related to types of use and other characteristics within use areas. Table 540-3 lists recommended levels of illumination.

Table 540-3. RECOMMENDED LEVELS OF ILLUMINATION

Area/activity	Outdoor facilities	Lux (lx)	Footcandles (fc)
Building exterior			
	Entry		
	Active use	50	5.0
	Locked or infrequent use	10	1.0
	Vital locations or structures	50	5.0
	Building surrounds	10	1.0
Building and monuments (floodlighted)			
	Bright Surroundings		
	Light surfaces	150	15.0
	Medium light surfaces	200	20.0
	Medium dark surfaces	300	30.0
	Dark surfaces	500	50.0
	Dark surroundings		
	Light surfaces	50	5.0
	Medium light surfaces	100	10.0
	Medium dark surfaces	150	15.0
	Dark surfaces	200	20.0
Bikeways			
	Along roadside		
	Commercial areas*	10	0.9
	Intermediate areas*	5	0.5
	Residential areas*	2	0.2
	Distant from roadside	5	0.5
Bulletin and posterboards, signs			
	Bright surroundings		
	Light surfaces	5	0.5
	Dark surfaces	1000	100.0
	Dark surroundings		
	Light surfaces	200	20.0
	Dark surfaces	500	50.0
Roadways			
	Expressways		
	Commercial areas*	14	1.4
	Intermediate areas*	12	1.2
	Residential areas*	9	.9
	Major Roads		
	Commercial areas*	17	1.7
	Intermediate areas*	13	1.3
	Residential areas*	9	.9
	Collector roads		
	Commercial areas*	12	1.2
	Intermediate areas*	9	0.9
	Residential areas*	6	0.6
	Local Roads		
	Commercial areas*	9	0.9
	Intermediate areas*	7	0.6
	Residential areas*	4	0.4
Walkways			
	Along roadside		
	Commercial areas*	10	0.9
	Intermediate areas*	5	0.5
	Residential areas*	2	0.2
	Distant from roadside	5	0.5
	Park walkways	5	0.5
	Pedestrian tunnels	20	2.0
	Pedestrian overpasses	2	0.2
	Pedestrian stairways		
	Light surfaces	200	20.0
	Dark surfaces	500	50.0
Gardens			
	General lighting	5	0.5
	Path, steps away from home	10	1.0
	Backgrounds, fences, walls, trees, shrubbery	20	2.0
	Flower beds, rock gardens	50	5.0
	Trees, shrubs (when emphasized)	50	5.0
	Focal points (large)	100	10.0
	Focal points (small)	200	20.0
Loading and unloading platforms		200	20.0
Parking areas			
	Self parking	10	1.0
	Attendant parking	20	2.0
Piers			
	Freight	200	2.0
	Passenger	200	2.0
	Active shipping area surrounding	50	5.0
Playground		50	5.0
Badminton (outdoor)			
	Recreational	100	10
	Club	200	20
Baseball			
	Recreational		
	Infield	105	15
	Outfield	100	10
	Junior League (Class I and 11)		

Table 540-3. RECOMMENDED LEVELS OF ILLUMINATION (continued)

Area/activity	Outdoor facilities	Lux (lx)	Footcandles (fc)
	Infield	300	30
	Outfield	200	20
Semipro and municipal league			
	Infield	200	20
	Outfield	150	15
	On seats during game	20	2
	On seats before and after game	50	5
Basketball (outdoor) recreational		100	10
Football			
	Distance from nearest sideline to the farthest rows of spectators:		
	Class I (over 30,000 spectators) over 100 ft (30 m)	1000	100
	Class II (10 to 15,000 spectators) 15 to 30 m (50 to 100 ft)	500	50
	Class III (5 to 10,000 spectators) 9 to 15 m (30 to 50 ft)	300	30
	Class IV (under 5,000 spectators) under 9 m (30 ft)	200	20
	Class V (no fixed seating facilities)	100	10
Handball and racquetball (outdoor)			
	Recreational (two-court)	100	10
	Club (two-court)	200	20
Hockey (outdoor)			
	Recreational	100	10
	Amateur	200	20
Horse shows			
	Recreational	50	5
	Tournament	100	10
Shuffleboard			
	Recreational	50	5
Skating			
	Roller rink	100	10
	Ice rink (outdoor) 50	5	
	Lagoon, pond, or flooded area	10	1
Ski slope		10	1
Soccer (see Football)			
Softball			
	Slow pitch, recreational (6 pole)		
	Infield	100	10
	Outfield	70	7
	Slow pitch, tournament		
	Infield	200	20
	Outfield	150	15
	Recreational (6-pole)		
	Infield	100	10
	Outfield	70	7
	Industrial League		
	Infield	200	20
	Outfield	150	15
	Semiprofessional		
	Infield	300	30
	Outfield	200	20
	Professional and championship		
	Infield	500	50
	Outfield	300	30
Swimming (outdoor)			
	Recreational	100	10
	Underwater	600	(60)
	Exhibitions	200	20
Tennis (outdoor)			
	Recreational	100	10
	Club	200	20
	Tournament	300	30
Volleyball			
	Recreational	100	10
	Tournament	200	20

Source: Illuminating Engineering Society of North America, Mark Rea, (ed.). *IES Lighting Handbook,* Reference Volume and Application Volume, IES, New York, 1993.

*Areas are defined as follows:

Commercial areas: Dense business districts with heavy vehicular and pedestrian traffic throughout the day and night.

Intermediate areas: Moderately heavy pedestrian traffic during nights (libraries, recreation centers, large apartment complex, neighborhood retail stores).

Residential areas: Predominantly a residential area with light pedestrian traffic at night (single family,multifamily apartments).

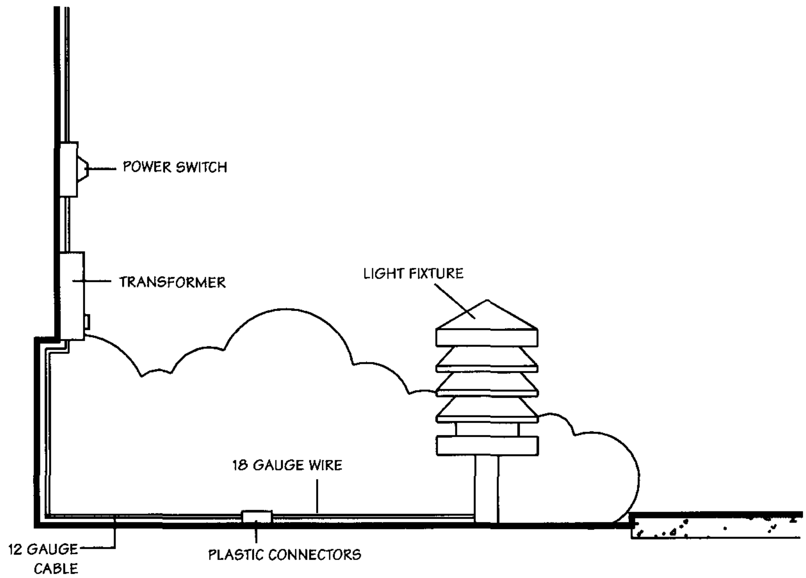


Figure 540-26. Low-voltage lighting system.

5.0 LOW VOLTAGE SYSTEMS

Low voltage lighting systems offer an alternative to more energy-consumptive 120 volt systems. These systems work particularly well in informal, small-scale, residential settings. In addition to reduced energy usage, low voltage systems offer safe and easy installation, longer lamp life (up to twice as long as 120 volt lamps), small fixtures that can be hidden in the landscape, and very low light levels to achieve a variety of lighting effects. Low voltage systems are not typically appropriate for larger projects requiring significant levels of illumination, or public sites where durability is a concern.

Low voltage systems include a transformer, cable, connectors, and the fixtures. Figure 540-26 illustrates the components of a typical system.

Transformers are required to convert standard 120 volt output to the proper operating voltage. They must provide adequate power to accommodate all fixtures proposed, including anticipated expansion. The transformer's wattage rating must be equal to or greater than the wattage of all fixtures combined. Large or diverse lighting schemes may require multiple transformers. Transformers may use manual, automatic timer, or photocell systems that detect light levels to turn power on and off for the system. Current photocell technology is suitable only for small-scale residential applications due to reliability concerns.

Systems typically use 12 gauge low voltage cable feeds with 18 gauge fixture wire, unless otherwise specified by the manufacturer. Plastic connectors are used to join each fixture to the cable feed.

A wide variety of low voltage fixtures are available to achieve various lighting effects. Refer to 4.4 Landscape Lighting Effects in this section for information on different lighting strategies.

6.0 RECOMMENDED LEVELS OF ILLUMINATION

The levels of illumination listed in Table 540-3 represent current standards in the lighting industry.

REFERENCES

Iluminating Engineering Society of North America, Recommended Lighting for Walkways and Class 1 Bikeways, *DG-5, 1993.*

Moyer, Jan Lennox. The Landscape Lighting Book, *John Wiley & Sons, New York, 1992.*

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Plants and Planting

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CONTENTS

1.0 INTRODUCTION AND PURPOSE

The methods by which plants are chosen and the functions that they are intended to serve in designed landscapes have been expanding. While serving as sources of aesthetic pleasure, plants also reinforce the existing native ecosystem and work as bioengineering agents for soil retention and restoration.

This section provides information on planting design and plant-related technology. It is assumed that the reader has a working knowledge of plant materials and their uses or has sought such information elsewhere.

2.0 DESIGN CRITERIA

Certain procedures are common to many planting design processes. A balance must be struck between considerations of plant function, cost, hardiness, safety, and maintenance.

2.1 Major Functions of Plant Materials

Aesthetics:

Visual principles of color, texture, scale, and rhythm can be used to create an aesthetically pleasing human environment. Special plantings of high visual interest or quality, like specimen trees or perennial borders, can be used to dramatize certain views or alter a user's perception of scale.

Table 550-1 is a crown density matrix which illustrates the shade characteristics of a variety of trees.

Fragrant plants also contribute to the quality of human experience in the landscape. Conversely, the unpleasant odor of some plants may make some people nauseous (Refer to Table 240-2 in Section 240, Outdoor Accessibility, for a listing of some plants that bear unpleasant odors).

Efforts should also be made to support the existing visual character and ecological function of the site within its regional context wherever possible. The use of native plants mixed with a small proportion of compatible exotics is generally encouraged in order to add interest and variety while reflecting a regional context.

Environmental Modification:

Outdoor spaces that do not fall within the physical range of human comfort will not be used. The microclimate of an outdoor space can be changed through the careful placement of trees and shrubs to block excessive sun or wind. Plantings can also reduce snow drifting across roads and other passageways. For more information on climate control, refer to Section 220: Energy and Resource Conservation.

Screening:

Living barriers can range from semitransparent visual screens to formidable thorned hedges. Plant screens can provide privacy, mark boundaries, discourage intruders, or block unpleasant views.

Circulation Control:

Plantings can control and direct the movements of people, animals, or vehicles. Where established pedestrian shortcuts are to be discouraged, thorned, dense-growing plants may be necessary to change user habits.

Production:

Plants have long been harvested for food, flowers and raw building materials. They also provide food and shelter for wildlife. Planting can encourage the presence of birds, butterflies or other forms of wildlife for human enjoyment. In some cases, a site can be designed to support regional ecosystems.

Bioengineering and Other Forms of Structural Mitigation:

The natural regenerative tendency of plant material can be used to stabilize eroded banks, revitalize damaged soils, or strengthen wildlife habitats. Some of these mitigation techniques are discussed in 6.0, Specialized Planting Strategies, of this section and in Section 640: Disturbed Landscapes.

2.2 Cost

Initial nursery and planting costs must always be balanced against the cost of long-term maintenance. Some slow-growing trees are expensive as nursery stock but require little care once established and can grace the landscape for hundreds of years. The initial labor expense of careful planting may also be balanced in the long term by the sturdiness of a vigorous, healthy plant that has been handled gently, planted properly, and placed suitably for its requirements.

Plant materials are available at nurseries in different forms, depending on the cultural practices of each nursery and on market demands. Some of the most common forms are discussed in Table 550-2, grouped by plant type.

Specimen Plantings:

A "specimen" plant is chosen for the high visual quality of texture, color, or form it can provide at a crucial focal point in the landscape. A specimen plant is generally installed as a mature plant, when its true form and unique, individual character has begun to emerge; thus, it will be more expensive than plant materials used for massing.

Table 550-1. CROWN DENSITY OF VARIOUS TREES

Least Dense	Less Dense	Moderately Dense	Somewhat Dense	Most Dense
Palo Verde	Larch	Tree of Heaven	Tulip Tree	Japanese Pagoda Tree
Horsetail Casuarina	Kentucky Coffee Tree	Bald Cypress	Sweet Gum	Littleleaf Linden
Thornless Honeylocust	Ginkgo	Camphor Tree	Dawn Redwood	Norway Maple
Jacaranda	Amur Cork	London Plane	Pin Oak	Willow Oak
Desert Willow	Yellowwood	Red Maple	Modesto Ash	Live Oak
California Pepper Tree			Sugar Maple	Chinese Elm
			Red Oak	Sterile Mulberry
				Indian Laurel
				American Holly
				Southern Magnolia

Plantings vs. Hardscape Costs:

Plants can be used in many of the same ways that "hard" building materials are used - to form outdoor walls, ceilings, fences, etc. Although they require more space on a site, plants are typically less expensive to buy and install than hardscape materials, and can require less maintenance if properly chosen.

2.3 Hardiness

Within the United States, the hardiness rating of a given cultivar can easily be checked against the zones for hardiness established by the USDA (Figure 550-1). However, the hardiness of individual specimens of a given variety will vary greatly depending upon the climate in which they have been raised. Therefore, locally grown plant materials that are fully adapted to the region should be used whenever possible. Use reliable, local nurseries that know the origins of their plant materials.

Favorable microclimates on-site can also be exploited to allow the use of plants that might not normally survive the conditions of a region.

2.4 Safety Considerations

Designing safe environments depends on matching the proper plant to the proper place. Some plant characteristics that should be considered include whether parts of the plant are poisonous, how much litter the plant produces, the weakness of limbs, whether drooping branches will obstruct pathways, whether roots will break pavement, the existence of thorns, and whether the plant attracts stinging insects or other pests. See Table 240-2 in Section 240 Outdoor Accessibility, for listings of specific plants in these categories.

Poisonous Plants:

Plants with brightly colored poisonous berries or leaves should not be used where children may be tempted to eat them. Some plants can cause an allergic reaction when touched. These should be located out of reach. Table 550-3 lists some common poisonous and allergy-inducing plants.

Litter-producing Plants:

Plants that produce messy fruit or nuts, cones, seed pods or excessive leaf litter are hazardous to pedestrians and hinder passage of many wheeled vehicles like strollers and wheelchairs. In addition, some may stain clothing or pavement surfaces.

Weak-branched Plants:

Large branches may be susceptible to breaking from wind and ice and can cause damage and/or pose obstacles if they fall. Weak forks in trees may also present serious safety implications.

Plants with Drooping Branches:

Branches that hang into walkways or streets can injure pedestrians and cyclists and may cause damage to larger vehicles.

Plants with Shallow Roots:

Roots near the surface can cause sidewalk heaving, creating uneven paths that are impassable for small-wheeled vehicles and are dangerous for pedestrians.

Thorned Plants:

Thorned plants can be dangerous to brush into or fall against. Thorned leaves, twigs and branches that litter the ground can also be dangerous for people wearing light shoes or going barefoot.

Plants that Attract Insects:

Some people have severe reactions to insect bites and stings. Plants that attract stinging pollinators or other insect pests should be placed away from sitting areas and walks.

2.5 Maintenance Considerations

Important considerations for minimizing long-term maintenance problems include physical separation of incompatible elements and designing with integrated pest management in mind. These maintenance problems can be grouped in the following categories:

Proximity to Mechanical Activity:

The vigor of a tree or shrub can be greatly reduced through repeated wounding by lawnmowers and string trimmers that girdle the trunk, or passing vehicles that may break branches. Soil compaction caused by pedestrian or vehicular traffic can also damage plantings.

KEY POINTS: Planting Design Criteria

Planting design must strike a balance between considerations of plant function, cost, hardiness, safety, and maintenance.

1. Efforts should be made to support the existing visual character and ecological function of the site within its regional context, through the use of native plant materials wherever possible.

2. Plant material can be used to create comfortable microclimates, provide screening, circulation control, wildlife habitat, and mitigate erosive slopes or contaminated sites.

3. Initial nursery and planting costs must always be balanced against the cost of long-term maintenance. Plants are typically less expensive to buy and install than hardscape materials, and can require less maintenance if properly chosen.

4. In the United States, the hardiness rating of a given cultivar can be checked against the zones for hardiness established by the USDA (Figure 550-1). locally grown plant materials that are fully adapted to the region should be used whenever possible to ensure hardiness.

5. Many plant materials are poisonous, thorny, produce excessive litter, are susceptible to broken or drooping branches, have shallow roots, or attract undesirable insects. Care must be taken in selecting plants which are safe for users and suitable for a given purpose.

6. Variety is encouraged to promote a diverse plant community that has a healthy resiliency to attack by insects or disease, especially in urban street tree applications. No single genus should be represented in an area by more than ten percent of the overall planting scheme.

7. Trees and shrubs should be protected from lawnmowers and string trimmers that girdle the trunk. Passing vehicles may break branches and compact the soil which can also damage plantings.

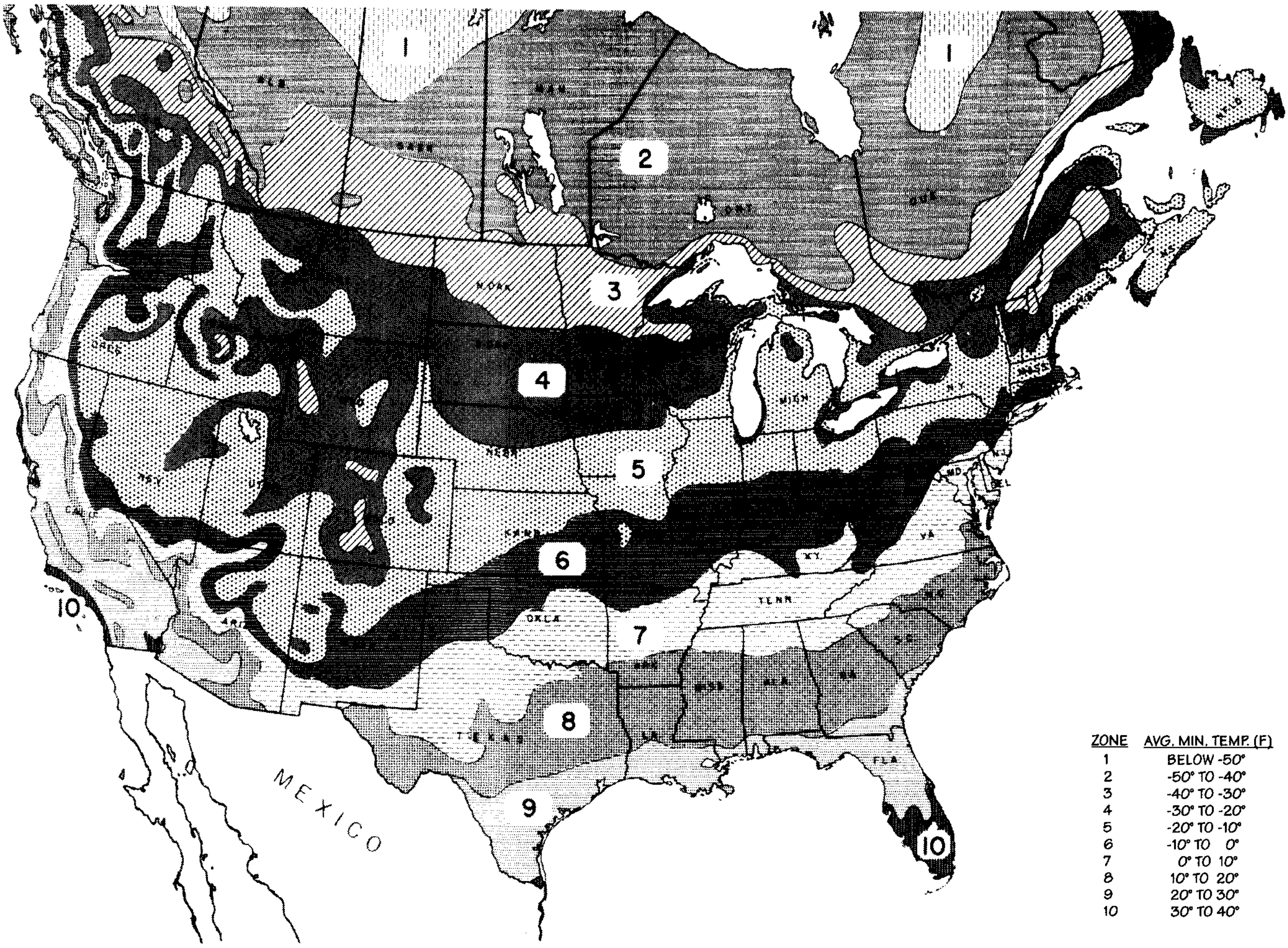


Figure 550-1. USDA Plant hardiness zones.

Placement of Plantings:

Plant saplings that will become large trees under electric utility right-of-ways necessitates major trimming of limbs that often results in misshapen trees with weakened defenses. Close study of cultural requirements and mature size will eliminate many similar problems. Fitting the right plant to the right place includes using plant materials whose requirements for water, light and soil match the site conditions; placing plants that will be large when mature away from electric lines and other structures; and using hardy plant materials as discussed in Subsection 2.3, Hardiness, of this section.

Diversity of Plant Communities:

As chemical measures for fighting attacks of insects and disease become less effective, designing to resist these attacks becomes crucial. Monocultures can provide a fertile breeding ground for these problems. Designs that group large numbers of trees of the same cultivar or even from the same genera are highly vulnerable to attack. As Dutch Elm Disease has demonstrated, reliance on a single plant is also risky when that plant provides the backbone of a design. If the plant is wiped out by disease, the landscape will take many years to repair. For these reasons, no single genus should be represented in an area by more than ten percent of the overall planting scheme. Variety within these genera is further encouraged to promote a diverse plant community that has a healthy resiliency to attack by insects or disease, especially in urban street tree applications.

Disease and Insect Resistance:

In conjunction with the recommendations above, it is important to study the conditions of the site and to select a cultivar resistant to potential disease or insect problems. For trees, use of reference materials such as those found at the end of this section or consultation with a reliable arborist will aid in selection.

Proximity of Plants:

The root systems of large trees can extend out horizontally several times the height of the tree. Many trees suffer disease due to proximity to heavily irrigated lawns. Plants should be grouped according to their requirements for sun, water, and soil chemistry.

Some insects and diseases have developed a life cycle that relies on several plants. The Cedar-apple Rust that attacks crabapples from junipers is one example. These plants should be kept separate to avoid outbreaks.

Long-Term Maintenance Costs:

Determining how much a client is willing to spend on long-term maintenance is very important for ensuring a good fit between site and design. No design is maintenance-free, but the plants used can be tailored to fit the budget that will provide for their

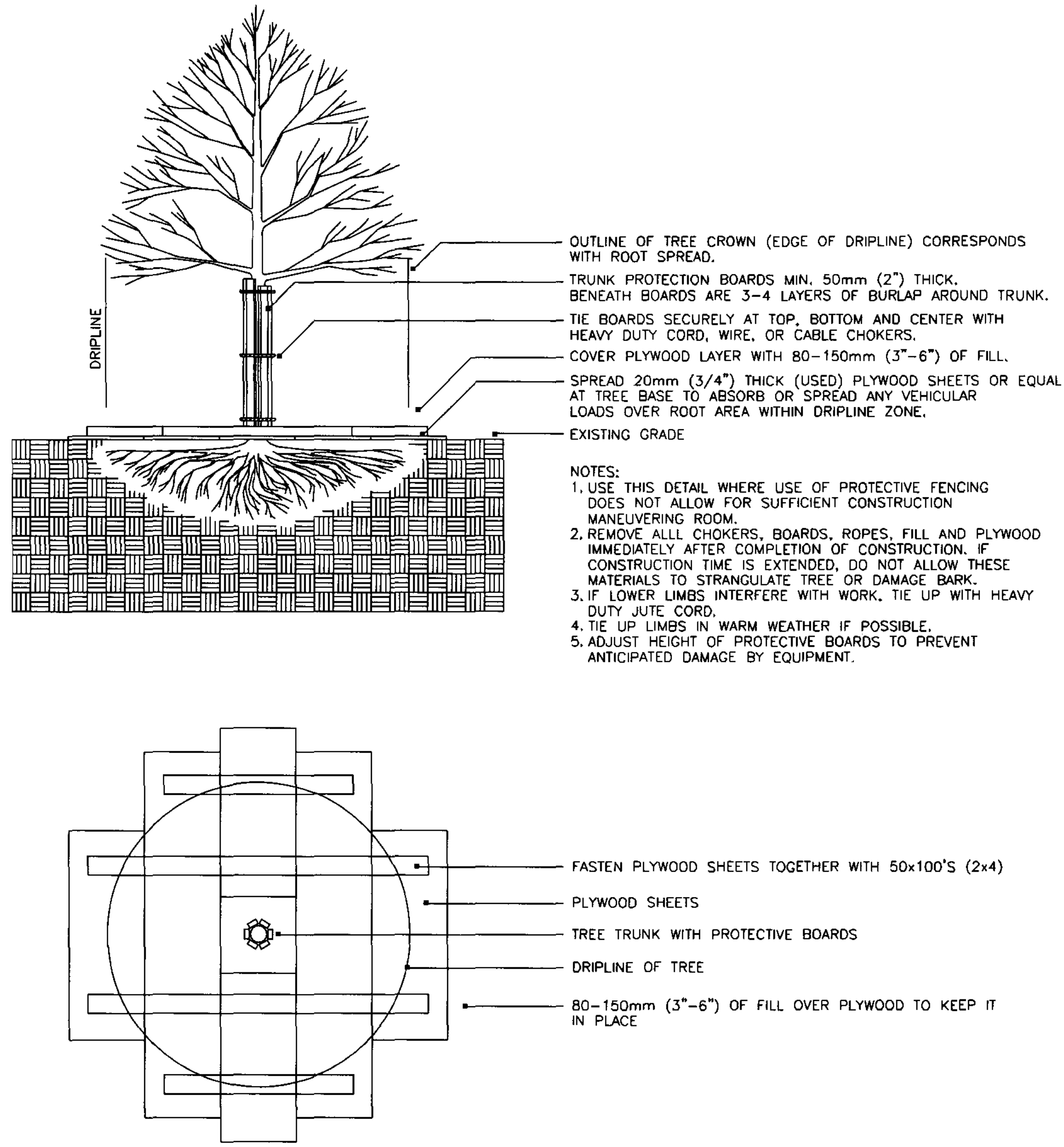


Figure 550-2. Protection of existing tree during construction.

weeding, pruning, and other necessary maintenance.

3.0 ASSESSING EXISTING VEGETATION

One of the first steps in assessing a landscape is examining the existing vegetation on the site. The age and health of existing plants generally determine their value as a continuing element of the landscape. Appropriateness of existing materials to the site, aesthetically and functionally, should also be taken into account.

3.1 Protecting Existing Plant Materials

Existing plants and new plantings need to be protected from physical injury and root zone compaction during periods of construction. When the root system is damaged or impaired, the loss of moisture through leaves can quickly outpace the amount taken up by roots. Young fibrous growing root tips must be protected as they are the primary absorptive parts of the system.

During Construction:

A common method for protecting existing plants during construction is to erect a barrier around the plant, enclosing an area as large as the root zone of the plant or plants to be protected. This prevents compaction of soil and other forms of damage to the existing roots and also prevents mechanical damage to the plant. Figures 550-2 and 550-3 illustrate ways to protect plant materials during construction.

Long-Term Protection:

Roots require a continual supply of air, which is normally present in tiny air spaces

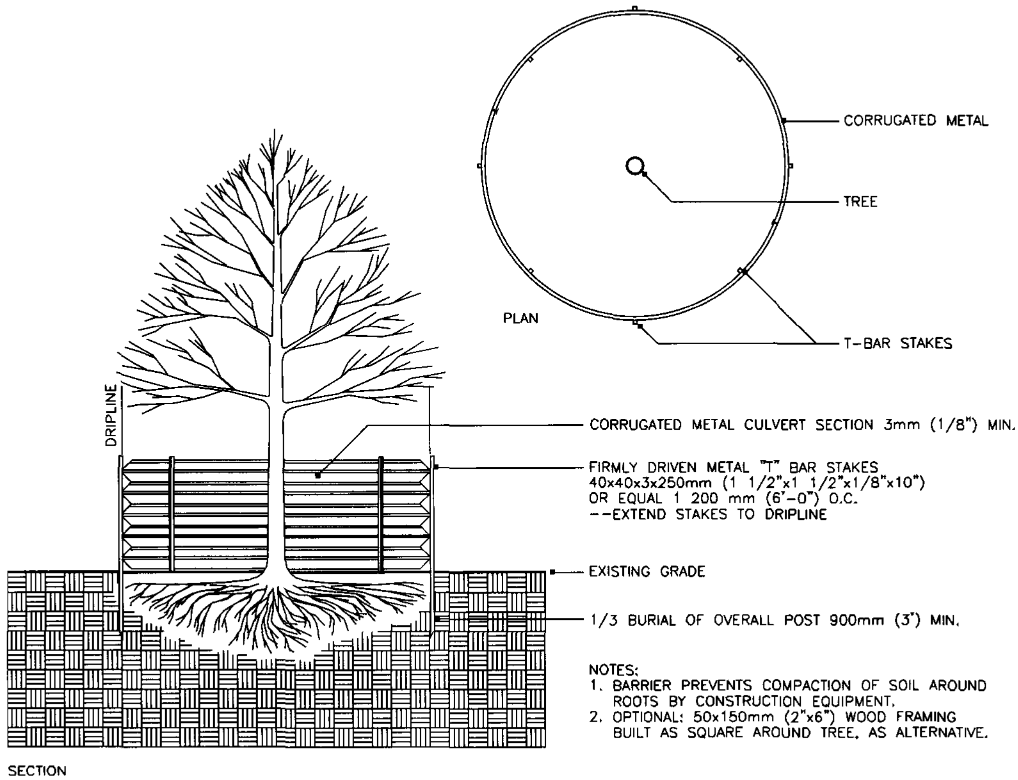


Figure 550-3. Protection of existing tree during construction.

(pores) between the soil particles surrounding the roots. Because of this need for air, as well as the need for water, the majority of a plant's root system lies within the top 450 mm (18 in) of soil, regardless of the type or size of plant. Measures must be taken to ensure that the root zone of a plant (the area within the dripline of the plant) is neither compacted nor covered with a material that would restrict the amount of air or moisture reaching the root zone. This type of protection is particularly important in stressful situations such as urban environments, which is discussed in 6.3: Urban Forestry, of this section. Division 900 illustrates techniques for restricting compaction of the root zone in heavily trafficked areas such as pedestrian walkways.

3.2 Invasive Species

The widespread availability and use of certain non-native plant species in commercial planting has provided a base for these introduced plants to invade native wild areas. Plants introduced to a region where they do not naturally occur can have serious impacts upon the ecosystems of that region, choking out native growth and eliminating the food and forage the native plant provided. Other consequences of invasive plants include altering water table levels, changing the levels of nutrients and the chemistry of soils, harboring insect pests, and interrupting the proper succession of native plant communities.

Frequently the qualities that make a plant valuable in the cultivated landscape (vigorous growth, tolerance of poor growing conditions, resistance to local diseases and insect pests, etc.) are those qualities that allow it to out-compete natives in the wild. Thus many of the plants that appear on "problem-solving" lists are also invasive plants.

Table 550-4 lists invasive species by botanical name, common name, and the regions in which they are most destructive. It is difficult to predict the behavior of a new species when first introduced to a region. Responsible planting plans avoid untested exotics as well as those known to be aggressive invaders.

4.0 PLANTING PLANS, DETAILS, AND SPECIFICATIONS

Most proposals for site development require preparation of planting plans, details, and specifications that direct the work of installing plant materials. Planting plans, together with construction details for their installation, typically comprise part of a complete set of working drawings for project construction.

Planting plans should include common and botanical names of all plant materials, their proposed locations (as well as locations of existing plant material), their sizes, and quantities. Most of this information typically is shown in a plant list somewhere on the drawing(s). Plant size designations, including height, caliper, ball or pot size, etc., are referred to in the United States by national voluntary standards set up by the American Association of Nurserymen in their publication American Standard for Nursery Stock. Figure 550-4 illustrates a sample planting plan and schedule.

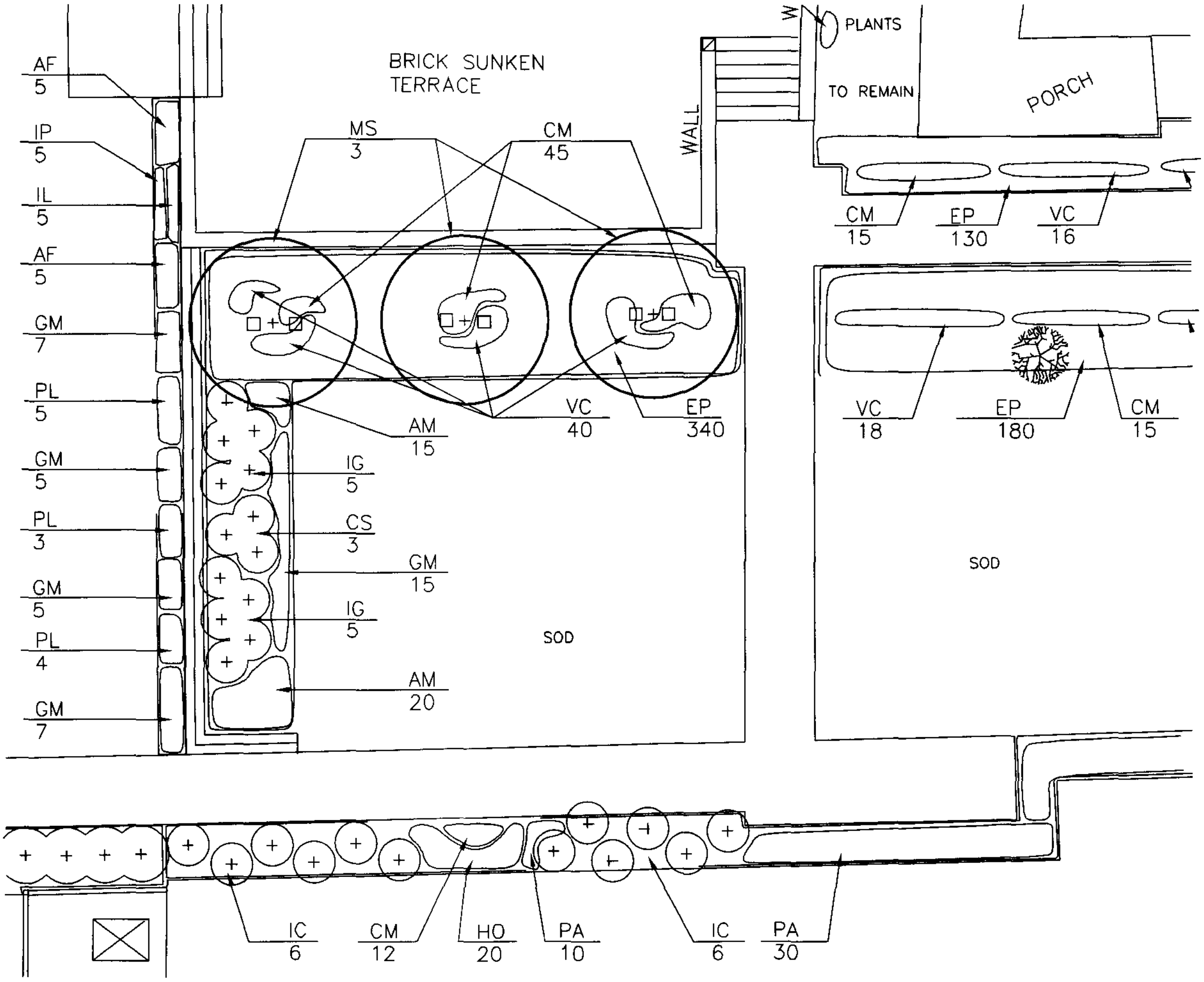
4.1 Proper Techniques for Planting

Poor installation kills many plants before they reach maturity. Research has demonstrated that many traditional planting practices are detrimental to the long-term health of plants. The following techniques are necessary to insure the survival and long-term health of installed plant material (Refer to Table 550-5 as a general guide to

Table 550-2. COMMON FORMS OF PLANT MATERIALS

PLANT	ADVANTAGES	DISADVANTAGES
Trees		
Container trees are young trees in plastic or metal cans. Containers typically come in sizes of 1, 3, 5, and 7 gallons.	• younger trees establish themselves faster and have more flexibility to adapt to the conditions of their new homes • container trees can be healthier in the long run than older stock	• do not provide "mature" appearance for many years • may develop circling roots if left in container too long
Balled and burlapped trees are the most common medium sized specimens. They are field-grown and dug for the planting season, with a ball of field soil retained around the roots. The ball is then wrapped with burlap, or less frequently with plastic cloth or wire cages.	• no circling roots • can be more hardy than other forms and wrapping the root ball • more care must be taken at planting time to ensure that the wrapping materials are adequately removed to avoid future root and trunk girdling	• some roots may have been damaged or severed in the process of digging
Boxed trees are commonly older, larger trees that have been moved to large wooden containers.	• provides instant effect • more expensive to purchase and install • harder to handle in the field	• can be slower to recover from transplant
Shrubs and Perennials		
Bare-root plants are sold in a dormant stage. Tops and roots are pruned back, and most of the soil is washed away from the roots.	• cheaper than container plants • often establish themselves faster than container plants and can be healthier in the long-run	• must be bought and planted in the proper season • characteristics like flower and leaf color are not visible at time of purchase
Container plants are sold with upper branches and root systems intact and are available year-round.	• flower and leaf color are easy to verify • a wider variety of plant material is available in container form • can be planted year-round	• can be root-bound, leading to poor root development later • more expensive than bare-root
Smaller perennials can be found in four-inch *pots*, either plastic or peat. Plastic pots are handled as container plants and share the same advantages and disadvantages. Peat pots are not as common but have some advantages over plastic pots.	• peat pots can be set directly in the soil and left in place, where they will biodegrade, minimizing root disturbance	• peat pots can slow the initial root growth as roots attempt to push through peat walls
Groundcovers		
Containers are used for large prostrate shrubs that function as groundcovers.	• better for large areas of groundcover • sturdier at outset	• planting grid must be worked out carefully to avoid bare patches • take longer to fill in than more closely planted flats
Flats are trays of small, quick-spreading plants that have been started from cuttings or seed. Plants are grown to form a mat of stem and root growth that must be cut into plugs or separated by hand for planting.	• economical, can be planted quickly and easily	• smaller root balls are more susceptible to drying out during and immediately after planting
Seeds are not commonly used in commercial landscaping, although they are popular for home gardeners. Exceptions to this include hydroseeding, discussed below; regenerative planting techniques, discussed in Section 640; and popular mixtures of wildflower seed that can be scattered to form a "natural" looking meadow within a season.	• seed is the cheapest way to plant • plants grown from local seed are well-adapted to the site, a necessity for restoration • it is easier to achieve a random pattern • If "wildflower mixtures" or "native mixtures" are to be used, the composition of the mix must be checked carefully	• patterning of plants is harder to control • long growing period before plants begin to bloom, usually much later than greenhouse grown annuals
Hydroseeding is used for vegetative stabilization of slopes that are difficult to access by other means. A chosen seed mixture is sprayed directly onto the slope in a solution of fertilizer and water.	• large areas can be planted quickly and cheaply • areas can be planted which are otherwise difficult or impossible • choice of seed may be limited	• initial appearance is unattractive (the solution is dyed to aid in the application process)
Annuals		
Multi-pack annuals are sold with each plant in a separate plug of soil.	• economical • wide range of plants available in this form	• take longer to fill in than larger plants
Container annuals are larger.	• mature and fill in faster	• more expensive than multi-pack
Seeds are not commonly used in commercial or residential applications. See the section for seeds under Groundcovers above for a discussion of advantages and disadvantages.		
Turf		
Sod is grown in a field. Upon ordering, the sod is peeled up, rolled or stacked, and delivered to the site. Sod is the most common way to install lawn turf.	• instant effect • good, even coverage • has to be installed very soon after delivery	• not appropriate for steep slopes or vary very large areas
Seed is sown directly into a prepared plot.	• economical • wide variety available via mail order	• slower to grow to finished appearance • can require touch-up seeding if initial application was uneven
Sprigged lawns are started from plugs of grass planted at set intervals.	• economical • faster to establish than seed	• take several weeks to fill in • requires care to keep weeds from growing between plugs of grass

Adapted from *Trees and Urban Design*, by Henry F. Arnold, 1980.



PLANT SCHEDULE

KEY	BOTANICAL NAME	COMMON NAME	QUANT.	SIZE	ROOT	SPACING
TREES						
AG	Amelanchier x grandiflora (multi-stem)	Apple Serviceberry	1	10'-12' HT.	B&B	As Shown
MS	Magnolia x soulangiana	Saucer Magnolia	3	8'-10' HT.	B&B	As Shown
SHRUBS						
CS	Cytissus scoparius	Scotch Broom	3	3'-4'	B&B	As Shown
IC	Ilex crenata 'convexa'	Japanese Holly	12	2'-2.5'	B&B	As Shown
IG	Ilex glabra 'compacta'	Inkberry	10	2'-2.5'	B&B	As Shown
MP	Myrica pennsylvanica	Northern Bayberry	22	5'-6'	B&B	3' o.c.
PERENNIALS						
AM	Achillea "Moonshine"	Yarrow	95	1 GAL.	CONT.	18" o.c.
AF	Aster x frikartii	Aster	10	1 GAL.	CONT.	18" o.c.
CR	Campsis radicans	Trumpet Creeper	4	1 GAL.	CONT.	As Shown
CM	Convallaria majalis	Lily-of-the-Valley	102	1 GAL.	CONT.	12" o.c.
CZ	Chrysanthemum zawadskii 'Clara Curtis'	Chrysanthemum	12	1 GAL.	CONT.	24" o.c.
EP	Epimedium pinnatum	Persian Epimedium	967	1 GAL.	CONT.	12" o.c.
GM	Geranium macrorhizum	Hardy Geranium	39	1 GAL.	CONT.	24" o.c.
IP	Iris pumila	Dwarf Bearded Iris	15	1 GAL.	CONT.	12" o.c.
IL	Iris laevigata 'Variegata'	Variegated Rabbitear Iris	15	1 GAL.	CONT.	12" o.c.
HO	Helleborus orientalis	Lenten Rose	20	1 GAL.	CONT.	24" o.c.
PA	Pulmonaria angustifolia	Blue Lungwort	40	1 GAL.	CONT.	12" o.c.
PL	Paeonia lactiflora	Chinese Peony	12	1 GAL.	CONT.	30" o.c.
VC	Viola canadensis	Canada Violet	89	1 GAL.	CONT.	18" o.c.

NOTE: The Plant Schedule shall have precedence over the Planting Plan labels in the event of any quantity discrepancies.

Figure 550-4. Sample planting plan and schedule. *(Courtesy of Denig Design Associates, Inc., Northampton MA.)*

Table 550-3. POISONOUS AND ALLERGY - INDUCING PLANTS

Botanical / Common name	Poisonous berries or seeds	Poisonous leaves	Skin irritant	Other information
Abrus precatorius / Rosary pea	Shiny red seeds			Highly toxic; ingestion of one seed can be fatal
Aconitum sp. / Monkshood	x	x		Paralysis, can be fatal
Aesculus sp. / Buckeye, horsechestnut	x	x		Vomiting & diarrhea, can be fatal
Agave americana			Spines	Some people are allergic to spines
Ailanthus altissima			Leaves/ flowers	Mild skin irritation in some people
Areca catechu / Betel nut	x			Narcotic effect, convulsions; can be fatal
Buxus sempervirens / Boxwood	x	x		Vomiting & diarrhea, convulsions
Caryota sp / Fishtail Palm			Fruit, sap	Severe itching and skin irritation
Celastrus scandrens / Oriental bittersweet	Yellow/orange berries			Vomiting, nausea
Cestrum sp / Jessamine	x	x		Hallucinations,fever, paralysis; can be fatal
Colocasia esculenta / Elephant ear			Leaves	Mild skin irritation
Convallaria majalis / Lily of the valley	Bright red berries		x	
Cycads	x	x		nausea, vomiting & diarrhea
Daphne sp.	Red berries, not often seen	x		Highly toxic, a few berries swallowed usually fatal
Datura sp.	x	x		Hallucinations, rapid heartbeat, paralysis
Dicentra sp. / Bleeding heart		x		Convulsions, trembling
Digitalis purpurea / Foxglove	x	x		
Duranta repens / Golden dewdrop	Yellow fruit			Drowsiness, fever, can be fatal
Euphorbia sp.			Sap	Skin irritation, blistering
Gelsemium sempervirens / Carolina jessamine	x	x		Weakness, respiratory failure, can be fatal
Gymnoclaudus dioica / Kentucky coffee tree	x	x		Vomiting & diarrhea
Hedera helix / English ivy	Black berries	x		Difficult breathing and coma; can be fatal
Helleborus niger / Christmas rose		x		Skin irritation, vomiting & diarrhea
Hura crepitans / Sandbox tree	x	x		Vomiting & diarrhea, skin irritation
Hydrangea sp.	x	x		Mild nausea
Iris sp.		x		Vomiting & diarrhea
Jatropha gossypifolia / Bellyache bush	x			Nausea, vomiting
Kalmia latifolia / Mountain laurel	x	x		Highly toxic in large quantities, but bitter tasting, not dangerous
Laburnum anagyroides / Goldenchain tree	Seed pods			Vomiting & diarrhea, loss of muscle coordination
Lantana sp.	Black berries	x		Severe vomiting & diarrhea, lethargy, difficulty breathing; can be fatal
Ligustrum vulgare / Privet	Blue berries	x		Severe vomiting, nausea, & diarrhea
Melia azedarach / Chinaberry tree	Small orange berries	x		Nausea, vomiting, shortness of breath, paralysis, can be fatal
Mirabilis jalapa / Four o'clocks	x	x		Nausea, vomiting, & diarrhea
Nerium oleander / Oleander	x	All parts, esp. leaves		Nausea, vomiting, & diarrhea, irregular heartbeat; can be fatal
Nicotiana sp.		x		Nausea, vomiting & diarrhea, slow pulse, dizziness
Opuntia sp. / Prickly pear and cholla			Spines/ bristles	Work into skin, Prickly pear and cholla causing irritation and soreness
Parthenocissus quinquefolia / Virginia creeper	Blue berries			May be poisonous; few poisonings reported
Poinciana gilliesii / Bird of paradise	Seed pods			Nausea, vomiting
Rhododendron sp. / Rhododendron, azalea	x	x		Poisoning is very are, but when reported, symptoms include vomiting, slowed pulse, loss of muscle coordination
Ricinus communis / Castor bean	x	x		Highly toxic: ingestion of only four seeds can be fatal
Robinia pseudoacacia / Black locust	x	x		Nausea, vomiting, depression
Sambucus sp. / Elderberry	Berries poisonous until ripe	x		Nausea, vomiting & diarrhea
Schinus terebinthiofolius / Brazilian pepper tree			x	Some people are mildly allergic to berries and leaves
Sesbania punicea / Scarlet wisteria tree	Flowers and seeds			Diarrhea, rapid pulse, difficult breathing; can be fatal
Solandra sp.		Leaves and flowers		Vomiting & diarrhea, drowsiness, paralysis, can be fatal
Solanum sp. / Potato vine, belladonna, nightshade				Nausea, vomiting, drowsiness paralysis; can be fatal
Sophora secundiflora / Mescalbean	Seeds			Nausea, vomiting, & diarrhea, hallucinations; one seed can be fatal
Taxus sp.	Bright red berries	x		Nausea, vomiting, difficult breathing; can be fatal
Thevetia sp. / Yellow oleanders	x	x		Vomiting, irregular heartbeat; can be fatal
Wisteria sp.l	Seed pods			Nausea, vomiting & diarrhea

plant spacing when placing plants in rows or large masses).

Condition of Plants Upon Installation:

The health of plants upon installation is the most important factor for their long-term health. Inspect plants carefully upon their arrival at the site. Damage to leaves and stems can occur during transport and handling. There should be no unhealed wounds in the bark or stem of the plant and no major broken branches. Container plants that are extremely root-bound should be rejected. Root-bound plants can be spotted by clumps of root tendrils pushing through drainage holes or by tops that are excessively large for the container in which they are growing. If there are many roots circling the outside of the ball, the plant has been left in the container too long. Girdling roots eventually strangle themselves if not redirected.

Planting Holes:

Plants require soil with more air for initial rooting than they will for long-term growth, although even mature trees will have the major part of their root systems within the top few feet of soil where the most air is present. Planting holes should be wide and shallow, not narrow and deep. The hole should be at least two times wider than the root ball, but no deeper. If properly dug, the hole will support the root ball on firm subsoil, with the root flare set at the same level it has grown. A hole that is slightly shallow is better than a hole that is too deep.

Non-biodegradable nursery wrappings (i.e. plastic or wire) around the roots must be carefully removed or they will constrict the roots. Burlap can be left in place if the top third of the root ball is unwrapped. Container plants should be planted as quickly as possible upon removal from the container. The white, growing root tips are crucial to the quick establishment of a healthy root system and are damaged by even brief exposure to air.

Plants installed in the fall benefit from warm soils, stored energy, and a long dormant period for good root establishment before the stresses of summer heat and drought. Favoring one season over the others is not always feasible for commercial applications, but a broad range of species benefit from fall planting. A few species are not recommended for fall planting and are referred to as "fall hazards." Consult a nursery or arborist for a complete list of these plants.

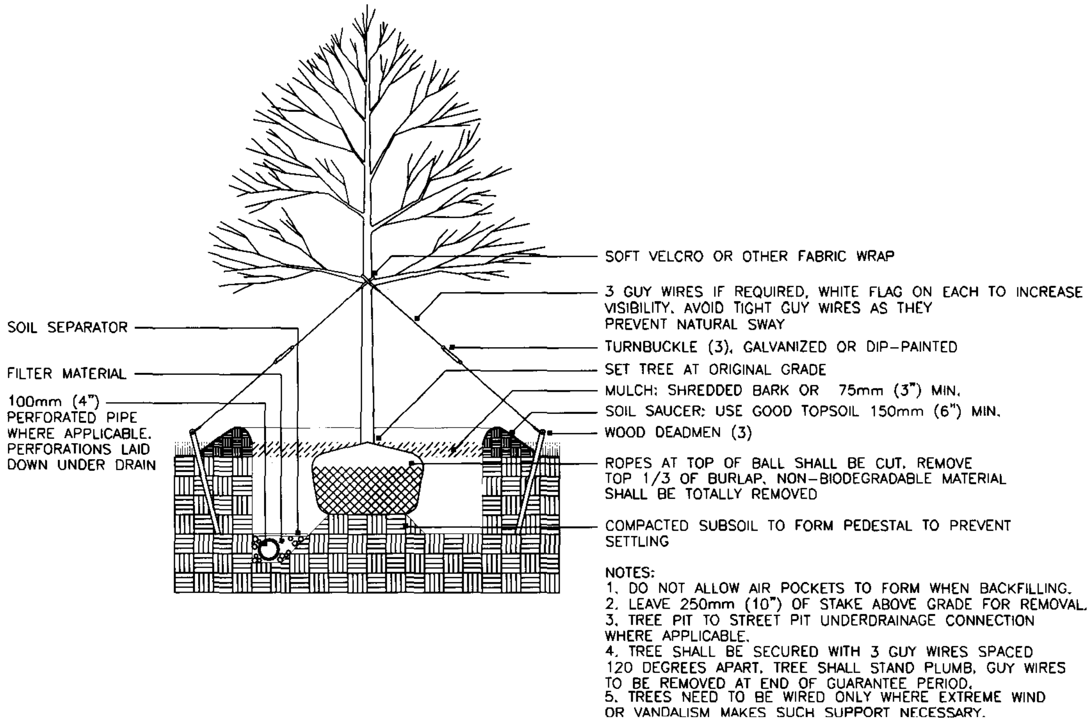


Figure 550-5. Typical tree planting and guying (12-ft height and larger).

Mulches and Fertilization:

Mulches moderate soil temperatures, retain moisture and air around roots, and suppress weed growth that competes with plant roots for water and nutrients. Spreading 75 to 100 mm (3 to 4 in) of mulch 1.5 to 2.1 m (5 to 7 ft) around trees and a meter around other plantings is most effective. Bare soil should be left at the base of the plant to avoid trunk suffocation or rot. Permeable weed barrier fabrics may be used under mulches, but impermeable weed materials such as black plastic restrict oxygen reaching the root zone and should not be used. Fertilize on the surface at spring or fall, or use slow-release tablets in tree planting holes. Plants need extra nitrogen right after planting and especially in the fall when their roots are most active.

Backfills:

Planting holes should be backfilled with the same soil that was removed, with no amendments. Amendments such as compost, peat and sand may actually inhibit the root penetration of surrounding soil and slow overall growth due to poor capillarity. Fill material should be thoroughly watered as it is backfilled into the hole to remove any air pockets. Soil should be firm enough to support the root ball, but not packed to the point that the tiny pores that hold water and air between soil particles disappear. Aerated soil is crucial to root establishment. Watering berms help collect water and deliver it to the root ball. In heavy soils with poor drainage, or during excessively wet seasons, berms may need to be broken until dry weather makes them necessary again.

Trunk Wrapping and Sunburn:

Trunk wraps on nursery trees make a thorough inspection of bark and trunk health impossible, shelter insect infestations, and hold moisture around the bark where fungus or disease may cause problems. To prevent 'sunburn' after planting, note which side of the trunk was exposed to direct sunlight at the nursery and set the plant similarly when it is installed.

Staking and Guying:

Trees should be staked only when necessary. Trees will be healthier if allowed to adapt to the winds of the site naturally, and will develop sturdy, flexible trunks and branches. Where sites are unusually windy or specimens are too large to be stable initially, staking may be required until the plant can support itself. Two to three stakes should be placed around the plant and attached to the trunk with various types of fabric strapping systems. Stakes should be removed after the second growing season.

Pruning at Planting Time:

Remove only dead or damaged branches, or those that threaten the appearance and branching structure of the tree. Traditional pruning back of a third of the upper branches does not aid plant establishment in most ball and burlap stock, however forest-collected stock may benefit from such pruning prior to planting.

4.2 General Notes on Planting Plans

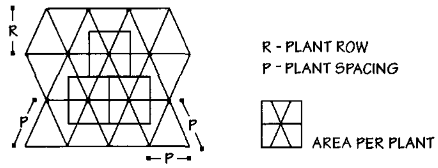
Shown below is a list of notes that are typically shown on planting plans and/or contained in related details and documents. Other notes needed for special circumstances are often added.

1. The contractor shall locate and verify the existence of all utilities prior to starting work.
2. The contractor shall supply all plant materials in quantities sufficient to complete the planting shown on all drawings.
3. All material shall conform to the guidelines established by the current American Standard for Nursery Stock, published by the American Association of Nurserymen.
4. No plant shall be put into the ground before rough grading has

Table 550-4. INVASIVE PLANTS BY REGION

Botanical Name	Common Name	Where Troublesome
Acacia melanaoxylon and many other Acacia species		Southwestern U.S.
Acer ginnala	Amur maple	E. Asia
Acer platanoides	Norway maple	Europe
Ailanthus altissima	Tree of heaven	Eastern U.S.
Albizia julibrissin	Mimosa	
Alliaria petiolata	Garlic mustard	Europe
Ammophila arenaria	European beach grass	Europe
Bamboo		Many parts of the U.S.
Bellis perennis	English daisy	Northwestern U.S.
Berberis thunbergii	Japanese barberry	Northeastern and Midwestern U.S.
Bromus inermis	Smooth brome,	Midwestern U.S.
Carduus nutans	Musk thistle	All of U. S.
Casuarina equisetifolia	She-oak, ironwood, Australian pine	Gulf states (U.S.)
Celastrus orbiculatus	Leafy spurge, Oriental	Northeastern and Midwestern U.S.
Chrysanthemum leucanthemum	Oxeye daisy	Northwestern U.S.
Cichorium intybus	Chicory	Many parts of the U.S.
Cirsium arvense	Canada thistle	All of U. S.
Coronilla varia	Crown vetch	Midwestern U.S.
Cortaderia jubata	Pampas grass	Southwestern U.S.
Cynodon dactylon	Common Bermudagrass	Southwestern U.S., Gulf states
Cytisus scoparius	Scotch broom	Northwestern U.S., most species invasive in Southwestern U.S.
Daucus carota	Queen Anne's lace	
Digitalis purpurea	Foxglove	Northwestern U.S.
Dipsacus laciniatus	Cut-leaved teasel	Europe
Dipsacus sylvestris	Wild teasel	
E. fortunei	Winter creeper	
E. umbellata	Autumn olive	Midwestern U.S.
Eichhornia crassipes	Water hyacinth	S. America
Elaeagnus angustifolia	Russian olive	Midwestern U.S.
Elaeagnus umbellata	Autumn olive	East Asia
Elymus arenarius	European lyme grass	Eurasian
Equisetum hyemale	Horsetail	Many parts of the U.S.
Eucalyptus spp. (many)	Gum	Southwestern U.S.
Euonymus alata	Winged wahoo, winged euonymus	
Euphorbia esula	Leafy spurge	
Festuca elatior	Tall fescue	
Festuca pratensis	Tall fescue	Europe
Galium verum	Yellow bedstraw	Northeastern, Midwestern U.S.
Glechoma hederacea	Ground ivy	Northwestern U.S.
Hedera helix	English ivy Hungarian brome	Southwestern, Northwestern U.S.
Hypericum calycinum	Aaron's beard, St. John's-wort	Northwestern U.S.
Imperata cylindria	Cogon grass	Pantropical
Ipomoea spp. (most)	Morning glory	Many parts of the U.S.
Juniperus virginiana	Eastern red cedar	
L. maackii	Amur honeysuckle	
L. tatarica	Tatarian honeysuckle	Eastern U.S.
Lantana hybrids		Gulf states (U.S.)
Lespedeza cuneata	Sericea lespedeza	
Ligustrum obtusifolium	Blunt-leaved privet	Japan
Ligustrum vulgare	Privet	Eastern U.S.
Lonicera japonica	Japanese honeysuckle	Northeastern, Midwestern U.S.
Lonicera maackii	Amur honeysuckle	Eurasia
Lonicera tatarica	Tatarian honeysuckle	
Lysimachia vulgaris	Garden loosestrife	
Lythrum salicaria	Purple loosestrife	Northeastern, Midwestern U.S.
M. officinalis	Yellow sweet clover	
Maclura pomifera	Osage orange	
Melaleuca quinquenervia	Punk tree, Cajeput tree	Gulf states (U.S.)
Melia azedarach	Chinaberry	Asia
Melilotus alba	White sweet clover	Midwestern U.S.
Melilotus officinalis	Yellow sweet clover	
Mesembryanthemum ssp.	Ice plant	Africa
Myriophylium brasiliense	Water-feather	
Nasturtium officinale	Watercress	Many parts of the U.S.
P. pratensis	Kentucky bluegrass	
P. sylvestris	Scotch pine	
P. thunbergii	Japanese black pine	
Pastinaca sativa	Wild parsnip	
Paulownia tomentosa	Princess tree	
Pennisetum setaceum	Fountain grass	Southwestern U.S.
Phalaris arundinacea	Reed canary grass	Midwestern U.S.
Phragmites communis	Reed	
Pinus nigra	Austrian pine	
Pinus sylvestris	Scotch pine	Europe
Pinus thunbergii	Japanese black pine	East Asia
Poa compressa	Canada bluegrass	
Poa pratensis	Kentucky bluegrass	Eurasia
Polygnum cuspidatum	Japanese knotweed	Many parts of the U.S.
Populus alba	White poplar	
Portulaca oleracea	Purslane	Many parts of the U.S.
Potamogeton crispus	Pondweed	
Pteridium aquilinum	Bracken fem	Northwestern U.S.
Pueraria lobata	Kudzu vine	Southeastern U.S.
R. frangula	Alder buckthorn	
Rhamnus cathartica	Common buckthorn	Midwestern U.S.
Rhamnus davurica	Dahurian buckthom	E. Asia
Rhodomyrtus tomentosus	Downy myrtle	E. Asia
Robinia pseudoacacia	Black locust	Midwestern U.S.
Rosa multiflora	Multiflora rose	Northeastern, Midwestern U.S.
Rubus procerus	Himalayan blackberry	Southwestern, Northwestern U.S.
Schinus terebinthifolius	Brazilian pepper tree	Gulf states (U.S.)
Solidago canadensis	Goldenrod	Northwestern U.S.
Sorghum halepense	Johnson grass	
Tamarix spp. (many)	Tamarisk	Western U.S.
Typha angustifolia	Narrow-leaved cattail	
U. pumila	Dwarf elm	
Ulmus procera	English elm	
V. minor	Common periwinkle	Eastern U.S.
Verbascum thapsus	Common mullein	
Viburnum lantana	Wayfaringtree	Europe
Viburnum opulus	Guelder rose	
Vinca major	Large periwinkle	Eastern, Northwestern U.S.
Vinca minor common	Periwinkle	Eastern, Northwestern U.S.

Table 550-5. PLANT SPACING CHART



$$\text{NO. PLANTS} = \frac{\text{AREA}}{\text{AREA PER PLANT}}$$

Plant Spacing (On Center)				Area per Plant	
P (m)	P (ft)	R (m)	R (ft)	m^2	ft^2
.15	.50	.13	.43	.0195	.2150
.20	.67	.18	.58	.0360	.3886
.25	.83	.22	.72	.0550	.5976
.30	1.00	.26	.87	.0780	.8700
.38	1.25	.33	1.08	.1254	1.3500
.46	1.50	.40	1.30	.1840	1.9500
.61	2.00	.53	1.73	.3233	3.4600
.76	2.50	.66	2.17	.5016	5.4250
.91	3.00	.79	2.60	.7189	7.8000
1.00	3.28	.87	2.84	.8700	9.3152
1.22	4.00	1.06	3.46	1.2900	13.8400
1.25	4.10	1.08	3.55	1.3500	14.5550
1.50	4.92	1.30	4.27	1.9500	21.0084
1.52	5.00	1.32	4.33	2.0064	21.6500
1.75	5.74	1.52	4.97	2.660	28.5278
1.83	6.00	1.58	5.20	2.8914	31.2000
2.00	6.56	1.73	5.68	3.4600	37.2608
2.44	8.00	2.11	6.92	5.1484	55.3600
2.50	8.20	2.17	7.10	5.4250	58.2200
3.00	9.84	2.60	8.47	7.8000	86.3448
3.05	10.00	2.64	8.66	8.0520	86.6000
4.00	13.12	3.46	11.37	13.8400	149.1744
4.57	15.00	3.96	12.99	18.0972	194.8500
5.00	16.41	4.33	14.21	21.6500	233.1861
6.00	19.69	5.20	17.05	31.2000	335.7145
6.10	20.00	5.28	17.32	32.2080	346.4000
8.00	26.25	6.93	22.73	55.4400	596.6625
10.00	32.81	8.66	28.41	86.6000	932.1321
15.00	49.22	12.99	42.62	194.8500	2097.7564

*This chart is used when plants are to be spaced equidistant from each other as shown.

been finished and approved by the project architect or equal.

5. All plants shall bear the same relationship to finished grade as the plant's original grade before digging.
6. All plants shall be balled and wrapped or container grown as specified. No container grown stock will be accepted if it is root bound. All root wrapping material made of synthetics or plastics shall be removed at time of planting.
7. With container grown stock, the container shall be removed and the container ball shall be cut through the surface in two vertical locations.
8. The day prior to planting, the location of all trees and shrubs shall be staked for approval by the project landscape architect or equal.
9. All plant material shall be selected at the nurseries by the project landscape architect or equal.
10. All plants shall be sprayed with an antidessicant within 24 hours after planting. In temperate zones, all plants shall be sprayed with an antidessicant at the beginning of their first winter.
11. All plants shall be installed as per details and the contract specifications.
12. All plants and stakes shall be set plumb unless otherwise specified.
13. The landscape contractor shall provide fill as per the contract specifications.
14. All plants shall be watered thoroughly twice during the first 24-hour period after planting. All plants shall then be watered weekly, if necessary, during the first growing season.
15. The landscape contractor shall refer to the contract specifications for additional requirements.
16. The landscape contractor shall refer to the plant list for seasonal requirements related to the time of planting.

4.3 Notes and Details

Notes:

Notes are usually added to insure that plant material is installed properly. They often reiterate special instructions and specifications contained in contract documents.

Planting Details:

Figures 550-5 through 550-14 illustrate typical planting details for different situations and types of plants. Local practice may require minor variations of these details.

4.4 Contract Specifications

Whenever possible, all contract specifications related to plants and planting should conform to current standardized practices used in building and site construction. In the United States, the Construction Specification Institute (CSI) has produced a widely accepted and used format. The CSI Format is a consistent, nationally unified system which consists of 16 Divisions ranging from General Requirements to Electrical. Division 2 is assigned to Site Work. Sections within Division 2 pertain to technical sections or basic units of work, such as Landscaping (02800). Refer to Table 110-2 in Section 110 for the complete CSI Division 2 Site Work listing.

4.5 Standards for Nursery Stock

Plants should be closely examined on-site before planting to insure their health and continuing vigor. A accepted set of standards has been developed by the American Association of Nurserymen (AAN) to guarantee quality and to facilitate commerce in nursery stock. These are voluntary national standards subject to rules and approval by the American National Standards Institute (ANSI). Similar standards for other countries may be available and may differ in some ways from those developed by the AAN. Table 550-6 was prepared for the AAN publication in cooperation with the Canadian Nursery Trades Association to facilitate nursery trade between the United States and Canada as well as with other countries that use the international metric system of measurement. It lists rounded metric equivalents as recommended for use in sizing nursery-grown plants.

5.0 MANAGEMENT STRATEGIES

There are two sets of standards for landscape management. The National Arborist Association (NAA) has provided standards for tree care in the past. A set of new standards is being prepared by the American National Standards Institute (ANSI) to replace the older NAA standards within the next thirty years. As new ANSI guidelines are completed, the corresponding NAA guidelines will be phased out. Currently, ANSI standards for pruning (ANSI A300) and safety requirements for tree care operations (ANSI Z133) are complete. Other areas of maintenance are still governed by NAA standards.

6.0 SPECIALIZED PLANTING STRATEGIES

6.1 Using Native Plants

Native plants are becoming more popular in designed landscapes for the advantages they hold over introduced exotic plants. Natives are adapted to seasonal extremes of temperature and moisture and thus are often able to survive frosts and droughts that hardy exotics cannot. They require less irrigation out of season. They reinforce local ecosystems, bringing butterflies, birds and other animals into contact with people. Natives require very little maintenance once properly established and help to preserve the unique character of a region.

The first step towards designing with native plants is understanding the plant communities that exist in undisturbed conditions in the region. The Küchler map divides North America into ecoregions based on plant associations, watersheds, and general climate. Native plant communities differ from traditional garden plantings in several important ways. Traditional planting plans often seek to moderate change and to organize space through grouping plants by their color and texture. These objectives are supported by thousands of years of plant hybridization that has produced cultivars with large, brightly colored flowers and long bloom periods. By contrast, native communities rely on change and diversification to buffer them from stress. Many species are intermixed and produce overlapping waves of short bloom periods. Native flowers tend to be smaller and more subtly colored. In addition, the composition of native plant communities can change radically from one year to the next, in response to seasonal climate and stress. Understanding the character of native plant communities is a prime requirement for designing with native plants.

Natives can be planted in drifts, but those that spread by seed will not necessarily stay where they are placed. It is better to orchestrate overall bloom times and heights of a mixture, so that the newest blooms will be visible. Some spring wildflowers bloom early and then enter summer dormancy. Take advantage of their early color and then cover the same area with more persistent plants that emerge and bloom later.

Finding native seed or nursery stock in sufficient quantity can be a problem. Many mail-order companies exist that deal in native seeds, but the best seed stock is from a local source. Use reputable nurseries that propagate natives responsibly and can document their sources. In most states, digging up rare specimens from the wild is illegal, but the practice persists. Do not use plant material whose source you cannot trace. Native plantings can be labor-intensive to establish, but once they are stable and mature they will require little to no maintenance.

6.2 Xeriscaping and Water-Efficient Landscapes

Xeriscaping is a planting practice that relies on minimal or no irrigation, eschewing heavily watered landscapes in favor of those that combine low water requirements with the unique beauty of plants adapted to the region. In arid climates, the importance of plants that are adapted to local conditions is well-recognized, but almost all regions of the United States suffer from some annual drought, requiring supplemental watering of lawns and planting

KEY POINTS: Planting Techniques

Research has demonstrated that many traditional planting practices are detrimental to the long-term health of plants. The following techniques are necessary to insure the survival and long-term health of installed plant material.

1. Inspect plants carefully upon their arrival at the site. There should be no unhealed wounds in the bark or stem of the plant and no major broken branches. Container plants that are extremely root-bound should be rejected.
2. The planting hole should be at least two times wider than the root ball, but no deeper, and the plant should be set on firm subsoil. The root flare should be set at the same level it has grown.
3. Non-biodegradable nursery wrappings (i.e. plastic or wire) around the roots must be carefully removed. Burlap can be left in place if the top third of the root ball is unwrapped.
4. About 75 to 100 mm (3 to 4 in) of mulch should be spread 1.5 to 2.1 m (5 to 7 ft) around trees and a meter around other plantings. Bare soil should be left at the base of the plant to avoid trunk suffocation or rot.
5. Plants need extra nitrogen right after planting, especially in the fall when their roots are most active. Fertilize on the surface at spring or fall, or use slow-release tablets in tree planting holes.
6. Planting holes should be backfilled with the same soil that was removed. Amendments such as compost, peat and sand should not be used, as they may actually inhibit the root penetration of surrounding soil and slow overall growth.
7. Trunk wrapping should not be used, as they may shelter insect infestations, and hold moisture around the bark causing fungus or disease.
8. Staking should be avoided. Where sites are unusually windy or specimens are too large to be stable initially, staking may be required until the plant can support itself, but should be removed after the second growing season.
9. Pruning after planting should be limited to dead or damaged branches, or those that threaten the appearance and branching structure of the tree. Traditional pruning back of a third of the upper branches does not aid plant establishment in most ball and burlap stock.

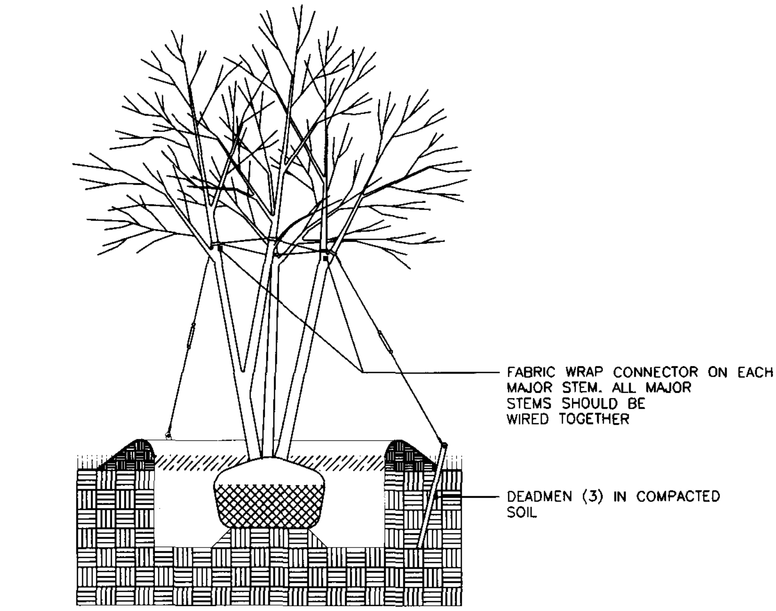


Figure 550-6. Typical multi-stem tree planting and guying.

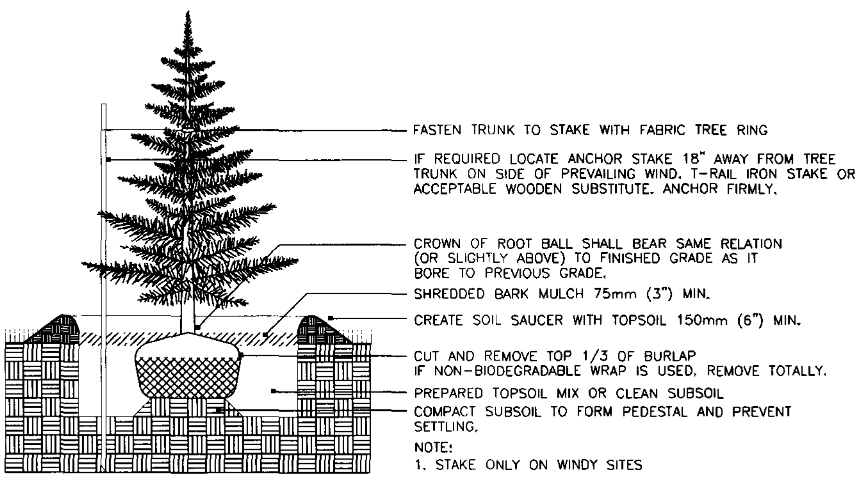


Figure 550-7. Typical coniferous tree planting (6-ft height and smaller).

beds. During even short periods of drought, widescale residential irrigation can threaten supplies of drinking water.

The seven areas of concern in xeriscape designs as defined by the National Xeriscape Council, Inc. (NXCI) are:

Planning and Design:

A rich palette of drought-tolerant plant materials exists worldwide, although natives are best adapted and should form the overall framework for a dry garden. Where traditional garden styles from other climates are required, adapt to the dry environment. Xeriscape gardens do not have to be spare and bare; drought-tolerant plants can look lush without heavy irrigation.

Soil Analysis and Improvements:

Soil quality is the major determining factor in a well-planned xeriscape garden, directly affecting the vigor and water efficiency of plants.

Structure: Soil that has been heavily amended with organic material helps plants survive periods of drought, although some plants prefer poor soil. However, amending within planting holes is actually detrimental to the long term health of plants—complete replacement of soil or no amending is better in this case.

Chemistry: Soil pH is largely determined by underlying material and the amount and pH of available water. These natural factors have a more profound, long lasting influence upon the soil's chemistry than amendments or mulches. Choose plants adapted to site conditions rather than trying to alter the pH of the soil. Many arid regions in the American West have soils with high concentrations of salt due to agricultural practices or natural conditions. Table 550-7 shows some plants that are tolerant of saline soils.

There is no 'perfect' soil. Designers must develop a good understanding of the soil structure and chemistry on site, and then aim for a good match between soil characteristics and plant requirements.

Practical Turf Areas:

Where lawn is necessary, follow these guidelines:

In arid climates (where turf has to be irrigated to survive):

1. Use turf only where it is clearly serving a purpose such as play areas, sports fields, etc.
2. Shape turf areas to allow maximum irrigation efficiency. The ratio of area to perimeter should be high. Do not use lawn in areas too small or narrow to be irrigated efficiently.
3. Avoid using turf on slopes where irrigation cannot be efficient—use alternate groundcovers or low-water use grass.

In wetter climates (where turf can survive without heavy irrigation):

1. Even without heavy irrigation costs, lawns are still high-maintenance elements of the landscape. Evaluate turf areas against maintenance budgets and functional needs.
2. Consider using a variety of turf that can survive in that climate without any supplemental irrigation.

Improving the efficiency of irrigation for turf, in both cases:

1. Some grasses develop root systems that penetrate the soil to a depth of 1.5 m (5 ft) or more in the wild. Wait as long as possible into the spring to

Table 550-6. METRIC EQUIVALENTS FOR SIZING NURSERY PLANTS

Plants Sized by Height or Spread		Plants Sized by Caliper	
U.S. Measure	Recommended Metric Equivalent	U.S. Measure, in	Recommended Metric Equivalent, cm
6 in	15 cm	3/8	1.0
8 in	20 cm	1/2	1.5
10 in	25 cm	3/4	2.0
12 in	30 cm	1	2.5
15 in	40 cm	1-1/4	3.0
18 in	50 cm	1-1/2	4.0
2 ft	60 cm	1-3/4	4.5
2-1/2 ft	80 cm	2	5.0
3 ft	90 cm	2-1/2	6.0
3-1/2 ft	1.00 m	3	8.0
4 ft	1.25 m	3-1/2	9.0
5 ft	1.50 m	4	10.0
6 ft	1.75 m	4-1/2	11.0
7 ft	2.00 m	5	13.0
8 ft	2.50 m	5-1/2	14.0
		6	15.0

* Metric equivalents have been rounded off.
Source: Prepared by the American Association of Nurserymen in cooperation with the Canadian Nursery Trades Association.

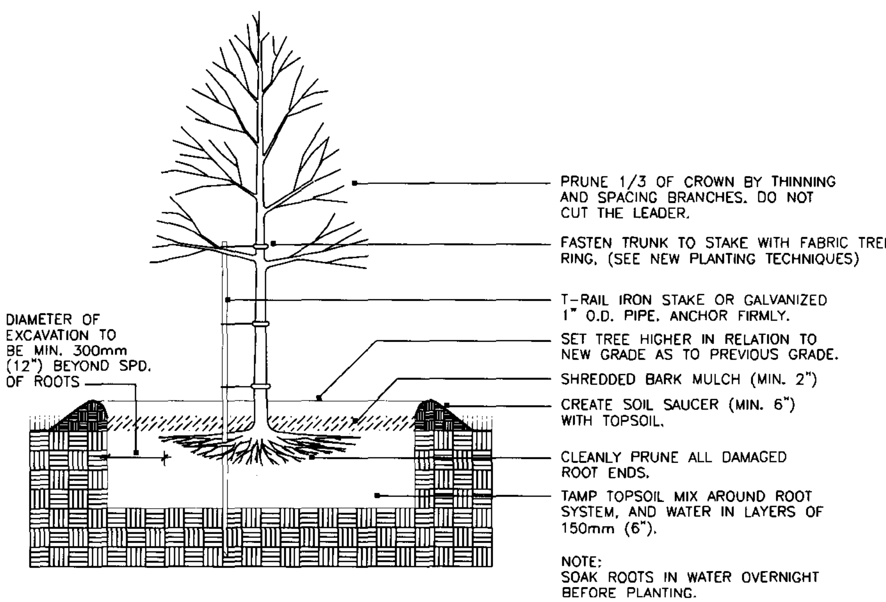


Figure 550-8. Typical deciduous tree planting (bare root) (10-ft height and smaller).

begin irrigation (when the soil is dry to a depth of several centimeters)—this promotes deep, drought-resistant root systems.

2. During periods where irrigation is necessary, irrigate deeply and infrequently.

Both of these practices will also discourage weed growth.

Characteristics of Appropriate Drought-Tolerant Plants:

Appropriate plants are not necessarily constant low-water users. An appropriate plant is one whose growth cycle is well adapted to the specific seasonal pattern of the climate in which it is planted, which may include short periods of intense drought or rain. Indeed, when these plants are established, supplemental moisture during their "dry" cycle can lead to root rot and disease. Plants native to a region will be the best adapted and will be able to survive seasonal extremes of drought and temperature, but many exotics from similar climates are also appropriate. When using non-natives, avoid destructive invasive species.

Develop a working knowledge of the adaptations that plants and plant communities native to a particular region have evolved. Plants adapted to dry climates can be either deep or shallow rooted depending on the above-ground adaptations they have evolved. Most natural plant communities are self-reinforcing; associated species support each other when grown together.

Many plants can survive drought, but some do so by entering dormancy until moisture is present again. Others have adaptive strategies that allow them to look healthy and attractive during drought periods. Consider the behavior of potential plants when they are subjected to drought stress when placing them in the landscape. Irrigation is crucial during the first several years to establish new plantings, but will become unnecessary and even detrimental to the continuing health of plants when mature if they have been well-chosen for their new locations.

Efficient Irrigation:

Harvest rainwater from impervious surfaces such as roofs and pavements; run downspouts into planting beds; grade pavement to run off into lawns or beds; terrace steep slopes to collect rainwater; use collection swales at the foot of slopes to collect runoff.

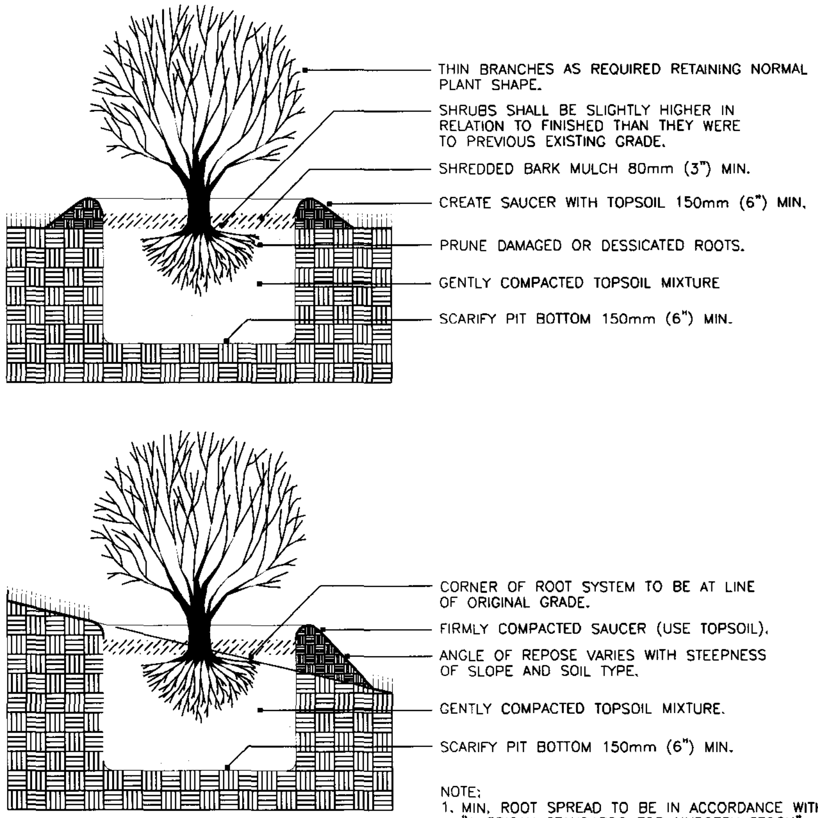
All plants require irrigation for the first few years after planting. If the design aims for eventual independence from irrigation, hand-watering or use of a minimal, inexpensive system may be enough.

For permanently irrigated landscapes, use drip irrigation wherever possible. Drip systems waste very little water, as they deliver water directly to the roots. This also promotes deeper root systems and leads to fewer problems with insects and diseases that are fostered by wet leaves and stems.

Sprinklers are the only option for lawns and some other situations. Sprinklers that spray water high into the air lose more water to evaporation than lower spraying. Irrigate with sprinklers in the early morning (before sunrise) wherever possible.

The following recommendations apply to all forms of irrigation, whether in arid or wet climates (Refer to Section 750, Irrigation, for more detailed information):

1. Irrigate deeply and infrequently to promote resilient, deep root systems.
2. Calibrate rate and duration of water delivery to minimize runoff.



NOTE:
1. MIN. ROOT SPREAD TO BE IN ACCORDANCE WITH "AMERICAN STANDARDS FOR NURSERY STOCK".
2. PRUNE ALL DAMAGED, DISEASED, OR WEAK LIMBS AND ROOTS.
3. CLEANLY PRUNE ALL DAMAGED ROOT ENDS.
4. DO NOT ALLOW ROOTS TO DRY OUT DURING INSTALLATION PROCESS.
5. SOAK ROOTS IN WATER OVERNIGHT BEFORE PLANTING.

Figure 550-9. Typical shrub planting (bare root). *Continuous trenches are often dug for hedge plantings.*

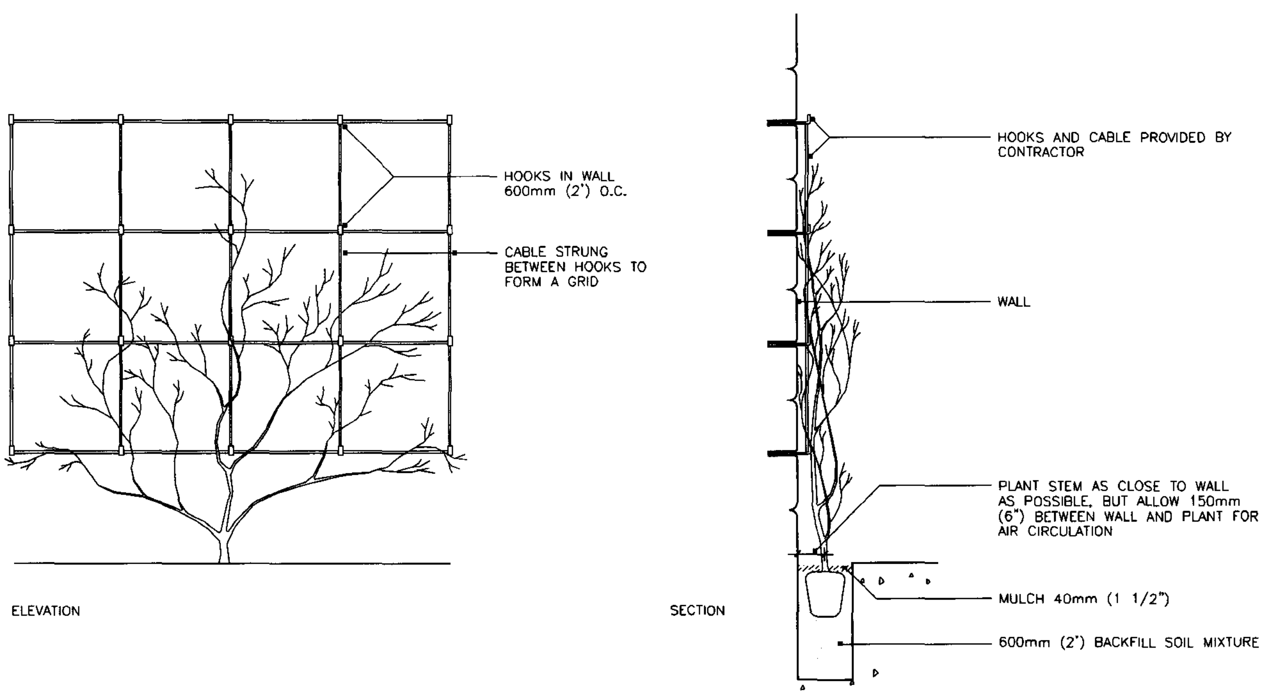


Figure 550-10. Typical espalier planting. *Hooks are fastened to wall 24 in on center, and cable is strung taut between hooks.*

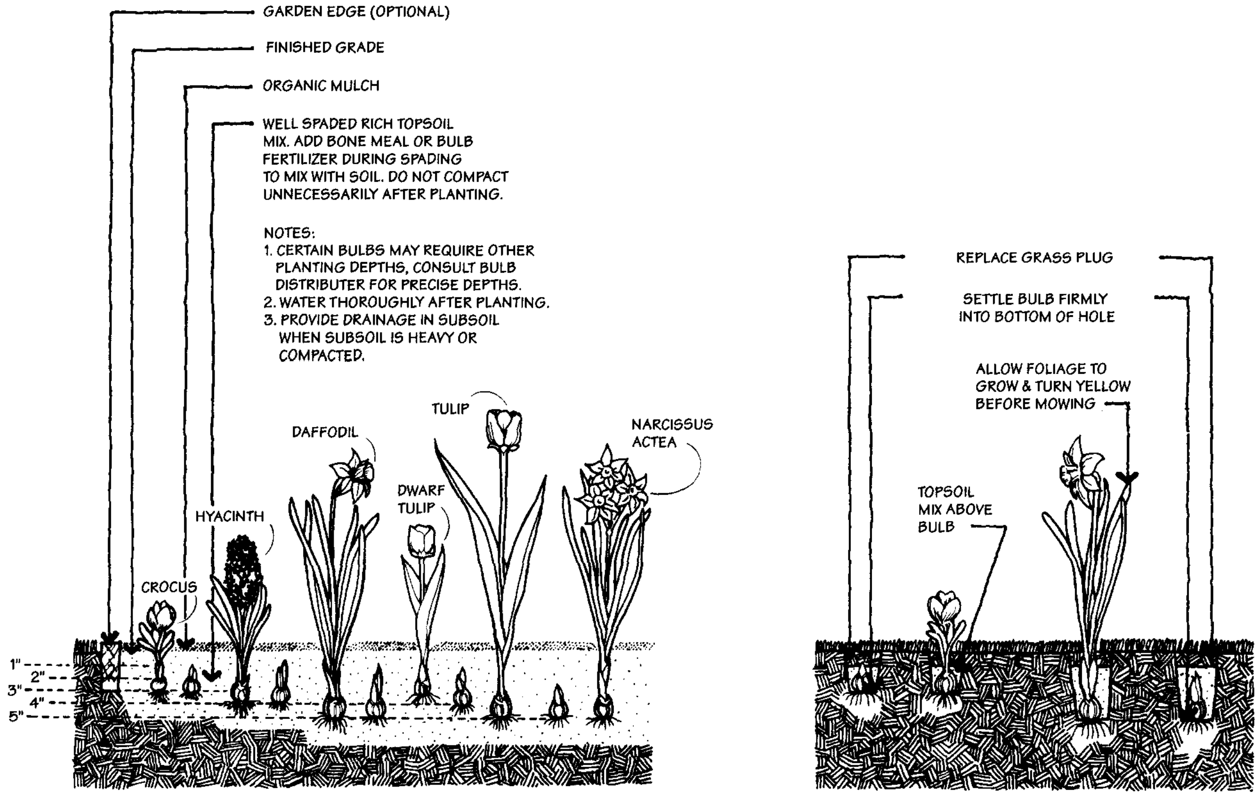


Figure 550-11. Typical bulb plantings. *Spacing will vary depending on desired effect of plantings.*

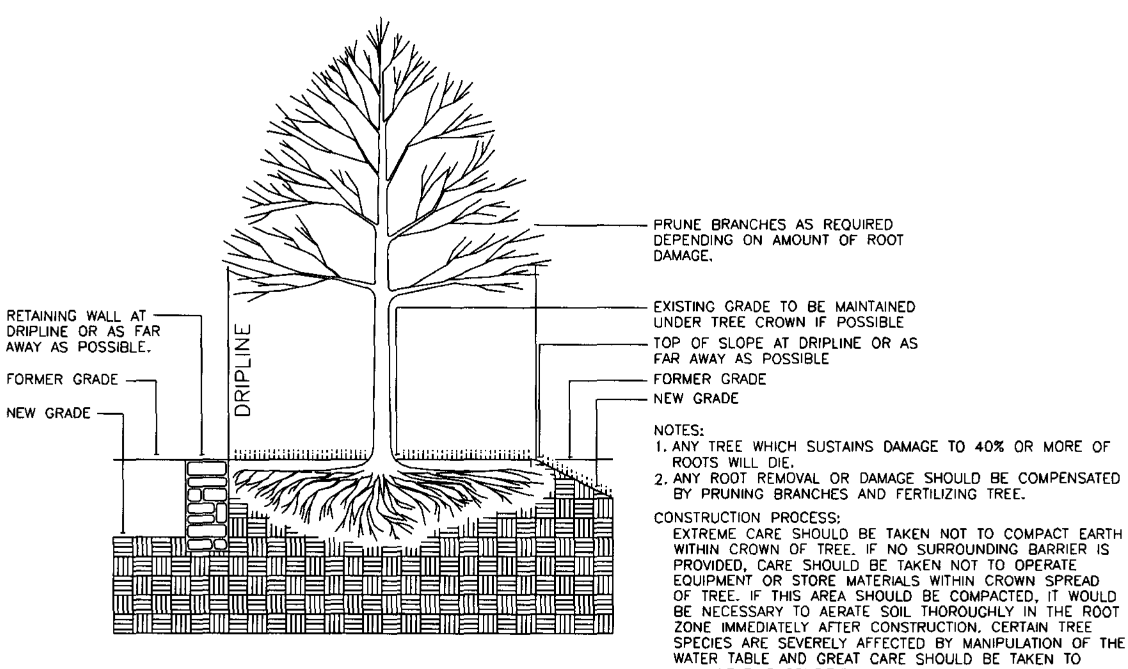


Figure 550-12. Cutting or lowering a grade near an existing tree.

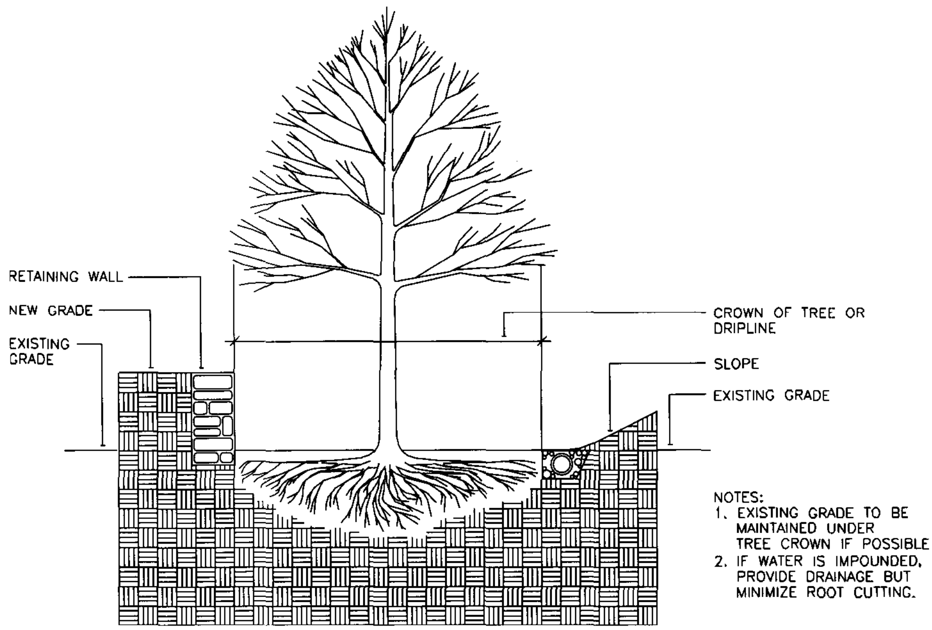


Figure 550-13. Filling or raising a grade near an existing tree.

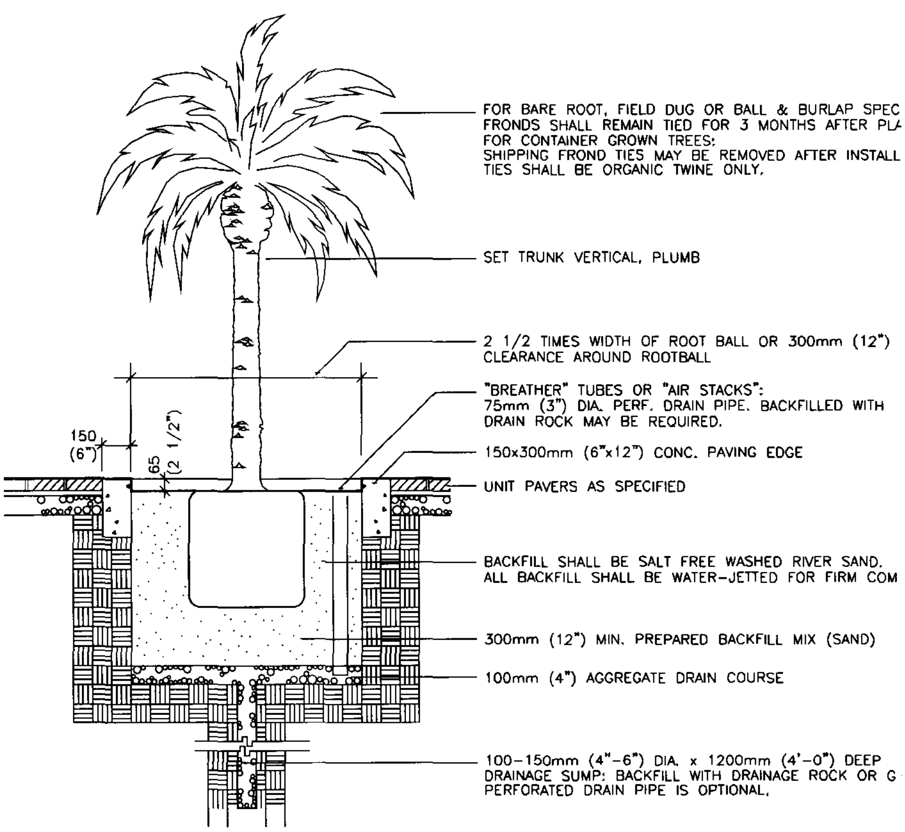


Figure 550-14. Palm tree planting in paving.

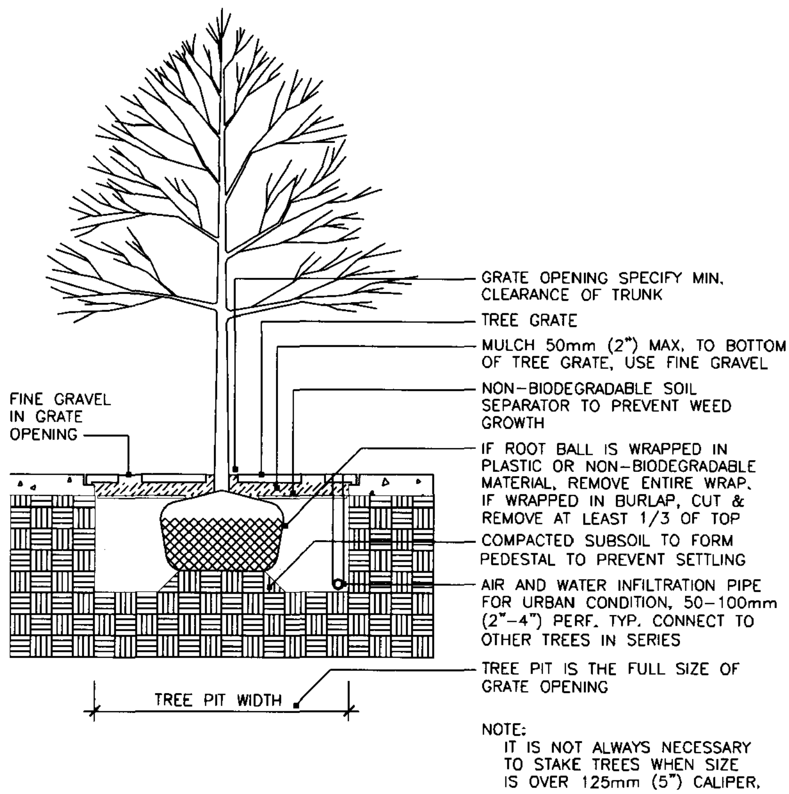


Figure 550-15. Urban tree planting.

3. Monitor irrigation consumption and adjust monthly to meet changing conditions.

4. Allow for regular maintenance of irrigation systems. Leaks and plugs in irrigation lines not only waste water; they can kill plants and damage structures.

Mulching:

Mulch is a crucial component of a water-efficient landscape. Mulch conserves soil moisture, moderates soil temperatures, limits reflected heat that damages plants, holds and builds the soil, prevents weeds, and helps control erosion from wind and rain.

There are several cautions that apply to mulches. Some mulches, such as shredded bark or pine needles, are flammable when dry. Use caution when mulching near sources of heat or sparks. Fresh mulches, such as new wood chips or sawdust, draw nitrogen from the soil when they begin to decompose. Use a slow-release nitrogen fertilizer with these mulches. Any organic mulch can provide cover for such pests as slugs, sowbugs, earwigs, and rodents. If these pests become a problem, pull mulch back at least 150 mm (6 in) from the base of plantings that are under attack or consider using a different type of mulch.

Appropriate Maintenance:

Monitor conditions on a regular basis to head off problems of insect attack, irrigation, disease, or soil problems. Fertilizer may be necessary to counteract nitrogen drain of fresh, decomposing mulch. Monitor plant conditions and apply slow release nitrogen fertilizer if necessary. Mow turf at a high setting. This improves drought resistance by shading the soil and allowing deeper roots to form.

6.3 Urban Forestry

The conditions which must be endured by trees in urban areas cause the majority of street tree plantings to die within ten years of their installation. Extreme heat, soil that has been compacted or contaminated with building fill or other urban contaminants, and damage from vandals are only a few of the factors that urban trees must contend with. Traditional planting techniques contribute to this high mortality rate because they do not provide sufficient root space and drainage. Table 550-8 lists common causes of urban tree mortality and remedies. Figure 550-15 illustrates a detail for urban tree planting.

6.4 Planting on Disturbed Sites

Restoration of disturbed landscapes involves work on many different levels. Plant species must be well-adapted to the site in order to grow into self-sustaining populations. This implies primary reliance upon native species that have been raised in conditions that approximate those of the site. Plants are frequently transplanted or direct-seeded from material gathered nearby. Sometimes nurse crops or pioneer plantings are introduced as a way to arrive at the target plant community.

Grasses can be used for fast stabilization of slopes and soil improvement. For a list of suitable grasses and more information about techniques for planting used in restoring disturbed landscapes refer to Section 640.

6.5 Planting for Bioengineering

Bioengineering relies on plant materials to stabilize eroded stream banks and other areas suffering damage from excessive runoff. It generally involves replacing hard, inflexible support structures that degrade over time with soft, flexible systems of plants that grow and improve over time and increase the wildlife habitat values of the area. Plants that are well-suited to these techniques share certain characteristics. They are generally native successional plants that can tolerate moist conditions, have the ability to root quickly from stem nodes, can spread vegetatively, and form strong root systems when established. For more information about regional applications of bioengineering techniques, consult the references at the end of this section.

Table 550-7. SALT TOLERANT PLANTS

	Botanical Name / Common Name	
	Trees	**Shrubs**
Moderate Tolerance	Acer negundo / Box elder Betula populifolia / Gray birch Celtis occidentalis / Hackberry Fraxinus excelsior / European ash F. quadrangulata / Blue ash Juniperus scopulorum / Juniper J. virginiana / Eastem red cedar Koelreuteria paniculata / Goldenrain tree Maclura pomifera / Osage orange Robinia pseudoacacia / Black locust Sophora japonica / Japanese pagoda tree, Chinese scholar tree Ulmus pumila / Siberian elm	Caragana arborescens / Siberian pea shrub Elaeagnus commutata / Silverberry E. multiflora / Cherry elaeagnus Juniperus chinensis / 'Pfitzerana' J. conferta / Japanese shore juniper Lonicera tatarica / Tatarian honeysuckle Rhamnus frangula / Glossy buckthom Spiraea vanhouttei / Vanhoutte spirea
High Tolerance	Ailanthus altissima / Tree-of-heaven Amelanchier canadensis / Shadblow serviceberry Crataegus crus-galli / Cockspur hawthom Elaeagnus angustifolia / Russian olive Pinus thunbergii / Japanese black pine Ptelea trifoliata / Wafer ash Thuja occidentalis / American arborvitae	Atriplex canescens / Four-wing saltbush Baccharis halimifolia / Groundsel Cytisus scoparius / Scotch broom Halimodendron / Salt tree halodendron Hippophae rhamnoides / Sea buckthorn Myrica pensylvanica / Bayberry Rhamnus cathartica / Common buckthorn Rosa rugosa / Rugosa rose Shepherdia canadensis / Buffaloberry Tamarix gallica / Tamarisk T. parviflora
	Grasses (ranked lowest to highest)	
	Agrostis palustris / Creeping bentgrass Agropyron Smithii / Westem wheatgrass A. elongatum / Tall wheatgrass Elymus canadensis / Canada wildrye Cynodon dactylon / Bermudagrass Puccinellia airoides / Alkaligrass Distichlis stricta / Saltgrass Sporobolus airoides / Alkali sacaton	

Source: Dr. James Feucht and Jack Butler, *Landscape Management* (New York: Van Nostrand Reinhold Company, 1988)

Table 550-8. CAUSES OF URBAN TREE MORTALITY AND REMEDIES

Causes	Remedies
soil compaction	Provide large areas of rooting space wherever possible, through tree strip trenches rather than pits
sterile or toxic soils	Test soils frequently. Urban soils are by definition highly disturbed, and conditions can vary widely within a small area. Options for dealing with this problem range from replacing soils entirely (i.e. on a large enough scale to provide enough root space horizontally) to planting trees that will tolerate the true conditions of the site. This may mean using "weed" trees.
over-irrigation	Timer irrigation systems frequently do not respond to the real conditions at the roots of a tree. Many trees drown in their pits due to excess water combined with poor drainage. Use timer systems only where absolutely necessary and provide as much drainage as possible.
repeated wounding from trees, maintenance vehicles, vandals	There is no good solution to this type of problem, but damage can be reduced by understanding the zones in which regular activity is likely to occur. Low-branching trees should not be planted right next to the curb or street edge. All street trees need to be located to avoid being whacked by car doors or providing an obstacle to passengers trying to disembark. Studying the needs of the community and involving them in the design process is always a good practice, and can frequently reduce the amount of vandalism trees must endure.
insufficient air space around roots	A side effect of compaction. See Figure 550-21 for a sample detail that provides for air and drainage around upper level roots. Protecting root space with tree grates or decking is also beneficial.
neglect, failure to remove lines or wraps causing girdling of bark or roots	The best solution to this problem is to avoid using techniques that will require a single visit or unique maintenance after the contractor has left the site. Staking, guying and trunk wrapping should be avoided whenever possible. Consider the maintenance budget when designing, or find some way to make long-term maintenance part of the contract.

Source: Henry F. Arnold, adapted from *Trees and Urban Design*, 1980

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DIVISION 600

Special Conditions

Roof and Deck Landscapes

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CONTENTS

1.0 INTRODUCTION

The high cost of land in urban areas has caused a reappraisal of the usable space on the roofs of buildings. Flat space, whether above underground structures or on levels above the street, is expensive to obtain. Consequently, the development and use of roof areas is rapidly becoming an economic necessity.

Although aesthetic and social needs regarding roof and deck spaces have prevailed for centuries, most structures depend on economic justification to be built and maintained. Aesthetic justification is obvious from a superficial downward glance at the roofscape of our cities. The social justification is almost as obvious when comparison is made between undeveloped roof terraces and the public and commercially developed areas throughout the world. Roof and deck landscapes provide outdoor areas for social interchange that are otherwise almost impossible to obtain in most densely developed cities.

There are important design and structural differences between ground level landscape development and rooftop developments. This section deals with the following special construction requirements:

1. Protection of the integrity of the roof and structure.
2. Positive drainage.
3. A long-term, lightweight planting medium.
4. Adaptation to climate.
5. Optimum irrigation.
6. Selection of paving, structural materials, site furnishings, and water as a design element.
7. Provision of utilities.
8. Public safety and security.
9. Ease of maintenance.

This section covers only new construction. Construction methods needed for existing or historic buildings are too complex and unique to each situation to be included, although the above-listed construction requirements may be involved.

2.0 PROTECTION OF THE ROOF AND STRUCTURE

The single most important consideration concerning rooftop landscape construction is protecting the integrity of the roof and structure beneath the garden. For this reason, there must be waterproofing of exceptional security and longevity to prevent damage. The roof structure and waterproofing is an integral part of the building; consequently, it is the building architect's responsibility to: (1) waterproof the roof, (2) protect the waterproofing from mechanical damage, and (3) insulate the roof for energy conservation. The landscape architect or rooftop designer has no final responsibility for the design and construction of these items, she or he can only specify the roof's physical requirements. However, it is the rooftop designer's responsibility to protect the roof from damage during garden construction. As a general rule, this responsibility begins with the bottom of the drainage layer that is added to the finished roof.

2.1 Load Bearing Capacity

The maximum load bearing capacity of a roof is established by the structural engineer and must never be exceeded. In new construction, the roof structure can usually be strengthened to accommodate heavier loads. Typically, a minimum additional dead load limit of 7.18 kPa (150 psf) between columns is needed to accommodate the construction of a roof garden, although the loads above columns and at the bearing edges of a roof can be considerably greater. A structural engineer should always be consulted before beginning any type of roof or deck landscape design and construction.

2.2 Waterproofing

Waterproofing is another important factor in the design of a roof garden. A typical section through a roof consists of the structural framing or reinforced concrete slab, sometimes sloping to provide drainage to roof drains, a layer of waterproofing material, a layer of insulation, and a layer of lightweight concrete to protect the insulation and the waterproof membrane (Figure 610-1). Alternatively, the insulation may be installed inside the ceiling of the structure. The final layer of lightweight concrete is sloped to drain.

There are an increasing variety of waterproof membranes, employing different materials and methods. Elastomeric materials offer the greatest protection. Bituminous waterproofing should be avoided. Areas where the waterproofing is exposed should be flashed and protected from potentially harmful sun rays.

A complete and long-lasting seal must be achieved before any additional materials can be placed on top of the membrane. Quality control and testing by the building architect is crucial at this stage, to ensure the integrity of the roof, and thereby to prevent costly repairs if leaks occur under the finished roof or deck landscape. A properly installed waterproof membrane can last for the life of a building, however, a single leak may require the removal of the entire garden in order to find the leak.

KEY POINTS: Protection of Structure

The single most important consideration concerning roof and deck landscape construction is protecting the roof and structure from damage due to excessive loading or leaks.

1. The building architect and/or structural engineer should always be consulted prior to roof or deck landscape design and construction.
2. Rooftops must typically be able to support a dead load limit of 7.18 kPa (150 psf) to accommodate the construction of a garden. The loads above support columns and at the edges of a roof can be considerably greater.
3. The roof should be completely covered by a waterproof membrane. Elastomeric materials offer the greatest waterproof protection currently available. Bituminous waterproofing should be avoided.
4. The best drainage system for the roof garden is usually through the same system used by the building. A typical design incorporates a drainage mat placed on the protection board/slab, that directs all filtration water into the roof drains.
5. Anchoring structures to the rooftop slab and penetrating the waterproof membrane should be avoided whenever possible. Figures 610-22 through 610-24 illustrate alternative methods of anchoring.

Even small leaks in the membrane may create water-filled openings into which tree roots may penetrate. Over time, these roots can enlarge the openings, causing additional hidden damage to the waterproof membrane and eventually to the roof and building below.

3.0 SPECIAL PROVISIONS

3.1 Drainage

Drainage for roof gardens must be as effective as the building roof. The best way to handle the drainage for the roof garden is through the same system used by the building. There is no need to duplicate or add a larger system unless required by the roof garden design. Extra surface drains may be installed by connecting them to additional pipes laid on the roof surface, which in turn are connected to the roof's drainage system. Roof drains should be designed to collect both surface and lateral subsurface drainage water whenever possible.

The planting medium used on roofs allows almost immediate downward percolation of water. Positive lateral drainage should be provided through the subsurface of the soil toward the drains.

Figure 610-1 illustrates a typical section through a roof planting. The structural slab is covered with a waterproof membrane, a rot-resistant protection board, an insulation board (unless insulation is installed within the structure), and a lightweight concrete protective slab sloped to drain. A lightweight drainage mat placed on top of the concrete. A rot-resistant filter layer of nonwoven polypropylene fabric (filter blanket) is placed over the drain mat, to prevent the planting soil medium from entering and clogging the drainage system. It is crucial that the planting medium contain no fine silts which will clog the filter blanket and block drainage. This cross section allows water to penetrate the soil layer, pass through the filter blanket into the drainage mat, and flow across the protective concrete slab into openings in the sides of the roof drain, and out through the stormwater system. Any excess water will flow across the surface of the soil to the perforated upper surface of the roof drains. This system has proved to be very effective even in areas of extremely heavy rainfall.

Figures 610-2 through 610-15 illustrate a number of drainage details that can be incorporated into typical rooftop landscapes. Any of these can be adapted or combined to fit special circumstances.

All concealed pipes and drains should be carefully recorded on an as-built plan of the roof garden. This is important not only to prevent possible damage due to later digging but also to provide easy access for cleaning and/or repairing these elements.

Provisions should be made for the periodic cleaning of trapped sediment and the removal of roots growing into the drainage system, whenever possible.

3.2 Lightweight Planting Medium

The critical criteria in the formulation of a suitable planting medium for roof gardens are light weight, the ability to hold nutrients and adequate moisture for plant growth, and the capability of developing a firm but easily drained soil structure. Ready-mixed soils are available commercially, but a suitable soil mixture can be prepared for each project following the given formula per cubic meter (cubic yard):

½ m^3 (½ yd^3) fine to medium sand (No. 18 to No. 60 sieve size, with no silt)

½ m^3 (½ yd^3) 2-5mm (1/8-1/4 in) expanded shale

add to the above:

10% 2-5mm (⅛-¼ in) nitrolized pine bark

1 kg (2 lb) UF-38 Nitroform slow release fertilizer or equal

0.75 kg (1.5 lb) 6-20-20 fertilizer

1 kg (2 lb) 0-25-0 single super phosphate

0.5 kg (1 lb) iron sulfate

Expanded shale is commonly used in place of gravel in lightweight concrete and is generally available from suppliers of concrete materials.

Fine Sand:

The fine sand used in soil mixes is of critical importance to the soil's drainage characteristics. Sand with the physical properties listed in Table 610-1 and the chemical properties listed in Table 610-2 has proven effective for roof garden soil mixes.

Soil Amendments:

Any soil amendments to be used in the mix should be tested by an approved laboratory for the minimal properties listed in Table 610-3.

Organic materials such as fertilizers, particularly nitrogen and other minerals that dissolve, will gradually be leached away by

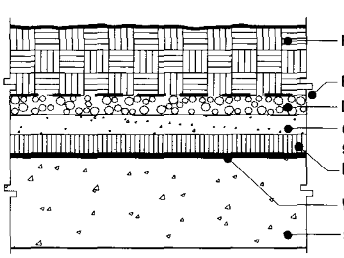

Figure 610-1. Typical cross section of roof or deck landscape.

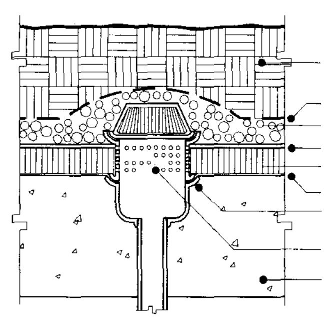

Figure 610-2. Roof drain under planting area. *Insulation layer placed directly on waterproof membrane with perforated protection board to prevent damage to insulation. Water reaching the insulation is carried off through the roof drain.*

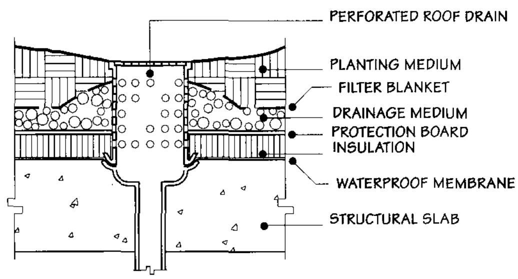

Figure 610-3. Roof drains for flat planted surfaces. *On flat planted surfaces, both surface and subsurface drainage is accomplished with perforated roof drain flush with planting medium. Filter blanket prevents seepage of planting medium into the draining layer.*

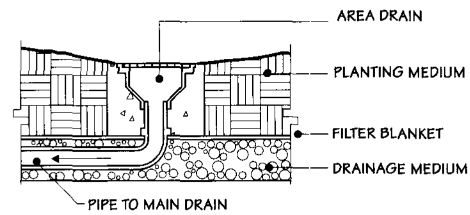

Figure 610-4. Drains for low areas. *When low places occur on the surface not near a major subsurface drain, a lateral pipe and drain can carry water quickly to the main drain.*

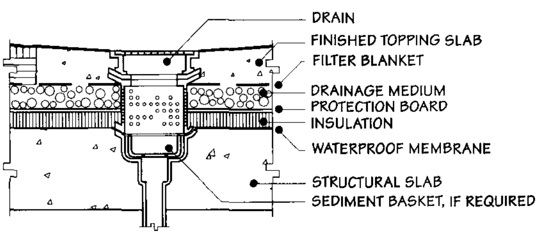

Figure 610-5. Drains for paved areas near planting beds. *For drains in paving near an area of planting medium, topping slab is installed directly on the drainage medium after filter blanket is first placed to prevent loss of wet concrete into the drainage medium.*

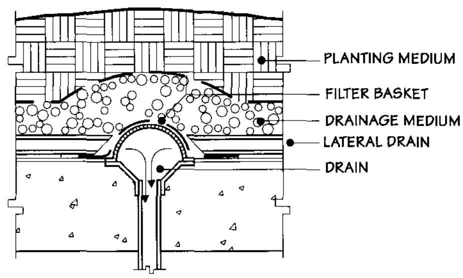

Figure 610-6. Main roof drain under planting. *Main roof drain can be located under a thickened section of the drainage medium, which is protected by a filter blanket. A second filter blanket over the drain strainer and the ends of the lateral drain pipes prevents plugging of drain openings by planting medium.*

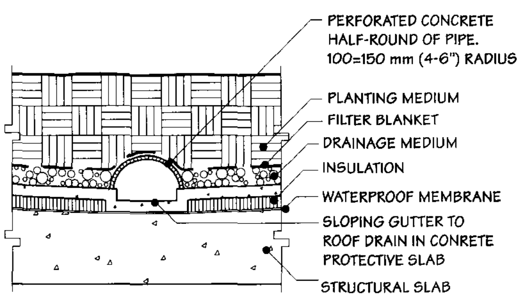

Figure 610-7. Half-round drainage channel under planting. *A sloping drainage channel formed in the concrete protective slab is covered with half-round perforated pipe in 600-900 mm (2 to 3 ft) lengths and a filter blanket.*

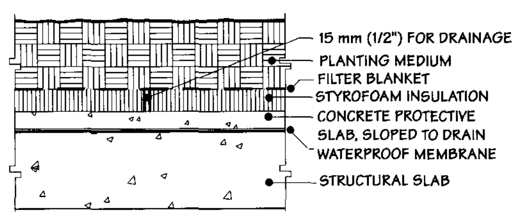

Figure 610-8. Lightweight drainage techniques. *In small areas where a lightweight drainage medium is needed, slope the protective slab to the roof drain, and cover with 1 200 x 1 200 x 50 mm (4 ft x 4 ft x 2 in) Styrofoam sheets. Sheets must be square with 50 mm (2 in) spaces between for adequate drainage. Cover with filter blanket.*

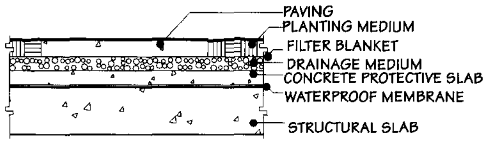

Figure 610-9. Subsurface drainage under paving. *Paved area is placed directly on surface of the drainage medium to allow a continuous subsurface drainage layer sloped toward the roof drains. Filter blanket prevents wet concrete from penetrating drainage material. Drainpipe under the paving at intervals improves drainage.*

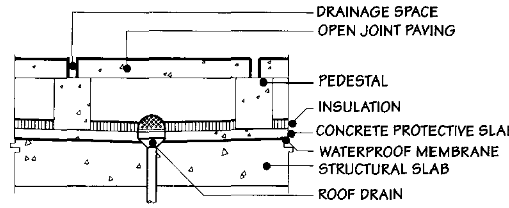

Figure 610-10. Subsurface drainage for paving on pedestals. *Pedestal-mounted, removable, open-joint paving provides positive drainage, adjustable heights, and easy access to the roof surface for cleaning or repair. Insulation is fitted between the pedestals.*

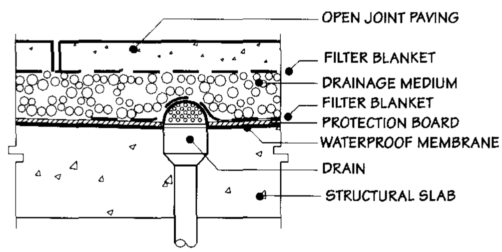

Figure 610-11. Subsurface drainage under paving on grade. *In open-joint paving without pedestals, where no insulation is needed, filter blanket is held to the protection board by mastic or hot tar at its outer edges to prevent seepage of silt into the drain, and the gravel drainage layer is compacted with a 180 kg (400-lb) roller.*

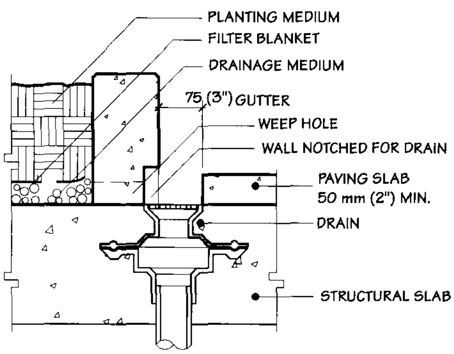

Figure 610-12. Weep holes and gutter to roof drain. *Where a waterproof roof is not necessary, paving slab is poured directly onto the structural slab. Planting medium behind wall is drained through weep holes to an open gutter.*

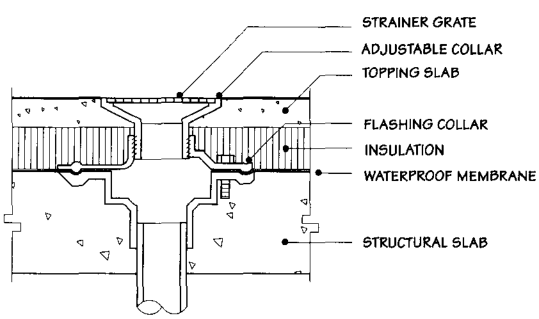

Figure 610-13. Roof drain through topping slab. *Basic method used to drain a roof which has a topping slab protecting the waterproof membrane. Insulation is optional. Common when roof plantings are held in pots or tubs only, or when the deck includes no plantings at all.*

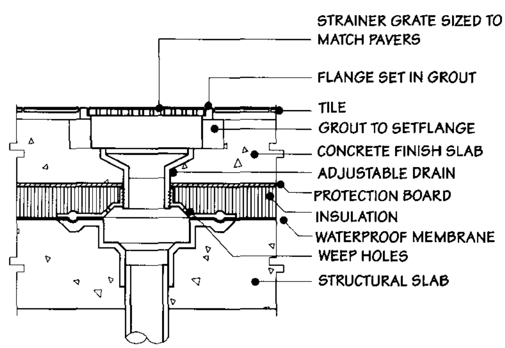

Figure 610-14. Square surface drain. *A typical round drain is installed with its grating below the top of the basic finish slab, to allow installation of a square grill on a square-patterned surface. The finish slab is formed with an indentation for the grout.*

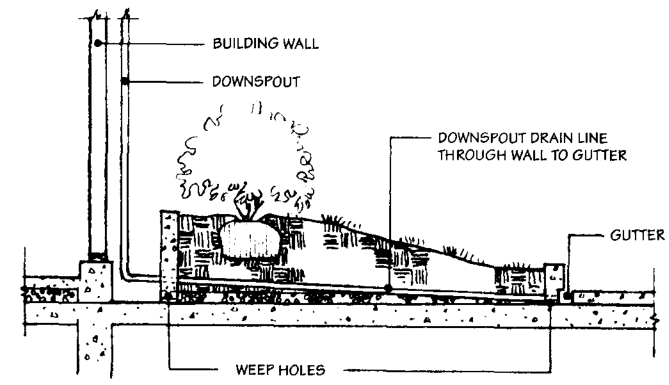

Figure 610-15. Drainage through raised planting bed. *Raised planting areas can be separated from a porous building wall to protect it from soil dampness. Allow clearance for repairs. Downspouts are brought through the planting bed to a walkway gutter. The back space is drained by weep holes through the drainage medium to the front gutter and/or by slope to either end of the back space.*

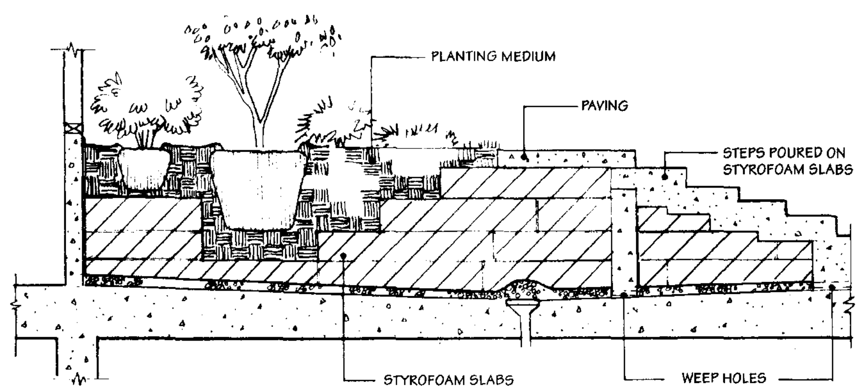

Figure 610-16. Lightweight alternative for raising planting bed. *Alternative method for raising a planting bed adjacent to a building wall. A concrete wall is carried 150 mm (6 in) above the finished grade of the planting level and waterproofed. The planting medium can include lightweight Styrofoam blocks for weight reduction.*

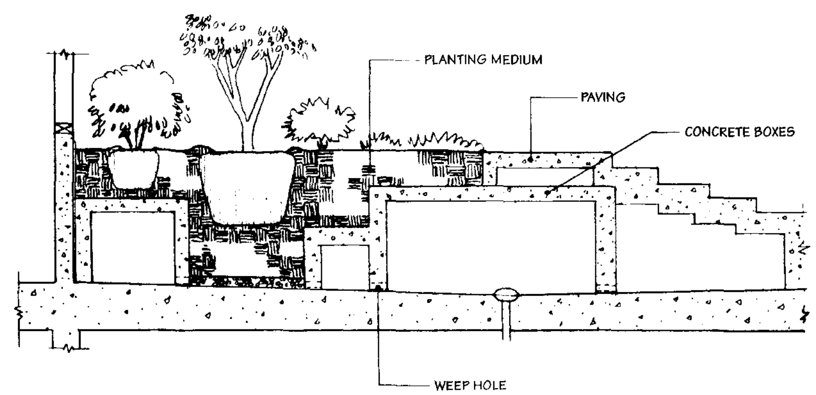

Figure 610-17. Concrete boxes used to raise beds. *Concrete boxes, instead of soil or Styrofoam, are used for lightweight structural strength.*

watering. Local public water supplies may also lack calcium, iron, magnesium, and sulfur. Thus, periodic replacement of these and other materials by surface application may be needed. Annual soil tests should be made by a soils laboratory to determine deficiencies and recommend additives.

Depths and Weights of Planting Medium and Plants:

Table 610-4 shows the minimum soil depths needed for different types of rooftop plantings, Table 610-5 shows typical dry and damp weights of various planting media, and Table 610-6 shows the weight of container and field-grown plants.

Ways to Reduce Weight:

Light-weight soil mixes are an alternative if optimum soil depths result in excessive weight on the structure. However, if the subsurface drainage system fails and the soil becomes saturated, even light-weight planting mix can weigh as much as 585 kg/m^3 (120 pounds per cubic foot [pcf]). Voids must be created beneath the soil medium if the roof cannot withstand a loading of this magnitude (Figures 610-16 through 610-18). The most common methods of creating these voids include casting a false bottom or using large blocks of high-density Styrofoam, typically 1 200 mm x 2 400 mm x 250 mm (4 ft x 8 ft x 10 in) thick.

Figure 610-19 shows how a roof structure can be designed to provide a recessed planting area over a column for a large tree. Figure 610-20 illustrates a method to change grades between an on-grade sidewalk and roof deck without using excessive depths of planting media. Figure 610-21 shows one way to reduce weights for plants in containers.

3.3 Adaptation to Climate

Climate:

Wind, sun, shade, and extremes of temperature, as well as long dry or wet periods, snow loads and frost, are much greater problems for roof or deck gardens than for other landscapes. The greatest problems are found in climates where there are extremes of both heat and cold. In such areas, all piping must be drained completely or insulated against freezing prior to the onset of winter. The weight of accumulated ice and snow must not exceed the weight limits of the roof's structural system. In areas of heavy rains, there must be quick and positive surface and subsurface drainage to prevent flooding. Even in

**Table 610-1.
SIEVE ANALYSIS FOR SAND***

Sieve Size	Weight (% passing)
No. 4	100
No. 10	95-100
No. 18	90-100
No. 35	65-100
No. 60	0-50
No. 140	0-20
No. 270	0-7

**Table 610-2.
SUITABLE CHEMICAL PROPERTIES**

Chemical Property	Permissible range
Salinity (millisiemens per cm of saturation extract at 25(°C)	0-3.0
Saturation extract concentration of boron	0-1.0
Adsorption ratio of sodium (SAR)	0-6.0

Table 610-3. MINIMAL PROPERTIES OF SOIL AMENDMENTS

Physical properties:	Percent passing	Sieve designation
	95-100	6.35 mm, 1/4 in mesh
	75.100	2.38 mm, No. 8, 8 mesh
	0.30	500, No. 35, 32 mesh
Source:	**Nitrogen content, dry weight basis, if nitrogen stabilized**	**Dry bulk density, kg/m³ (lb/y³)**
Redwood sawdust	0.40-0.60%	159-218 (270-370)
Redwood bark fiber	0.35-0.50%	147-206 (250-350)
Fir or cedar sawdust	0.56-0.84%	159-218 (270-370)
Fir or pine bark	0.80-1.20%	265-341 (450-580)
Hardwood bark	0.80-1.20%	265-294 (450-500)
Iron content	Minimum 0.08% dilute acid soluble iron based on dry weight if specified as, or claimed to be, iron treated.	
Soluble salts	Maximum 3.0 ms/cm at 25° C as determined in saturation extract.	
Organic content	Minimum 92% based on dry weight and determined by ash method.	
Mineralized	Other mineral fertilizers or chemical amendments may be specified for incorporation.	
Wettability	The air-dry product shall, when applied to a cup or small beaker of water at 70° F in the amount of 1 tsp, become completely wet in a period not exceeding 2 minutes. Any wetting agent added to accomplish this shall be guaranteed to be nonphytotoxic at rate used.	

regions where these extremes of climate are diminished, there can be temporary extremes caused by storms or unusual weather patterns.

Wind:

Trees, vertical structures (such as fences, walls, and light standards), and other similar elements must be designed or selected to resist wind damage due to overturning or breaking. Plants are also subject to flagging, or lopsided growth, due to strong, persistent winds. More typically, even normal wind flow can cause excessive drying of plant materials and soils and even high evaporation of water.

Sun and Shade:

The planting must be selected in accordance with its adaptability to either sun or shade conditions. In sunny areas the water requirements may be greater because of more rapid drainage and evaporation. The creation of natural or artificial shade can reduce water loss. Human use and enjoyment of gardens varies considerably between sunny and shady areas, and this distinction should therefore be taken into account in the location and layout of any roof or deck landscape.

3.4 Irrigation

The relatively thin, well-drained soil mixtures typically used in roof gardens cannot provide plants with the subsurface water normally available to ground level plantings. Care must be exercised to prevent the planting medium from drying out and causing damage to plant materials. Drying and overheating of soil can often be controlled by the application of a 25 mm (1 in) topping of pine, redwood or fir bark in 5-20 mm (1/4-3/4 in) sizes.

Hand watering is usually too labor-intensive and unreliable for large roof or deck landscapes. An underground sprinkler or irrigation system with automatic controls is the most reliable and cost-effective method of watering plants and lawns on roofs. These systems can be made of plastic pipe and fittings, which are durable, lightweight, easy to install, and often the least expensive to operate.

Piping should be installed directly on top of the filter blanket. The riser heads should be temporarily capped and tested under

KEY POINTS: Planting Medium

Planting medium for roof and deck landscapes must be light-weight, provide the proper balance of nutrients, and provide positive drainage. Ready-mixed soils are commercially available, or can be produced on-site.

1. The planting medium must allow for downward percolation of water, and be free of fine silts that will clog the filter blanket and block drainage
2. Periodic replenishment of fertilizers, dissolving minerals and other materials in the soil may be required.
3. If optimum soil depth results in excessive weight on the structure, various techniques may be used to minimize soil depths and reduce loading (Figures 610-16 through 610-21).

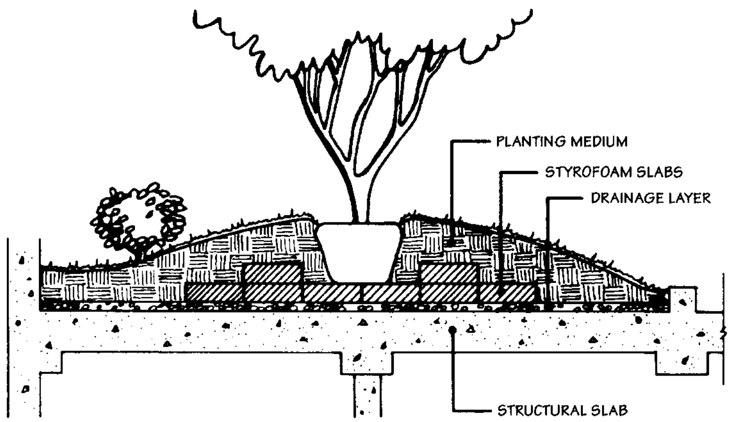

Figure 610-18. Alternative way to reduce weight of planting medium. *Styrofoam blocks placed at suitable depths reduce the weight and mass of the planting medium.*

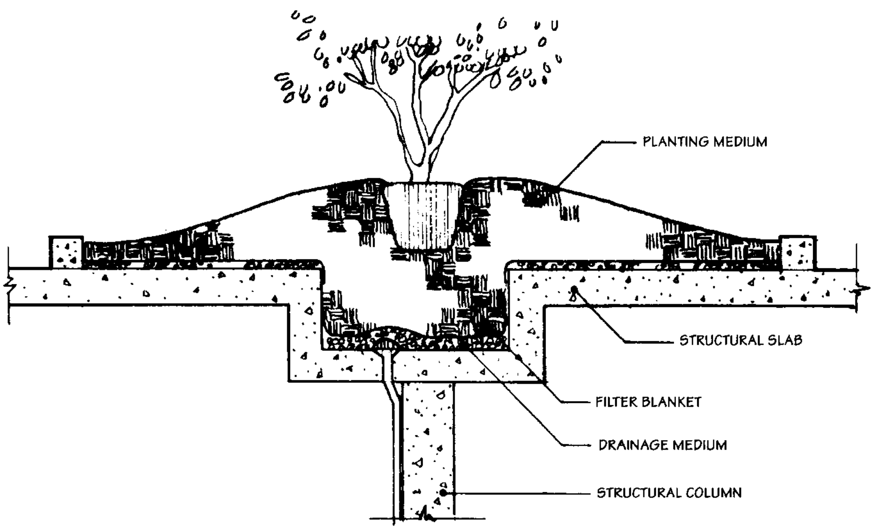

Figure 610-19. Recessed area for large plants. *Roof structure is designed to provide a recessed planting area over a column for a large tree.*

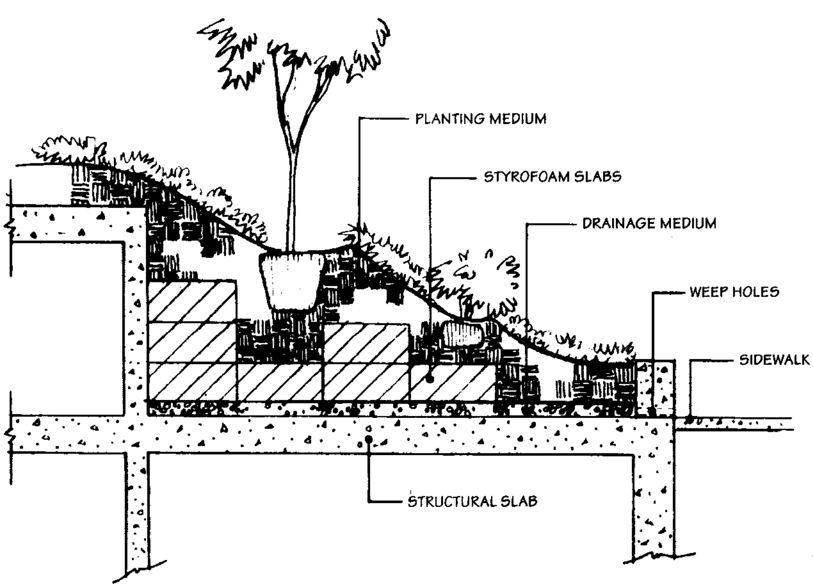

Figure 610-20. Lightweight method for changing grades. *Method to change grades between sidewalk and roof deck.*

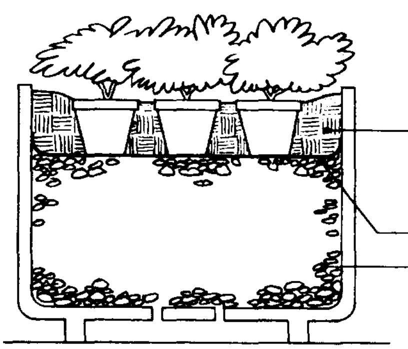

Figure 610-21. Lightweight plant containers. *Method for stringent weight restrictions. Plastic containers are substituted for clay, and lightweight drainage medium is substituted for soil. For planting directly in soil, 200 to 250 mm (8 to 10 in) of lightweight soil is placed on drainage medium covered with a filter blanket.*

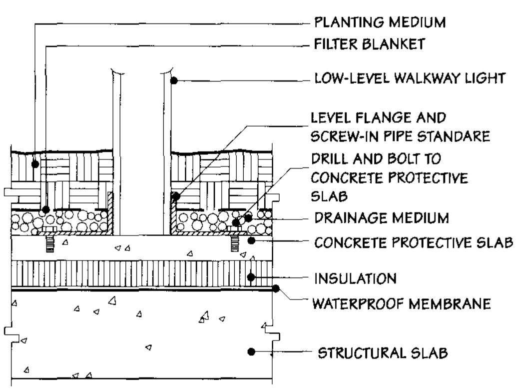

Figure 610-22. Anchoring light standards to protective slabs. *The base flange of low-level [750 to 1 200 mm (30 to 48 in)] light standards can be anchored to the concrete protective slab by bolts either screwed into expansion shields set in drilled holes or fired into the slab by explosive cartridges.*

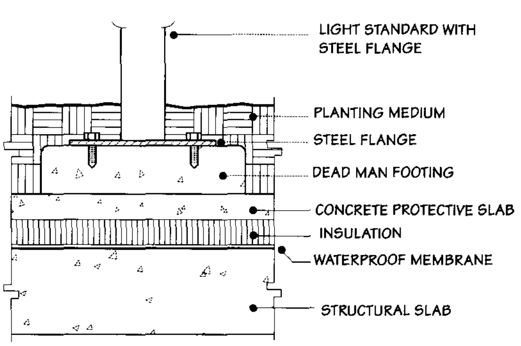

Figure 610-23. Use of deadmen as anchors. *Deadman footings can anchor light standards.*

Table 610-4. MINIMUM SOIL DEPTHS

Planting	Minimum soil depths*
Lawns	200-300 mm (8-12 in)
Flowers and ground covers	250-300 mm (10-12 in)
Shrubs	600-750 mm (24-30 in)†
Small trees	750-1 050 mm (30-42 in)
Large trees	1 500-1 800 mm (5-6 ft)

* on filter blanket and drainage medium.
† Depending on ultimate shrub size.

Table 610-5. WEIGHT OF PLANTING MEDIUM

	Dry		Damp	
Material	**kg/m³**	**lb/ft³**	**kg/m³**	**lb/ft³**
Fine sand	1440	90	1920	120
Cedar shavings with fertilizer	148	9	208	13
Peat moss	154	10	165	10
Red lava 8 mm (5/16 in) maximum	800	50	859	54
Redwood compost and shavings	237	15	355	22
Fir and pine bark humus	355	22	533	33
Perlite	104	7	518*	32*
Vermiculite				
Coarse	100	6		
Medium	92	6		
Fine	120	8		
Topsoil	1216	76	1248	78

* Applies to wet, not damp, perlite

TABLE 610-6. Weight of Container and Field-Grown Plants

Container size	Container grown in mushroom compost, kg (lb)	Field-grown, kg (lb)
55-L (15-gal) can	35 (80)	-
500-mm (20-in) box	90 (200)	180 (400)
600-mm (24-in) box	180 (400)	325 (725)
750-mm (30-in) box	360 (800)	675 (1,500)
900-mm (36-in) box	590 (1,300)	1 125 (2,500)
1 200-mm (48-in) box	1 575 (3,500)	2 700 (6,000)
1 350-mm (54-in) box	1 800 (4,000)	3 150 (7,000)
1 500-mm (60-in) box	2 250 (5,000)	3 600 (8,000)
1 800-mm (72-in) box	3 150 (7,000)	5 400 (12,000)
2 100-mm (84-in) box	4 050 (9,000)	7 200 (16,000)
2 400-mm (96-in) box	5 400 (12,000)	9 000 (20,000)
3 000-mm (120-in) box	6 300 (14,000)	10 800(24,000)

Note: All the above are shipping weights, including the box.

pressure for leaks before the planting medium is added. Sprinkler controllers may be placed in a locked outdoor cabinet or placed in an adjacent inside room. Complete drainage of all the lines and fixtures should be provided in regions where freezing can occur. Access to a source of electrical power of 110 - 120 V ac is required for the controller clock and step-down transformer. Close coordination with the building's electrical and mechanical engineers is required to ensure that all of the water, electrical, and drainage needs for the roof garden are provided, and that the responsibility for this work is described in the building's construction specifications.

4.0 SELECTION OF MATERIALS AND METHODS OF ANCHORING

4.1 Structural Materials

The construction of light standards, walls, fences, wind screens, pergolas, curbs, steps, and other structural elements should all be considered in relationship to the structural limitations of the roof and its supports below. The omnipresent factor of weight has a strong effect on which materials are used. Aluminum light standards, lightweight concrete for paving, curbs and walls, and other strong but lightweight materials should be used whenever such elements are needed. Tables 610-7 and 610-8 give typical weights for some of the common materials used in the construction of roof gardens.

4.2 Paving

The type and pattern of paving materials chosen are as important to the viewers from surrounding buildings as they are to the actual users of the roof garden. The color, tone, texture, and contrast of these materials can sometimes be greater than ordinarily found in a typical ground level landscape. For instance, the color and texture of concrete or brick as seen from above can contrast with the planting and water surfaces, thereby creating strong visual impressions. Materials should also be selected for their light weight and durability. Brick pavers, tiles, textured wood decking (where permitted by local codes and weather conditions), and colored or exposed aggregate concrete are all excellent choices for rooftop developments.

4.3 Methods of Anchoring

The structural elements, including light fixtures, need to be carefully anchored when used on rooftops. Figures 610-22 through 610-24 show ways that this can be accomplished without penetrating the waterproof membrane or structural slab. Figures 610-25 and 610-26 illustrate ways to secure an element to a roof when such anchorage is mandatory. Typically, nothing should be tied to the structural slab without the approval of the building architect. Other techniques for anchoring elements are shown in Figures 610-27 through 610-29. In many cases, raised planting beds or similar structures are secured by the weight of the soil or materials, and may not require anchoring.

Rooftop furniture often does not need to be fixed in place but can be left to be moved as needed, unlike the chairs, benches, and other site furniture in most on-grade public landscapes. However, it is best to use heavy metal or wood furniture to prevent its movement by strong winds.

5.0 POOLS AND FOUNTAINS

5.1 General Considerations

The use of water can add greatly to the interest and enjoyment of roof deck areas. There are several factors to consider, however, regarding the weight of the water and its container, as well as the dangers of possible leaks into the structure below. If it is known prior to the roof's structural design that a pool or fountain is to be used, then it can often be easily accommodated, although there may be considerable constraints on the amount of water that can be used.

Where possible, the heaviest water elements should be located directly over support columns. The illusion of greater water depth can be achieved by coloring the bottom and sides of the pool dark gray or black. Satisfactory water effects can be achieved in depths as shallow as 100 - 400 mm (4 - 16 in). This is particularly true if the surface can be kept agitated so that visibility to the bottom is obscured. (Refer to Section 530: Pools and Fountains, for information on the design and detailing of these elements.)

Roofs with very stringent weight constraints may require a shallow pool created by using preformed shapes made from 5 mm (1/4 in) fiberglass. A satisfactory water surface can be obtained with a very shallow depth (Figure 610-30). This detail is often used in garden ponds to provide a natural appearance.

5.2 Waterproofing and Anchoring Pool Walls

Unless pool walls are properly anchored and sealed, they can cause serious leaks. Figures 610-31 through 610-34 illustrate different methods of achieving a positive, leakproof seal. In Figure 610-31, the pool bottom and wall are poured as an integral unit directly on the continuous waterproof membrane of the roof. The anchoring reinforcing rods may be placed when pouring the structural slab if recommended by the structural engineer. In Figure 610-32, a smaller core wall is poured and tied into the structural slab with preplaced rods. The waterproof membrane is then laid on the structural slab and brought over the core wall and down to the slab surface again in a continuous run. The pool bottom, as well as the balance of the wall, is then poured separately over the core wall. Because of the chance of cracking, this separate pour should be reinforced with wire mesh, and consultation with a structural engineer is recommended. The water surface elevation of the pool is established just below the height of the core wall.

Figure 610-33 is a variation of Figure 610-32. The core wall is poured on top of

KEY POINTS: Climatic Issues

The effects of wind, heat, cold, drought, and precipitation, are amplified in rooftop and deck landscapes, because of their shallow planting medium and the importance of protecting the structure below.

1. In cold climates, all piping must be drained completely or insulated against freezing. The weight of accumulated ice and snow must also be accounted for, so as not to exceed the limits of the roof's structural system.
2. Trees and vertical structures must be designed or selected to resist wind damage due to overturning or breaking.
3. Drying and overheating of planting medium can often be controlled by the application of mulch and the installation of an irrigation system.

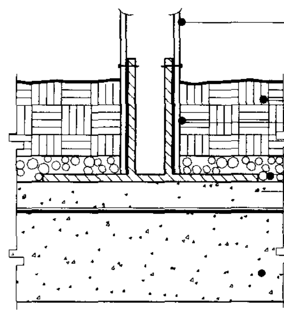

Figure 610-24. Anchoring low-level light standards. *A low-level light standard held in place by the weight of soil on the flange; best-suited for areas where vandalism is negligible.*

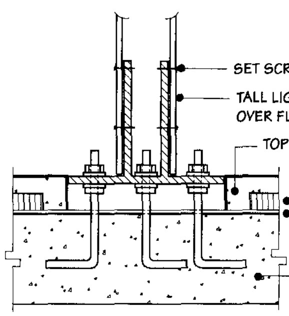

Figure 610-25. Anchoring tall light standards. *Tall, wind-resistant light standard attached to bolts set into the structural slab when poured. Bolts are sealed against leakage. The flange can be set at any desired grade. Also useful for shelters, benches, fences, etc.*

KEY POINTS: Pools and Fountains

When designing water features for roof and deck landscapes, there are several factors to consider regarding the weight of the water, as well as the dangers of possible leaks into the structure below.

1. Where possible, the heaviest water elements should be located directly over support columns within the structure.
2. Minimum water depths should be used. A darkly-colored bottom and sides of the pool, as well as agitation of the water will allow for satisfactory effects in depths as shallow as 100-400 mm (4-16 in)
3. Pools must be properly anchored to the structure, and sealed to prevent leaks. Figures 610-31 through 610-34 illustrate various anchoring methods that preserve the integrity of the waterproof membrane.

the finished protective slab. Inside the pool area, a waterproof membrane is placed and brought to the top of the core wall. The bottom and wall of the pool are then poured separately as a unit. Figure 610-34 shows a variation where the pool is lined with tile. In areas where freezing occurs in the winter, pools should be drained for the duration of the season to prevent damage to the waterproof structure.

6.0 PROVISION FOR UTILITIES

6.1 Electrical

A standard 110 - 120-volt ac electrical supply is sufficient for most roof garden uses, such as lighting, barbecuing, appliances, fountain and irrigation controllers. Outdoor heaters, electrically powered mobile window washing machines, and occasionally fountain pumps may require 220 volt ac. All electrical requirements should be met in accordance with the recommendations of an electrical engineer.

All electrical supply conduits should be enclosed in metal for protection from digging, given the shallow soil conditions, although low-voltage lighting may be supplied by flexible cable. The subsurface distribution system should be placed prior to installing the planting medium and/or paving. Electrically operated or photocell-controlled timing devices are additional conveniences for gardens which are regularly lighted at night.

6.2 Water

A supply of clean water is needed for irrigation, ornamental pools and fountains, the cleaning of roof surfaces, and fire protection. Water pressure for irrigation systems should be provided from a minimum level of 240 kPa (35 psi) to a maximum of approximately 480 kPa (70 psi). This supply, if connected to the building's potable water system, can also be used for drinking fountains. Water for fire protection can be separate and need not be potable. Irrigation and fountain water supplies must contain suitable backflow prevention devices to guard against contamination of potable water sources.

Provision should be made for indoor locations of lighting and irrigation controllers, electrical panels, pumps, motors, and other mechanical equipment needed for the garden, as well as for gardening tools and supplies.

7.0 SAFETY AND SECURITY

Most roof gardens are several stories above ground level, creating a need to alleviate psychological fears as well as to provide physical barriers for safety. Given limited roof space, it may be necessary to allow users to approach the edge of a roof, but it is generally more appealing to have a space or barrier between the roof edge and the usable areas. Figure 610-35 shows three different ways to handle parapet walls.

It may be desirable to provide places where people can gain access to a railing on the roof's parapet in order to look downward as well as horizontally for those who desire to do so. The spaces between railings and posts should be closed in with wire fabric, safety plate glass, fiberglass, or other suitable material to prevent easy or accidental penetration by small children, pets, or others. Figure 610-36 shows how guard railings can be attached to the top or roof side of the parapet or set slightly back from the parapet. Higher barriers of opaque or transparent material can be substituted in these same locations for both safety and wind protection.

8.0 MAINTENANCE

Most roof gardens require consistent maintenance. This includes watering, fertilizing, shearing, pruning, bracing, raking, replanting, sweeping, the removal of debris, the repair and adjustment of irrigation and lighting equipment, and the clearance of obstructions in the drainage system.

8.1 Paving, Fixtures, and Furnishings

Paving, drinking fountains, light fixtures, benches, pools, fountains, decks, walls, fences, steps, ramps, etc., require little special maintenance associated with roof and deck landscapes.

Planted areas near pavement edges should be checked every 2 to 3 years to determine whether roots have penetrated under the pavement. Roots growing under paving can heave the paving and as a result change the surface drainage. These roots should be cut to slow further growth.

8.2 Plant Maintenance

Normal levels of maintenance are needed each season. Special attention should be given to pruning trees and shrubs in order to maintain a balance between branching and root growth. Regular maintenance will not only prolong the life of the plants but

Table 610-7. WEIGHT OF COMMON BUILDING MATERIALS

Material	lb/ft^3	kg/m^3
Granite	170	2720
Marble	170	2720
Slate	160-180	2560-2880
Limestone	155	2480
Sandstone	145	2320
Shale	160	2560
Expanded shale	40-45	640-720
Field stone	95	1520
Gravel	120	1920
Pebbles	120	1920
Pumice	40	640
Concrete		
Lightweight	80-100	1280-1600
Precast	130	2080
Reinforced	150	2400
Concrete block: 200 mm (8 in)	50-60	800-960
Brickwork (average)	115	1840
Cast iron	450	7200
Steel	490	7840
Bronze	513	8210
Timber		
Hardwood (average)	45	720
Softwood (average)	35	560
Sand		
Dry	90-110	1440-1760
Wet	110-130	
1760-2080		
Sand and gravel: mixed	115	1840
Clay soil		
Compacted, dry	75-100	1200-1600
Compacted, wet	125	2000
Loam		
Dry	80	1280
Wet	120	1920
Special commercial soil: wet	110	1760
Topsoil		
Dry	80	1280
Wet	120	1920
Peat		
Dry	50	800
Wet	60	960
Humus		
Dry	35	560
Wet	80	1280
Water	60	960
Flagstone and setting bed	25 lb/ft^2	122 kg/m^2
Tile and setting bed	15-73 lb/ft^2	73-353 kg/m^2

Source: A. F. Weddle, *Landscape Techniques*, Van Nostrand Reinhold, New York, 1983; C. G. Ramsey and H. R. Sleeper, *Architectural Graphic Standards*, 9th ed., Wiley, New York, 1994; Olwen C. Marlowe, *Outdoor Design*, Watson-Guptill, New York, 1977; American Institute of Steel Construction, Inc.

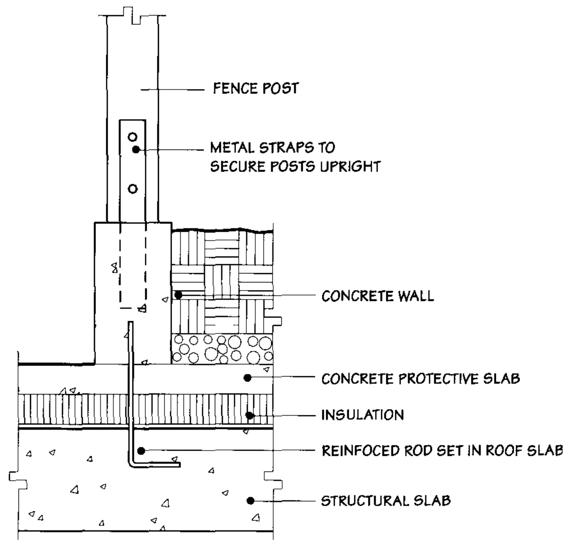

Figure 610-26. Attaching fences to walls. *Preferred attachment of fence to the top of a wall instead of directly to roof surface. Fittings should be durable and strong, or galvanized pipe posts can be substituted and placed when wall is poured.*

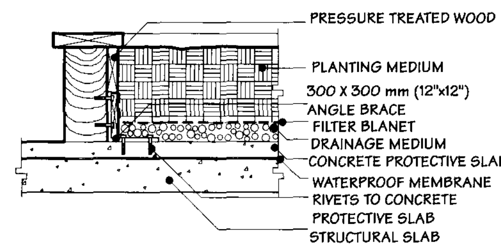

Figure 610-27. Attaching wood to concrete decks. *Wood posts and planks of a garden, flower bed, or sandbox attached to concrete deck. Walls not over 600 mm (2 ft) in height are braced with 300 mm x 300 mm x 5 mm (1 ft x 1 ft x 1/4 in) galvanized angle braces. Small four-sided beds need only corner braces. Soil or rivets hold bed in place.*

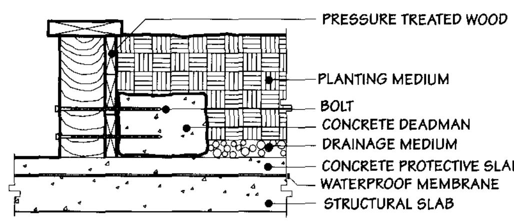

Figure 610-28. Use of deadmen to anchor wood structures. *Alternative method for anchoring wood posts and plants to concrete deadmen.*

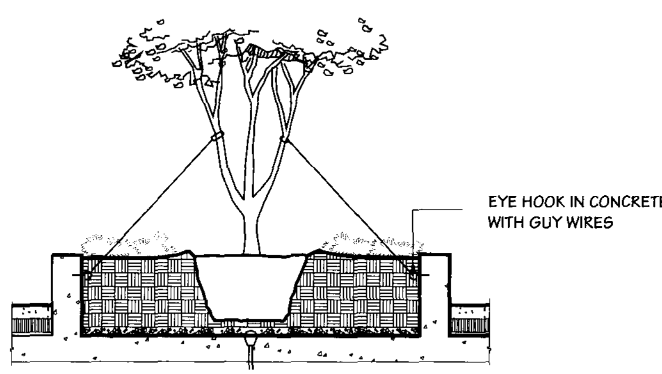

Figure 610-29. Anchoring large plants and trees. *Method for securing guy wires to concrete beds. Galvanized eye-hook bolts are placed when the walls are constructed. Eye bolts can also be attached to masonry building surfaces. Waterproofing is necessary at attachment points.*

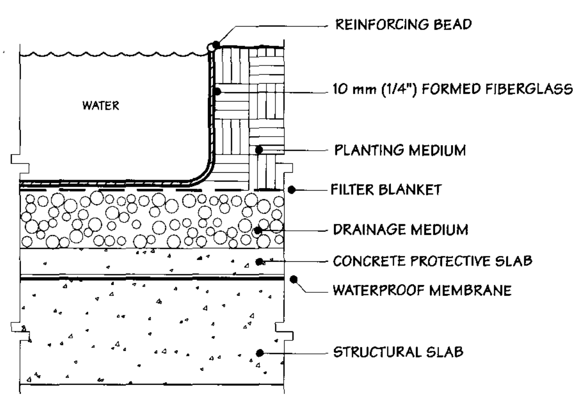

Figure 610-30. Fiberglass pool wall.

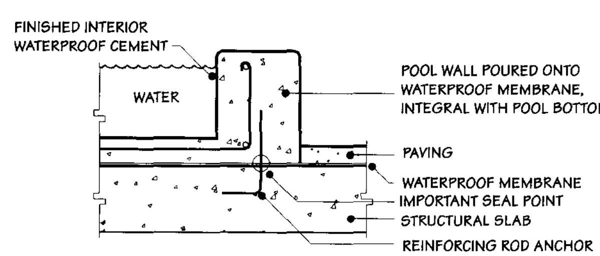

Figure 610-31. Pool wall and bottom poured as one.

Table 610-8. WEIGHT OF WOOD

	Green				Dried to 12% moisture content			
	lb/ft³	kg/ft³	lb/fbm	kg/fbm	lb/ft³	kg/ft³	lb/fbm	kg/fbm
Douglas fir	38	17	3.17	1.43	34	15	2.83	1.27
Redwood	52	23	4.33	1.95	28	13	2.33	1.05
Cedar, western red	27	12	2.25	1.01	23	10	1.92	0.86

*1 ft³ = 12 board ft (fbm) of lumber.

Source: Courtesy of the California Redwood Association.

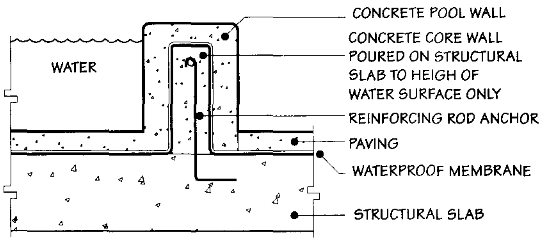

Figure 610-32. Pool wall tied to structural slab (alternative 1).

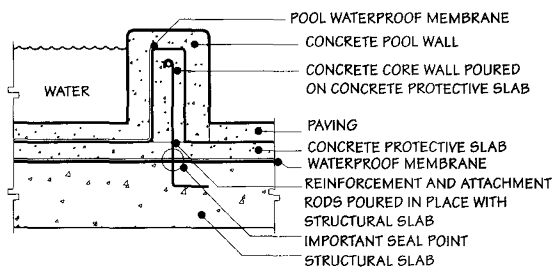

Figure 610-33. Pool wall tied to structural slab (alternative 2).

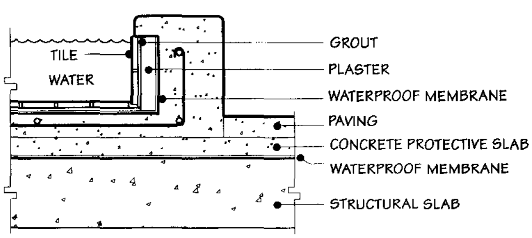

Figure 610-34. Pool wall faced with tile.

will also help prevent the overturning of top-heavy plants due to strong winds. Periodic thinning should be done to allow the wind to pass through the foliage, except in areas where plants are used for windbreaks.

Plants on roofs or decks are, in effect, growing in containers. Therefore, the roots of large trees and shrubs will tend to dominate the planting medium and inhibit the growth of smaller plants. The areas near the edges of the containers should be checked for roots and if they appear to be affecting the growth of smaller plants, roots should be pruned.

Roof gardens must be well-drained and plants require more frequent feeding and related care. A year after installation, all planted areas should receive a top dressing, approximately 5 mm (1/4 in) thick, made up of a mixture similar to the original planting medium. This should be continued annually or adjusted to maintain the original level of the grades and planting mixture.

Failing plants should be replaced as soon as their condition becomes apparent. Usually, these plants should be replaced with the same variety unless it can be determined that the particular plant is not hardy in a specific location.

Lastly, maintenance can be simplified if plants are selected for their zonal hardiness, for their resistance to wind and human abuse, for their noninvasive root systems, and for their reliability in not exceeding a specified size. There are few ornamental landscape plants used in the world which will not grow in well-designed roof gardens in their own locality. However, just as designers must carefully choose plants for the specific microclimate, soil, and other habitat conditions found in ground level landscapes, so they also must exercise sound judgment in selecting plants for roof landscapes.

The intent of this section has been to help provide the physical context needed for plants to grow successfully rather than to provide data on the large number of

KEY POINTS: Maintenance

In addition to standard maintenance practices associated with all types of landscapes, roof and deck gardens require special attention to protection of the structure below and replenishment of the growing medium.

1. Plants should be checked every 2 to 3 years to determine whether roots have penetrated into the roof structure, or are adversely affecting the growth of smaller plants. These roots should be cut to slow further growth.

2. Special attention should be given to pruning trees and shrubs in order to maintain a balance between branching and root growth. This will help prevent the overturning of top-heavy plants due to strong winds.

3. All planted areas should annually receive a top dressing, approximately 5 mm (1/4 in) thick, made up of a mixture similar to the original planting medium.

plants that may be suitable from every climatic zone in the world (refer to Section 550: Plants and Planting for additional information).

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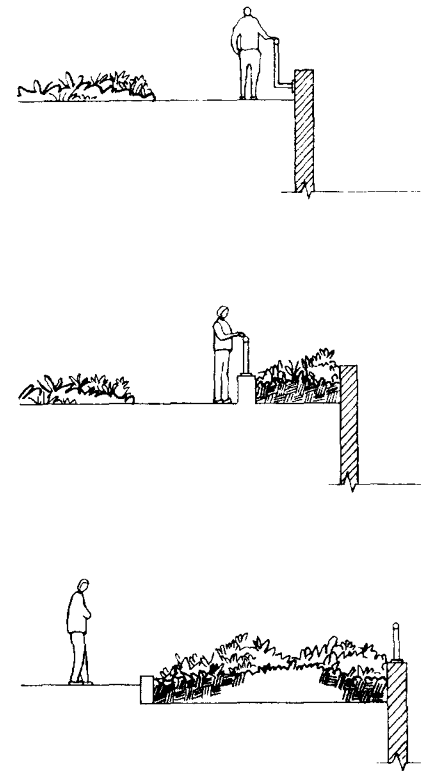

Figure 610-35. Techniques for creating safety barriers.

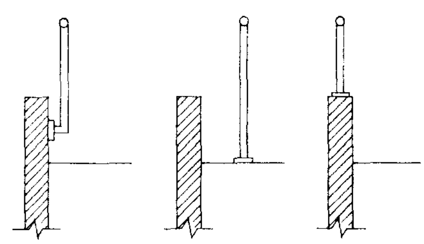

Figure 610-36. Techniques for attaching railings.

SECTION 620

Interior Landscapes

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CONTENTS

1.0 INTRODUCTION

The interior landscape designer must be mindful that the primary function of most interior environments is to serve people rather than to grow plants. With the exception of facilities specifically designed for the display or growth of plants (such as greenhouses or conservatories), plant materials must be able to tolerate the environmental conditions created for human comfort. Budgetary considerations will often preclude the adaptation of a building's environmental systems to accommodate plant needs. However, with minor modifications to the physical conditions within a building, it is possible to find many plants from the tropical and subtropical regions of the world that will survive indoors in the temperature and humidity ranges also comfortable for human activity.

The "hardscape" aspects of interior landscape design and construction, (such as paving materials, landscape furniture, pools and fountains) are not significantly different than those same elements in the exterior environment.

This section will focus primarily on the physical needs and requirements of plant materials used within interior, climate controlled spaces.

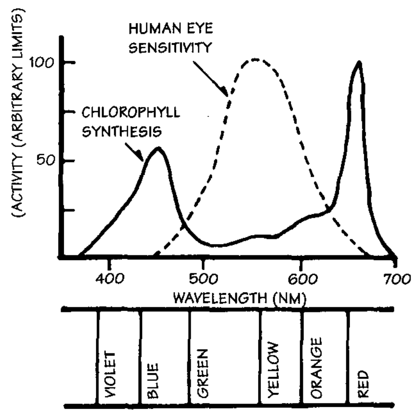

Figure 620-1. Response curves for the manufacture of chlorophyll.

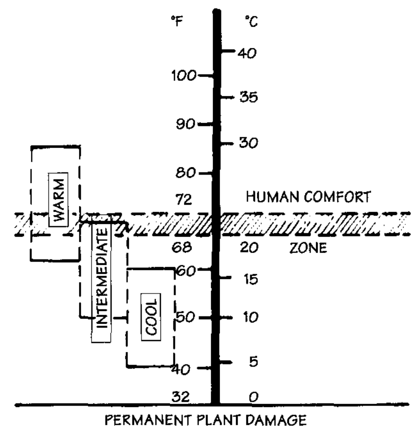

Figure 620-2. Temperature range of plants.

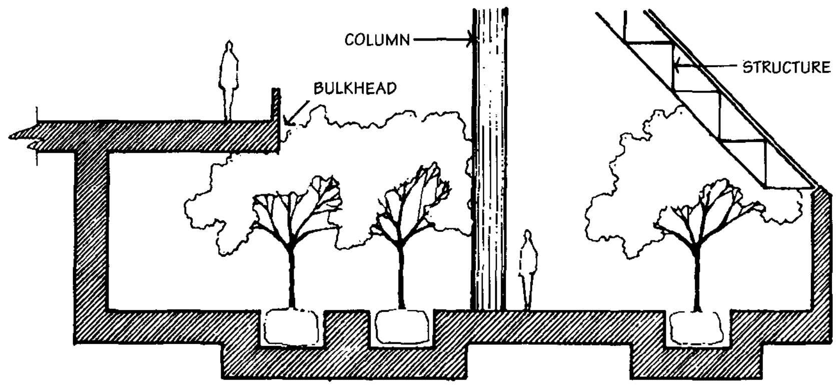

Figure 620-3. Height and spread of large materials.

2.0 PHYSICAL REQUIREMENTS OF PLANTS

2.1 Light

Growing plants convert radiant energy (from daylight or electric light sources) into food. Plants use radiant energy of wavelengths in the 400- to 850-nanometer (nm) range. White light, the visible part of the radiant energy spectrum, consists of wavelengths in the 430- to 700-nm range. Light for plant growth is typically described in terms of intensity, duration, and quality.

Intensity:

Intensity of light is a quantitative figure typically measured in lux (footcandles), or lumens per square meter (square foot). A lumen is the specific quantity of light emitted by a light source without regard to the direction of its distribution. A lux (footcandle) is a quantitative measure referring to how much light is being received on a surface. (Refer to Section 540: Outdoor Lighting, for more information on definitions and principles of lighting.)

Different plants have varying minimum requirements for light intensity (Table 620-4). Bright daylight is typically about 53 500-128 400 lx (5,000-12,000 fc), depending on latitude, season, and time of day. The average working environment in a building interior sometimes only receives 535 lx (50 fc) or less.

Duration:

While research continues to seek the necessary balance between intensity and duration for optimum plant growth, it is apparent that continuous illumination is not a suitable substitute for less than the minimum required intensity. Plants need periods of rest, each species having evolved unique preferences for particular photoperiods, the relative lengths of lightness and darkness affecting the growth of an organism. The average photoperiod for plants is 8 to 12 hours of darkness and 12 to 16 hours of light. If only minimum light intensity is provided, optimum light duration must be provided.

Quality:

Light quality refers to the type of radiant energy available to plants. Figure 620-1 shows that plants use radiant energy primarily from the blue and red ends of the visible spectrum. Most electric light sources are primarily monochromatic and tend to emphasize the yellow-green part of the visible spectrum. Natural light, which contains the entire spectrum of visible light plus ultraviolet and infrared wavelengths, is ideal for plant growth. However, light passing through tinted or reflective glass will have its spectral energy distribution altered in addition to reducing its intensity. Glazing manufacturers can provide the designer with data documenting both the spectral energy distribution and percentage of light transmittance of their products.

2.2 Temperature, Humidity, and Air Quality

Plant requirements for air typically refer to temperature, relative humidity, and air quality.

Temperature:

Most plants prefer a stable range of temperatures, with a drop of no more than 5°C (10°F) from daytime to nighttime temperature. Tropical region plants generally fall into three categories, each with a preferred range of temperature: Cool [5 to 15°C (40 to 60°F) daytime]; intermediate [10 to 20°C (50 to 70°F) daytime]; and warm [15 to 30°C (60 to 85°F) daytime]. Cold temperatures 0°C (32°F) or less even for a short period, can cause permanent damage to foliage. If the temperature of the root ball falls below 10°C (50°F), plant growth will stop; and plants will die if the temperature drops below −1°C (30°F) (Figure 620-2).

Relative Humidity:

Tropical plants prefer a relative humidity of 60 to 90 percent, but many are adaptable to the 35 to 50 percent relative humidity typical of building interiors. This low relative humidity, while drier than most plants prefer, is a better range for prevention of diseases such as mold or leaf rot. If the humidity is ±30 percent or lower, then most plants will require greater amounts of water.

Air Quality:

Plants require carbon dioxide (CO^2) to complete photosynthesis. Forced air circulation through building ventilating systems helps to maintain ready supplies of CO^2 and to reduce any excessive buildup of heat, but plants can be harmed by hot or cold blasts of air. If the flow of air causes the leaves to move at excessive velocities, damage to the plants is likely. Excessive levels of pollutants in the air, such as cleaning fluids, paints, or petroleum products, can have a devastating effect on plant foliage, usually turning it black. Plants are most at risk from problems relating to poor air quality during or immediately following building construction, when chemical pollutants from curing paint or new carpeting are most prevalent, and when contracting operations such as drywall construction create massive amounts of dust. Most interiors do not have the optimum environmental conditions necessary for plants to regenerate a large amount of damaged foliage.

Recent studies have proven indoor plants can reduce, or even eliminate, "background" levels of ubiquitous chemical pollutants such as benzene, formaldehyde, and trichloroethylene from indoor air. They do this by metabolizing these elements into non-toxic substances plants can use as nutrients.

2.3 Water

The amount of water needed by indoor plants indoors depends on a variety of factors: seasonal fluctuations governing the duration of daylight and angle of the sun; the size, shape and orientation of windows; the size and amount of a plant's foliage; the volume, composition, and porosity of the planting medium; the temperature and humidity of the interior space; and the general health of the plant. Plants will transpire rapidly in conditions of high light and/or high temperature and/or low humidity, requiring more frequent watering. One of the most important reasons for regular maintenance is to monitor each plant's special need for water. Unsoftened water at a temperature between 15° and 25°C (60° and 80°F) should be used. Plants may be grouped according to their water requirements in order to simplify maintenance. Some plants require that their root balls dry out to an extent, while others require their roots to remain moist or even wet most of the time.

2.4 Planting Medium

The planting medium, which may or may not contain any soil, must accomplish three functions:

1. Allow water and nutrients to reach the plant through the roots.
2. Allow oxygen to reach the roots.
3. Anchor and give stability to the plant.

A planting medium should be:

1. Porous
2. Easy to drain
3. Capable of retaining water
4. Sterile
5. Low in soluble salts
6. Lightweight (where needed)

2.5 Space/Volume

It is important to know both the existing and potential height, breadth, and character of each type of plant in order to minimize interference not only between plants but also with such architectural features as columns, bulkheads, stairs, and low ceilings (Figure 620-3). With large species of plants, this need for adequate room becomes critical. A plant whose innate form has to be reshaped to accommodate architectural features may appear misshapen and incongruous with its interior setting if improperly pruned. It is preferable to specify plant materials whose natural shape can be maintained either by slow growth without pruning, or by standard pruning practices. Upper story plants specified for two story or tall one story spaces should not exceed ⅔ the height of the space when they are planted. Tall speci-

KEY POINTS: Climactic Requirements & Strategies

1. Most common interior plants prefer a stable range of temperatures, with a diurnal change of no more than 5°C (10°F). Freezing temperatures may damage foliage or kill the plant if the root mass is subject to cold conditions. Avoid plantings over unheated and non-insulated spaces such as parking garages.

2. Many plants are adaptable to the relative humidity typical of building interiors (35 to 50 percent). While plants in drier climates may require more frequent watering, low humidity is better for prevention of mold and diseases.

3. Blasts of air are likely to damage plant foliage. Avoid plantings near outside doors and HVAC vents. Most interiors do not have the optimum environmental conditions necessary for plants to regenerate a large amount of damaged foliage.

4. Recent studies have demonstrated that plants can reduce, or even eliminate, "background" levels of ubiquitous chemical pollutants such as benzene, formaldehyde, and trichloroethylene from indoor air. However excessive level of pollutants, commonly occurring during construction, can severely damage plant foliage, usually turning it black.

5. Large trees [3 000 mm (10 ft) or larger] should be allowed at least 3 to 6 months during the growing season to acclimate to their new environment, and small material [600 mm (24 in) or less] at least 6 to 10 weeks. During this time, the amount of light should be gradually reduced.

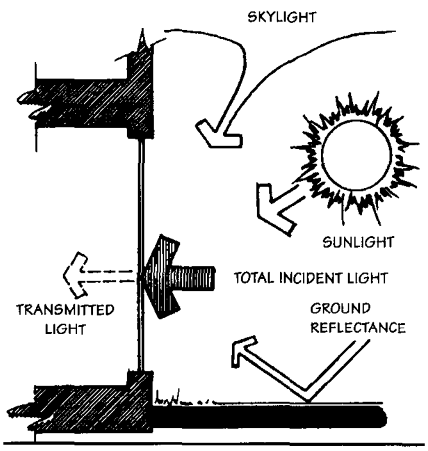

Figure 620-4. Daylight through vertical glazing.

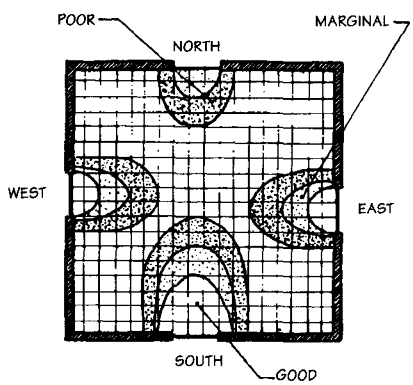

Figure 620-5. Effectiveness of daylight *through vertical glazing 900 mm (3 ft) wide by 1 500 mm (5 ft) high (northern hemisphere).*

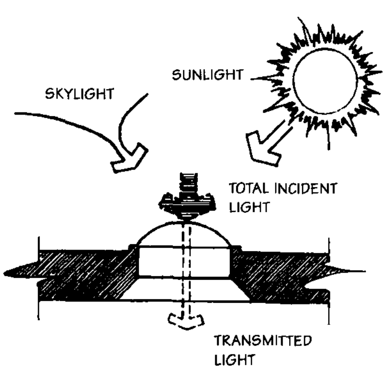

Figure 620-6. Daylight through skylight.

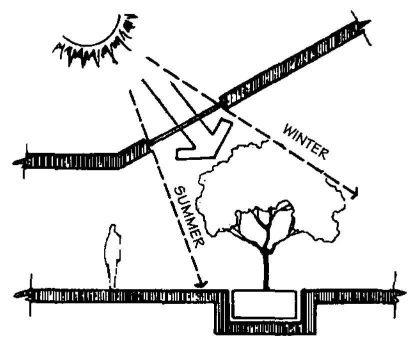

Figure 620-7. Optimum skylight features.

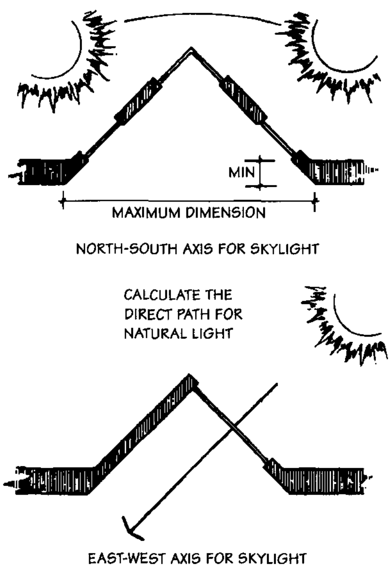

Figure 620-8. Placement of skylights.

mens leave too little room for growth and may block too much incoming light to their own inner foliage or to understory plants beneath them. Palms or other species which cannot be pruned should always be given adequate vertical space above them for future growth.

2.6 Weight of Plants

The weight of the plants and their planting medium is an important consideration when they are a part of the load calculations for a structural slab or an upper floor planter. The weight of a plant will depend upon its age (caliper), height, crown size, foliage type and density, and planting medium volume and density. The weight of the planting medium varies according to both the material used and the amount of water it contains. A lightweight soil mix is given in Section 610: Roof and Deck Landscapes, and other qualities of the planting medium are covered in Section 810: Soils and Aggregates.

2.7 Acclimatization

Plants being moved from the ideal light conditions of a shade house, greenhouse or nursery into a building interior must slowly be acclimatized to the lower light conditions. Without this period of adjustment, most plants will go into shock, stop growing, become weakened, and possibly die. The length of time required to acclimatize a plant depends on the species, the degree of change in light intensity, and the size of the plant. Large trees [3 000 mm (10 ft) or larger] should be allowed at least 3 to 6 months during the growing season to acclimate, and small material [600 mm (24 in) or less] at least 6 to 10 weeks. During this time, the amount of light should be gradually reduced to half of the original amount or less if needed.

KEY POINTS: Water Requirements & Strategies

1. Plants will transpire rapidly in conditions of high light, warm temperatures, or low humidity, and will require more frequent watering. Unsoftened water between 15° and 25°C (60° and 80°F) should typically be used.
2. Hand watering allows the maintenance technician to tailor the watering needs to the individual plants and particular environmental conditions. However, it is extremely labor intensive, requires that all plants be accessible, and will result in the gradual compaction of planting medium due to continuous top-watering.
3. Subirrigation may be used to reduce the frequency of watering, avoid the gradual compaction of planting medium, and deliver water to the root system as needed, as opposed to the flood/drought/flood cycle of hand watering.
4. Drip irrigation or other automatic systems may be used to water inaccessible plants and minimize labor requirements. However, they are expensive to install, may be prone to vandalism and require monitoring for seasonal adjustments. Automatic systems are most successful if species with similar water needs are planted in groups.

2.8 Maintenance

The main purpose of plant maintenance is to meet all the physical requirements of the plants on a continual basis. Specific maintenance tasks include the supplying of water and fertilizer, the control of insects on an as-needed basis, and pruning. The quality of maintenance will often be the primary factor in determining the actual versus potential life of the plants.

3.0 TECHNIQUES TO MEET PHYSICAL REQUIREMENTS

3.1 Light

Light can be provided either from daylight or electric light. Daylight is preferable because it provides a greater spectrum of the radiant energy needed by most plants, and is generally provided more diffusely than electric light. Diffused light is preferable to light from a point source because it allows better light penetration to the inner foliage of a specimen, as well as better light penetration through upper story specimens into the plants below. However, where daylight is insufficient in quantity or duration (due to the season or the time of day), electric light is often an essential supplementary source, or the sole source, of light for plant growth.

Daylight:

Daylight refers to the sum of direct sunlight, reflected sunlight, and (on overcast days) skylight. Daylight can be admitted into interior landscapes through windows, clerestories, or skylights.

Table 620-1. RECOMMENDED LIGHT SOURCES

Distance between light source and plant	Recommended light source
3 m (10 ft) and less	Daylight: vertical glazing,skylights Cool-white fluorescent Natural-light fluorescent Mercury lamp low wattage Incandescent
3.0-4.5 m (10- 15 ft)	Daylight: vertical glazing, skylights Quartz-metal halide combination High-pressure sodium lamp (only for plant lighting) Metal halide lamp,phosphor-coated Mercury lamp, deluxe-white Mercury lamp, warm deluxe-white High-pressure sodium (color-rendition a design factor) Quartz-halogen lamp Incandescent
4.5 m (15 ft) and greater	Daylight: vertical glazing, skylights Quartz-metal halide combination High-pressure sodium lamp (only for plant lighting) Metal halide lamp, clear Metal halide lamp, phosphor-coated Mercury lamp, deluxe-white High-pressure sodium (color rendition a design factor) Quartz-halogen lamp Incandescent

Windows and Clerestories:

Windows and clerestories are only about one-third as efficient in admitting light as the overhead horizontal or angled openings of skylights (Figures 620-4 and 620-5). Window efficiency is determined by its size, the orientation of the opening, and the type of glazing. In the northern hemisphere, the effective area for plant growth, given a southerly solar orientation, is equal in depth only to the height of the window, assuming that the plants are located at sill height.

Skylights:

Skylights have the advantage of encouraging plants to grow upward toward the light (Figure 620-6). If skylights are included as part of the building design for the purpose of providing daylight for interior plants, then there are a number of important considerations for maximizing their effectiveness:

1. *Location:* skylights and plants are more effectively related if they are not aligned in plan but aligned for the angle of the sun to hit the plants.
2. *Orientation:* in the northern hemisphere, north facing skylights are only minimally effective in terms of the intensity of light penetration, but large areas of north-facing skylight can provide reasonable levels of well-diffused light. South facing skylights (east-west axis) can provide too much direct light and cause a one-sided plant growth, but they are a good source of reflected light. A mix of east and west facing skylights (north-south axis) provides a better balance of light (Figure 620-7).
3. *Details:* the design of a skylight system that will admit the maximum amount of light possible is as follows:
   a. Bulkhead: a minimal distance from ceiling to skylight frame will permit a more direct path for the daylight. Light-colored walls surrounding the bulkhead will increase the amount of reflected light (Figure 620-8).
   b. Ceiling opening: if the ceiling opening is larger than the skylight open-

KEY POINTS: Lighting Requirements & Strategies

1. Light in typical building interiors is seldom of sufficient intensity to sustain most plants without skylights or supplemental electrical lighting. Table 620-1 lists possible light sources in order of preference. .
2. Continuous illumination is not a suitable substitute for low light intensity, as plants require periods of light and dark (photoperiods). The average photoperiod for plants is 12-16 hours of light, and 8-12 hours of darkness.
3. Natural light is ideal for plant growth, however tinted or reflective glass will alter its spectral energy and intensity. Glazing or artificial light sources should provide radiant energy from the blue and red ends of the spectrum (Figure 620-1).
4. Windows and clerestories are only about one-third as efficient in admitting light, as skylights. In the northern hemisphere, the effective area for plant growth in south-facing windows is equal in depth to the height of the window (Figure 620-5).
5. A mix of east and west-facing skylights typically provide the best balance of light for

Table 620-2. CHARACTERISTICS OF ELECTRIC LAMPS

Characteristics	Tungsten, halogen, and incandescent	Fluorescent	Mercury vapor	Metal halide	High-pressure sodium	Low-pressure sodium
Lumens per watt	6–23	25–100	30–63	68–125	77–140	137–183
Lumens	40–33 600	96–15 000	1 200–63 000	12 000–125 000	5 400–140 000	4 800–33 000
Lumens per watt maintenance (%)*	75–97	75–91	70–86	73–83	90–92	75–90
Wattage range†	6--1 500	4–215	40–1 000	175–1 500	70–1 000	35–180
Life†	750–8 000	9 000–20 000	16 000–24 000+	1 500–15 000	20 000–24 000	18 000
Color temperature†	2 400	3 100	2 700–6 500	3 300–5 900	3 200–4 700	2 100–1 780
Color rendition†	95–99	55–95	22–52	65–70	21	0
Color breadth of application	Good	Good	Fair	Good	Fair	Poor
Control	Excellent	Poor	Fair	Fair to good	Good	Poor
Initial Cost (per lamp)	Low	Moderate	Moderate	High	High	Moderate
Operational cost (power)	High	Moderate	Moderate	Low	Low	Low
Breadth of application	Wide	Wide	Medium	Medium to wide	Narrow	Narrow

*Percentage of output in lumens during life of the bulb.
†Lumens.
Source: Courtesy of GTE Sylvania Lighting Products.

ing, the area influenced by the brightness from the skylight will be extended.

Glazing Materials:

The glass or plastic used in windows or skylights will have varying properties of light transmittance, absorption and reflection. The pre-construction calculations should include daylight figures which take into account the type of glazing material and the amount of light it will transmit. This information is available from all manufacturers of glass and plastic. The range varies from clear glass at 84 percent transmission to double-glazing with bronze tint at 18 percent transmission. (Refer to Section 870: Glass, Plastics, and Fabrics, for more information on the types and properties of glass and plastic for glazing purposes.)

Electric Light:

Normally, electric lighting should be treated only as a supplement to daylight. Electric light has the advantage of being flexible and can therefore achieve good light distribution over plants at optimum lux (foot-candle) levels by varying the location, quantity, and type of fixtures used. The beamspread of lamps should be considered in the design of lamp spacing. Uplighting will not contribute significantly to plant growth, and close proximity of uplights to foliage can burn the foliage or heat the root mass enough to cause damage.

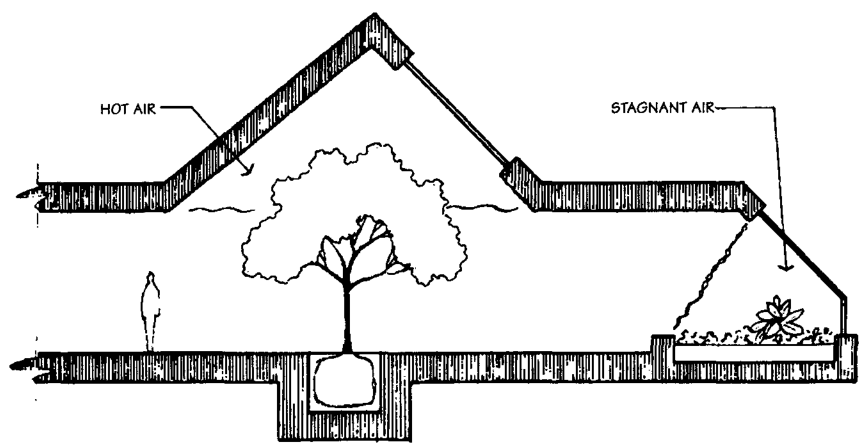

Figure 620-9. Air circulation problems.

Table 620-1 shows the recommended lighting sources for plants. They are listed in order of priority based on plant growth efficiency, color rendition preference, and energy efficiency. Table 620-2 gives data on the characteristics of electric lamps, and Table 620-3 gives information on the suitability of various lamps for plant growth.

3.2 Air

Providing plants with proper above ground and in-ground temperatures is important and should be considered during the conceptual stage of any building design (Figure 620-9). In temperate climates, the following locations should be avoided:

1. Plantings over unheated spaces such as parking garages because root balls need protection from low temperatures, unless the planting medium is insulated sufficiently to keep root mass temperatures above 15°C (60°F)
2. Plantings near outside doors because drafts are difficult to control
3. Plantings immediately adjacent to heating and air-conditioning supply vents because air temperature and

Table 620-3. LAMP SUITABILITY FOR INTERIOR PLANT LIGHTING

Types of lamps	Responses to interior plants
Incandescent and tungsten halogen	Lamps produce high amounts of infrared energy, which increases the transpiration rate in foliage. They have a high ratio of red to blue energy, which causes long internodes and spindly growth.
Fluorescent	Cool-white and warm-white lamps are deficient in the red and far-red wavelengths. Add 10 to 20% (by wattage) of incandescent lamps to promote more normal growth responses. Standard Gro-Lux and wide spectrum Gro-Lux provide a balance in the red, far-red, and blue regions of the spectrum for optimum plant responses.
Mercury	Of the lamps in the mercury family, bright-white deluxe lamps provide the best light characteristics for plant growth.
Metal halide	Coated metal halide (Metalarc-coated) lamps provide the best light characteristics (red, far-red, and blue wavelengths) of all high-energy discharge (HID) lamps. These are especially suitable for totally enclosed growth areas, such as growthrooms and interior landscapes.
High-pressure sodium (HPS)	These lamps distort colors of ornamental plants because of insufficient blue wavelength emissions. Therefore, they should not be used alone for lighting interior plants. HPS lamps are useful to supplement natural daylight (sunlight).
Low-pressure sodium (LPS)	These lamps are poor sources of light for interior plants because they are monochromatic, emit light in the yellow wavelength, and give poor color renditions.

Source: Adapted from a table prepared by Christos Mpelkas, Plant Pathologist, GTE Sylvania Lighting Products.

movement normally exceeds the tolerance of most interior plants

If interior landscape design is studied in both plan and section as well as coordinated with the mechanical systems involved, then such problems as the following can be avoided:

1. Plants located in dead-air corners
2. Plants located against glass walls with no mechanical system to modify extremes in temperature
3. The tops of large plant material or hanging plants located in the poorly conditioned zones near high ceilings and in multistory spaces

3.3 Water

The two fundamental methods of watering plants are hand watering and automatic system watering. Many techniques are used that vary and combine these two basic methods.

Hand Watering:

Hand watering is a popular technique because its main advantage is the ability to tailor the watering needs to the individual plants and particular environmental conditions, including seasonal changes in the water requirements of plants.

Tools and facilities needed for hand watering include:

1. Hose bibbs or box hydrants convenient for use with 15 m (50 ft) hoses.
2. Access to a sink for a watering cart. The sink should have a threaded hose faucet and at least a 600 mm (24 in) clearance from faucet to sink or floor.
3. A hot-and-cold water mixer faucet.
4. A wand used to water hanging baskets or hard-to-reach ledges.
5. Water carts and watering cans of assorted sizes.
6. Custom-designed equipment for special situations. If such equipment is needed, it typically must be stored in a lockable closet within the building.

Three disadvantages of hand watering are:

1. It is labor-intensive.
2. All plants must be accessible.
3. The soil will gradually compact over time from continuous top-watering.

One variation on hand watering which continues to gain popularity is subirrigation, a system in which reservoirs are placed beneath the planting medium (Figure 620-10). Water loaded into the reservoir by hand is drawn out by capillary action into the planting medium, using wicks which vary in composition by the manufacturer. Advantages to subirrigation are:

1. Depending on the size of the reservoir, it is possible to reduce the frequency of watering, the single most time-consuming task of an interior landscape maintenance technician.
2. The planting medium will not compact, because water is drawn from below.
3. With the proper planting medium, water will be provided to the root system as needed, as opposed to the normal flood/drought/flood cycle of hand watering.

Automatic Systems:

Most irrigation systems for exterior landscapes (such as spray or impact rotor) are technically possible for interiors but may have one or more of the following disadvantages:

1. They are expensive to install.
2. The components may be prone to vandalism.
3. The system is often ill-suited to the different watering requirements of any multi-variety plant palette.
4. The system needs to be monitored for seasonal adjustment and for adjustments required by temporary changes in growing conditions.
5. Interior plants, even species with relatively high watering requirements, need far less water than exterior plants, and it can be difficult to adjust automated systems to provide very low water delivery rates.

One popular exterior system that can be successfully adapted for indoor use is drip irrigation. Drip systems solve two of the more significant problems of spray or impact rotor systems by delivering very low quantities of water to precise locations. However, it is still subject to the other disadvantages of automated systems.

The main advantages of an automatic system are that plants in inaccessible locations are often more easily reached, and once an automated system is balanced, it requires less labor than a non-automated system. An automatic system may also be advantageous if plants with similar water needs are planted in groups. The near future may provide the advent of a sensor-controlled drip irrigation system that provides water delivery on an as-needed basis. Such a system, while continuing to be more expensive than a manual system and still

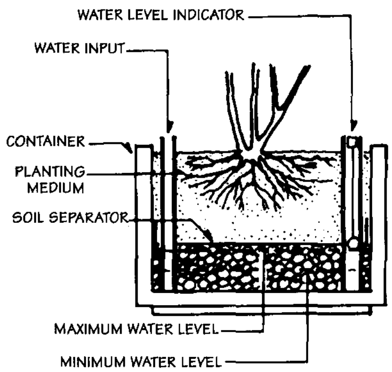

Figure 620-10. Planter with reservoir.

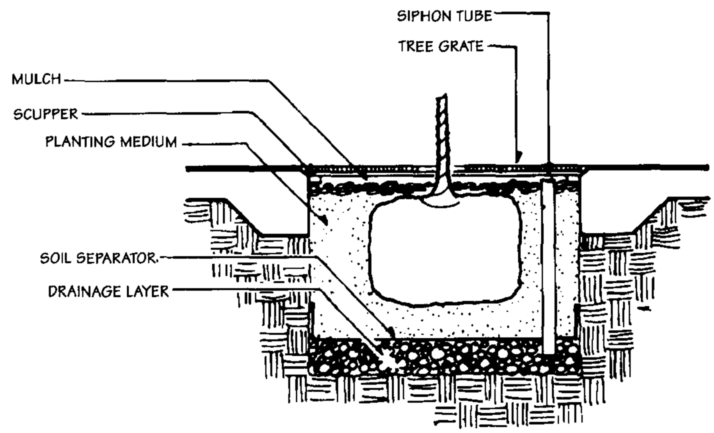

Figure 620-12. Basic components of a tree pit.

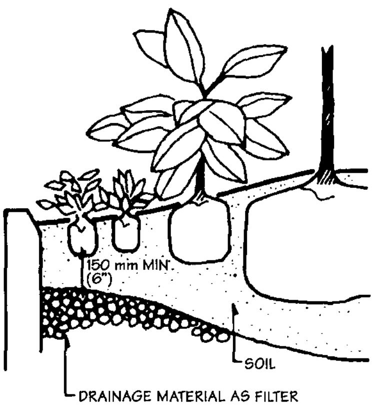

Figure 620-11. Necessary soil depth.

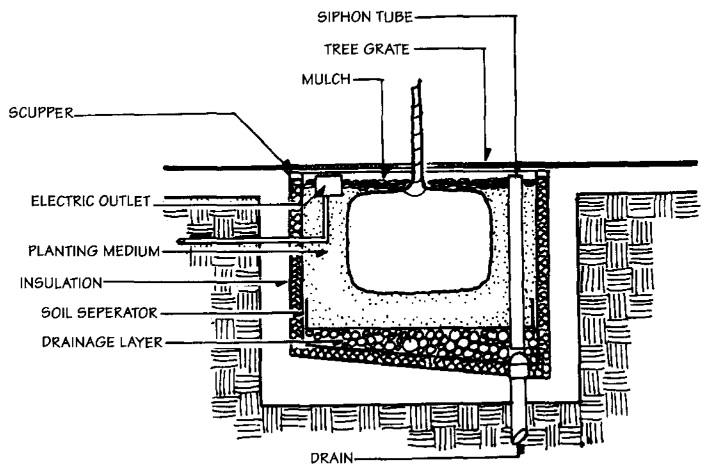

Figure 620-13. Optional features of a tree pit.

subject to vandalism, would resolve all the other concerns regarding automated systems, and provide a substantial reduction to the cost of maintaining an intensively planted interior landscape.

3.4 Planting Medium

The ingredients used in a planting mix will depend on their availability, on weight restraints, and on the needs of the particular plants. Soil and non-soil mixtures may contain various proportions of the following ingredients and have the indicated weights per cubic meter (cubic foot):

Topsoil: Sandy loam, uniform in composition and free of debris. Weight: 1600 kg/m³ (100 lb/ft³)

Peat: Has good water holding capacity, but does not compact readily. Weight: 130 to 160 kg/m³ (8 to 10 lb/ft³).

Sand: Has poor water holding capacity. Weight: 1600 kg/m³ (100 lb/ft³).

Shredded bark: Pine bark is best; hardwood is good. Both have good water holding capacity.

Vermiculite: A soil additive made of expanded mica. It contains some nutrients and has good water holding capacity. It breaks down under sterilization and therefore cannot be used repeatedly. Weight: 95 to 130 kg/m³ (6 to 8 lb/ft³).

Perlite: A soil additive made of siliceous volcanic rock. It contains fluoride, which will damage some plants. It has good porosity and some water holding capacity. Because it does not deteriorate, it can be re-sterilized and reused. Weight: 95 to 130 kg/m³ (6 to 8 lb/ft³).

Calcined clay: A soil additive made of fired clay particles. It retains water and can be reused.

Styrofoam particles: A soil additive made of plastic. It holds no water, increases the porosity of the mix, and disintegrates under sterilization; therefore, it cannot be reused.

Soil mixtures normally consist of 20 to 30 percent soil and 70 to 80 percent soil additives (see Figure 620-11). Mixtures without soil use variations on the following proportion:

1/3 sand

1/3 shredded bark

1/3 soil additives

3.5 Construction Details

Tree pits and built-in planters for interior plantings have some features that distinguish them from exterior plantings.

1. The need for a tree pit (with sides and a bottom) should be determined after investigation of existing conditions of

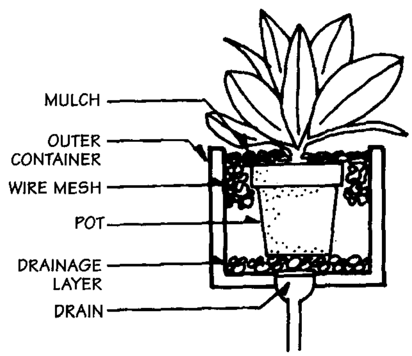

Figure 620-14. Features of built-in planters.

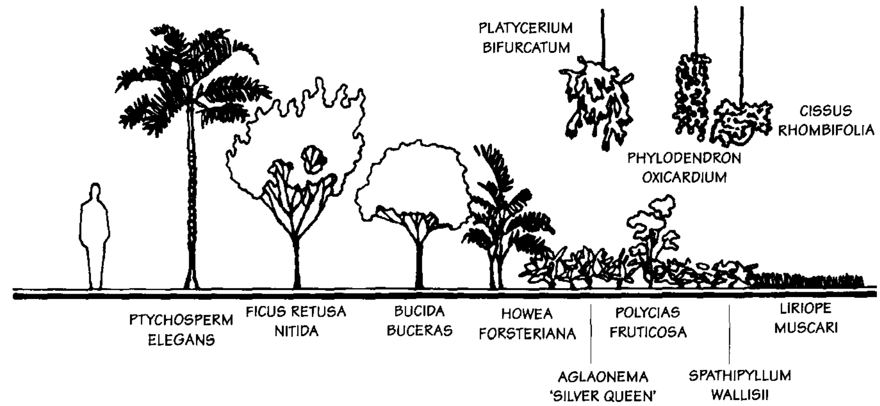

Figure 620-15. Size comparison of interior plants.

the soil, underground springs, and draining ability (Figure 620-12).

2. Insulation may be necessary if the tree pit is above an unheated space in temperate climates, such as a parking garage. Heating coils might also be necessary to maintain the root ball temperature above 15°C (60°F).

3. Drains should be included whenever possible and appropriate. A siphon pipe can be used to check the viability of the drain or to check the water retention in the absence of a drain (Figures 620-13 and 620-14).

4. A scupper around each tree pit will serve to catch toxic floor cleansers and waxing liquids.

5. When hose bibbs and electrical junction boxes are included in tree pits or planters, they should be located to the sides, away from where the major plants are located.

6. Planters should be waterproofed if they are surrounded by a fountain. Water from a fountain may contain chemicals harmful to plants.

4.0 DESIGN PROCESS

The following considerations and procedures are offered as guidance on projects involving the design and construction of interior landscapes. The steps in this procedure focus on the use of plants inside buildings.

1. Review the expected role of the interior landscape with the client and the design team working on the project. Determine whether it is to be a major statement or a background complement to the building.

2. Based upon its role, determine the environmental needs of the interior landscape as early in the design process as possible.

3. Determine the sizes of the largest plants so that sufficient space can be provided without interference from columns, stairs, and similar major elements of the building. The structural engineer needs to know where the major plants will be placed and whether they will be put into tubs sitting on the floor slab or put into pits set into the floor.

4. Plants should be located to minimize unnecessary physical contact with people, but access to all plants for maintenance purposes should be provided.

5. Plants should be selected that will survive under the expected levels of light but will not outgrow their space in a short time. (Note that in most cases, plants in interior spaces grow very slowly if at all after they are installed.)

6. All constructed elements, such as built-in planters and watering and drainage systems, should be coordinated with the overall design of the building.

7. If possible, select contractors who have prior experience with interior plantings.

8. Select and tag all large and specimen plant materials far enough ahead of time to allow the plants to be acclimatized in some reliable way before they are installed.

9. All of the interior landscape's environmental systems (lighting, water, air handling, etc.) should be tested and working before any plants are installed. Responsibility for alternative solutions should be established in advance in case any system fails.

KEY POINTS: Planting Medium & Construction

1. The planting medium may or may not contain soil, depending on the physical requirements of the plant, availability of ingredients, or weight restraints.

2. Soil mixtures normally consist of 20 to 30 percent soil and 70 to 80 percent soil additives (see Figure 620-11). Mixtures without soil use varying combinations of sand, shredded bark and soil additives.

3. Tree pits and planters should provide mulch to retain moisture, planting medium, fabric separator and a drainage layer (Figure 620-12). A drain pipe should also be provided whenever possible. Insulation may be needed if placed above an unheated space in temperate or cold climates (Figures 620-13 and 620-14).

4. Tree pits and planters should prevent harmful toxins from entering the planting medium. Planters placed in pools or fountains should be waterproofed, and scuppers should be used around at-grade pits to catch toxic floor cleansers and liquids.

10. Maintenance should begin at the time of installation.

11. Access from the outside of a building to interior locations where the planting is being done should be provided. For example, a 750-L (200-gal) plant will require an opening at least 2 400 mm (8 ft) square in order to enter a building. There is also the need for a long-term access route if major plants have to be replaced.

5.0 PLANT PALETTE

5.1 Design Objectives

1. A feeling of transition from exterior space to interior space should be created.

2. A proper sense of scale should be given to large interior spaces.

3. Different functions should be separated physically and visually.

4. Architectural forms should be complemented with plants primarily through contrast in form, texture, and color.

5.2 Character of Interior Plants

Size:

Interior plants can be grouped by the following categories of sizes: groundcovers, small understory, large understory, upper story (trees and palms), and vines and hanging plants (Refer to 5.4 Commonly Used Plants in this section for height ranges in each of these categories).

Many plant species can be used in more than one category, depending on their particular size and habit of growth. The height and spread at the time of planting becomes very important because most plants will not continue to grow significantly, once planted indoors, unless given more than their minimum light requirements. Detailed height and spread information is available in the United States from growers through the Associated Landscape Contractors of America (ALCA) guide (see the References at the end of this section). Normal size ranges are shown on the scale in Figure 620-15.

Growth Habit:

Growth habit refers to the distribution of foliage on a plant and the character of its trunk or trunks. Plants for interior landscapes can be selected that have a wide variety of growth habits from stems or trunks that are single, multiple, straight, or

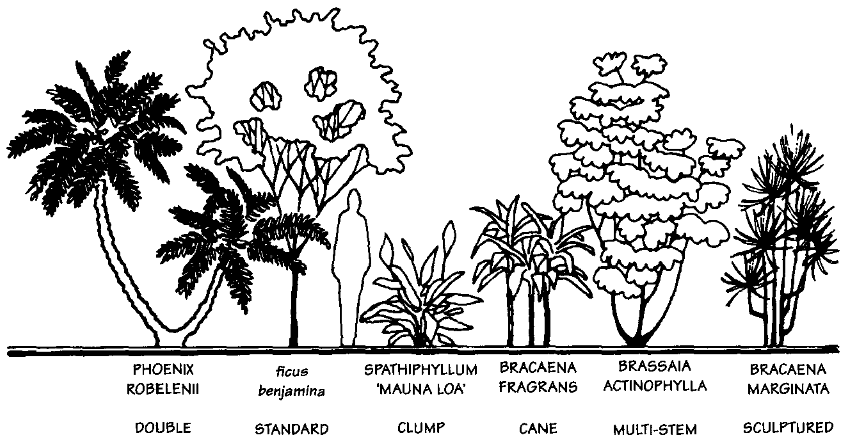

Figure 620-16. Various growth habits of interior plants.

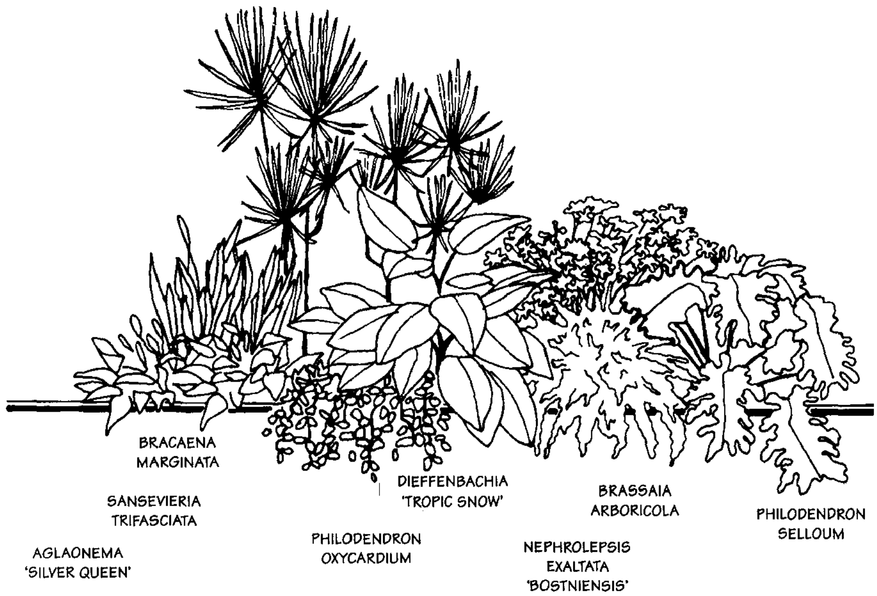

Figure 620-17. The textural range of interior plants.

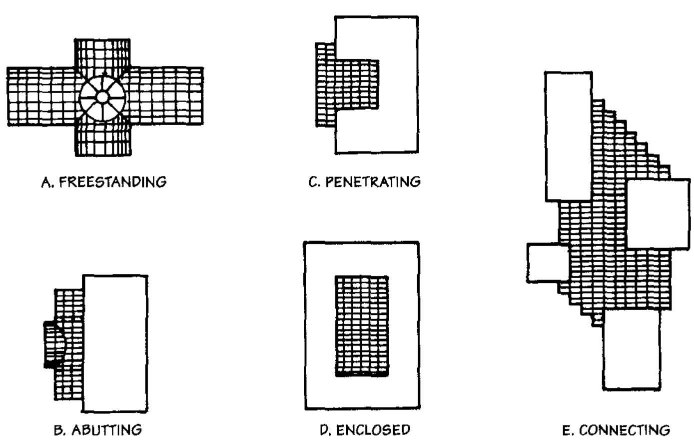

Figure 620-18. Building prototypes with interior landscapes.

Figure 620-19. Plants as part of a total interior landscape composition.

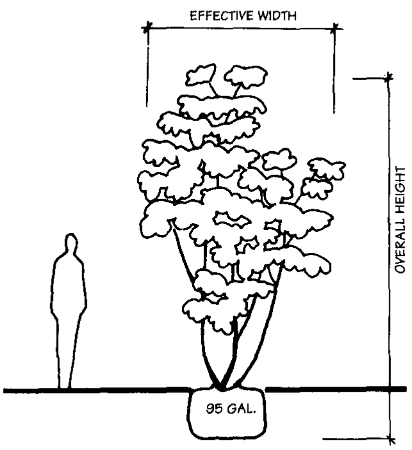

Figure 620-20. *Brassaia actinophylla.*

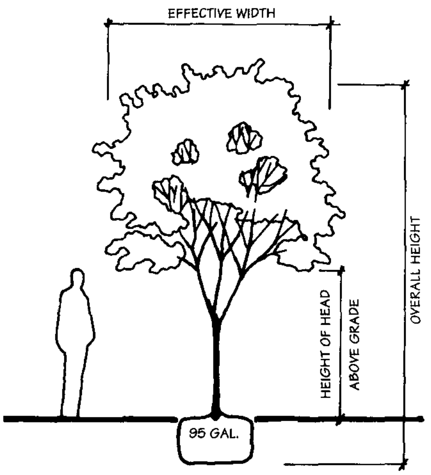

Figure 620-21. *Ficus benjamina* **(standard).**

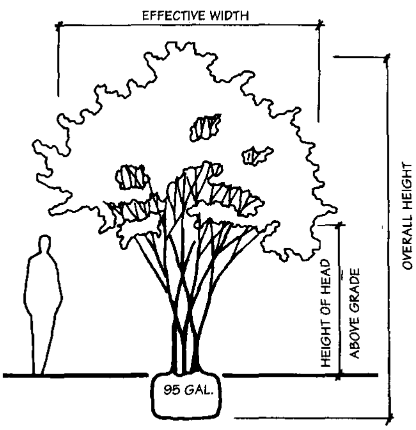

Figure 620-22. *Ficus benjamina* **(multitrunk).**

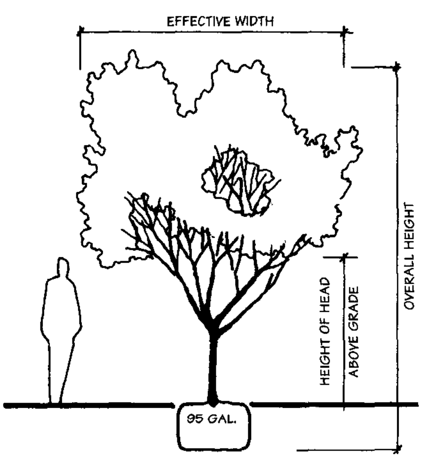

Figure 620-23. *Ficus retusa nitida.*

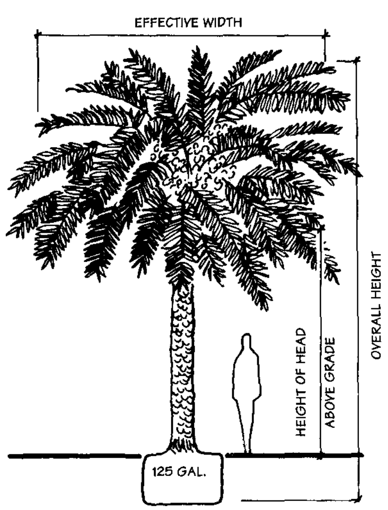

Figure 620-24. *Phoenix canariensis.*

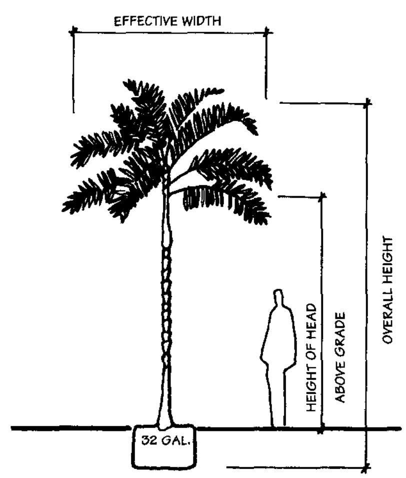

Figure 620-25. *Ptychosperma elegans* **(single).**

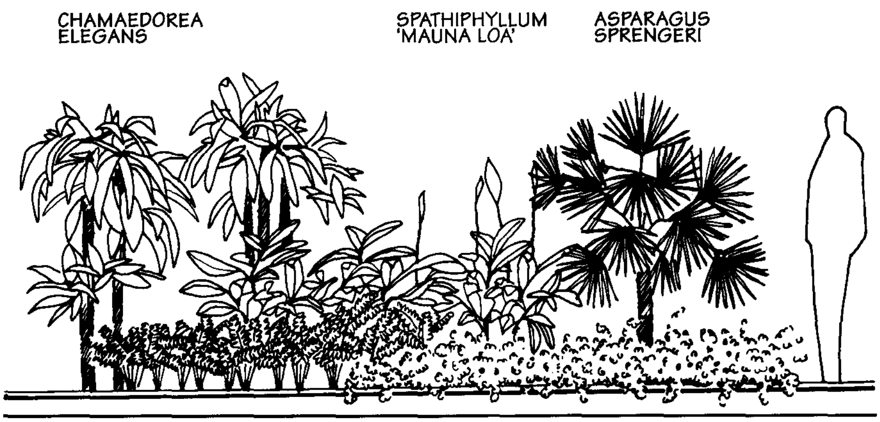

Figure 620-26. Large understory specimens.

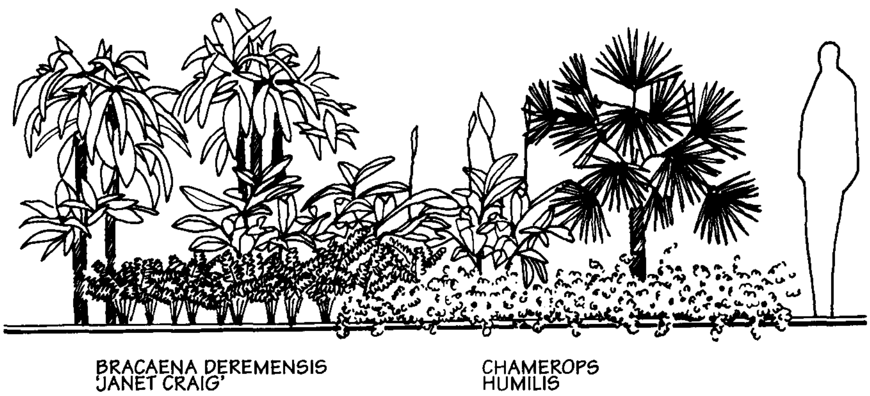

Figure 620-27. Small understory specimens.

KEY POINTS: Planting Design

1. Table 620-4 lists the environmental requirements of a number of species common to North American interior landscapes. Selection of plant materials is based on these requirements and the design objectives.

2. It is preferable to specify plant materials whose natural shape can be maintained either by slow growth without pruning, or by standard pruning practices (see Figures 620-20 through 620-27 for the size and shape of commonly used plants). Upper story plants specified for well-lit two story or tall one story spaces should not exceed 2/3 the height of the space in when they are planted, to insure adequate room for growth (Figure 620-3).

3. Size at the time of planting is very important because most plants will not continue to grow significantly, unless given more than their minimum light requirements. Sufficient access from the outside of a building to interior landscapes must be provided.

4. Texture and color are important design considerations, often highlighted by emphasizing contrasts between various species. Foliage is typically the primary source of color, as flowers usually require high levels of light and plants must be frequently rotated.

5. A number of commonly used building prototypes for interior landscapes have been developed based on architectural and lighting requirements (Figure 620-18). Plants are often massed and complimented with water features, landforms and rocks within these landscapes to counterbalance the more dominant architectural forms.

curved (Figure 620-16), and from branching structures such as oval, pyramidal, fastigiate, lollipop, sculptured, braided, weeping or topiary.

Texture:

Tropical plants are particularly versatile in terms of texture, given their wide range of leaf sizes. The juxtaposition of plants with widely different textures is one of the characteristics associated with creating a tropical appearance (Figure 620-17). Foliage textures range from the fine lacy delicacy of a Maidenhair Fern to the coarseness of a Bird-of-Paradise's huge leaves or the many lobes of a Selloum Philodendron. Many trunks and stems also give a feeling of texture, from the smooth trunk of the Ficus to the coarse trunk of some of the palms.

Color:

Flowers are the source of color for most plantings, but flowering typically requires a high level of light, and plants must be rotated every 3 to 4 weeks. A wide range of colors is available via plant foliage, however, including a range of greens (dark to light), yellow-greens to blue-greens, and variegated varieties (light and dark markings). Color variation is sometimes highlighted, as with texture, by placing plants to emphasize the contrasts.

5.3 Design Suggestions

1. The need for high levels of light, particularly natural light, and the use of glass-enclosed spaces to achieve a transition from exteriors to interiors have resulted in a few common identifiable architectural and interior landscape prototypes (Figure 620-18).

2. Plants should be grouped into massings as a counterbalance to the more dominant architectural forms. Although a matter of subjectivity, most interior planting designs cannot function effectively as part of the overall design unless they are dramatic in quantity, size, and arrangement (Figure 620-19).

3. Regional differences and styles in design can be achieved by selecting plants based on their character, size, and texture, and by the manner in which they are composed. The character of a temperate, tropical, or arid exterior landscape can be replicated indoors through the choice and use of various plants and construction materials. Also, the use of specimen plantings can make a design especially dis-

tinctive. The style of planters can also set a tone or establish a particular character.

4. In addition to plants, other landscape elements, such as water features, landforms, and rocks-can be used to help create a variety of landscape effects.

5. Given the relatively low light conditions in typical interior settings [1 600 lx (150 fc) or less], most interior plants will usually not flower [Spathiphyllum is one exception that will flower at 1 070 lx (100 fc) or greater]. For permanent color in the design, therefore, plants grown specifically for their flowers should be used. Flowering plants will need to be changed approximately every 2 to 6 weeks, depending on their species and the amount of light and water they receive, if the flowers are to remain fresh in appearance. A flower selection schedule should be established and coordinated with whatever materials are available locally.

5.4 Commonly Used Plants

Size Categories:

Interior plants are typically categorized according to the following sizes:

1. Trees: 1 500 to 75 000 mm (5 to 25 ft) or more
2. Large understory: 900 to 1 500 mm (3 to 5 ft)
3. Small understory: 300 to 900 mm (1 to 3 ft)
4. Groundcover: less than 300 mm (1 ft)
5. Vines and hanging plants: Not categorized by size

Plant List:

Figures 620-20 through 620-27 show various plants that have proved to be viable as interior plants and are readily available in North America. Many other species and additional varieties exist that may be as good or better for specific purposes. Designers are urged to keep alert to new plants and to explore new ways to use other familiar plants.

Environmental Conditions:

The number of plants available to the designer increases dramatically as the physical requirements of plants (particularly light) are optimized. Table 620-4 gives information on the range of environmental conditions that various plants require.

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Table 620-4a. LIGHTING USE REQUIREMENTS FOR COMMONLY USED PLANTS—TREES

	LIGHT				TEMPERATURE (F)			MOISTURE			SIZE (HEIGHT)		WEIGHT		CHARACTER			USE
Botanical name, common name	**Low, 50 fc**	**Medium 75-100 fc**	**High 200 fc**	**Very high 500 fc**	**Cool 40-60°**	**Intermediate, 50-70°**	**Warm, 62-85°**	**Dry**	**Moist**	**Wet**	**Normal m (ft)**	**Max, m (ft.)**	**Normal kg (lb.)**	**Max, kg (lb.)**	**Broadleaf**	**Palm**	**Other**	**Large Understory**
Aiphanes caryotaefolia spine palm		•		•			•			1.5-6	9 (5-20)	1125 (30)	2700 (2500)	(6000)	•			
Araucaria heterophylla, Norfolk Island pine			•			•			•		9-4.5 (3-15)	7.5 (25)	675 (1500)	2250 (5000)			•	•
Arecastrum romanzoffianum, queen palm			•				•			•	1.5-6 (5-20)	9 (30)	1125 (2500)	2700 (6000)		•		
Beaucarnea recurvata, ponytail palm				•		•		•			.6-3 (2-10)	6 (20)	675 (1500)	1125 (2500)		•		
Brassaia actinophylla, schefflera				•			•	•			.9-6 (3-20)	12 (40)	1125 (2500)	3600 (8000)			•	•
Bucida buceras, black olive				•							1.5-3 (5-10)	4.5 (15)	225 (500)	675 (1500)	•			
Butia capitata, jelly palm				•		•		•			1.5-6 (5-20)	9 (30)	1125 (2500)	2700 (6000)		•		•
Caryota urens, fishtail palm			•				•		•		1.5-6 (5-20)	9 (30)	1125 (2500)	2700 (6000)		•		
Clusia rosea, autograph tree			•				•			•	1.5-6 (5-20)	9 (30)	125 (2500)	2700 (6000)	•			•
Coccoloba uvifera, sea grape			•				•		•		1.5-4.5 (5-15)	6 (20)	675 (1500)	1125 (2500)	•			
Ficus benjamina, . weeping fig			•			•			•		9-6 (3-20)	12 (40)	1125 (2500)	3600 (8000)	•			•
Ficus benjamina 'Exotica,' Java fig			•			•			•		.9-6 (3-20)	12 (40)	1125 (2500)	3600 (8000)	•			
Ficus elastics 'Decora,' rubber plant			•			•			•		.9-6 (3-20)	12 (40)	1125 (2500)	3600 (8000)	•			•
Ficus lyrate, fiddle leaf fig			•			•			•		9-6 (3-20)	12 (40)	1125 (2500)	3600 (8000)	•			•
Ficus retusa nitida, Indian laurel			•			•			•		.9-6 (3-20)	12 (40)	1125 (2500)	3600 (8000)	•			•

Table 620-4b. LIGHTING USE REQUIREMENTS FOR COMMONLY USED PLANTS—LARGE UNDERSTORY

	LIGHT				TEMPERATURE (F)			MOISTURE			SIZE RANGE (FT.)	USE
Botanical name, common name	**Low, 50 lc**	**Medium, 75–100 fc**	**High, 200 fc**	**Very High, 500 fc**	**Cool, 40–60°**	**Inter-mediate, 50–70°**	**Warm, 62–85°**	**Dry**	**Moist**	**Wet**	**Size Range, m (ft.)**	**Small under-story**
Brassaia arboricola Hawaiian schefflera		•					•	•			To 4.5 (15)	•
Caryota mitis, clumping fishtail palm			•				•			•	To 7.5 (25)	
Chamaedorea erumpens, bamboo palm		•					•		•		To 4.5 (15)	
Chamaedorea Seifrizii, reed palm		•					•		•		To 4.5 (15)	
Chamaerops humilis, European fan palm				•		•				•	To 6 (20)	
Chrysalidocarpus futescens, butterfly palm (Areca palm)			•				•			•	To 7.5 (25)	•
Cibolium schiedes, tree fern			•				•		•		To 4.5 (15)	
Cycas circinalis, fern palm			•			•		•			To 3.6 (12)	
Cycas revoluta, sago palm			•			•		•			To 3 (10)	
Dicksonia fibrosa, golden treefern			•			•				•	To 6 (20)	
Dieffenbachia amoena, giant dumbcane		•					•	•			To 1.8 (6)	
Dieffenbachia 'Tropic Snow,' tropic snow dumbcane		•					•	•			To 1.8 (6)	•
Dizygotheca elegantissima, false aralia			•				•		•		To 7.5 (25)	
Dracaena deremensis 'Janet Craig,' Janet Craig dracaena		•					•			•	To 1.5 (5)	•
Dracaena deremensis 'Warneckii,' Warneckii dracaena		•					•			•	To 1.5 (5)	•
Dracaena fragrans 'Massangeana,' corn plant		•					•			•	To 6 (20)	•
Dracaena marginata, Madagascar dragon tree		•					•			•	To 6 (20)	•
Draecana reflexa angustifolia (Pleomele) Malaysian dracaena		•					•			•	To 6 (20)	•
Howeia forsterana, kentia palm		•				•			•		To 4.5 (15)	•
Phoenix roebelenii, dwarf date palm			•			•	•			•	To 3.6 (12)	
Polyscias fruticose, Ming aralia				•			•		•		To 3.6 (12)	
Rhapsia excelsa, lady palm			•			•				•	To 6 (20)	
Spathiphylium 'Mauna Loa,' Mauna Loa peace lily	•	•					•			•	To 1.5 (5)	•
Yucca elephantipes, spineless yucca				•		•			•		To 6 (20)	

TABLE 620-4c. LIGHTING REQUIREMENTS FOR COMMONLY USED PLANTS—SMALL UNDERSTORY

	LIGHT				TEMPERATURE (F)			MOISTURE			HEIGHT
Botanical name, common name	**Low 50 fc**	**Medium 75–100 fc**	**High 200 fc**	**Very high 500 fc**	**Cool, 40–60°**	**Inter-mediate 50–70°**	**Warm, 62–85°**	**Dry**	**Moist**	**Wet**	**Size range, m (ft.)**
Aglaonema commotatum, variegated Chinese evergreen	•						•		•		To .6 (2)
Aglaonema 'Fransher,' To Fransher evergreen	•						•		•		.6 (2)
Aglaonema 'Malay Beauty' ('Pewter'), pewter aglaonema	•						•		•		To .6 (2)
Aglaonema 'Parrot lungle,' parrot jungle evergreen	•						•		•		To .6 (2)
Aglaonema 'Pseudo-bracteatum,' golden evergreen	•						•		•		To .9 (3)
Aglaonema 'Silver Queen,' silver queen evergreen	•						•		•		To .6 (2)
Asparagus piumosus, fern asparagus				•		•			•		To .6 (2)
Asparagus sprengeri, fern asparagus				•		•			•		To .6 (2)
Aspidistra elatior, cast-iron plant	•					•				•	To .9 (3)
Aspienium nidus, bird's nest fern	•					•			•		To 1.2 (4)
Chamaedorea elegans, Neanthe Bella palm	•						•		•		To 1.2 (4)
Codiaeum X Karen, croton				•			•		•		To 1.8 (6)
Dieffenbachia X Exotica, dumbcane			•				•	•			To 1.2 (4)
Dracaena deremensis 'Janet Craig'Compacta, dwarf Janet Craig dracaena		•					•		•		To .6 (2)
Fatsia japonica, Japanese fatsia		•			•				•		To 1.2 (4)
Nephrotepis exaltata 'Bostoniensis,' Boston fern			•			•			•		To .6 (2)
Philodendron selloum, saddle-leafed philodendron		•					•		•		To 1.8 (6)
Polypodium aureum 'Mandaianum,' blue hare's-foot,fern			•			•	•		•		To .9 (3)
Polyscias batfouriana, Balfour aralia				•			•		•		To 3.6 (12)
Sansevieria trifasciata laurentii, snake plant	•	•	•	•			•	•	•		To 1.2 (4)
Spathiphylium 'Clevelandii,' Cleveland peace lily	•	•					•			•	To .9 (3)
Spathiphyllum wallisii, white flag	•	•					•			•	To .3 (1)
Spathiphylltim 'Mauna Loa Supreme,' Mauna Loa peace lily supreme	•	•					•			•	To .6 (2)
Zamia furfuracea, Jamaica sago tree	•	•				•	•		•		To 1.5 (5)

Table 620-4d. LIGHTING REQUIREMENTS FOR COMMONLY USED PLANTS-GROUNDCOVER, VINES, AND HANGING PLANTS

	LIGHT				TEMPERATURE (F)			MOISTURE			USE		HANGING	SIZE RANGE
Botanical name, common name	**Low, 50 fc**	**Medium, 75–100 fc**	**High, 200 fc**	**Very High, 500 fc**	**Cool,**	**Inter-mediate,**	**Warm, 62-85°**	**Dry**	**Moist**	**Wet**	**Ground cover**	**Vine**	**Hang-ing**	**Size range m (ft)**
Anansa comosus variegates, variegated pineapple			•			•		•		•				To .6 (2)
Asparagus plumosum, fern asparagus			•			•			•				•	To .9 (3)
Asparagus sprengeri, fern asparagus			•			•			•				•	To .9 (3)
Chlorophytum comosum 'Variegatum,' variegated spider plant		•				•			•		•		•	To .6 (2)
Cissus antarctica, kangaroo vine		•				•	•	•	•			•	•	To .9 (3)
Cissus rhombifolia 'Mandaiana,' grape ivy		•				•	•	•	•		•		•	To .9 (3)
Cissus rhombifolia 'Ellen Danica,' oakleaf grape ivy		•				•	•	•	•		•			To .9 (3)
Crytomium faicatum, holly fern	•					•			•		•	•	•	To .6 (2)
Epipremnum aureum, golden Pothos	•						•		•			•		To .9 (3)
Fatshedera lizei, 'Pia,' aralia ivy				•	•	•			•			•		To .9 (3)
Ficus pumila, creeping fig		•					•		•			•		To .6 (2)
Hedera canariensis, Algerian ivy				•	•	•			•		•	•		To .9 (3)
Hedera helix, English ivy				•	•	•			•		•	•		To .3 (1)
Hoya carnosa, Indian rope plant			•			•		•				•		To .9 (3)
Liriope moscari, monkey grass			•		•	•			•		•			To .3 (1)
Maranta leuconeura carolinae Kerchoviana, prayer plant			•				•		•		•			To .25 (.75)
Monstera deliciosa, Mexican breadfruit			•				•		•		•	•		To .9 (3)
Neoregelia carolinae 'Tricolor,' tricolor bromeliad			•				•		•		•			To .3 (1)
Nephrolepsis exaltata 'Bostoniensis,' Boston fern			•			•			•				•	To .6 (2)
Philodendron oxycardium, hearileaf philodendron		•					•		•			•		To .9 (3)
Philodendron panduraeforme, fiddleleaf philodendron		•							•			•		To .6 (2)
Platycerium bifurcatum, staghorn fern			•			•	•		•				•	To .9 (3)
Sanseveria trifasciata 'Hahnii,' bird's nest snake plant	•	•	•	•		•	•		•		•			To .15 (.5)
Stephanotis floribunda, Madagascar jasmine		•					•		•			•		To .9 (3)
Syngonium podophyllum 'Noack White,' Noack White nephthytis		•					•		•		•		•	To .6 (2)
Tradescantia fluminensis, wandering Jew		•				•		•						To .15 (.5)

Disturbed Landscapes

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CONTENTS

1.0 INTRODUCTION

A disturbed landscape is any portion of land surface that has been drastically altered and is not in an attractive, stable, or productive condition. Disturbed lands are extremely vulnerable to erosion, and they may have surfaces unsuitable for plant growth because of compaction, steepness, stoniness, infertility, phytotoxic chemicals, acidity, alkalinity, or instability. Floods, fire, volcanic eruption, agriculture, mining, highway construction, overuse, and land development are examples of natural events and human activities which create disturbed landscapes.

1.1 Problem of Erosion

The impact of a particular land disturbance is rarely limited to the altered site. Soil erosion is inevitable on disturbed landscapes and will significantly affect downstream waters. The U.S. Environmental Protection Agency (EPA) reports that sediment yields from areas undergoing construction are 20 to 40,000 times greater than from undisturbed woodlands. Each year in the United States, 3 600 billion kg (4 billion tons) of soil erode from the land. Sediment accounts for more than 2/3 of all pollutants entering U.S. waterways. Estimates indicate up to $13 billion per year is spent in the U.S. to directly mitigate the off-site impacts of erosion and sediment. Sediment adversely affects recreational areas, aquatic life, and domestic water supplies.

Soils develop slowly through complex organic and inorganic processes. One hundred years are required for the formation of 25 mm (1 in) of topsoil in typical subhumid regions. In arid regions and high-altitude areas, where natural processes are much slower than in humid regions, 1000 years may be required. Topsoil is clearly a most valuable and limited natural resource which has to be managed with great care and responsibility.

In response to this increasing environmental awareness, important legislation has been drafted to help control the problems of erosion and water pollution. The U.S. federal government passed the National Environmental Policy Act in 1969 and later passed Public Law (PL) 92-500, an amendment to the Federal Water Pollution Control Act Amendments of 1972. In 1972, the Federal Clean Water Act established the National Pollutant Discharge Elimination System (NPDES) permit system. This amendment encourages states to establish regulations to control non-point sources of water pollutants. Public Law (PL) 95-87, the Surface Mining Control and Reclamation Act (SMCRA) of 1977, created the Office of Surface Mining. These two acts set out a variety of specific requirements, but their common goal is to limit erosion and return the landscape to a stable and productive condition. Since SMCRA, a variety of other laws have been enacted that ultimately impact large scale disturbance activities and include: Water Quality Act of 1987 which outlined the National Stormwater program; Hazardous and Solid Waste Amendments to RCRA (1984) and RCRA, subtitle D (1991) which called for minimum nationwide standards for protecting human health and the environment and provided technical support to states to develop environmentally sound waste management standards; Amendment to the Clean Water Act of 1992 began requiring disturbances greater than 5 acres to obtain a NPDES permit to help identify and quantify releases of pollutants into our watersheds.

Section 640 describes general principles and methods of reclamation useful in accomplishing that goal.

2.0 RECLAMATION PROCESS

Although the basic reclamation process is the same for both existing and proposed landscape disturbances, there are several significant advantages to planning the reclamation prior to the disturbance. Prior planning can limit both on- and off-site impacts, make the operations and use of equipment more efficient, speed up the reclamation process, provide better reclamation conditions, and significantly reduce the costs.

The following steps are essential:

1. Establishing objectives
2. Determining factors that may influence methods of reclamation
3. Selecting appropriate reclamation methods, materials, and developing a plan

2.1 Establishing Objectives

Meeting Government Standards:

The standards established in the United States (and in many other countries) by federal, state, and local governments provide the basis for many reclamation objectives. The standards typically require such measures as returning the ground surface to approximately its original contour, reestablishing vegetative cover to control erosion at a degree equal to predisturbance levels, and covering all acid-forming and other toxic materials. Additional objectives are derived from the land use goals for the disturbed area.

Economic and Social Objectives:

Determining potential uses for any given site may be made by:

1. Identifying uses for which there may be a demand or a need
2. Analyzing proposed uses to confirm the degree of demand or need through a market analysis
3. Analyzing the site to determine engineering and environmental feasabilities
4. Analyzing costs and benefits to determine the return on investment and the social, environmental, and economic consequences of development
5. Creatively applying principles of landscape architecture to achieve efficiencies, maximize benefits, and minimize adverse environmental impacts
6. Organizing public meetings to solicit input from the community

Environmental Objectives:

In addition to economic and social objectives, consideration should be given to such environmental factors as:

1. Water quality
2. Air quality
3. Erosion
4. Aesthetics
5. Wildlife
6. Adjacent areas
7. Long-range productivity
8. Post-disturbance landuse

Evaluation of Objectives:

Objectives should be specific and quantifiable. They must be realistic and matched to acceptable risks and reasonable costs. For example, it is possible to:

1. Determine the amount of erosion which will occur on a disturbed site during certain high-precipitation events.
2. Determine the frequency of these events and establish the risk for any given year.
3. Determine the loss and damage which would result from the event.

Table 640-1. SOIL MATERIAL SUITABILITY FOR SALVAGE AND RECLAMATION USE.

	Levels of suitability by soil group*			
Major parameters	GOOD	FAIR	POOR	UNSUITABLE
USDA soil texture	Fine sandy loam, very fine sandy loam, loam, silt loam, sandy loam	Clay loam, sandy clay loam, silty clay loam	Sandy, loamy sand, sandy clay, silty clay, clay	Clay-textured soils with more than 60% clay
*Salinity, mmhos**/cm*	<3	3-6	6-9	>9
Alkalinity (exchangeable sodium percentage, ESP)	<4	4-8	8-12	>12
Concentration of toxic or undesirable elements; i.e., boron, selenium, arsenic, % lime, etc.	Very low	Low	Moderate	High
Soil pH	6.1-7.8	5.1-6.1 7.9-8.4	4.5-5.0 8.5-9.0	<4.5 >9.1
Additional parameters to be evaluated				
Moist consistency	Very friable, friable	Loose, firm	Very firm, extremely firm	
Coarse fragments, % by volume	0-10	10-20	20-35	>35
Available water-retention capacity, mm/mm (in/in)	>0-400 (0-16)	2-4 (0.08-0.16)	<2 (<0.8)	
Permeability, mm/hr (in/hr)	15-150 (0.6-6.0)	5-15 (0.2-0.6)	<5 or >150 (<0.2 or >6.0)	
Organic matter, %	>1.5	0.5-1.5	<0.5	
Soil structure	Granular, crumb	Platy, blocky	Massive, single grain	

* Ratings may be raised one class if soil amendments or management practices can be applied to overcome the limitations.
Source: From USDA Forest Service, *User Guide to Soils: Mining and Reclamation in the West,* General Technical Report INT-68, Intermountain Forest and Range Experiment Station.
** millimoles per cubic meter

4. Design features to mitigate erosion and siltation from the event.
5. Determine the cost of mitigation measures and compare these with anticipated damages and projected benefits.

   If the costs exceed the damages or benefits, then the project and its objectives should be reexamined.

2.2 Factors Influencing Methods of Reclamation

The key to successful reclamation begins with a basic knowledge of the site and the nature of the disturbance.

There are many site factors that influence the various methods of reclamation, including: (1) existing soil characteristics, (2) existing vegetation, (3) annual and seasonal precipitation, (4) temperature extremes, (5) evapotranspiration rate, (6) wind, (7) growing period, (8) slope, (9) aspect, (10) elevation, (11) drainage patterns, and (12) animal, insect, and human behavior patterns.

This section primarily addresses the first two of these factors because of their critical importance in all reclamation projects. The other factors, however, could prove to be of equal or even greater importance in some circumstances, depending on the region and its climactic characteristics, etc.

It is often the interaction of these factors that is most critical when working with disturbed sites. One or more of these factors may be in an extreme condition; e.g., the soil might be extremely dry or extremely wet, very high in acidity, very low in organic materials, and part of a steep, unstable slope.

In most parts of the world and on most projects, the two fundamental aspects of reestablishing a disturbed landscape are: (1) to provide a viable growing medium (soils, water, suitable slopes, etc.) and (2) to select or encourage appropriate vegetation.

Soil Characteristics:

Soil Mapping- The Natural Resource Conservation Service (NRCS) in the United States (or its equivalent in other countries) has general soil maps for most areas. Most of this mapping is considered reconnaissance level, or Order 3, mapping. Order 3 mapping refers to map scales of 1:12,000 to 1:250,000 or smaller with minimum delineations on the order of 4 ha (10 acres). Order 2 mapping refers to scales of 1:12, 000 to 1:31,680 with minimum delineations of 0.6 to 4 ha (1.5 to 10 acres). Order 1 mapping refers to scales of less than 1:12,000 and is used for mapping complex areas or where there is a scarcity of topsoil.

Soil Testing- Soil tests provide the fundamental information needed to select measures for establishing vegetation. Important soil characteristics which can be identified by field observation include: horizon thickness, lithology, color, texture, structure, coarse fragments, consistency, hardness, root distribution, presence of lime, presence of soluble salts, and kinds of vegetation. Lab analysis determines: texture, dispersion, weatherability, water retention capacity, saturation percentage, hydraulic conductivity, nutrient content, trace elements, and pH (if pH is greater than 7 or less than 6, additional tests are run for salinity, sodicity, or acidity, respectively). Lab tests for toxicity determine the presence of elements such as boron, molybdenum, selenium, aluminum, iron pyrite, and manganese.

In mining, borehole data is invaluable in determining the amount and character of soil materials. When the mine plan and the reclamation plan are integrated, the most efficient use of equipment and operations results.

Table 640-1 provides data on soil suitability for salvage and reclamation use. Suitability, as used in this table, refers to the qualities and properties of natural soils or to soil materials that chemically and physically provide the necessary water and nutrient supply for the top growth and root development of plants. The ratings are indicators of the potential quality of natural soil profiles, certain soil horizons, or the underlying parent material, disregarding nutrient levels.

Vegetation:

Another critical factor influencing methods of reclamation is the selection and/or encouragement of appropriate vegetation. Listed below are typical conditions most often considered unfavorable for establishing vegetation on a disturbed landscape.

1. Soil materials on very steep, droughty, or unstable slopes
2. Shallow or stony soils with too little silt, clay, and humus to serve as reservoirs for plant nutrients and soil moisture
3. Strongly acid, strongly alkaline, or high-salt soils
4. Soil materials containing reactive pyrite (FeS_2), which oxidizes to form sulfuric acid (H_2SO_4)
5. Soils with toxic materials such as soluble copper, aluminum, or manganese
6. Soils very low in available nitrogen and phosphorus
7. Wet and ponded soils
8. Very high rainfall or very low and uncertain rainfall
9. Active frost heaving
10. Absence of essential Rhizobium (legume) bacteria and mycorrhizal fungi and other beneficial microorganisms

The U.S. NRSC soil surveys contain vegetation data for various site types. Additional site descriptions provide a detailed breakdown by species and include other relevant data. Where difficult or unprecedented soil conditions exist, on-site test plots should be specified to determine the response of selected plants to proposed reclamation techniques.

Other Considerations:

The U.S. Weather Service (and similar agencies in other countries) publish climatological data, and U.S. Geological Survey maps provide data needed to determine slope, aspect, elevation, and drainage patterns. Information on animals, insects, and human behavior patterns may be obtained through the NRCS, state fish and game departments, local universities, local governments, and knowledgeable area residents.

2.3 Selecting Appropriate Reclamation Methods, Materials, and Developing a Plan

The actual methods used to reclaim disturbed landscapes will vary somewhat from region to region, depending on the many differences involved between basic site factors. The overall reclamation process, however, remains the same and includes the following elements:

1. Protection of soil, water quality, wildlife, and adjacent undisturbed areas
2. Landshaping and stratigraphy
3. Surface conditioning
4. Planting
5. Establishment and maintenance of vegetation

Each of these elements is covered separately and in more detail in 3.0 of this section.

3.0 PROTECTION OF SOIL, WATER QUALITY, AND ADJACENT UNDISTURBED AREAS

Principles and basic measures of controlling and limiting the effect of disturbances include:

1. Carefully limiting the size of disturbances during construction by indicating them on the plans and by using barricades and boundary markers on-site
2. Correcting unstable conditions by removing problem areas and by constructing walls
3. Protecting disturbed surfaces from erosion as soon as possible by covering, mulching, and seeding
4. Keeping storm runoff velocities low by roughening surfaces and by constructing check dams
5. Protecting disturbed surfaces from storm runoff by constructing diversion ditches, dikes, and conduits
6. Retaining sediment on-site by constructing sediment ponds, silt fences, and filter boxes, and by using chemical flocculents
7. Ensuring the soil surface has adequate roughness to lessen the impacts of overland water flow and sediment transport (the rougher the better)

Figures 640-1 through 640-10 illustrate various ways to limit erosion on disturbed landscapes. Table 640-2 is a checklist of sediment control measures.

KEY POINTS: Reclamation Process

In reclaiming a disturbed site it is essential to establish objectives, determine factors influencing methods of reclamation, select the appropriate reclamation methods and materials, and finally develop a plan.

1. Successful reclamation begins with a basic knowledge of the site and the nature of the disturbance. Understanding existing soil characteristics and vegetation are two site factors that are of critical importance in all reclamation projects.
2. Other site factors that may influence the methods of reclamation are: precipitation, temperature, evapotranspiration rate, wind, growing period, slope, aspect, elevation, drainage pattern, and animal, insect, and human behavior.
3. The two fundamental aspects of reestablishing a disturbed landscape are to provide a viable growing medium (Table 640-1) by managing soil disturbance to prevent erosion and to select or encourage the appropriate vegetation that will stabilize the soil (Table 640-4).

3.1 Use of Sediment and Erosion Control Devices

One of the objectives of any revegetation or erosion control plan should be to stabilize soils and manage erosion and sediment deposition in an economical manner. Project managers and key decision makers are often hard pressed to reclaim disturbed sites at a minimum cost. Given site conditions such as slope angles, climate, runoff, soil condition and end land use, a specifier must select with confidence a technique he/she feels will perform up to expectations at the lowest cost. Frequently the selection of appropriate sediment and erosion control techniques, in combination, may provide the greatest opportunity for success (Figure 640-1).

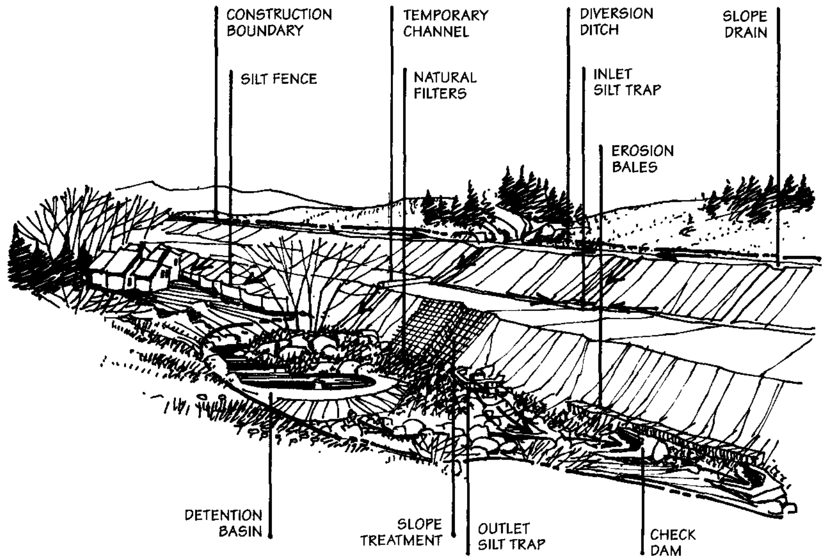

Figure 640-1. Methods of limiting disturbance to site.

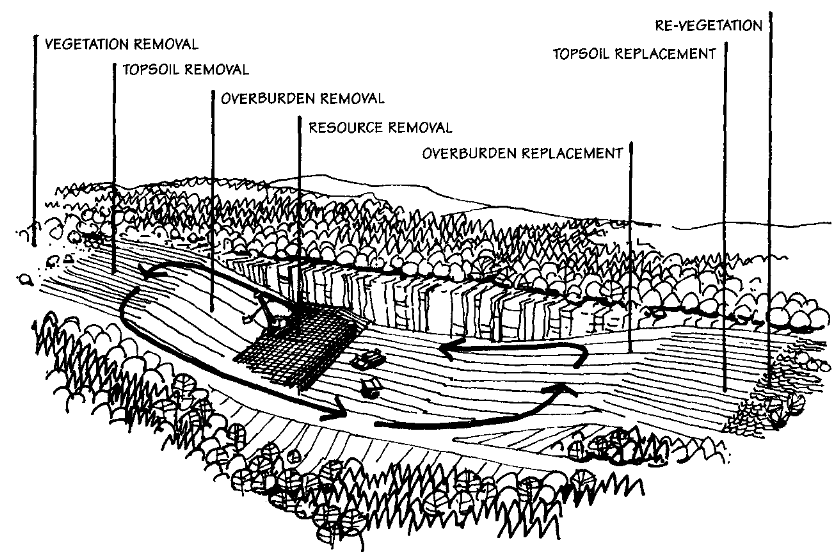

Figure 640-2. Soil haulback method.

Sediment Control Techniques:

Sediment basin - Sediment basins are ponds created by excavation that are usually temporary in design and are intended to collect and store sediment from sites that are cleared and/or graded during construction. Frequently these sites are left exposed for extended periods of time before either permanent vegetation is reestablished or permanent drainage structure completed. Basin construction is intended to trap sediment before it leaves the disturbed site. Since sediment basins are temporary, they must be maintained until the disturbance area is permanently stabilized (Fig. 640-6).

Straw bale dikes - Straw bale dikes intercept and detain small amounts of sediment transported by sheet and rill type runoff. The dikes trap sediment by ponding water and allowing sediment to settle out. Straw bale dikes also slow runoff velocities, acting to reduce sheet, rill and gully erosion. Straw bale dikes may also be used to reduce erosion and sedimentations around the disturbance area perimeter (Figure 640-7).

Silt fence - A silt fence is a temporary polypropylene sediment barrier placed on the slope contour to trap sediment by ponding water behind it and allowing sediment to settle out. Silt fence can effectively trap sheet and rill erosion within small drainage areas and on slopes with gradients up to 2:1. Silt fence is most cost effective when used for sediment and erosion control around the perimeter of a disturbance area.

Gravel bag structures - Similar to straw bale dikes and silt fence, gravel bag structures are temporary structures used along construction perimeters or within flow channels to trap sediments and/or slow runoff velocities. Bags are constructed of burlap or polypropylene, filled with suitable material (sand or sediments) and placed or stacked on the soil surface to create a continuous berm.

Continuous berms - A continuous berm is a temporary diversion or sediment barrier constructed with infill material and used to divert and intercept sheet runoff. Continuous berms are useful for erosion and sediment control around the perimeter of construction sites. The berms detain and pond sediment laden stormwater, resulting in sediment deposition.

Rock check dams - Check dams are rock dams constructed across drainageways to dissipate the energy of flowing water and reduce gully erosion. They are temporary stabilization structures that are used until the drainageway is permanently stabilized. Check dams are used in ephemeral streams to reduce flow velocities, trap and store larger-sized sediment and provide stabilized drops.

3.2 Erosion Control Technologies

It is important to make a distinction regarding the intended use of erosion and sediment control materials. For many installations, vegetation alone will provide adequate long-term erosion protection. However, getting vegetation established requires a variety of techniques. Materials of a temporary nature which facilitate vegetative establishment, then degrade, are called temporary erosion and revegetation materials.

As previously discussed, these temporary materials consist of degradable natural and/or synthetic components which provide temporary erosion control and aid in the growth of vegetation. In only a few instances are temporary products totally organic. Vital geosynthetic components include nettings, stitchings and adhesives. These short-term materials degrade leaving only vegetation.

Temporary techniques include the use of straw, hay and hydraulic mulches, tackifiers and soil stabilizers, hydraulic mulch geofibers; erosion control nets, meshes, blankets, bonded fiber matrices and fiber roving systems.

Site conditions requiring the higher performance of reinforced vegetation or revetment systems will require permanent erosion and revegetation materials. Permanent materials may be subdivided into biotechnical composites™ when vegetation is reinforced or hard armor systems when nonvegetated inert materials are installed.

Biotechnical composites™ are composed of non-degradable materials which furnish temporary erosion protection, accelerate vegetative growth and ultimately become entangled with living plant tissue to extend the performance limits of vegetation.

Reinforced vegetation provides a permanent moderate-to-high flow resistance when biotechnical composites are protected from sunlight by shading from vegetation and soil cover.

Examples of biotechnical composites include UV stabilized fiber roving systems; erosion control revegetation mats; turf reinforcement mats; permanent erosion reinforcement matrices; soil and sports turf geofibers; vegetated geocellular containment systems; and vegetated concrete block systems. Hard armor systems generally employ inert materials used to provide high to maximum flow resistance where conditions exceed performance limits of reinforced vegetation systems. Hard armor systems also are used to provide permanent erosion protection of areas subject to high flows, wave action and/or scour attack. Examples include geocellular containment systems; fabric formed revetments; concrete block systems; gabions, riprap, composites and hybrids.

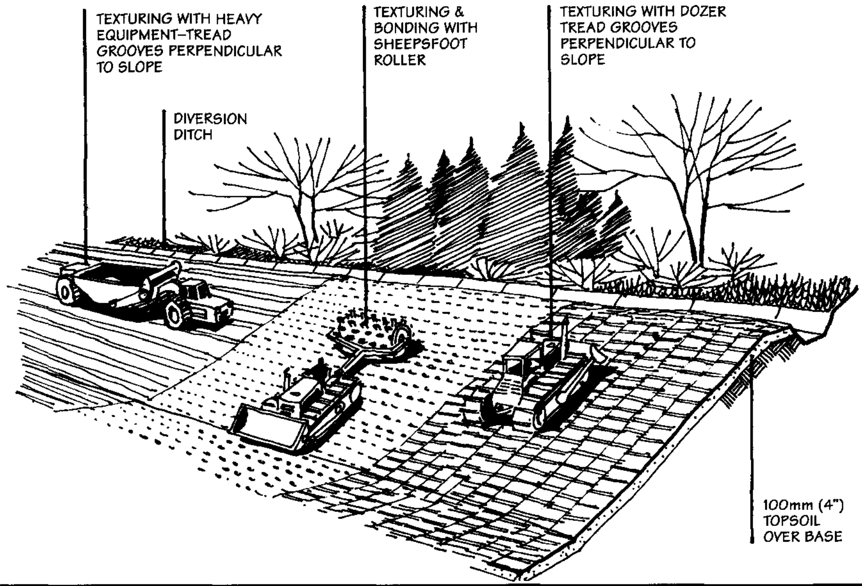

Figure 640-3. Methods of roughening slopes to slow runoff.

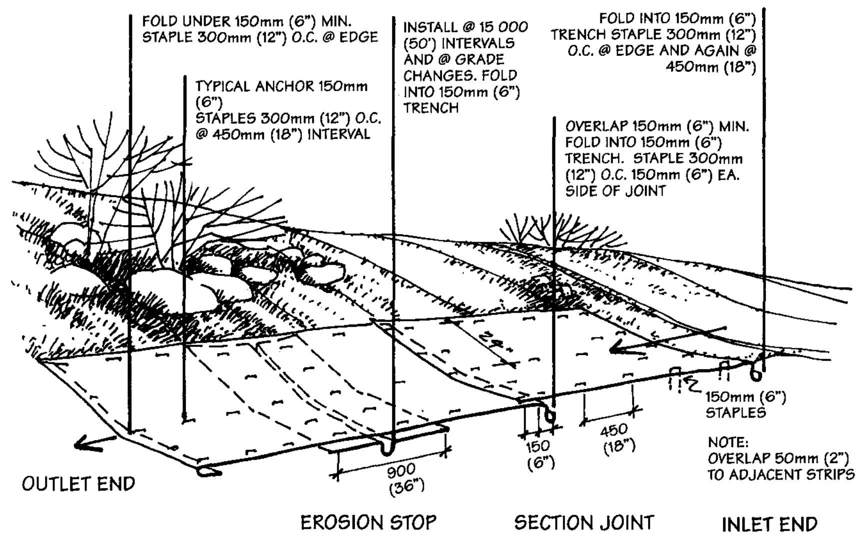

Figure 640-4. Methods of installing jute in drainage way.

3.3 Temporary Degradable Materials

Mulches-Mulch applications include the use of straw or hay that is blown or hand spread onto the surface, hydraulically applied mulches from recycled paper, virgin wood fiber, or a blend of both.

Straw or hay mulch must be anchored into the soil immediately to minimize loss by wind or water. Straw/hay mulch is anchored by crimping, tracking, disking, punching, netting or gluing. Gluing can be accomplished with a variety of organic and acrylic tackifiers.

Recycled paper mulch is made from newsprint, magazines and other waste paper sources. Wood fiber mulch is manufactured from wood waste and the mulch blend is comprised of 70% wood fiber and 30% paper fiber. The hydraulic mulch is mixed in a hydraulic application machine (hydroseeder) and applied as a liquid slurry which contains the recommended rate of seed and fertilizer for the site. Often hydraulic mulches are manufactured containing a tackifier to anchor the material to the soil surface.

Tackifiers-Tackifiers are typically used to anchor or glue mulch or straw to increase their effectiveness for erosion control, thus resisting movement by wind or water. Some tackifiers such as those made from polymers, plant muselage or guar are extremely important to lubricate the slurries and increase application efficiency and performance. Liquid co-polymers and natural products, to a limited extent, can also be specified alone to control erosion and dust, and stabilize the soil surface.

Biaxially oriented process nets - Biaxially oriented process nets are typically manufactured from polypropylene or polyethylene resins. These nets are extremely versatile in that composition, strength, elongation, aperture size and shape, color and ultraviolet stability can easily be designed into the product for site-specific requirements. Biaxially oriented nets have proven to be so adaptable they are being used to

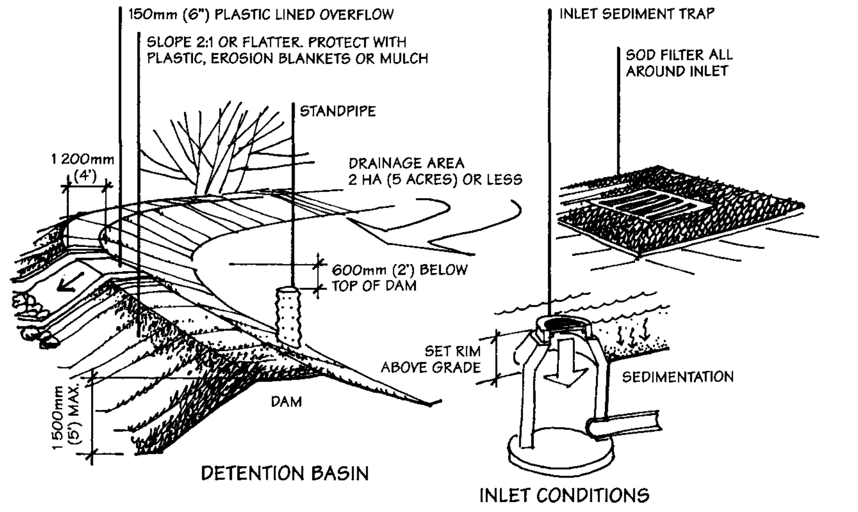

Figure 640-5. Sediment trapping methods.

Table 640-2. SEDIMENT CONTROL CHECKLIST

CONTROL MEASURES PRIOR TO OR CONCURRENT WITH CONSTRUCTION	**CONSTRUCTION OPERATIONS**														
	Clearing and grubbing	*Culverts*	*Channel changes*	*Structures*	*Pier construction*	*Stream crossings*	*Temporary roads*	*Excavation borrow*	*Wasting embankment*	*Subgrade*	*Base coarse*	*Paving*	*Perimeter areas*	*Landscaping*	
Sediment basins															
Check dams															
Filter barriers															
Silt fence															
Continuous berm															
Gravel bag structures															
Diversion dikes and ditches															
Berms															
Slope drains															
Seeding, mulching, and netting															
Mulching (hydraulic and/or straw)															
Soil binders															
BFM's															
FRS's															
Sodding															
Natural Erosion Control Blankets															
Synthetic soft armor															
Ditch paving															
Slope paving															
Rip-rap (and other Hardarmor Systems)															
Other															

Source : Modified from the Colorado Department of Highways, I-70 in a Mountain Environment - Vail Pass, Colorado, Denver, Colorado.

create more complex products and are even used alone to anchor loose fiber mulches such as straw, hay and wood chips. The lightweight nettings placed over mulches come in rolls which are 3 000 to 4 500 mm (10-15 ft) in width, weight only about 55 kilograms (120 lbs) and will cover 0.4 hectare (one acre) or more. Installation of these products is less labor intensive than traditional nettings products.

Bonded fiber matrix systems- Bonded fiber matrices (BFM's) are hydraulically applied systems that conform to the soil surface and are used on steep slope applications. Once dry, the matrix forms a blanket of continuous 100% coverage which adheres to the soil. The resulting blanket is water insoluble which means it can be re-wet repeatedly and will hold soil and seed without washing away.

Bonded fiber matrices are fully biodegradable and are comprised of wood fibers, organic tackifiers and mineral bonding agents or may have a wood fiber-gypsum component. As vegetation takes hold, bonded fiber matrix systems slowly decompose. Polypropylene geotextiles may be added to BFM's to further enhance tenacity and performance.

Fiber roving systems- Developed in the late 60's, rovings are applied in a continuous strand for protection of drainage swales and slopes.

Fiberglass roving is a material formed from fibers drawn from molten glass and gathered into strands to form a single ribbon. Polypropylene roving is formed from continuous strands of fibrillated yarns wound onto cylindrical packages such that the material can be fed continuously from the outside of the package. Use of fiberglass roving has been declining and is being displaced by more versatile "environmentally friendly" polypropylene roving.

Erosion control roving is unusual because of the flexibility of application, allowing for any width or thickness of material to be applied. Other erosion control materials, such as blankets or mats require the user to apply the width or thickness of material supplied. Fiber rovings may be viewed as an "*in situ*" erosion control geosynthetic with reduced labor and material costs over traditional blanket materials. The continuous strand concept provides ease of installation with minimal waste factors from overlap.

Using compressed air, roving is rapidly applied through a nozzle over the seeded surface and then anchored in place using emulsified asphalt or other natural or synthetic soil stabilizers. Photobiodegradable polypropylene roving may be used for temporary applications or when UV stabilizers are added for extended use situations.

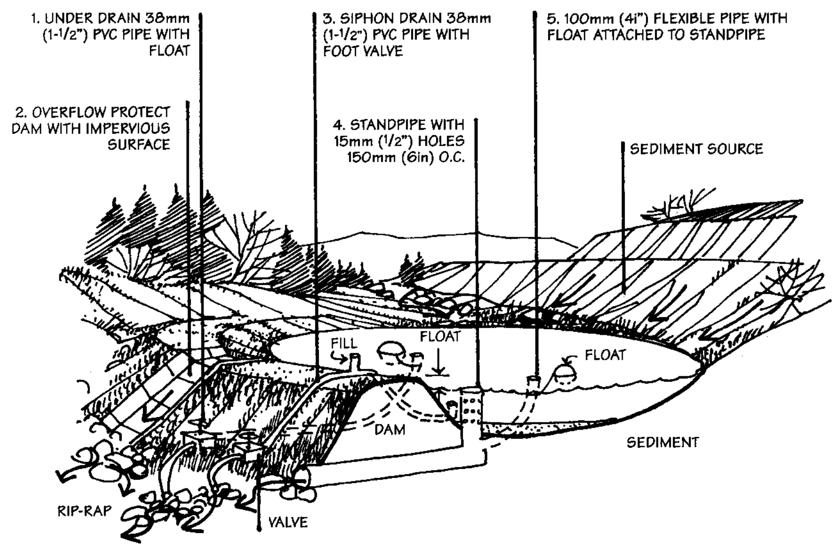

Figure 640-6. Alternative sediment basin drain methods.

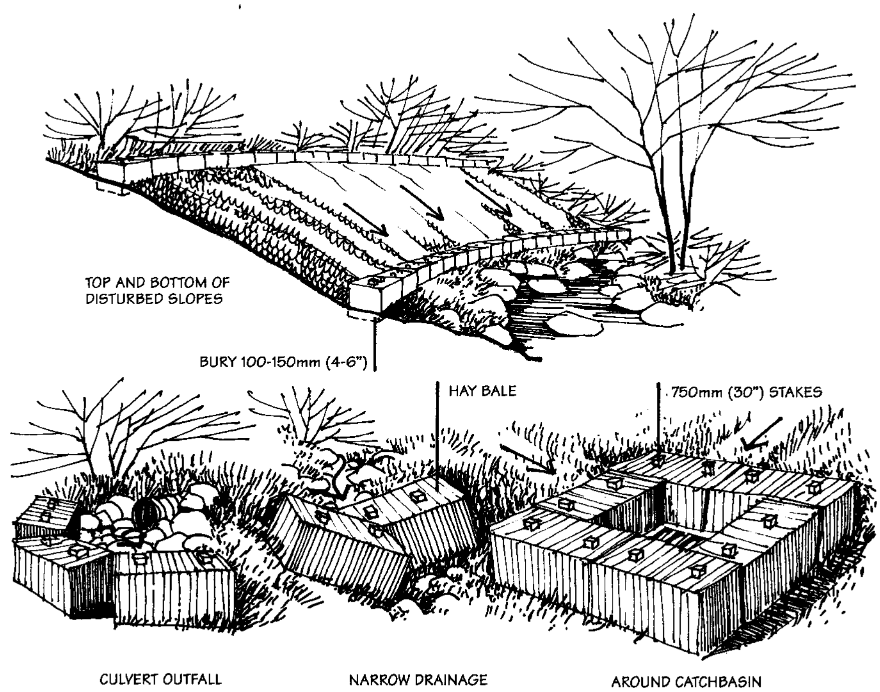

Figure 640-7. Sediment control methods using erosion bales.

Erosion Control Blankets/Mats- Temporary erosion control blankets are used to stabilize and protect disturbed soils from rainfall impact and surface erosion, to increase infiltration, decrease composition and soil crusting,to conserve soil moisture, to keep seed in place and to increase plant germination (Figure 640-4). Biaxially oriented nettings or woven meshes of varying characteristics are placed on one or both sides of finely tuned erosion control blankets adapted to anticipated site conditions. These one to two meter wide biodegradable fiber erosion control blankets are composed of straw, excelsior, cotton, coconut, polypropylene or blends. Nettings or meshes may contain ultraviolet (UV) stabilizers for controlled degradation or long chain interrupters to accelerate photodegradation. Additionally, nettings can be manufactured with 100% biodegradable natural materials. Colors vary from clear, tan, green to black. Methods of holding the fibers in place range from glues and glue strips to more superior parallel lock stitching with cotton, polyester or polyolefin threads. Applications for the wide variety of blankets range from protection of gradual slopes to low flowing channels. The top of the line natural blankets may provide temporary resistance to short duration flow velocities of up to nearly three meters (10 ft) per second.

Perhaps most advantageous to the environment, these meshes and blankets may ultimately become biodegradable. As photodegradation progresses, the plastic chains associated with the natural blankets break into shorter and shorter segments down to a plastic "sand" which becomes part of the soil. These short segments become biologically degradable and are attacked by soil microorganisms and converted to carbon dioxide and water. The natural components within the netting biodegrade and ultimately increase soil fertility. Fully biodegradable natural blankets not constructed with synthetic netting include coir and jute materials.

Open weave polypropylene geotextiles can provide comparable performance to natural fiber erosion control blankets. These photobiodegradable, natural looking, high strength polypropylene meshes protect the soil surface from water and wind erosion while accelerating vegetative development, and are available in 38 000 mm (12½ft) wide light weight rolls suitable for slopes and channel installation. Erosion control meshes may be used alone, with dry mulches or as a stabilizing underlay for sod reinforcement. They also show promise as an open weave geotextile facing for fostering vegetation on geosynthetically reinforced steepened slopes or bioengineering installations where establishment of woody plant species is desired. Displaying rapid photobiodegradation in one direction, these meshes allow woody vegetation to freely sprout and emerge through the installation with little potential of girdling.

When project sensitivity requires the use of a fully biodegradable material, natural coir (coconut) matting can be utilized for shoreline stabilization, streambank protection and other bioengineering applications where woody plant establishment is desirable. This durable material of high tensile strength typically last 4-10 years allowing ample time for vegetation establishment. Presumably these products cannot withstand shear stresses equivalent to select synthetic turf reinforcement materials, however they are tested to withstand flow velocities between 2-3.1m/sec (6-10 ft/sec). Logs made of flexible coir material are also used to effectively manage the changes in stream flow velocity, provide channel and shoreline stabilization, and a planting medium for vegetation.

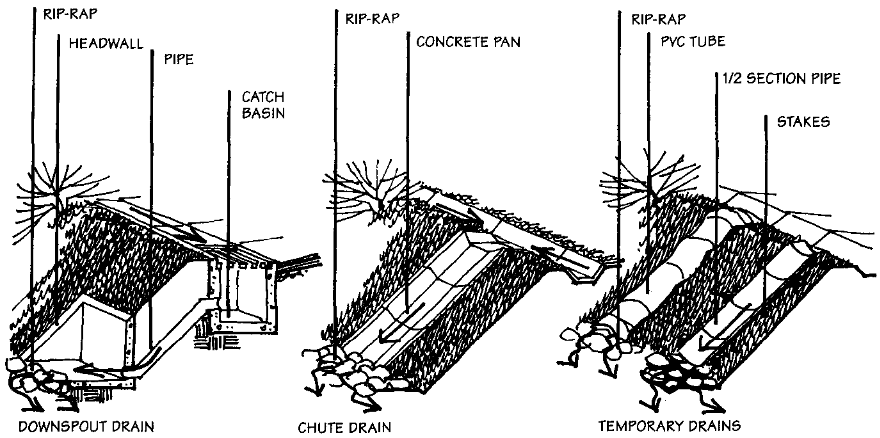

Figure 640-8. Slope drain methods.

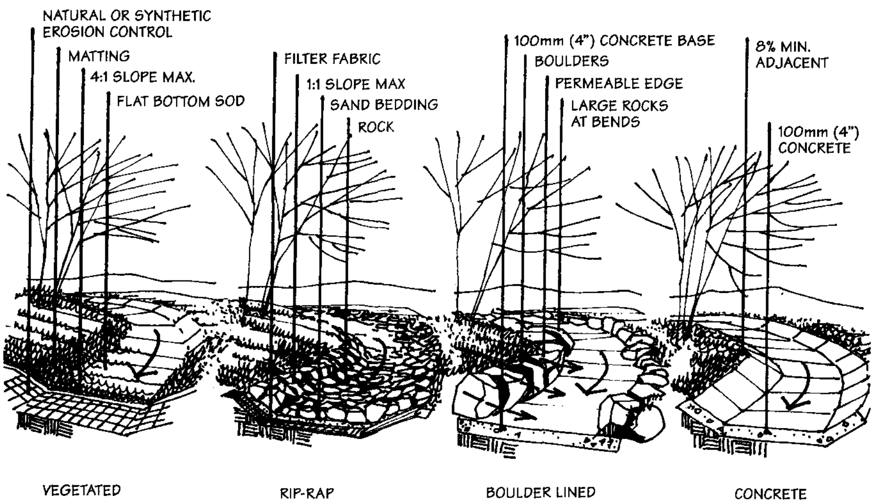

Figure 640-9. Drainage channel methods.

3.4 Turf Reinforcement Mats

Turf reinforcement is a method or system by which the natural ability of plants to protect soil from erosion is enhanced through the use of geosynthetic materials. A flexible three-dimensional matrix retains seeds and soil, stimulates seed germination, accelerates seedling development and most importantly, synergistically meshes with developing plant roots and shoots. In laboratory and field analyses, biotechnically reinforced systems have resisted flow rates in excess of 4.2m/sec (14 ft/sec) for durations of up to two days, providing twice the erosion protection of unreinforced vegetation.

Such performance has resulted in the widespread practice of turf reinforcement as an alternative to concrete, riprap and other armor systems in the protection of open channels, drainage ditches, detention basins and steepened slopes.

Permanent turf reinforcement mats are composed of durable synthetic materials that are stabilized against ultraviolet degradation and inert to chemicals normally encountered in a natural soil environment. These mattings consist of a lofty web of mechanically or melt bonded polymer nettings, monofilaments or fibers which are entangled to form a strong and dimensionally stable matrix. Polymers include polypropylene, polyethylene, nylon and polyvinyl chloride.

Specific turf reinforcement mats have been developed for the most critical applications and are frequently referred to as permanent erosion reinforcement matrices. Having a very high coefficient of friction with soil, reinforcement matrices complement vegetation and provide long-term performance in channels and on slopes under the most adverse conditions. These three-dimensional permanent erosion reinforcement matrices provide unparalleled strength and dimensional stability. Due to their high strength properties, reinforcement matrices may be used as a form which is filled with concrete or grout to create an inexpensive hard armor system.

High strength turf reinforcement mats provide sufficient thickness and void space to permit soil filling/retention and the development of vegetation within the matrix. Turf reinforcement mats are installed first, then seeded and filled with soil.

Seeded prior to installation, erosion control revegetation mats are dense, lower profile mats designed to provide long-term ground cover and erosion protection. Erosion control revegetation mats provide superior temporary erosion protection.

By their nature, permanent erosion reinforcement matrices and turf reinforcement mats can be expected to provide more vegetation entanglement and long term performance than erosion control revegetation mats.

3.5 Hard Armor Systems

Geocellular containment systems - Geocellular containment systems work in a unique fashion in that strength or stabilization by confinement is achieved by a series of three-dimensional cells up to 200 mm (8 in) deep. When expanded into position, the polyethylene or polyester cells have the appearance of a large honeycomb, one of nature's most efficient structures. The cells are then backfilled with soil, sand, gravel, or rock depending upon application. For vegetation, the soil-backfilled cells are seeded, fertilized and covered with a variety of either temporary or permanent erosion control mulches that provide surface protection while the cells greatly reduce the chances of subsurface failure and act as a deeper rooted biotechnical composite. Shallow lateral root development is limited by the geocell walls. Vegetated geocellular systems withstand flow velocities of 1.8-2.4m/sec (6-8 ft/sec).

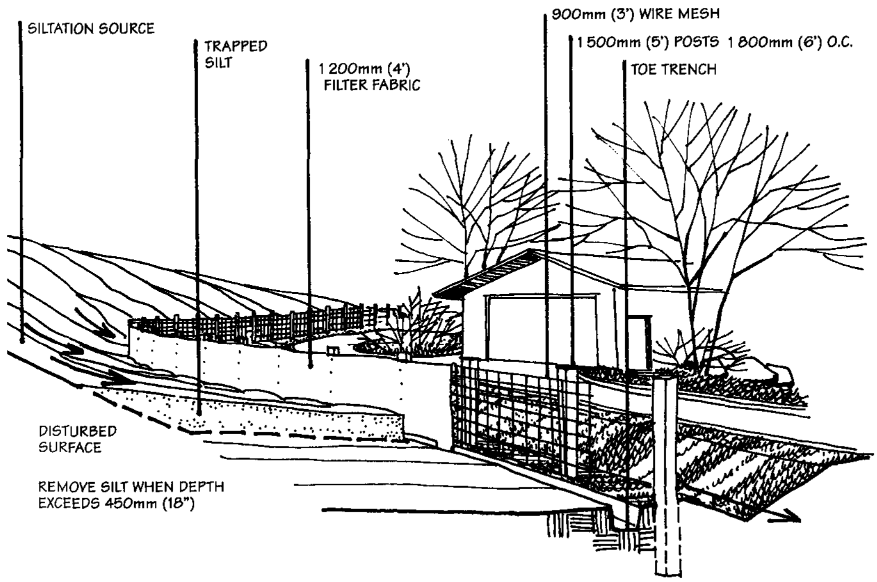

Figure 640-10. Filter fence method for trapping silt.

For higher flow conditions, geocellular containment systems may act as an easy to install form which is filled with concrete or grout to create a hard armor system. Typically a geotextile will be placed beneath the expanded web to provide separation and/or filtration. Erosion control applications for geocellular containment systems are many, including: steep slope revegetation, channel liners, shoreline revetments, retaining walls, boat ramps, and low flow stream crossings.

Fabric formed revetments - Fabric forming systems are mattresses typically constructed of water permeable, double layer woven geotextiles which are positioned on the area to be protected and filled with a pumpable fine aggregate concrete (structural grout). The two layers of geotextile are joined at discrete points to create a form which when filled with grout will conform to most subsoil conditions. Thickness and geometry are determined by internal spacer threads woven into the upper and lower sheets of fabric. In many cases the mattresses may be installed for less cost than conventional armor systems since all construction is conducted in place with no heavy equipment or skilled labor required.

Fabric formed revetments are generally available in three styles: filterpoint, uniform section, and articulating block mats. Filter point mats are formed with a double-layer woven fabric, joined together by interwoven filter points which relieve hydrostatic pressure. Uniform section mats are formed with a double-layer woven fabric, joined together by spacer cards on closely spaced centers. Relief of hydrostatic uplift pressure may be provided by inserting plastic weep tubes through the mat at specified centers. Articulating block mats are formed with a double-layer woven fabric, joined together into a matrix of rectangular compartments each separated by a narrow perimeter of interwoven fabric.

High strength cables may be threaded between the two layers of fabric to interconnect the concrete filled compartments (blocks), and provide for block articulation. Hydrostatic pressure relief is achieved by slits cut between adjacent blocks and/or inserting plastic weep tubes. A filtration geotextile is recommended beneath all fabric formed revetments.

Concrete block systems - Concrete block systems consist of prefabricated concrete panels of various geometries which may be attached to and laid upon a woven monofilament or non-woven geotextile. Bending and torsion are accommodated by having the concrete blocks articulated with joints, weaving patterns or connection devices. Concrete block systems may be subdivided into three groups: non-tied interlocking blocks, cable-tied blocks, and in-situ concrete.

Concrete block revetments incorporate cellular concrete blocks, either open or closed, and are underlain with a properly designed filtration geotextile. The blocks are held on the slope by anchors placed at the top of the slope and/or by friction between the slope and the blocks. The blocks can be assembled into fabricated mats either at the factory or on site. Sections of precabled concrete blocks may be placed by using a special spreader bat, which may lower costs on large projects. The blocks may also be handplaced with or without cable subsequently installed.

Articulated concrete block revetment systems combine the favorable aspects of lightweight blankets and meshes (such as porosity, flexibility, vegetation encouragement, wildlife habitat enhancement, and ease of installation) with the nonerodibility, self weight, and high tractive force resistance of rigid linings. These specially designed interlocking precast concrete grids are a proven cost-effective, aesthetic, and functional alternative to dumped stone rip-rap, gabions, structural concrete, and other heavy-duty, durable channel protection systems. Additionally, these systems offer enhanced flow efficiencies, nurturing of vegetative cover and safe access.

Gabions- Gabions are compartmented rectangular containers made of galvanized steel hexagonal wire mesh or rectangular plastic mesh and filled with hand-sized stone. Cells of equal capacity are formed by factory-inserted plastic or wire netting diaphragms or partitions which add strength to the container and help maintain its shape during the placement of stone. In highly corrosive conditions, a polyvinyl chloride coating is used over the galvanized wire.

Advantages of gabions include flexibility, durability, strength, permeability and economy versus rigid structures. The growth of native plants is promoted as gabions collect sediment in the stone fill. A high percentage of installations are underlain by woven monofilament and nonwoven geotextiles to reduce hydrostatic pressure, facilitate sediment capture and prevent wash out from behind the structure.

Rip-rap - Rip-rap consists of stone dumped in place on a filter blanket or prepared slope to form a well graded mass with a minimum of voids. Stone used for rip-rap is hard, dense, durable, angular in shape, resistant to weathering and to water action;

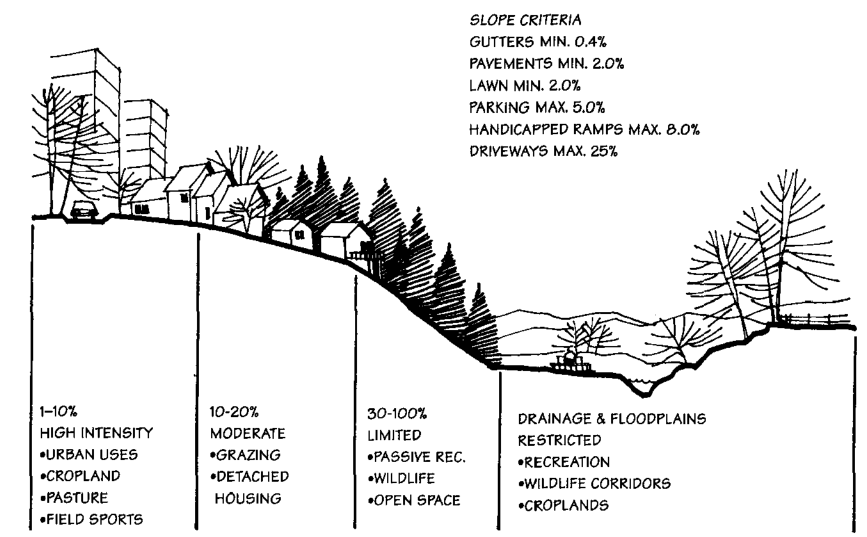

Figure 640-11. Appropriate land use related to slope.

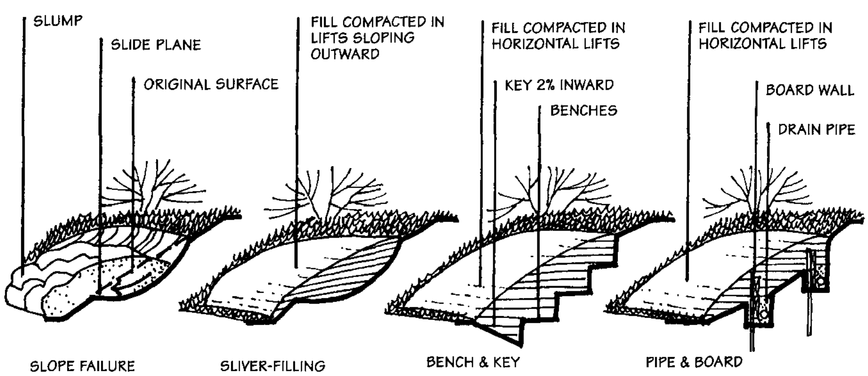

Figure 640-12. Slope failure repair methods.

and free from overburden, spoil, shade and organic material. The rip-rap material is generally placed on a gravel bedding layer and/or a woven monofilament or nonwoven geotextile fabric.

4.0 LANDSHAPING AND STRATIGRAPHY

Landshaping:

The aesthetic character of landshaping is largely dependent upon the proposed land use objectives, but care should be taken to create reasonable slopes. The steeper and longer the disturbed slope, the more difficult it is to reclaim. A general rule of thumb is that as the percent of slope doubles, soil loss increases 2.6 times, and as the length of slope doubles, soil loss increases 3 times. Slopes 3:1 or steeper call for special reclamation measures. In most of these cases, no topsoil is present and compaction is inordinately high.

Figures 640-11 through 640-14 illustrate several considerations and treatments related to reclamation of slopes.

Stratigraphy:

Stratigraphy refers to the layering of subsurface materials. The characteristics of the subsurface structure will have a significant impact on stability, on water holding capacity, and on the effect of buried toxic materials. Toxic materials should be placed as deep as possible in locations unaffected by groundwater. In the United States, Public Law (PL) 95-87 requires a minimum of 1 200 mm (4 ft) of soil cover over acid-generating materials.

The amount of a plant growth medium necessary to establish a stable vegetative community is 450 to 600 mm (18 to 24 in).

This depth is needed to serve as a reservoir, making water available to plants during periods of low precipitation. When the materials below this medium are too porous to retain water, an artificial moisture barrier (plastic, asphalt, or similar material) can be placed between the strata. When placing topsoil on a soil medium, the subgrade should be sufficiently rough to ensure a bond between the two layers.

5.0 SURFACE CONDITIONING

Surface conditioning is concerned with the chemical and physical nature of the top several centimeters (inches) of growth medium.

Topsoil:

Topsoil is the preferred growing medium. The cost of topsoil removal, stockpiling, and replacement is typically less than changing the chemical and physical properties of subsoil to make it suitable as a plant growing medium. Research has shown that neither the age nor the depth of a stockpile will significantly affect the quality of the soil as a growing medium. However, freshly moved topsoil is easier to spread and is an excellent source of viable native seed and other plant propagules. Older stockpiles, if not properly managed, can be a source of undesirable plants.

Unlike subsoil or mining spoils, topsoil contains important soil fauna and bacteria which are active in maintaining aeration, water infiltration, and root penetration and in transforming minerals into forms useful to plants. Moist, well-aerated, warm soils containing organic matter provide the best conditions for this biological activity.

Stabilizing Topsoil:

It is difficult to create a good bond between topsoil and subsoil or to stabilize topsoil thicknesses of more than 75 to 100 mm (3 to 4 in) on slopes greater than 3:1. Stabilization of the topsoil on such slopes is typically accomplished by using a sheepsfoot roller or by ribbing on contour.

Improving Water Retention Capacity:

Soil materials which have little capacity to retain water can be improved by adding organic matter, such as treated sewage sludge, manure, or compost. Sewage sludge is good because it contains nutrients and trace elements essential to plant growth. Application rates are determined by testing for concentrations of various chemicals in order to prevent excess nitrogen from polluting ground or surface

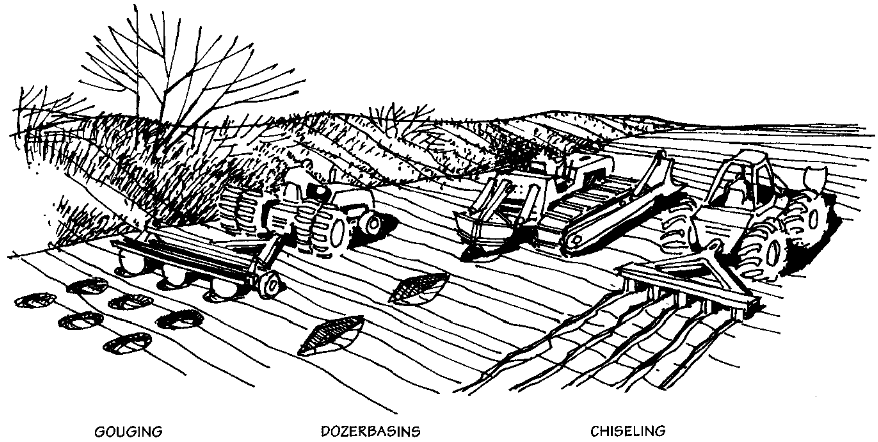

Figure 640-13. Surface-roughening methods of concentrating precipitation.

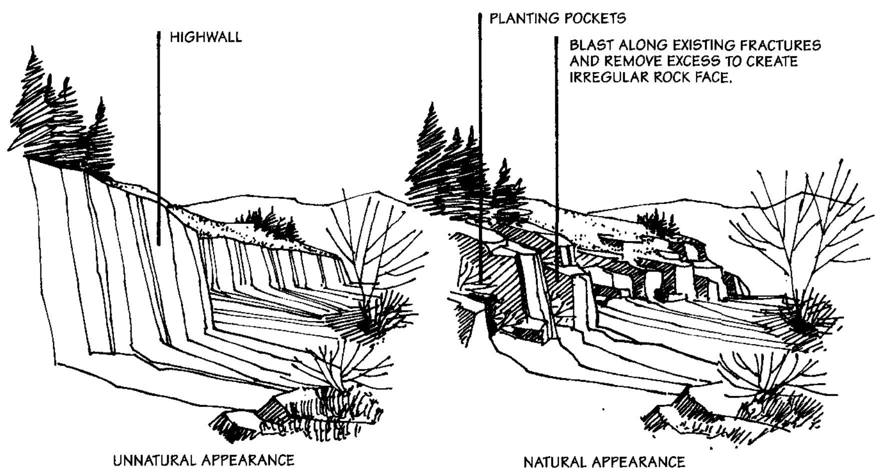

Figure 640-14. Methods of naturalizing highwalls and rock cuts.

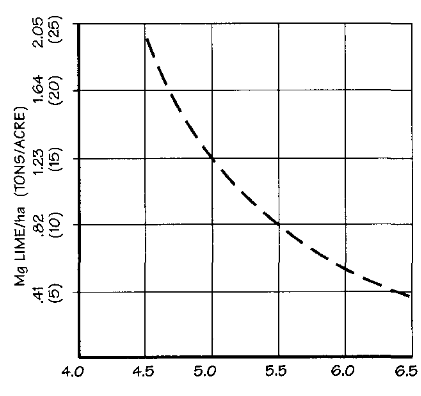

Figure 640-15. *Approximate limestone application rates required to adjust spoil to pH 6.4 for buffer pH readings.*

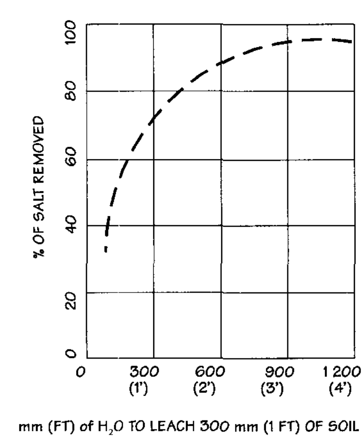

Figure 640-16. *Amount of water required to leach salt from saline soil.*

Table 640-4. GRASSES FOR LANDSCAPE RECLAMATION*

Species	Scientific name	Variety	Eastern to midwestern states	Midwest to western states	Species availability	Seeds per 454 kg (1000 lb)
Drought-tolerant bunchgrass						
Beardless wheatgrass	*Pseudoroegneria spicata ssp. inermis*	Whitmar		X	A	142
Big bluegrass	*Poa ampla*	Sherman, Service, or Canbar		X	A	900
Bluebunch wheatgrass	*Pseudoroegneria spicata*	Secar or Goldar	X	X	A	117
Hard fescue	*Festuca ovina, variety duriuscula*	Durar, Aurora	X	X	A	565
Indian ricegrass	*Oryzopsis hymenoides*	Nezpar or Paloma		X	L	188
Needle and thread	*Stipa comata*			X	L	123
Russian wildrye	*Psathyrostachys juncea*	Sawki, UNS, Bozoisky, or Vinal		X	A	175
Sand dropseed	*Sporobulus cryptandrus*		X	X	L	5,000
Siberian wheatgrass	*Agropyron sibiticum*			X	A	206
Slender wheatgrass	*Elymus trachycaulus*	Native, Pryor, San Luis, Primar, or Revenue	X	X	A	160
Weeping lovegrass	*Eragrostis curvula*	Ermelo or Morpha	X (W)	X	A	1,500
Sheep fescue	*Festuca ovina*	Covar, Mx-86 or Azy	X	X	A	565
Drought tolerant sod forming grasses						
Canada bluegrass	*Poa compressa*	Rubens, Standard, Maverick, Olympic or Safari	X	X	A	2,495
Tall fescue	*Festuca arundinacea*	Pennlawn	X		A	227
Creeping red fescue	*Festuca rubra*			X	A	615
Pubescent wheatgrass	*Elytrigia intermedia*	Greenleaf, UNS, Luna, Mandan		X	A	90
Pubescent wheatgrass	*Elytrigia intermedia*	Topar or Manska	X	X	A	0
Streambank wheatgrass	*Elymus lanceolatus*	Sodar		X	A	170
Intermediate wheatgrass	*Elytrigia intermedia*	Oahe, Rush, Tegmar, Slate or Greenar		X	A	93
Thickpike wheatgrass	*Elytrigia dasystachyam*	Critana		X	L	186
Western wheatgrass	*Pascopyrum smithii*	Arriba, Burton, Native, or Rosana	X	X	A	126
Bermudagrass	*Cynodon dactylon*	Guymon or Hulled	X (W)	X	A	1,787
Timothy	*Phleum pratense*	Climax or Outlaw	X	X	A	1,230
Kentucky bluegrass	*Poa pratensis*	Troy, Challenger, Freedom or 30 other varieties	X	X	A	2,150
Sand stabilizing plants						
Prairie sandreed	*Calamovilla longifolia*	Goshen		X	L	274
Switchgrass	*Panicim virgatum*	Pathfinder, Blackwell, or Nebraska 28	X	X	A	389
Sand bluestem	*Andropogon hallii*	Garden, Elidar, Woodward or Goldstrike		X	L	113
Indian ricegrass	*Oryzopsis hymenoides*	Nezpar or Paloma		X	L	188
Needle and thread	*Stipa comata*			X	L	123
Sand lovegrass	*Eragrostis trichodes*	Bend		X	A	1,300
Beachgrass	*Ammophilia spp.*		X		NA	114
Blowout grass	*Redfieldia flexuosa*		(W)	X	L	263
Sandhill muhly	*Mulhenbergia pungens*		(W)	X	L	614
Acid tolerant grasses						
Canada bluegrass	*Poa compressa*	Rubens	X	X	A	2,495
Perennial ryegrass	*Lolium perenne*	Linn, Moy, or Zero Nui	X	X	A	247
Colonial bentgrass	*Agrostis tenius*	Highland	X	X	A	8,723
Creeping bentgrass	*Agrostis palustris*	Cato or Cobra	X	X	A	7,800
Creeping foxtail	*Alopecurus arundinaceus*	Garrison	X	X	A	400
Hard Fescue	*Festuca ovina, variety duriuscula*	Durar or Aurora	X	X	A	565

Table 640-4. GRASSES FOR LANDSCAPE RECLAMATION* (continued)

Bermudagrass	*Cynodon dactylon*	Guyman or Hulled	X (W)	X	A	1,787
Meadow foxtail	*Alopecurus pratensis*	Garrison	X	X	A	580
Red fescue	*Festuca rubra*	Penn lawn	X	X	A	615
Redtop	*Agrostis alba*		X	X	A	4,990
Switchgrass	*Panicum virgatum*	Pathfinder, Blackwell or Nebraska 28	X (W)	X	A	389
Weeping lovegrass	*Eragrostis curvula*	Ermelo or Morpha	X (W)	X	A	1,500
Alkaline tolerant grasses						
Alkali sacaton	*Sporobulus airoides*	Saltalk or Salado		X	A	1,750
Alkali grass	*Puccinellia lemmoni*	Lemmons, Nuttall, Fults		X	A	1,200
Bermudagrass	*Cynodon dactylon*	Guymon or Hulled	X (W)	X	A	1,787
Foxtail barley	*Hordeum jubatum*		X	X	A	352
Perennial ryegrass	*Lolium perenne*	Linn, Moyou Zero Nui	X	X	A	247
Streambank wheatgrass	*Agropyron riparium*	Sodar	X	X	A	170
Tall wheatgrass	*Agropyron elongatum*	Alkar, Jose	X	X	A	79
Western wheatgrass	*Agropyron smithii*	Arripa, Barton, Native or Rosana	X	X	A	126
Alkali cordgrass	*Spartina gracilis*			X	NA	224
Basin wildrye	*Elymus cinereus*	Magnar		X	NA	95
Canada wildrye	*Elymus canadensis*		X	X	NA	106
Saltgrass	*Distichlis stricta*		(W)	X	NA	83
Russian wildrye	*Elymus junceus*	Sawaki, UNS, Bozoiski or Vinal		X	A	175
Crested wheatgrass	*Agropyron desertorum*	Ephriam, Fairway, Hy-crest or Nordan		X	A	175
Alkali grass	*Puccinellia lemmoni*	Lemmons, Fults		X	A	2,100
Slender wheatgrass	*Agropyron trachycaulum*	Native, Pryor, San Luis, Primar, or Revenu				160
Grasses and legumes tolerant of moist soils						
Alsike clover	*Trifolium hybridum*		X	X	A	680,000
Alkali cordgrass	*Spartina gracilis*			X	A	224,000
Reed canarygrass	*Phalaris arundinacea*		X	X	A	506,000
Colonial bentgrass	*Agrostis tenuis*	Highland	X	X	A	8,723,000
Creeping bentgrass	*Agrostis palustris*	Cato, Cobra	X	X	A	7,800,000
Poa trivialis	*Poa trivialis*	Sabre	X		A	2,540,000
Creeping foxtail	*Alopecurius arundinaceus*	Garrison	X	X	A	400,000
Meadow foxtail	*Alopecurius pratensis*	Garrison	X	X	A	580,000
Perennial ryegrass	*Lolium perenne*	Linn,Moy or Zero Nui	X	X	A	247,000
Legumes						
Crown vetch	*Coronilla varia*	Penngift,Chemung or Emerald	X	X	A	110,000
Birdfoot treefoil	*Lotus corniculatus*	Empire, Dawn, Leo,Norcen, Cascade or MacKinaw	X	X	A	407,000
Sericea lespedeza	*Lespedeza cuneata*		X	X	A	350,000
White clover	*Trifolium repens*		X	X	A	850,000
Alsike clover	*Trifolium hybridum*					680,000

* Codes are as follows; an X indicates presence of species in a given aras, A indicates commericially available, L indicates limited availability, NA indicates not commerically available and W indicates a warm-season grass best adapted to the southern states, or similar culture.

waters, and to prevent a buildup of toxic trace elements. A USDA Forest Service publication entitled *A Guide for Revegetating Coal Mine Soils in the Eastern United States* suggests the following rates of application:

1. Barnyard manure and composted garbage at 34 000 to 68 000 kg/ha (15 to 30 tons/acre)
2. Air-dried leaves at 4 550 to 9 070 kg/ha (2 to 4 tons/acre)
3. Sewage sludge and effluent at volumes equivalent to 45 000 to 113 000 kg/ha (20 to 50 tons/acre) of dry matter

Any one of a family of gel-like chemical products called supermoisturizers can also be used to improve the water retention capacity of dry soils. When mixed into soil, these products act like tiny sponges, expanding many times their original volume and holding water for use by plants. As they have a useful life of only several months, these products are used only to help establish plants.

Modifying Acidic Soils:

High acidity results from the oxidation of minerals like sulfides. Soil materials which are acidic can be modified by adding lime (Table 640-3). The SMP buffer pH test is used for mine spoils to determine lime application rates. Lime should be applied as far in advance of seeding as possible and as deeply as possible, at least to the depth that the materials are exposed to the air during the conditioning process. In addition to correcting low pH, lime will:

1. Improve the physical condition of soil.
2. Add calcium to the soil.
3. Accelerate the decomposition of organic matter, releasing nitrogen.
4. Increase fertilizer efficiency.
5. Increase nutrient availability.
6. Decrease toxicity of aluminum and ferric ions as well as decrease the availability of heavy metals such as lead, mercury, and cadmium.

The approximate amount of lime that should be applied to adjust spoil pH is shown in Figure 640-15.

Modifying Saline Soils:

Saline soils can be modified by leaching excess soluble salts through the soil (Figure 640-16). This can be done by adding organic matter or other such material to improve the infiltration quality of the soil, and by irrigating with low-salt water. Sodic and saline-sodic soils are a different matter, as water alone will not leach out excess exchangeable sodium. The modification procedure involves replacing sodium by another cation and then leaching, initially with salty water. Gypsum is commonly used for this purpose. The gypsum requirement (GR) to reclaim sodic soil is calculated as follows: GR=3.85(Na_x) in metric tons/ha [GR=1.72(Na_x)in tons/acre]of gypsum. The sodium index number (Na_x) is determined by chemical analysis of the subject soil and is expressed in milliequivalents of exchangeable sodium to be replaced by calcium. Other materials used for this purpose are sulfuric acid, sulfur, lime-sulfur, and iron sulfate.

Table 640-3. FORMS OF LIME

Type	Characteristic
Ground limestone (calcium carbonate)	• Insoluble in water but soluable in acid • Long-range effect [mix at least 250 mm (10") deep]
Burnt lime (calcium oxide) and hydrated lime (calcium hydroxide)	• Very soluable in water • Immediate but short-range effect

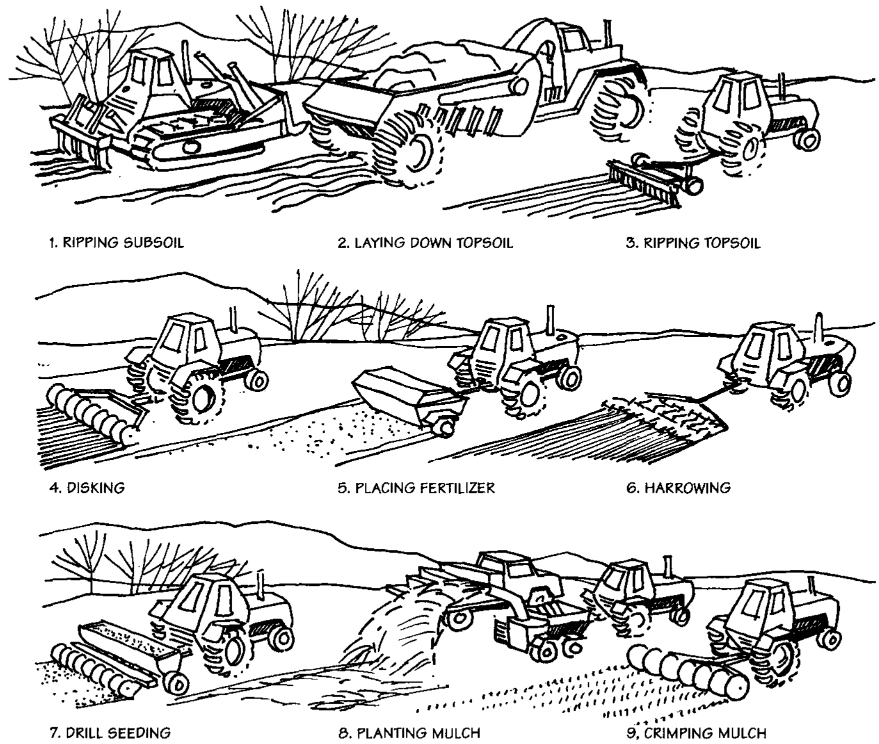

Figure 640-17. Methods of surface conditioning.

Applying Fertilizers:

Soil materials low in nutrients can be improved by applying fertilizer. Sufficient nitrogen is usually available in topsoil for plant establishment, while subsoils and geologic materials are usually deficient. Nitrogen is more of a limiting factor in plant productivity than it is in the establishment of plants. Although nitrogen is needed the first season on some sites, its application is most beneficial during the second growing season. Since nitrogen is water soluble, its effect is immediate but short-term. Applications before the desired perennial materials are established will favor annual weeds instead. It is common practice to apply additional nitrogen at the time of mulching to make up for the short-term depletion of available nitrogen by microorganisms when mulch is added. The amount of nitrogen used for 4 550 kg/ha (2 tons/acre) of straw is 23 to 27 kg (50 to 60

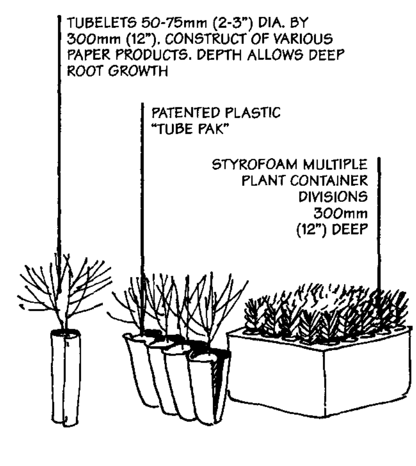

Figure 640-18. Methods of containering reclamation plants.

lb). In the long term, legumes are an important factor in sustaining sufficient nitrogen levels and should be considered in the plant mix.

Unlike nitrogen deficiencies, phosphorus deficiencies will limit and even prevent seedling establishment. On soil materials which test low in phosphorus, 112 kg/ha (100 lb/acre) of P_2O_5 are applied to coarse-textured soil, and 228 kg/ha (200 lb/acre) are applied on fine-textured soils. Since phosphorus is not mobile in the soil, it is important to mix it into the rooting medium.

Seedbed Preparation:

At a minimum, the physical condition of the surface material must be developed into a good seedbed. A good seedbed has the following properties:

1. Firm, but not compacted, under the seeding depth
2. Relatively loose above the seeding depth to allow seed penetration and cover
3. Free of weeds
4. Capable of holding moisture

Favorable physical conditions are typically developed through cultivation by ripping or plowing compacted materials, then disking and harrowing (Figure 640-17). If the surface is partially vegetated and inhibiting erosion, it may be desirable not to cultivate. In such areas, allow existing plants to remain, or use herbicides to eliminate weeds, and deep-furrow the seed directly into the soil. Roughening the surface with dozer tracks, pockets, gouges, and furrows slows runoff, checks erosion, and in dry areas provides for the accumulation and retention of snow and rain (see Figure 640-13).

Mulches:

Mulches are helpful in creating favorable surface conditions for plant establishment by:

1. Inhibiting wind and water erosion
2. Facilitating water infiltration
3. Inhibiting evaporation, and thereby reducing the upward movement of salts
4. Moderating soil temperatures
5. Adding desirable propagules to the seedbed when it is comprised of fresh native materials
6. Adding beneficial microorganisms to the soil

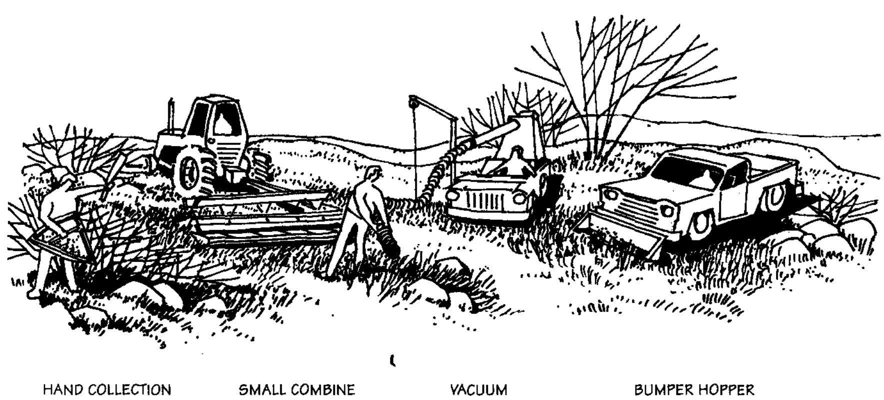

Figure 640-19. Seed collecting methods.

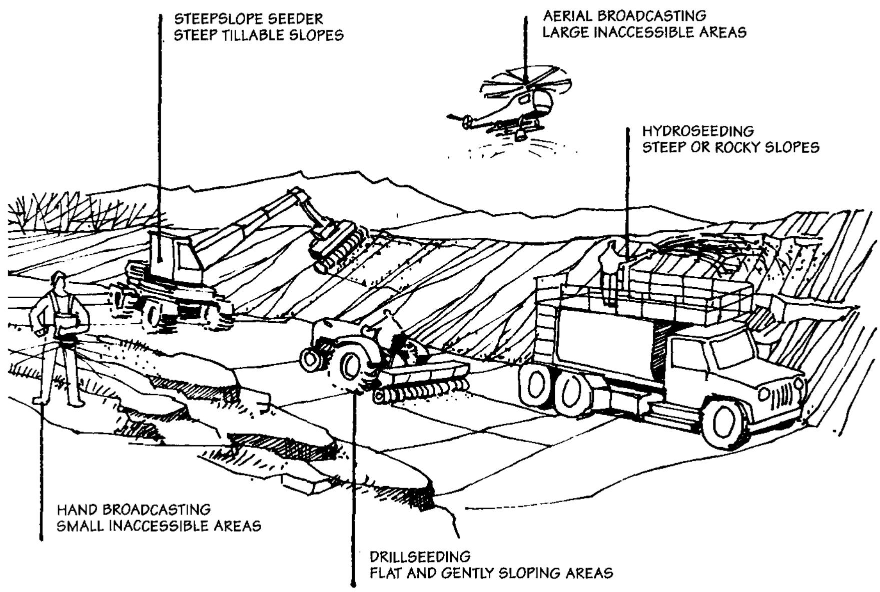

Figure 640-20. Seeding methods and applications.

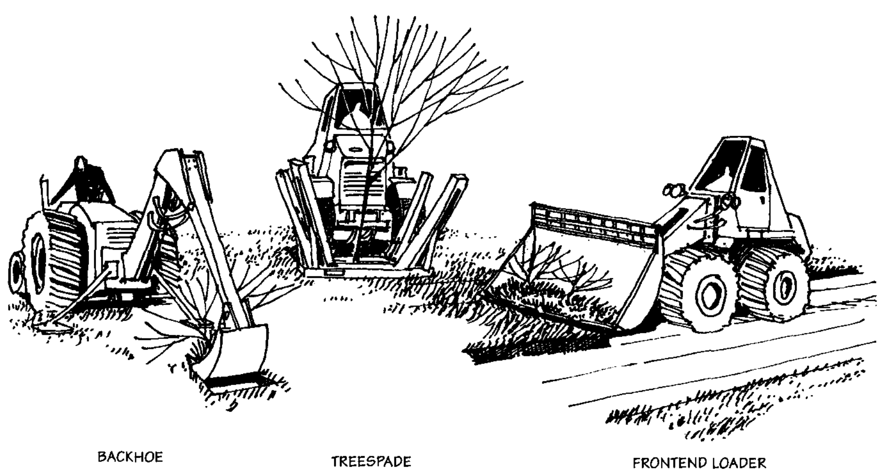

Figure 640-21. Shrub and tree collection methods.

In more humid climates, seeding, fertilizing, and mulching are commonly done in one operation hydraulically. In such climates, wood fiber at 2 260 kg/ha (1 ton/acre) is used. In arid climates it is important to place seed beneath the soil surface, and mulch is applied as a separate operation. The most common practice is to apply hay or straw at 3 400 to 4 500 kg/ha (1-1/2 to 2 tons/acre). The straw is crimped into the surface with a disk-type packer. On slopes greater than 3:1 or in high-wind areas, mulch is anchored with special equipment, nets, and tackifiers such as:

1. Asphalt emulsion at 11 200 L/ha (1200 gal/acre)
2. Resin emulsion in water at 5 600 L/ha (600 gal/acre)
3. Latex emulsion at the manufacturer's recommendations
4. Natural soil binders (guar or plantago) at the manufacturer's recommendations
5. Wood fiber hydromulch at 840 kg/ha (750 lb/acre)

Mulch may also be integrated into erosion control blankets or mats made of jute, paper, excelsior, straw, coconut, or synthetic materials.

Other types of mulch include:

1. Woodchips, pole peelings, and shredded bark or woodchips at 44 800 kg/ha (20 tons/acre)
2. Shredded native grasses and brush at 3 360 to 4 480 kg/ha (1-1/2 to 2 tons/acre)
3. Manure or dried sewage sludge at 11 200 to 33 600 kg/ha (5 to 15 tons/acre)
4. Rocks and gravel at 25 to 50 mm (1 to 2 in) deep [302 400 kg/ha = 25 mm deep (135 tons/acre = 1 in deep)]
5. Plastic films

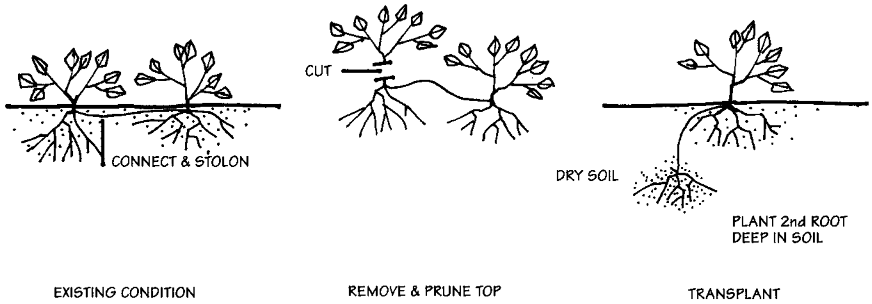

Figure 640-22. Methods of transplanting stoloniferous plants in arid areas.

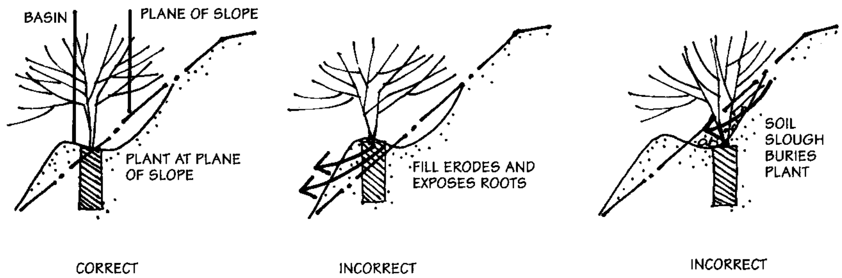

Figure 640-23. Correct slope planting method.

6.0 PLANTING

The selection of plant materials is dependent upon land use objectives and various site factors.

Temporary Erosion Control Plantings:

Temporary erosion control plantings are selected for their ability to establish a quick cover. If these temporary plants are undesirable in the long run, then they can be prevented from going to seed and may be readily eliminated or succeeded by permanent plantings when grown under the nurse crop concept. Commonly used plants for temporary erosion control include annual grasses such as annual ryegrass, barley field brome, oats, winter rye, wheat, sorghums, and millets. Several sterile grass hybrids are also available and provide excellent vegetation cover and erosion protection without the seed volunteering associated with annual grasses (Table 640-4).

Permanent Plantings:

It is essential that species which are intended to be permanent should be well-adapted to the site; that is, they should be able to reproduce and sustain their populations for a substantial period of time. A process of ecological succession can be promoted by using a wide variety of plant materials, thus facilitating gradual changes in the communities of plants. Nurse crops or pioneer plantings may be required for selected sites to make microclimatic conditions more favorable for latter-stage species. This is particularly important on sites with severely constraining conditions and on those at high elevations. Pioneer tree species unable to reproduce under their own canopy include aspen, bristlecone pine, limber pine, and lodgepole pine. Eventually, these species are either rejuvenated by disturbance or succeeded by species like spruce and fir.

In natural settings, a visual blending of disturbed and undisturbed areas is achieved by selection of new plant materials similar

KEY POINTS: Landshaping & Surface Conditioning

1. A general rule of thumb is that as the percent of slope doubles, soil loss increases three times. Slopes 3:1 or steeper call for special stabilization measures (see Fig. 640-3).
2. The amount of plant growth medium necessary to establish a stable vegetative community is 450 to 600 mm (18 to 24 in).
3. The cost of topsoil removal, stockpiling, and replacement is typically less than changing the chemical and physical properties of subsoil to make it suitable as a plant growing medium.

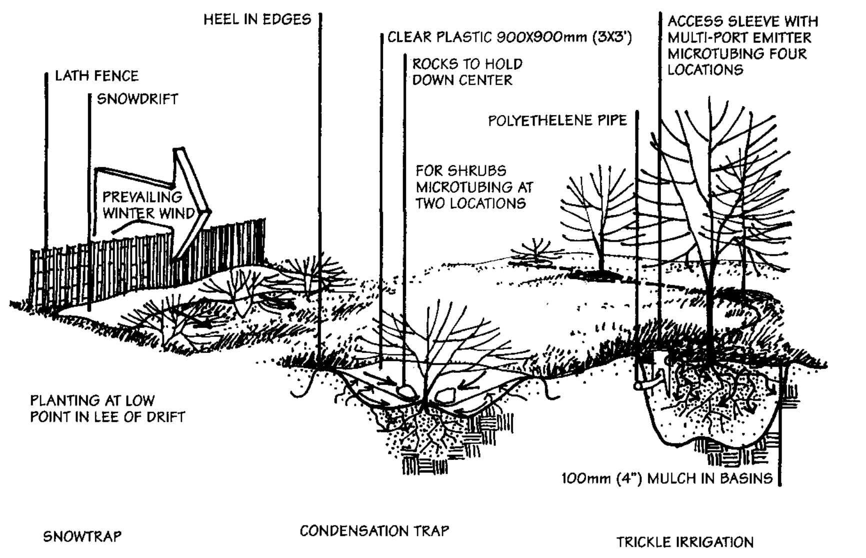

Figure 640-24. Methods of increasing water.

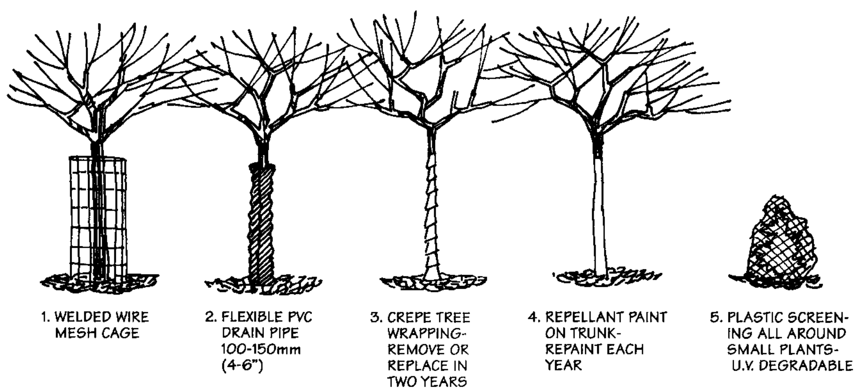

Figure 640-25. Methods of protecting plants from pests.

in size, form, texture, and color to those in adjacent undisturbed areas. Most erosion control grasses are selected for their sod forming characteristics. Deep rooting plants are best for slopes.

Selecting Plant Material:

Sources of technical assistance on selecting plant materials for reclamation of disturbed landscapes include:

1. Universities and their extension services.
2. U.S. Natural Resource Conservation Service offices.
3. U.S. Surface Environment and Mining publications.
4. U.S. Natural Resource Conservation Service plant materials centers. (These centers are located throughout the United States and have been set up for the development of forage and erosion control plants.)
5. PIN (Plant Information Network). This network is a computer-based data bank for information on native and naturalized vascular plants of several western states in the United States. PIN information is a service of the U.S. Department of Interior's Fish and Wildlife Service, Western Energy Land Use Team, located at Fort Collins, Colorado.

Acquiring Plant Material:

Plant material can be obtained from one or more of the following sources (the NRCS and U.S. Forest Service distribute lists):

1. The predisturbance vegetation and topsoil
2. Existing vegetation collected from the area
3. State nurseries
4. Commercial native plant nurseries
5. Commercial seed suppliers
6. U.S. NRCS plant materials centers
7. U.S. Forest Service nurseries
8. Small private seed collectors

Native Regrowth:

A method proved effective for establishing native vegetation on steep slopes is described in an article entitled "The Native Regrowth Method for Steep Slopes," *Landscape Architecture*, January 1979, by Wayne Tyson. This method, using predisturbance vegetation and topsoil, recommends the following steps:

1. Crush or shred low vegetation on the site and remove it with 100 to 150 mm (4 to 6 in) of topsoil.
2. Stockpile the soil/mulch mixture, keeping the surface moist to preserve inherent moisture.
3. Spread the soil mulch evenly over a moist, roughened subgrade. On steep slopes, do not exceed a soil/mulch layer of 100 mm (4 in), and bond it to the subgrade with a sheepsfoot roller.

Nursery Stock:

Collected trees and shrubs are transplanted during their dormant season. Sods and shrub pads are readily transplanted by use of front-end loaders. Containerized materials may be planted during any part of the growing season, provided that ample water is available (Figure 640-18). Some nurseries specializing in reclamation plants have developed specialized minicontainers for seedling stock. Actual planting methods follow standard nursery practices. Basins are constructed around plants and are either covered with plastic or mulched to trap and retain moisture and to reduce competition by weeds.

Seeding Methods:

Seed from the area to be disturbed or from nearby areas may be collected by using combines, bumper hoppers, or various hand methods (Figure 640-19). Cleaning and sorting of seed is necessary only for commercial operations. When legumes are used, the seed is typically inoculated with nitrogen-fixing bacteria. The ideal time to collect seed is under dry conditions just before the seeds begin to disperse naturally, which is usually 6 to 8 weeks after blooming. The seed should be spread out and allowed to dry thoroughly for 1 to 2 weeks immediately after collection. Store seeds in dry, ventilated locations. Fabric containers are better than plastic bags.

Seed is planted by broadcasting, hydroseeding, or drilling (Figure 640-20). Broadcasting requires at least twice as much seed as drilling, and poorer sites need more seed than favorable sites. Seeding rates are based on the number of individual plants (PLS) desired per square meter (ft^2) [converted to kilograms (lbs) of seed per area]. The formula for calculating the seeding rate is as follows: 10 000m^2 (43,560 ft^2) X PLS desired per square meter (ft^2) ÷ seeds per kilogram (lb) X purity X germination = planting rate of commercial seeds in Kg/ha (lbs/acre).

In arid areas, it is important to drill the seed 5 to 10 mm (1/4 to 1/2 in) under the surface to prevent germinating seeds from drying out. It is important that the seedbed be firm; otherwise, its moisture holding capacity will be reduced. Rolling before and/or after seed placement is beneficial.

Broadcasting is the least expensive and fastest seeding method; it is not so dependent upon surface conditions and it has the advantage of handling uncleaned seed. Broadcasting can also be accomplished aerially. When broadcasting or hydraulically applying seed, the seeding rate should be doubled compared to drill seeding rates. Broadcast seeding may be effective in arid areas under the following conditions:

1. On loose soil where sloughing will cover the seed
2. Following plowing or disking
3. Ahead of mechanical treatment providing seed coverage
4. In deep ashes after burns
5. Under deciduous trees prior to leaf fall

Planting Schedules:

In general, the best season to plant is just prior to the season that receives the most dependable precipitation, usually spring or fall in North America. Cover can be established during any part of the growing period when moisture is available and by proper selection of species. Perennial grasses that grow in cool seasons usually do better when planted in the fall; legumes and woody plants do better when planted in the spring; some annuals can be successful when planted in mid to late summer. In critical areas, clear plastic may be used as a temporary way to increase seed germination. This material helps preserve soil moisture and will increase early and late season soil temperatures, but it requires careful management to prevent excessive temperatures in some areas. Table 640-4 lists grass species recommended for use in landscape reclamation.

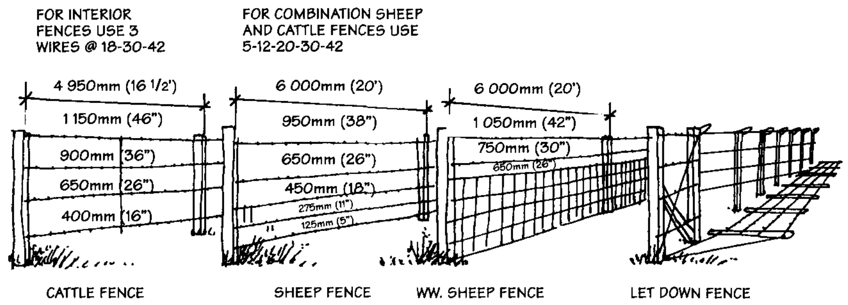

Figure 640-26. Range fencing methods.

7.0 ESTABLISHMENT AND MAINTENANCE OF VEGETATION

Figures 640-21 through 640-26 illustrate a variety of techniques for transplanting, watering, and protecting vegetation.

Once plant materials are established, the following management practices can help achieve desired densities and relatively stable conditions:

1. Supplemental watering (particularly important for trees and shrubs in arid areas)
2. Periodic fertilization to increase plant vigor
3. Mowing or burning to favor perennials
4. Fencing, screening, and the use of chemical repellents (Table 640-5) and poisons for pest control
5. Providing roosts and rockpiles to encourage natural predator control

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KEY POINTS: Planting

1. Commonly used plants for temporary erosion control include annual grasses such as annual ryegrass, barley field brome, oats, winter rye, wheat, sorghums, and millets (Table 640-4).

2. A process of ecological succession can be promoted by using a wide variety of plant materials, thus facilitating gradual changes in the communities of plants.

3. The formula for calculating seeding rates is as follows: 10 000 m^2 (43,560 ft^2) X PLS (number of plants) desired per square meter (ft^2) divided by seeds per kilogram (lb) X purity X germination=planting rate of commercial seeds in kilograms per hectare (lb/acre).

SECTION 660

Sound Control

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CONTENTS

1.0 INTRODUCTION

This section provides design and planning guidelines for the reduction or elimination of unwanted sound in the landscape. Because sound control is a very large subject, the amount of technical information presented here is necessarily limited. However, sources of additional information are listed under References at the end of this section. Regulations and standards for noise abatement and acoustical planning are not common, but an investigation of local ordinances is nevertheless essential when one is involved in any land use planning project.

The science of sound control in the landscape involves much more than the simple quantification of data. The quality of sound may be as important as the quantity of sound. Some sounds can have profound psychological effects on people. For example, the constant drone of cars on a highway is rarely as offensive as the squealing of brakes at an intersection. Masking unwanted sound (by falling water, for instance) is a technique which can mitigate noise disturbance by modifying the quality of the sound received by the ear.

1.1 Basic Approaches to Sound Control

Two approaches to sound control in the landscape include acoustical planning, where potential noise problems are minimized during design stages, prior to any construction, and retrofitting, where noise problems are mitigated by alteration to existing developments.

Acoustical Planning (Preplanning):

Where acoustical planning is possible, setbacks and other methods can be employed to minimize sound transmissions. Acoustical planning should be part of any land use planning project, especially with such major projects as airports, highways, and railroads. Acoustical models should be developed and tested to assess the planning implications both on and off the property.

Acoustical planning is more desirable than retrofitting, because as potential noise problems are identified, cost-saving mitigative measures can be taken to reduce noise levels to acceptable standards while at the same time designing a physical landscape with improved visual qualities. This can be achieved, for instance, through grading concepts that retain significant natural landforms and existing vegetation, as well as incorporate noise buffer mounds where necessary. Preplanning can accommodate public and private interests by reducing noise to acceptable levels, while retaining landscapes of high quality.

Retrofitting:

Acoustical planning principles can also be effectively applied to existing development, but the aesthetic results are often unattractive. Establishing adequate rights-of-way or buffer zones is difficult, typically including architectural barriers or walls. Capital construction and eventual maintenance costs can become limiting factors.

1.2 Acoustic Variables

Three acoustic variables to address when attempting to minimize noise problems in the landscape are: (1) the source of the sound, (2) the path and distance of the sound transmission, and (3) the receiver of the sound.

Source of the Sound:

Most noise can be modified by acoustical treatment at its source; however, this is often not as economically feasible as control of noise by various landscape planning techniques.

Path and Distance of Sound Transmission:

The path and the distance of sound transmission constitute an important variable in any strategy of noise reduction. A valley or a downwind site, for instance, can make any development located in these areas more susceptible to noise. Valleys and ravines can exacerbate conditions by channelizing sound waves. Such topographic conditions can present problems when intensively used highways or railways cross a valley, for instance. Analyses of topographic and climatic factors are required to assess the directions of sound transmission.

Receiver of the Sound:

People who are accustomed to quiet landscapes are significantly less tolerant of noise than people accustomed to suburban or urban environments. Masking of noise can sometimes be accomplished by introducing pleasant sounds, such as the sound of flowing water or rustling leaves.

Table 660-1. TYPICAL SOUND LEVELS OF EVERYDAY OCCURANCES

Occurrence	Sound level, dB(A)
Weakest sound that can be heard (threshold of hearing)	0
Inside broadcast studio	20
Rural area at night	25
Whispered conversation at 2 m (6 ft)	30
Library	35
Residential area during daytime	
Rural	40
Suburban	50
Suburban, adjacent to airport	60
Conversation at 1 m (3 ft)	60
City center	65
Major roads (adjacent property ±20 m (65 ft) inside)	
Township road	50
Highway	60
Freeway (12-lane)	75
Diesel truck at 15 m (50 ft)	90
Noisy metal-working shop	100
Impulsive pile driving at 10 m (32 ft)	110
Jet taking off at 50 m (165 ft)	120
Pain begins	>120

2.0 PHYSICS OF SOUND

2.1 Nature of Sound Waves

Sound waves are generated by any pulsation or vibration of a source. The surrounding air is disturbed, thereby causing pressure changes which can be heard. The greater the change in pressure, the louder the sound.

The rate of repetition of these sound waves is referred to as frequency. It is measured in cycles per second or units of hertz (Hz). The normal audible range for humans is 20 to 20,000 Hz.

2.2 Sound Pressures and Decibels

Although the human ear acts like a sound filter by discriminating against some frequencies and giving preference to others, the range of sound pressure which the human ear can detect is relatively broad.

Given this broad range, the measurement of sound is made more convenient by use of a logarithmic scale called the decibel (dB) scale.

To simulate human hearing, a sound measuring instrument is equipped with an electronic A-weighting filter which corresponds to human detection of sound. Sound pressure levels measured with the A-weighting filter switched on are given in dB(A).

Table 660-1 lists typical sound levels of everyday occurrences.

Table 660-2. NOISE SURVEY (LONDON, EARLY 1960'S)

	Percentage of persons questioned who were disturbed by noise		
Source of noise	**When home**	**When outdoors**	**When at work**
Street traffic	36	20	7
Aircraft	9	4	1
Railway	5	1	4
Industry and buildings	4	—	4
Internal noises at home	4	—	—
Noise from neighbors	6	—	—
Children	9	3	—
Adults (talking)	10	2	2
Radio and television	7	1	1
Bells and sirens	3	1	1
Pets	3	—	—

3.0 NOISE

3.1 Definition and Sources of Noise

Under all circumstances, any unwanted, unpleasant, loud, or harsh sound is referred to as noise.

Table 660-2 summarizes a noise survey carried out in London, England. This survey and more recent studies confirm that vehicular traffic is the major source of urban noise.

3.2 Psychological Response to Noise

Although the acceptability of the type and level of noise is highly subjective, noise often disturbs people by interfering with communication, sleep, and other everyday activities. Noise can also cause physical discomfort and, if intense enough, can cause damage to hearing. People are usually annoyed more by high-frequency sound than by low-frequency sound, by certain tonal qualities (e.g., whines, hisses, or squeals), by impulsive sound (e.g., bangs and clanks), and by intermittent sound. Any frequent or continuous exposure to noise can lead to a reduction of human efficiency by a deterioration of physical and emotional well-being.

3.3 Units of Noise Measurement

The A-weighted sound level [db(A)] is typically used to measure sound levels in environmental studies. It is good practice to state the mode of measurement used when referring to noise levels measured with a meter (i.e., slow, fast, or peak). Three noise descriptions are: L_{eq}, L_{dn}, and L_n.

L_{eq} (Equivalent Noise Level):

Even though noise levels may be fluctuating continuously, a single-figure dB(A) measurement will only refer to noise levels at a particular point in time. To use a single, or equivalent, level which has the same effect on human ears, the average sound energy of the fluctuating noise is calculated. This is termed the equivalent energy concept, and the single-figure level, measured in units of dB(A), is called the equivalent noise level, or L_{eq}. L_{eq} can be determined over any time period and is usually expressed in brackets, e.g., L_{eq} (1 hour). Instruments are commercially available which measure L_{eq} directly.

L_{dn} (Day-Night Equivalent Noise Level):

The day-night equivalent noise level L_{dn} is a noise unit which is obtained by combining the equivalent energy level for the daytime period (07:00 to 22:00 hours) with the equivalent energy level for nighttime (22:00 to 07:00 hours). Because noise at night is more disturbing and more annoying than noise during the day, a weighting factor of 10 is applied to the nighttime noise.

L_n (Noise Level):

The noise level L_n refers to that level which is exceeded for n percent of the measurement time period. L_n is used to provide statistical information about a fluctuating noise signal. Some representative examples of L_n are L_{10} (peak), L_{50}, and L_{90} (ambient).

4.0 NOISE ESTIMATIONS AND CALCULATIONS

To assess the potential impact of noise from a proposed major facility such as a new highway or airport expansion, noise levels must be predicted. Common sources of noise and characteristics from which calculations can be made are described below.

Table 660-3. CALCULATING DIFFERENCES BETWEEN DECIBEL LEVELS

Difference between the two levels, dB	Addition to higher level, dB
0	3
1	3
2	2
3	2
4	1
5	1
6	1
7	1
8	1
9	1
10	0

Example: 50 dB + 50 dB + 50 dB + 60 dB

53 dB 60 dB

61 dB

4.1 Traffic Noise

Noise generated by traffic depends on:

1. Volume
2. Mix (e.g., cars and trucks)
3. Speed
4. Road characteristics (e.g., gradient and surface)

Noise propagated to a receiver depends on:

1. Distance from traffic
2. Type of ground
3. Height of receiver
4. Amount of shielding
5. Height of source

The easiest way to incorporate all these variables in any calculation is by use of a computer, especially if a large number of positions along a road have to be considered. Several calculation methods are available. A guide which gives detailed instructions for both a manual and a computer method of noise prediction has been produced in Alberta, Canada. The L_{eq} nomograph shown in Figure 660-1 can be used to illustrate a simple example as follows:

1. A straight line is drawn from the starting point through 60 mph on the auto speed scale to the turn line.
2. A second straight line is drawn from this turning point to the point on the volume scale indicating 5000 vehicles per hour. The intersection of this straight line with the pivot line is boxed.
3. A third straight line is drawn from this box to the 500 ft point on the distance scale.
4. The intersection of this line with the L_{eq} scale gives the predicted L_{eq} at the observer: 65 dB(A).

This method can be repeated for both medium and heavy trucks, and the resultant of all three values is obtained by using the dB additions method shown in Table 660-3.

A completed calculation of noise prediction involves additional calculations which take into account road and noise propagation characteristics. A comprehensive traffic noise study typically involves calculating the L_{eq} for both the day and night periods and then combining them to obtain the L_{dn}.

4.2 Train Noise

The L_{eq} nomograph used for traffic noise can also be used for train noise prediction (Figure 660-1). Adjustments to the basic calculated level have to be made for such factors as the existence of welded tracks or whether or not the railway crosses a steel structure (i.e., an overpass).

4.3 Aircraft Noise

Aircraft noise predictions are usually represented by a set of noise contours for areas surrounding the airport. Several methods for rating aircraft noise exposure have been developed, including:

NEF	noise exposure forecast
NNI	noise and number index
CNR	composite noise rating
L_{dn}	day-night sound level

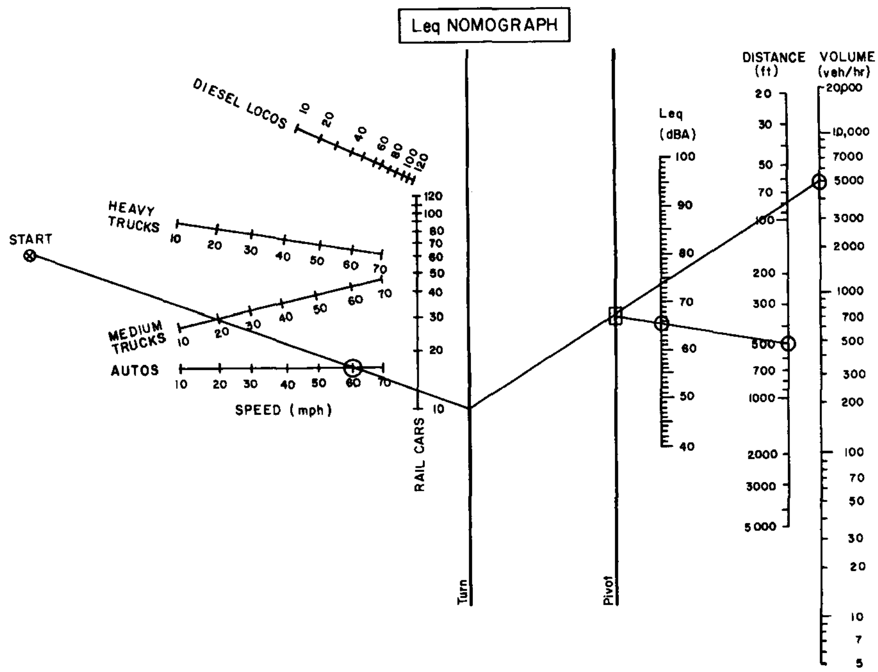
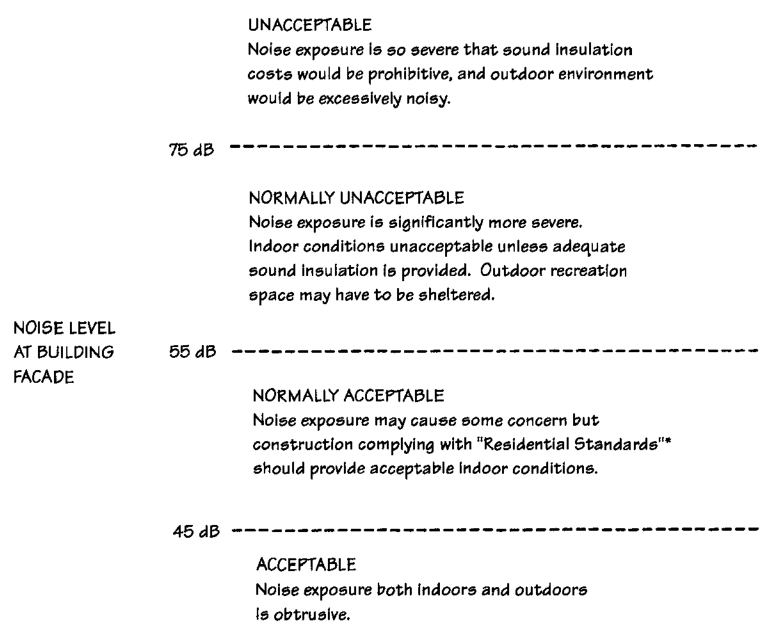


Figure 660-1. L_{eq} Nomograph. *This nomograph can be used to predict noise levels of vehicular traffic. The L_{eq} scale gives the predicted L_{eq} at the observer.*



* Referring to Canadian Central Mortgage and Housing Corporation standards

Figure 660-2. Noise levels at building facade. *This chart shows noise standards developed by the Canada Mortgage and Housing Corporation for evaluation of proposed residential development within its jurisdiction (Canada Mortgage and Housing Corporation, Ottawa, Canada, 1979).*

Table 660-4. ACCEPTABLE NOISE LEVELS FOR RESIDENTIAL AND OUTDOOR RECREATION ENVIRONMENTS.

Environment	Noise level, $L_{eq}(24h)$
Bedrooms	35
Living, dining, recreation rooms	40
Kitchens, bathrooms, hallways, utility rooms	45
Outdoor recreation areas	55

Source: Courtesy of Canadian Mortgage and Housing Corporation.

Table 660-5. COMMUNITY REACTION TO AIRCRAFT NOISE

Noise exposure forecast (NFF)	Community response prediction
> 40	Repeated and vigorous individual complaints are likely. Concerned group and legal action might be expected.
35–40	Individual complaints may be vigorous. Group action and appeals to authorities might result.
30–35	Sporadic to repeated individual complaints. Group action is possible.
< 30	Sporadic complaints may occur. Noise may interfere occasionally with resident's activities.

The first three of these are similar because they combine many factors into a single number evaluation. The formulas require information about the types of aircraft using the airport, the number of movements, and the amount of noise generated, measured in terms of effective perceived noise decibels (EPN dB).

The L_{dn} method of aircraft noise annoyance assessment has been adopted in the United States. This is the same unit as described in 3.3 Units of Noise Measurement in this section.

4.4 Industrial Noise

Industrial installations generate noise from a wide variety of sources, such as fans, blowers, transformers, heating and ventilating systems, and reciprocating or turbine engines. Methods for estimating noise emission and for controlling noise are therefore varied. For a useful description of various methods, refer to Harris in the References at the end of this section.

5.0 NOISE CONTROL STANDARDS

Noise control legislation in North America can be found at federal, provincial/state, and local levels. Regulations commonly deal with the following:

1. Transportation
2. Source emission (maximum levels)
3. Nuisance
4. Zoning
5. Recreational areas

5.1 Acceptable Sound Levels in Residential and Recreational Environments

Table 660-4 shows maximum acceptable levels of road and rail traffic noise for residential environments and outdoor recreational areas, as recommended by the Canadian Central Mortgage and Housing Corporation (CMHC). (Note that this is the recommendation of only one authority.)

5.2 Noise Rating

The International Standards Organization document ISO 1996 (1971) shows how to assess the following:

1. The acceptability of a noise level
2. The setting of noise limits
3. Appropriate noise criteria

The ISO document uses a basic criterion of 35 to 45 dB(A) for residential purposes. Corrections to this are applied for different times of the day and for different community zones. In order to establish the acceptability of a measured noise level (called the rating level), this criterion is used for comparative purposes.

5.3 Sound Level Zoning and Land Use Planning

Sound level zoning, or acoustical planning, refers to the separation between the source of noise and the receivers of that noise (usually in residential areas). Such planning is accomplished by categorizing various land uses in a developing community, and then prescribing design noise levels not to be exceeded in any particular area. In this manner, sensitive buildings such as schools, churches, and hospitals can be separated from industrial areas and traffic noise. In established communities, however, acoustical planning is usually a difficult concept to implement. Certain types of activity and development have to be restricted, prohibited, or confined to certain areas to meet planning requirements. Of current interest is the retrofitting of highways with noise barriers to reduce noise levels in surrounding residential areas.

In most cases, local, state, or federal governments have noise control standards for various types of land use. For example, the CMHC recognizes three different categories of noise level (L_{eq}/24 hours) at the building facade and applies the following recommended policy to new residential development (Figure 660-2):

1. In the lower noise zone, where the noise level is between 45 and 55 dB (Figure 660-2), new housing construction meeting Canada's National Housing Act Residential Standards is considered to have sufficient sound insulation.
2. In the intermediate noise zone, between 55 and 75 dB (Figure 660-2), housing shall be denied financing under the National Housing Act unless special and adequate sound insulation is provided.
3. In the upper noise zone, where the level exceeds 75 dB (Figure 660-2), financing for housing shall be denied under the National Housing Act.

The Canadian Ministry of Transport has implemented the guidelines shown in Table 660-5 for assessing likely community reaction to noise created by aircraft.

6.0 CONTROL OF NOISE OUTDOORS

Measures to control noise can be divided into three categories, each of which can be addressed in a noise control strategy. These are:

1. Source of the sound
2. Path and distance of the sound transmission
3. Receiver of the sound

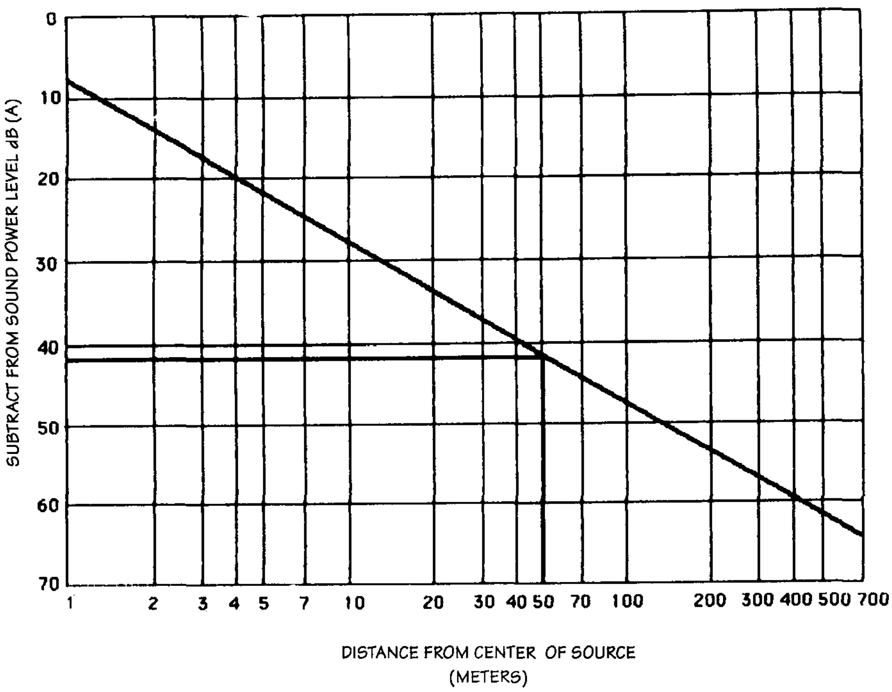


Figure 660-3. Effect of distance from a line source. *This chart shows the amount to be subtracted from a sound power level at the source in order to determine the sound level at some distance. Note that sound levels determined with this graph are unreliable if at distances less than three major dimensions from the source, and if the source radiates sound in a marked directional manner.*

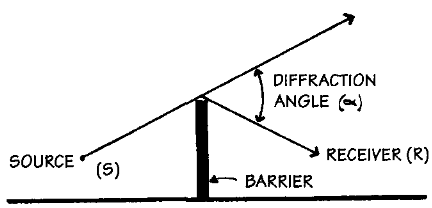


Figure 660-4. Sound level attenuation as a function of diffraction angle.

6.1 Source of the Sound

Noise can be reduced at the source either by architecture or equipment modification. In some instances the amount of noise generated is so great that it is rarely cost-effective or feasible to abate the noise at the source. In such cases a combination of other acoustical control measures may be required.

6.2 Path and Distance of the Sound Transmission

Noise can be attenuated by increasing the distance between the source and the receiver and/or by introducing noise screening.

At sufficient distances, all noise sources can be considered a point source. Thus, the sound level at a receiver can be calculated by the following equation:

$L_p = L_W - (20 \log R) - 8$

where:

L_p =sound level at receiver, dB(A)

L_W = sound level of source, dB(A) (If the noise is caused by a machine, the value of L_W can sometimes be obtained from the manufacturer.)

R = distance between source and receiv er, (ft) (A useful criterion for a suffi cient distance is that R should be greater than the sum of the three prin ciple dimensions of the source. At dis tances less than this, the equation is unreliable.)

Figure 660-3 shows how the sound level given by the above equation can be obtained graphically.

Example (Figure 660-3): Given a welding machine with a sound level of 110 dB(A), the sound level 50 m (164 ft) away is determined. The graph shows that, at distance, 42 dB(A) can be subtracted from the sound level at the source [110 dB(A)], resulting in a sound level at the receiver of 68 dB(A).

Effect of Distance from a Point Source:

Referring to the above example, note that each time the distance is doubled, the sound level falls off by 6 dB(A). Therefore, if the distance away from the same welding machine were increased to 100 m (300 ft), the sound level would be 62 dB(A).

Effect of Distance from a Line Source:

For line sources such as trains or continuous traffic, the sound level will decay by 3 dB(A) per doubling of distance, up to a distance of about half the length of the line source.

Other Effects (Point and Line Sources):

The dependence on distance given above is for propagation of noise over hard ground (such as pavement), or for an elevated source or receiver over soft ground (such as a grassy field or a garden). The decay rate over soft ground, when both source and receiver are less than 2 m (6 ft) above the ground, is increased by 1-1/2 dB per doubling of distance. Sound levels and attenuation over a distance may also vary substantially according to wind, air turbulence, and temperature. These effects are difficult to predict.

6.3 Sound Barriers

The degree of attenuation provided by a noise barrier is mainly a function of (1) the diffraction angle a through which the sound path must be bent in order to get from source to receiver and (2) the frequency of the sound source (Figure 660-4).

Five main factors that influence the acoustic effectiveness of a barrier are: (1) distance (offset), (2) height, (3) continuity, (4) length, and (5) mass.

An additional factor influencing the acoustic effectiveness of a barrier is the sound absorption capability of the barrier, i.e., the degree to which it minimizes reflection of sound.

Distance (Placement of Barrier):

A sound barrier should be erected as close as possible to either the noise source or the receiving position in order to maximize the diffraction angle (Figure 660-5).

Height of Barrier:

The minimum height of the barrier should be such that the line of sight between source and receiver is interrupted (Figure 660-6).

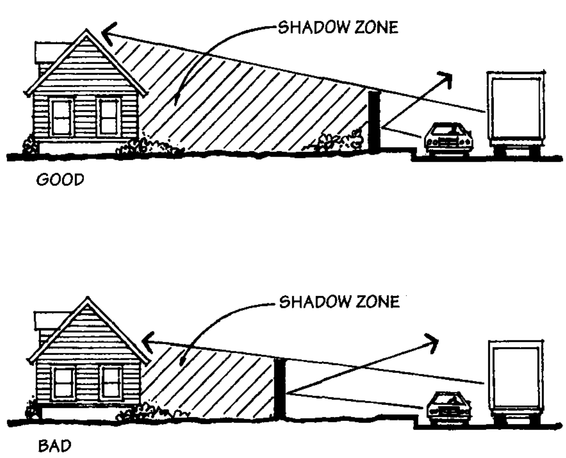


Figure 660-5. Distance as a variable influencing the effectiveness of a noise barrier. *Barriers should be placed to maximize the diffraction angle.*

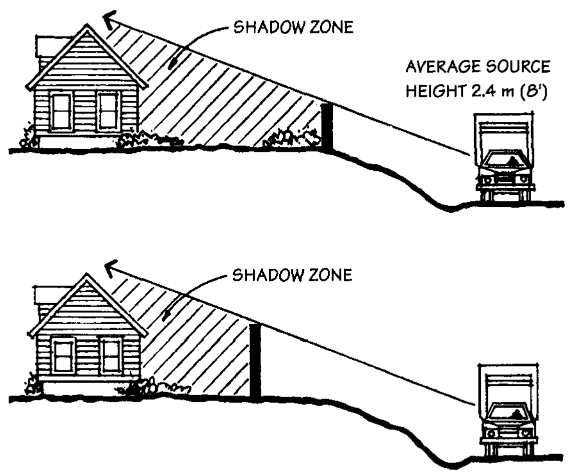


Figure 660-6. Height as a variable influencing the effectiveness of a noise barrier. *Barriers should be placed to interrupt lines of sight.*

Continuity of Barrier:

No gaps or holes should be present in a noise barrier. It must be effectively airtight (Figure 660-7).

Length of Barrier:

As a guideline, the length of a noise barrier should be at least 1 to 2 times the distance between the barrier and the protected structure to minimize sound diffraction around the ends of the barrier (Figure 660-8).

Physical Mass of a Barrier (Material):

To minimize sound passing through a barrier, it should have a surface weight, or mass, of at least 6 to 12 kg/m^2. A noise level reduction of 10 to 15 dB(A) is possible with such a barrier; however, a reduction of 5 to 10 dB(A) is considered to be more cost-effective.

6.4 Earth Berms

The careful design and situation of earth berms can be an effective way of reducing noise from traffic or construction operations. Berms can either be temporary or remain as a permanent feature of the landscape (Figures 660-9 and 660-10). The slope of a berm depends on the type of surface treatment or maintenance involved. For instance, a mowed grass berm is easier to maintain if graded to a slope of 1:3 or less.

6.5 Barrier Walls and Earth Berms

Barrier walls can be used separately or in combination with earth berms to minimize noise levels (Figure 660-11).

6.6 Vegetation

The type of ground surface over which sound travels does have a substantial effect on sound attenuation, particularly when traveling over large distances. Areas covered with grass or other types of groundcover are more absorptive than hard, paved surfaces, which tend to reflect the sound. Taller plantings, such as hedges or shallow screen plantings (even though they may completely block the view of the noise source), will not significantly reduce actual noise levels. However, dense plantings of trees with an understory of shrubs can result in a reduction of 3 to 5 dB(A) per 30 m (100 ft) of depth from the sound source (Figure 660-12).

KEY POINTS: Noise Control

Noise can be attenuated by increasing the distance between the source and the receiver and/or by introducing noise screening. Table 660-4 lists acceptable noise levels for residential and recreational environments. Table 660-1 lists typical sound levels of various noise generators.

1. Generally speaking, each time the distance from a point source of sound is doubled, the sound level falls off by 6 dB(A). Each time the distance from a line source, such as a roadway, is doubled, the sound level will decay by 3 dB(A). The type of ground surface, wind, and temperature will further modify these sound levels.

2. Five main factors that influence the effectiveness of a noise barrier wall are distance, height, continuity, length, and mass. Figures 660-5 through 660-8 illlustrate the influence of these factors.

3. Earth berms can be an effective noise reduction technique (Figure 660-9 and 660-10). They may be used in combination with barrier walls to achieve the desired effect (Figure 660-12).

4. Dense plantings of trees with an understory of shrubs can result in a reduction of 3 to 5 dB(A) per 30 m (100 ft) of depth from the sound source (Figure 660-12). Areas covered with grass or other types of groundcover will absorb more sound than hard, paved surfaces.

5. In addition to specially constructed devices, the use of existing or proposed buildings to shield others that are more sensitive, and the use of natural or constructed landscape features, can be effective sound control techniques.

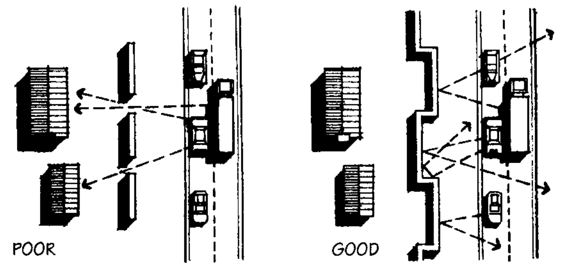


Figure 660-7. Continuity as a variable influencing the effectiveness of a noise barrier. *Barriers should be solid rather than perforated.*

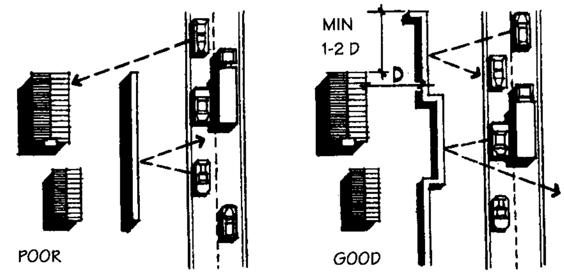


Figure 660-8. Length as a variable influencing the effectiveness of a noise barrier. *Barriers should extend beyond the protected structure to minimize sound diffraction around the ends of the barrier.*

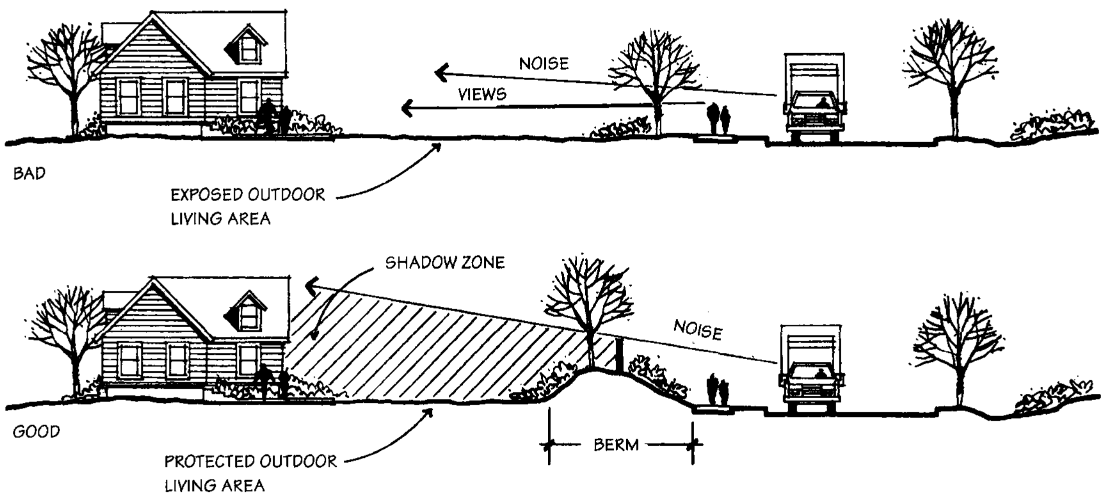


Figure 660-9. Earth berms for noise control. *Earth berms and walls can help control wind and noise. Plantings can provide psychological relief from noise and also help to control wind.*

The primary value of vegetation in connection with sound control in the landscape is for its aesthetic and psychological appeal. Perhaps the most important value of planting is to make barrier walls, berms, and other sound control devices seem less visually intrusive in the landscape.

6.7 Building Layout and Site Selection

Specially constructed noise barriers are expensive, but fortunately are not the only means available for noise control. Other means available include:

1. The use of existing or proposed buildings to shield others that are more sensitive
2. The use of natural or constructed landscape features (hills and valleys, earth berms, etc.)
3. The optimization of other site planning or design criteria (discussed in 7.0, which follows)

7.0 DESIGN PRINCIPLES

7.1 Design Criteria

The three most important criteria for noise barrier design are acoustic effectiveness, economic feasibility, and visual attractiveness. Acoustic criteria include the site planning objectives, the choice of barrier material, and the quality of construction. Economic criteria include the cost of materials and labor, implementation ease, and operating and maintenance costs. Visual criteria include environmentally acceptable alternatives for highway users as well as for people who have to live near the barriers.

The design of noise barriers should incorporate both the functional requirements and the aesthetic preferences of all who are affected. In the case of a highway, for instance, both the actual users of the highway as well as the users of adjacent lands are factors to consider. Design criteria are not limited to aesthetic concerns alone but should also address a set of program objectives established for the roadway, taking into account the views to both natural and built surroundings. Noise barriers can aid driver orientation and decision making and provide sequential visual experiences. They should integrate well with the existing landscape and promote feelings of security and comfort for both drivers and passengers.

7.2 Aesthetic Issues

Noise barriers along highway corridors should be seen as elements which define and enclose linear space. Visual perception in these corridors will be influenced by travel speed, light, spatial quality, location, physical distances, roadway characteristics,

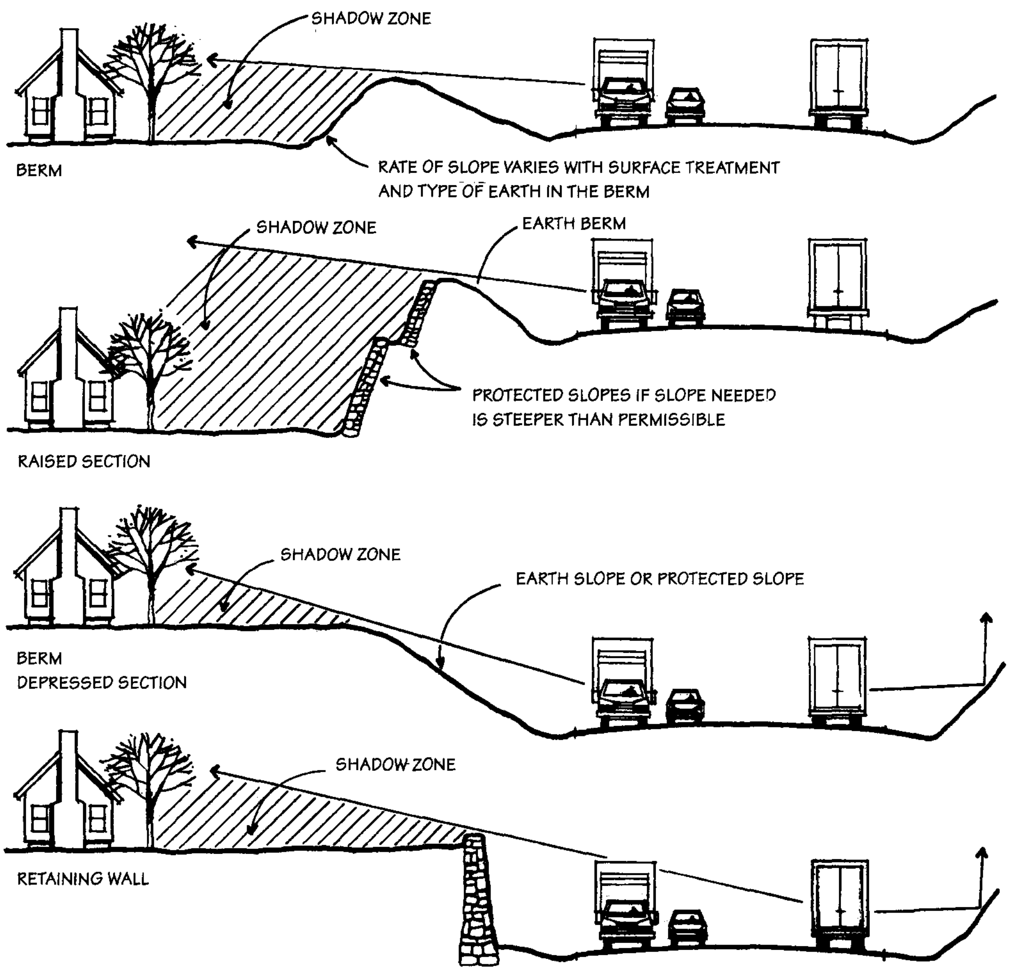


Figure 660-10. Earth berms for noise control. *Various types of embankments can be used to maximize diffraction angles.*

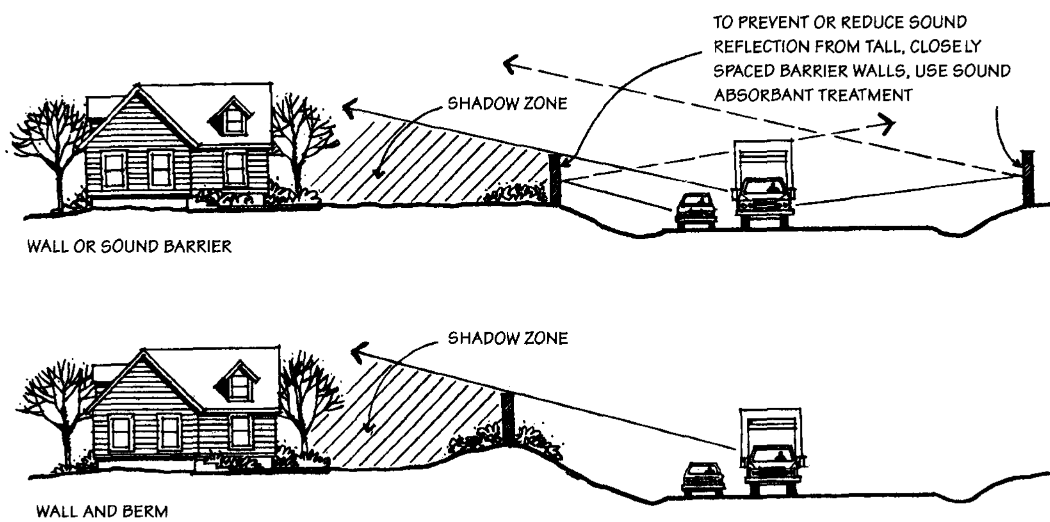


Figure 660-11. Barrier wall or combination of wall and berm.

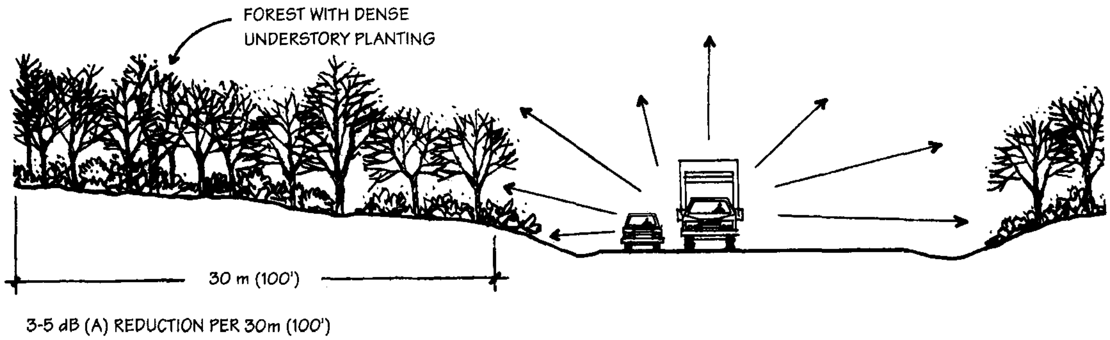


Figure 660-12. Vegetation as a noise barrier. *Vegetation will not significantly reduce sound levels unless plantings are dense and 30 m (100 ft) deep or greater.*

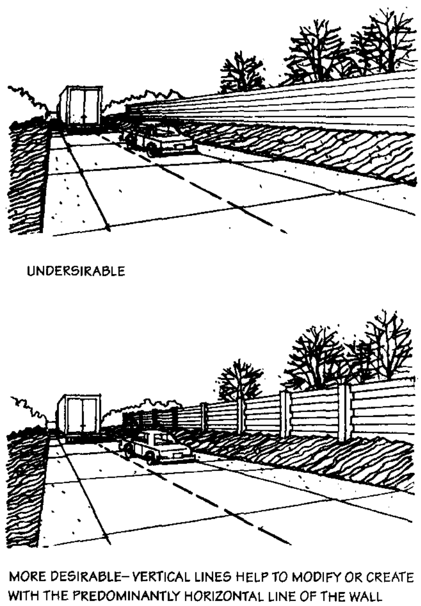


Figure 660-13. The apparent height of a wall. *A combination of vertical and horizontal lines in a wall (i.e., articulation and texture rather than a monolithic mass) can reduce the apparent height of the wall.*

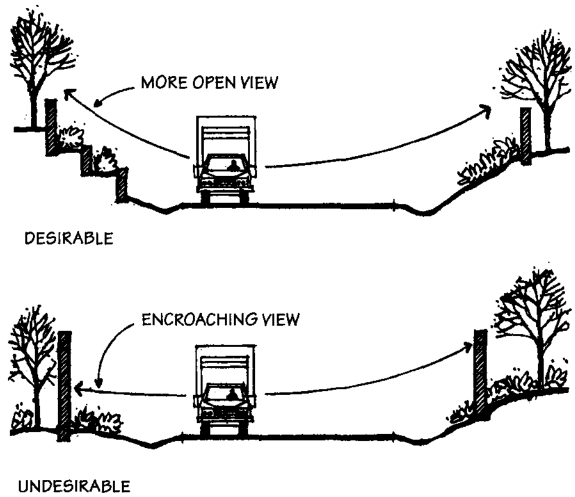


Figure 660-14. Stepped-back wall. *A wall which steps back can open up the view for the motorist and provide psychological relief from feelings of tight enclosure.*

and viewing height, all modified by the basic design elements of planes, mass, and texture.

Planes:

Planes are an important element in noise barrier design. In highway design, for instance, where minimal rights-of-way exist, barriers can provoke feelings of excessive enclosure or give a monotonous appearance. In such circumstances, it is necessary to create variety and interest in the design of the barriers and related landscape by changing the textures, choosing different materials, using color, and articulating the forms (Figure 660-13).

Mass:

Mass refers to the form and shape of a barrier. Massive, unrelieved forms can sometimes arouse uncomfortable feelings of claustrophobia or insecurity (Figure 660-14).

The apparent mass of a noise barrier can be minimized by means of stepped wall sections, staggered alignments, plantings, shadow lines or reveals, color variation, articulation of form, and integration with landform (Figure 660-15).

Texture:

Texture is a visual, surficial quality referring to the extent of detail of a material or design (Figure 660-16). Increased speed of travel, angle of vision, and distance from an object all tend to decrease the apparent degree of texture. Surfaces that are relatively smooth (i.e., fine-textured) not only cause undesirable reflections of light and sound but also promote monotony in the landscape (Figure 660-17).

8.0 DESIGN APPLICATION (CASE STUDIES)

To illustrate the application of noise abatement techniques and design principles, four case studies are presented below. All four cases are assumed to be based upon preplanned sites.

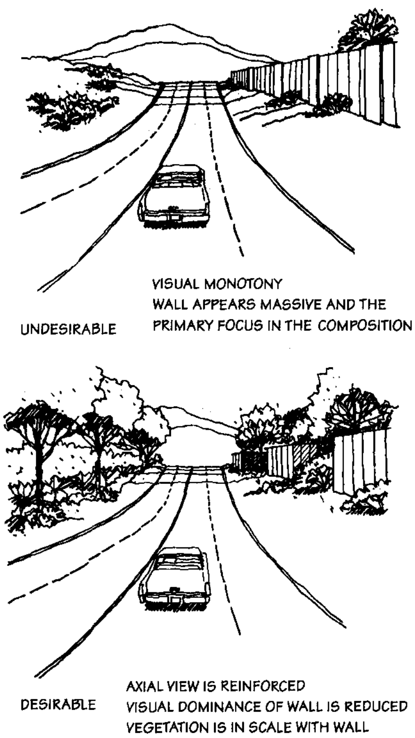


Figure 660-15. Visual diversity along highways. *Wall design and plantings can be composed to provide interesting visual sequences along highway corridors. Scale is important.*

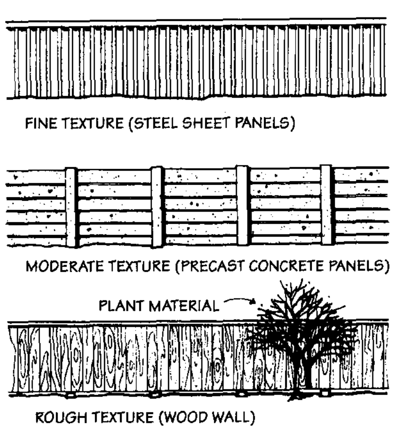


Figure 660-16. Wall texture. *Fine-textured walls are often monotonous, and may cause problems of reflective glare.*

Table 660-6. ASSESSMENT OF COMMUNITY RESPONSE TO VARIOUS NOISE LEVELS

Intruding noise, L_{eq} minus existing ambient L_{eq}	Impact catagory	Estimated community response description
−5	None	No observed reaction
0	Little	Sporadic complaints
+5	Medium	Widespread complaints
+10	Strong	Threats of community action
Greater than +10	Very strong	Vigorous community action

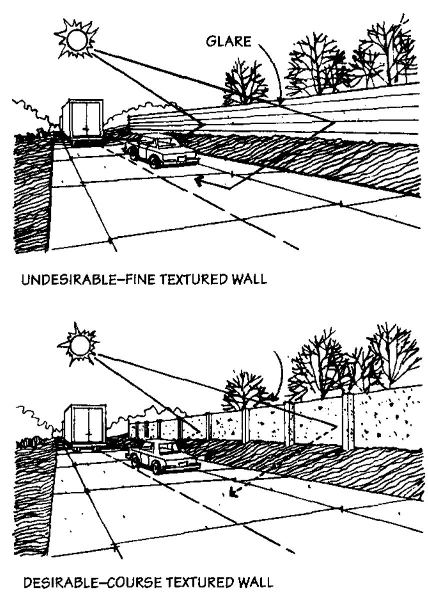


Figure 660-17. Coarse-textured walls minimize reflective glare and provide visual diversity along highways. *Plantings can also be used to minimize glare and enhance visual diversity.*

8.1 Recreational Development (Example Problem)

Description:

A major highway is proposed on the periphery of a proposed recreational park. Prior to development, it is necessary to assess the likely impact of traffic noise on the park (Figure 660-18).

Procedure:

1. Existing L_{eq} ambient noise levels at 12 positions in the park are measured at morning, evening, and night (Figure 660-19).
2. Projected traffic volumes for the proposed highway are obtained and used to predict traffic noise levels at various distances throughout the park.
3. The existing and predicted noise levels are compared, and an impact category is assigned to each of the 12 positions in the park according to Table 660-6.
4. An analysis of park program components is completed to assess plan relationships and sensitivity to noise.
5. A conceptual land use plan is prepared. The plan includes consideration of future noise levels for each program element, utilization of existing and proposed vegetation for noise buffering [30 m (100 ft) minimum], and placement of the least noise-sensitive facilities in the noisiest zones (e.g., parking lot, park building, and active recreational areas).

8.2 Residential Development (Example Problem)

Description:

A housing development is proposed next to an existing major highway. A noise limit of Ldn 60 dB(A) at the facades of the nearest houses is required (Figure 660-20).

Procedure:

1. Computer predictions show that with no noise screening, traffic noise levels would be 8 dB(A) above the limit.
2. The relative ground heights of the housing lots and the roadway vary along the length of the development. Sections are taken along this length and the height and position of berms and/or barrier walls are tested (Figure 660-21).
3. In the final design of the site plan, an earth berm solution is chosen. Care is given to its layout and form in order to minimize monotonous elevations and to ensure that slopes can be easily

Table 660-7. NOISE LEVEL DATA AT SITE FOR VARIOUS PHASES OF MINING (EXAMPLE PROBLEM)

	Plant				Noise-level data	
		Power				
Phase	Type	hp	kW	Number	At 10-m (32') distance	Sound power level
Initial ground clearance	Dozer	282	210	2	86	114
	Dump truck	416	310	2	81	109
	Excavator	101	75	2	80	108
	Loader	101	75	2	79	107
Overburden removal	Excavator					
	Electric	268	200	2	75	103
	Diesel	268	200	1	85	113
	Dump truck	416	310	18	81	109
	Grader	188	140	1	80	108
	Rock drill	—	—	1	90	118
	Hydraulic breaker	—	—	1	85	113
Coal extraction	Excavator					
	Electric	268	200	2	75	103
	Diesel	268	200	1	85	113
	Loader	268	200	1	85	113
	Dump truck	416	310	3	81	109
Waste-tip dressing	Dozer	282	210	2-3	86	114
	Grader	188	140	1	80	108

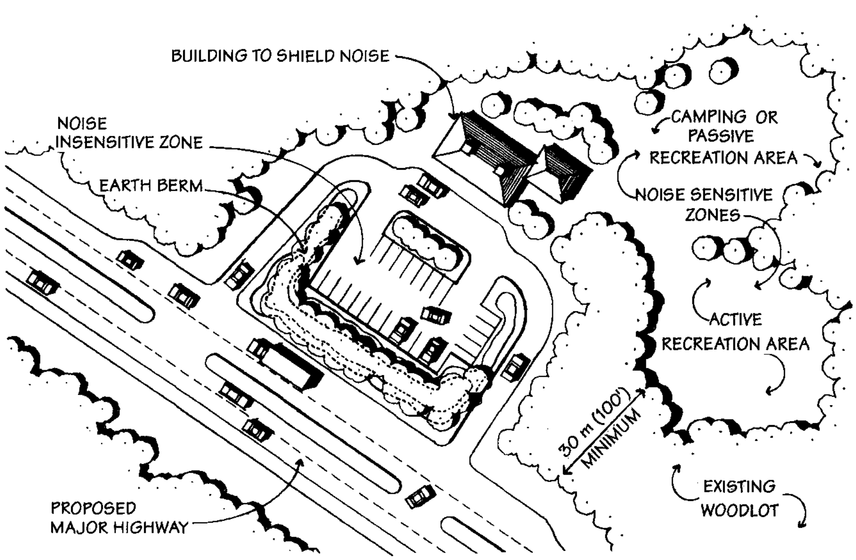


Figure 660-18. Acoustical site planning (example problem). *In this example, the noise-insensitive area (parking lot) is used as a buffer zone between the highway and the recreational areas.*

maintained. A variety of shrub and tree species is recommended to enhance the visual quality of the berm.

In the overall site plan of the community, the concern for sound control results in the integration of open space with the noise berm; this includes a pedestrian walkway, playground areas, and infill buffer planting. Housing units are laid out in clusters to maximize open space and to minimize the undesirable visual effects of a long, continuous facade. The buildings are used as shielding elements, and the spaces within the clusters are oriented away from noise sources to prevent a reverberation of sound within the spaces.

8.3 Industrial Development: Open-Pit Mine (Example Problem)

Description:

The development and operation of an open-pit coal mine is proposed in an area close to existing residential areas. Noise levels from earthmoving, blasting, transportation, and coal processing are a major concern.

Procedure:

1. A baseline survey is undertaken to measure existing L_{eq} ambient noise levels at 10 selected locations in the vicinity of the proposed mine.
2. Noise level data for each type of equipment to be used during the various phases of mining are compiled in Table 660-7. These data are then plotted on the community map to produce noise contours of the noise levels that can be expected at any place in the community (Figure 660-22).
3. Groups of dwellings where noise intrusion is expected to be a problem are identified.
4. Various methods of noise control are recommended, depending on the extent of expected intrusion. These include:
   a. Choice of quieter equipment
   b. Design of noise berms or other sound control structures where appropriate
   c. Acoustic insulation of certain dwellings
   d. Restriction of some mining operations to certain hours of the day

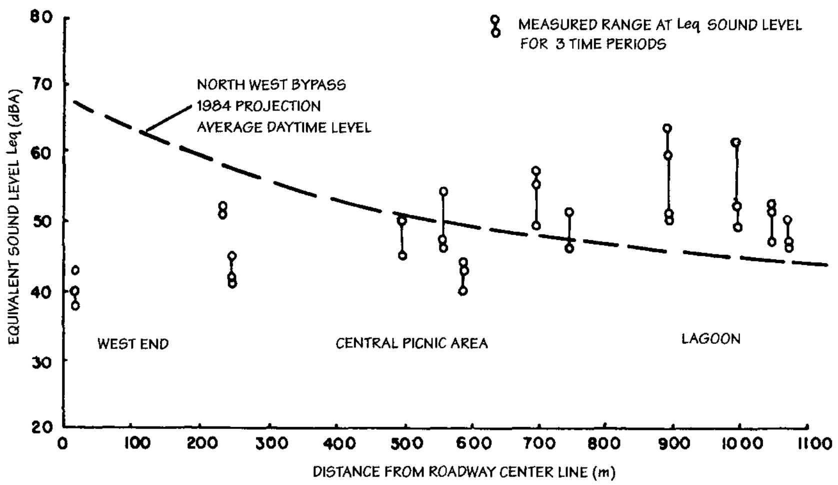


Figure 660-19. Existing l_{eq} ambient noise levels (example problem). *Noise levels are measured at twelve different places in the park. Small circles refer to morning, evening, and nighttime readings.*

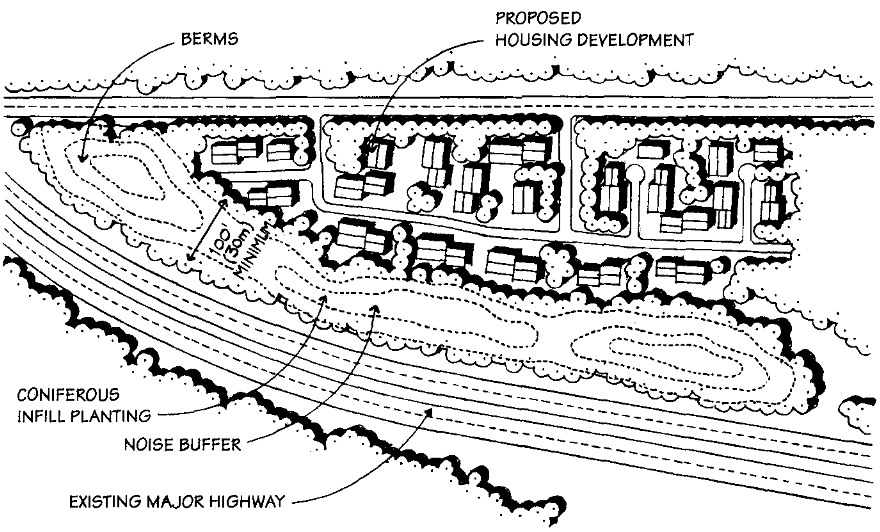


Figure 660-20. Acoustical site planning (example problem). *In this example, a greenbelt is used as a noise buffer between the major highway and the proposed residential development.*

e. Choice of transportation routes to minimize the extent of truck use in or near residential areas

8.4 Industrial Development: Steel Plant (Example Problem)

Description:

A steel mill is proposed adjacent to existing public recreational areas and a small rural community. Noise levels during the construction phase and afterwards from the operation of either blast or electric reduction furnaces are of great concern to the community and the regulating agencies (Figure 660-23).

Procedure:

1. A baseline survey is undertaken to measure existing L_{eq} ambient noise levels at selected locations within the existing recreational and residential areas.
2. Noise level data for the proposed blast and electric arc furnaces are collected.
3. A generalized site master plan evaluation is prepared to assess the most desirable location for the proposed furnaces.
4. After establishing the most feasible site locations, calculations of noise levels at the property line are made to determine where the levels would exceed 55 dB(A).
5. For those areas where noise levels would exceed 55 dB(A), recommendations are prepared to reduce the noise by the preservation of woodlot stands and/or the design of earth berms, etc.
6. Overall grading plans for the site are integrated with the requirements for earth berms to minimize construction costs.
7. A parkway belt is created to separate the construction and plant traffic from the recreational and residential areas.

The integration of noise berm design with a comprehensive master plan for the steel plant leads to the creation of a greenbelt area, which is constructed for the advantage of the public with little additional cost to the owner.

9.0 MAINTENANCE CONSIDERATIONS

A major concern in the design of acoustical barriers is the long-term maintenance involved. Ease of access, intrusion on adjacent property owners, durability of materials, minimum cost, ease of replacement, and visual appearances are the major considerations. Initial least-cost options may, in fact, have the highest cost when considering the implications of long-term maintenance.

9.1 Earth Berms

The development of earth berms as noise barriers requires the manipulation of landforms and the stabilization of the soil. The manipulation of landforms involves careful consideration of the surrounding grading and drainage conditions. New grading should blend into existing landscape as much as possible. Slopes should not exceed 1:3 for ease of grass cutting and equipment access. Groundcovers other than grass may be used; they usually require less maintenance, although weed control can be a

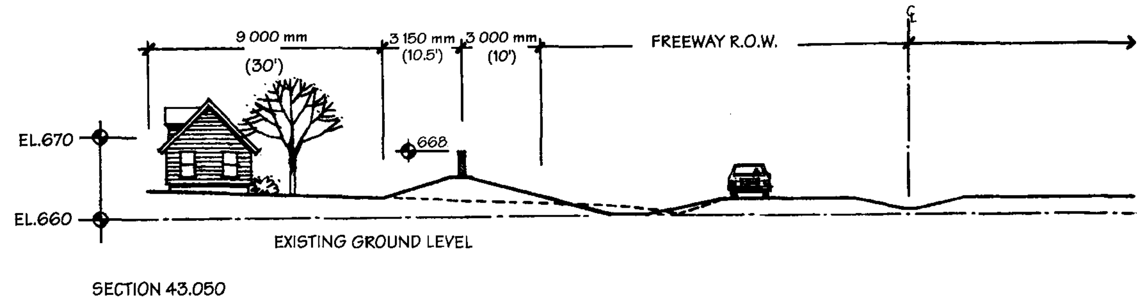


Figure 660-21. Berm height design (example problem). *Elevations are taken of all pertinent elements to determine whether or not diffraction angles are adequate, etc.*

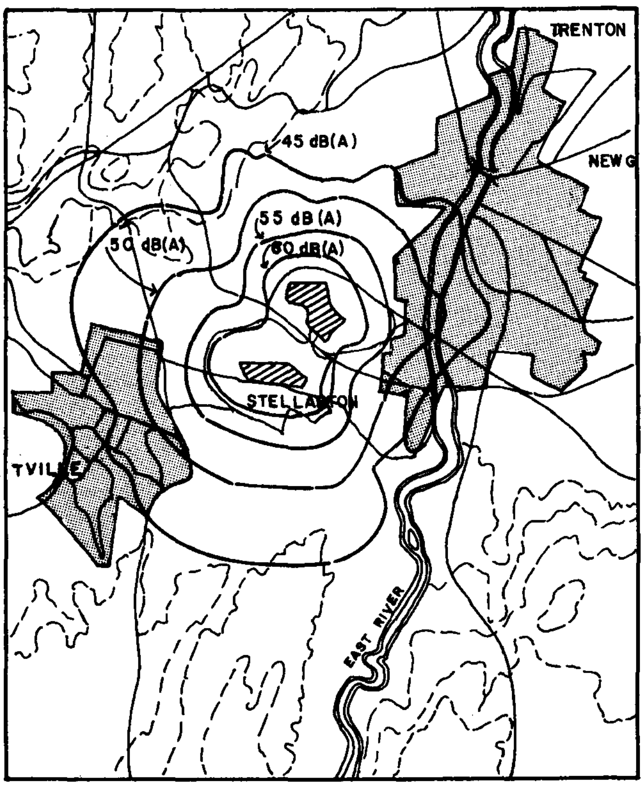


Figure 660-22. Mine location and predicted noise contours (example problem). *Contours show what noise levels can be expected at any location in the community.*

KEY POINTS: Barrier Design Principles

Visual attractiveness is a critical criteria for barrier design, in order to be an acceptable strategy for area residents, as well as highway users. The manipulation of planes, mass, and texture will alter the visual perception of these barriers.

1. A combination of vertical and horizontal lines can reduce the apparent height and monolithic appearance of the noise barrier.
2. The apparent mass of a noise barrier can be minimized by use of stepped wall sections, staggered alignments, plantings, shadow lines, color variation, articulation of form, and integration with landform (Figure 660-15).
3. Surfaces that are relatively smooth (i.e., fine-textured) not only cause undesirable reflections of light and sound but also promote monotony in the landscape (Figure 660-17). Increased speed of travel, angle of vision, and distance from an object all tend to further decrease the apparent degree of texture.

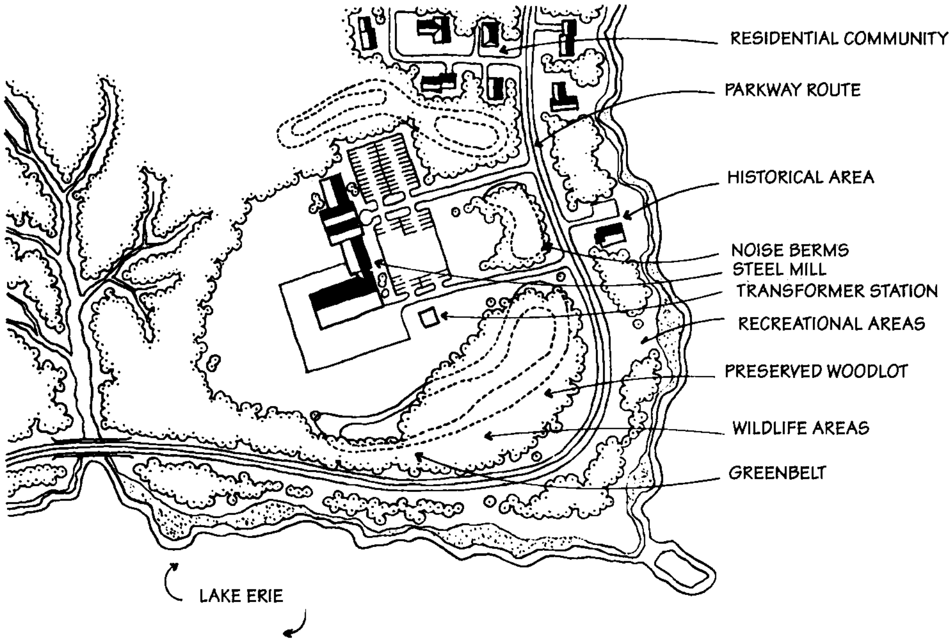


Figure 660-23. Preplanning of grading (example problem). *In this example, a greenbelt with noise berms buffers sensitive areas from industrial noise and visual intrusion, and also blends in integrally with existing public open space.*

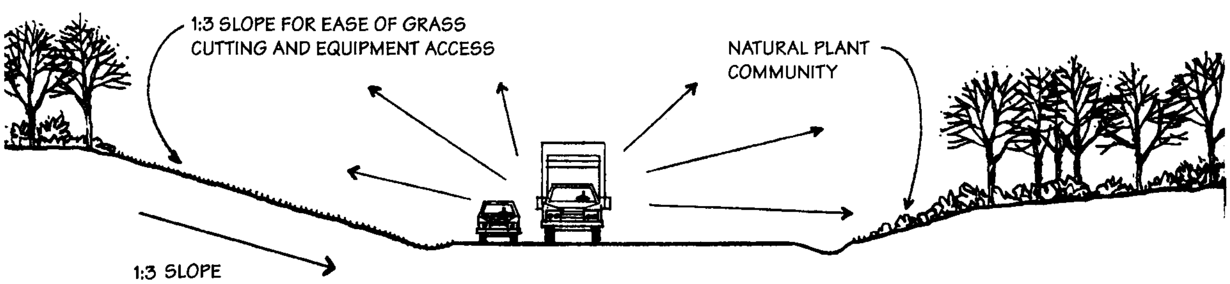


Figure 660-24. Low-Maintenance ground covers for earth berms. *Long-term, self-maintaining plant communities can be used as low-maintenance ground covers for earth berms.*

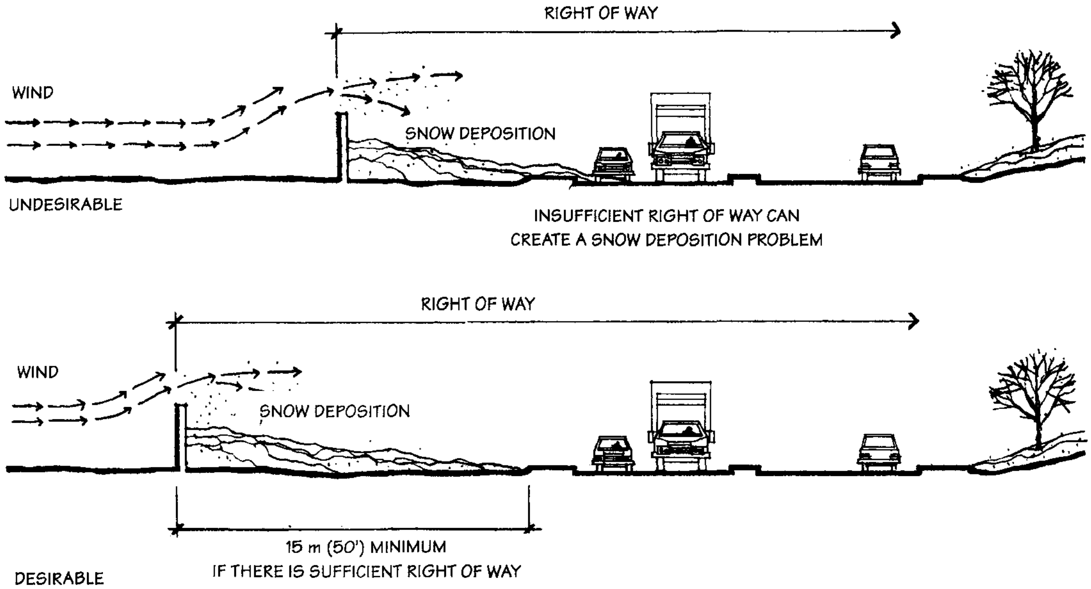


Figure 660-25. Noise barriers and snow deposition. *Rights-of-way should be established where possible to allow for accumulations of snow.*

major problem, especially in municipalities which have weed control legislation.

Recently, there has been an increased use of various groundcovers, shrubs, and trees in an attempt to provide a long-term, self-maintaining natural plant community, although the initial maintenance requirements can be higher (Figure 660-24).

9.2 Barrier Walls

The maintenance implications of noise barrier walls include such basic consideratins as access to both sides of the barriers and access to possible cutoff land. Design complexity, quality control during construction, and the choice of materials to minimize damage and abuse are factors that will affect long-term maintenance costs. As with berms, the location and alignment of noise barriers require study in order to prevent or reduce problems of snow drifting across roadways and walks, etc. (Figure 660-25).

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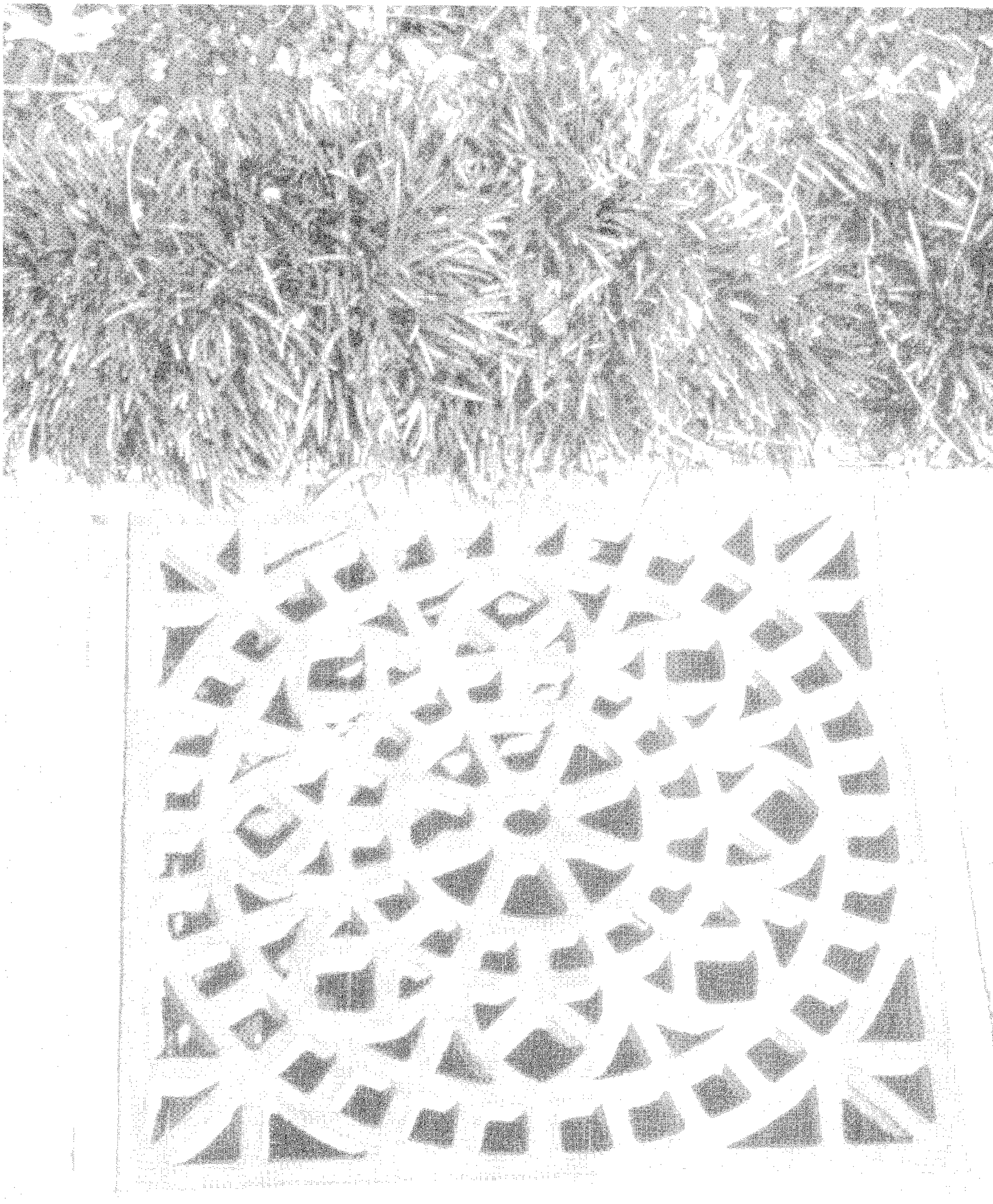

DIVISION 700

Site Utilities

Water Supply

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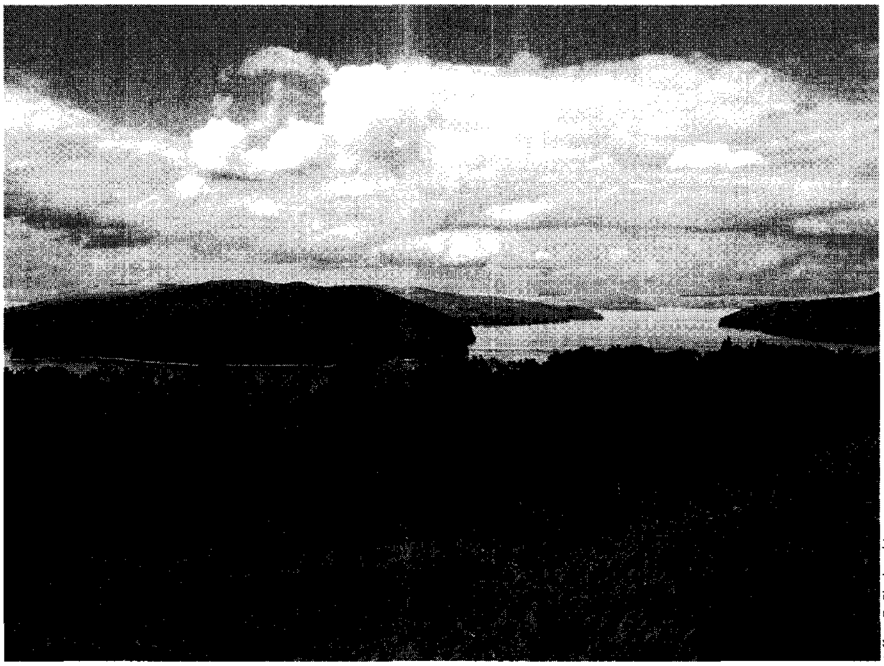

Jeffrey D. Blankenship

CONTENTS

1.0 INTRODUCTION

Piped water supplies are ordinarily used for:

1. Potable water for homes, schools, industries, etc.
2. Fire fighting
3. Nonagricultural irrigation (lawns and gardens)

In many cases, all three uses are supplied by a single system of piping, although there are cases where all three are supplied by separate systems.

2.0 STANDARDS AND CRITERIA

2.1 Water Quality

Water intended for human consumption must meet extensive physical, chemical, and biological standards for quality and reliability. These standards include color, taste, and transparency as well as freedom from bacteria and chemicals related to human or industrial wastes.

Specific water quality standards are published in the United States by individual state and federal agencies, but there are variations between states and counties and these standards do change with time. Some existing public water supplies do not meet all the standards to which they are subject because (1) most of these standards are very conservative and (2) some are not related to public health or safety but rather to aesthetic qualities of water (e.g., the ease of use in washing machines).

2.2 Water Quantity

The amount of water used in various parts of the world varies with regional legal, and political traditions. For instance, in the northeastern United States the average water use is about 75 gal (285 L) per capita per day in rural areas, and 150 gal (570 L) per capita per day in metropolitan areas. This is a region (1) where the English common-law tradition limits the right to water to nonconsumptive uses (use and return to stream), (2) where little water is used for irrigation, and (3) where water supply systems are funded entirely with local fees and taxes. In metropolitan areas of the southwest, where the Spanish law tradition grants preemptive rights to water on a first-come-first-established basis, average (publicly supplied) water use is about 350 gal (1325 L) per capita per day.

Table 710-1. PLANNING GUIDE FOR WATER

Types of establishments	Gallons per person per day (unless otherwise noted)
Airports (per passenger)	5
Apartments, multiple family (per resident)	60
Bathhouses and swimming pools	10
Camps:	
Construction, semipermanent	50
Day (with no meals served)	15
Luxury	100
Resorts, day and night, with limited plumbing	50
Campground with central comfort facilities	35
Cottages and small dwellingswith seasonal occupancy	50
Country clubs (per resident member)	100
Country clubs (per nonresident member present)	25
Dwellings:	
Boardinghouses	50
Additional for nonresident boarders	10
Luxury residences and estates	150
Multiple-family apartments	60
Rooming houses	40
Single-family houses	75
Factories (gallons per person per shift, exclusive of industrial waste)	35
Highway rest area (per person)	5
Hotels with private baths (two persons per room)	60
Hotels without private baths	50
Institutions other than hospitals (per person)	125
Hospitals (per bed)	250+
Laundries, self-serviced (gallons per washing, i.e., per customer)	50
Mobile home parks (per space)	250
Motels with bath, toilet, and kitchen facilities (per bed space)	50
Motels (per bed space)	40
Picnic parks (toilet wastes only, per picnicker)	5
Picnic with bathhouses, showers, and flush toilets (per picnicker)	10
Restaurants with toilet facilities (per patron)	10
Without toilet facilities (per patron)	3
With bars and cocktail lounge (additional quantity per patron)	2
Schools:	
Boarding (per pupil)	100
Day, with cafeteria, gymnasiums, and showers (per pupil)	25
Day, with cafeteria but no gymnasiums or showers (per pupil)	20
Day, without cafeteria, gymnasiums, or showers (per pupil)	15
Service stations (per vehicle)	10
Stores (per toilet room)	400
Theaters:	
Drive-in (per car space)	5
Movie (per auditorium seat)	5
Trailers without individual baths and sewer (per person)	50

Tables 710-1 and 710-2 illustrate the specific water requirements for various land uses and the rates of flow for various plumbing fixtures.

2.3 Fire Fighting Requirements

For fire fighting, the amount of water that should be immediately availableóparticularly the rate at which it should be capable of being delivered to any building or group of buildingsóis a function of the size, density,

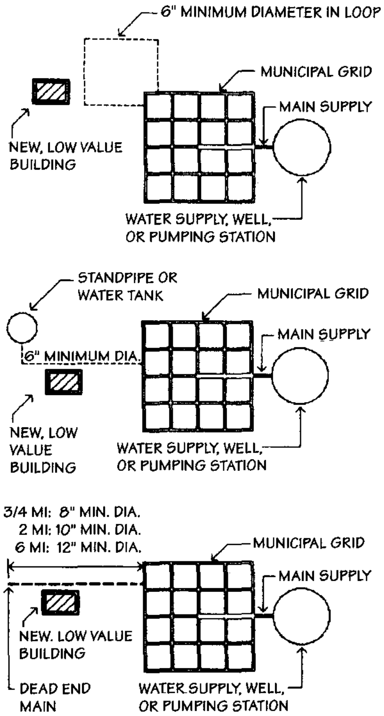


Figure 710-1. Water supply system configuration for fire fighting.

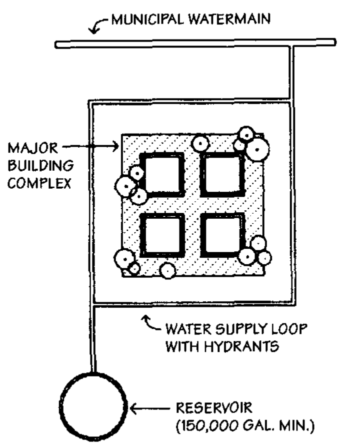


Figure 710-2. Firefighting water supply system configuration for highly valued development.

Table 710-2. RATES OF FLOW FOR CERTAIN PLUMBING, HOUSEHOLD. AND FARM FIXTURES.

Location	Flow pressure Kpa (psi)*	Flow rate, 1pm (gpm)
Ordinary basin faucet	55.2 (8)	7.6 (2.0)
Self-closing basin faucet	55.2 (8)	9.2 (2.5)
Sink faucet, 3/8-in	55.2 (8)	17.0 (4.5)
Sink faucet, 1/2-in	55.2 (8)	17.0 (4.5)
Bathtub faucet	55.2 (8)	22.7 (6.0)
Laundry tub faucet, 1/2-in	55.2 (8)	18.9 (5.0)
Shower	55.2 (8)	18.9 (5.0)
Ball-cock for closet	55.2 (8)	11.34 (3.0)
Flush valve for closet	103.4 (15)	56.7-151.2 (15-40)~
Flushometer valve for urinal	103.4 (15)	56.7 (15.0)
Garden hose (50 ft, 3/4-in sill cock)	206.8 (30)	18.9 (5.0)
Garden hose (50 ft, 5/8-in outlet)	103.4 (15)	12.6 (3.33)
Drinking fountains	103.4 (15)	2.8 (0.75)
Fire hose 11/2-in, 1/2-in nozzle	206.8 (30)	151.2 (40.0)

* Flow pressure is the pressure in the supply near the faucet or water outlet while the faucet or water outlet is wide open and flowing.
~ Wide range is due to variation in design and type of closet flush valves.
Source: EPA, *Manual of Water Supply Systems*, U.S. Government Printing Office, Washington, D.C.,1973.

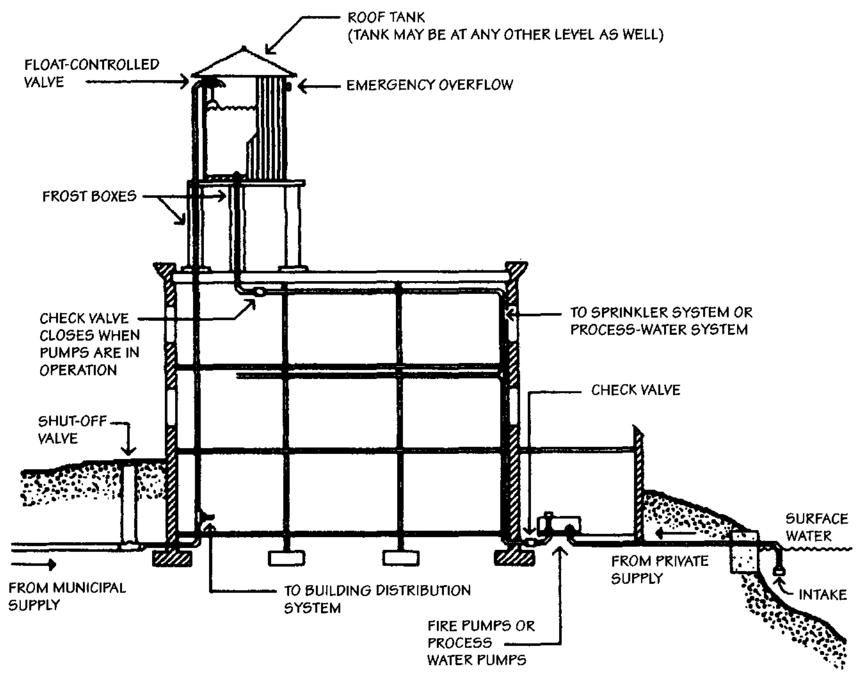


Figure 710-3. Private water supply for fire fighting.

and value of the building or group of buildings.

Successful fire fighting depends more on the speed with which coolant (water, typically) can be applied to a fire rather than the total amount of water available. The key to success is the speed with which fire fighting equipment can get onto the site and the rate at which water can be applied.

To minimize damage, it is essential to apply coolant to the fire before any room is fully involved. This is usually done either with hand-held chemical extinguishers or with water carried to the site by fire trucks. These trucks typically have 500- to 1000-gal (1900- to 3800-L) water tanks and a booster hose coiled on a spool for immediate use.

Once a room or building is fully involved, larger amounts of water are necessary for control. In low-density residential areas, the ability to supply at least three full-size fire hose streams [500 to 750 gpm

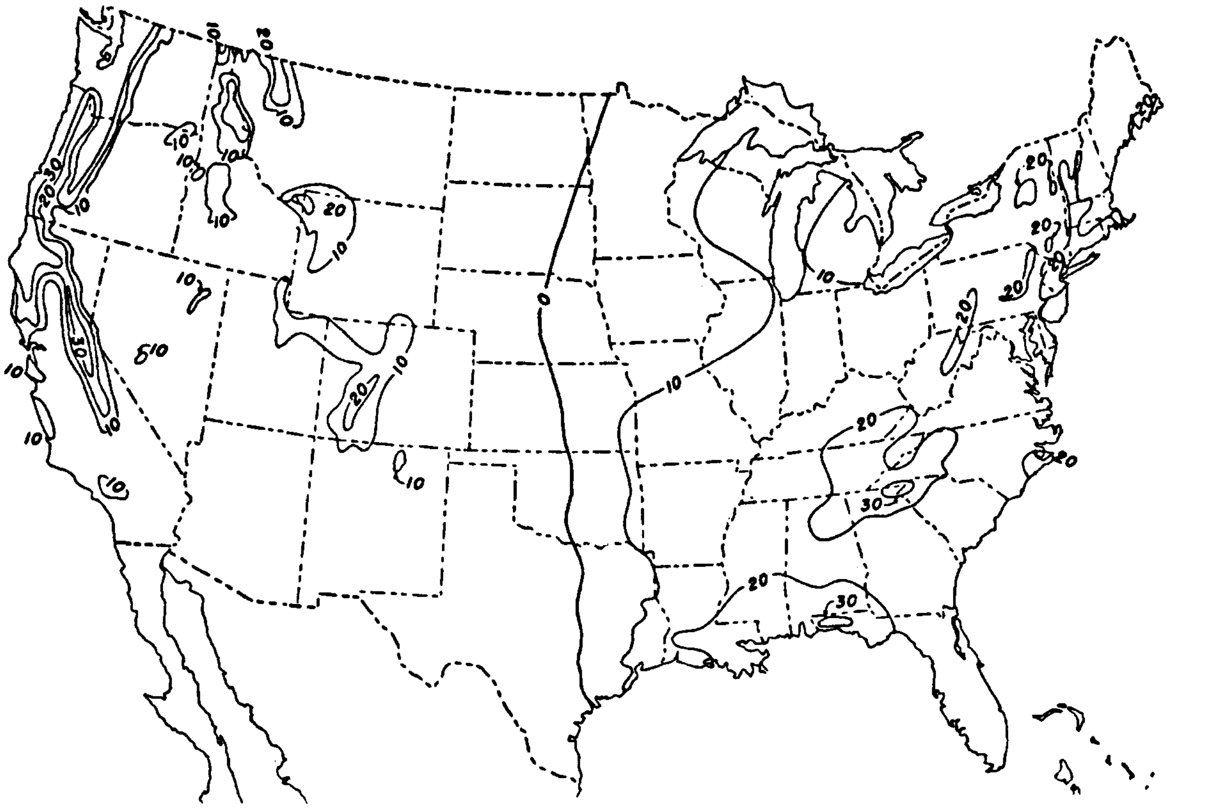


Figure 710-4. Areas of the United States where rainfall exceeds evapotranspiration (inches). *Note that west of the zero line there is generally no annual excess except in mountain areas and in the Pacific Northwest.*

(1900 to 2840 Lpm)] is recommended. Figure 710-1 shows the size of the mains and the length of the runs for a typical water pressure of 60 psi (413.7 Pa).

For large building complexes or denser urban development, conflagration control becomes the key consideration. The recommended design includes delivery rates of 2500 gpm (9500 Lpm) or more, with reserves of over 150,000 gal (570,000 L). To meet these goals in rural or suburban areas without excessive investment in very large diameter water mains, which are costly, adequate reserves of water should be provided as close as conveniently possible to the highly valued buildings.

This reserve usually takes the form of elevated tanks or standpipes linked to the water supply system with large-diameter or redundant mains from the standpipes to the vicinity of the highly valued development (Figure 710-2).

Alternative water reserves for conflagration control could be provided by surface impoundments located close to the highly valued buildings. Such surface supplies would have to be placed (1) so that fire trucks can park immediately adjacent to the impoundment [less than 20 ft (6 m) away] and (2) so that all parts of the buildings can be reached with not more than 600 ft (180 m) of hose. Alternatively, a separate water main and hydrant system can be provided to increase the effectiveness of the impoundment. Figure 710-3 shows a classical application of this principle.

Proper site design for fire fighting includes:

1. Direct, easily perceived, all-weather vehicular access to each building, to each hydrant, and, where appropriate, to each surface water impoundment
2. Control of the massing of any development with firebreaks or fire walls to reduce the possibility of conflagration
3. Site layout that allows fire hoses to be run to all sides of each building

In areas prone to brushfires, site design should include control of flammable vegetation around or near buildings, including the use of pavements, mowed lawns, irrigated plantings, and the avoidance of flammable shrubs (cedar, pine, spruce, etc.).

Hydrants should be laid out so that at least two are within 500 to 600 ft (150 to 180 m) of every building, with a larger number within that distance of any major building or congested area.

2.4 Nonagricultural Irrigation

Piped water supply systems are often used for non-agricultural irrigation. Normally, most communities regulate the time and condition of its use and design the supply system to handle an unrestricted flow. While the total volume of water used for such purposes in most areas is small compared to potable use, the peak rate of flow in suburban neighborhoods on the afternoon of hot summer days can be greater than the flow required for fire fighting. Unless the distribution system has been specifically designed for it, this peak demand will substantially reduce the ability of the system to deliver water to fires at the necessary rates, both during the peak hours and for several hours thereafter.

Since the use of water for non-agricultural irrigation is essentially an aesthetic or recreational concern, its provision cannot be considered essential to public health, safety, or welfare. Options include: (1) restrictions on the use of water, either prohibiting irrigation entirely or limiting it to

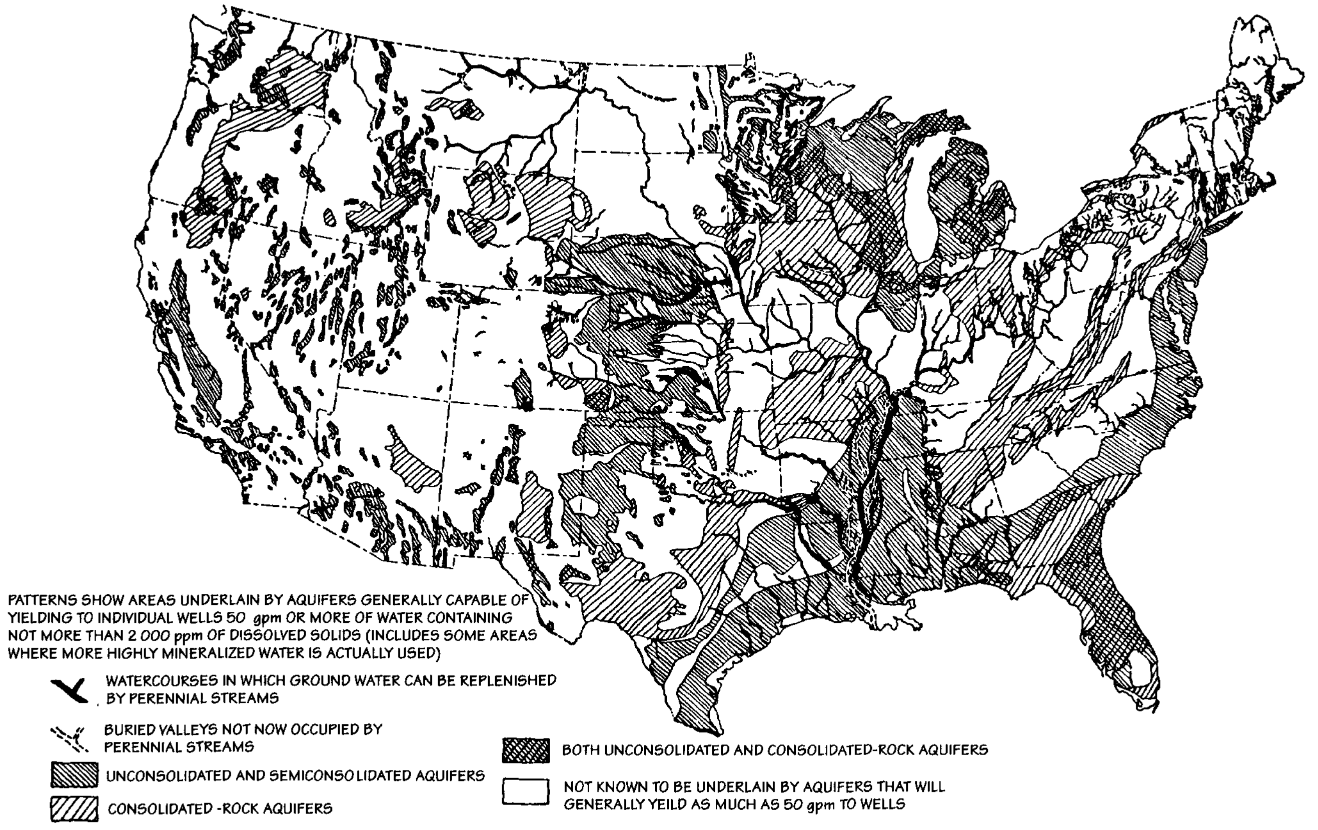


Figure 710-5. Principal aquifers of the United States.

hours of low water demand; (2) provision of automatic irrigation systems that operate at off-peak hours only; or (3) development of alternative water sources for irrigation. It must be recognized that waters diverted from ponds, streams, or groundwater, if drawn from sources of limited storage capacity, can have significant adverse effects both on the ponds and streams from which such water is drawn and on downstream waterbodies as well.

KEY POINTS: Standards and Criteria

Water supplies are typically used for human consumption, fire fighting, and irrigation. The quality and quantity of water required will vary by region and intended use.

1. The amount of water used in various parts of the world varies with regional climate, legal, and political traditions. Tables 710-1 and 710-2 illustrate the specific water requirements for various land uses and the rates of flow for various plumbing fixtures.

2. Elevated tanks linked to the water supply system, or surface water impoundments may be used as fire fighting reserves for large building complexes or dense development.

3. Fire hydrants should be laid out so that at least two are within 150 to 180 m (500 to 600 ft) of every building, with a larger number within that distance of any major building or congested area.

4. The peak rate of flow in suburban neighborhoods on hot summer days can substantially reduce the ability of the system to deliver water required for fire fighting. Nonessential water use may need to be restricted.

5. Alternative water sources for non-agricultural irrigation may have adverse impacts on the pond and stream system from which they are diverted, and should be discouraged unless carefully studied.

3.0 SOURCES OF WATER

3.1 General

Alternative sources of potable water for any building project include: (1) public water supply systems, (2) on-site wells of various kinds, and (3) surface reservoirs and ponds. Selection of the source depends on location and project size. In arid areas, public systems that draw their water from distant sources may be the only alternative. In more humid regions, especially away from urbanized areas, on-site sources may be the only alternative. In general, public sources, where available, will be the least costly and complex, and their use will often be mandated by local officials. Selection of the type of on-site source will depend on geologic opportunity.

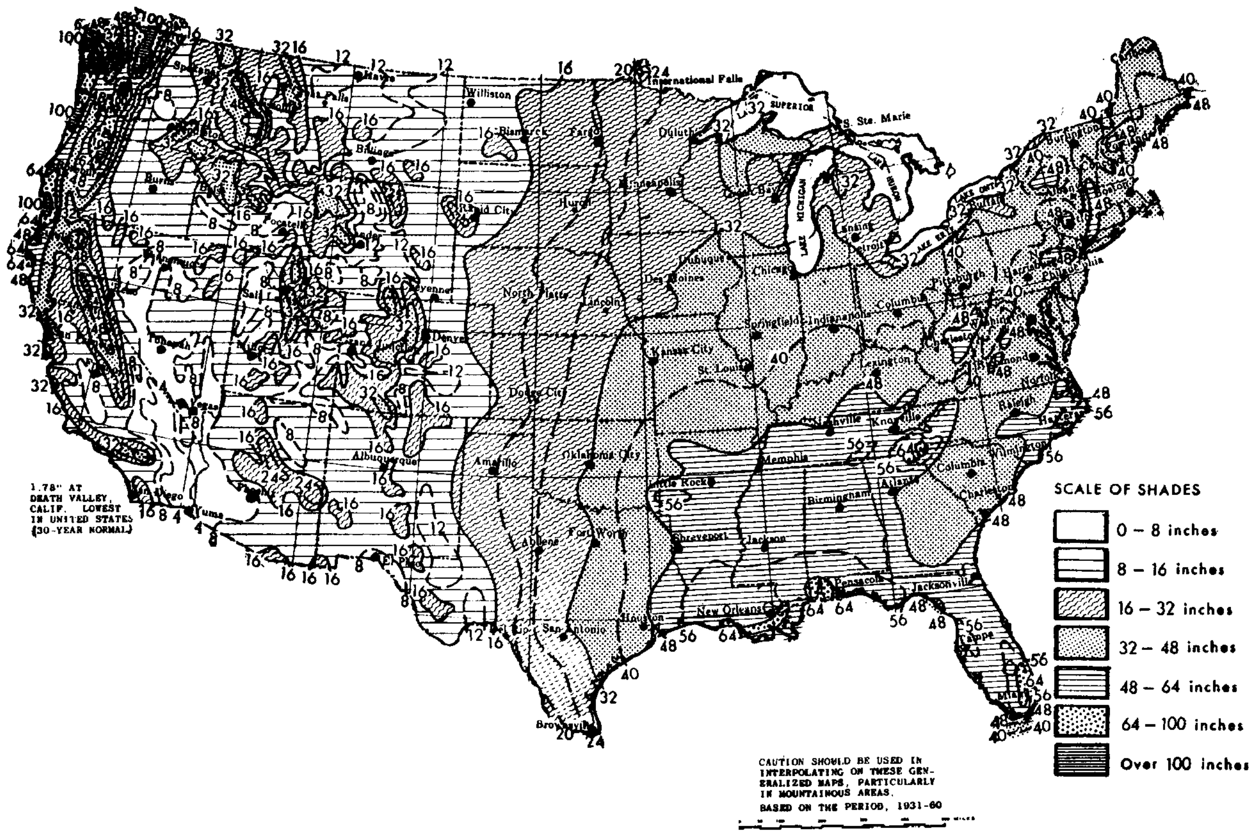


Figure 710-6. Mean annual precipitation in the United States.

3.2 Low-Yield Systems

For small projects requiring only a limited water supply, there are several possible sources, including wells, springs, cisterns, and surface impoundments (or catchments). The choice of system generally depends on regional geohydrologic conditions, with wells (where they are feasible) usually being the most cost-effective alternative.

Wells:

In most areas where annual rainfall exceeds evapotranspiration, sufficient moisture is retained in the soil to make low-yield wells feasible. Figure 710-4 shows the areas in the United States where adequate soil moisture can be expected, and Figure 710-5 shows principal aquifers. Note that the aquifer map shows only those aquifers that can be expected to produce at least 50 gpm (190 Lpm) per well, a yield sufficient to support a community of 1000 people. If lesser aquifers were included on the map, including those capable of supplying enough water for a single dwelling unit, then virtually the entire area where rainfall exceeds evapotranspiration would be indicated.

Many of these lesser aquifers are in areas that, upon casual examination, would not appear promising. In glaciated regions of the northeastern United States, for example, wells are commonly drilled into areas that have a thin mantle of compact glacial till overlying hard, seemingly impermeable rock in order to draw water from fractures in the upper 200 ft (60 m) of the bedrock. For specific information on the feasibility and cost of a low-yield well in any locality, contact local well contractors, local public health officials, or state or federal geologists. Table 710-3 shows a summary of the kinds of wells that have been used under various geological conditions.

Cisterns:

In areas where there is insufficient soil or fractured rock to retain enough water for wells, where the water table is inaccessible, or where the groundwater is contaminated, but where there is sufficient rainfall, potable water may be supplied by catching the rainfall on a controlled, impermeable surface and storing it in a cistern or covered reservoir. A typical installation would include a building roof to provide the catchment area, some form of pretreatment system (to keep debris, leaves, insects, bird droppings, etc., out of the cistern), the cistern itself (a large reinforced concrete or masonry tank), a water pump, and some form of final treatment or disinfection (chlorination) system.

The catchment area necessary to yield 100 gal (380 L) of water per day, assuming 75 percent capture and a dry year, would be 2000 ft^2 for 60 in of mean rainfall per year (185 m^2 for 1525 mm), 3000 ft^2 for 40 in (280 m^2 for 1015 mm), and 6000 ft^2 for 20 in (560 m^2 for 510 mm). Figure 710-6 shows mean annual rainfall figures for the United States.

The cistern volume required is a function of the distribution of rainfall through the year. In areas with rainfall limited to only one season, a very large storage capacity, about 30,000 gal (a volume 10 ft x 15 ft x 30 ft), or 115,000 L (a volume 3 m x 5 m x 9 m), will be required per 100 gal (380 L) of water use per day. In regions with rainfall distributed throughout the year, only a fraction of this, perhaps 20 to 25 percent would be required. Figure 710-7 shows the seasonal distribution of rainfall for the United States.

Table 710-3. SUITABILITY OF WELL CONSTRUCTION METHODS FOR DIFFERENT GEOLOGICAL CONDITIONS *

					Drilled		
					Rotary		
Characteristics	**Dug**	**Bored**	**Driven**	**Percussion**	**Hydraulic**	**Air**	**Jetted**
Range of practical depths (general order of magnitude)	0-15 m (1-50')	0-30 m (0-100')	0-15 m 0-50')	0-300 m (0-1000')	0-300 m (0-1000')	0-225 m (0-750)	0-30 m (0-100')
Diameter	.9-6 m (3-20')	50-750 mm (2-30")	31-50 mm (11/4-2")	100-450 mm (4-18")	100-600 mm (4-24")	100-250 mm (4-10")	50-300 mm (2-12")
Type of geologic formation: Clay	Yes	Yes	Yes	Yes	Yes	No	Yes
Silt	Yes	Yes	Yes	Yes	Yes	No	Yes
Sand	Yes	Yes	Yes	Yes	Yes	No	Yes
Gravel	Yes	Yes	Fine	Yes	Yes	No	6 mm (1/4") pea gravel
Cemented gravel	Yes	No	No	Yes	Yes	No	No
Boulders	Yes	Yes,if less than well diameter	No	Yes,when in firm bedding	Difficult	No	No
Sandstone	Yes, if soft and/or fractured	Yes, if soft and/or fractured	Thin layers only	Yes	Yes	Yes	No
Limestone	Yes, if soft and/or fractured	Yes, if soft and/or fractured	No	Yes	Yes	Yes	No
Dense igneous rock	No	No	No	Yes	Yes	Yes	No

* The ranges of values in this table are based upon general conditions. They may be exceeded for specific areas or conditions.
Source: EPA, *Manual of Water Supply Systems*, U.S. Government Printing Office, Washington,D.C., 1973

Figure 710-8 shows a typical cistern design with a simple pretreatment device shown between the roof drain downspout and the cistern. The cistern itself must be structurally designed to withstand the hydrostatic pressure inherent in liquid containers (as in swimming pools). The pretreatment system shown is intended only to screen coarse debris and to divert the dust-laden first flush away from the cistern. Final treatment of the water would be performed between the cistern and the user and should include filtration and chlorination.

Figure 710-9 shows a very old type of cistern and pretreatment system used in dry areas of the Mediterranean to capture rainwater that fell in village or palace courtyards. The surface runoff would infiltrate to the system all around the perimeter of the cisternís apron and be filtered through sand fill to the cisternís water level. Storage includes both the cistern itself and the saturated sands (percent water in total volume = about 40 percent). This construction

KEY POINTS: Sources of Water

Sources of potable water for any building project include: (1) public water supply systems, (2) on-site wells of various kinds, and (3) surface reservoirs and ponds. Selection of the source depends on location and project size.

1. In general, public water sources, where available, will be the least costly and complex, and their use will often be mandated by local officials.
2. Low yield wells are feasible for on-site use in most regions where rainfall amounts exceed evapotranspiration. Consult local officials or well contractors for specific information on the feasibility and cost of these wells for a particular site.
3. Cisterns may be used to capture runoff from a controlled surface in areas where sufficient rainfall is available throughout the year. Water must be filtered and disinfected prior to human consumption.
4. Surface catchments may be possible if runoff from a large enough area can be intercepted and impounded on site. The drainage area should be clean and free of all livestock uses or other sources of pollution. Water must be filtered and disinfected prior to human consumption.
5. For larger projects, a larger well or surface reservoir may be required. The design of either system will require specialized engineering and/or hydrogeologic expertise.

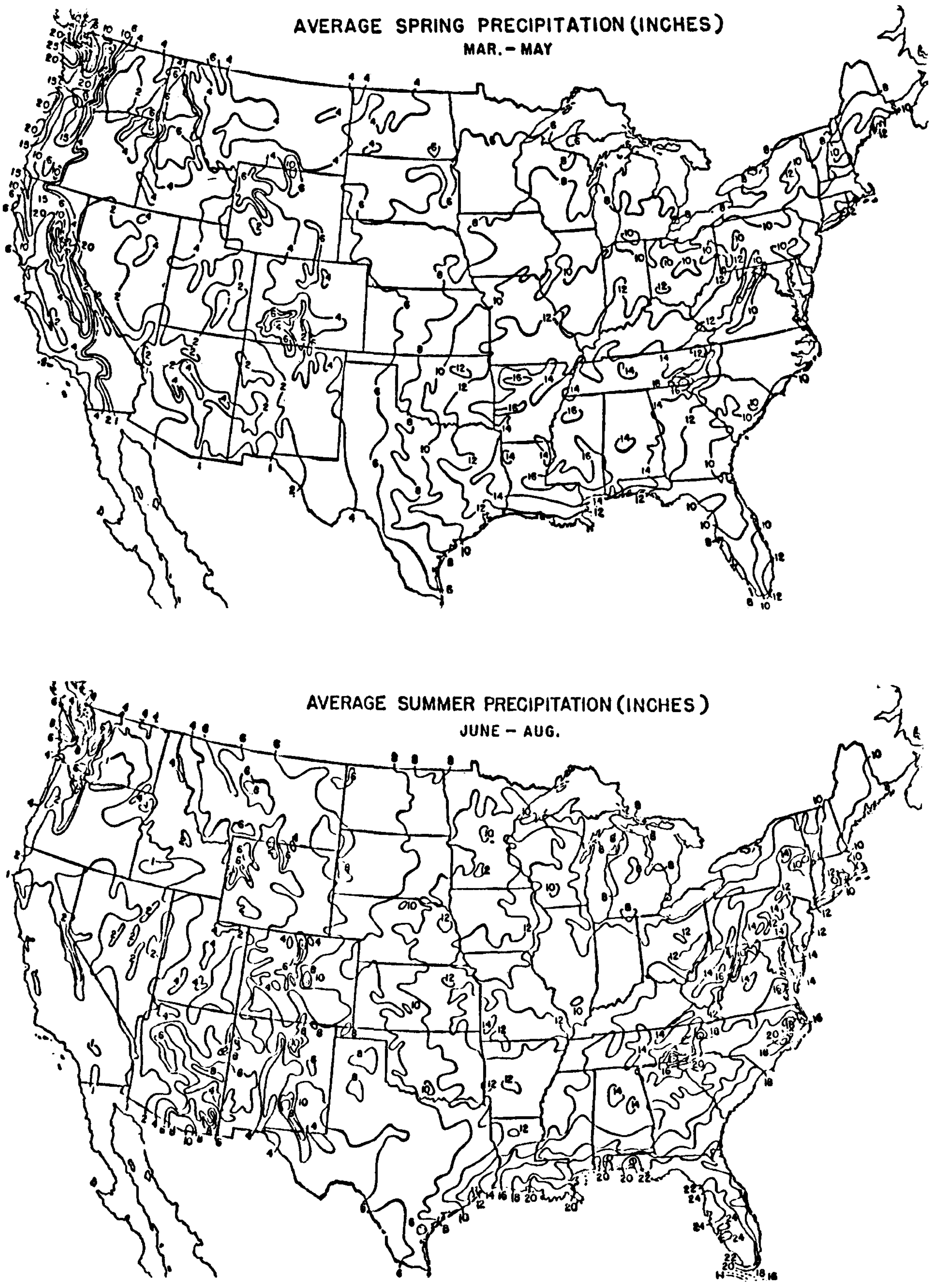
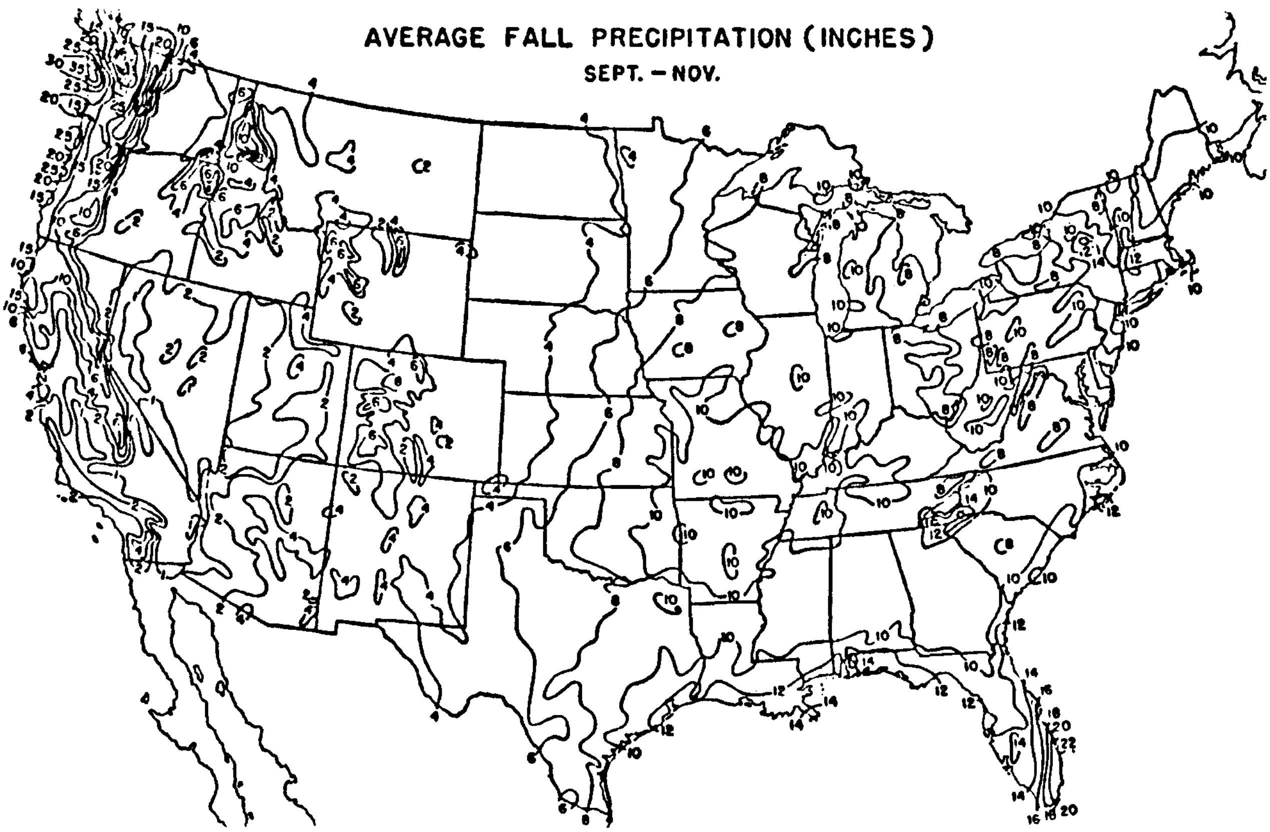


Figure 710-7. Seasonal rainfall distribution in the United States.



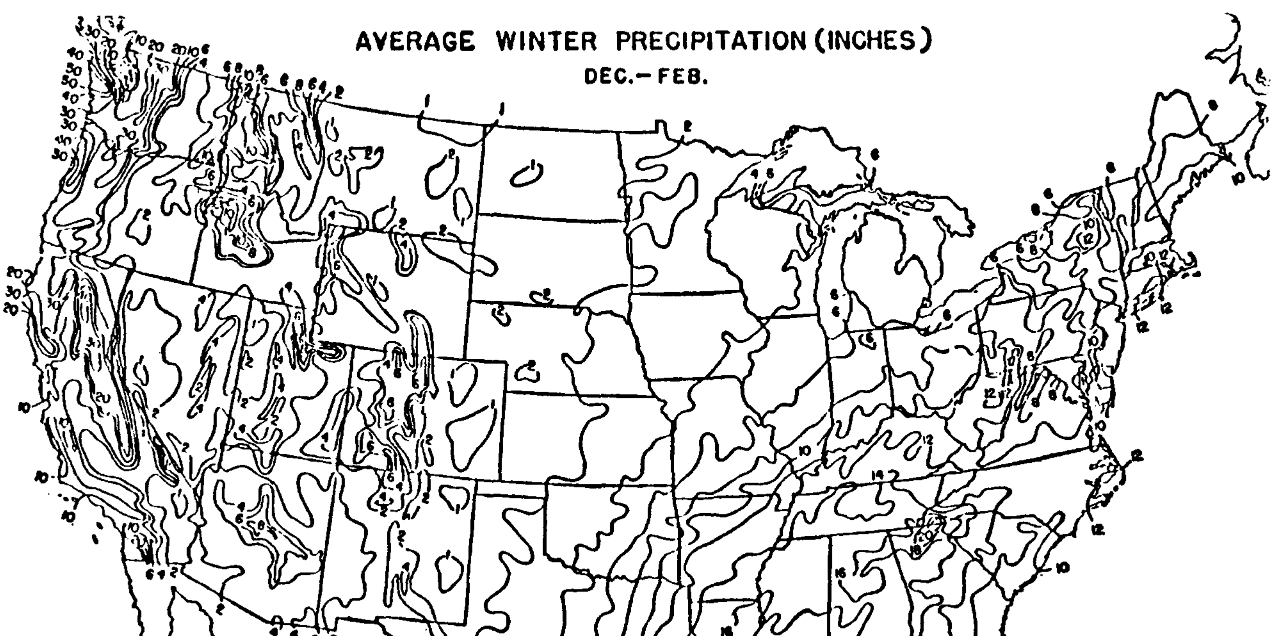


Figure 710-7 (cont.). Seasonal rainfall distribution in the United States.

requires no reinforcing and relatively little cement.

Surface Catchments:

In areas where groundwater is not available and where rainfall is not well-distributed throughout the year, individual water collection and storage may be possible if the runoff from a large enough area can be intercepted and impounded. Figure 710-10 shows the drainage area in acres required to supply 1 acre-foot (1233.5 m^3) [326,000 gal (1,304,000 L), or enough for the domestic use of two to three dwelling units] of water for various parts of the United States, or for similar areas in other parts of the world. This drainage area should be clean (preferably grassed) and free of all livestock uses or other sources of pollution.

The reservoir should be no less than 8 ft (2.4 m) deep at its maximum and should be large enough to store at least 1 year's average runoff from its tributary watershed. Figure 710-11 shows a plan and section of a typical storage pond.

Treatment should include filtration and disinfection (chlorination). Filtration could be by slow, sand filtration in a treatment facility constructed of concrete built on-site for the purpose, or by pressure sand filtration or diatomaceous filtration in a prefabricated metal or plastic package system. For detailed information on treatment systems and disinfection available in any locality, consult local health officials, equipment suppliers, and the U.S. Natural Resource Conservation Service or a similar agency outside the United States.

3.3 High-Yield Wells

For larger projects, such as a large institution or a new town, a larger well or surface reservoir may be required. The design of either system will require specialized engineering and/or hydrogeologic expertise. In the northeastern United States and southeastern Canada, wells can be expected to be less costly and require less (if any) water treatment, if they are geologically feasible. The feasibility of high-yield wells is highly dependent on local conditions, with yields ranging from 50,000 to 1 million gal (190,000 to 3,800,000 L) per well per day. Well sites with good yield potential can be very valuable, and they should be carefully considered in planning any large land area. Unfortunately, local water supply officials usually lack the funds, foresight, and capability to protect good well sites from development for other uses.

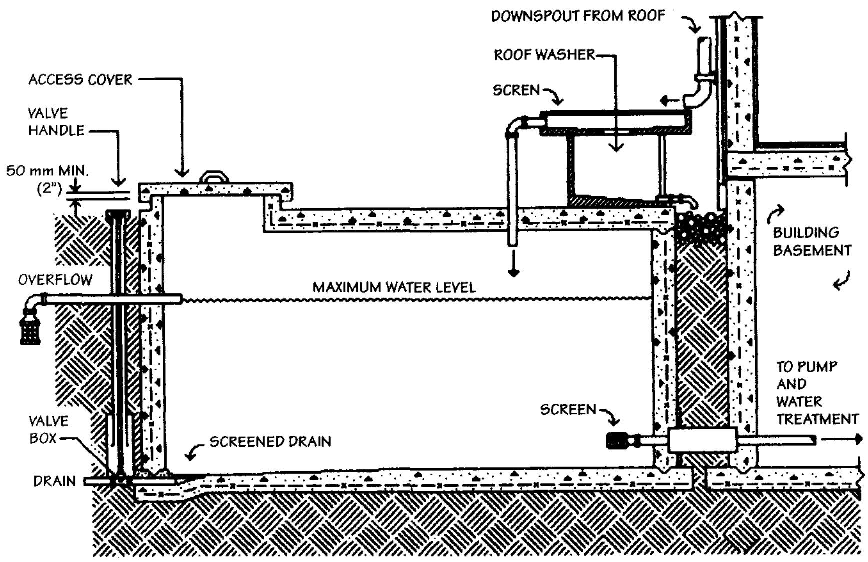


Figure 710-8. Typical cistern design.

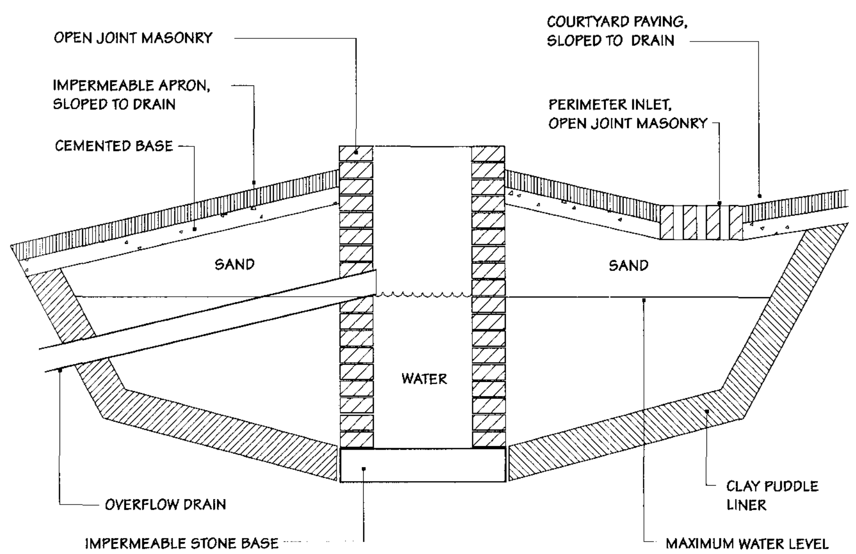


Figure 710-9. Ancient Mediterranean cistern.

In the glaciated northeastern United States, good sites for high-yield wells include coarse outwash plains, ice channel fillings along valleys, river terraces, kame fields, and similar surficial deposits. Shallow aquifers are often characterized on their surface by xerophytic species such as pitch pine (*Pinus rigida*).

Development of high-yield wells should take into account:

1. State well protection requirements
2. The character and land use history of the tributary area

When used for public water supplies, high-yield wells are often required to be protected by a buffer zone on which most other land uses are prohibited. Such zones can be several hundred feet wide [e.g., in Massachusetts a 400-ft (120-m) radius is required].

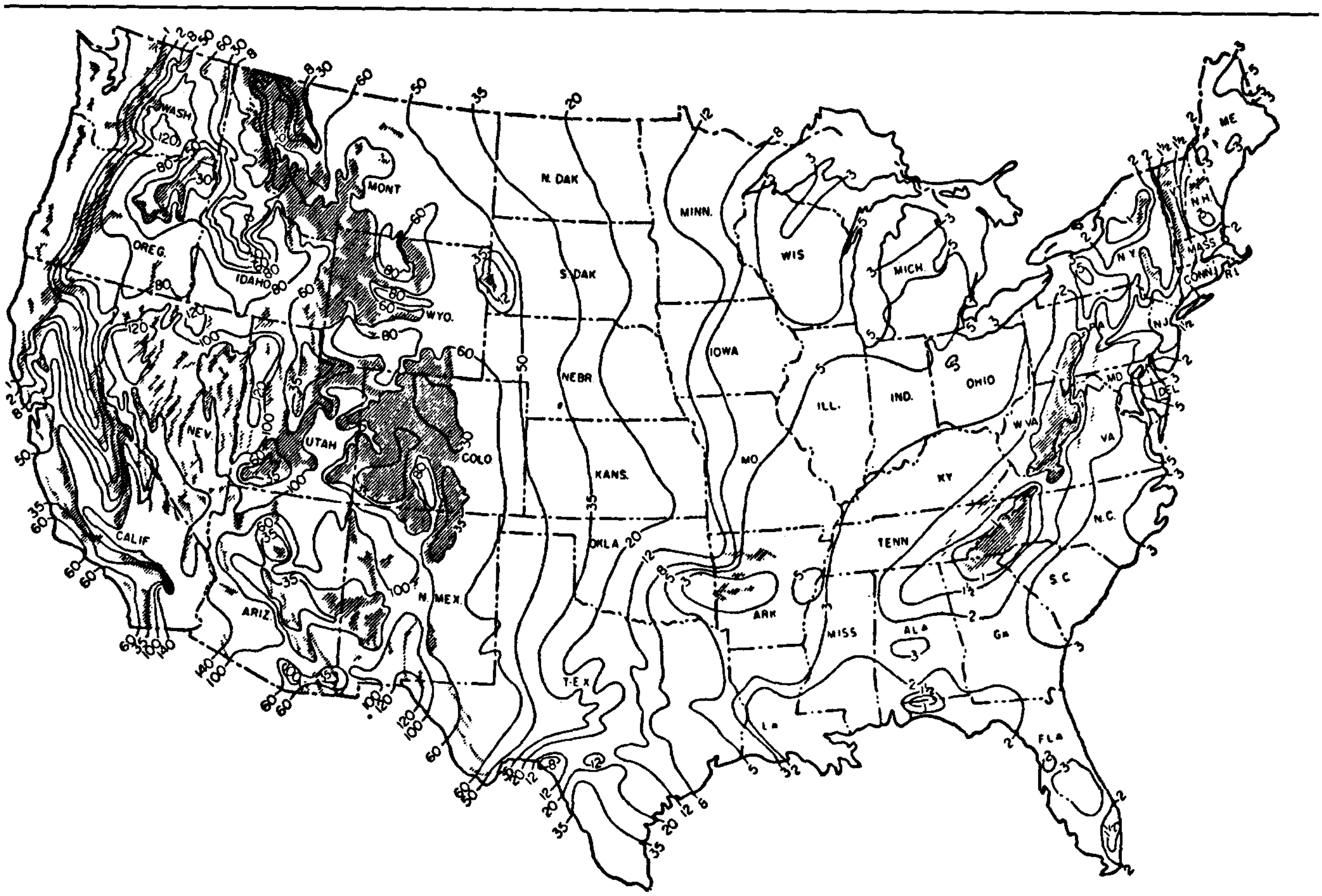


Figure 710-10. Approximate drainage area required per acre-foot of storage. *Note that mountainous areas have been crosshatched to signify that the numbers may not apply, since rainfall in these areas is highly variable.*

3.4 Surface Water Supplies

Surface water supplies include:

1. Uncontrolled run-of-river systems (as in St. Louis and New Orleans)
2. Main stream, multipurpose dams (e.g., Hoover Dam/Lake Mead)
3. Special-purpose reservoirs built on tributary streams (e.g., Massachusetts Quabbin and a multiplicity of small reservoirs throughout the northeastern United States)
4. Natural ponds and lakes with clean waters (e.g., Lake Michigan)

Water drawn from run-of-river and main stream, multipurpose dams requires extensive treatment before use, including clarification, filtration, and chlorination, with constant quality control.

Water drawn from tributary reservoirs and from clean ponds and lakes can be used with relatively little pretreatment, depending on the specific case and on state standards.

For information on surface water quality, consult state and other water quality agencies. In the United States, surface waters are generally classified by state as Class A, suitable for drinking with little or no treatment; Class B, suitable for drinking with treatment; and Class C or lower, not suitable for drinking.

4.0 CONSTRAINTS ON WELL DEVELOPMENT

The development of high-yield wells can lower water tables significantly and draw water from considerable distances. The planning of a high-yield well should include consideration of the following development constraints:

1. Proximity to seawater and the possibility of salt intrusion
2. Proximity to organic deposits(swamps, marshes, etc.)
3. Possible urban land use conflicts
4. Possible industrial and waste disposal contamination

4.1 Proximity to Seawater

Figure 710-12 shows the typical relationship of fresh groundwater to brackish groundwater in ideally homogeneous soils in seacoast conditions. Note that the fresh water, in effect, floats on top of the salt water because of its lower specific gravity. Figure 710-13 shows the effect of lowering the water table with a well. The area of the cone of the depression will be such that the annual yield of the well will equal the annual surplus of rainfall over runoff and evapotranspiration for the area of the cone, and the depth of the cone will be whatever is necessary to provide a steep enough gradient to move the water to the well. The more permeable the soil, the flatter the cone. The greater the yield, the larger the cone in all dimensions.

In a seacoast condition, if too high an annual volume is withdrawn, so that the water table falls to mean sea level, brackish water will enter the well, ruining it for water supply purposes.

4.2 Proximity to Organic Deposits

Figure 710-14 shows a typical high-yield well installation in the northeastern United States. Both the organic deposits and the unconsolidated aquifer lie along a valley. A specific problem is that organic deposits tend to be concentrators of metallic sulfides (bog iron) by the decomposition of organic detritus. These sulfides are stable only as long as they are surrounded by water devoid of dissolved oxygen. Fortunately, these organic deposits also tend to be relatively impermeable; as a result, the cone of depression at nearby wells will deform, drawing a relatively small proportion of the wellís total flow from the organic deposit.

However, if too high an annual volume of water is withdrawn from such a well, waters bearing oxygen will both dissolve the metallic sulfides and increase the permeability of the deposit, significantly increasing the iron and/or manganese content of the well, ruining it for water supply purposes. (Resting the well, allowing anaerobic conditions to reestablish themselves in the organic deposits, will often restore the status quo ante.)

4.3 Land Use Density and Waste Disposal

The urbanized use of land and the potable use of the waters underlying it are compatible, subject to the following conditions:

1. The wastewater is disposed of through leaching systems that do not intersect or penetrate the water table.
2. The land use density is not excessive.
3. The past land uses of the recharge area did not involve the use, storage, shipment, or disposal of chemicals.

Relationship between Sewage Leaching Systems and the Water Table:

All modern sanitary codes in the United States require at least 600 mm (2 ft) of free percolation between the bottom of any infiltration device (cesspool, leaching bed, leaching trench, leaching pit, etc.) and the water table. This percolation is essential to the effective control of pathogens and the oxidation of wastes.

Unfortunately, in the last century no such restrictions existed, and in fact the

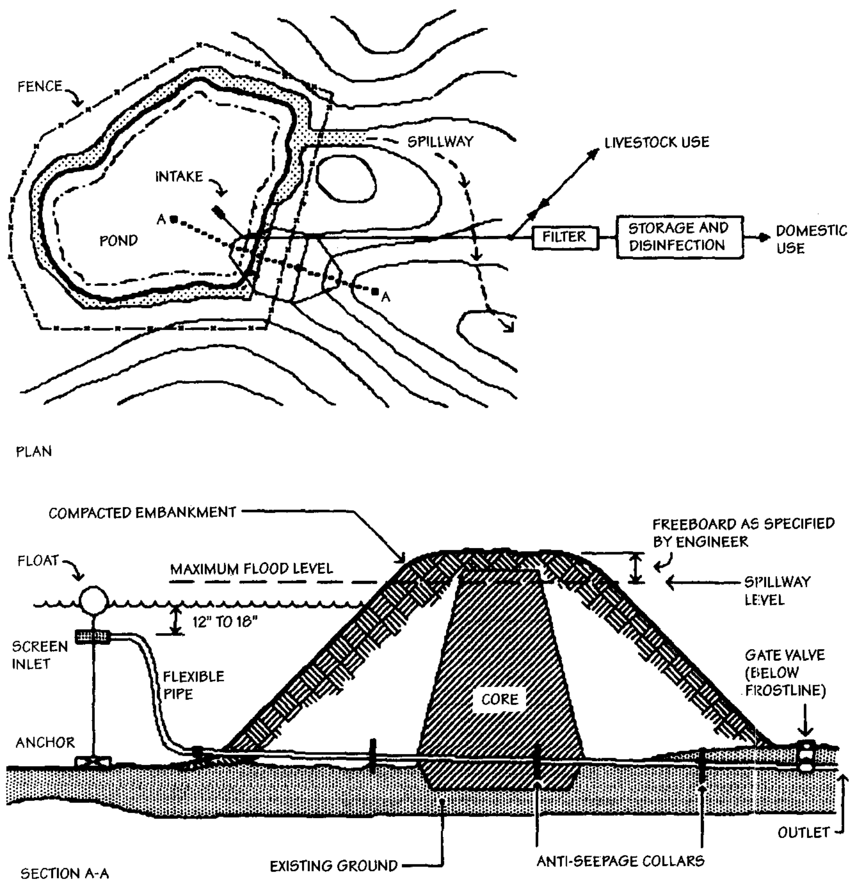


Figure 710-11. Storage pond.

KEY POINTS: Constraints on Well Development

The development of high-yield wells can lower water tables significantly and draw water from considerable distances. The planning of a high-yield well should include consideration of the following development constraints:

1. Wells in seacoast environments must maintain adequate water table levels. If the water table falls to mean sea level, brackish water enters the well, and ruins it for water supply purposes.
2. In areas where wells are adjacent to organic deposits, withdraw of significant volumes may increase the iron and/or manganese content of the well, ruining it for water supply purposes. Resting the well, will often correct the problem.
3. Contamination from wastewater is a concern in areas with old or failing cesspools, leaching fields, etc. No well should be developed in areas where the its cone of depression would include any significant number of old buildings, unless site analyses demonstrate that no contamination problem exists.
4. The denser the development, the higher the concentration of nitrates from on-site wastewater disposal which may pollute groundwater. Acceptable densities are a function of rainfall amounts, soil permeability and infiltration rates.
5. Active or vacant Industrial sites, including processing, chemical storage, shipping, or waste disposal, should not be included in the recharge cone of any potable well, unless site analyses demonstrate that no contamination problem exists.

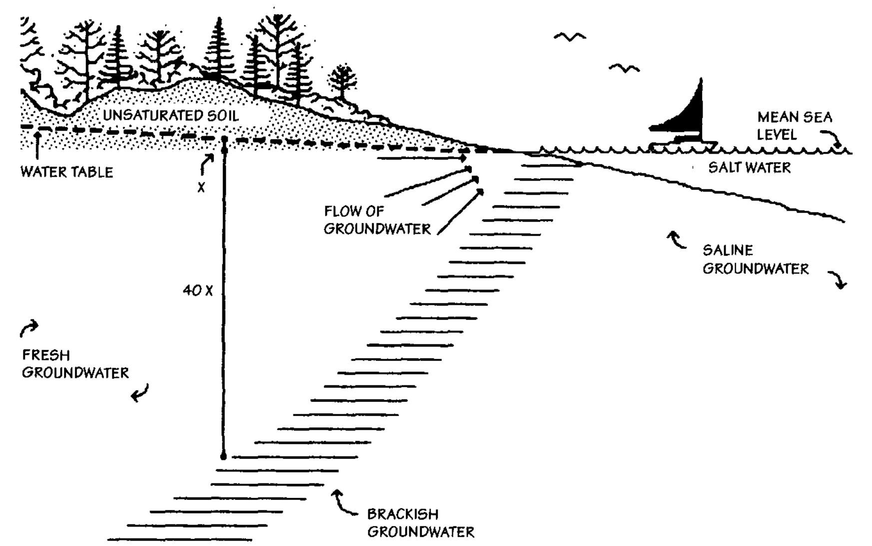


Figure 710-12. Groundwater environment at seacoast.

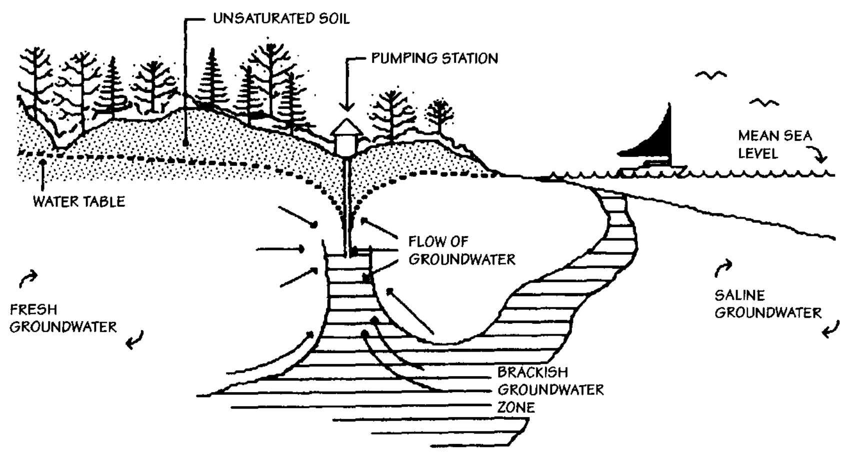


Figure 710-13. Effect of well drawdown below mean sea level on groundwater flow.

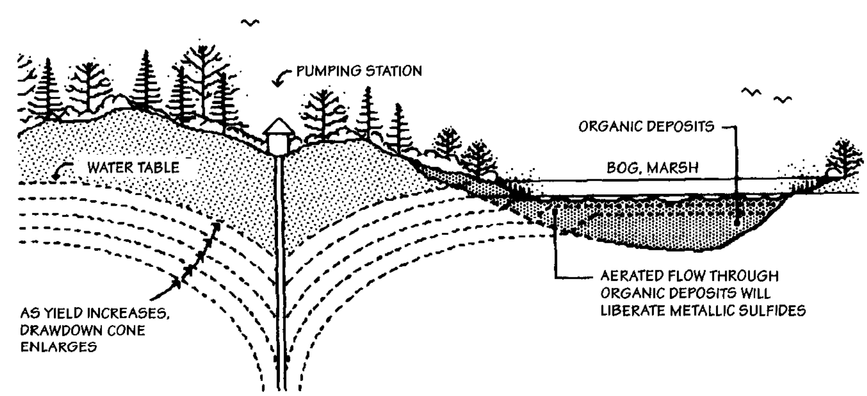


Figure 710-14. Effects of well drawdown on metallic sulfides in organic deposits.

Table 710-4. REQUIRED LOT SIZES FOR INCHES OF EXCESS RAINFALL OVER EVAPOTRANSPIRATION (U.S. UNITS)

Excess rainfall, in	Lot size, ft2/d.u.
5	120,000
1	60,000
20	30,000
30	22,500
40	15,000

*Ft^2 per dwelling unit.

texts of the period recommended that cesspools and leaching pits be dug down into the water table. Furthermore, in many older neighborhoods where the cesspools were not deliberately dug deeply, the advent of public water supplies led to the conversion of the old dug wells to cesspools. The result is that no well should be developed in an area where the wellís cone of depression would include any significant number of old buildings, unless site specific analyses demonstrate that no problem exists.

Density of Development:

Although proper on-site wastewater disposal will eliminate or destroy most water contaminants, it does increase significantly the nitrate concentration of the groundwater. The denser the development, the higher the concentration, but higher rainfall spread over the entire year will lower the concentration. As a general measure of the acceptable level of concentration for any region, densities of 1 to 2 dwelling units per acre are considered an upper limit in the United States (where the excess of rainfall over evapotranspiration is 500 mm(20 in) per year). Where the excess of rainfall is less, the density would also be less. Table 710-4 shows the lot sizes required for adequate dilution of on-site sewage disposal nitrates in the underlying groundwater for various parts of the United States, assuming highly permeable soils and rapid infiltration of rainwater.

4.4 Industrial and Waste Contamination

Regarding past land uses, both new and old industries use an enormous variety of chemicals whose effects on human health are insufficiently understood and whose effects were totally misunderstood in the past. Many of these chemicals are quite stable in the soil and may, as a result of ion

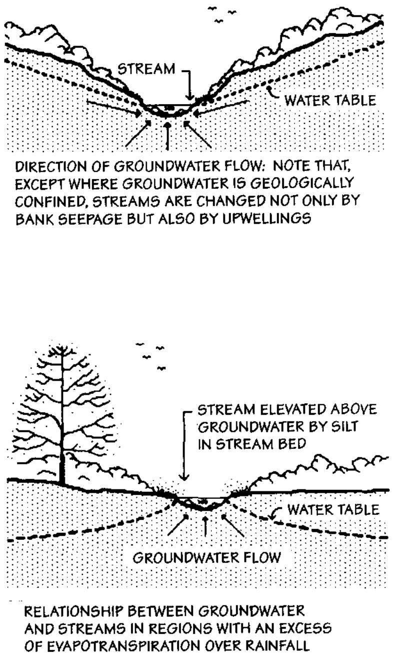


Figure 710-15. Relationship between groundwater and streams.

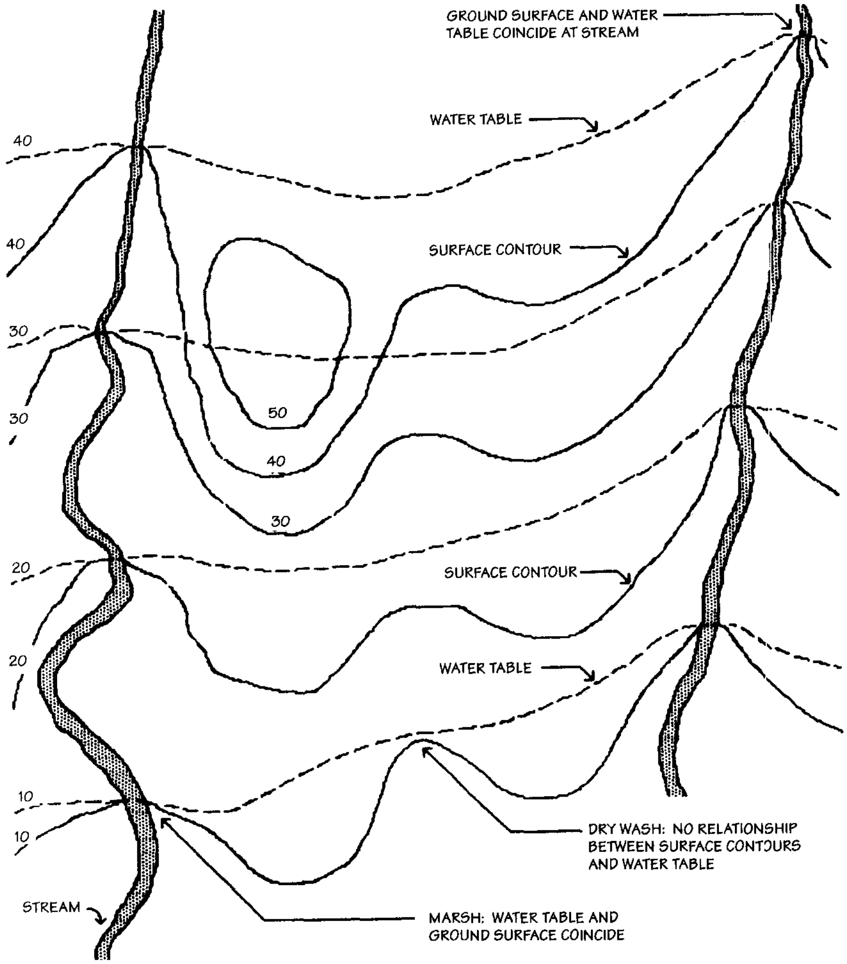


Figure 710-16. Relationship of groundwater and water table in unconsolidated and unconfined aquifers in regions where rainfall exceeds evaporation.

interaction with soil particles, move at rates much slower than the normally slow rates of groundwater flow. As a result, it is prudent to assume that any area ever used for industrial purposes, including processing, chemical storage, shipping, or waste disposal, should not be included in the recharge cone of any potable water supply well, unless site specific analyses prove otherwise.

5.0 GROUNDWATER FLOW ANALYSIS

Determining patterns of groundwater flow is similar to determining patterns of surface flow. First a contour map of the upper surface of the groundwater (i.e., the water table) is constructed, and then the pattern of flow through the ground is considered as though it were a surface flow across the water-table contours. Like surface water, the flows will be perpendicular to the lines of equal potential (contours), and again like surface water, the flows will be faster where the contours are closer together, adjusting for the permeability of the soil (like the coefficient of roughness on surface flow).

To construct a water-table contour map:

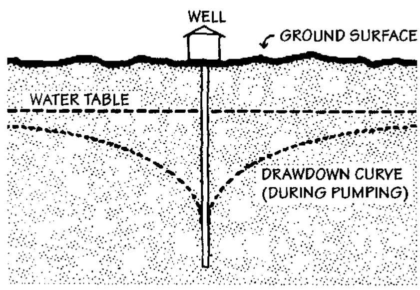


Figure 710-17. Drawdown cone in uniformly permeable sands and a flat water table. *Note that the drawdown curve is not a simple cone but is hyperbolic.*

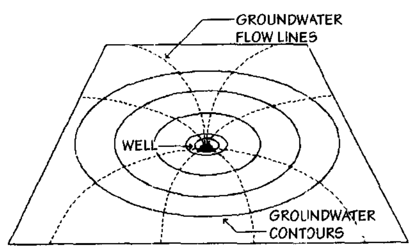


Figure 710-18. Oblique view of figure 710-17. *Note that the intersection of the drawdown cone and the water table is circular.*

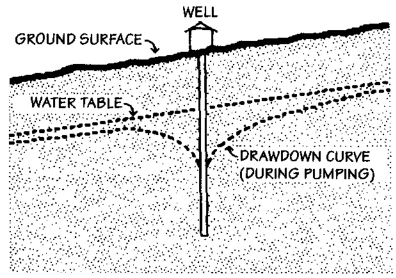


Figure 710-19. Drawdown cone in uniformly permeable sands and a uniformly sloping water table.

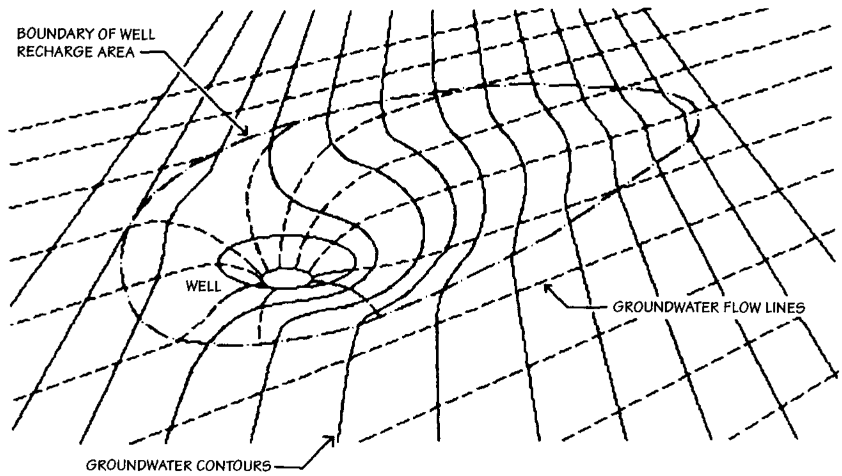


Figure 710-20. Oblique view of Figure 710-19.

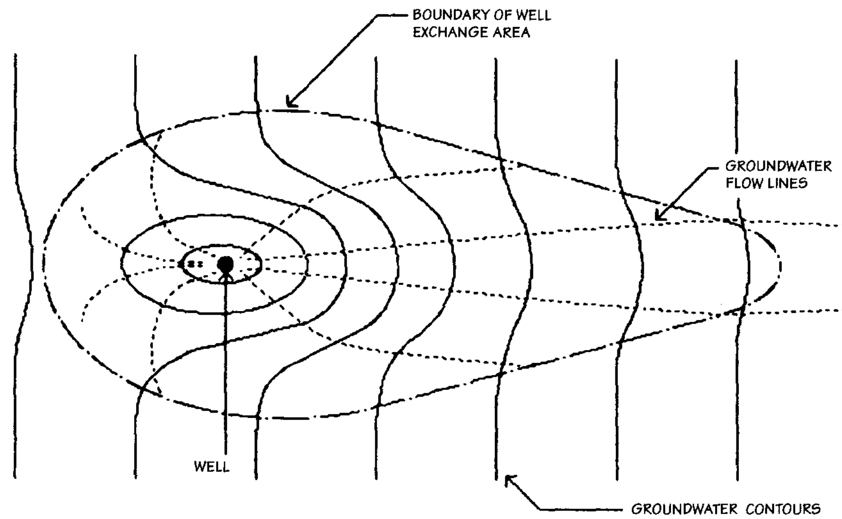


Figure 710-21. Plan view of Figure 710-19. *The contour lines are lines of uniform, constant elevation; the dashed lines show the direction of slope and water flow.*

1. Plot all known water-table elevations on ponds, streams, swamps, wells, etc.
2. Assume that the water table is lower than the ground surface at all low spots where no surface water is evident, and that the two surfaces coincide wherever there is a pond or wet spot, unless there is solid evidence to the contrary.
3. In regions where rainfall exceeds evaporation (i.e., humid regions), assume that the water table is higher than adjoining streams (Figure 710-15, top). In regions where evapotranspiration exceeds rainfall (i.e., arid regions), assume that the water table is lower than adjoining streams (Figure 710-15, bottom).
4. Interpolate the contours in the same manner in which ground surface topography is interpolated. (Check that the groundwater surface is not higher than the ground surface.)

Obviously, where there are ample exposures of water on the surface, the groundwater surface will be close to the ground surface and there will be little doubt as to the depth and slope of the groundwater surface. In places where there is little surface water, the water table is likely to be well down and not much can be deduced about it.

In highly permeable soils, where groundwater can move easily, the watertable surfaces are likely to be quite flat and only minimally reflect the shape of the ground surface, but in less permeable soils the water table is more likely to reflect the contour of the ground surface (Figure 710-16). The groundwater contours in valleys can be expected to assume the same V form as the surface contours, where there is a stream in the valley. However, where there is no surface stream and impermeable strata are well down, the groundwater surface is not likely to be influenced by the surface topography at all.

Interpretation of a groundwater contour map is similar to interpretation of surface topography. In general, flows are perpendicular to contours, so that it is reasonably possible to delineate groundwater watersheds of ponds, streams, and estuaries and to forecast the directional movement of contaminants.

6.0 WELL RECHARGE AREA ANALYSIS

To determine the area from which a high-yield well will draw its water, a cone of depression must be drawn into the groundwater surface. Figure 710-17 shows a cross section through a hypothetical well in uniformly permeable sands with a flat water table (an improbable situation). Figure 710-18 shows the same cone in an oblique view. Figure 710-19 is the same situation as Figure 710-17 but with a uniformly sloping water table (a somewhat more realistic assumption, but still only theoretical). Figure 710-20 is an oblique view of Figure 710-19. Note that the plan view of the cone is no longer circular but oval. Figure 710-21 is the same situation as Figure 710-20 but as a contoured surface viewed as a horizontal map. Figure 710-22 is similar to 710-21 but is drawn on a three-dimensionally curved groundwater surface in a relatively shallow aquifer, the kind of groundwater surface likely to be found in a complex outwash or kame plain.

Where aquifers are deep, it is essential to assume that groundwater flow is laminar. Figure 710-23 shows a section through a deep but homogeneous aquifer. The groundwater does not mix but remains stratified.

Figure 710-24 shows the effect of this laminar flow on water movement to a well in the upper portion of an aquifer. Note that groundwater from distant recharge areas can pass entirely under a low-yield well. The larger the well, the larger its recharge area and the deeper its draw on the ground.

Figure 710-25 shows the effects of small and large wells on the same aquifer. Note that aquifers that have been satisfactorily serving low-yield wells cannot be assumed to be suitable for high-yield wells.

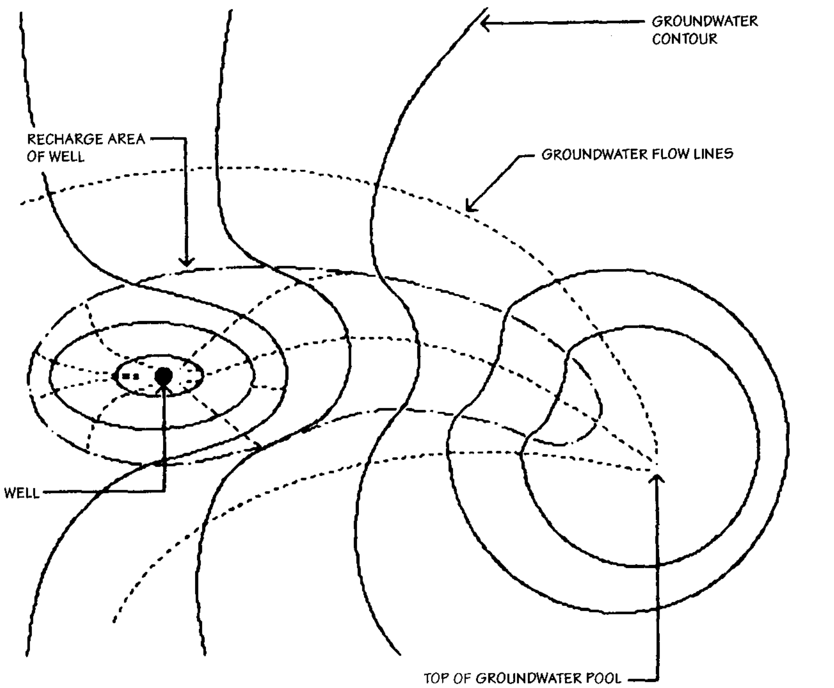


Figure 710-22. Drawdown cone in uniformly permeable sands and a three-dimensionally curved groundwater surface.

7.0 RESERVOIR DESIGN CONSIDERATIONS

Site selection criteria for a water supply reservoir should include:

1. A watershed large enough to yield an adequate water supply
2. An impoundment volume large enough for adequate, long-term water storage
3. Suitable soil conditions (i.e., the less permeable, the better)
4. A topographic form capable of being shaped into a reservoir at reasonable cost (minimum regrading)
5. A watershed free of contaminants
6. A reservoir site free of excessive organic materials

7.1 Size of Watershed

Per capita potable water use in the United States varies from under 570 L (150 gal) per day in the northeast to over 1325 L (350 gal) per day in the southwest (where extensive irrigation takes place). In periods of drought in the northeast, with restrictions on lawn irrigation, automobile wash-

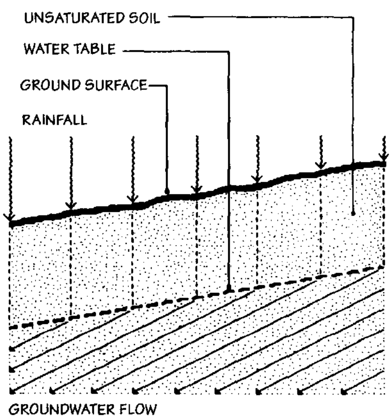


Figure 710-23. Longitudinal section through homogeneous aquifer, showing laminar flow in ground.

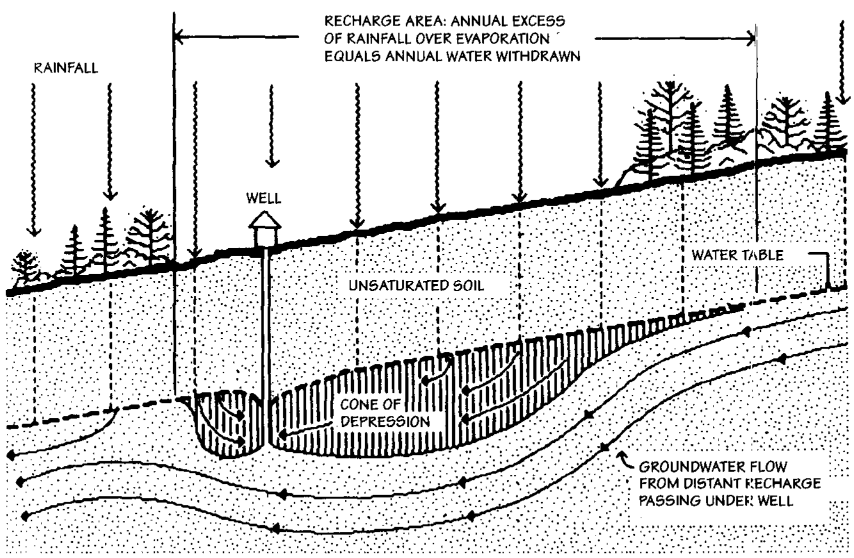


Figure 710-24. Longitudinal section showing flows passing under well.

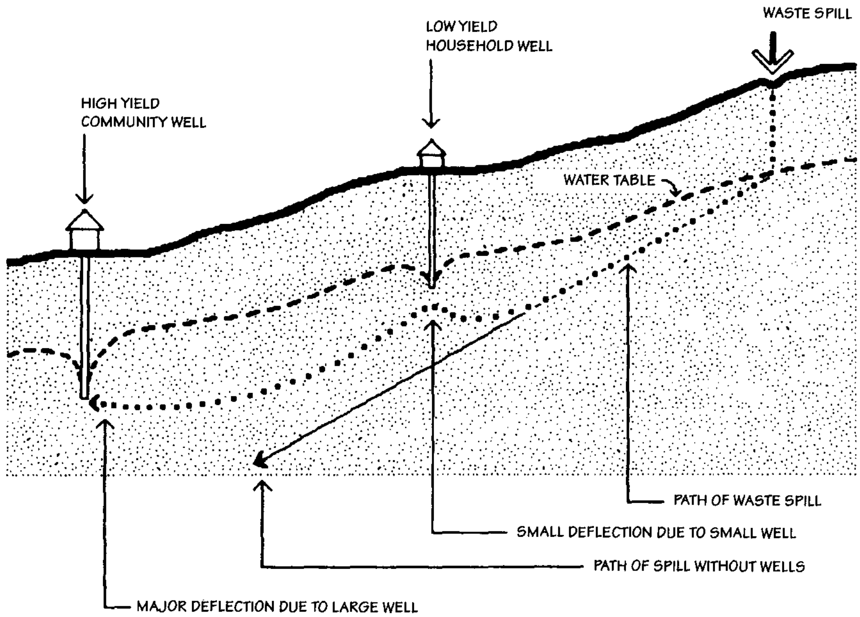


Figure 710-25. Effects of well size on groundwater flow.

ing, etc., water use can be reduced by 50 percent. Such drought restrictions on use are normal and widespread in the rural northeast.

The annual gross yield of a watershed, assuming a very large, long-term storage volume, could reach the average annual rainfall for the watershed less the watershedís evapotranspiration and the reservoirís evaporation and leakage. (Figure 710-26 shows the average annual runoff per square mile for the United States.) However, to provide that much storage is likely to be very costly. The most cost-effective use of a stream is likely to be achieved with an amount of storage equal to 1 year's average annual runoff (the critical point on Hazenís yield-storage curve). At this level of storage, the gross annual safe yield would be equal to the gross runoff of a typical drought year (about one-half that of an average rainfall year).

With no storage, the safe yield of any stream would fall to a fraction of its lowest summer flows. For most streams, this is a very small amount.

KEY POINTS: Reservoir Design Considerations

Design of water supply reservoirs is dependent on water needs, watershed characteristics, and site topography. The following factors should be considered.

1. The most cost-effective use of a stream for a water supply reservoir is likely to be achieved with an amount of storage equal to 1 year's average annual runoff.
2. Any pond large enough to contain at least 1 year's flow-through is likely to be adequately deep. In general however, the deeper the pond, the clearer the water.
3. Watershed characteristics for potable water reservoirs include: (1) freedom from past industrial and waste disposal uses, (2) freedom from geologic sources of phosphorus, and (3) freedom from urbanization-related sources of phosphorus.
4. Surface water will generally require some form of treatment under state law. Treatment is likely to include filtration and disinfection.
5. The reservoir bottom should be stripped of all debris, organic deposits, and topsoil, unless water supplies are not needed for immediate use.
6. The services of a geotechnical engineer, sanitary engineers, and hydrologists should be retained for the design of reservoirs and the testing of water supplies.

7.2 Size of Reservoir

The size of a reservoir with respect to its watershed size determines both the safe yield of the system and the quality of the water. The minimum size of a reservoir to be used for potable water should be at least equal to 1 year's annual average runoff from its tributary watershed in order to achieve good water quality (without extensive treatment), although a somewhat larger volume (e.g., 1-1/2 year's runoff) would be better. A small reservoir (i.e., one that stored much less than 1 year's runoff) would unlikely have very clear water because of suspended colloidal materials; a larger reservoir, if it were low in phosphates, would be likely to have much clearer water.

7.3 Shape and Depth of Reservoir

Much concern has arisen in times past about the shape and depth of reservoirs, based on the belief that shallow water encouraged the growth of aquatic weeds, imparting a foul taste to the water. Several major reservoirs were built on this premise in the 1890's with dredged-and-filled bathtublike edges. These reservoirs have not all been successful, and a few (as at Hopkinton and Ashland, Massachusetts) have never been regularly used for water supply. Some minimum depth is essential to the natural semiannual thermal and chemical stratification and turnover required to settle organic detritus and other suspended materials, but any pond large enough to contain at least 1 year's flow-through is likely to be adequately deep. In general, the deeper the pond, the clearer the water, all else being equal.

7.4 Watershed Characteristics

Watershed characteristics for potable water reservoirs include: (1) freedom from past industrial and waste disposal uses, (2) freedom from geologic sources of phosphorus, and (3) freedom from urbanization-related sources of phosphorus.

A search should be made for industrial and waste disposal activities in the past, and suspicious sites should then be investigated with test wells and chemical sampling. Many early industries used large amounts of toxic substances for a variety of purposes and no potentially contaminated site should be accepted without testing, regardless of the kind of industry.

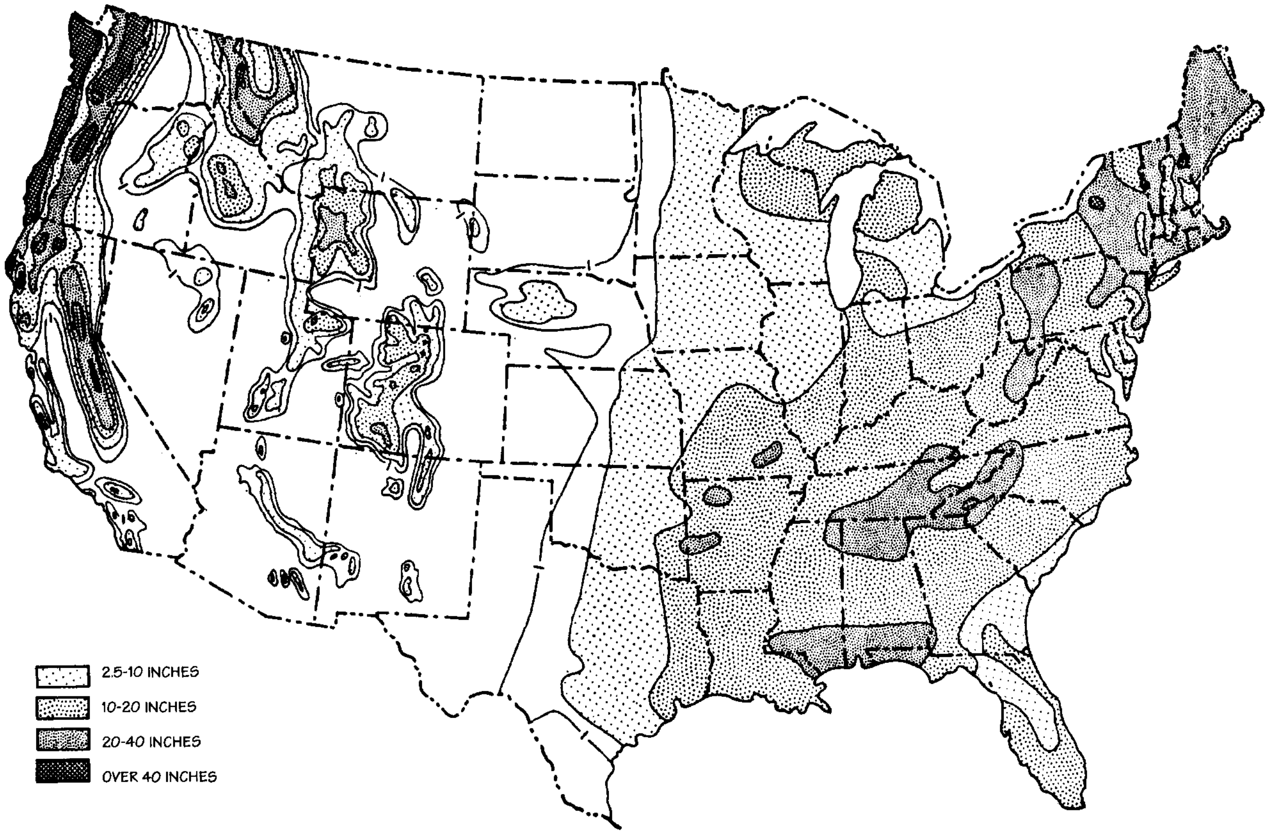


Figure 710-26. Average annual runoff in the United States.

Geologically occurring phosphates can support enough algae to make untreated water unacceptable for drinking. Surface water at the reservoir site should be chemically tested for its phosphate content. Levels above 15 parts per billion (ppb) may be high enough to rule out a successful surface water supply without algae controls. Samples should be collected in acid-washed bottles available from an analytical testing laboratory that does water testing. Samples should be collected without disturbing bottom sediments. Guidance on sampling techniques should be requested from an analytical laboratory.

Urbanization-related phosphate enrichment appears to be a result of atmospheric phosphate dust falling onto dry roofs and pavements and then being washed into drains and streams. (Phosphate dust, which falls onto moist soil, will be absorbed by the soil particles and become insoluble. Phosphate fertilizers tend to be adsorbed even more rapidly.)

Conventional approaches to surface drainage, even if buffered with retention basins to control flood peaks and sediments, will sweep the more soluble (and more damaging) surface phosphates into streams and reservoirs too quickly for them to be adsorbed by soil particles. The better control of soluble phosphate can be achieved by restricting the amount of land development within a watershed, restraining the use of impermeable surfaces, and/or by design of the drainage for maximum on-site soil infiltration.

7.5 Dam Location

Dams for water supply can be located either on the stream from which they will draw their water or at some other convenient location. Any reservoir site, to be economical, should take advantage of natural topographic containment, but this is not always essential. It is more important that the underlying materials be relatively impermeable so that seepage waters will not undermine the structure. Since many stream bottoms are alluvium or outwash sand, off-stream reservoirs are sometimes used with water pumped from the supply stream to the storage reservoir during spring flow peaks. The same concerns apply to off-stream reservoirs as to on-stream reservoirs, i.e., water quality, control of urbanization, and adequate volume of storage (more than 1 year). (Refer to Section 420: Small Dams, for more information about the selection of dam sites and the types of dams that can be used for water supply.)

7.6 Water Treatment

Surface water will generally require some form of treatment under state law. Treatment is likely to include chlorination and pH adjustment, and it may also include fluoridation and/or filtration, depending on raw water characteristics.

7.7 Site Preparation

To achieve high water quality in a short period of time, the reservoir bottom should be stripped of all debris, organic deposits, and topsoil. For water supplies not needed for immediate use (future growth a decade or more away), this step can sometimes be eliminated (Figure 710-27).

7.8 Consultants

The services of a geotechnical engineer should be retained for the design of dams and dikes; the services of a sanitary engineer should be retained for water testing

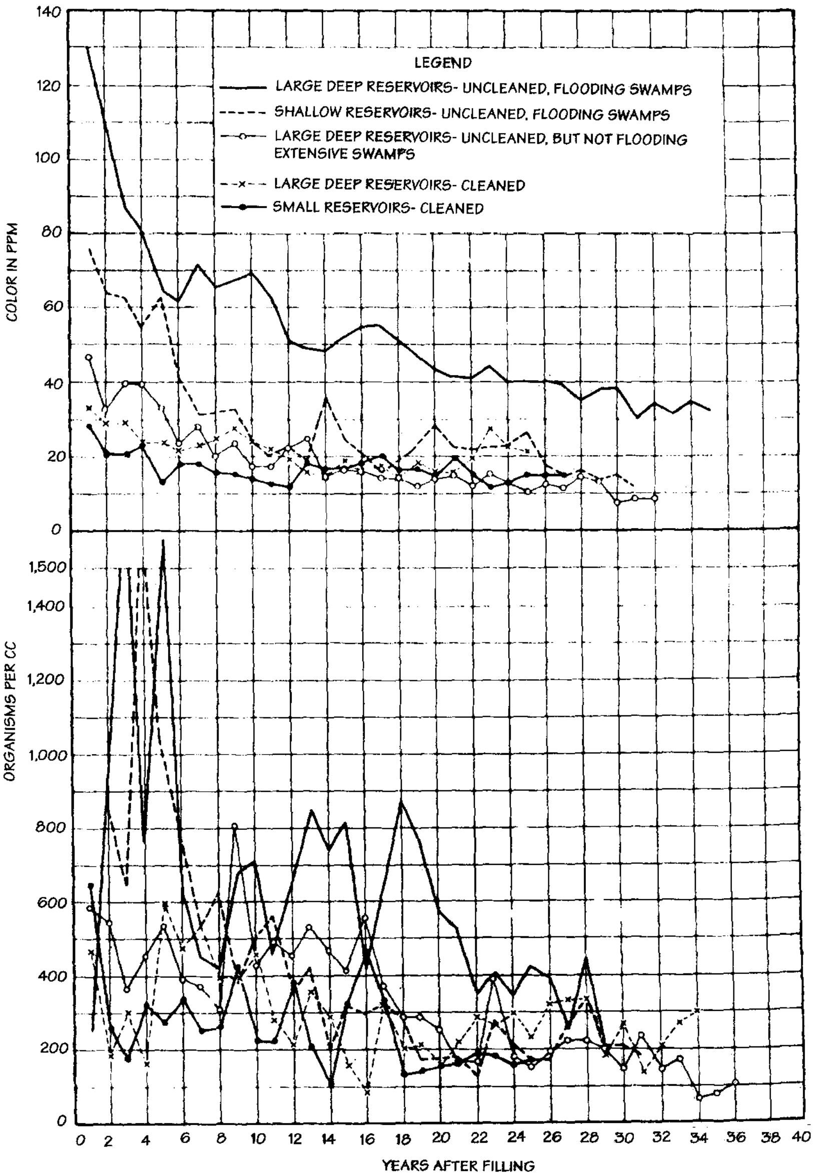


Figure 710-27. Color and Algae in Water Supply Reservoirs. *This graph shows progressive reduction in color and algae in impounding reservoirs subsequent to their filling.*

and for the design of pumping stations and water treatment equipment; and the services of a hydrologist should be retained to ensure that spillways are adequate to protect the dam from flood damage.

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Sewage Disposal

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CONTENTS

1.0 INTRODUCTION

Some form of sewage disposal is necessary in most building or land development projects for the disposal of domestic waterborne wastes. Such wastes are either piped off-site to a municipal sewer system or are treated and disposed of on-site. Proper design for the treatment and disposal of domestic waterborne wastes is essential for the protection of public health, safety, and welfare.

1.1 Types of Sewage Systems

The type of sewage disposal system chosen for the development of any tract of land will influence the pattern and density of that development. The sewerage for any project can include:

1. Simple, economical systems for the safe, environmentally sound disposal of wastewater
2. More complex and costly systems for overcoming the limits of poorly drained or impermeable soils on sites that have good locations or other valuable aspects
3. More complex and costly systems for increasing the density of development on a site (Figure 720-1)

1.2 On-Site Disposal

It is expected that the use of on-site disposal will increase as urban development spreads outward beyond the extent of existing sewage collection systems and as existing public treatment plants run out of reserve capacity.

Some developments, particularly industrial use, will require special on-site systems for wastes that cannot be discharged to municipal sewer systems or that cannot be disposed of through on-site systems designed for domestic or human wastes. Site designers should be aware: (1) that many industrial wastes require special treatment (designed by specialists in the specific industry) and (2) that for such industrial wastes, after removal of hazardous compounds, the treated effluent may be disposed of by ordinary on-site leaching or by discharge to a municipal sewer.

2.0 DESCRIPTION OF SEWAGE SYSTEM PROCESSES

Effective sewage disposal includes physical disposal of the sewage into the environment without adverse health, odor, aesthetic, or nutrient (fertilization) effects.

All currently permissible sewage disposal systems include some method for separation of solids from wastewater, for disposal of the solids, for oxidation of putrescible substances dissolved in the wastewater, for destruction of pathogens, and ultimately for discharge of the resulting effluent to the ground, to a waterbody, or to the atmosphere.

At a typical modern large-scale municipal treatment plant, the solids are settled out and then physically skimmed off the top and bottom of the wastewater stream and either incinerated or landfilled, the wastewater is actively aerated to biologically remove most of the dissolved putrescibles and suspended organic solids, and the resulting effluent is dosed with chlorine and discharged to a river or large body of water.

For a small on-site system, the processes would include the digestion of solids into liquids and gases, the oxidation of dissolved putrescibles, the destruction of pathogens by biologically active filtration, and the discharge of effluent, preferably to the ground or, alternatively, to a waterbody or to the atmosphere.

The average amount of domestic sewage disposed in the United States is about 245 L (65 gal) per capita per day. About one-third of domestic sewage is toilet waste; one-third, laundry waste; and one-third, drainage from sinks and tubs.

3.0 SYSTEM ALTERNATIVES

Alternative methods of sewage disposal on a tract of land include: (1) discharge to a municipal sewer system and (2) various kinds of on-site disposal systems. Selection of the method depends on location, geohydrologic conditions local codes, and density of development.

In general, connection to an existing municipal system will be the least complex method. In addition, where such connec-

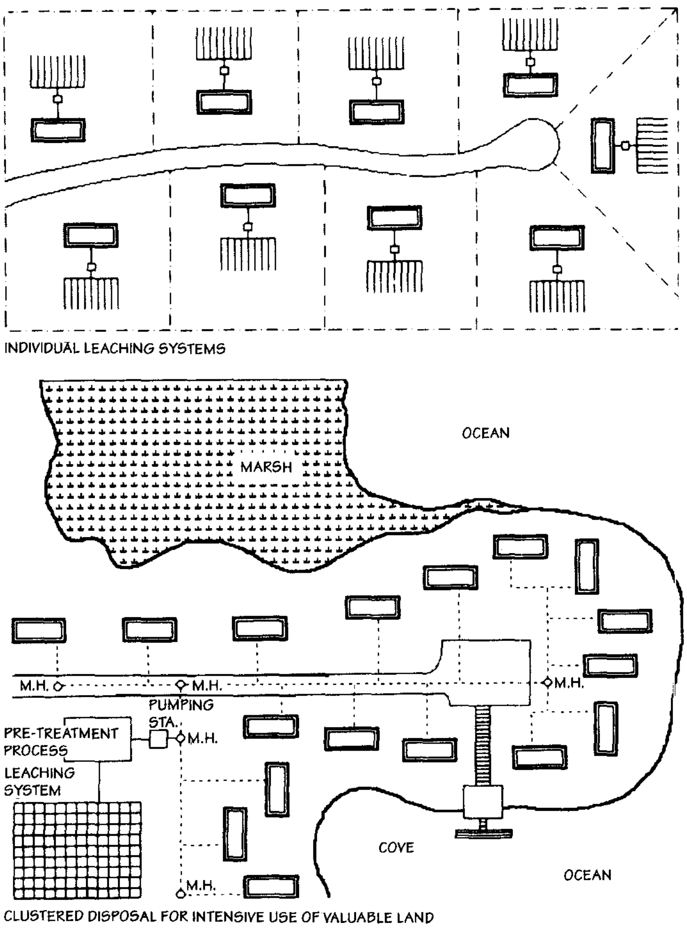


Figure 720-1. Alternative land use and alternative on-site disposal.

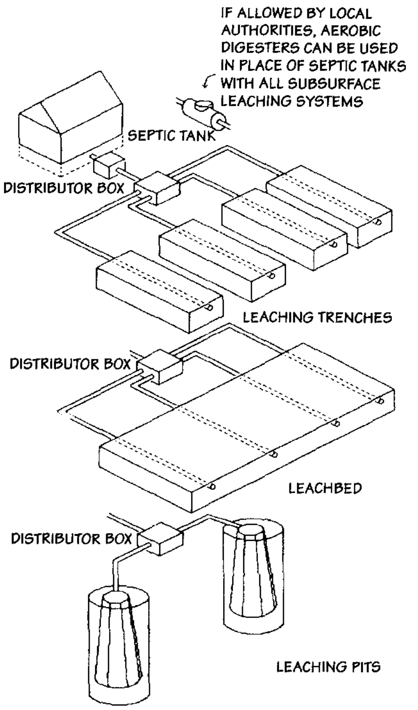


Figure 720-2. Types of subsurface leaching systems. *Septic tanks or aerobic digesters can be used with any of these three systems if allowed by local authorities.*

tions are available, they are often mandated by local officials. (Note that this may not be the least costly or the most environmentally desirable alternative.)

Considerations for on-site disposal include the following alternatives:

1. For overall system configuration:
   a. Small individual systems scattered over the site
   b. Large clustered or community systems concentrated at one or a few points on the site
2. For ultimate wastewater disposal:
   a. Soil leaching with subsurface effluent application
   b. Soil leaching with surface effluent application
   c. Evapotranspiration
   d. Surface water discharge
3. For processing before disposal:
   a. Simple anaerobic (septic) digestion of solids
   b. Oxidation
4. Miscellaneous variants:
   a. Clivus multrum and other composting systems
   b. High-tech mechanical systems
   c. Holding tanks
   d. Cesspools

3.1 System Components

Small Individual Systems:

Specific small individual systems include:

1. Septic tanks combined with any of a variety of subsurface leaching systems (leaching trenches, leaching beds, leaching pits, etc.). All septic systems are limited to subsurface effluent disposal because of the odor inherent to septic effluent (Figure 720-2).
2. Aerobic digesters with subsurface leaching systems can also be used with a variety of leaching system configurations (Figure 720-2).
3. Aerobic digesters with surface infiltration beds (Figure 720-3).
4. Aerobic digesters with evapotranspiration disposal systems (Figure 720-4).
5. Composting toilets for human wastes and garbage, combined with an appropriate disposal system for wash waters.
6. Cesspools.

Large Cluster Systems:

Specific large cluster systems include:

1. Large septic tanks with subsurface leaching systems
2. Large aerobic digesters (often called package plants) with surface infiltration beds
3. Large aerobic digesters with evapotranspiration disposal of effluent
4. Unaerated lagoons with overflow disposal to surface infiltration beds (Figure 720-5)
5. Aerated lagoons with overflow disposal to surface infiltration beds (Figure 720-6)

3.2 System Configuration

Regarding the selection of the overall system configuration (i.e., individual systems versus cluster systems), the designer should consider:

1. Costs
2. Density of development
3. Site suitability
4. Local governmental regulations and policies

Costs:

Regarding costs, any type of individual onsite approach (where acceptable) is likely to be much less expensive than a cluster system, often by a ratio of 10:1. The major economy of individual systems is the elimination of pipelines, pumping stations, and manholes between individual buildings and the cluster disposal site. Operation and maintenance costs are also a significant factor when considering cluster systems.

Density of Development:

Regarding the density of development, individual on-site disposal (with systems large enough to be relied on for trouble-free long-term service) limits the development density to about 2 dwelling units (du) per hectare (5 du per acre) for single detached housing, and to about 5 du per hectare (12 du per acre) for three-story apartment buildings (Figures 720-7 and 720-8).

Community disposal systems could raise the density of such development somewhat, but a separate land allocation for the community system would be required; consequently, the overall dwelling density might not be significantly higher.

Site Suitability:

Regarding the suitability of sites, individual on-site disposal can be accommodated only if adequate permeability and depth to groundwater exist.

3.3 Additional Factors

Regarding the selection of ultimate wastewater disposal alternatives, whether to groundwater, surface water, or the atmosphere, the designer should consider:

1. Site conditions
2. Costs
3. Local governmental regulations and policies
4. Impacts on water quality

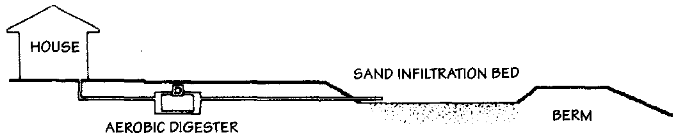


Figure 720-3. Aerobic digester with surface infiltration bed.

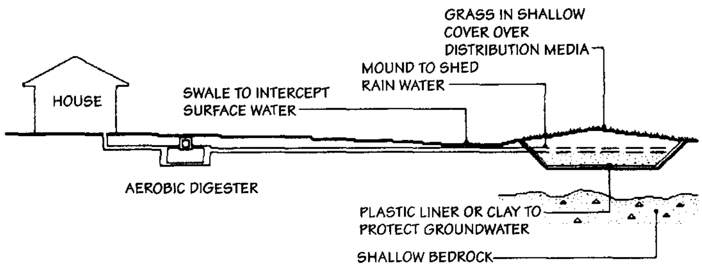


Figure 720-4. Aerobic digester with evapotranspiration system.

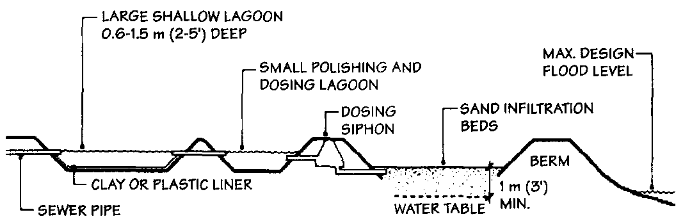


Figure 720-5. Unaerated lagoon system (schematic section).

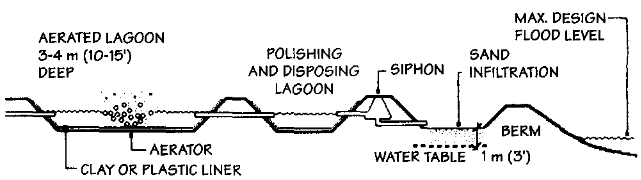


Figure 720-6. Aerated lagoon system (schematic section).

Filtration through Soil:

Overall, the most effective, economical, and environmentally safe method for disposing of wastewater (and simultaneously oxidizing its putrescibles and ammonia, destroying its pathogens, and immobilizing its phosphates) is the slow filtration of the wastewater through soil. The soil bacteria, at the interface of the wastewater distribution system and the soil, multiply and form a gelatinous, organic slime which holds the wastewater and allows it to filter slowly into the soil. As the wastewater passes through the slime, soil bacteria digest the putrescibles, pathogens, ammonia, and organic phosphates. The resulting filtered effluent is clean, odor-free, and nearly suitable for drinking except for its significantly high nitrate content and its moderately high salt content.

For low-density developments, depending on regional hydrologic characteristics (see Section 710: Water Supply), the resulting nitrate concentration from scattered small systems will usually not affect the potable quality of underground water. For large systems or for high-density developments, the chemical effects on groundwater should be examined and evaluated on a case-by-case basis.

Removal of Nitrates:

The removal of nitrates is inherently difficult, costly, and experimental at this time. At Lake Tahoe, in the western United States, effluent from the community treatment plant is air-stripped of ammonia (the chemical antecedent of the nitrates in filtered effluent) and requires complex mechanical and chemical processes. Elsewhere, nitrate removal has been achieved biologically by using spray irrigation, shallow ponds and marshes, or, after filtration, an additional stage of anaerobic digestion.

The alternative that uses spray irrigation requires a large land area, winter storage of effluent in cold climates, and energy for pumping. It can increase the sodium content of the groundwater beyond acceptable levels, and its acceptability for use on crops appears to depend on whether the effluent has been previously filtered. (Tests of spray irrigation to date have been limited primarily to unfiltered effluent.)

Shallow pond or marsh denitrification alternatives require ideal site conditionsó-such as a large, preexisting marsh or swamp that can be used without diminishing other environmental values.

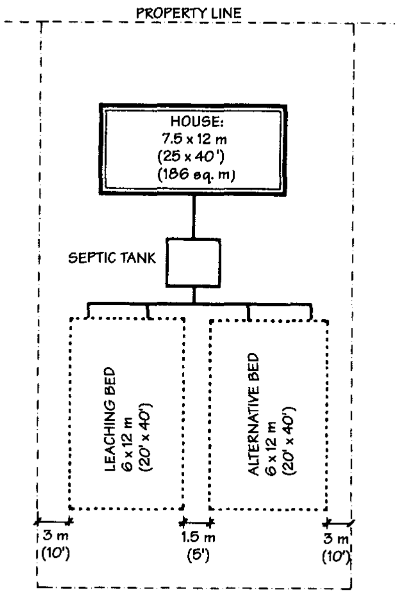
The anaerobic decomposition alternative is more costly, requires the collection of the filtered effluent, and is not well understood technically.

Soil Modification:

In some cases, where soils are not suitable for slow infiltration, they can be modified. If they are too permeable (too coarse) to support a biogenic slime, finer soil can be placed along the bottom and sides of leaching beds, but this cannot be done as conveniently when trenches or pits are used (Figure 720-9).

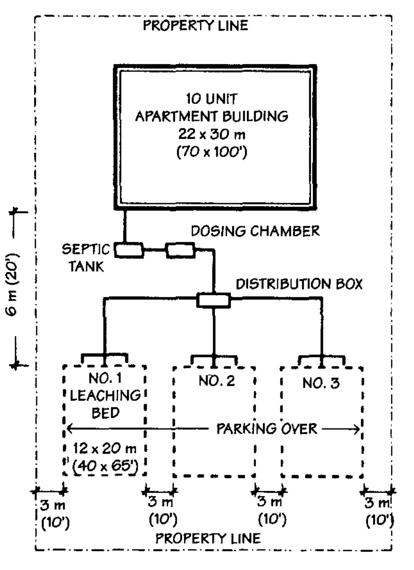
Where the soil stratum is too shallow to groundwater or too impermeable, earth fill can be brought in to correct the inadequacy. This method can be very costly, especially if suitable fill is not available on or near the site.

To mitigate the costs of extensive earth fill, where fill is necessary, it is sometimes feasible to upgrade the quality of the wastewater effluent applied to the soil, reducing its nutrient value to soil bacteria. Such improved treatment would reduce the



NOTE: 3 BEDROOMS @ 490 L (130 gal) PER BEDROOM PER DAY
OR
6 PEOPLE @ 250 L (65 gal) PER CAPITA PER DAY @ 20.3 L (.5 gal) PER SQUARE METER PER DAY = 74 SQUARE METERS PER LEACHING BED

Figure 720-7. Single-home densities attainable with on-site disposal.



NOTES:

10 APARTMENTS WITH 3 BEDROOMS EACH AT 180 sq m (2 000 sq ft) ON 3 FLOORS, WITH AN AVERAGE OCCUPANCY OF 4 PEOPLE PER DWELLING UNIT (D.U.) AND CONSUMPTION OF 245 L (65 gal) PER CAPITA PER DAY (I.E. 9 900 L (2 600 gal) PER DAY)

1. PROVIDE A MINIMUM OF 1 sq ft OF LEACHING AREA FOR EACH 1.9 L (0.5 gal) (I.E. 468 sq m (5 200 sq ft).

2. INSTALL 3 LEACHING BEDS SO THAT 2 CAN BE USED IMMEDIATELY AND ONE CAN BE KEPT IN RESERVE.

Figure 720-8. Apartment densities attainable with on-site disposal.

density of the biogenic slimes produced in the soil and so reduce the size of the leaching area required. In general, the better the processed effluent, the smaller the leaching area required. With septic tank effluent, the maximum long-term loading appears to be about 0.19 L/m^2 (1/2 gal/ft^2) per day. With effluent from more effective processing, as in a lagoon system, loading rates up to 1.76 L/m^2 (5 gal/ft^2) per day are possible.

In more extreme cases, where the soil itself is insufficiently permeable to accept the filtered effluent, sewage can be disposed of by some form of evapotranspiration system or by discharge to surface waters. In desert areas, simple evaporation off the surface of a lagoon is possible. In warm, wetter climates, grasses can transpire large amounts of water during the growing season; using this approach may only be feasible for campgrounds, parks, or summer resort developments. For either direct evaporation or for transpiration, sewage processing would require some form of aeration, both to control odor (for evaporation ponds) and to prevent root rot (for transpiration systems).

Before effluent can be discharged to surface water, local public health regulations normally require a detailed analysis of and an impact statement on downstream water resources, a consideration of all other alternatives beforehand, and a compelling case made for developing the specific site in the manner proposed.

3.4 Solids Removal/Digestion Systems

Regarding the selection of alternative systems for the removal and/or digestion of solids, consideration should be given to:

1. Costs
2. Site adaptability
3. Local government regulations and policies

The alternatives include septic systems, various forms of aerobic processors or digestion, and several hybrid systems.

Septic Systems:

In terms of cost, septic systems are usually the least-expensive small systems, having no machinery, no energy inputs, and no requirements for security, regular maintenance, or frequent inspection.

In terms of site adaptability, simple septic systems can only be used in areas where subsurface effluent disposal is practical, i.e., where there is sufficient soil permeability [2 to 3 cm (3/4 to 1 in) per day]. Where the depth to groundwater is inadequate, the soil surface must be built up with fill material so as to provide adequate depth for percolation through the soil without saturating it and to provide enough cover over the leaching system to control odors.

Aerobic Systems:

Aerobic systems ordinarily require the same site conditions as septic systems, but their odor-free effluent can be applied to a surface infiltration bed, usually at much higher rates of application, thus reducing both the size of the leaching facility and the costs per square foot. However, this practice is not readily approved by local health officials except under unusual circumstances, since aerobic systems require systematic maintenance and the exposed effluent can transmit a variety of pathogens and parasites.

Aerobic processing of sewage can be accomplished either in some form of energy-intensive and mechanically complex package plant, usually prefabricated, or in one of two kinds of lagoons.

Package Plants: The package plant appears to have special applicability where space and site conditions are constrained. Package plants are miniature versions of municipal sewage treatment plants and, as such, have as their primary functions: (1) the settling of solids and (2) the conversion of dissolved organics into settleable solids. When operating properly, they produce effluent that can be applied to infiltration beds at quantities up to 18.9 L (5 gal/ft^2) per day (10 times the loading rate of septic tank effluent). However, since these devices generally have no provision for automatic, systematic removal of the accumulated solids, they are subject to solids overloads, the washing of solids into leaching systems, and mechanical breakdown unless they are pumped out once or twice a year.

If not adequately sized and carefully maintained, package plants perform no better than septic tanks and require equally large leaching systems.

Passive Lagoons: Passive lagoons, or stabilization ponds, are large shallow ponds [0.6 to 1.5 m (2 to 5 ft) deep] aerated by natural processes (sun and wind) through their extensive upper surface. They are commonly used in very rural areas where adequate space is available and where they can be sited far enough away from people to minimize the odor nuisance of their twice-a-year thermal turnovers (which bring odorous bottom sediments to the surface).

Aerated Lagoons: Aerated lagoons are deeper and smaller than passive lagoons and use sufficient mechanical aeration to preclude thermal stratification and the resulting twice-a-year thermal turnovers. These types of lagoons have been used on sites that are large enough for passive lagoons but are too close to abutting land uses that require positive odor control. The water in these lagoons is mixed and aerated by small streams of air that are pumped through weighted plastic tubes by relatively small compressors.

3.5 Other Sewage Disposal Alternatives

Miscellaneous alternatives are usually limited to sites where either the disposal of normal amounts of wastewater or a supply of adequate amounts of water are not feasible. These include composting toilets, high-technology recirculating systems, and holding tanks.

Composting Toilets:

At one extreme, such limited sites have been dealt with by a combination of simple actionsósuch as using an old-fashioned pit toilet (or outhouse) or a composting toilet (an inside outhouse), taking laundry out to a commercial facility, and not using garbage grinders. Under such conditions, water use and wastewater generation in a residence can be reduced about 75 percent, pathogens can be kept out of the wastewater stream, and wastewater treatment facilities can be kept small and simple. However, it should be noted that both local permits and mortgages for such facilities are difficult if not impossible to obtain.

Recirculating Systems:

At the other extreme, systems have been developed that allow normal washing, flushing, etc., without normal water supplies or normal wastewater discharges; the systems accomplish this by recycling and treating washwater within the building, and then using the filtered washwater for toilet flushing, etc. These systems are very costly and complex, and they require unusual amounts of space within the buildings.

Holding Tanks:

For severely constrained sites where no discharge to the environment can be permitted, wastes can be drained to a holding tank [of up to 19 000 L (5000 gal)] for periodic pumping or, for larger water users, drained directly to a tank truck.

3.6 Cesspools

Cesspools are a very low cost but effective disposal technique for very small systems [up to 375 or 575 L (100 or 150 gal) per cesspool per day] or for systems with intermittent use. They require suitable soils and a water table at least 3 m (10 ft) deep. They combine, at their center, the anaerobic digestion process of the septic tank and, around their vertical perimeter, the filtering process of the leaching pit (Figure 710-10).

Their only disadvantage is that, like any other soil infiltration mechanism (leaching bed, leaching field, leaching trench, leaching pit, etc.), they will contaminate groundwater with pathogens, unoxidized putrescibles, ammonia, and organic phosphates unless there is an adequate zone of unsat-

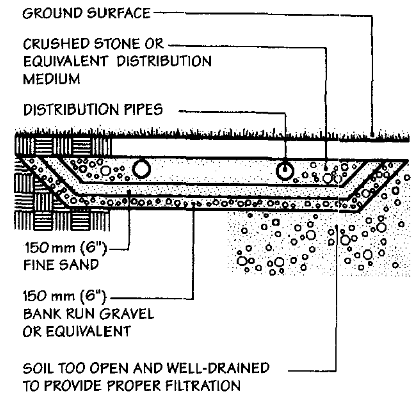


Figure 720-9. Leaching bed in excessively drained soils (schematic section).

KEY POINTS: Sewage Disposal System Alternatives

A number of alternatives are available for sewage disposal. Selection of a particular method depends on location, geohydrologic conditions, local codes, and density of development.

1. Connection to an existing municipal system is typically the least complex method and may be mandated by local officials, although this may not be the least costly or the most environmentally desirable alternative.

2. Systems may serve individual sites, or neighborhoods if larger cluster systems are used. Any type of individual on-site approach is likely to be much less expensive than a cluster system, due to the elimination of pipelines, pumping stations, and manholes.

3. The most effective, economical, and environmentally safe method for disposing of wastewater is the slow filtration of the wastewater through soil. Individual on-site disposal can be accommodated only if adequate space, permeability and depth to groundwater exist.

4. In terms of cost, septic systems are usually the least-expensive small systems, having no machinery, no energy inputs, and no requirements for security, regular maintenance, or frequent inspection.

5. Package plants are aerobic systems that have special applicability where space and site conditions are constrained. They are miniature versions of municipal sewage treatment plants. They typically require periodic pumping to remove solids.

6. Passive lagoons, are large shallow ponds [0.6 to 1.5 m (2 to 5 ft) deep] aerated by natural processes. They are commonly used in very rural areas where adequate space is available and where odor nuisance is not a concern. Mechanically aerated lagoons are used on sites that require positive odor control.

7. For severely constrained sites where no discharge to the environment can be permitted, wastes can be drained to a holding tank [of up to 19 000 L (5000 gal)] for periodic pumping.

8. Cesspools are a low cost technique for very small systems [up to 375 or 575 L (100 or 150 gal) per cesspool per day] or for systems with intermittent use. They require suitable soils and a water table at least 3 m (10 ft) deep.

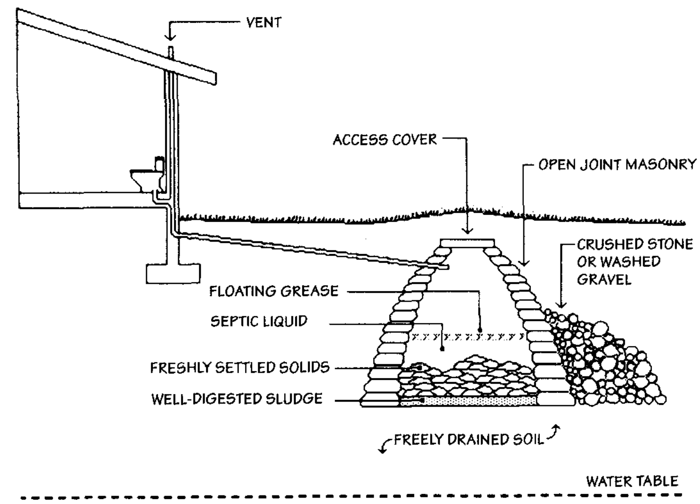


Figure 720-10. Typical cesspool system.

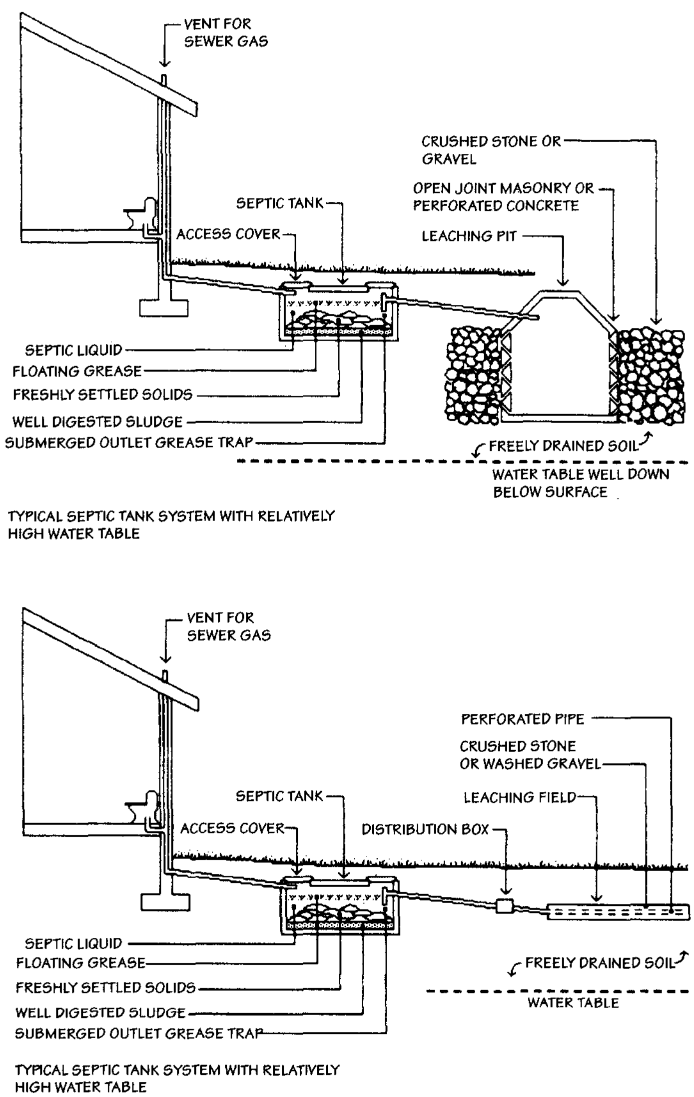


Figure 720-11. Typical septic tank installation.

urated soil between the bottom of the infiltration mechanism and the groundwater. This unsaturated soil is essential for the formation of a biologically active filter and for the oxidation of effluents. (In the nineteenth century it was noted that if cesspools were dug down into saturated soils, the cesspools would have a high infiltrative capacity as a result, and so, where possible, most new systems were deliberately extended down into groundwater. This approach caused disease and eventually earned a bad reputation for all cesspools.)

4.0 DESIGN OF SEPTIC TANKS AND LEACHING SYSTEMS

4.1 Applications

Septic tanks and leaching fields are the most economical, adaptable, trouble-free, and generally accepted form of treatment and disposal suitable for small and medium-size sewage disposal systems, i.e., up to about 57 000 L (15,000 gal) per day. They can be adapted to a great range of sites, including slowly permeable silts and relatively high water tables.

Figure 720-11 shows a section through a typical installation. The key siting requirement for any soil disposal system is an adequate depth of unsaturated soil between the effluent leaching device and the water table. State and local requirements vary, 1 to 1.2 m (3 to 4 ft) being typical. Note that the system can have very little slope, as little as 150 mm (6 in) across the length of the system.

For sites with higher water tables, many jurisdictions will allow septic tank effluent to be pumped to a mounded leaching field (Figure 720-12). Where the underlying soils are permeable (even though they are saturated), this is an acceptable approach. Where the underlying soils are not permeable (rock or clay), there is likely to be seepage at the toe of the mound, a condition unacceptable in most jurisdictions.

For sites with lower water tables, particularly where the land slopes steeply, some jurisdictions will allow the use of leaching pits in place of leaching trenches or leaching beds (Figure 720-13).

In areas where leaching pits are not allowed, or where a hillside site is underlain with impermeable materials, shallow leaching trenches are possible, but they must be designed to prevent a tilted distribution box (or distribution tee) from directing too much flow to any one trench. Figure 720-14 shows two suitable layouts for such

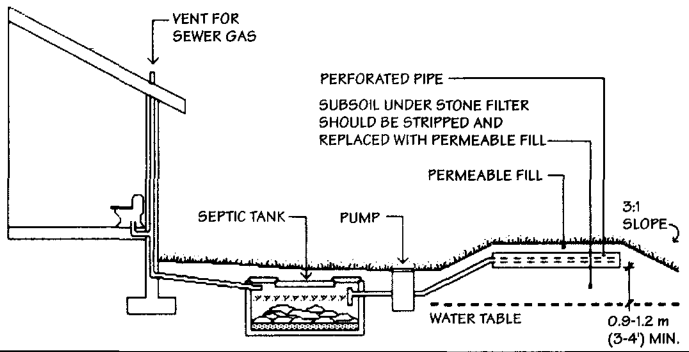


Figure 720-12. Mounded leaching field system.

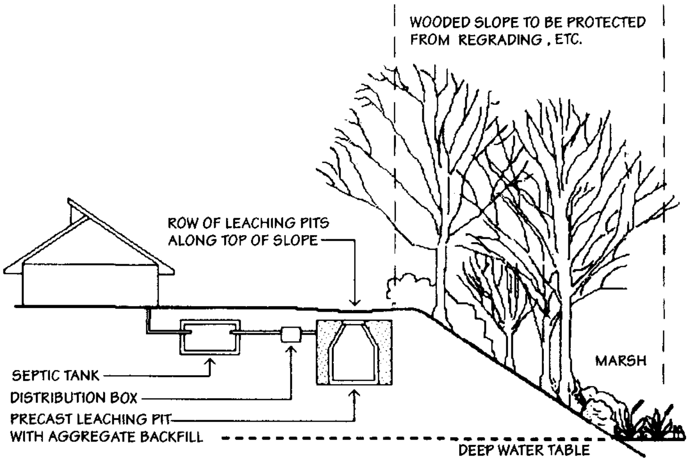


Figure 720-13. Typical leaching pit system.

conditions. Note that the leaching trenches are horizontal, following the contours, and that each trench is loaded with the overflow from higher ones. No distribution box is used.

4.2 Theory

Primary Functions:

Septic tanks are baffled containers that serve three primary functions: They (1) trap grease and floating solids on the top of sewage flows, (2) allow most heavy solids (including paper products and laundry lint) to settle out of the sewage flows to the tank bottom, and (3) permit bacterial decomposition of putrescible solids into simple soluble compounds for disposal with the effluent waters. They also precipitate some inorganic chemicals out of the liquid, convert some organic materials into methane gas (which vents off through the inflow sewer to the house plumbing stack), and destroy some pathogens. However, none of these latter effects is important to the overall waste disposal objective.

The effluent from the septic tank is rich in dissolved putrescible organics, ammonia, organic phosphates, suspended organic particles, and pathogens and is offensively odorous. When this effluent is applied to unsaturated soil (or to a sand filter), it stimulates the growth of a bacterial slime on the soil particles. This slime acts as a very effective filter, physically trapping the suspended particles and biologically digesting putrescible organics and ammonia. The slime also destroys pathogens and odors, and it converts the organic phosphates into inorganic phosphates, a form which can either precipitate out of solution or adsorb to soil particles.

The resulting filtered effluent is relatively harmless except for (1) its higher concentrations of nitrates and (2) an occasional, localized death of the bacterial slime, which permits small, short-lived breakthroughs of untreated effluent. Protection against these occasional breakthroughs is usually provided by setting the leaching facilities back some 15 or 30 m (50 or 100 ft) from wells and surface waters, and protection against the nitrate contamination of drinking water is provided by limiting the density of development. (Refer to Section 710: Water Supply, for more information.)

Maintenance:

The maintenance of septic tanks is limited to (1) infrequent pumping of the septic tank to remove accumulated nondegradable solids (sand, paper, laundry lint, etc.) and (2) resting of the leaching facility.

Recommendations for frequency of septic tank pumping vary, the need being a function of the tankís size and its usage. The need for pumping should be accommodated in the design and location of a septic tank. Local boards of health in the United States require that septic tank locations be clearly marked and be accessible to pump trucks. Beyond this, it is important to recognize the following considerations regarding pump trucks:

1. Most pump trucks carry hoses only 20 to 30 m (70 to 100 ft) long, although some carry hoses up to 60 m (200 ft) long.
2. Although most pump trucks cannot pump septic tanks whose tops are more than 3 m (10 ft) below the elevation of the truck, some special pump trucks can lift up to 9 m (30 ft). As a general rule the shorter the hose, the higher the lift. Check with local experts to confirm what standards are recommended for a specific project.

The need to rest a leaching facility periodically has been well documented in recent years but is usually not provided for in leaching facility design. Its basis is that the long-term continuous loading of septic tank effluent onto soil or sand will result in a gradual filling of the soil pores with ferrous sulfide particles and perhaps also with cellulose fibers (from paper and laundry lint) and grease. Taking a leaching facility off-line and allowing it to rest for a few months will allow the clogging materials to decay by natural processes.

In order to take a leaching facility offline (except for seasonal uses), a second, alternate leaching facility should be available. However, since the original leaching facility will function well for 20 years in this regard, it is not necessary to build a second leaching facility until the need becomes apparent. Proper site design would in most cases require: (1) layout for two parallel systems, (2) initial construction of only one, and (3) provision for access of construction equipment to the second site.

Figure 720-15 shows the overall layout of a septic tank/leaching field facility with parallel fields and a switching valve.

NOTE OF CAUTION: Most codes, especially for larger systems, require alternating leaching facilities fed by alternating dosing siphons. Where required, they must be used, but they do not provide the long-term resting required for removal of soil clogging and are not a substitute for the second leaching facility recommended herein. For long-term on-site system viability, a parallel system for long-term alternation will still be necessary.

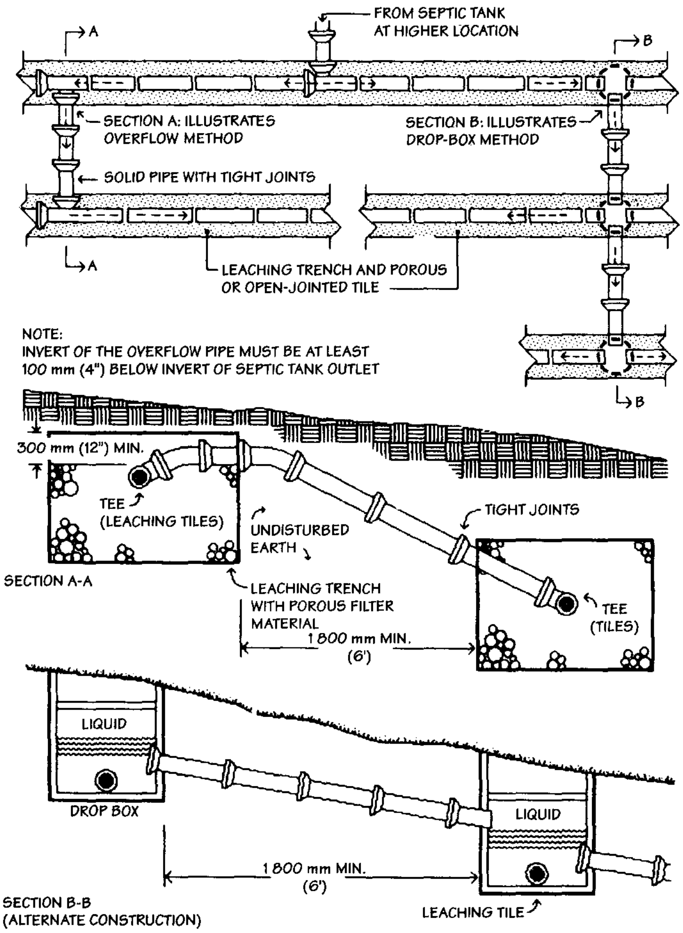


Figure 720-14. Leaching trenches on shallow hillside. *Differing ground slopes over subsurface disposal field may require the use of various combinations of fittings.*

4.3 Sizing and Details: Septic Tanks

Sizing:

Septic tanks are ordinarily sized to hold 1 to 2 days average sewage flow, the larger ratio for smaller buildings such as houses, and the smaller ratio for larger systems. Local code requirements vary, but the specific size is not crucial. In general, larger tanks will likely require less frequent pumping.

Table 720-1 shows estimated sewage flows for various generators. For specific flows in any locality, check local codes.

Design Details:

Regarding the design of the tank, shape and size are relatively unimportant. Figure 720-16 shows a typical 3 785 L (1,000 gal) tank made by a precast concrete products company. Essential characteristics include:

1. A relatively deep shape to allow solids and greases to separate vertically
2. A deeply baffled outlet to draw liquids from mid-depth
3. A baffled inlet to keep grease from plugging the inlet
4. Positive drop for the influent, also to prevent plugging of the inlet
5. Access holes for clearing clogs from the inlet and outlet
6. Access for the pumping of bottom sediments
7. Through ventilation to allow gas flows from the leaching field to vent off through the building vent stack

Figure 720-17 shows a typical 56 775 L (15,000 gal) tank. It has the same essential features as the 3 785–L (1,000-gal) tank, but it uses pipe tees instead of concrete inlet and outlet baffles, and it can be supplied with an intermediate baffle to provide a settling, or clarification, tank at its outlet end. For details and specifications in any locality, contact local precast concrete products suppliers.

4.4 Sizing and Details: Leaching Facilities

Sizing:

Leaching facilities are ordinarily sized to expected sewage flows and soil permeabilities. Local codes give instruction on techniques for measuring soil permeability and

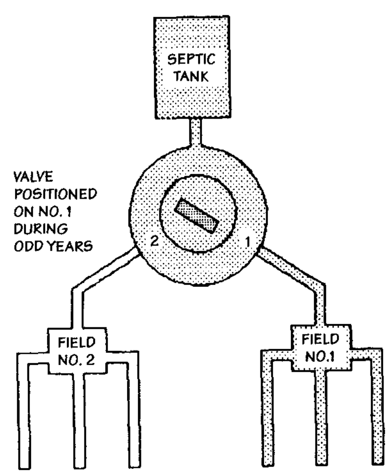


Figure 720-15. Alternating leaching systems.

Table 720-1. QUANTITIES OF SEWAGE FLOWS

Types of establishments	Gallons per person per day (unless otherwise noted)
Airports (per passenger)	5
Apartments, multiple family (per resident)	60
Bathhouses and swimming pools	10
Camps:	
Construction, semipermanent	50
Day (with no meals served)	15
Luxury	100
Resorts, day and night, with limited plumbing	50
Campground with central comfort facilities	35
Cottages and small dwellings with seasonal occupancy	50
Country clubs (per resident member)	100
Country clubs (per nonresident member present)	25
Dwellings:	
Boardinghouses	50
Additional for nonresident boarders	10
Luxury residences and estates	150
Multiple-family apartments	60
Rooming houses	40
Single-family houses	75
Factories (gallons per person per shift, exclusive of industrial waste)	35
Highway rest area (per person)	5
Hotels with private baths (two persons per room)	60
Hotels without private baths	50
Institutions other than hospitals (per person)	125
Hospitals (per bed)	250+
Laundries, self-serviced (gallons per washing, i.e., per customer)	50
Mobile home parks (per space)	250
Motels with bath, toilet, and kitchen facilities (per bed space)	50
Motels (per bed space)	40
Picnic parks (toilet wastes only, per picnicker)	5
Picnic with bathhouses, showers, and flush toilets (per picnicker)	10
Restaurants with toilet facilities (per patron)	10
Without toilet facilities (per patron)	3
With bars and cocktail lounge (additional quantity per patron)	2
Schools:	
Boarding (per pupil)	100
Day, with cafeteria, gymnasiums, and showers (per pupil)	25
Day, with cafeteria but no gymnasiums or showers (per pupil)	20
Day, without cafeteria, gymnasiums, or showers (per pupil)	15
Service stations (per vehicle)	10
Stores (per toilet room)	400
Theaters:	
Drive-in (per car space)	5
Movie (per auditorium seat)	5
Trailers without individual baths and sewer (per person)	50
Trailers with individual bath units, sewer connection (per trailer)	100
Workers:	
Construction (per person per shift, at camps)	50
Day (school or offices per person per shift)	15

Source: EPA, *Manual of Water Supply Systems*, U.S. Government Printing Office, Washington, D.C., 1973

for sizing leaching facilities. Each jurisdiction has its own method, and local codes usually must be satisfied or exceeded.

The typical procedure is to dig one (or more) small-diameter holes [100 to 300 mm (4 to 12 in)] to the depth of the proposed leaching system, fill the hole with 0.3 m (1 ft) of water, keep the water level stable for a specified period of time, and then measure the vertical drop of the water surface in the hole during another specified period of time (typically 30 minutes). The rate of fall, called the percolation rate (or perc rate), is then entered in a table provided by the code which specifies a corresponding size of leaching facility in terms of square meters (feet) of leaching area per liter (gallon) of wastewater or per bedroom. This number is then used to size the bottom area of the leaching trenches or beds, or the combination of vertical and horizontal surfaces of the trenches up to the inverts of the distribution pipes, or some other parameter (e.g., 100 percent of the vertical surfaces plus 50 percent of the bottom surface), as specified by code.

It must be recognized that many (or most) of these requirements have little or no basis either in scientific analysis of leaching system hydraulics or in experience with what actually has worked historically in the field. Consequently, a design that meets the local code is no guarantee that the system will perform satisfactorily.

The designer should note the following:

1. Except for the finest-grained soils (i.e., clayey silt and clays), it is the permeability of the bacterial slimes generated in the soil by the sewage itself, not the permeability of the soils, that limits effluent absorption.

2. Percolation tests yield results in centimeters (inches) of infiltration per hour, but the permeability of the bacterial slime is in fractions of millimeters (inch) per day. As a result, most codes use a factor of safety of about 100 to compensate.

3. In the United States, leaching systems designed according to inadequate codes often are not loaded at the maximum flow rates possible from the buildings they serve; i.e., a three-bedroom dwelling unit that could serve five, six, or seven people usually serves only three people. At three people per dwelling unit, typical code-designed leaching systems suffice; at six people per unit, the same design fails.

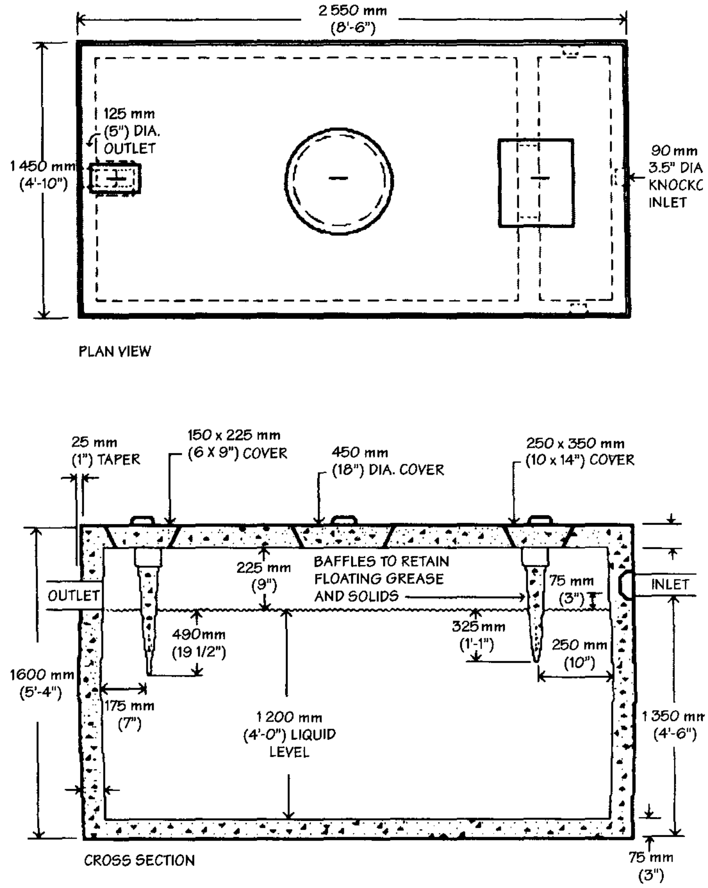


Figure 720-16. Typical precast septic tank (1000 gal).

KEY POINTS: Septic Systems Design

Septic tanks and leaching fields are the most economical, adaptable, trouble-free, and generally accepted form of treatment and disposal for small and medium-size sewage disposal systems [57 000 L (15,000 gal) per day].

1. The key siting requirement for any septic system is an adequate depth of unsaturated soil between the effluent leaching device and the water table [typically 1 to 1.2 m (3 to 4 ft)]. Many jurisdictions will allow mounded leaching fields for sites with high water tables (Figure 720-12), and leaching pits or leaching trenches for hilly sites (Figures 720-13 and 720-14).

2. Protection against breakthroughs of untreated effluent is typically provided by setting the leaching facilities back 15 to 30 m (50 to 100 ft) from wells and surface waters. Protection against nitrate contamination of drinking water is provided by limiting the density of development.

3. Septic tanks require infrequent pumping to remove accumulated nondegradable solids (sand, paper, laundry lint, etc.). Site planning should ensure access to tanks by pump trucks.

4. Leaching systems should function well for about twenty years before requiring resting. Site planning should provide for the layout for two parallel systems, although only one may be constructed initially.

5. Leaching facilities are typically sized to expected sewage flows and soil permeabilities. Local codes outline techniques for measuring soil permeability and for sizing leaching facilities.

4. Effluent does not percolate into the soil at the rate at which it is applied; instead, it ponds up, filling the coarse distribution media until the rate of infiltration matches the rate of effluent application.

5. The maximum steady-state long-term absorption capacity of the bacterial slime in a leaching facility for ordinary septic tank effluent is about 0.19 L/m^2 (1/2 gal/ft^2) per day regardless of whether the infiltrative surface is vertical or horizontal.

6. The permeability of the slime appears to be inversely proportional to the nutrient concentration of the effluent; thus, a vigorous water conservation program without a corresponding reduction in organic loading will have no long-term benefit. (It will appear to work for 2 to 3 months.)

Figure 720-18 shows the key characteristics of a leaching trench system. The system includes both an initial leaching area and space for future construction of an alternative leaching area. Each should be sized for application of not more than 0.19 L/m^2 (1/2 gal/ft^2) per day, measured over the entire trench surface below the invert.

Design Details:

The distribution of the septic tank effluent can be either by a distribution box or by pipe tees. The distribution box is traditional, and although it has been found to offer no advantage in studies by the U.S. Federal Housing Administration, it is more likely to be accepted by conservative public officials. The distribution box can be converted into a diversion device between parallel leaching systems by inserting a simple board (of rot-proof material) diagonally into the box and changing its position as needed. A plastic diversion valve, a newer and neater device, can be used for the same purpose.

The layout of the system can take whatever form fits the site, but a plan that looks rational and orderly (symmetrical, etc.) is more likely to be approved. Table 720-2 shows typical setback requirements for various parts of the system. These vary from code to code.

4.5 Grease Traps

For restaurants and other food preparation areas, a separate grease trap between kitchen drains (those without garbage grinders) and septic tanks is often required. The design of a grease trap is identical to the design of a septic tank except that its

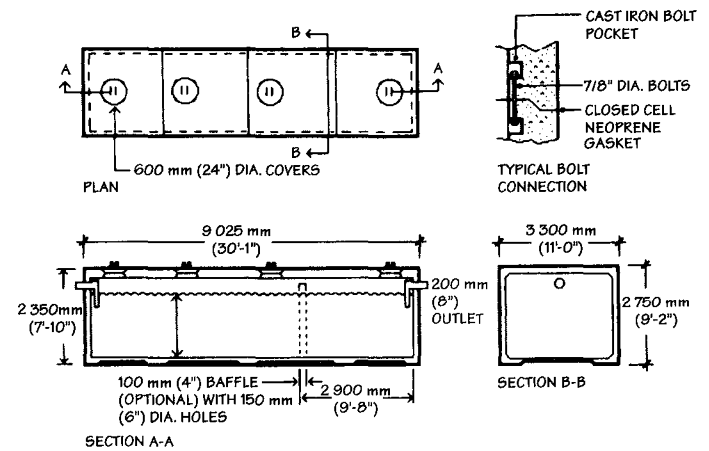


Figure 720-17. Typical precast septic tank (15,000 gal).

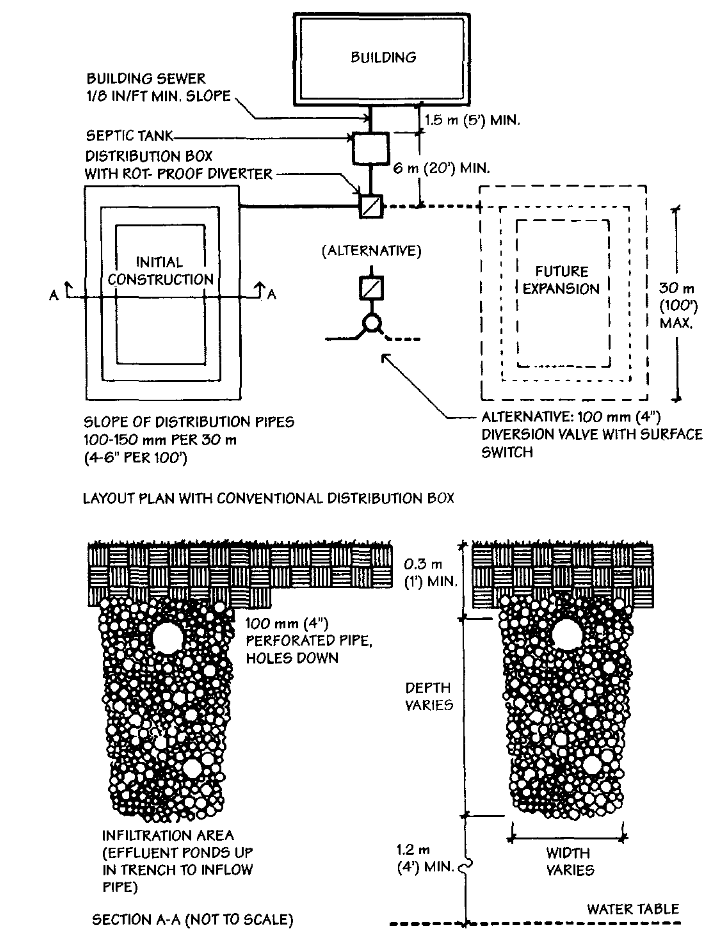


Figure 720-18. Key elements of a leaching trench system. *In Section A, the distance between trenches should be 3W (3 times the width of the trench), or 2D (2 times the depth of the trench), whichever is greater. The distance between the pipe and the top of the trench should be 50 mm (2 in.).*

outlet pipe is placed much lower in the tank to provide maximum volume for the grease.

Figure 720-19 shows a typical precast 3 785 L (1,000 gal) trap. The trap size is 473 L (125 gal) per 50 patrons (U.S. Public Health Service).

4.6 Dosing Chambers

For large systems, many codes require that septic tank effluent not be allowed to trickle into the leaching facility at the rate at which it is displaced from the septic tank by new inflows, but that it instead be collected in a dosing chamber for slug discharge to the leaching facility via one or two automatic siphons every 3 or 4 hours. It is claimed that this procedure results in a more even distribution of effluent within the leaching facility and that it allows the system to rest, i.e., allows the soil to reaerate between doses.

Unfortunately, none of this is true in most cases, since in a typical leaching facility the effluent ponds up, creating a more or less constant underground pool that extends full-time across the full width and length of the facility.

Where leaching is to be accomplished in several separate leaching facilities at more than one level, dosing siphons and distribution boxes can be used advantageously to balance the loading of the various parts. Figure 720-20 shows a typical precast dosing chamber. Note that the chamber is designed to provide a maximum of volume with a minimum of head loss. The siphons themselves have no moving parts.

Figure 720-21 shows a plan of the principal elements of a large system.

4.7 Relationship of On-Site Systems to Trees and Paving

Trees:

Regarding the relationship of disposal systems to trees, note that the effluent in and near the leaching facilities, the septic tank, and the pipelines between are anaerobic and hence not attractive to most plant roots, with the possible exception of such trees as larch, willow, and alder. The sewer pipe between the building and the septic tank is not anaerobic, however, and can be invaded and clogged by roots. Consequently, except for the building sewer pipe, no special care need be given to the relationship between trees and septic on-site sewage facilities.

TABLE 720-2. Typical Setback Requirements

Component of system	Well or suction line	Water supply line pressure	Stream	Dwelling	Property line
	Horizontal distance, m (ft)				
Building sewer	15 (50)	3 (10)	15 (50)	-	-
Septic tank	15 (50)	3 (10)	15 (50)	1.5 (5)	3 (10)
Disposal field and seepage	30 (100)	7.5 (25)	15 (50)	6 (20)	1.5 (5)
Seepage pit	30 (100)	15 (50)	15 (50)	6 (20)	3 (10)
Cesspool	45 (150)	15 (50)	15 (50)	6 (20)	4.5 (15)

Note: This table refers to minimum distances between components of sewage disposal systems.

Paving:

Regarding the relationship between disposal facilities and paving, some codes prohibit leaching facilities under pavements, others permit them if the leaching fieldsí distribution pipes are vented, and still others have no restrictions. For heavy traffic, pipes should either be adequately covered with roadbase material [e.g., 0.6 m (2 ft)] or be made of crush-proof materials (cast iron or precast concrete, etc.).

Vents, where required, are typically vertical 100 mm (4 in) cast-iron pipes affixed to tees on the outer ends of the leaching pipes, topped with 180-degree bends, and protected from traffic by a cluster of bollards or other traffic control devices.

5.0 AEROBIC SYSTEMS WITH SURFACE INFILTRATION

5.1 Application

As septic tank/subsurface disposal systems get larger, their costs and space requirements increase proportionately, with little economy of scale. At some point over 56 775 L (15,000 gal) per day, other approaches become competitive. These approaches include not only the settlement and digestion of the suspended solids in the wastewater before its application to the leaching fields, but also the removal of dissolved organic compounds by biological processes.

The resulting effluent can contain as little as 10 percent of the bacterial nutrients of septic tank effluent and thus can be applied to the soil at several times the rate practical for septic tank effluent. Furthermore, because these alternate processes are aerobic rather than septic, their effluent normally and theoretically is odor-free and thus can be applied to surface infiltration beds as well as to subsurface filters. Alternatives suitable for smaller communities include lagoons or stabilization ponds and package plants.

5.2 Lagoons

The most economical and most trouble-free of these alternatives are the various forms of lagoons. Basically, the lagoon is a shallow pond [0.6 to 1.5 m (2 to 5 ft) deep], open to the sun and wind, used to retain sewage for about a month. Like the septic tank, it relies entirely on natural processes and, with favorable topography, on gravity flow. The solids settle to the bottom and decompose anaerobically (as in a septic tank), but their odor is contained and absorbed by the overlying aerated water. The mineral nutrients released in the decomposition, together with the sun shining on the pondís surface, support a vigorous growth of algae. The algae produce

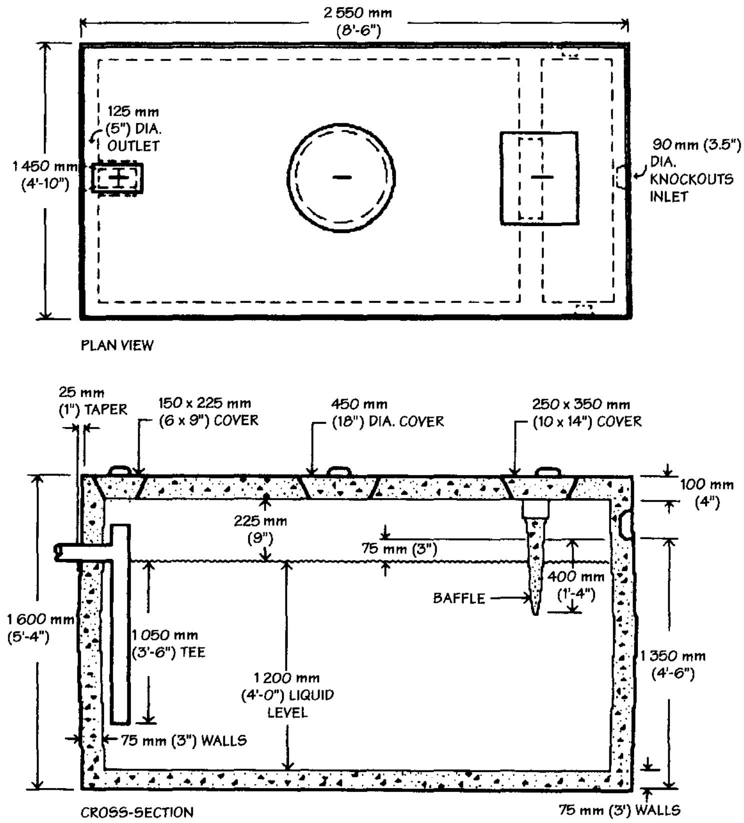
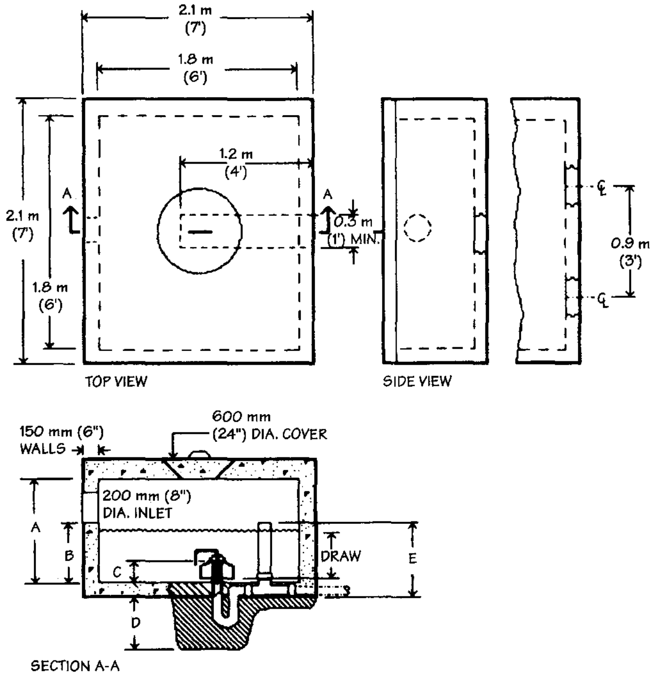


Figure 720-19. Typical precast grease trap (1000 gal).

720 Sewage Disposal



SIPHON	L (GAL)	DRAW	A	B	C	D	E
750 mm (3")	1 100 (290)	325 mm (13")	725 mm (29")	475 mm (19")	180 mm (71/4")	375 mm (15")	575 mm (23")
100 mm (4")	1 440 (380)	425 mm (17")	825 mm (33")	575 mm (23")	290 mm (113/4")	450 mm (18")	700 mm (28")
125 mm (5")	1 950 (515)	625 mm (23")	975 mm (39")	725 mm (29")	240 mm (91/2")	725 mm (29")	900 mm (36")

Figure 720-20. Typical precast dosing chamber.

oxygen; this, along with the oxygen absorbed by the pondís surface, keeps the upper layers of the pond fresh and odor-free.

The effluent from the stabilization pond is siphoned off the top to a polishing lagoon (about 1 dayís flow) and then dosed onto sand filters at rates up to 0.95 L/m^2 (2 1/2 gal/ft^2) per day.

This system, like septic systems, requires almost no management or maintenance. It must be fenced, however, since it has surface ponds and sewage on the ground surface in various stages of beneficiation. The ponds do have to be drained and cleaned (like septic tanks) at infrequent intervals (up to 20 years) and the leaching beds do need to be alternated and rested, if and when they show signs of clogging.

Unlike septic tanks with subsurface filters, the land used for lagoon systems and surface infiltration cannot be used for other purposes.

In regions where winter freezing does not occur, unaerated lagoons are usually odor-free, but in areas where freezing does occur there will be serious odor generated during the twice-a-year thermal turnovers of the ponds.

To control these turnovers and their resulting odors, each lagoon can be very gently mixed with a low-energy aerator (a small air compressor and a weighted polyethylene tube run into the lagoon to generate columns of bubbles). This mixing not only effectively controls the odors but allows the pond to be deepened to 3 to 4.5 m (10 or 15 ft), further reducing space requirements.

The aerated lagoon system is in all other respects similar to the passive lagoon.

Figure 720-22 shows the overall space requirements for septic leaching and aerated leaching systems for housing clusters of various sizes. Note that septic systems are quite competitive at the lower end of the range, especially since their space requirements are subsurface.

Figure 720-23 shows a schematic aerated lagoon system. The aerated lagoon is divided into two or more ponds so that half of the system can be drained and cleaned when the need arises. On favorable topography it can be designed to work hydraulically, with no pumps. The only inputs to the system are the sewage itself and compressed air.

Actual design configurations of lagoons vary. Advantage should be made of existing topography where possible; since there is no mechanical equipment to be incorporated other than the compressed-air lines, the ponds and beds can be any shape desired.

The lagoon can usually be built of locally available or on-site materials. Lagoons can be contained by seeded earthen berms of clayey or silty soils. If sited so that the lagoon bottoms are a minimum of 1 to 1.2 m (3 to 4 ft) above the local water table, no serious groundwater contamination is likely after the lagoons have been in use for a period of time. Natural processes will tend to seal the soil with organic slimes.

5.3 Package Plants

Package plants, or prefabricated secondary sewage treatment plants, can accomplish the same effluent quality as lagoons, usually in less space, and within a building if desired. These systems are mechanically complex, require constant energy inputs, and must be regularly and competently maintained. In addition, the U.S. Environmental Protection Agency has recommended that they be pumped once or twice a year to remove accumulating biomass. If not pumped, the biomass can overload the equipment or wash out into the infiltration beds. Contact a manufacturerís representative for specific details.

In some jurisdictions, package plants are either not allowed or must have oversized infiltration beds to accommodate the washed out biomass.

5.4 Subsurface Leaching

Aerobic systems of any kind can be used with subsurface leaching beds, and the leaching beds can be smaller than those used for septic tank effluent. These subsurface beds would be identical to those used with septic systems, with the exception of size.

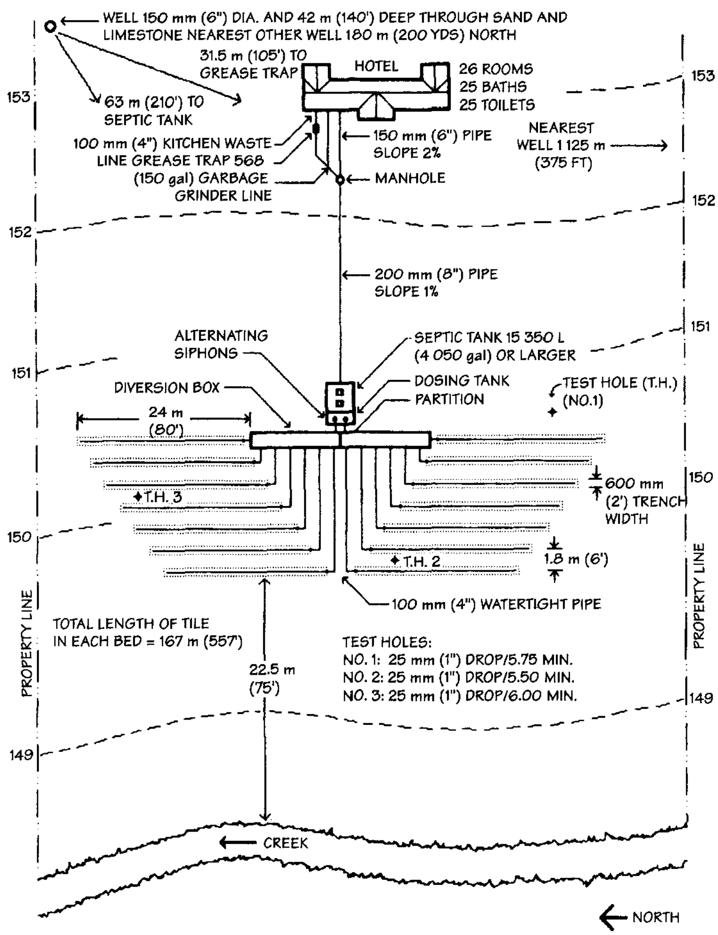


Figure 720-21. Principal elements of a large leaching system.

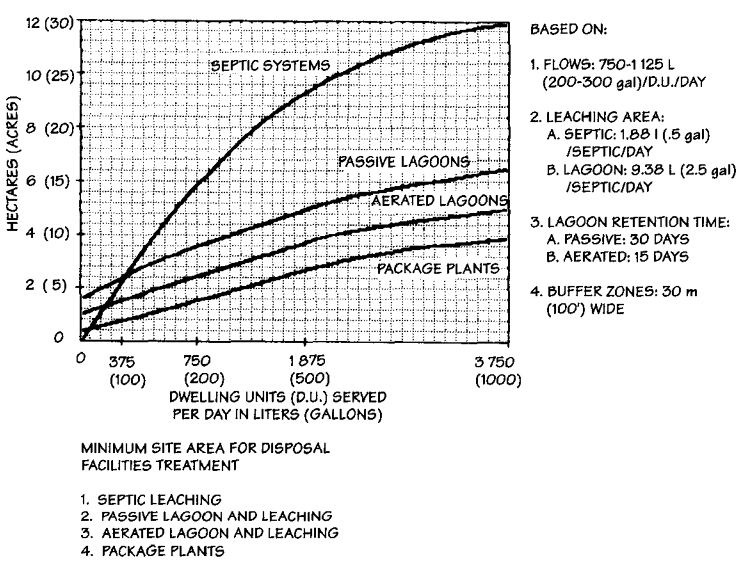


Figure 720-22. Minimum site area required for disposal facilities.

6.0 AEROBIC SYSTEMS WITH EVAPOTRANSPIRATION SYSTEMS

For sites with limited absorptive capacity where the usage is limited to the growing season, it is possible to dispose of a high proportion of wastewater by evapotranspiration. This approach has been used for summer resorts and as a seasonal alternative to discharge into streams.

NOTE: Streams in various regions have seasonal variations in the quantities of flow. For instance, streams in the eastern United States have the lowest ability to dilute wastewater at the height of the growing season.

For evapotranspiration to work, the effluent must be well aerated so that plant roots will readily take up the liquid. As a consequence, evapotranspiration is not feasible with effluent from septic systems, but it can work with any aerobic effluent. The effluent can be applied by a number of methods, including subirrigation, surface flooding, and spray irrigation.

For subirrigation, the system would be similar to a shallow trench infiltration system for septic effluent, but it should be constructed as close to the ground surface as possible. Like the subsurface disposal of septic effluent, the subirrigation method does not pose any hazards to surface use of the land.

For surface flooding or spray irrigation, consideration must be given to the potential pathogenic hazards of the unfiltered effluent. The areas used for surface irrigation are not normally available for other uses, at least during the seasons in which they are used for wastewater disposal. Crops that might be grown on the land are not normally used for human food. Compatible land uses and crops include game habitat and hunting grounds, forest products, and forage crops for horses.

The application rates for any evapotranspiration system are a function of temperature, hours of sunshine, wind velocity and duration, rainfall, etc. All these vary considerably with the location and the season; thus, any evapotranspiration system will require careful custom design to the specific case.

7.0 AEROBIC SYSTEMS WITH SURFACE WATER DISCHARGE

The discharge of sewage to surface waters, whether treated or untreated, is an ancient

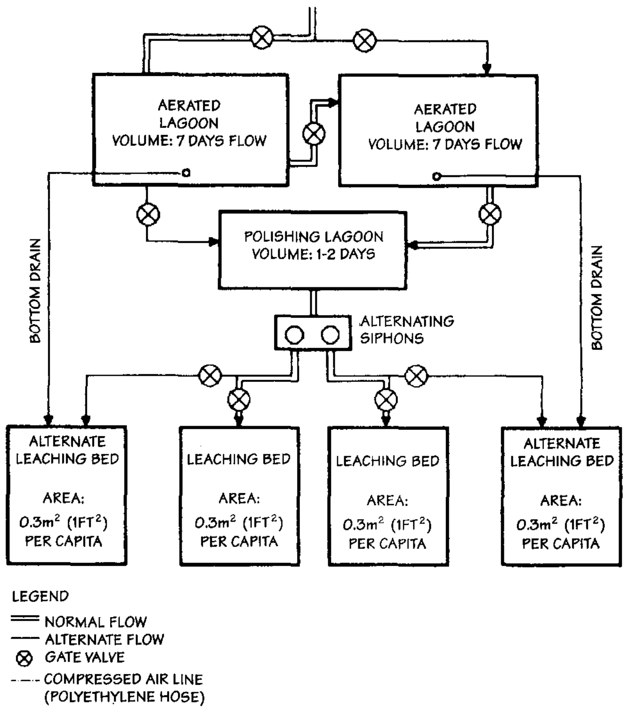


Figure 720-23. Typical aerated lagoon system (schematic diagram).

practice which has been widely used because of its low cost and ease of accomplishment. As long as the total discharge was small and scattered and the volume of the receiving waters large, it was considered acceptable.

However, as the discharges increased in size and in number, their impacts grew. In an attempt to reverse this trend, the art and science of sanitary engineering was invented and various forms of sewage treatment were developed. Various treatment techniques applied to large volumes of municipal sewage, usually on limited sites in congested urban waterfront areas, have done much to ameliorate the adverse effects of the water discharges, but these techniques are far from perfect. Indeed, almost no municipal treatment plant approaches the overall treatment effectiveness (or low cost) of the common backyard leaching field.

In most areas of the United States, in order to obtain permits for discharging sewage effluent directly into surface waters from new developments, the designer must demonstrate that there are no feasible alternatives including no action (either foregoing the project or siting it elsewhere) and that the treatment process will produce no significant environmentally adverse impacts on the receiving waters (including the biochemical effects of chlorine or other disinfectants). The degree and type of treatment for the effluent will depend in large part on the character of the receiving waters, but the designer of a new project should anticipate much more extensive treatment than that usually applied at a municipal treatment plant.

For land development planning purposes, space should be provided for some form of digestion (a package plant or an aerated lagoon), for a sand filter, and for some form of denitrification for the filtered effluent-perhaps a second lagoon, shallow and weedy, 0.6 to 1 m (2 to 3 ft) deep. Marsh areas are often considered valuable environmental resources and cannot be used as a part of the treatment process.

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Recreational Water Bodies

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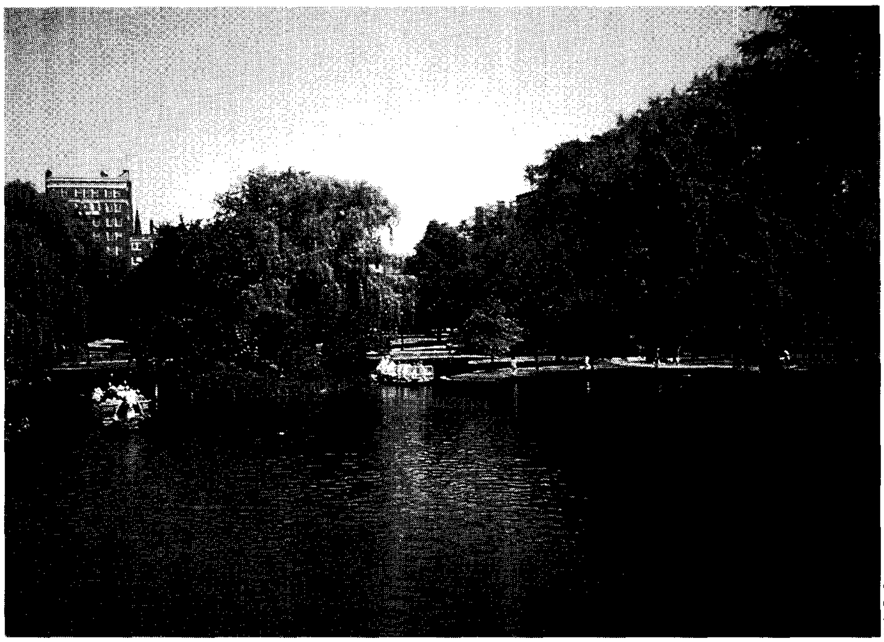

Kyle D. Brown

CONTENTS

1.0 INTRODUCTION

Impounded surface waters are often valued for:

1. Swimming and related recreation
2. Wildlife habitat
3. Aesthetic (i.e., visual) reasons

Principal concerns in the design of recreational water bodies are control of (a) water quality, (b) water level fluctuation, and (c) edge treatment. Each of these concerns should be addressed and specifically incorporated into the plans and designs for recreational water bodies. Unless the water body is large enough to establish zones, it is often not feasible to incorporate several recreational functions into one area. For instance, swimming and boating do not mix.

Impoundments designed primarily for power and flood control tend to have short periods of water detention, i.e., their annual flowthrough is larger than their storage capacity, hence their retained water tends to be turbid and tactilely unattractive. On the other hand, impoundments designed for water storage (i.e., water supply and large-scale irrigation) tend to have long periods of retention, and therefore their water is more transparent and tactilely more attractive.

Similarly, reservoirs that are small with respect to the amount of water drawn from them may have wider variations of water levels. This makes the shorelines more difficult to use for recreational purposes and may affect the aesthetic values during certain seasons. Large reservoirs tend to have more stable water levels with respect to their slower rates of withdrawal and, therefore, are more suitable for recreational uses.

Note that daily flowthrough, a key parameter in the design of mechanically filtered swimming pools, is not appropriate to determine for ponds and lakes. They typically have far more water per swimmer than the typical large public swimming pool.

2.0 EVALUATIVE CRITERIA FOR RECREATIONAL WATER BODIES

Waters for recreational use must meet various standards of quality, appearance, and ease of maintenance.

2.1 Water Quality

1. In a public health sense, fresh water used for swimming should approach the quality standards used for drinking waters.
2. In an aesthetic sense, swimming waters should be as transparent as possible, including being free from algae, weeds, organic detritus, and suspended silts and clays.
3. In a public safety sense, intensively used swimming waters should have sufficient transparency to facilitate rescue of drowning victims.
4. For wildlife habitat and scenic values, any water quality except the most seriously polluted will be appropriate. A diversity of water body characteristics (i.e., quality, depth, temperature, and form) will support the greatest number of species.

2.2 Water Levels

1. For swimming uses, water control systems should be designed so that levels can be maintained during dry summer seasons, or so that access to the water can be maintained when water levels fall.
2. For aesthetic (i.e., nonswimming) reasons, water bodies that are expected to lose a major portion of their water during the summer should be shaped as a shallow basin to support a vegetative cover (i.e., marsh, shrub swamp, etc.) to avoid revealing a muddy edge or bottom.

2.3 Side Slopes

The action of waves will eventually erode any pond embankment to a wavecut beach (except those heavily armored with stone, concrete, or metal). The eventual slope of the beach will depend on the texture of the soil involved. For instance, coarse sand will form an approximate 10 percent slope, and finer sands a 5 percent slope. The vertical extent of the erosion will approximate the height of waves generated on the pond. Wave height is a function of pond size, its wind exposure, and other factors, including the size of boats and the relative exposure of the particular reach of shoreline.

Figure 740-1 shows the form of a wave-cut beach, with 300 mm (1 ft) waves and a stable water level, on a 1:5 slope in coarse sand. Note the steep drop that can form just below the beach. On a steeper average slope, say 1:3, or in fine sand, the drop would be over 1 m (3 ft) deep and could constitute a safety hazard for swimmers, especially children.

Alternative shoreline treatments include riprap, stone armor, and various types of walls. In each, consideration should be given to the human usage of the surrounding area, including ways to escape if anyone happens to fall into the water.

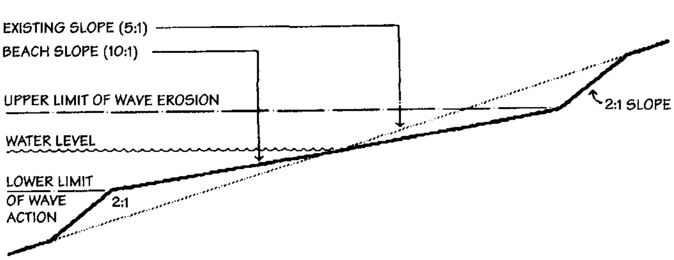

Figure 740-1. Wave-cut beach form on erodible shore.

3.0 SWIMMING WATERS

3.1 General

Two common alternatives for swimming include:

1. Swimming pools with:
   a. Filtration to remove suspended materials
   b. Algicides to control algae
   c. Chlorination to control bacteria
2. Ponds and lakes with:
   a. Long storage times to settle suspended materials
   b. Control of algae by controlling watershed land use and drainage

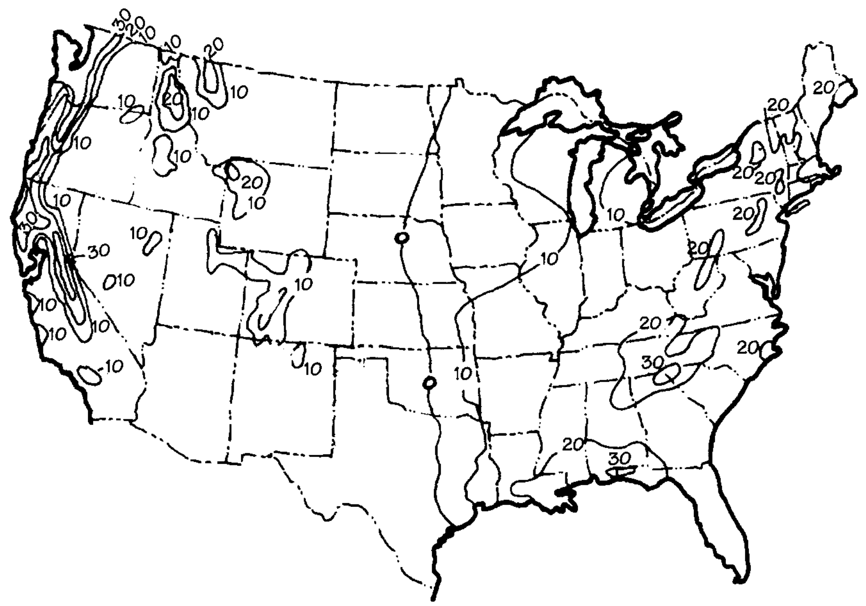

Figure 740-2. Average dry year rainfall less lake evaporation.

c. Control of bacteria and viruses by natural processes (e.g., maintaining natural biota, including predators)

The selection of an alternative for swimming depends on the purpose of the project, the necessary size of the water body, and the particular amenities of the site. For small swimming areas, filtered, chemically treated swimming pools are usually the most appropriate, and they can be built almost anywhere. For larger facilities, ponds or lakes are likely to be the most appropriate, but their feasibility is a function of hydrologic, geologic, and topographic opportunities.

3.2 Swimming Pools

For small residential swimming pools, a variety of design alternatives are possible, ranging from prefabricated aboveground plastic-lined metal containers to in-the-ground concrete structures, all connected by some means to the necessary filtering equipment. For specific design information in any locality, local swimming pool supply houses or contractors should be contacted and their offerings adapted to specific site conditions.

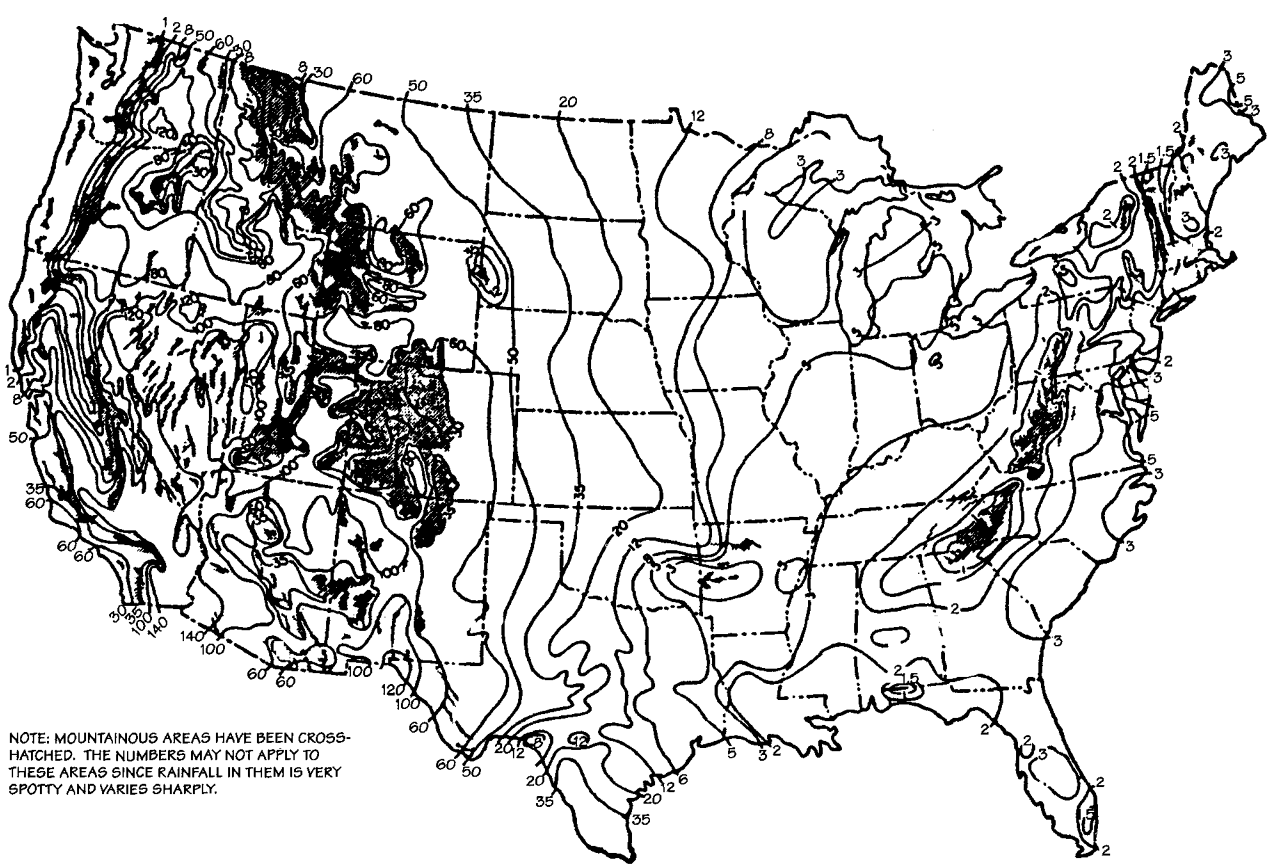

Figure 740-3. Runoff area required to produce a given volume.

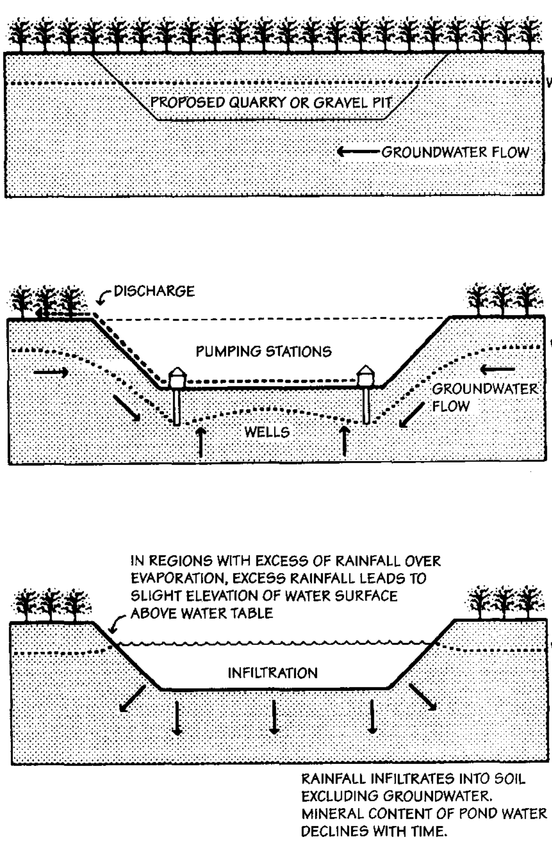

Figure 740-4. Hydrologic progression in permeable soils with a flat water table.

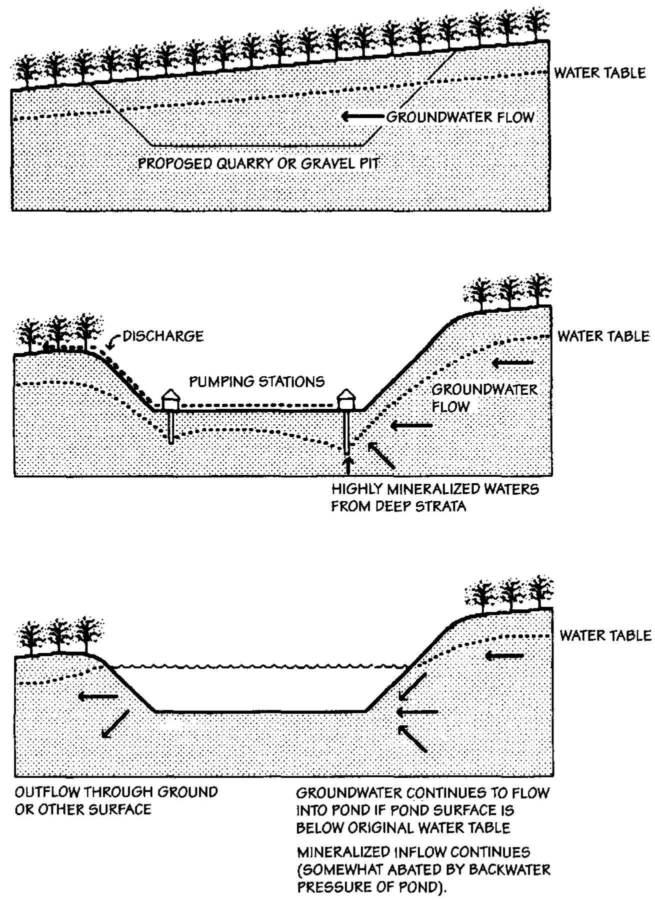

Figure 740-5. Hydrologic progression in permeable soils with a sloping water table.

For larger swimming pools, those for institutional or public use, specialized professional engineering of the structural containment and mechanical systems will usually be necessary to optimize effectiveness and costs.

3.3 Ponds and Lakes

High-quality water for swimming can be found in naturally clean, existing ponds and lakes or in ponds and lakes specifically designed to control suspended sediments and nutrient inputs. (Refer to Section 330: Stormwater Management for information on the control of suspended sediments and nutrient inputs.)

3.4 Stream Impoundments

Site Selection:

General design considerations for swimming impoundments on streams include:

1. Suitable soil conditions on the bottom (i.e., the less permeable, the better)
2. A topographic form capable of being shaped into a pond at reasonable cost (minimum regrading)
3. A site free of excessive organic materials
4. An adequate water supply
5. A watershed free of contaminants
6. An impoundment volume large enough for long-term water storage

A large watershed is in most cases neither necessary nor desirable since, except for the initial filling of the pond, only enough additional water to compensate for leakage and evaporation is needed. (Refer to Section 330: Stormwater Management, for information on the calculation of runoff quantities.)

Water Supply:

Figure 740-2 shows the average dry year rainfall, less evaporation, for the United States. Note that in many areas the dry year rainfall exceeds the evaporation, so that if the impoundment had no leakage, no watershed beyond the water body itself would be necessary. However, since leakage will occur and since the reservoir must be filled initially, some tributary area will be necessary. A professional geohydrologist should be consulted to estimate leakage. (Refer to Section 710: Water Supply, for more information.)

Figure 740-3 shows the size of tributary area required to produce a given volume of makeup water to replace likely water losses. Note that even in areas that are relatively dry (except for very dry deserts), enough runoff water can be gathered during the rainy season if the watershed is carefully selected.

Water Quality:

To meet water quality standards desirable for swimming:

1. The site of the impoundment should be stripped of all organic material (i.e., vegetation, topsoil, peat, etc.).

2. The retention time of the water in the impoundment should be greater than 1 year (i.e., the volume of the reservoir divided by the annual rainfall runoff to it should be greater than 1).
3. Suspended sediments and limiting plant nutrients (phosphates) must be rigorously excluded.
4. The reservoir should be suitably shaped to allow natural pond clarification processes to occur.

Reservoir Form:

Naturally clear ponds will result from a number of mechanisms that contribute to water quality, including:

1. Adequate depth, typically over 3 m (10 ft), to allow thermal stratification of the water and seasonal turnovers. This process leads to the seasonal formation of a natural ferrous sulfate floc, which traps and removes suspended particles that would otherwise be too fine to settle of their own weight. Note that the depth need not occur over the entire pond bottom but can be limited to a single large hole (probably near the dam). Refer to Section 420: Small Dams, for information on the design and construction of small dams.
2. Adequate shoal water, less than 1 to 1.5 m (3 to 5 ft) deep, away from swimming areas and close to inflows to the pond. This will allow rooted aquatic vegetation to establish itself and absorb plant nutrients, thereby partially denying the nutrients to algae. Over time, this vegetation can be expected to occur through natural processes, but it can also be introduced artificially.

Watershed Considerations:

The watershed of a swimming pond need not be much larger than what is necessary to provide adequate makeup water for leakage and evaporation in a dry year, and it should not be large enough to yield more runoff in a wet year to drop the reservoir's storage ratio below 1. If this happens, it tends to create problems of increased sediment.

Equally important, the nutrient intake (especially phosphates) of the watershed must be carefully controlled to inhibit eutrophication. Common sources of phosphates are geologic in origin (i.e., springs, seeps, and geohydrologic upwellings) and urban in origin (runoff from roofs, pavements, etc.).

To control urban runoff, a development's drainage that would normally flow into the pond should either be filtered in some way or diverted around the pond by ditch or culvert, including diversion of the entire inflow stream if necessary.

To control geologic phosphate sources, the surface streams that flow into the impoundment should be tested. If they are phosphate-enriched (more than 15 parts per billion), they should be excluded or an alternative site should be found.

Construction of Small Dams:

Where a small dam or dike is needed to help retain water, several considerations regarding the location, design, and construction of the dam are important. Section 420: Small Dams, discusses these and provides information on the design and construction of several types of dams.

3.5 Excavated Ponds

General:

Ponds are sometimes feasible in borrow pit excavations and quarries. Their suitability for swimming is partially a function of their water quality and partially a function of safety (i.e., their form and depth). The latter can often be improved by grading.

Water Supply and Quality:

Ponds in borrow pits or quarries are usually fed by a mixture of rainwater, runoff, and groundwater. If the runoff and groundwater are bacterially clean and low in phosphates (i.e., less than 15 parts per billion), the pond is likely to be attractive to swimmers regardless of the source of the water. However, where the runoff or groundwater is a problem either geologically or because of improper disposal of wastes in the region, the monitoring and control of runoff and groundwater flow into the pond is essential to the pond's acceptability.

Surface runoff can be controlled by ditching and culverting, but groundwater flows must be controlled by the design of the excavation in order to achieve a hydrostatic balance between rainwater and groundwater that excludes the unwanted groundwater.

Figure 740-4 shows the hydrologic progression that would occur in the development of a borrow pit in readily permeable soils in an area with a flat or nearly flat water table. Note that the natural processes in regions with an excess of rainfall over evaporation (average year, not just dry year) will normally result in a clean, transparent water body.

Excavation in an area with a sloping water table, however, will not produce the same effect unless carefully designed. Figure 740-5 shows a similar progression with a sloping water table.

KEY POINTS: Swimming Ponds

The selection and design of a pond or impoundment for swimming depends on the purpose of the project, the size of the water body needed, and the particular amenities of the site.

1. A large watershed for a stream impoundment is in most cases neither necessary nor desirable. The volume of the reservoir divided by the annual rainfall runoff into it should be greater than 1, to minimize sedimentation.
2. Swimming ponds should provide adequate depth, typically over 3 m (10 ft) to allow for thermal stratification and seasonal turnovers. These depths may be limited to a single large hole within the pond.
3. Adequate shallow areas [less then 1.5 m (5 ft)] should be provided at inflow points, away from swimming areas, to absorb plant nutrients. This will minimize algae growth in the swimming areas.
4. The nutrient intake (especially phosphates) from geologic and urban causes must be carefully controlled to inhibit eutrophication. Runoff from development should be filtered or diverted around the pond. If streams that flow into the pond are phosphate-enriched (>15 ppb), an alternative site should be found.
5. Shoreline treatments include riprap, stone armor, and various types of walls. Consideration should be given to human use, including ways to escape if someone falls into the water.

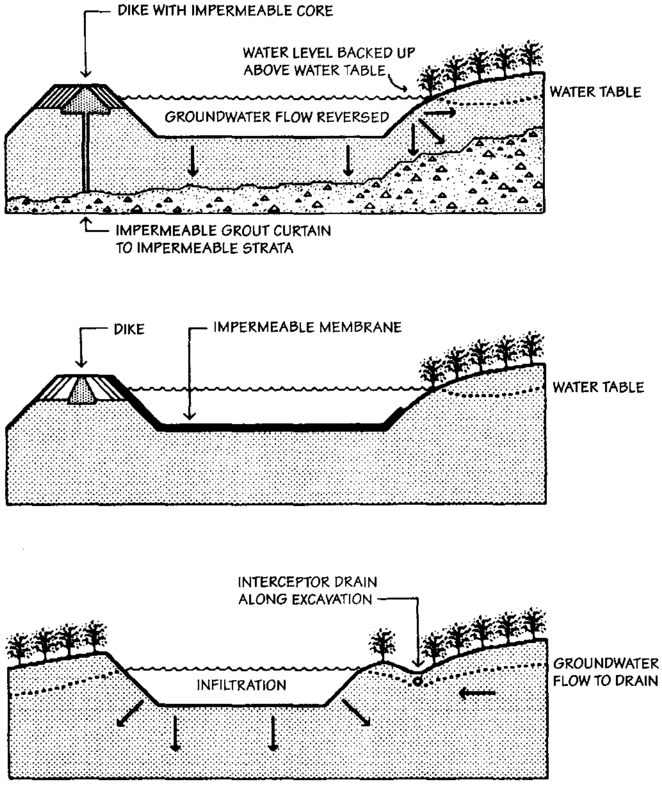

Figure 740-6. Correction strategies if pond surface is below original water table.

In the case illustrated, with the resulting pond lower than the water table, groundwater will continue to flow in, and if the groundwater contains phosphates from any source, the pond is likely to become eutrophic. Correction of this condition is possible. Figure 740-6 shows several possible correction strategies, all costly.

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Irrigation

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1.0 INTRODUCTION

1.1 General

Irrigation is sometimes necessary to keep landscapes at an optimum functional or aesthetical peak. Although all geographic areas receive rainfall sufficient to sustain indigenous plant materials growing under natural conditions, situations involving introduced species, or species growing under less-than-ideal conditions, often require some form of irrigation to maintain healthy plant growth.

This section focuses on various types of irrigation systems and on means for selecting the most economical system for any given situation.

1.2 Important Considerations

Plant Growth Requirements:

The quantity of water necessary for healthy plant growth must be determined in order to design an irrigation system of highest efficiency. If growth conditions are less than ideal, supplemental water may be necessary to overcome incidences of plant stress.

Some plantings may require irrigation during construction processes, or during and after transplantation until established. A controlled application of water will greatly improve the germination rate in seeded areas and will enable seedlings to develop to maturity. Turfgrass is used most often in nonnative environments, and even though some varieties are drought-tolerant, a regular schedule of water is necessary to maintain a green, healthy turf.

Conservation of Water:

Conservation of water is an important ecological issue. Along with water depletion, common problems include saltwater intrusion and land subsidence. The rising cost of water requires efficient use and management of all water resources.

Automatic sprinkler systems are designed to increase the efficiency of landscape water usage. Efficiency is accomplished by first determining which plant materials require irrigation and how much water is required, and then designing irrigation systems which apply that water with minimum waste.

Effluent water is being used in many areas as a conservation measure, with considerable success. (Refer to 2.4 Effluent Water in this section for more information.)

2.0 WATER SOURCES

2.1 Municipal Water

Most landscape projects use potable water provided by the local water district.

Research necessary at the outset of an irrigation project includes:

1. The possibility of an alternative source of water that would be more cost-effective on a long-term basis.

2. A determination of existing static pressure in municipal lines (including high and low times), of the size of the main line in closest proximity to the project site, and of any local codes that may be pertinent to the installation of an irrigation system.

Table 750-1. RAINFALL AND EVAPOTRANSPIRATION DATA (EXAMPLE)

Massachusetts	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Western (Pittsfield)													
RF	3.39	2.69	3.56	3.90	4.00	3.96	4.41	3.73	4.43	3.25	4.06	3.41	44.79
EVT	0.00	0.00	0.46	1.51	3.33	4.78	5.77	4.93	3.05	1.61	0.58	0.00	26.02
DIFF	3.39	2.69	3.10	2.39	0.67	−0.82	−1.36	−1.20	1.38	1.64	3.48	3.41	18.77
Central (Springfield)													
RF	3.86	3.10	4.09	3.84	3.58	3.71	3.60	3.79	3.95	3.23	4.14	3.60	44.49
EVT	0.00	0.00	0.67	1.79	3.66	5.30	6.38	5.50	3.55	1.89	0.76	0.00	29.50
DIFF	3.86	3.10	3.42	2.05	−0.08	−1.59	−2.78	−1.71	0.40	1.34	3.38	3.60	14.99
Coastal (Boston)													
RF	4.04	3.37	4.19	3.86	3.23	3.17	2.85	3.85	3.64	3.33	4.11	3.73	43.37
EVT	0.00	0.00	0.73	1.71	3.37	4.95	6.18	5.48	3.58	2.05	0.87	0.30	29.22
DIFF	4.04	3.37	3.46	2.15	−0.14	−1.78	−3.33	−1.63	0.06	1.28	3.24	3.43	14.15

Note: RF—rainfall, EVT—evapotranspiration rate, DIFF—the average amount of water needed to be added per month to sustain healthy turf.

3. Investigation into municipal water and sewer rates, based on water meter readings. Separate water meters for the irrigation system may exclude owners from paying a sewer surcharge.

2.2 Lakes, Ponds, Reservoirs, Streams, and Rivers

Natural bodies of water can be used very effectively, depending on the riparian rights of that water.

Design considerations include:

1. Pump capabilities and the power (usually electric) required to operate the pump.
2. The quality of water at different seasons during usage (filtration must usually be provided).
3. The possibility of having to transport water from one source to a holding pond or reservoir (depending on the water requirements). This is especially common in golf course applications, where even potable city water is used on occasion to maintain water levels in a body of water that is ultimately used for irrigation.

2.3 Wells

High water tables are a good source of irrigation water, even for small installations.

Design considerations include:

1. The amount of water available, i.e., how much consistent flow is realized (sometimes water is available, but replenishment is not achieved at a rate adequate for the system's demand).
2. The amount of sand particles pumped with the water. Sprinkler heads with small orifices in the nozzle may have to be avoided.

2.4 Effluent Water

Effluent water (also referred to as recycled water, gray water, sewage effluent, wastewater, and recycled sewage) is basically liquid sewage from a municipal sewage plant or industrial plant which has been treated and is ready for disposal. Effluent water is more than 99 percent pure water and by recent federal legislation is treated in a manner similar to drinking water.

In the United States, the vast majority of effluent water is pumped into rivers or streams (eventually to end up in the ocean), although it has seen much greater use for irrigation of agricultural fields and other land uses in recent years. Many industrial plants use their own effluent to irrigate their grounds, and a number of golf courses use effluent water for irrigation. Some new communities have built networks of pipe (separate from potable water and sewage lines) for carrying effluent water. In such communities, effluent water would not be affected by the possibility of rationing.

Most states in the United States do not bar the use of effluent to irrigate turfgrasses. Not only can the use of effluent be a real aid to turfgrass maintenance, but it can serve to replenish groundwater resources. Turfgrass will effectively remove most of the impurities in effluent, and percolation through the soil will remove the remainder.

Acquisition:

Both municipal and industrial sewage treatment plants can supply effluent water for use in irrigation. The facilities should be relatively close to the site requiring irrigation, since piping long distances is usually cost-prohibitive. Facilities will provide effluent in volumes ranging from a few thousand gallons to several million liters or gallons per day.

Analysis:

Effluent water available from any source should be analyzed for its suitability as irrigation water. Not all effluent can be used on turfgrasses, for instance. Chemicals that exist in the potable water supply of a municipality will exist in even greater concentrations in its effluent water (sometimes at a level toxic to plants); chemicals such as boron and sodium are especially important to monitor. The salt levels may not be toxic, but a means may have to be provided to prevent the problem of salt buildup.

The levels of nitrogen, phosphorus, and potassium found in most effluent are often high enough that users may only have to use one-fourth as much fertilizer as without effluent water, or sometimes none at all.

Permits and Regulations:

When effluent water is used for irrigation, permits have to be secured from appropriate authorities. Pollution control agencies will be involved, as well as county health departments.

Public Attention:

In many jurisdictions, regulations now require the identification of effluent water use for irrigation. There is no reason to be secretive about using effluent for landscape irrigation purposes, but public attention will nevertheless be drawn to practices that seem potentially harmful.

Assessing Water Requirements:

Before an agreement can be signed with a municipal agency or industrial treatment plant to accept effluent for irrigation, the amount of water required to irrigate the site must be accurately calculated. Overcommitments are as problematic as undercommitments.

3.0 DESIGN CRITERIA

3.1 Climatic Conditions

Rainfall:

The amount of annual rainfall in a given area will determine the selection of plant materials as well as the type of irrigation system most appropriate in that area. The U.S. Weather Service keeps annual rainfall data for the entire United States but such data alone will not determine whether or not an irrigation system is necessary in any particular region.

Six major factors determine the need to apply water in quantities greater than annual precipitation. These are: (1) the length of the growing season, (2) the rainfall or precipitation rate (during the growing season), (3) the evaporation rate, (4) the type of soil present, (5) the transpiration rate of the plants to be irrigated, and (6) the water requirements of the plant materials. In this regard, the factor of greatest importance is the water deficit, i.e., the difference during the growing season between natural precipitation and the amount of water required for satisfactory growth.

Rainfall and evapotranspiration data for the United States, Canada, and other parts of the world are readily available. In the United States, local offices of the U.S. Weather Service can provide rainfall data. Data on evapotranspiration are available in a report by Marvin E. Jensen (ed.), Consumptive Use of Water and Irrigation Water Requirements (cited in the References at the end of this section).

Table 750-1 is an example of rainfall and evapotranspiration data for the state of Massachusetts.

Wind:

Wind will disrupt the uniform distribution of water from a conventional irrigation system, causing areas not intended to be watered to be irrigated and causing areas intended to be watered to develop dry spots. Timers should be set to irrigate when the wind speeds are minimal, such as in the early morning hours. In addition, sprinkler head spacing, arc, and location can be designed to compensate for prevailing winds. Sprinkler heads with lower trajectories and larger orifice sizes can also be used.

Windy areas also have a greater evaporation rate than do similar areas that are not windy and thus may require more water.

3.2 Soil Characteristics

The percolation rate is an important characteristic influencing the design of conventional irrigation systems, and capillary action becomes important when lateral movement of water is required (as in drip systems and furrow flooding). In drip irrigation, the area of soil wetness is commonly referred to as the onion since a soil profile in a loam soil will produce a wet area shaped like an onion. A sandy soil will produce a shape similar to a carrot.

With a conventional sprinkler system, the main objective is to apply water at a rate that the soil can accept, without causing runoff. A typical soil will accept about 8 mm (1/3 in) of water per hour before runoff occurs. Some sprinkler systems have a precipitation rate as high as 100 mm (4 in) per hour. Station timing can be adjusted according to the percolation rate of the soil and the precipitation rate of the sprinkler. Often, a repeat cycle or additional watering cycles of shorter duration must be planned in order to prevent runoff.

Precipitation rates for sprinklers in milliliters per hour (mlh) or inches per hour (in/h) can be calculated by using the three formulas below. The first two formulas apply only to systems using matched precipitation heads (i.e., a quarter-circle head emits exactly one-quarter that of a full circle head).

Precipitation rate formulas (in/h or mlh): For triangle-spaced sprinklers with matched full-circle heads:

$$\text{mlh} = \frac{\text{LPM} \times 60}{(\text{spacing})^2 \times 0.866}$$

$$\left[\text{in/h} = \frac{\text{GPM X } 96.3^*}{(\text{spacing})^2}\right]$$

For square-spaced sprinklers with matched full-circle heads:

$$\text{mlh} = \frac{\text{LPM} \times 60}{(\text{spacing})^2}$$

$$\left[\text{in/h} = \frac{\text{GPM X } 96.3^*}{(\text{spacing})^2}\right]$$

For sprinkler heads that are not matched and for layouts with irregular spacing of sprinkler heads, an average precipitation rate can be determined by using the following formula:

$$\text{mlh} = \frac{\text{LPM} \times 60}{\text{meters}^2}$$

$$\left[\text{in/h} = \frac{\text{GPM X } 96.3^*}{(\text{feet})^2}\right]$$

With drip irrigation systems, it is important to determine the extent of the root zone to be irrigated and then to design the onion to envelop that zone. In areas of infrequent rainfall, where the primary source of water is the drip system, the roots will seek that onion. Where irrigation is supplemental, the designs are more critical because the roots are more dispersed. Sandy soils may require the use of more emitters and shorter watering cycles.

3.3 Plant Materials

A knowledge of plant materials is invaluable when designing irrigation systems. All plants have special requirements which have to be met if optimum health and physical appearance are to be maintained. For instance, roses are subject to powdery mildew, rust, and other diseases if subjected to water on their leaves (as are a host of other plants), and plants like camellias, azaleas, and rhododendrons prefer to be (and look their best when) watered from an overhead system.

3.4 Available Watering Time

Available watering time is usually a concern only when designing large projects, such as golf courses. After the water requirements and the number of hours available to water

* 96.3 is a constant based on the fact that 1 gal = 231 in^3 and there are 144 in^2/ft^2; thus, 231/144 = 1.604 in/(ft^2) (gpm),and 1.604 x 60 minutes = 96.3 in/(ft^2)(hour)

KEY POINTS: Design Criteria

Climate, soils, plant materials, site layout and economic concerns all influence irrigation strategies.

1. The climatic factor of greatest importance is the water deficit, the difference during the growing season between natural precipitation and the amount of water required for satisfactory growth.

2. Windy areas have a greater evaporation rate and may require more water. To avoid disruption from air movement, timers should be set to irrigate when the wind speeds are minimal, or heads with lower trajectories and larger orifice sizes may be used.

3. With a conventional sprinkler system, the main objective is to apply water at a rate that the soil can accept, without causing runoff. Station timing can be adjusted according to the percolation rate of the soil and the precipitation rate of the sprinkler. With drip irrigation systems, it is important to determine the extent of the root zone to be irrigated and then to design the area of wetness to envelop that zone.

4. Early morning hours are usually the best time to water because wind speeds are typically low, evaporation is at a minimum, and plant leaves do not remain wet for long periods of time.

5. Most small system designs tend to use square spacing unless the area is a free-form or irregular shape. Large areas like athletic fields, however, are typically designed for triangular spacing.

6. Sprinklers should not spray directly into a plant, building or other structures at close range because of possible damage and to prevent a void from occuring on the opposite side of the disrupting object.

7. Changes in elevation will affect water pressure, may cause low-head drainage, and disrupt the distribution of irrigation spray. Irrigation design must compensate for such occurrences by the selection of proper equipment and appropriate layout.

have been determined, the pump size can be determined (or the size of the main line if connecting to the municipal water). The more sprinklers that are on at any given time, the greater the water demand will be and the larger the water source required.

Early morning hours are usually the best time to water because wind speeds are typically low, evaporation is at a minimum, and plant leaves do not remain wet for long periods of time.

3.5 Property Size and Shape

In landscape projects, the shapes of the areas to be irrigated seldom lend themselves to an exact equilateral triangular spacing of sprinklers (as is recommended by sprinkler manufacturers). Most small system designs tend to use square spacing unless the area is a free-form or irregular shape. Large areas like athletic fields, however, are typically designed for triangular spacing.

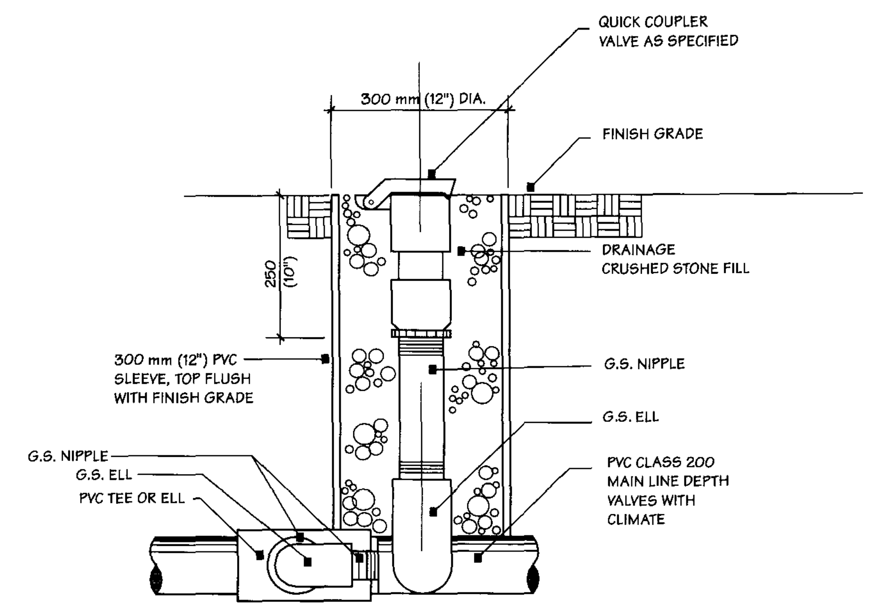


Figure 750-1. Quick-coupler valve.

3.6 Location of Buildings, Trees, and Other Fixed Objects

Fixed objects have to be accounted for in the design of sprinkler systems and should be marked on a plot plan at the outset of the project. Sprinklers should not spray directly into a tree or shrub at close range because of possible harm to the plant and because a void results on the opposite side of the disrupting object. Buildings located within the sprinkler pattern cause a wasting of water, create saturated areas on the ground, and may cause brick and other types of masonry to effloresce (become powdery), and cause unsightly discoloration.

Concern should also be given to walkways and property lines. Some walkway systems are sufficiently complex that the most efficient design will simply ignore the walkways and include these areas as part of the pattern. This often allows the use of larger rotating heads instead of spray heads. However, the use of the walkway and local codes may preclude such efficiency. The likelihood of surprised or annoyed pedestrians is also a consideration.

If overthrow of water will occur on neighboring property, the owners should be contacted before proceeding with the design.

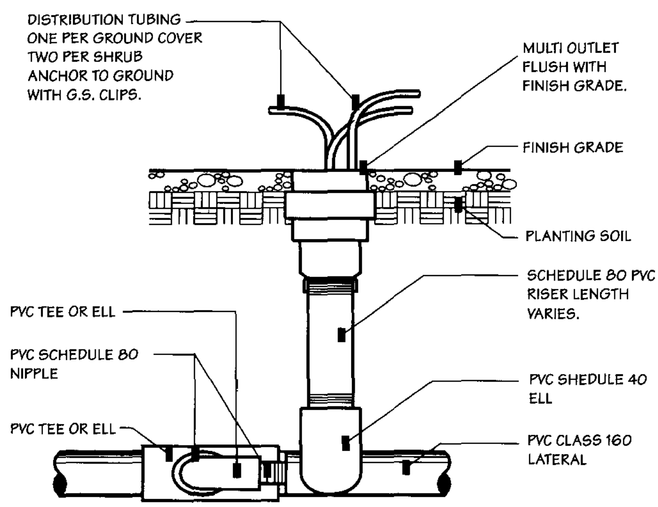


Figure 750-2. Typical drip emitter.

3.7 Elevation Changes

Any site with significant elevation differences will require the use of a topographic map. Pressure in kilopascal (kPa) or pounds per square inch (psi) is an important factor in an irrigation system. Each foot of elevation change brings a corresponding change in pressure of 2.986 kPa (0.433 psi). It is important that the sprinkler pressure recommended by the manufacturer be realized. Too little pressure will alter the pattern and create dry spots and will sometimes prevent a rotating head from rotating. Excessive pressure will cause such atomization that much of the water will be lost to the atmosphere.

Another problem associated with significant changes in elevation is low-head drainage; that is, when a valve is turned off, the sprinkler at the lowest elevation in that system will continue to drain until all pipes located higher than that head are void of water. This may necessitate the use of check valves or the selection of heads with built-in check valves. On large turfgrass projects, another solution may be to design valve-in-heads, i.e., heads with an automatic valve built into the unit or valve under head.

On landscape projects with built-up berms, similar considerations are important. Berms are sometimes built from an outside

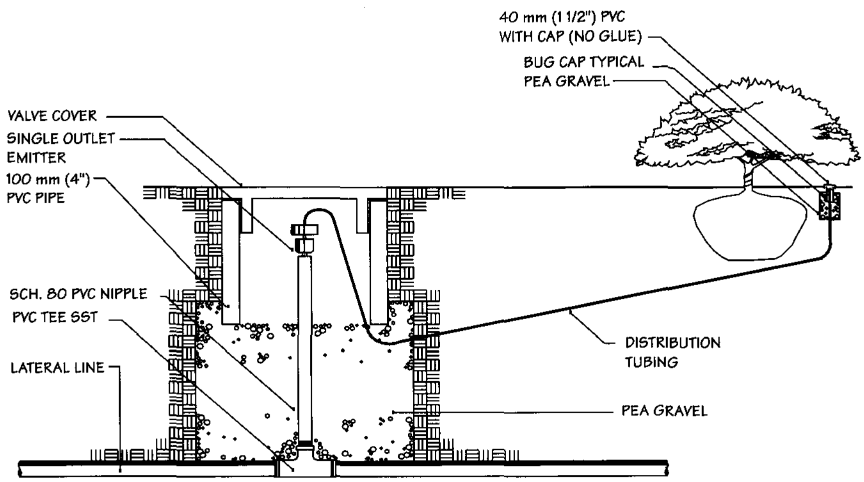


Figure 750-3. Single-outlet emitter installation (lateral line).

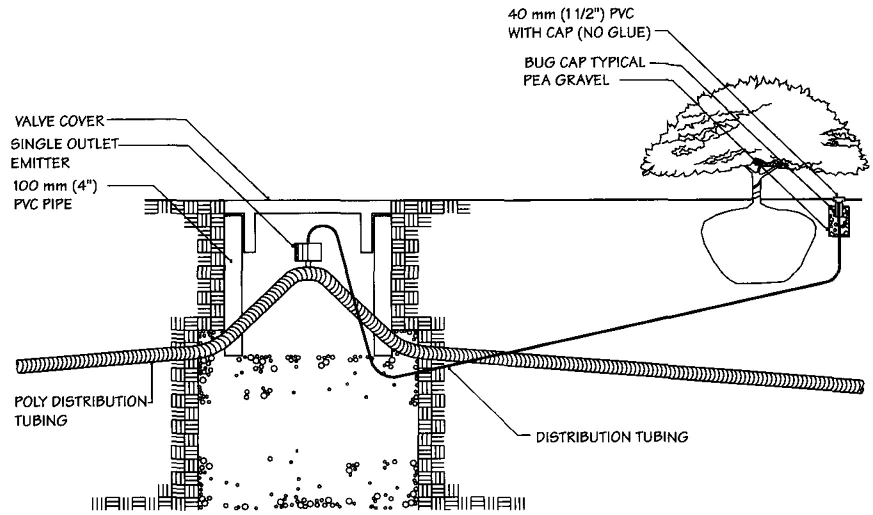


Figure 750-4. Single-outlet emitter installation (polyvinyl tubing).

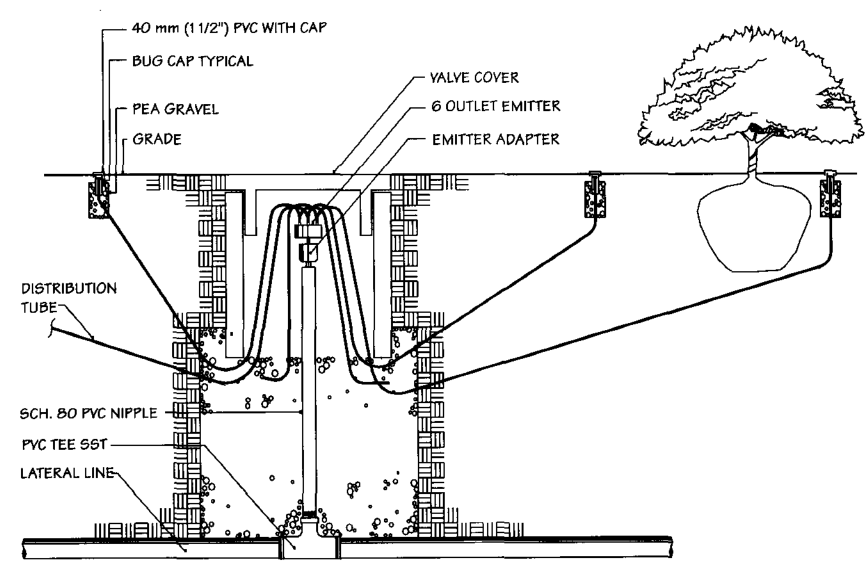


Figure 750-5. Multiple-outlet emitter installation (lateral line). *Future distribution tubes can be installed but not connected.*

source of soil which may differ, in terms of drainage characteristics, from existing on-site soils. Berms will also drain faster than level ground because of slope. Berms are often irrigated by a separate station, or, alternatively, system layouts are designed so that berms will receive more water. Careful attention should also be given to the actual location of the sprinklers and the plant materials. For example, sprinklers placed at the bottom edge of a mound can cut into the base of plants located higher up on the mound.

3.8 Economic Considerations

The costs of an irrigation system are difficult to determine until a design and a set of specifications have been completed. The costs also vary significantly from one geographic area to another. On a price-per-square-foot basis, large turf areas cost considerably less to irrigate than do areas consisting of smaller mixed plantings. Installation techniques and maintenance problems also have to be considered. Proper hydraulic engineering will prevent costly problems later in the life of a system.

The long-term maintenance expense of an irrigation system is an important consideration. For example, the initial cost of a pop-up sprinkler head may exceed that of a stationary head, but in a lawn area the savings are rapidly lost to additional maintenance expenses. Vandalism is also an issue especially with systems that include exposed components.

4.0 TYPES OF IRRIGATION

4.1 Sprinkler Irrigation Systems

Sprinkler irrigation systems refer to those with sprinkler heads. Because these systems are so widely used, they are given detailed coverage in 6.0 Hydraulics Engineering and 7.0 Sprinkler Irrigation Systems later in this section.

4.2 Quick-Coupler Systems

Often referred to as a snap-valve system or manual system, a quick coupler is a valve which is opened when a quick-coupler key is inserted (Figure 750-1). As the key is rotated, an increase in water volume is realized, much as when turning the handle on a hose bibb. A hose or sprinkler head can be attached to the key to distribute the water as required. Even on totally automatic system designs, quick couplers are often dispersed throughout the design to provide additional water access for maintenance purposes. On golf course and other large turfgrass projects, quick couplers are spaced at appropriate intervals to accommodate large rotary heads. For reasons of water economy and lack of control, however, the use of quick couplers on large turfgrass projects is declining in favor of a fully automatic sprinkler system.

4.3 Drip/Trickle Systems

Although drip systems are most applicable to types of agriculture in which the plant material is of the same variety, with uniform size and spacing, they are increasingly being designed into landscape projects because of their efficiency. The orifices of a drip system are small, however, and can sometimes become clogged if the system is improperly designed for the purpose intended.

The primary element of a drip system is the emitter, of which several types are available (Figure 750-2). Some emit droplets of water, while others (referred to as aerosol emitters) emit minute streams of water. Generally, emitters fall into one of two categories: compensating emitters and noncompensating emitters. Noncompensating emitters will release a set amount of water at a given pressure (determined by graphs provided by the manufacturer); greater pressures emit more water, and lower pressures emit less water. Friction loss and elevation changes have to be carefully determined when using noncompensating emitters.

For maximum efficiency in water use, all systems with long pipe runs or significant elevation changes are best designed with pressure compensating emitters. These are designed to compensate for pressure differences and will emit a predetermined amount of water through each emitter at a uniform rate within a particular pressure range.

Since clogging is sometimes a problem with drip irrigation systems, special attention should be given to filtration design. When the water source for an irrigation system is potable or otherwise clean and free of visible particulates, screen filters are usually adequate to protect the system from any pipe breaks upstream. Exceptions occur in some areas when diatomaceous skeletal remains occur in the form of a slime during certain seasons (usually late summer and fall).

Diatomaceous slime will accumulate rapidly around the screen filter, causing flow loss downstream (flow loss is often an indicator of a dirty filter). As pressure builds up at the filter, slimy debris is forced through the screen and eventually clogs the

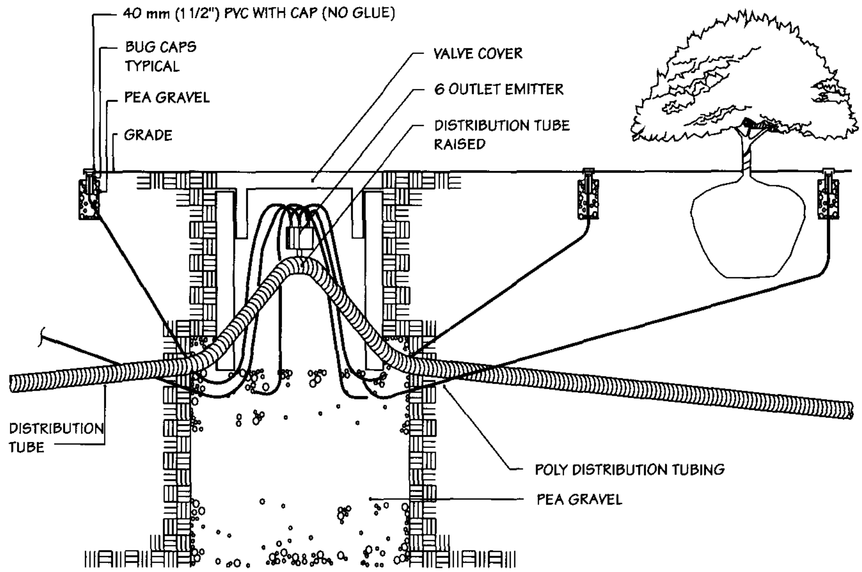


Figure 750-6. Multiple-outlet emitter installation (polyvinyl tubing).

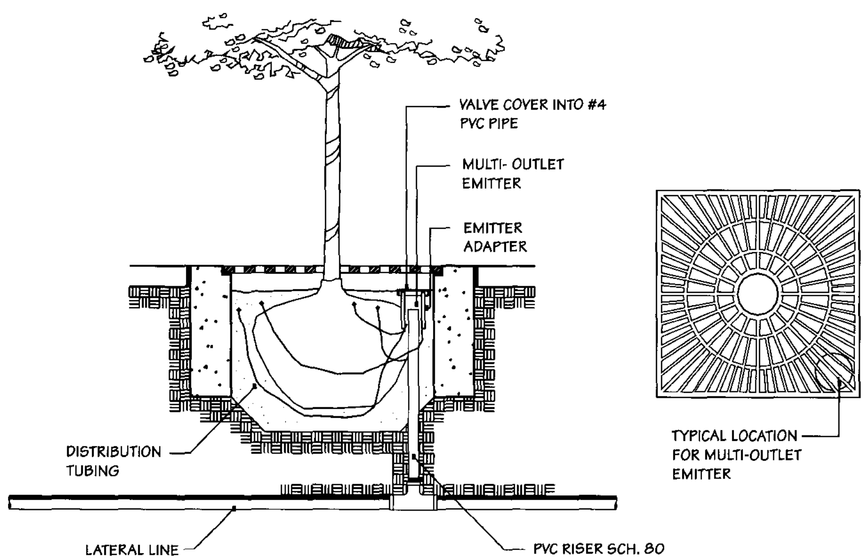


Figure 750-7. Typical emitter installation for trees with tree grates.

KEY POINTS: Types of Irrigation

Selection of the appropriate irrigation technique is based on the size of the project, site conditions, climate, and local practices.

1. Sprinkler systems are the most widely used type of irrigation. Refer to 7.0 Sprinkler Irrigation System for information on sprinkler head selection and layout.
2. Quick-coupler systems include a valve which is opened when a key is inserted (Figure 750-1). A hose or sprinkler head can be attached to the key to distribute the water as required. They are often used in combination with automatic systems to provide supplemental water access.
3. Drip systems are increasingly being designed into landscape projects because of their efficiency. The orifices of a drip system are small, however, and can sometimes become clogged if the system is improperly designed for the purpose intended.

emitters. Similar problems with slimy material exist if the pipe is not absolutely opaque (i.e., is subjected to sunlight) because algae can grow on the internal walls of the pipe and eventually break free. Algal growth can be eliminated by specifying quality opaque drip hose and by burying all other pipe. When slimy matter is encountered in the source water, a sand filter should be used. For small systems in which a sand filter would not be economically practical, the maintenance schedule should include frequent filter cleaning.

Filters should be located throughout larger drip systems so that a pipe break near the beginning of the system will not contaminate the entire system. Ideally, the system should be buried, yet accessible. Figures 750-3 through 750-7 show typical installations of both single- and multi-outlet emitters.

5.0 APPLICATION AND DESIGN

5.1 Golf Course Irrigation

Specialized systems for golf course irrigation often provide functions beyond that of satisfying the water requirements of turfgrasses, although that is their primary function. For instance, there can be provided a syringe cycle, which is a sprinkle cycle that is operated from the central control for only a few minutes, rather than the full irrigation cycle. Syringe cycles are used to provide earlier play schedules by eliminating dew or frost from tees and greens. During hot afternoons, a short syringe cycle will add humidity to the air, which can reduce stress on turfgrasses.

The desire for greens and fairways that are closely cropped—as well as the traffic from golf carts, heavy mowing equipment, and golfers—places unusual stress on the turfgrasses of most golf courses. Turfgrasses must be kept in a healthy, turgid state if they are to remain resilient to such use. Although designing the irrigation system for golf courses is not difficult, it is an extensive procedure and does require a good understanding of pumps and special design techniques. Consultation with irrigation specialists, golf course architects, and manufacturers of irrigation equipment is recommended.

5.2 Interior Plantings

Interior plantings often have special irrigation requirements that are best accomplished manually. A quick coupler or a hose bib can be located at each planted area in order to avoid extensive dragging of hose line. The type of irrigation employed for interior plantings will largely depend on the plant materials involved and the microclimatic conditions present. Some planting designs require nozzles that fog an area (to increase the humidity level), and some require sprays to keep plant leaves clean. Some are best watered by drip systems so that an appropriate amount of water is delivered to each plant.

5.3 Athletic Fields

The components of irrigation systems for athletic fields must be as inconspicuous as possible, because anything that projects above ground will become both a safety hazard and subject to vandalism. Sprinkler heads with a low profile are preferable. Several types of heads are available that are designed especially for athletic fields.

Since athletic fields are standard in measurement, most sprinkler manufacturers have typical designs available on request. Most manufacturers also have heads with rubber covers, or have rubber cover kits available.

5.4 Other Applications

Sprinkler systems are available that are specially designed for dust control, including some for use during construction and some for clay tennis courts, etc.

6.0 HYDRAULICS ENGINEERING

In all piped irrigation systems, designs will include calculations for hydraulic pressure (measured in kPa or psi), velocity (measured in m/s or fps), and flow (measured in mlh or gpm).

6.1 Sprinkler Water Requirement

Sprinklers are designed by manufacturers to emit a specific amount of water (mlh or gpm) at a specific pressure (kPa or psi). These data will vary by type of head and between manufacturers. Most manufacturers will list a range of pressures for a particular head, with the corresponding ml (gallons) and radius of throw at each pressure listed.

Velocity is a relevant quotient not in terms of meters per second (fps), but rather in terms of radius of throw. This will determine the spacing of the sprinkler heads. Sprinkler charts will show that the pressure (kPa or psi), flowrate (mlh or gpm), and radius of throw are all relative to one another. As one value increases, the other two will also increase. However, this relationship will not hold true in pressure ranges that exceed the chart, since excess atomization caused by excess pressure will actually decrease the radius of throw. Conversely, a pressure which is less than that listed in a manufacturer's chart will distort the distribution pattern to a point at which it is no longer functional. In the case of rotating heads, some may not rotate.

The ideal working pressure of a particular sprinkler head, if not specifically listed by the manufacturer, will usually fall near the middle to high end of the pressures listed. The results achieved at this middle to high end psi are a maximum radius, an ideal water breakup, and a uniform rotation for the rotating heads.

6.2 Pipe Sizing

In any irrigation system, the sizing and routing of pipe should be done in a matter which is most economical during installation, yet which is also durable to the extent that unnecessary long-term maintenance and repair will be avoided. The particular sprinkler heads selected, the nozzle sizes, and the number of heads running together determine the required flowrate (mlh or gpm).

The static pressure in a system must be greater than the sprinkler head requirement, since a certain amount of pressure is always lost to friction (unless there is downhill elevation change or a booster pump which will increase pressure). The friction loss varies with the length of pipe, the type of pipe, the pipe size, and the quantity and speed at which the water is moving through the pipe. Pipe fittings also contribute to friction loss, especially fittings (such as 90-degree elbows) that cause a major change in water direction. This is normally significant; however, it should be noted that some pipe friction-loss charts account for an average number of fittings in a system (Table 750-2). When working on small areas that require many fittings, additional friction loss should be calculated by using a fitting friction-loss chart. These are normally included as part of the data supplied with various manufacturers' charts for pipe friction loss and are not included here.

The velocity of water in a system is perhaps the most overlooked aspect of pipe sizing. Although a system with excess velocities will still function, problems of surge pressure and water hammer can be minimized by keeping the velocities throughout the pipe at 1.52 m/s (5 fps) or less. This ultimately results in less maintenance and less chance of pipe breakage. When compensating for excess pressures due to high static pressure at the source or

Table 750-2. FRICTION-LOSS TABLE FOR PIPE (PVC 1120-1220 CLASS 160 IN)*

		Loss per pipe length noted, psi §										
GPM†	Velocity‡	5	10	20	30	40	50	60	70	80	90	100
						1/2-in pipe, 0.720-in-inside diameter						
1	0.8	0.01	0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20
2	1.6	0.04	0.07	0.15	0.22	0.30	0.37	0.44	0.52	0.59	0.67	0.74
3	2.4	0.08	0.16	0.31	0.47	0.62	0.78	0.94	1.09	1.25	1.40	1.56
4	3.2	0.13	0.27	0.54	0.80	1.07	1.34	1.61	1.88	2.14	2.41	2.68
5	4.0	0.20	0.40	0.81	1.21	1.62	2.02	2.42	2.83	3.23	3.64	4.04
6	4.8	0.29	0.58	1.15	1.73	2.30	2.88	3.46	4.03	4.61	5.18	5.76
7	5.6	0.38	0.77	1.53	2.30	3.06	3.83	4.60	5.36	6.13	6.89	7.66
8	6.4	0.49	0.98	1.96	2.93	3.91	4.89	5.87	6.85	7.82	8.80	9.78
						3/4-in pipe, 0.930-in-inside diameter						
2	0.9	0.01	0.02	0.04	0.07	0.09	0.11	0.13	0.15	0.18	0.20	0.22
4	1.9	0.04	0.08	0.16	0.23	0.31	0.39	0.47	0.55	0.63	0.70	0.78
6	2.8	0.09	0.17	0.34	0.50	0.66	0.83	1.00	1.16	1.34	1.49	1.66
8	3.8	0.14	0.28	0.56	0.85	1.14	1.42	1.70	1.99	2.27	2.56	2.84
10	4.7	0.22	0.43	0.86	1.29	1.72	2.15	2.58	3.01	3.45	3.87	4.30
12	5.7	0.30	0.60	1.20	1.80	2.40	3.00	3.60	4.20	4.80	5.40	6.00
14	6.6	0.40	0.80	1.60	2.40	3.20	4.00	4.80	5.60	6.40	7.20	8.00
						1-in pipe, 1.195-in-inside diameter						
6	1.7	0.03	0.05	0.10	0.15	0.20	0.24	0.29	0.34	0.39	0.44	0.48
8	2.3	0.04	0.08	0.16	0.25	0.34	0.42	0.50	0.59	0.67	0.76	0.84
10	2.9	0.07	0.13	0.26	0.38	0.50	0.63	0.76	0.88	1.02	1.13	1.26
12	3.4	0.09	0.18	0.36	0.53	0.71	0.89	1.07	1.25	1.43	1.60	1.78
14	4.0	0.12	0.24	0.48	0.71	0.94	1.18	1.42	1.65	1.89	2.12	2.36
16	4.5	0.15	0.30	0.60	0.91	1.21	1.52	1.82	2.12	2.43	2.73	3.04
18	5.1	0.19	0.38	0.76	1.13	1.50	1.88	2.26	2.63	3.01	3.38	3.76
20	5.7	0.23	0.46	0.92	1.37	1.82	2.28	2.74	3.19	3.65	4.10	4.56
22	6.3	0.28	0.55	1.10	1.65	2.20	2.75	3.30	3.85	4.40	4.95	5.50
24	6.8	0.38	0.65	1.30	1.94	2.58	3.23	3.88	4.52	5.23	5.81	6.46

* Name of pipe and its pressure grouping. The C value constant used in determining friction losses, based on relative smoothness of the interior of the pipe is 150.

† Gallons per minute flow is given in equal increments with logical increment spacing to satisfy most designer needs.

‡ Velocity of water through pipe. In no instance are friction losses given where the velocity exceeds 7 fps as this should be the extreme limit of velocity in design.

§ Friction loss of water through pipe in increments of 10 ft up to 100 ft with an additional column for 5 ft. This enables rapid selection of loss in all length pipe runs.

to large downhill elevation changes, pipe velocities should continue to be designed at 1.52 m/s (5 fps) or less. Excess pressures should be controlled by devices such as pressure regulators and pressure regulating valves and by adjusting the flow control of a valve.

6.3 Valve Sizing

Most automatic valves withstand velocities well in excess of 1.52 m/s (5 fps), and most actually function better with greater differentials between the inlet and outlet pressures (i.e., a friction loss through the valve must occur in order for most automatic valves to operate). The main concern when sizing valves is to determine how much pressure (friction loss) can be lost while still achieving the desired working pressure at the last sprinkler head. It is relatively common to use a valve smaller than the downstream pipe (which may be larger to keep the pipe velocities under 1.52 m/s (5 fps).

Valve sizes should be designed so that the flow rates fall toward the middle of the manufacturer's friction-loss chart for a particular valve size. This will usually give the best performance, efficiency, and economy.

6.4 Flow and Friction Loss through Other System Components

All system components that have water flowing through them will have some friction loss. If the point of connection is a potable water supply with a meter, the friction loss through the meter must be calculated, along with the pipe friction loss from the street to the meter. From the point of connection, the friction loss must be calculated through the following: the main line, the valves, and the backflow or antisiphon device; any manual gate, globe, or ball valves in the line; and other special components, such as filters or chemical injecters. Friction-loss charts are provided by component manufacturers and will vary from one manufacturer to another. Unless velocity data are given for each component, they can be treated as if they were valves, in that for a given size, a specific friction loss will be realized at any flow.

6.5 Control Wire and Control Tubing Sizing

Just as friction losses occur in pipe, voltage drops occur through electrical wire. If a cur-

Table 750-3. MAXIMUM CONTROLLER TO SOLENOID WIRE LENGTH, FT

Copper wire size		Maximum number of solenoids activated simultaneously by controller = M							
		M = 1							
		Controller output voltage (VAC)							
Control	Common	21	22	23	24	25	26	27	28
18	18	225	450	667	890	1112	1335	1557	1780
18	16	273	546	819	1092	1366	1639	1912	2185
16	16	354	707	1061	1415	1768	2122	2476	2829
16	14	431	861	1292	1723	2153	2584	3015	3446
14	14	550	1101	1651	2202	2753	3303	3854	4404
14	12	677	1353	2029	2706	3382	4058	4735	5411
14	10	789	1578	2367	3156	3946	4735	5524	6313
12	12	877	1753	2630	3507	4384	5261	6138	7014
Control	Common	M = 2							
18	18	112	222	333	445	556	667	779	890
18	16	137	273	409	546	683	819	956	1092
16	16	177	353	530	707	884	1061	1238	1415
16	14	216	430	646	861	1007	1292	1507	1723
14	14	276	550	826	1101	1376*	1652	1927	2202
14	12	338	676	1014	1353	1691	2029	2367	2706
14	10	394	789	1183	1578	1973	2367	2762	3156
12	12	439	877	1315	1754	2192	2630	3069	3507
Control	Common	M = 3							
18	18	74	148	222	297	371	445	519	593
18	16	91	182	273	364	455	546	637	728
16	16	117	235	353	471	589	707	825	943
16	14	143	287	430	574	718	861	1005	1148
14	14	183	367	550	734	918	1101	1285	1468
14	12	226	451	676	902	1127	1353	1578	1804
14	10	263	526	789	1052	1315	1578	1841	2104
12	12	293	584	877	1169	1461	1754	2046	2338

- Divide distance in feet by 3.28 to convert to meters.
- Table is based on solenoid consumption of 8.5VA (0.35 amp).
- Wire sizes smaller than no. 14 (first four rows) may not carry the UL listing for direct burial application.
- *Example: A controller is activating two solenoids simultaneously and the output is 25 VAC. Using 14-14 wires, the maximum run is 1376 ft (419 m).

rent is increased by starting several valves on one station, the voltage drop will increase. The number of valves that can be operated on one station depend on the size of the transformer and the inrush amperage requirement of the solenoid (valve) (Table 750-3). This information should be furnished by the manufacturer.

Wire no smaller than No. 18 gauge UF (direct burial) should be used in irrigation systems, not because a smaller-gauge wire is inadequate, but because smaller-gauge wire is more easily kinked or broken during installation. Smaller gauges are also more susceptible to nicks and scrapes because of a thinner insulation jacket. A 0.25-ampere inrush solenoid and a No. 14 gauge wire are ideal for a run of 2 300 m (7500 ft). A run of 760 m (2500 ft) could be achieved with a solenoid requiring a 0.847-ampere inrush.

For runs longer than 2 300 m (7500 ft), wire gauges larger than No. 14 must be used. In large systems with controllers far away from the power source, or in central/satellite systems (described in 7.3 Controllers of this section), the wire must be correctly sized from the source to the controller as well as from the controller to the solenoid (valve). The manufacturer should indicate the amperage requirements for valves and control satellites or should supply charts or formulas for determining the most efficient wire size at various points throughout the project.

In a hydraulic system, 5 mm (1/4-in) tubing is the standard-size line used to control valves. The length from the controller to the valves should not exceed 300 m (1000 ft).

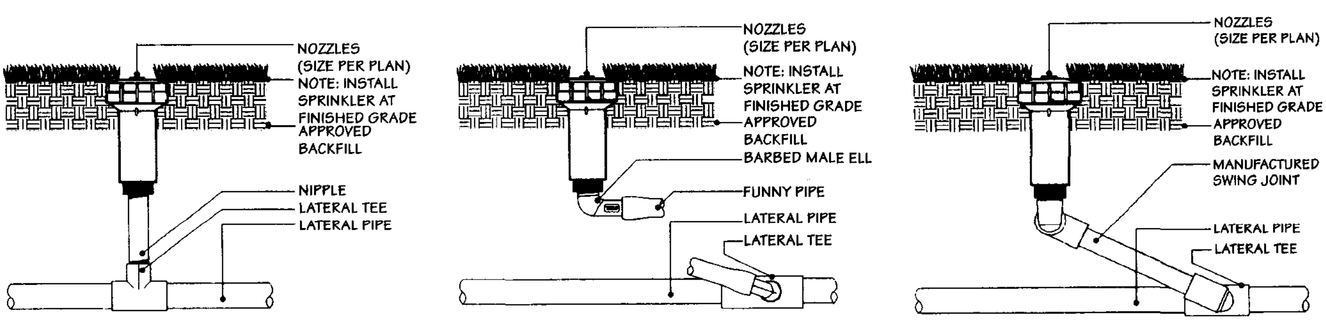


Figure 750-8. Typical pop-up spray head assemblies.

750 Irrigation

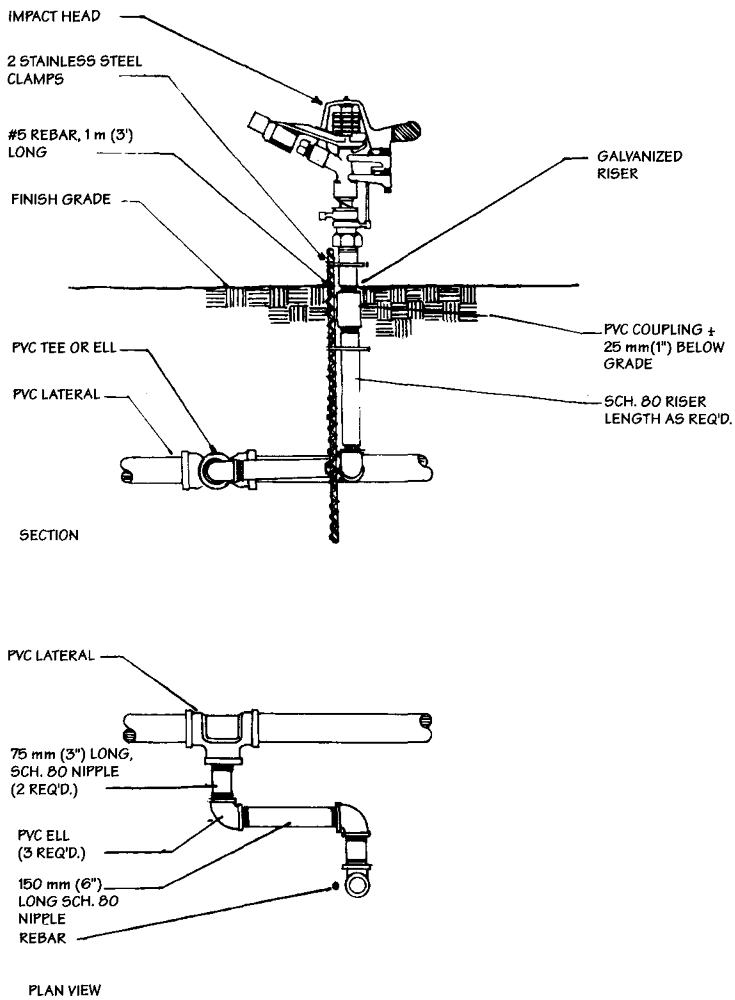


Figure 750-9. Typical impact head assembly.

7.0 SPRINKLER IRRIGATION SYSTEM (DESIGN PROCEDURE)

7.1 Sprinkler Head Selection and Layout

Sprinkler head selection and layout is the most difficult aspect of sprinkler irrigation system design. Seldom will an area lend itself perfectly to a particular grid spacing, whether triangular or square, and seldom is an area free of objects such as trees, walkways, and buildings.

The first step in the selection and layout of sprinkler heads is to divide the area to be irrigated into zones that have similar water requirements, e.g., lawn areas, shrub areas, and different exposures to the sun. Where possible, the use of large-radius heads should be considered first, since their use will progressively decrease the cost of the system on a square-foot basis. Triangular spacing is more efficient than square spacing, although many areas lend themselves to square spacing (such as the small rectangular areas typical of most residential and small commercial projects).

The most important objective when laying out sprinklers is the even distribution of water. Sprinklers that produce different precipitation rates should not be used in the same zone. Sprinkler-to-sprinkler dimensions should be based on manufacturer's recommendations, with deviations for wind velocity. Spacing for triangular and square patterns varies with brand and model.

When designing with single-row spacing through the center of an area, only about two-thirds of the radius will give effective

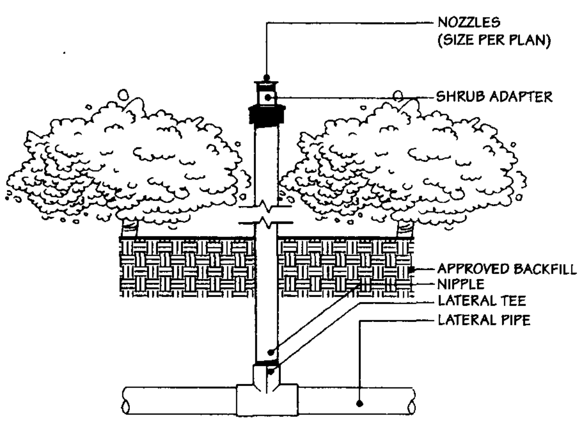


Figure 750-10. Typical shrub head assemblies.

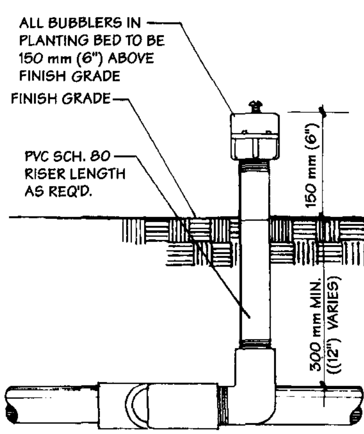


Figure 750-11. Typical bubbler assembly.

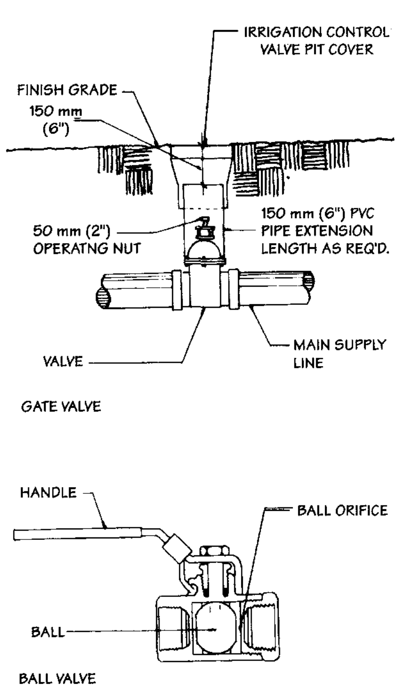


Figure 750-12. Typical gate-valve and ball-valve assemblies. *Soil around control-valve pit assembly must be compacted to same density as adjacent undisturbed soil. Note that the lever arm will require a larger valve box.*

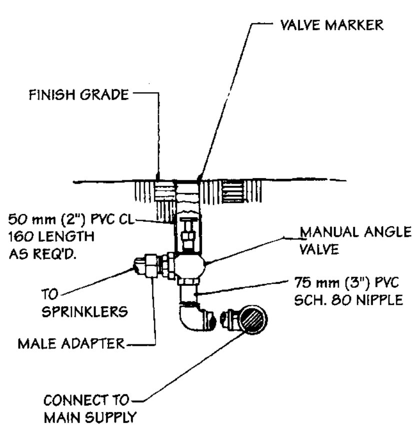


Figure 750-13. Typical manual angle-valve assembly.

coverage. Consequently, single-row spacing should only be used in special circumstances.

Many spray heads have matched precipitation rates, allowing quarter-circle heads to be used on the same line as half- and full-circle heads. However, rotary heads may not be matched; consequently, water distribution with rotary heads must be balanced by using a smaller nozzle size for particular heads in relation to full-circle heads on the same line. When the nozzle size is decreased, the radius also decreases and must be accounted for in the design. Under such circumstances, it is best to isolate heads with similar arcs in one zone and to balance the zones at the controller; for example, full-head zones would be programmed to water 4 times as long as quarter-head zones.

Flood and stream bubblers are often used to water small shrub areas and to water plants that prefer dry foliage (Figure 750-11). Bubblers emit water at a much faster rate than the soil can absorb it and are used only to flood an area rapidly. Bubblers do not work well on sloping ground. Pressure-compensating bubblers should be used in areas with potential pressure fluctuations or high pressures.

Several features of sprinkler heads are commonly available which require consideration by the designer:

1. Stationary heads versus pop-up heads (if pop-up, how high?)
2. Filtration
3. Ease of maintenance
4. Guarantee
5. Type of material (brass, plastic, stainless steel, etc.)
6. Positive retraction for pop-ups
7. Angle of trajectory
8. Exposed surface area
9. Speed of rotation
10. Distribution curve
11. Adjustment (arc and radius)
12. Built-in check valve to prevent low-head drainage
13. Vandal resistance
14. Gear, impact, cam, or ball drives
15. Pressure compensation

Figures 750-8 through 750-11 show typical examples of various types of conventional sprinklers.

7.2 Control Systems

Manual Systems:

Manual systems require an individual to open and close a valve by hand. Since manual systems are rarely as efficient as automatic systems and no significant cost savings are realized, few manual systems are now designed except for special circumstances.

Automatic Systems:

In theory, automatic systems are much more efficient than manual systems since optimal water requirements can be satisfied by programming a controller. Controllers can send signals to the valves in two ways: electrically through wires or hydraulically through control tubing (see Figures 750-15 and 750-16). Most areas of the world predominantly use electricity, although there are exceptions. For reasons of availability, electrical systems do not include thermohydraulic systems, and hydraulic systems do not include normally closed hydraulic systems. (These are control systems once available in whole product, but now available only for replacement.)

Electrical systems:

The advantages of electrical systems include:

1. Faster response time
2. Longer runs between controller and valve
3. Ease of use with solid-state controllers
4. Unaffected by elevation
5. Normally closed system (if a control wire is severed, the valve will remain closed)

The disadvantages of electrical systems include:

1. Susceptible to lightning damage
2. Susceptible to dirty water clogging the orifices which allow the valve to open and close (through the use of contamination-resistant valves which have two noncontinual bleed-through orifices that make operation less susceptible to dirty water).

7.3 Controllers

Controllers are programmed to determine when to water, how long to water, and the time(s) of day to begin watering. Many optional features are available for controllers. Generally, the more features a controller has, the more complicated the programming becomes.

On large projects, a central/satellite system is often used. A central controller sends signals to satellite controllers regarding the day and starting time(s) to water, with only the station's run time set at the satellite. These systems are also available with many features to satisfy specific requirements.

7.4 Valves

Manual Valves:

Gate valves are used as emergency shutoff valves or as isolation valves and are not designed for regular use (Figure 750-12). Since there is no rubber seat or washer, frequent usage will create wear and cause the valve to leak. Gate valves are used mainly because they have almost no friction loss.

Ball valves are similar to gate valves in that little friction loss exists. However, ball valves are advantageous in that frequent usage is less apt to cause leakage. Ball valves are increasingly being used in place of gate valves (Figure 750-12).

Globe or angle valves are used in manual systems where the valve is used regularly (Figure 750-13). Like a hose bibb, a globe valve has a replaceable rubber washer. Globe valves are not used as isolation valves since there is considerably more friction loss than with a ball or gate valve. An angle valve is simply a globe valve whose inlet is at the bottom of the valve with an exit at the side. Less friction loss occurs with an angle valve than with a straight globe valve. Often, an angle valve will be connected to an atmospheric vacuum breaker as one unit. Local codes will dictate such an installation, but it is usually 150 mm (6 in) above the highest outlet.

Automatic drain valves are special valves which are sometimes used in geographic regions with freezing climates (Figure 750-14). Such valves drain the water in the line each time the system is shut off. In heavy soils, however, this can create a problem of excessive wetness during seasons when the system is in use. To be effective, automatic drain valves should be located at all the system low points. The best method for eliminating water in the lines is physically to blow out the system with an air compressor before heavy frosts occur.

Gas cocks are special valves often used by manufacturers of backflow devices and pressure vacuum breakers for testing purposes. They are also occasionally used on lateral lines on hilly sites to reduce excess pressure on long downhill runs.

Check valves are used on hilly sites to prevent low-head drainage.

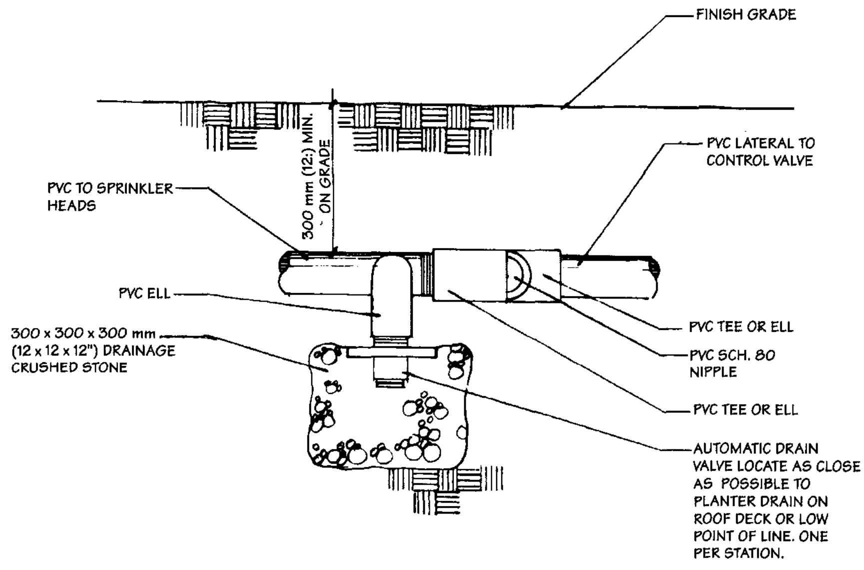
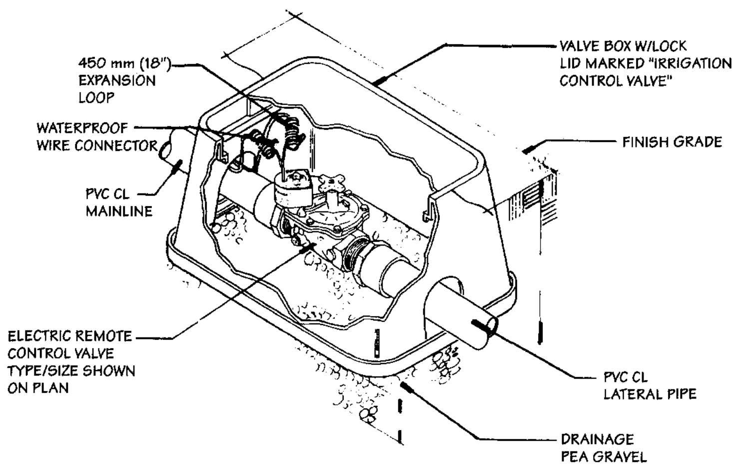


Figure 750-14. Typical automatic drain valve assembly.



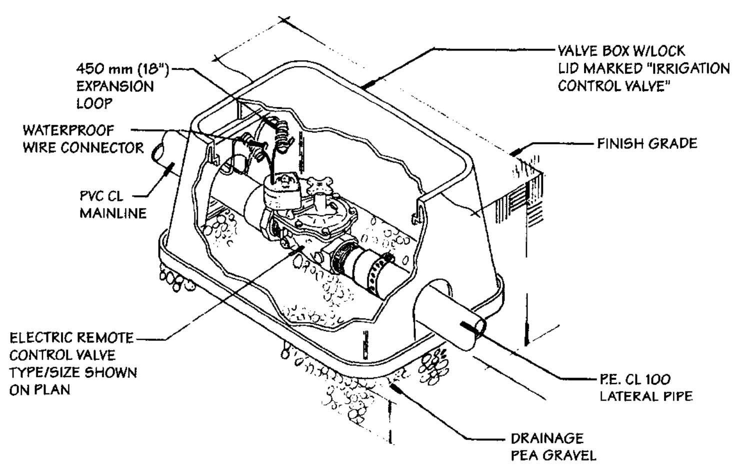


Figure 750-15. Electric remote control valve assembly.

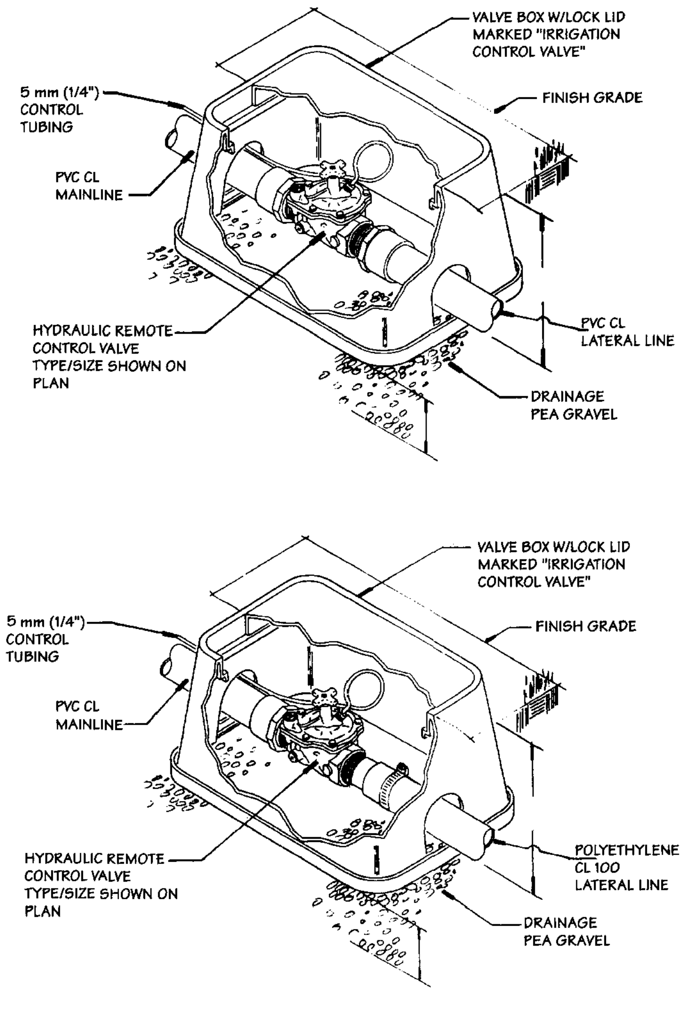


Figure 750-16. Hydraulic remote control valve assembly.

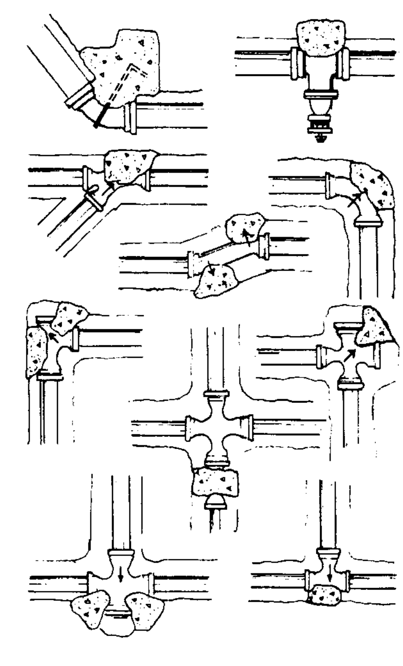


Figure 750-17. Thrust blocks for cast-iron pipe.

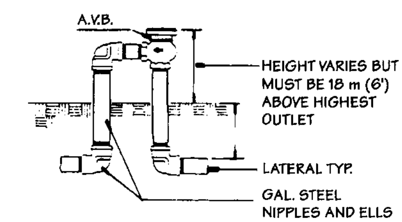


Figure 750-18. Typical atmospheric vacuum breaker.

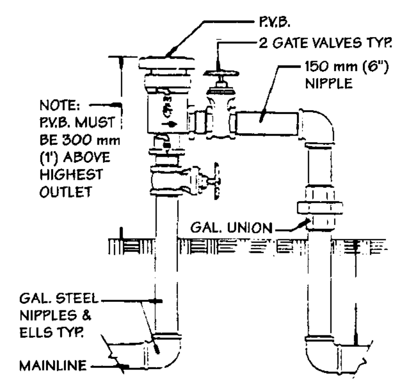


Figure 750-19. Typical pressure vacuum breaker.

Automatic Valves:

Electric valves are activated by an electric current sent from a controller (Figure 750-15). Although electric current is involved, hydraulic forces actually open and close the valve. Inside the valve is a diaphragm (or piston) which moves up or down to open or close the valve. The diaphragm (or piston) is designed to have a greater surface area on the upper chamber than on the lower area which rests on the valve seat. A small orifice connects the upper and lower portions of the valve so that pressure is equalized between the two. The greater surface area of the top portion creates a mechanical advantage and causes the valve to close. Another, larger orifice connects the upper chamber and the downstream portion of the valve. A solenoid-activated plunger sits over this orifice; when the solenoid is activated by electricity, an electromagnetic field is created within it which lifts the plunger off the orifice. Water is forced through the orifice faster than it can enter through the smaller orifice, and the diaphragm (or piston) is pushed up to open the valve. During operation, a steady stream of water is passing through both orifices.

Electric valves are subject to clogging by dirty water even though a filter is usually installed on the intake orifice (or a metering pin through the orifice) to clean the orifice each time the valve opens or closes. In some systems the solenoid plunger controls both orifices, thereby eliminating the constant stream of water passing through the orifice while the valve is on. However, an electric valve is still using system water to open and close.

Hydraulic valves are normally operated by water other than the irrigation water (Figure 750-16). Therefore, there is no small orifice to clog. The diaphragm (or piston) still has a greater surface area in the

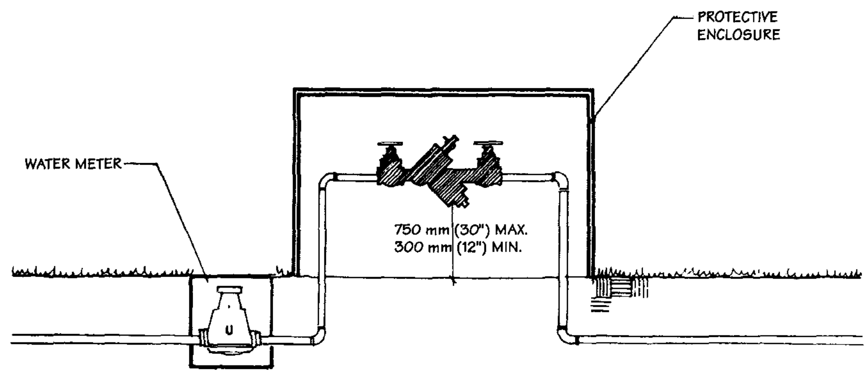


Figure 750-20. Typical double check backflow preventor.

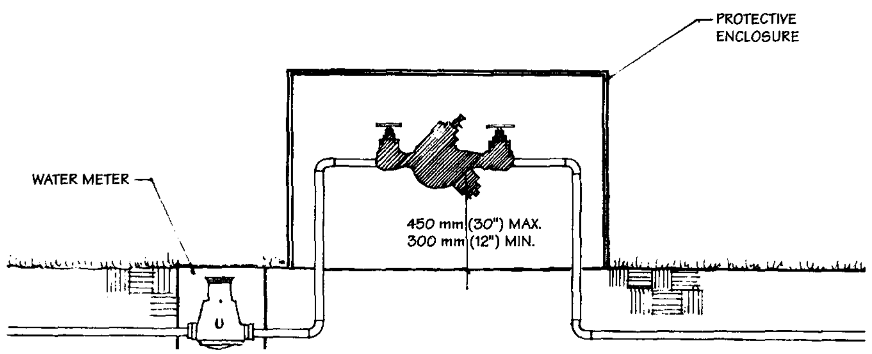


Figure 750-21. Typical reduced-pressure backflow preventor.

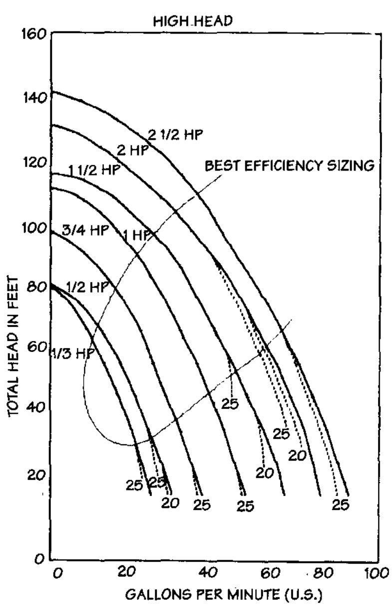


Figure 750-22. Pump curve.

upper chamber and uses the same mechanical advantage to shut the valve. However, the water used to control the valve comes from another source, possibly a clean potable supply, whereas the irrigation water may originate from an algae-laden pond.

The water used for the control system should be clean and under the same or greater pressure than the system water pressure. Since only a few tablespoonsful of water are used each time a valve is activated, the cost of potable water is not a factor, whereas it would be if potable water were used for the system. Because there is no orifice to clog with irrigation water, normally open hydraulic valves are the best to use with dirty water.

7.5 Pipe

Polyvinyl Chloride (PVC) Pipe:

PVC pipe has become the standard in the irrigation industry for several reasons:

1. Excellent flow characteristics.
2. Relatively lightweight (easy to work with).
3. Not subject to corrosion.
4. Relatively inexpensive.
5. Uses external solvent weld fittings.
6. Flexibility.
7. Durability.

PVC is available via two different designations: schedule pipe or class pipe. Schedule PVC pipe (e.g., SCH40 and SCH80) means that the wall thickness is the same as in steel pipe at the same schedule and pipe size. In the design of irrigation systems, schedule pipe is used primarily for precut threaded nipples for sprinkler risers in shrub beds. Class PVC pipe is customarily designated for other parts of the irrigation system because class pipe is designated by pressure ratings (such as CL160, CL200, and CL315).

Polyethylene (PE) Pipe:

Polyethylene pipe is widely used because it is easily pulled into the ground with a vibrating plow (i.e., it is very flexible). In cold climates, polyethylene pipe is often used instead of PVC for lateral lines since it is not nearly as subject to damage from freezing.

The most common classes of polyethylene pipe used are CL80 and CL100; although CL120 is sometimes available, connecting the fittings to CL120 is difficult. Polyethylene pipe uses internal, barbed fittings which must be secured by stainless-steel clamps or other tightening devices. Because of the internal fittings, the flow characteristics of polyethylene pipe are not as good as PVC.

Copper Pipe:

Type K copper pipe is used most commonly for irrigation purposes and has the thickest wall of all copper pipe sizes. Type L and Type M copper pipe are also used occasionally.

Copper is commonly used in situations where the pipe will be exposed to sunlight, such as when mounting a vacuum breaker or as a riser for shrub heads.

Galvanized Steel Pipe:

Since galvanized steel pipe is highly susceptible to deterioration caused by minerals in the water, it is seldom used except as risers for shrub heads and in areas with a high potential for vandalism.

Asbestos Cement (AC) Pipe:

Because asbestos cement pipe is difficult to install and not practical, it is seldom used except to repair existing systems.

Cast-Iron Pipe:

Cast-iron pipe is used around pumping stations where pipe is subject to thrust. The connections are flanged and fastened with bolts.

Thrust blocks are used to distribute pressures evenly to firm ground along the trench wall. They should be built in wedge form, with the widest area along the solid trench wall. A standard mix would consist of 1 part portland cement, 2 parts washed sand, and 5 parts washed gravel (Figure 750-17).

Table 750-4. PUMP GRAPH: HIGH HEAD

	Discharge pressure		Dynamic suction lift, gallons per minute				
Hp	Psi	Feet Head	5 ft	10 ft	15 ft	20 ft	25 ft
	20	46.2	47	45	43	40	38
1	30	69.3	36	33	31	27	23
	40	92.4	21	16	10	—	—
	20	46.2	58	56	54	51	48
1½	30	69.3	47	44	41	38	34
	40	92.4	31	27	21	12	—
	20	46.2	71	68	66	62	60
2	30	69.3	61	57	55	51	47
	40	92.4	45	40	36	31	26
	50	115.5	22	15	—	—	—
	20	46.2	78	76	73	71	68
2½	30	69.3	67	64	61	58	54
	40	92.4	52	48	44	40	36
	50	115.5	33	28	22	15	—

Concrete Pipe:

Concrete pipe is used primarily by water districts for city mainlines.

7.6 Backflow Preventors

As a consequence of the federal Clean Water Act, backflow preventors must be installed when working with potable water to protect the potable supply from a cross connection. Legally, irrigation systems are considered to be a high hazard. In most cases, local ordinances will dictate the type of backflow preventor to be installed.

Backflow preventors are categorized into one of two distinct types: antisiphon devices and back-pressure devices.

Antisiphon Devices:

Atmospheric Vacuum Breaker (AVB): Atmospheric vacuum breakers must be mounted downstream of any valve and be positioned in 6 in (150 mm) above the highest outlet (Figure 750-18). An AVB has a float which seals against a seat under pressure but which will drop down by gravity when the pressure ceases, thereby allowing air to enter the line and break any vacuum hold downstream.

Pressure Vacuum Breaker (PVB): The only functional difference between an AVB and a PVB is a small spring that assists the force of gravity in getting the float to drop down after pressure has been removed (Figure 750-19). Also, gate or ball valves and test cocks are added so that the unit can be tested for reliability. Pressure vacuum breakers may be mounted upstream of valves, and they are usually preferable to atmospheric vacuum breakers because only one per source is necessary. Pressure vacuum breakers must be mounted at least 300 mm (12 in), but less than 750 mm (30 in), above the highest outlet.

Back-Pressure Devices:

Double Check Valves: Double check valves are not approved for high-hazard situations, yet some local codes allow their use in irrigation (Figure 750-20). Check valves allow water to flow in one direction only. The second check valve is simply a safety feature in case the first check valve fails. Double check backflow devices do not have to be mounted above the highest outlet but should be accessible for testing purposes.

Reduced-Pressure Backflow Device (RP): Reduced-pressure devices are approved for high-hazard situations and are generally accepted as the surest safeguard against backflow for irrigation purposes (Figure 750-21). Reduced-pressure devices are also the most expensive and have the greatest friction loss of all backflow devices.

Like double check valves, reduced-pressure devices have two check valves, but the first valve has a stronger spring than the second in order to create a pressure differential between the two check valves. Should pressure ever vary from that desired between the two valves, a pressure-relief valve will open and dump the water to the atmosphere. Nothing should be connected to the relief valve.

To prevent flooding of a basement or area where the reduced-pressure device is located, an air gap should exist between the check valve and drain line to permit the water to flow to a drain. Reduced-pressure devices should not be located in a pit or in any area that might be submerged in water. Since these devices are meant to be checked annually by a certified tester, they should remain accessible.

7.7 Supplementary Equipment

Water Meters:

Although water meters are not used in irrigation systems per se, they are of concern to the designer because the meter, the static pressure, and the feed line from the street to the meter will ultimately determine how much water is available for the irrigation system. The friction loss through the meter must also be calculated when totaling all friction losses.

The amount of water available for an irrigation system is determined by taking a static pressure reading, noting the meter size, and noting the size and type of pipe coming into the meter. The following three criteria are then addressed; the most critical of the three [i.e., the smallest gpm figure] will determine the available water:

1. Seventy-five percent of the safe flow of the meter chart should not be exceeded. (Use the meter chart.)
2. The pressure loss through the meter should never exceed 10 percent of the static pressure. (Use the meter chart.)
3. The water in the service line should not exceed 1.52 mls (5 fps) though it is sometimes necessary to exceed this due to flow limitations of small service lines and the needs of the sprinkler system. It may be prudent to specify a new service line if the existing line supplies insufficient water due to size or mineral buildup.

Table 750-5. CLIMACTIC FACTORS RELATED TO WATER USE

Climate type	Average peak temperature,°F	Humidity	Potential use, in/day
Very cool	50°-60°	Humid	0.10
Cool	70°-80°	Medium-humid	0.20
Moderate	80°-90°	Medium-humid	0.25
Hot	90°-100°	Medium-humid	0.30
High desert	90°-100°	Dry	0.35
Low desert	100°+	Dry	0.40

Table 750-6. PLANT FACTOR (RESISTANCE TO STRESS)

Plant factor	Types of plants
1.0	Evergreens, fruit trees, small shrubs, vines, perennials, and lush ground cover
0.70	Newly planted native plants in semiarid and arid regions; ornamental or shade trees and shrubs native to more humid areas
0.40	Established plants native to the area

Table 750-7. IRRIGATION EFFICIENCY

Climate	Factor
Hot, dry, and high-desert	0.85
Moderate and hot	0.90
Cool and very cool	0.95

Table 750-8. EMITTER SIZES, NUMBERS, AND OPERATING TIMES (EXAMPLE)

Soil type	Emitter number	×	Emitter type, gph	×	Operating time, hr	=	Gph
Clay	2	×	1	×	15	=	30
Moderate	2	×	2	×	7.5	=	30
Sandy	5	×	2	×	3	=	30

Table 750-9. IRRIGATION DURATION FOR PLANTS IN CONTAINERS (MIN)

Container size, gal	Emitter flow size, Gph	Soil type			
		Sandy	Medium	Heavy	Potting
1	0.5	3	5	11	2
2	0.5	6	10	25	5
5	1.0	8	15	30	6
15	1.0	25	40	90	20
25	1.0	40	75	150	30

Table 750-10. FREQUENCY FOR PLANTS IN CONTAINERS (DAYS)

Climate	Soil type			
	Sandy	Medium	Heavy	Potting
Very cool	2	3	8	2
Cool	1½	2	6	1
Moderate	1½	2	6	1
Hot	1	2	5	1
High-desert	1	1½	4	1
Low-desert	1	1	3	1

Pumps:

If an existing pump is to be the water source for an irrigation system, the manufacturer, horsepower, and model must be noted, and a pump curve must be located so that the pressure and flowrate (l/s or gpm) can be identified (Figure 750-22 and Table 750-4). The type of pump to use depends on the number of hours per day available for irrigation; a pump that will satisfy this requirement during the most critical time of the year should be used. Before the system is actually designed, a calculation has to be made to determine the precipitation rate of the sprinkler heads intended and the number of hours per week that watering is required. This will determine the approximate number of zones to be irrigated and the average size of each zone. The flowrate of an average-size zone plus 10 percent will provide enough information to determine tentatively the pump size necessary. When the design is finished, an exact pump size can be determined.

In general terms, a pump operates by spinning its motor-driven impeller so that a pressure less than atmospheric pressure is created at the eye of the impeller, whereby the atmospheric pressure exerted upon a body of water outside of the pump forces the water up into the pump's suction line. For this to work, the impeller must be submerged in water (i.e., primed) and the suction line must be filled. Unless it is a self-priming pump, a pump will not work if it loses water in the suction line (i.e., loses prime); a self-priming pump has a reservoir in its volute case (impeller housing) so that prime cannot be lost even if water does not remain in the suction line. Usually, a foot valve is installed at the base of the suction line to prevent losing prime.

Because impellers do not create a perfect vacuum and because atmospheric pressure at sea level is about 9.5 m (32 ft) of water, no pump will function if placed 9.5 m (32 ft) above water level. Centrifugal pumps should be placed as close to water level as possible for maximum efficiency. Efficiency curves on a pump chart refer to the net positive suction head (NPSH); in reality, this is seldom over 5.4 to 6.0 m (18 to 20 ft). If the water is much deeper (as in a well), a vertical turbine pump is used (which has a long shaft and an impeller or a series of impellers attached at the end of the shaft); the shaft runs down the well casing and the impeller lies in the water. Pumps always have an easier time pushing water than sucking it.

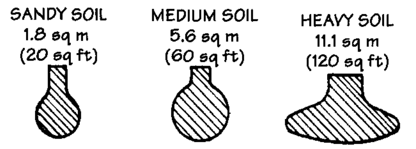


Figure 750-23. Soil wetting areas based on soil type.

In regard to pumps, pressure is usually expressed in terms of foot head (FH), which is multiplied by 0.433 to convert to psi.

Designers confronted with large uphill elevation changes or insufficient static pressure often use centrifugal pumps as booster pumps. The pressure at a given flowrate on the pump curve can be added to the existing pressure to arrive at the new boosted pressure. Since a booster pump does not create water, the flowrate will remain the same.

Pressure Regulators:

When the static pressure is greater than necessary for the sprinkler heads of a system, a pressure regulator can be used to lower the pressure. If the pressure is excessive only in certain areas (due to elevation or to the use of heads requiring low pressure), a pressure regulating valve can also be used to remedy the situation. Pressure regulators will convert a high pressure to a lower set pressure and regulate it regardless of any fluctuations that may occur on the high-pressure side of the system.

Valve Boxes:

Valves should not be buried below ground except under special circumstances. Valve boxes are designed to house irrigation valves and should remain accessible for ease of maintenance (see Figure 750-15). Boxes are available in a variety of materials, and some have locking devices for added security.

Pipe Sleeves/Chases:

Whenever possible, pipe sleeves (chases) should be installed under sidewalks, roadways, parking lots, etc., for ease of system installation and later maintenance. Pipe sleeves should be four pipe sizes larger than the pipe that will run through the sleeve.

Chemical Injection Devices:

Injection devices are used to inject fertilizer or other chemicals into the sprinkler system. Such devices are either flow-regulated (venturi principle) or physically injected by a pump. The effectiveness of an injection system is directly related to the efficiency of the sprinkler system. For this reason, these devices are most effective with drip irrigation systems.

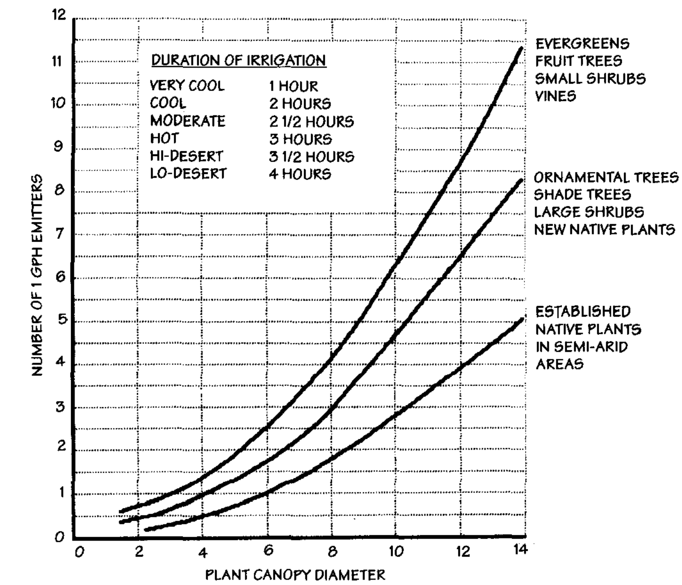


Figure 750-24. Simplified drip design.

8.0 DRIP IRRIGATION (DESIGN PROCEDURE)

8.1 Calculations

In drip irrigation, it is important to determine the amount of water that each plant will use and then to select the number and flow sizes of the emitters that will apply the water within a specified period of time. An important rule of thumb regarding drip irrigation design is to always design water applications so that at least 50 percent of the plant root zone will be wet.

Water Requirement of Plants:

A formula for determining the daily water requirement of a plant in liters (gallons) per day (mlh or gpd) is:

$$\text{Water requirement of plant (gpd)} = \frac{0.623 \times \text{canopy area} \times \text{potential use (inches per day)} \times \text{plant factor}}{\text{irrigation efficiency}}$$

Canopy area refers to the square-foot area or plan-view size) of the plant. To calculate the area, square the diameter of the canopy and multiply by 0.7854. For example, a tree with a canopy diameter of 3 m (10 ft) will have an area of 0.94 m^2 (78.54 ft^2).

Potential use factor, also referred to as the *climate factor* or the *potential evapotranspiration rate (PET),* refers to the amount of water required by the plant for healthy growth (depending on climate) in centimeters (inches) per day (Table 750-5).

Plant factor refers to the water requirements of plants. Plants are classified according to their resistance to stress (Table 750-6).

Irrigation efficiency refers to the ability of an irrigation system to deliver water to plants without evaporation or other means of water loss (Table 750-7).

Example of calculation for determining the daily water requirement of a plant: Given a tree with a 15-ft (4.6-m) canopy diameter in a moderate climate,

$$\text{water requirement of plant (gpd)} = \frac{\left(0.623 \times 152 \times 0.7824 \times 0.25 \times 1.0\right)}{0.90}$$

GPD = 30.5

Determining the Number of Emitters:

Figure 750-23 shows the shape and square footage (meters) of typical soil wetting areas as a function of soil type. Generally speaking, heavy soils have a larger, shallower bulb than sandy soils, which have a narrower, longer bulb.

The following formula is used to determine the number of emitters required for any plant:

$$\text{Number of emitters} = \frac{\text{50 percent canopy area, ft}^2\ (\text{m}^2)}{\text{soil wetted area, ft}^2\ (\text{m}^2)}$$

Fractional values for the number of emitters should be rounded up to the next highest positive integer (as illustrated in the following example).

Example of calculation for determining the number of emitters required (U.S. units): Given a tree with a 15-ft canopy diameter, where the canopy area is 176.7 ft2:

For a sandy (i.e., well-drained) soil;

$$\text{Number of emitters} = \frac{88.3\ \text{ft}^2}{20\ \text{ft}^2}$$

$$= 4.4 \approx 5 \text{ emitters}$$

For a moderately well-drained soil;

$$\text{Number of emitters} = \frac{88.3\ \text{ft}^2}{60\ \text{ft}^2}$$

$$=1.5 \approx 2 \text{ emitters}$$

For a heavy (i.e., poorly drained) soil;

$$\text{Number of emitters} = \frac{88.3\ \text{ft}^2}{120\ \text{ft}^2}$$

$$= 0.5 \approx 1 \text{ emitter}$$

Determining the Flowrate:

The following formula can be used to calculate the flowrate and length of time to operate each emitter:

liters/day (GPD) = number of emitters
x emitter flowrate
x duration of irrigation

The tree in a moderately well-drained soil will require two 0.002-l/s (2-gph) emitters for a period of 7.5 hours. A sandy soil will require five 0.002-l/s (2-gph) emitters for a period of 3 hours. Clay soils are a special case because one 0.002-l/s (2-gph) emitter could cause runoff; one solution might be to use two 0.001-l/s (1-gph) emitters for a period of 15 hours.

The duration of irrigation can be reduced by adding more emitters. In the tree example used, ten 0.001-l/s (1-gph) emitters would satisfy the water requirements in 3 hours of running time (Table 750-8).

8.2 Design Procedure

The following procedure can be used to design and lay out drip irrigation systems for small commercial and residential projects. This procedure and the guidelines listed below are based upon the warmest part of the season, with irrigation occurring every day. Depending on the soil conditions, the exposure, and seasonal change, the frequency of irrigation may have to be altered.

Procedure:

1. Make an accurate map of the area.
2. Locate all plant materials and indicate their plant classifications and canopy sizes.
3. Based on the map of the area, select the correct number of emitters required for each plant.
4. On the map, lay out the emitter locations to determine the fittings and various accuracies required.

Important Considerations:

The following guidelines will help simplify the hydraulics of small irrigation systems:

1. The lateral lengths should not exceed 60 m (200 ft).
2. The flow should not exceed 758 l/h (3.33 gpm or 200 gph).
3. The maximum working pressure should be 276 kPa (40 psi) [pressures over this amount should be regulated].
4. The line used should be 15 mm (½ in) PVC or polyethylene tubing.

Figure 750-24 provides a simplified means to design a drip irrigation system. Table 750-9 provides the duration of drip irrigation (in minutes) for plants growing in containers. Table 750-10 provides information on the frequency of watering required for plants growing in containers.

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DIVISION 800

Materials

Soils and Aggregates

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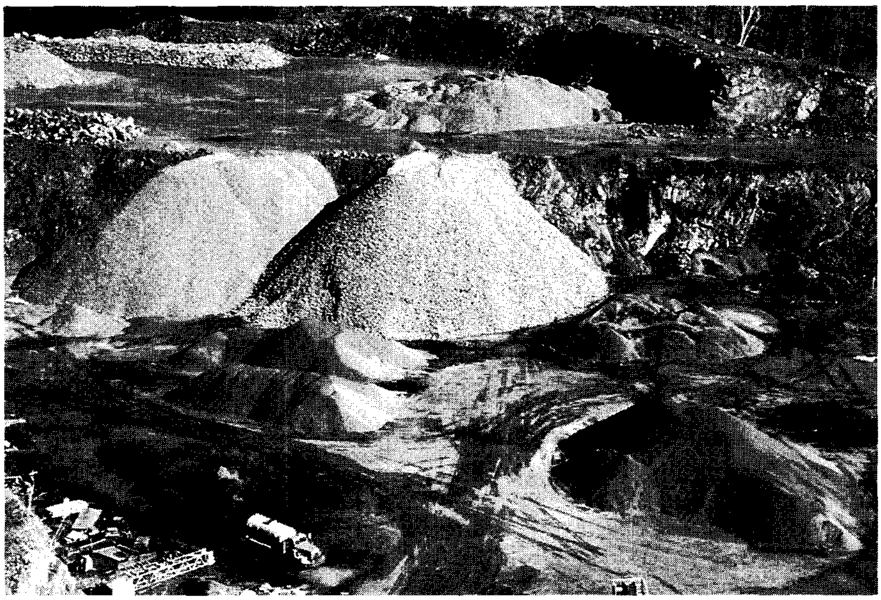


Kat Hardesty

CONTENTS

1.0 INTRODUCTION

1.1 Soils

Physical and chemical properties of soils are important site determinants influencing the spatial allocation of land uses, the design and construction of structures, and the selection and installation of plant materials.

Certain properties of soils can be readily deduced from knowledge of soil type, while others can only be determined by careful field and laboratory testing, especially urban soils which are not presently mapped except in rare cases. The properties of a soil that are relevant to consider depend on the type of land use and development proposed.

1.2 Aggregates

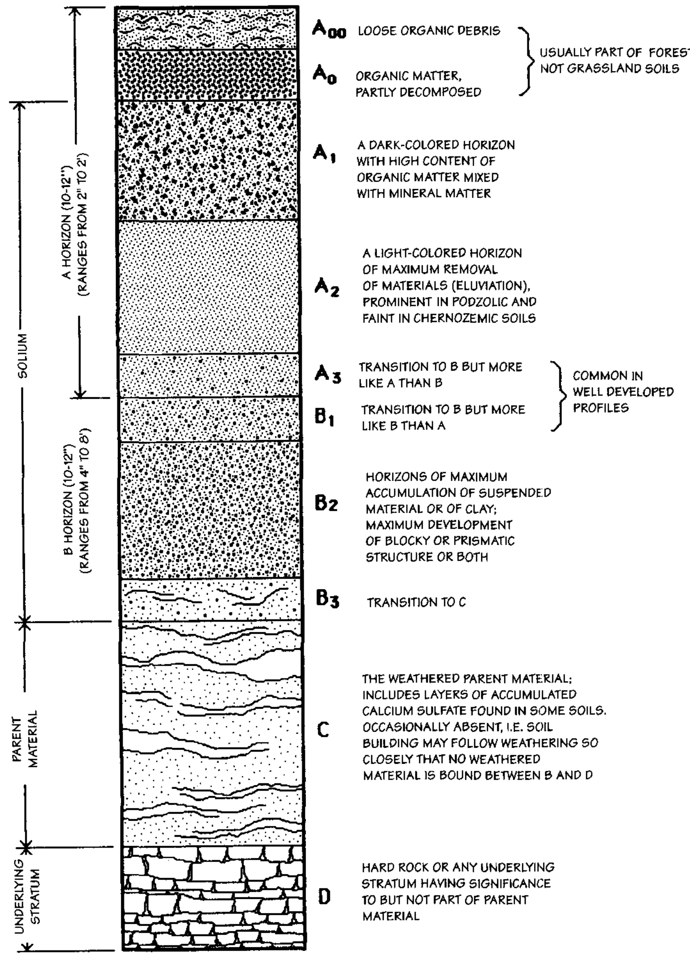
In landscape construction, the term aggregate typically refers to crushed rock or gravel rather than to the aggregation of soil particles. Information on the choice of an aggregate for specific purposes (foundations, road construction, etc.) is presented in 4.0 Aggregates of this section. Information on aggregates for making of asphalt or concrete is covered in Sections 820: Asphalt and 830: Concrete.

2.0 SOIL CLASSIFICATION SYSTEMS

This section describes the most common soil classification systems and the basic properties of soils that are critical for site development and horticultural applications. Typically, urban soils are drastically disturbed by human activities. As a result they are seldom classified because they do not fit in with the present USDA classification system. Presently they are being studied by the USDA-NRCS and they may soon come up with a classification system for them.

2.1 Soil Profile

In the process of natural formation, soil layers (i.e., horizons) develop with different textures, mineral contents, and chemical makeup. A soil profile is a vertical section through these horizons. A taxonomy has been developed to designate each horizon and zones within each horizon. The extent to which a profile becomes well-developed is largely a function of climate. Humid climates produce more fully developed profiles than arid climates. A typical profile in a humid climate has a well-developed A-, B-, C-, and sometimes D-horizon. Figure 810-



Master horizons and subordinate symbols for horizons of soil profiles

Master horizons

01	Organic undecomposed horizon
02	Organic decomposed horizon
A1	Organic accumulation in mineral soil horizon
A2	Leached bleached horizon (eluviated)
A3	Transition horizon to B
AB	Transition horizon between A and B—more like A in upper part
A&B	A2 with less than 50% of horizon occupied by spots of A2
AC	Transition horizon
B&A	B with less than 50% of horizon occupied by spots of A2
B	Horizon with accumulation of clay, iron, cations, humus; residual concentration of clay; coatings; or alterations of original material forming clay and structure
B1	Transition horizon more like B than A
B2	Maximum expression of B horizon
B3	Transitional horizon to C or R
C	Altered material from which A and B horizons are presumed to be formed
R	Consolidated bedrock

Subordinate Symbols

b	Buried horizon
ca	Calcium in horizon
cs	Gypsum in horizon
cn	Concretions in horizon
f	Frozen horizon
g	Gleyed horizon
h	Humus in horizon
ir	Iron accumulation in horizon
m	Cemented horizon
p	Plowed horizon
sa	Salt accumulation in horizon
si	Silica cemented horizon
t	Clay accumulation in horizon
x	Fragipan horizon
II,III,IV	Lithologic discontinuities
A'2, B'2	Second sequence in bisequal soil

Figure 810-1. Hypothetical soil profile showing all major soil horizons. *Note that no one soil has all of these profiles.*

Table 810-1. SOIL PARTICLE SIZE CLASSIFICATION

Particle size, mm	Sieve size	Unified Soil Classification	U.S. Department of Agriculture Soil Classification	American Association of State Highway Officials Soil Classification	American Society for Testing and Materials Soil Classification
0.001			Clay	Colloids	Colloids
0.002					
0.003				Clay	Clay
0.004					
0.006		Fines (silt or clay)			
0.008					
0.01			Silt		
0.02				Silt	Silt
0.03					
0.04					
	300				
0.06			Very fine sand		
0.08	200				
0.1	140				
0.2		Fine sand	Fine sand	Fine sand	Fine sand
0.3	60				
0.4			Medium sand		
0.6	40				
0.8			Coarse sand		
1.0	20	Medium sand		Coarse sand	Coarse sand
2.0	10		Very coarse sand		
3.0					
4.0		Coarse sand			
	4		Fine gravel	Fine gravel	
6.0					
8.0		Fine gravel			
10	½″				
	¾″			Medium gravel	Gravel
20					
30		Coarse gravel	Coarse gravel		
40				Coarse gravel	
60	3″				
80		Cobbles	Cobbles	Boulders	

*Corps of Engineers, Department of the Army, and Bureau of Reclamation.
Source: Douglas S. Way, *Terrain Analysis: A Guide to Site Selection Using Aerial Photographic Interpretation,* 2d ed., Douglas S. Way, Columbus, Ohio, 1978.

Table 810-2. CLASSIFICATION OF SOILS BY ORIGIN

TYPE	ORIGIN
Residual	Rock weathered in place—wacke, laterite, podzols,residual sands, clays, and gravels
Cumulose	Organic accumulations—peat, muck, swamp soils, muskeg, humus, bog soils
Transported:	
Glacial	Moraines, eskers, drumlins, kames—till, drift, boulder clay, glacial sands, and gravels
Alluvial	Flood plains, deltas, bars—sedimentary clays and silts, alluvial sands and gravels
Aeolian	Wind-borne deposits—blow sands, dune sands, loess, adobe
Colluvial	Gravity deposits—cliff debris, talus, avalanches, masses of rock waste
Volcanic	Volcanic deposits—Dakota bentonite, volclay, volcanic ash, lava
Fill	Synthetic deposits—ranging from waste and rubbish to bult embankments

Source: Adapted from Elwyn E. Seelye, *Design: Data Book for Civil Engineers,* 3d ed., Wiley, New York, 1945; and from the Portland Cement Association, *Soil Cement Laboratory Handbook,* Skokie, Il.

Table 810-3.THE NEW SOIL TAXONOMY (WORLD SEVENTH APPROXIMATION)

Soil order	Climatic range	Natural vegetation	Parent materials	Horizon development	Drainage	Colors
Entisol	All climates, arid to humid, tropical to polar	Highly variable. Forests, grass, desert, tidal marsh	Primarily free-draining alluvium and aeolian, and low-activity clays	None, except perhaps for a thin A horizon	Good; slopes not significant	Not significant
Vertisols	Subhumid to arid with wet and dry seasons, or arid areas subject to flooding	Grasses and woody shrubs	High-activity clays, shrinking when dry, swelling when wet, with montmorillonite common	B horizon commonly absent	Poor; slopes flat to gentle	Black, gray, brown
Inceptisols	Humid, from arctic to tropical	Mostly forests, occasionally grasslands	Young soils from residuum, loess, glacial till. Soils moist.	One or more formed without significant illuviation or eluviation. A horizon very organic	Slopes flat to moderately steep	Light to dark
Aridsols	Arid to semiarid	Sparse grasses and other desert vegetation	Generally alluvium	Poor horizon development and very little organic matter. Soil rich in lime, gypsum, or sodium chloride. Caliche common	Slopes flat to gentle	Light to red
Mollisols	Alpine to tropical; with cool, dry seasons, and hot, moist seasons	Grasses, sedges, hardwood forests	Variable: loess, alluvium, till, residuum	Distinct horizons. Highly organic A layer. B and C horizons may have secondary lime accumulations	Flat to slight slopes and poor drainage	Medium to dark colors
Spodosol	Humid regions, alpine to tropical	Coniferous forest, savannah, or rain forest	Usually siliceous, granular, and not very clayey	B horizon illuviated with organic matter, iron and aluminum oxides	Good	Black, brown, reddish
Alfisols	Cool humid to subhumid with seasonal rainfall	Deciduous forest, some tall grasslands	Variable, but generally young; alluvium, till, loess, or coastal plain. Calcareous in cool, humid climates	Thin, highly organic A horizon. B horizon illuviated with clay, organic matter, and iron oxide	Poor. Flat to gentle slopes	Black, brown, reddish
Ultisols	Humid	Forest, savannah, marsh, or swamp	Old and strongly weathered residuum or coastal plain	Thin A horizon with some humus over illuviated B horizon. Approaching a lateritic soil	Poor to fair. Slopes moderate to steep	Variable and often mottled with gray, yellow, and red
Oxisols	Tropics and subtropics with wet and dry seasons	Forest to savannah	Lateritic soils primarily from basic rock residuum	Little organic soil development. Clay content high but formation porous. Concentrations of iron and aluminum at various depths	Good	Reds, browns
Histosols	Moist to wet	Swamp, marsh, and bog	Organic materials	None visible	Very poor	Gray to black
Andisols	Dry to wet	Desert to forest	Volcanic ash	Surface may be the most unweathered; texture and composition highly variable with high amounts of allophane; may be very fertile	Well-drained	Gray to black

Source: Roy E. Hunt, *Geotechnical Engineering Investigation Manual*, McGraw-Hill, New York. [Original source: US Soil Conservation Service, *Soil Classification: A Comprehensive System* (7th Approximation), Washington D. C., 1960.]

Table 810-4. COMMON TERMS OF THE USDA SOIL CLASSIFICATION SYSTEM

General terms	Basic Soil-textural class names
Sandy soils, coarse-textured soils	Sands, loamy sands
Loamy soils	
Moderately coarse-textured soils	Sandy loam, fine sandy loam
Medium-textured soils	Very fine sandy loam, loam, silt loam, silt
Moderately fine-textured soils	Clay loam, sandy clay loam, silty clay loam
Clayey soils, fine-textured soils	Sandy clay, silty clay, clay

Source: U.S. Department of Agriculture, *Soil Taxonomy,* Washington, D.C., 1975.

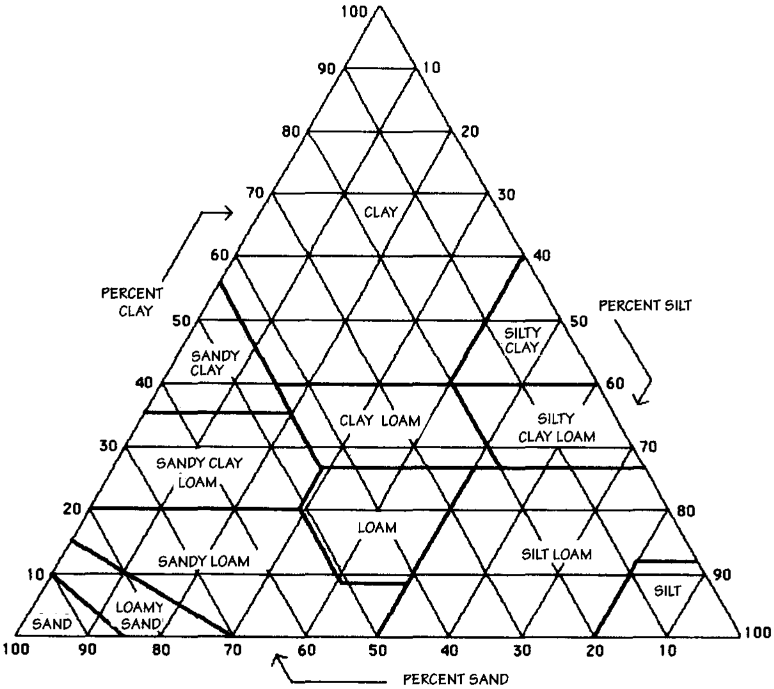


Figure 810-2. USDA Soil textural triangle.

Table 810-5. AASHTO SOIL CLASSIFICATION SYSTEM AND GENERAL RATINGS

General classification	Granular materials*							Silt-clay materials†			
Group classification‡	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5§ A-7-6¶
Sieve analysis:											
Percent passing											
No. 10	50 max.	—	—	-	—	—	—	—	—	—	—
No. 40	30 max.	50 max.	51 min.	—	—	—	—	—	—	—	—
No. 200	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.	36 min.	36 min.	36 min.	36 min.
Characteristics of fraction passing No. 40 sieve											
Liquid limit	—	—	—	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.	40 max.	41 max.
Plasticity index	6 max.	6 max.	Nonplastic	10 max.	10 max.	11 min.	11 min.	10 max.	10 max.	11 min.	11 min.
Group index	0	0	0	0	0	4 max.	4 max.	8 max.	12 max.	16 max.	20 max.
Usual types of significant constituent materials	Stone fragments: gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
General rating as subgrade	← Excellent to good →							← Fair to poor →		← Very poor →	

*35% or less passing through a No. 200 sieve.
†More than 35% passing through a No. 200 sieve.
‡Placing A-3 before A-2 is necessary in the left-to-right elimination process and does not indicate superiority of A-3 over A-2.
§Plasticity index of A-7-5 subgroup is equal to or less than the liquid limit minus 30.
¶Plasticity index of A-7-6 subgroup is greater than liquid limit minus 30.
Source: Douglas S. Way, *Terrain Analysis: A Guide to Site Selection Using Aerial Photographic Interpretation,* 2d ed., Douglas S. Way, Columbus, Ohio, 1978.

Table 810-6. SOIL TYPES AND THEIR PROPERTIES (UNIFIED CLASSIFICATION SYSTEM)

Division	Symbols		Soil description	Value as a foundation material	Drainage	Drainage
	Letter	Color				
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 LL <50†	ML	Green	Inorganic silts, 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 LL >50	MH	Blue	Inorganic silts, micaceous or diatomaceous 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

* Consult soil engineers and local building codes for allowable soil-bearing capacities.

† LL indicates liquid limit.

Source: Adapted from Charles G. Ramsey and Harold R. Sleeper, *Architectural Graphic Standards,* 7th ed., Robert T. Packard (ed.), Wiley, New York, 1981.

1 illustrates a hypothetical soil profile, showing all major soil horizons.

A number of soil classification systems have been developed for various purposes. The four most common classification systems are described below. Table 810-1 illustrates the differences between these systems in terms of soil texture and their relationship to standard American Society for Testing and Materials (ASTM) sieve sizes.

2.2 Classification of Soil by Origin

Soils can be broadly classified as either residual soils, formed in place through weathering of bedrock and disintegration of organic matter, or as transported soils, materials that have been moved from another place by glaciation, wind, water, or gravity. Table 810-2 provides a classification of soils according to their origin.

KEY POINTS: Soil Classification Systems

A number of soil classification systems have been developed to describe soils in terms of specific uses such as agriculture and highway construction. The choice of classification system depends on the nature of the project and available data.

1. USDA classification system is based on agricultural suitability and describes the relative proportion of clay, silt, and sand particles within the soil (Figure 810-2).

2. USDA classification system is limited to depths of about 1 m (3 ft.). This data cannot be used in situations where information about greater depths is needed.

3. The AASHTO system is based on highway construction suitability and classifies soils into two major categories (Table 810-5):
   a) Granular materials (groups A-1 through A-3) that are considered excellent to good as a subgrade.
   b) Silt-clay materials (groups A-4 through A-7) that are considered fair to very poor as a subgrade.

4. The unified system was devised for highway engineering and divides soil into three basic categories (Figure 810-3 and Table 810-6):
   a) Coarse-grained soils that are excellent to fair as foundation material.
   b) Fine-grained soils that are fair to very poor as foundation material.
   c) Organic soils that are not suitable as foundation material.

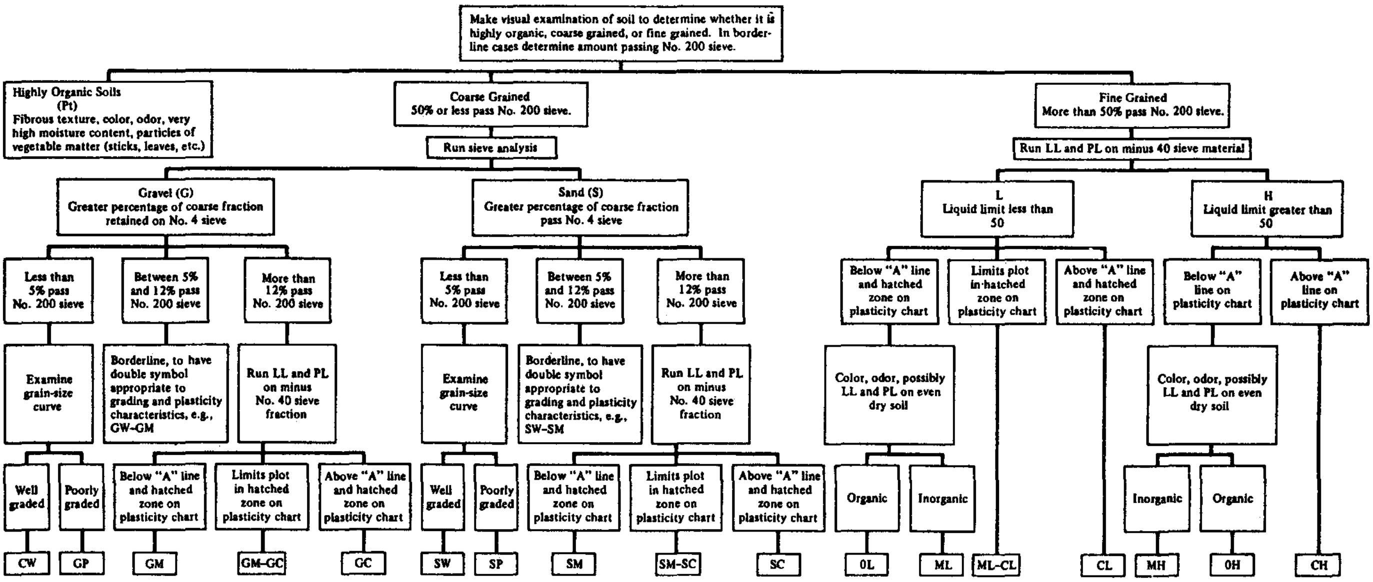


Figure 810-3. Classification procedure for the unified system.

2.3 The USDA System

The New Soil Taxonomy lists eleven basic soil orders based primarily on climate, parent material, and vegetation (Table 810-3). This classification system provides a framework for the United States Department of Agriculture Natural Resource Conservation Service (USDA) system.

Also, the USDA Natural Resource Conservation Service has developed a classification system that evaluates and classifies soils in terms of their genesis and morphology. Newer surveys are superimposed on aerial photographs and are supplemented with information applicable to land uses other than agriculture. In the USDA system, information on soils is limited to depths of about 1 m (3 ft). This data cannot be used to address problems requiring soil information at greater depths.

Figure 810-2 shows the USDA soil textural triangle, and Table 810-4 lists common terms used in the USDA classification system.

2.4 The AASHTO System

The American Association of State Highway Transportation Officials (AASHTO) has developed a soil classification system based on engineering properties of soils and their suitability for highway construction (Table 810-5). Soils are classified into seven groups (A-1 through A-7) based on laboratory determination of particle size distribution, liquid limit, and plasticity index. Soils are evaluated within each group by a group index value which is calculated from an empirical formula. Group classification and group index values determine the relative quality of soils for their suitability in embankments, subgrades, bases, and subbases. Soils are divided into two major groups: (1) granular materials, which pass less than 35 percent of materials through a 0.075 mm (No. 200) sieve, and (2) silt-clay materials, which pass more than 35 percent of the material through a 0.075 mm (No. 200) sieve.

2.5 The Unified System

The Unified Soil Classification System divides soils into three basic categories: (1) coarse-grained soils, (2) fine-grained soils, and (3) organic soils (Table 810-6). Coarse-grained soils pass less than 50 percent fines through a No. 200 sieve, and fine-grained soils pass more than 50 percent fines through a 0.075 mm (No. 200) sieve. Organic soils are identified by visual examination. Soil divisions are further delineated by 15 soil groups based on liquid limit, major soil textural fraction, and relative gradation. The unified system was devised mainly for highway engineering purposes. Figure 810-3 shows how specific classifications are determined.

3.0 SOIL PROPERTIES

Shown and explained below are several major properties of soils. These should be observed and measured to help guide proper site planning and landscape design solutions. They have been grouped under three headings: physical properties, properties related to site engineering and landscape construction and properties related to horticulture.

3.1 Physical Properties

Texture: Is a way to classify the range of particle sizes that make up soil. Most soils have several different sizes of particles. Figure 810-2 shows the 12 texture classes developed for use in the United States. This data can be obtained from a soil survey report, by field determination or by use of ASTMD-422-63 including a 300 mesh sieve.

Color: Color is the most obvious feature observed in a soil profile. An experienced soil scientist or landscape architect, civil engineer, grower or contractor can determine many characteristics by merely seeing and feeling the soil. In order to standardize the use of color, the Munsell color notation system has been adopted to read each horizon. The relationship between soil color, climate and soil maturity is used to classify soils.

Density: The total volume of solids and voids in soil is commonly referred to as its bulk volume or density. The relationship between bulk density and pore space is inverse.

Capillarity: This refers to the upward movement of moisture or water above the water table as a function of fine textured soil. Clay and silt soils have higher capillari-

Table 810-7. CAPILLARY ACTION IN VARIOUS SOIL TYPES

Capillary Rise			Saturation zone	
Ft	M	Soil Type	Ft	M
>8	2.4	Clay	>5	1.5
>8	2.4	Silt	>5	1.5
3-8	1-2.4	Fine sand	1-5	0.3-1.5
1-3	0.3-1	Coarse sand	0-1	0-0.3
0	0	Gravel	0	0

* Water rises in most soils by capillary action. Clays and silts may become fully saturated to almost 6 ft (2 m) above a water table, and some water may rise more than 11 ft (3.4 m). Note that coarse sand may allow a rise up to 3 ft (1 m). No capillarity results in coarse gravel.

Source: Adapted with permission from Harold B. Olin, John L. Schmidt, and Walter H. Lewis, *Construction: Principles, Materials, and Methods,* U.S. League of Savings Institutions, Chicago, 1983.

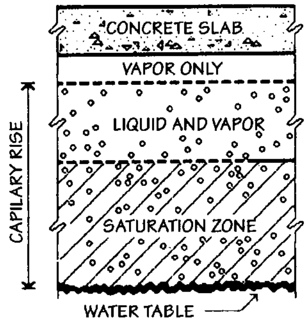


Table 810-8. PERMEABILITY AND DRAINAGE CHARACTERISTICS OF VARIOUS SOILS

Soil type	Approximate coefficient of permeability k, cm per sec	Drainage characteristic
Clean gravel	5–10	Good
Clean coarse sand	0.4–3	Good
Clean medium sand	0.05–0.15	Good
Clean fine sand	0.004–0.02	Good
Silty sand and gravel	10^{-5}–0.01	Poor to good
Silty sand	10^{-5}–10^{-4}	Poor
Sandy clay	10^{-6}–10^{-5}	Poor
Silty clay	10^{-6}	Poor
Clay	10^{-7}	Poor
Colloidal clay	10^{-9}	Poor

Source: Frederick S. Merritt, *Standard Handbook for Civil Engineers,* 3d ed., McGraw-Hill, New York, 1983.

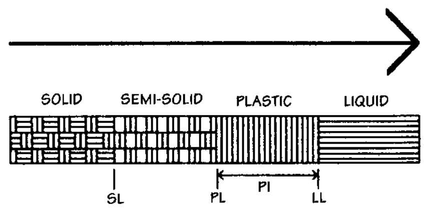


Figure 810-5. States of fine-soil consistency. *As water content increases, soils become increasingly fluid. PI refers to the plastic index, PL to the plastic limit, LL to the liquid limit, and SL to the shrinkage limit.*

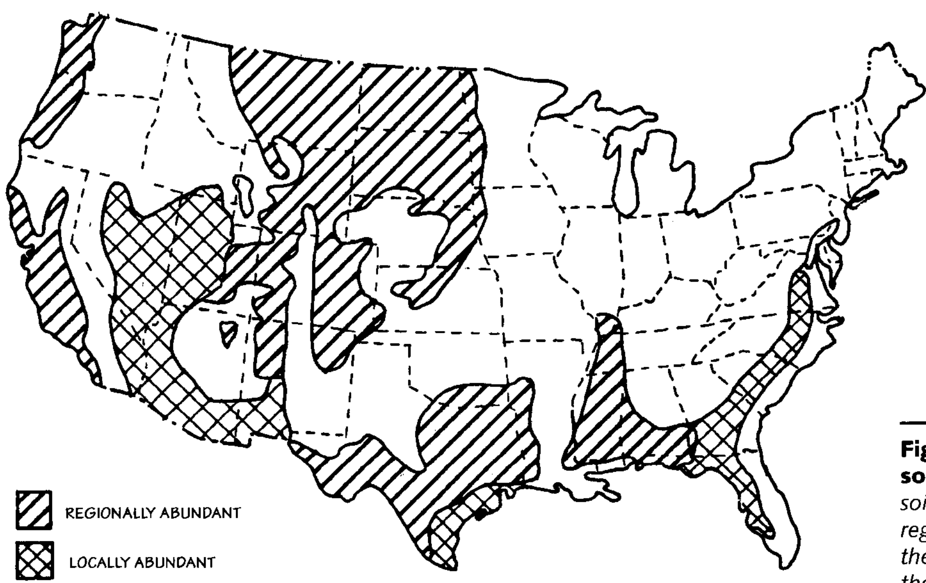


Figure 810-4. Areas of expansive soils in the United States. *Expansive soils are most widespread in areas labeled regionally abundant, but many locations in these areas will have no expansive soils. In the unshaded portions of the map, some expansive soils may be found, but not in major regional concentrations.*

ty action than coarse-textured soils (Table 810-7).

Permeability: This refers to the ability of a soil to transmit water downward due to gravity (Table 810-8). Permeability is a function of pore space and varies with void ratio, grain size and distribution, structure, degree of cementation, degree of saturation, and degree of compaction. Coarse-grained soils are typically more permeable than fine-grained soils. Percolation tests measure the permeability of a soil for example when designing leaching fields for septic systems.

Shrinkage and swell: Shrinkage and swell (volume changes) refers to the buildup and release of capillary tensile stresses within soil due to water. Volume changes are most profound among expansive soils. Figure 810-4 shows the general distribution of expansive soils in the United States. (Refer to Section 255: Natural Hazards: Expansive Soils, for more information on expansive soils and their implications in site planning, design, and engineering.)

Cohesion: Cohesion is the ability of a soil sample to bind together when moderately dry. Cohesionless soils (such as dry beach sand) are easy to excavate but vertical side slopes cannot be maintained without support.

3.2 Properties Related to Site Engineering and Landscape Construction

Elasticity: Elasticity refers to the ability of soil to return to its original shape after being deformed by a load. Conversely, it refers to the compatibility of a soil. In landscape construction, the relative elasticity of soils on a site may determine where heavy equipment can be moved to avoid undesirable compaction of soils.

Plasticity: Plasticity refers to the ability of soil to be deformed under pressure without cracking or crumbling and to maintain a deformed shape after pressure is released. Plastic deformation is an important factor in road and foundation work and is more significant under increasing loads. Given a sufficiently large load, a soil mass can shear and fail.

Liquid and plastic limit: Liquid limit refers to the moisture content at which a soil passes from a liquid to a plastic state as moisture is removed. Plastic limit refers to the moisture content when soil passes from

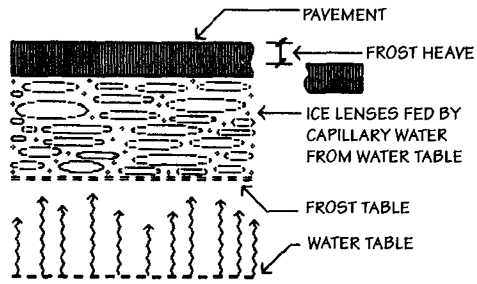


Figure 810-6. Dynamics of frost heave. *Frost heave is caused by ice lenses forming beneath the pavement structure.*

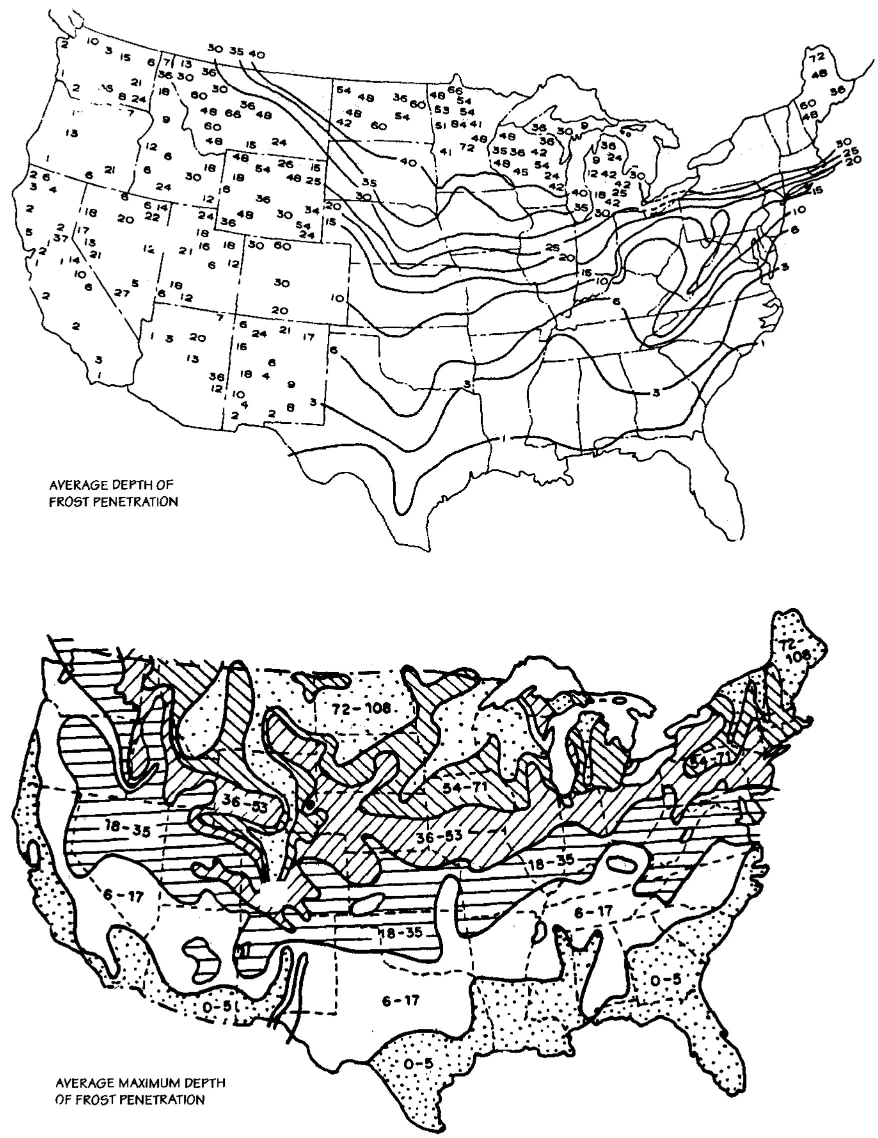


Figure 810-7. Depths of frost penetration in the United States (inches). *Note that depths of frost penetration can vary from these averages in specific geographical locations, especially in areas of significant topographic change. Always check local sources for more precise averages.*

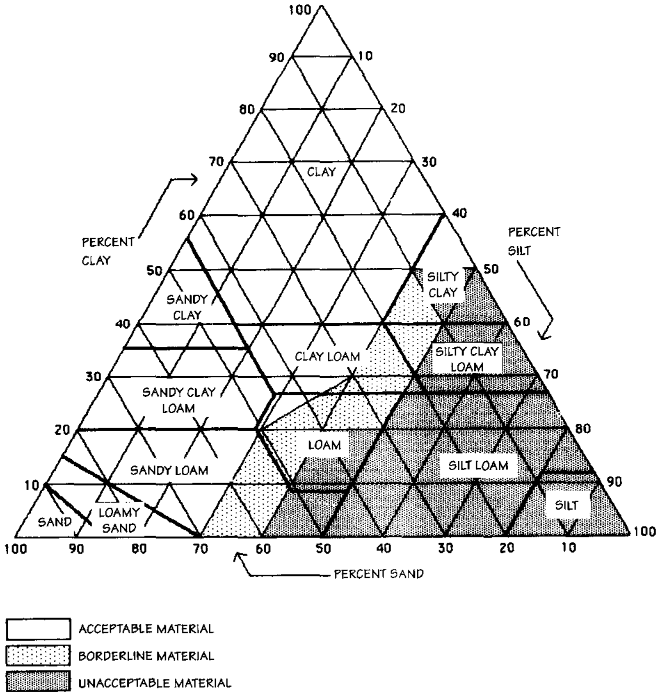


Figure 810-8. Soils most susceptible to frost heave.

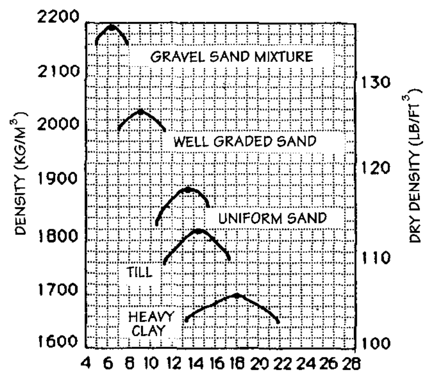


Figure 810-9. Optimum moisture contents (compaction curves) for various soil types (percent). *High point on curve denotes optimum moisture content for particular soil type.*

Table 810-9. COMPACTION TECHNIQUES FOR SOILS

General soil types	Compaction technique of fill	Compaction technique of natural formation
Cohesionless soil (sand and gravel)	Compaction is best when soil is vibrated and rolled. Rolling with saturated soil is possible, but rapid permeability makes continued saturation difficult.	Vibration by pile driving, vibroflotation or dynamite
Moderately cohesive soils (sand and silt)	Compacted in thin layers at optimum moisture content. Pneumatic rollers work best on slightly cohesive soils, gravel and silt soils, sandy soils, and nonplastic silt soils. Sheepsfoot rollers are better on plastic silt and clay soils.	Pile driving above water tabl Must lower water table and use pile driving to compact lower levels
Cohesive soils (clay and clay silt)	Soils should be compacted in thin layers at optimum moisture content. Pneumatic rollers work best on slightly cohesive soils, gravel and silt soils, sandy soils, and nonplastic silt soils. Sheepsfoot rollers are better on plastic silt and clay soils.	Clays, organic material, and loose silts are best compacted by surcharging, i.e., by covering the area with sufficient amounts of fill (weight) to a desired degree of settlement.

a plastic to a semisolid state as water is further removed. Plasticity index refers to liquid limit minus plastic limit (Figure 810-5).

Frost susceptibility: Frost susceptibility refers to the relative tendency of some soil to swell due to frost when the moisture in the soil freezes. Fine-grained soils exhibit a greater tendency to heave under cold temperatures than coarse-grained soils. The likelihood of heaving is dependent upon: (1) freezing temperatures in the soil, (2) a water table close to the frost line, and (3) soil characteristics favoring rapid upward movement of capillary water (i.e., clays and silts).

Preventative action against frost heave includes such measures as (a) the removal of the fine-grained material and its replacement with subbase and base (typically gravel or rock fill) that is not susceptible to frost, (b) the intentional lowering of water tables, and (c) the installation of some form of insulation above the frost-susceptible material (Figures 810-6 through 810-8).

Compressibility and compaction: Soil can be compacted and, thereby, change the volume and its ability to support weight. For landscape construction soils often have to be compacted to prescribed densities to meet predetermined performance criteria. The required compaction is best achieved when soils are of fairly specific moisture contents. This depends on the type of soil to be compacted. Table 810-9 describes various compaction techniques for soils and Figure 810-9 shows optimum moisture contents for compaction of various soil types.

Bearing Strength: This relates to the ability of a soil to support a load without failure. It depends upon internal friction between soil particles and upon cohesion. Bearing strength is affected by changes in water content, rate and time of loading, and confining pressure. Soils compacted at optimal moisture content typically exhibit greater shear strengths than wet soils. Approximate bearing strengths of various types of soils are shown in Table 810-10.

Drainage: Soil drainage has three components: (a) runoff, (b) internal drainage, and (c) permeability or porosity. Each one is in some way influenced by the other two. Topographic features (degree of slope, etc.) influence the volume and rate of runoff. The steeper the slope the less water can be absorbed into the ground. Internal drainage refers to the flow of water through the soil profile. This rate is also

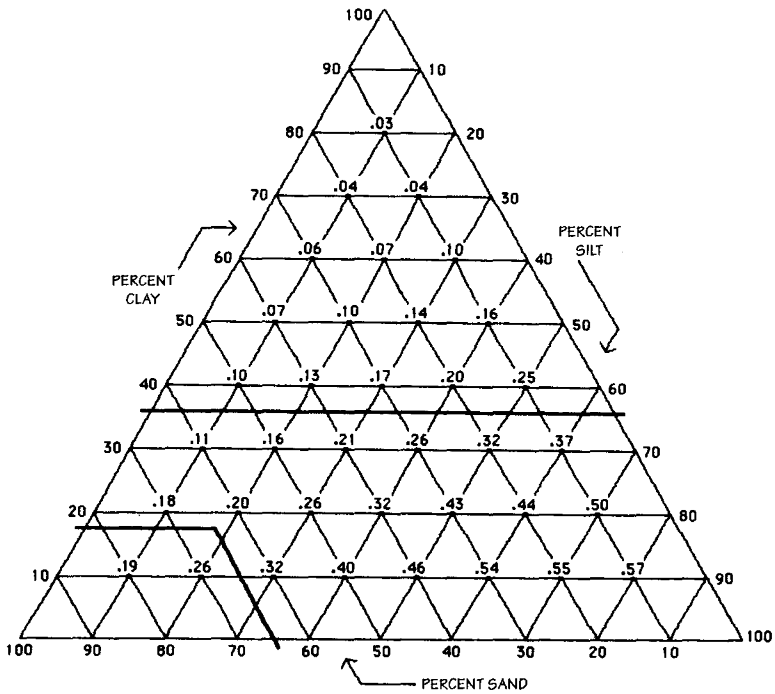


Figure 810-10. Soil erodibility factor (K). *USDA textural triangle with plotted K values to show relationships between sizes of mineral particles and soil erodibility.*

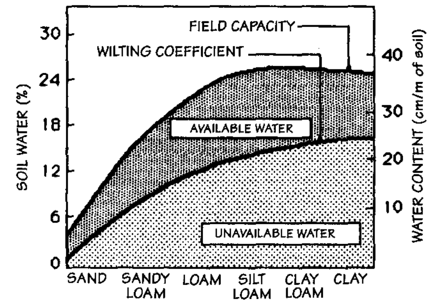


Figure 810-11. Water availability in soils (for plant growth). *This chart shows the general relationship between soil moisture characteristics and soil texture. Note that the wilting coefficient increases as soil texture becomes coarser. These are representative curves. Individual soils would likely have values different than those shown.*

effected by the permeability of the soil on the surface and below.

The depth and fluctuation of water penetration, coupled with the rate of aeration and oxidation of the minerals in the soil, causes distinctive color patterns in the soil horizon called "mottling". The USDA-Natural Resource Conservation Service has recognized seven drainage classes. These are shown in Table 810-11.

Erodibility: This refers to the extent to which a soil mass can withstand the forces of wind or water erosion. Figure 810-10 shows degrees of erodibility for various types of soils. (Refer to Section 253: Natural Hazards: Landslides and Snow Avalanches, for information on process of landslides attributable to various soil conditions.)

Spatial variability: Most urban sites consist of more than one soil type but these are seldom mapped. Depending on the projected uses of a site it is often necessary to take random or systematic profile samples to determine what are the significant types of soil.

Table 810-11. USDA SOIL DRAINAGE CLASSES

Depth to mottling cm	(inches)	Soil Drainage Class
15	(6)	very poorly drained
30	(12)	poorly drained
51	(20)	somewhat poorly drained
81	(32)	moderately well drained
107	(42)	well drained
132	(52)	somewhate excessively drained
>152	(>60)	excessively drained

Table 810-10. PRESUMED BEARING CAPACITY OF VARIOUS TYPES OF SOIL

Soil types	U.S. tons/ft²	Metric tons/m²
Well-graded, well-compacted clayey sands and gravels	10	120
Gravels and gravelly sands, ranging from loose to well-compacted	4–8	45–95
Coarse sands, from loose to well-compacted	2–4	25–45
Fine, silty, or clayey sands, not well-graded, from loose to well-compacted	1.5–3	20–35
Homogeneous, nonplastic, inorganic clays, from soft to very stiff	0.5–4	5–45
Inorganic, nonplastic silts, from soft to very stiff	0.5–3	5–35

Source: Kevin Lynch and Gary Hack, *Site Planning,* 3d ed., MIT Press, Cambridge, Mass., 1984.

3.3 Properties Related to Horticultural Applications

Many of the above properties of soils effect not only site engineering and landscape construction but also how plants can or cannot grow in these soils. Table 810-12 shows the general suitability of various soils for healthy plant growth. Table 810-13 illustrates the relationship of soil texture to other soil characteristics.

Available Moisture and Adequate Drainage: The existence of soil moisture does not ensure that water will be available to plants (Figure 810-11). Ideally, the ratio of air space to water in the soil should be 1:1. Plants begin to wilt at the point at which the remaining soil moisture is held in tension by hydroscopic forces. Most plants cannot not survive if the soil is too wet, thus adequate water and drainage are crucial to most plants.

Soil pH: This refers to the relative acidity or alkalinity of a soil. Table 810-14 and Figure 810-12 show how the levels of pH in the soil effects the availability of certain nutrients. Because all plants have specific tolerances for soil acidity or alkalinity, the pH tolerances for proposed plants must be

Table 810-12. RELATIVE SUITABILITY OF VARIOUS SOILS FOR HEALTHY PLANT GROWTH

Item affecting use	Soil suitability rating: Good	Moderate	Poor
Soil drainage class	Well and moderately well-drained	Somewhat poorly drained	Poorly and very poorly drained
Moist consistence	Very friable, friable	Loose, firm	Very firm, extremely firm
Textures	vfsl, fsl, l, sil, sl	cl, scl, sicl, sc	s, c, sic
Thickness of soil (above hard layer, water table, or bedrock)	>30 in	20–30 in	<20 in
Coarse fragments (volume)	<8%	8–15%	>15%
Slope	<8%	8–15%	>15%

Key:

Vfsl—very fine sandy loam
Fsl—fine sandy loam
L—loam
Sil—silt loam
Sl—sandy loam
Cl—clay loam
Scl—sandy clay loam
Sicl—silty clay loam
Sc—sand/clay mixture
S—sand
C—clay
Sic—silt/clay mixture

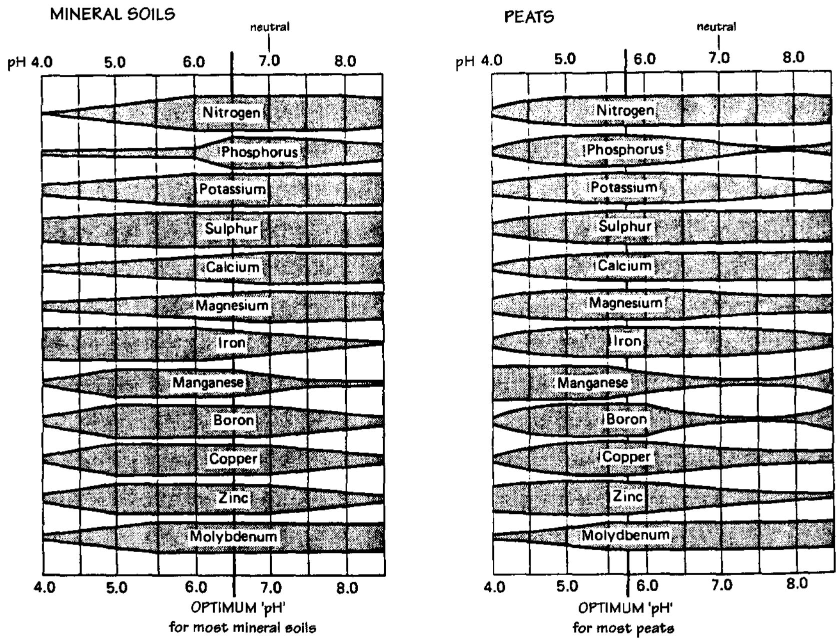


Figure 810-12. pH levels and nutrient availability. *These graphs illustrate the effect of soil pH on nutrient availability. The growing media should be kept at a pH level at which all essential nutrients are available for the plantings. For most plants, the optimum pH level is 6.5 in mineral soils and 5.8 in peats.*

Table 810-14. TERMS FOR VARIOUS pH LEVELS

Characteristics	pH
Extremely acid	Below 4.5
Very strongly acid	4.5–5.0
Strongly acid	5.1–5.5
Medium acid	5.6–6.0
Slightly acid	6.1–6.5
Neutral*	6.6–7.3
Mildly alkaline	7.4–7.8
Moderately alkaline	7.9–8.4
Strongly alkaline	8.5–9.0
Very strongly alkaline	9.1 and higher

* Strict neutrality is pH 7.0, but in field work those soils between pH 6.6 and 7.3 are considered neutral.

Table 810-13. RELATIONSHIP OF SOIL TEXTURE TO OTHER SOIL CHARACTERISTICS

Characteristic	Sand	Loam	Silt Loam	Clay
Identification	Loose	Cohesive	Shows fingerprints	Shiny streak
Permeability	Excessive	Good	Fair	Fair to poor
Available water	Low	Medium	High	High to medium
Tillability	Easy	Easy	Moderate	Difficult
Runoff potential	Low	Low to medium	High	Medium to high
Nutrient storage capacity	Low	Medium	Medium	High
Compactability	Low	Medium	Medium to high	High
Suitability	High	High	High to medium	Low
Susceptibility to problems of insufficient aeration	Low	Medium	Medium	High

Source: Phillip J. Craul, *Urban Forest Soils,* School of Forestry, State University of New York, Syracuse, N.Y. (From workbook for conference on Urban Forest Soils, sponsored by U.S. Forest Service, U.S. National Park Service, 1982.)

Table 810-15. COMPRESSIVE STRENGTH OF COMMON ROCK TYPES USED AS AGGREGATES

Characteristics	pH
Extremely acid	Below 4.5
Very strongly acid	4.5–5.0
Strongly acid	5.1–5.5
Medium acid	5.6–6.0
Slightly acid	6.1–6.5
Neutral*	6.6–7.3
Mildly alkaline	7.4–7.8
Moderately alkaline	7.9–8.4
Strongly alkaline	8.5–9.0
Very strongly alkaline	9.1 and higher

* Strict neutrality is pH 7.0, but in field work those soils between pH 6.6 and 7.3 are considered neutral.

known before specifying or modifying soils for particular landscape projects.

Colloidal Content: This refers to the amount of clay particles in a soil sample. A high clay content limits the permeability of the soil and affects the ability of plants to absorb dissolved nutrients in solution. Some clays (e.g., montmorillonite clays) have great absorptive capacity which means that they swell enormously when wet and shrink and crack when dry. (See Section 255: Natural Hazards: Expansive Soils for more information.)

Depth: Soil depth typically refers to depth to bedrock, to water table or to unweathered parent materials. There is no optimum depth because it depends on many variables. Most plants need sufficient depth of soil to allow root growth coupled with adequate minerals, water supply and appropriate aeration. No less than 450 mm (18 inches) and no more than 300 meter (36 inches) is typically necessary for most temperate climate plants.

Soils for Urban Planting: Planted areas in urban environments, particularly paved areas near streets and heavy pedestrian traffic, often have problems of compaction, limited nutrient availability, and pollution from poisonous elements. One of the most severe problems is compaction of soils which results in retarded water infiltration, increased surface runoff, inhibited gas exchange, an oxygen deficient environment, a reduction in valuable soil organisms, severely inhibited root growth, and increased thermal conductivity. Soils for all urban plantings require special preparation to ensure long-term healthy growth of plant materials. After considerable recent study and experimentation special mixtures of coarse to fine aggregates and organically enriched soils have been developed that are being used as a more optimum media to grow plants (particularly trees) in harsh urban environments. Readers are urged to seek the latest information for their area.

Table 810-16. COMMON LOOSE AGGREGATES USED FOR WALKWAYS

Material	Color	Physical properties	Considerations
Gravel:			
Pea gravel	Salmon, buff, off-white	Round-shaped (small)	Used for residential terraces and walks
Gravel	Varies with region	Dries quickly; washes easily; excellent base and margin for stepping stones, tile, or concrete paving	Easy to maintain by raking; stands up best when used as a topping over a more permanent bed
Crushed stone:			
Granite chips (1/16–1 in)		Angular shape; compacts well; particles interlock	Stays in place longer than rounded materials; can be manufactured with smooth edges; provides stable surface
Decomposed granite		Compacts solidly when dampened and rolled	Similar to redrock; wears better; costs $\pm$ 1/3 more
Colored rock	Pink, red, others	Small fragments make impervious bedding advisable	Not as economical as other gravels; some colored rocks only available locally
Dolomite	Stark white	Discolors easily	Requires extra care; not expensive; used best in small areas
Redrock		Compacts solidly when dampened and rolled; provides clean, hard, surface; surface breaks down into dust over time	Available under other names
Crushed brick	Venetian red (intense)	Fragments break up and wear down; stable base required	Good accent to planting; not suitable in areas with heavy traffic; expensive (10 times the cost of redrock)
Smelting byproducts:			
Chert		Medium to lightweight; compacts; crowns and rolls easily; soft, crunchy surface	
Red blaes		Medium to lightweight; porous; holds water	
Leca	Similar to pea gravel	Lightweight; absorbs water	Excellent for roof landscapes

Key Points: Soil Properties and Implications

There are several major properties of soils which should be observed and if necessary measured for proper site planning, design and construction. These have been grouped under three headings:

1. Physical properties: texture (Figure 810-2), color, density, capillarity (Table, 810-7), permeability (Table 810-8), shrinkage and swell (Figure 810-4), and cohesion.
2. Properties related to site engineering and landscape construction: elasticity, plasticity, liquid and plastic limits (Figure 810-5), frost susceptibility (Figure 810-6 -8), compressibility and compaction (Figure 810-9 and Table 810-9), bearing strength (Table 810-10), drainage (Table 810-11), erodibility (Figure 810-10), spatial variability.
3. Properties related to horticultural applications (Table 810-12 -13): available moisture (Figure 810-11), soil pH (Table 810-14 & Figure 810-12), colloidal content, depth, and soils for urban planting.

4.0 AGGREGATES

Aggregates refer to granular materials, including such natural materials as sand, gravel, and crushed stone to manufactured materials such as slag, vermiculite, pumice and crushed brick, etc. Aggregates have a wide range of uses in site engineering and landscape construction. Only two are listed below. Others uses are discussed in several other sections throughout the book.

KEY POINTS: Aggregates

1. Aggregates are graded by size and frequently combined in certain proportions to produce aggregate mixtures.
2. The ability to withstand abrasion from pedestrian and/or vehicular traffic is an important characteristic of aggregates (Table 810-15). This can be achieved by using a well-graded coarse aggregate combined with sand or similar fine aggregates to create a tight water-resistant surface and an interlocking of aggregates to resist shear forces.
3. Aggregates should support loads (pedestrian and/or vehicular) with little or no deformation. This can be achieved by adding some type of binding material, such as clay.
4. Drainage of surface water is important to prevent excess infiltration into the subgrade.
5. Aggregate surfaces should allow some upward movement of subsurface moisture to help maintain a desirable moisture level in the paving.

4.1 Relevant Properties of Aggregates

Cleanliness: Aggregates are considered clean if free of clay, silt, mica, and organic matter.

Soundness: An aggregate is physically sound if it remains dimensionally stable under temperature or moisture change and resists weathering without decomposition. If exposed aggregate is to be used in concrete, it may be necessary to conduct abrasion tests to determine its durability as part of the wearing surface. (Table 810-15).

Gradation: Aggregates are graded by size through progressively smaller sieves and then commonly combined in certain proportions to produce aggregate mixtures. The aggregate composition is defined by the percentage of the total sample (by weight) that passes through each sieve. Grading is controlled by the producer and can be adjusted to meet the grading requirements of project specifications.

4.2 Common Applications

Aggregates are used for a wide variety of purposes in landscape construction ranging from a foundation material to finished surfaces for walkways, driveways, and parking areas. Two of the most common uses of loose aggregate are for pedestrian walkways and vehicular roads and parking areas. Other uses of aggregate are discussed in other sections of this handbook.

Pedestrian Walkways: In regions where aggregate materials are readily available, aggregate walkways are inexpensive and easy to install. Table 810-16 describes the characteristics of common loose aggregates used for walkways. Aggregate walkways may be difficult to walk on, may limit accessibility, and they require periodic maintenance and replenishment. (Refer to Section 440: Surfacing and Paving, and Division 900: Details and Devices, for more information.)

Vehicular Roads and Parking Areas: Gravel, crushed stone, and other types of aggregates are used for finished surfaces of roads, driveways, and parking areas. These provide relatively inexpensive surfacing, but may not be appropriate for some situations. Dust from vehicular traffic and frequent maintenance may discourage its use for high-traffic areas.

AGENCIES AND ORGANIZATIONS

American Association of State Highway and Transportation Officials (AASHTO)
Washington, D.C.

American Society of Nurserymen
Washington, D.C.

American Society for Testing and Materials (ASTM)
Philadelphia, Pennsylvania

Ecological Services Laboratory (Urban Soils Research)
National Park Service
Washington, D.C.

National Crushed Stone Association
Washington, D.C.

National Sand and Gravel Association
Washington, D.C.

U.S. Soil Conservation Service
Department of Agriculture
Washington, D.C.

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SECTION 820

Asphalt

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CONTENTS

1.0 INTRODUCTION

1.1 General

Technically, the term asphalt refers only to asphalt cement or "binder," the basic cementitious material that is eventually mixed with aggregate to form pavements. In common usage, however, the terms asphalt, asphalt pavement, asphalt concrete, and bituminous concrete refer to the many available mixtures of asphalt and aggregate that are used for various purposes in landscape construction.

This section focuses exclusively on asphalt when used for paving, etc. although asphalt cement or binder is also commonly used as a sealant and as an adhesive (mastic).

1.2 Manufacturing Standards

The American Society for Testing and Materials (ASTM) and the American Association of State Highway and Transportation Officials (AASHTO) have established specifications on the manufacture and use of asphalt cement or binder products, and asphalt concrete mixtures commonly used in the United States. These specifications were used as a guide for data shown in this section.

It should be noted that in 1994 the industry formally accepted and began to implement the results of a ten year research effort conducted under the US Federal Strategic Highway Research Program (SHRP). This resulted in developing a new system for the design of asphalt paving to be known as Superpave. They are in the process of introducing a new designation for asphalt cement which hence-forth is to be called an "asphaltic binder." This binder will be known as PG (Performance Graded) binder and the new specifications for this asphaltic binder will be shown as a higher positive number followed by a negative number as for example PG 64-22. The first number represents a hot pavement design criteria in degrees centigrade and the second number represents the low or cold pavement design criteria in degrees centigrade. The grades will vary by 6 degree increments on both the high and low ends.

Since these new specifications are not officially available at the time of publication of this handbook (1997), the U.S. readers of this Section are urged to seek the latest detailed data from either national or local sources. Every major governmental unit throughout the world has established a set of standard specifications for asphaltic cement or binders that should be used as a guide to the production of quality asphalt pavements within its jurisdiction. Local standards and practices should always be consulted for the appropriate designs and specifications for any specific region or area.

Table 820-1. ASPHALT CEMENT GRADING SYSTEMS

Grading System*	Grades † Hard or thicker ⟵⟶ Soft, or thinner	Remarks
Penetration graded	40–50 60–70 85–100 120–150 200–300	Older system that measures needle penetration. Asphalt is sampled at 77°F (25°C). Still in use in Canada and in some states.
Viscosity graded	AC-40 AC-30 AC-20 AC-10 AC-5 AC-2.5	Newer system introduced in 1972. Scientifically measures viscosity of the asphalt at 140°F (60°C). Most states use this system.
Viscosity graded on aged residue (AR)	AR-160 AR-20 AR-40 AR-80 AR-10	A variation of the more standard viscosity graded system. Measures asphalt after simulated aging. Used in several western states.

* Consult local highway departments for criteria of local grading systems. Local criteria are often slight modifications of the above specifications, altered to suit local conditions.

† The hard-soft scale is used to indicate relative hardness within each grading system and not as a comparison of hardness from one grading system to another. The grades toward the harder, or thicker, end of the spectrum tend to be used in heavier traffic conditions or warmer climates. Cooler climates or lighter loads utilize grades toward the softer end of the spectrum.

2.0 ASPHALT CEMENT OR BINDER

2.1 Properties of Asphalt Cement or Binder

Asphalt cement or binder has several important properties that effect how this material can be used for various purposes and conditions.

Thermoplasticity: Asphalt cement or binder is an adhesive which deforms under loads or liquefies with heat. These properties cause it to be classified a flexible type of pavement.

Viscosity and Grades: The viscosity of asphalt is directly influenced by temperature. A temperature/viscosity slope can be plotted to define the temperature for mixing and compaction. An increase in temperature means a decrease in viscosity.

Asphalt cement or binder can have grades of hardness or viscosity (Table 820-1). Each grade is intended for specific purposes. There are three different methods for grading asphalt cement or binders used in the United States and Canada. All three grade asphalt according to degree of hardness. Table 820-2 lists various grades of asphalt's from each method that are appropriate for roads, depending on climatic conditions.

Weathering: The oxidation of the surface and the evaporation of lighter hydrocarbons (volatilization) causes asphalt to lose its plasticity and to become brittle with age. Properly sloped subbases and subgrades, proper compaction of layers, and timely sealing and surfacing treatments keep weathering to a minimum.

Insolvency: Asphalt is resistant to the chemical effects of water and of most salts, acids, and alkali's except petroleum-based materials, such as gasoline and oil-based paints if applied in concentrated amounts. Tar sealers are used on asphalt surfaces where concentrated spillage is expected.

Color: Asphalt is naturally black, but certain proprietary products or paving processes can alter that color. (Refer to 7.3 Colored Asphalt Pavements in this section for more information.)

Table 820-2. TEMPERATURE AND RECOMMENDED ASPHALT CEMENT GRADES FOR ROADS

Temperature condition	Asphalt grades*	
Cold, mean annual air temperature ≤7°C (45°F)†	AC-5 AR-2000 120–150 penetration	AC-10 AR-4000 85–100 penetration
Warm, mean annual air temperature between 7°C (45°F) and 24°C (75°F)	AC-10 AR-4000 85–100 penetration	AC-20 AR-8000 60–70 penetration
Hot, mean annual air temperature (≥24°C (75°F)†	AC-20 AR-8000 60–70 penetration	AC-40 AR-16000 40–50 penetration

* The above recommendations serve only as a guide. Consult local practices and standards to determine local specifications.

† Severely cold temperatures may require very soft asphalts to minimize cracking. In very hot climates, an asphalt mixture should be designed to resist rutting and to maintain stiffness.

Source: The Asphalt Institute, *Thickness Design: Asphalt Pavements for Highways and Streets,* MS-1, College Park, Md.

2.2 Selection Criteria for Asphalt Cements

Many tasks require specific asphalt cements or liquid asphalts. Table 820-3 lists various types and grades of asphalt cement and their appropriate uses. In all cases, local standards and practices should be consulted.

3.0 AGGREGATE FOR ASPHALT PAVEMENTS

The aggregate used in asphalt pavements must consist of an appropriate gradation and possess certain specific properties if it is to produce a strong and durable pavement. Local standards and practices often reflect readily available aggregate materials and gradations that have proved most suitable and economical to use in that area. In all cases, aggregate should be non-absorbent and non-laminar.

3.1 Sizes of Aggregate for Asphalt Pavements

Aggregate is typically classified according to size. The various sizes are mixed in certain proportions (i.e., gradations) for eventual use in an asphalt-aggregate mixture (e.g., asphalt concrete). (Refer to 3.2 Aggregate Gradations in this section for more information.)

Fine Aggregate: This refers to aggregates that pass the 2.36 mm (No. 8) sieve. Mineral dust refers to the portion of fine aggregate that passes the 0.075 mm (No. 200) sieve, and mineral filler refers to that portion of fine aggregate that passes the 0.60 mm (No. 30) sieve. Mineral dust and mineral filler are typically used in precise percentages to fill voids of coarse aggregate to produce a cohesive, dense, watertight asphalt concrete mixture.

Coarse Aggregate: This refers to aggregates retained on the 2.36 mm (No. 8) sieve. The interlocking and friction of coarse aggregates provide the major stability function in a pavement.

Macadam Aggregate: This refers to coarse aggregates of uniform size, nominally sized between 40 to 65 mm (1-1/2 to 2-1/2 in), usually of crushed stone, slag, or gravel. Such aggregate is typically used in macadam construction. Macadam construction mixes asphalt cement with these aggregates to form an inexpensive coarse wearing surface.

3.2 Aggregate Gradations

Aggregate gradations contain a selected range of aggregate sizes in desired proportions. Maximum particle or stone size is the smallest sieve that 100 percent of the aggregates will pass, and nominal maximum size is the largest sieve that retains any of the aggregates, but generally not more than 10 percent of the larger-size aggregates.

Asphalt mixtures are commonly referred to by their nominal maximum size (referring to the aggregate contained therein). Four common aggregate gradations are:

Fine-Graded Aggregate: Produces a surface of finer texture and less road noise than a coarse aggregates.

Coarse-Graded Aggregate: Produces a more stable pavement with coarser surface texture and, therefore, more road noise.

Dense-Graded (Well-Graded) Aggregate: Produces a surface that is very watertight, highly stable, and durable.

Open-Graded Aggregate: Contains little or no mineral filler, therefore, its larger aggregates create larger voids which interlock and produce a pavement with good strength, rough texture, and high permeability. This pavement is suitable for porous drainage pavements located in regions free of frost/thaw conditions.

Table 820-4 shows coarse aggregate gradations used for highway construction. When used singly or in combination, such gradations are also suitable for asphalt mixes. The proportional distributions shown in the table can be altered to suit job requirements and local conditions. Because of their permeability, they are restricted to special applications.

3.3 Recycled Glass as Aggregate

In the United States, some Federal projects require the use of recycled glass as aggregate within asphalt pavement. Glass must be carefully ground and rolled to minimize sharp edges that may become exposed with gradual wearing. Recycled glass works well in asphalt pavements of heavy use, such as roadways, because constant wearing continually grinds the glass edges. However, lighter uses, such as bicycle paths, can gradually expose the glass, and

KEY POINTS: Asphalt Cement or Binder

1. Local standards and practices should be consulted prior to selecting the appropriate grade of asphalt cement or binder.
2. Climate is an important factor in selecting asphalt cements. Severely cold temperatures may require very soft asphalt to minimize cracking, while very hot climates require harder asphalt to maintain stiffness and resist rutting.
3. Many applications require specific asphalt cements or liquid asphalts (see Table 820-3).

Table 820-3. GUIDE TO USES OF ASPHALT

TYPE OF CONSTRUCTION	ASPHALT CEMENTS														
	Viscosity graded original					Viscosity graded residue					Penetration graded				
	AC-40	AC-20	AC-10	AC-5	AC-2.5	AR-16000	AR-8000	AR-4000	AR-2000	AR-1000	40–50	60–70	85–100	120–150	200–300
Asphalt-aggregate mixtures															
Asphalt concrete and hot-laid plant mix															
Pavement base and surfaces															
Highways	X	X	X	X	X[7]	X	X	X	X	X[7]	X	X	X	X	X[7]
Airports		X	X	X			X	X				X	X	X	
Parking areas	X	X	X			X	X	X			X	X	X		
Driveways		X	X				X	X				X	X		
Curbs		X					X					X			
Industrial floors	X	X				X	X				X	X			
Blocks	X					X					X				
Groins	X	X				X	X				X	X			
Dam facings	X	X				X	X				X	X			
Canal and reservoir linings	X	X				X	X				X	X			
Cold-laid plant mix[10]															
Pavement base and surfaces															
Open-graded aggregate															
Well-graded aggregate															
Patching, immediate use															
Patching, stockpile															
Mixed in place (road mix)[10]															
Pavement base and surfaces															
Open-graded aggregate															
Well-graded aggregate															
Sand					X									X	
Sandy soil					X									X	
Patching, immediate use															
Patching, stockpile															
Recycling															
Hot mix			X	X	X			X	X	X			X	X	X
Cold mix[10]					X					X					X
Asphalt-aggregate applications															
Surface treatments															
Single surface treatment				X	X									X	X
Multiple surface treatment				X	X									X	X
Aggregate seal				X	X				X					X	X
Sand seal															
Slurry seal															
Asphalt applications															
Surface treatment															
Fog seal															
Prime coat															
Tack coat															
Dust laying															
Mulch															
Membrane															
Canal and reservoir linings	X										X				
Embankment envelopes	X	X				X	X				X	X			
Crack filling															
Asphalt pavements															
Portland cement concrete pavements	X[4]					X[4]					X[4]				

[1]Mixed in prime only. [2]Diluted with water; [3]Slurry mix. [4]Rubber asphalt compounds. [5]Diluted with water by the manufacturer. [6]MS-2 only.
[7]For use in cold climates. [8]Before using MC's for spray applications (other than prime coats), check with local pollution control agency.

Emulsified asphalts[9]														Cutback asphalts[11]								
Anionic								Cationic						Medium curing (MC)[8]					Slow curing (SC)			
RS-1	*RS-2*	*MS-1, HFMS-1*	*MS-2, HFMS-2*	*MS-2h, HFMS-2h*	*HFMS-2s*	*SS-1*	*SS-1h*	*CRS-1*	*CRS-2*	*CMS-2*	*CMS-2h*	*CSS-1*	*CSS-1h*	*30*	*70*	*250*	*800*	*3000*	*70*	*250*	*800*	*3000*
			X	X						X	X											
					X	X	X					X	X			X	X	X		X	X	X
						X	X					X	X			X	X				X	
																X	X			X	X	
			X	X						X	X						X	X			X	X
					X	X	X					X	X			X	X			X	X	
					X	X	X					X	X		X	X	X					
					X	X	X					X	X			X	X					
					X	X	X					X	X			X	X				X	
																X	X			X	X	
			X	X	X	X	X			X	X	X	X									
X	X							X	X													
X	X							X	X													
X	X	X						X	X													
X	X	X						X	X													
						X	X					X	X									
		X[5]				X[2]	X[2]					X[2]	X[2]									
			X[1,6]			X[1]	X[1]			X[1]		X[1]	X[1]	X	X	X						
X		X[5]				X[2]	X[2]	X				X[2]	X[2]									
						X[2]	X[2]					X[2]	X[2]	X	X	X			X	X		
						X[2]	X[2]															
						X[3]	X[3]					X[3]	X[3]									

[9]Emulsified asphalts shown are AASHTO and ASTM grades and may not include all grades produced in all geographical areas. [10]Evaluation of emulsified asphalt-aggregate system required to determine the proper grade of emulsified asphalt to use. [11]Use of the rapid cure (RC) asphalts is not shown on this chart since their use is becoming rare and is discouraged for energy and environmental reasons. Use of emulsified asphalts is encouraged instead. *Source:* The Asphalt Institute.

increase the chances of sharp edges coming to the surface.

3.4 Selection Criteria for Aggregates

Table 820-5 shows four important criteria to consider when assessing the value of a particular aggregate for use in an asphalt pavement. Each criterion is described below.

1. **Hardness (Toughness):** is the ability of the aggregate to withstand loads and wear.
2. **Resistance to Stripping:** hydrophilic (water loving) aggregates, tend to strip away from the asphalt bond, reducing the stability and skid resistance of the pavement. Anti-stripping compounds can be added to asphalt mixtures to permit the use of

KEY POINTS: Aggregates for Asphalt Pavement

1. Different types of aggregate provide varying degrees of suitability for asphalt paving with regard to hardness, resistance to stripping, surface texture, and crushed shapes (see Table 820-5).
2. The larger the size of aggregates in a gradation, the greater will be the strength and durability of the pavement.
3. Gradations with larger aggregates result in a rougher pavement (or surface texture) than do gradations with finer aggregate.
4. The larger the aggregates, the greater will be the road noise generated by vehicular traffic.
5. The color of a weathered asphalt pavement is also a function of the color of the larger aggregates.
6. In the United States, many Federal projects require the use of some percentage of recycled glass as aggregate within asphalt pavement. This is best for heavy use pavements. The glass must be carefully ground and rolled to minimize sharp edges that may become exposed with gradual wearing.

Table 820-4. COARSE AGGREGATE GRADATIONS FOR HIGHWAY CONSTRUCTION

Gradation size number	Nominal size of gradation, square openings	Sieve size (square openings)														
		100 mm (4")	90 mm (3-1/2")	75 mm (3")	63 mm (2-1/2")	50 mm (2")	38.1 mm (1-1/2")	25.0 mm (1")	19.0 mm (3/4")	12.5 mm (1/2")	9.5 mm (3/8")	4.75 mm (No. 4)	2.36 mm (No. 8)	1.18 mm (No. 16)	300µm (No. 50)	150µm (No. 100)
1	90–38.1 mm (3½–1½ in)	100	90–100		25–60		0–15		0–5							
2	63–38.1 mm (2½–1½ in)			100	90–100	35–70	0–15		0–5							
24	63–19.0 mm (2½–¾ in)			100	90–100		25–60		0–10	0–5						
3	50–25.0 mm (2–1 in)				100	90–100	35–70	0–15		0–5						
357	50–4.75 mm (2 in–No. 4)				100	95–100		35–70		10–30		0–5				
4	38.1–19.0 mm (1½–¾ in)					100	90–100		20–55	0–15		0–5				
467	38.1–4.75 mm (1½ in–No. 4)					100	95–100		35–70		10–30	0–5				
5	25.0–12.5 mm (1–½ in)						100	90–100	20–55	0–10	0–5					
56	25.0–9.5 mm (1–⅜ in)						100	90–100	40–75	15–35	0–15	0–5				
57	25.0–4.75 mm (1 in–No. 4)						100	95–100		25–60		0–10	0–5			
6	19.0–9.5 mm (¾–⅜ in)							100	90–100	20–55	0–15	0–5				
67	19.0–4.75 mm (¾ in–No. 4)							100	90–100		20–55	0–10	0–5			
68	19.0–2.36 mm (¾ in–No. 8)							100	90–100		30–65	5–25	0–10	0–5		
7	12.5–4.75 mm (½ in–No. 4)								100	90–100	40–70	0–15	0–5			
78	12.5–2.36 mm (½ in–No. 8)								100	90–100	40–75	5–25	0–10	0–5		
8	9.5–2.36 mm (⅜ in–No. 8)									100	85–100	10–30	0–10	0–5		
89	9.5–1.18 mm (⅜ in–No. 16)									100	90–100	20–55	5–30	0–10	0–5	
9	4.75–1.18 mm (No. 4–No. 16)										100	85–100	10–40	0–10	0–5	
10	4.75 mm (No. 4–0*)										100	85–100				10–30

* Screenings — Note that some of these gradations are suitable for use in a selected asphalt-concrete mixture (Refer to Table 820-8). For granular bases and granular surface courses, refer to Table 820-9 and 4.4 of this section.

some hydrophilic aggregates. Check local practice.

3. **Surface Texture:** a rough surface texture aids in bonding and makes the pavement more stable and resistant to abrasion and skidding.

4. **Crushed Shape:** cubic, angular, crushed shapes interlock and give the pavement more strength than do smooth, rounded aggregates.

In addition to these four criteria, a few other criteria must be considered when selecting an aggregate for an asphalt concrete mixture (see Key Points - Aggregates for Asphalt Pavement).

Table 820-5. PROPERTIES OF VARIOUS AGGREGATE TYPES FOR ASPHALT PAVEMENTS

	Hardness, toughness	Resistance to stripping	Surface texture	Crushed shape
Igneous				
Granite	Fair	Fair	Fair	Fair
Syenite	Good	Fair	Fair	Fair
Diorite	Good	Fair	Fair	Good
Basalt (trap rock)	Good	Good	Good	Good
Diabase (trap rock)	Good	Good	Good	Good
Gabbro (trap rock)	Good	Good	Good	Good
Sedimentary				
Limestone, dolomite	Poor	Good	Good	Fair
Sandstone	Fair	Good	Good	Good
Chert	Good	Fair	Poor	Good
Shale	Poor	Poor	Fair	Fair
Metamorphic				
Gneiss	Fair	Fair	Good	Good
Schist	Fair	Fair	Good	Fair
Slate	Good	Fair	Fair	Fair
Quartzite	Good	Fair	Good	Good
Marble	Poor	Good	Fair	Fair
Serpentine	Good	Fair	Fair	Fair

Source: W. A. Cordon, *Properties, Evaluation and Control of Engineering Materials*, McGraw-Hill, New York, 1979.

4.0 ASPHALT PAVING MIXTURES

4.1 Asphalt Concrete

Asphalt concrete, the most widely used asphalt paving mixture, consists of a dense-graded aggregate heated to approximately 150° C (300° F), which is then mixed (at a plant) with asphalt cement heated to a temperature of 135° C (275° F). The heated mixture is taken to the site, placed either by paving machines or by hand, compacted to achieve maximum density, and allowed to cool. Asphalt concrete is typically applied in compacted thicknesses ranging from 20 mm (3/4 in) to more than 300 mm (1 ft). The thickness of any layer of asphalt concrete should always be at least twice the nominal maximum size (or maximum particle size) of the aggregate. Table 820-6 shows the composition of various asphalt concrete mixtures.

A finished asphalt concrete pavement should contain 2 to 7 percent voids (air) by volume to allow for expansion of the pavement and to allow for compaction of the aggregate over the life of the pavement.

4.2 Surface Treatments

Surface treatments refer to special asphalt-aggregate applications laid in less than 25-mm (1-in) thicknesses on existing or new pavement. Surface treatments are used for color coating, sealing, improving skid resistance, or prolonging the service life of a fair to good pavement surface.

The application of a surface treatment involves spraying heated asphalt cement (emulsified or cutback asphalt) onto a surface, followed by the desired aggregate. The application is then rolled, thereby forcing the asphalt and aggregate to firmly set together. Some surface treatments have the aggregate and asphalt premixed, while others do not use aggregate at all. Various surface treatments are described in Table 820-7 and illustrated in Figure 820-1.

Table 820-8 provides information on the quantities of asphalt and aggregate necessary for single surface treatments and seal coats. Table 820-9 provides information on aggregate gradations appropriate for surface treatments. Surface treatments extend the pavement's life but do not increase the structural strength of the pavement.

4.3 Asphalt Paving Blocks

Premolded asphalt blocks are often used for pedestrian paving and some vehicular surfacing. The precise mixture of asphalt, aggregate, and rock dust varies in manufacture to suit specific uses. Smooth surfaces are available as well as exposed aggregate finishes in colors of black, brown, gray, and tan. After placement, the aggregate may be further exposed and given a weathered effect by sandblasting.

Table 820-10 shows thicknesses and typical applications of asphalt paving blocks. Figure 820-2 shows a few standard shapes that are commercially available. Special orders are also possible. Block pavements require base and subbase courses and typically require some type of edging for containment. Information on construction specifications and the availability of particular thicknesses, shapes, and colors can be acquired from the manufacturer.

KEY POINTS: Asphalt Paving Mixtures

1. The thickness of any layer of asphalt concrete should always be at least twice the nominal maximum size (or maximum particle size) of the aggregate.

2. A finished asphalt concrete pavement should contain 2 to 7 percent voids (air) by volume to allow for expansion of the pavement and compaction of the aggregate over time.

3. Surface treatments are used for color coating, sealing, improving skid resistance, or prolonging the service life of a fair to good pavement surface, but do not increase its structural strength.

4. Block pavements require base and subbase courses and typically require some type of edging for containment (consult manufacturer for construction specifications).

5. Granular materials unsuitable for base courses can be treated with an asphalt cement to produce a stabilized base course.

Table 820-6. COMPOSITION OF ASPHALT MIXTURES

Sieve size	Asphalt concrete [b,c,d,e,f]					Sand asphalt [g]	Sheet asphalt [g,h]
	Mix designation and nominal maximum size of aggregate [i]						
	1½ in (37.5 mm)	1 in (25.0 mm)	¾ in (19.0 mm)	½ in (12.5 mm)	⅜ in (9.5 mm)	No. 4 (4.75 mm)	No. 16[h] (1.18 mm)
	Typical pavement courses for corresponding mix designation						
	Base courses [j]		Intermediate or binder courses [j]	Surface courses [j]			
	Grading of total aggregate (coarse plus fine, plus filler if required) Amounts finer than each laboratory sieve (square opening), weight percent [f]						
2 in (50 mm)	100	—	—	—	—	—	—
1½ in (37.5 mm)	90 to 100	100	—	—	—	—	—
1 in (25.0 mm)	—	90 to 100	100	—	—	—	—
¾ in (19.0 mm)	56 to 80	—	90 to 100	100	—	—	—
½ in (12.5 mm)	—	56 to 80	—	90 to 100	100	—	—
⅜ in (9.5 mm)	—	—	56 to 80	—	90 to 100	100	—
No. 4 (4.75 mm)	23 to 53	29 to 59	35 to 65	44 to 74	55 to 85	80 to 100	100
No. 8 (2.36 mm)[k]	15 to 41	19 to 45	23 to 49	28 to 58	32 to 67	65 to 100	95 to 100
No. 16 (1.18 mm)	—	—	—	—	—	40 to 80	85 to 100
No. 30 (600 μm)	—	—	—	—	—	20 to 65	70 to 95
No. 50 (300 μm)	4 to 16	5 to 17	5 to 19	5 to 21	7 to 23	7 to 40	45 to 75
No. 100 (150 μm)	—	—	—	—	—	3 to 20	20 to 40
No. 200 (75 μm)[l]	0 to 6	1 to 7	2 to 8	2 to 10	2 to 10	2 to 10	9 to 20
	Asphalt cement, weight percent of total mixture [f,m,n]						
	3 to 8	3 to 9	4 to 10	4 to 11	5 to 12	6 to 12	8 to 12
	Suggested coarse aggregate sizes, number [o]						
	4 and 67 or 4 and 68	5 and 7 or 57	67 or 68 or 6 and 8	7 or 78	8		

[a] Consult local standards and practices for composition mixes and durabilities at local construction sites. These figures serve as a guide only.

[b] Typical life expectancy is about 20 years, at which time resurfacing operations would be needed. Durability based upon a number of factors, including traffic, environment, maintenance, climate, materials, and construction of pavement.

[c] The larger the maximum stone size, the louder the traffic noise will be.

[d] Color of normal pavements (after initial wear) is a function of the color of the larger aggregate. Darker tones are achieved by increasing amounts of finer sand and filler.

[e] Mixtures with coarse aggregate have rougher finished surface texture than mixtures with fine aggregate.

[f] The unit of measures for asphalt concrete is tons. Commonly, a square yard of asphalt concrete pavement one inch thick weighs .055 tons (110 lbs). In some instances, the specific gravity of the aggregate may be higher or lower than normal, thereby altering this figure accordingly. For most jobs up to 1 to 2 acres in size, the figure mentioned is adequate. Consult local practices and standards.

[g] Sheet and sand asphalt have finer texture. However, these mixtures lack the larger aggregate that tend to produce stable, dense, strong pavements. Where stability and fine texture are important factors, utilize the more common ⅜-in nominal mix designation.

[h] Sheet asphalt produces a clean, relatively noiseless surface that has been used in many areas for decades. The relatively higher asphalt content and increasing amounts of finer mineral dust causes mixture to be somewhat more expensive to produce. An excess in asphalt could produce an unstable surface, bleed asphalt to surface, or be slick when wet. Sheet asphalt scuffs more easily than coarser mixtures.

[i] The thickness of any compacted pavement layer should be at least twice the nominal maximum size or maximum stone size (whichever term is used).

[j] Asphalt pavement courses typically used for the corresponding asphalt concrete nominal mix designations. Surface courses typically are ⅜-in and ½-in mix designation reserved for surface courses where heavier duty is expected. See note i above.

[k] In considering the total grading characteristics of an asphalt paving mixture, the amount passing the 2.36 mm (No. 8) sieve is a significant and convenient field control point between fine and coarse aggregate. Gradings approaching the maximum amount permitted to pass the 2.36-mm sieve will result in pavement surfaces having comparatively fine texture, while gradings approaching the minimum amount passing the 2.36-mm sieve will result in surfaces with comparatively coarse texture.

[l] The materials passing the 75-μm (No. 200) sieve may consist of fine particles of the aggregates or mineral filler, or both. It shall be free of organic matter and clay particles and have a plasticity index not greater than 4 when tested in accordance with ASTM Method D 423 and ASTM Method D 424.

[m] The quantity of asphalt cement is given in terms of weight percent of the total mixture. The wide difference in the specific gravity of various aggregates, as well as a considerable difference in absorption, results in a comparatively wide range in the limiting amount of asphalt cement specified. The amount of asphalt required for a given mixture should be determined by appropriate laboratory testing or on the basis of past experience with similar mixtures, or by a combination of both.

[n] Table 820-3 lists asphalt cement grades appropriate for certain pavements.

[o] Refer to Table 820-4 for coarse aggregate gradations.

Source: Adapted from ASTM Designation 3515, *Standard Specifications for Hot-Mix, Hot-Laid Bituminous Paving Mixtures.*

Table 820-7. SURFACE TREATMENT TYPES AND CHARACTERISTICS

Surface treatment type	Intended uses	Constituent materials	Remarks[a,b,c]
Prime coat[d] (Fig. 820-1)	To waterproof and provide some structural strength to untreated gravel base by penetration	Heavy application of dilute or thin liquid asphalt of low viscosity to gravel base	Penetrates gravel road surface ½ in, more or less. Saturates gravel base so subsequent surface treatments will not be absorbed. Not intended to be applied to paved surfaces. Applied on aggregate bases when asphalt pavements are less than 3 in thick.
Dust palliative[d] (Fig. 820-2)	To reduce road dust produced by wind or moving vehicles	Best slow-curing cutback asphalt or diluted (4:9 with water) slow-setting emulsified asphalt, medium-curing asphalt or medium-setting emulsified asphalt	Penetrates surface about ½ in binding particles together. Light applications are typical (about 0.2 gal/yd^2). Consult local practices and standards. Medium-curing and medium-setting asphalts typically become brittle and crack, thus their use is limited. Slow-curing cutback asphalts endure longest.
Fog seal[d] (Fig. 820-3)	To seal and fill very small cracks and voids in open-graded pavements	Slow-setting emulsified asphalt diluted with water	Apply only on coarse-textured surface so fog can be absorbed into surface. Do not use on dense smooth surfaces or slickness will result. Over-applications produce a slippery surface.
Slurry seal,[d] (Fig. 820-4)	To seal previously paved surfaces and fill cracks in old pavements that otherwise are in good condition	Slow-setting emulsified asphalt, fine aggregate, mineral filler, and water	Provides smooth, tight surface. Most often handled by specialty contractor.
Sand seals[d,f] (Fig. 820-5)	To fill fine cracks and to seal existing pavement	Low viscosity or moderately diluted asphalt with sand aggregate	Very low-cost sealing treatment as done by local labor, material, and/or contract. Generally restricted to low-volume rural road maintenance. Rarely used in commercial applications.
Single-surface treatment[c,f] (chip, seal, or aggregate seal) (Fig. 820-6)	To seal and waterproof, provide a wearing course, increase skid resistance, or provide color over other pavement.	Liquid asphalt followed by uniform-sized aggregate, ⅜ to ½ in most common, sometimes ³⁄₁₆ to ⁵⁄₁₆ in	Moderate cost sealing and surface rejuvenation. Difficult to apply in small areas such as parking lots. More common for roads.
Multiple surface treatment[e,f] (Fig. 820-7)	To seal and provide wearing course over other pavements	Two or more surface treatments applied on top of one another	Aggregate sizes vary as maximum-sized aggregate of successive treatment is usually one-half of the previous one. Difficult to apply in small areas such as parking lots. More common for roads.

[a] Consult local sources for standards and practices for specific construction jobs.

[b] Use of liquid asphalts necessitates a period of airing time during which pavement is unusable. Failure to take precautions during application results in tracking and improperly sealed pavement.

[c] Because of thinness, average life expectancies for surface treatments range from 3 to 8 years, based on factors such as traffic, climate, environment, and quality of original pavement. Consult local practices and standards for expected durabilities at local job sites.

[d] Applied from a prepared mixture.

[e] Applied by placing the liquid asphalt on the desired surface first, then covering with a layer of aggregate particles. Compaction forces the aggregate down, mixing with the asphalt.

[f] Refer to Table 820-3 for information on surface treatments and specific liquid asphalt grades and viscosities. Refer to Table 820-8 for the asphalts and Table 820-9 for the aggregates used in these surface treatments.

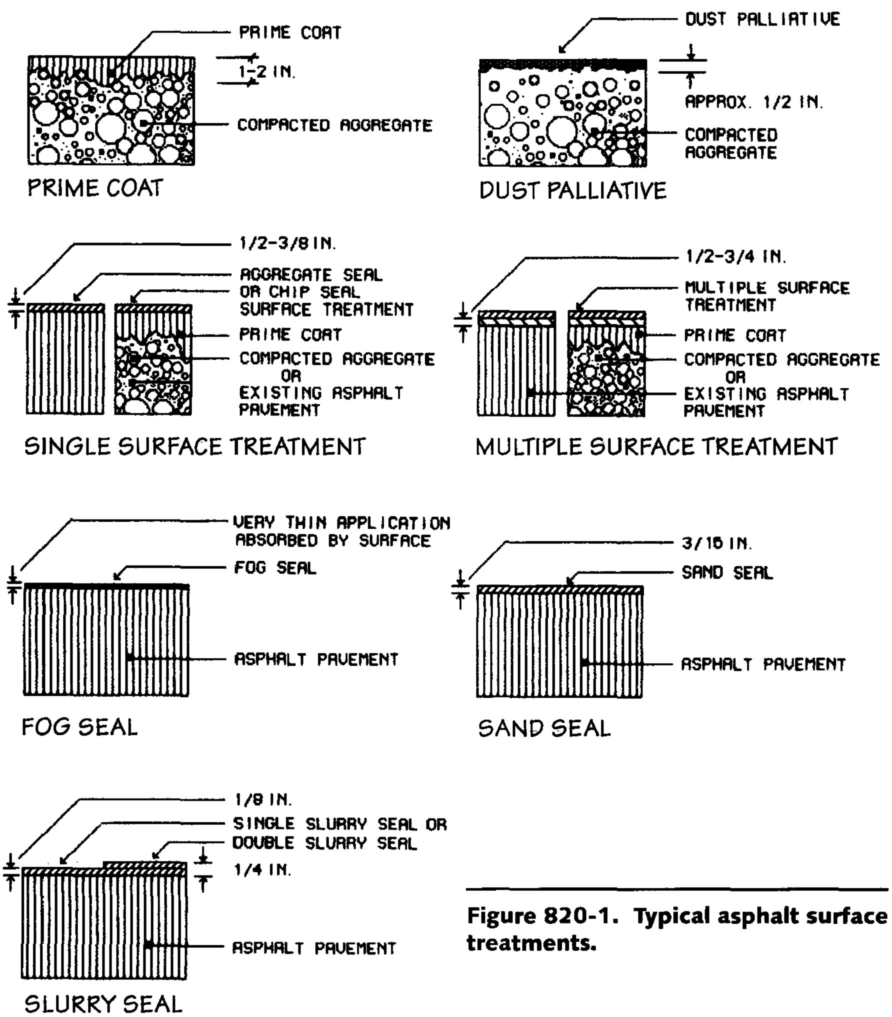


Figure 820-1. Typical asphalt surface treatments.

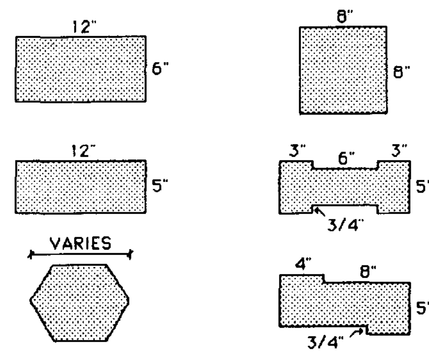


Figure 820-2 Typical asphalt surface treatments.

4.4 Asphalt-Treated Granular Base Courses

Granular materials unsuitable for base courses (e.g., because of poor interlocking ability) can be treated with an asphalt cement to produce a stabilized base course (i.e., bituminous stabilization). Although this is used less commonly than aggregate or asphalt base courses, it can provide a suitable base at less cost in some situations.

4.5 Less-Common Asphalt Mixtures

Commercially available asphalt paving mixtures less commonly used than those previously described are shown in Table 820-11.

5.0 PRINCIPLES OF ASPHALT PAVEMENT DESIGN

5.1 Typical Pavement Sections

Asphalt pavements typically consist of layered asphalt-aggregate mixtures placed either directly on a subgrade or improved subgrade, or on an aggregate base over a subgrade or improved subgrade, or on an existing pavement made of concrete, brick, or stone. Figure 820-3 shows several typical pavement profiles, each designed for specific purposes (refer to Section 440: Surfacing and Paving for more information on pavement design).

5.2 Pavement Functions

The aggregate of the various pavement layers supports the loads imposed on it while the asphalt cement waterproofs and helps to bind everything together (Figure 820-4). The water tightness prevents moisture from entering and weakening the subgrade. For heavier loads and weaker subgrades thicker layers of asphalt mixtures and/or base and subbase aggregates are required to distribute the loads and to prevent pavement failure. The top surface needs to be smooth, resistant to wear, distortion, and deterioration by weathering and deicing chemicals.

5.3 Asphalt Pavement Construction

Asphalt pavement design tends to be an empirical (or experience-based) technology derived from local practices and materials. The information on pavement construction contained in this section is a summary of what is required to produce a conservative design that performs well and requires little or no maintenance for approximately 20 years. Designs that vary significantly from the ones suggested herein can be used where local experience demonstrates an equal or satisfactory performance is assured. Where ranges are shown then a precise figure for each layer should be based upon local practice and standards. If such data are not known, then the higher pavement design value should be used.

The minimum total thickness of the combined asphalt concrete layers in a pavement designed to carry very light loads (e.g., playgrounds and walkways) is 75 mm (3 in). to 100 mm (4 in).

In the United States, the subgrade and base supporting capacities for flexible pavements are typically measured by the California bearing ratio (CBR). Some states use the R-value test, while others determine subgrade strength based on soil classification or other less-common soil strength tests. Refer to Section 810: Soils and Aggregates for additional information on bearing strength of soils.

All subgrades for pavements must be stable and designed to minimize possible heaving due to frost. All subgrade layers require adequate compaction to ensure maximum strength and bearing potential. Good drainage is essential, and subgrades must be reasonably and uniformly dry so that localized poor drainage does not affect their strength. Subgrades should drain parallel to the pavement surface.

Types of Asphalt Pavement Construction:

The two basic types of asphalt pavement construction commonly used in the United States are: (1) full-depth design and (2) aggregate base design.

Full-Depth Design: This refers to an asphalt concrete or other asphalt-aggregate mixture that is placed directly on a subgrade without an aggregate base (see Figure 820-3).

The subgrade should be finished to uniform grade and compacted at or near optimum moisture level. The existence of unusually wet, plastic soil requires replacing the soil with 100 mm (4 in) or more of untreated, coarse aggregate material or consult local practices for other options.

Aggregate Base Design: Aggregate base design refers to an asphalt concrete or other asphalt-aggregate mixture that is placed on an untreated aggregate base over a prepared subgrade (see Figure 820-3). This type of construction is most appropriate in areas where soils are highly susceptible to frost action.

The prepared base and subbase aggregate layer minimizes frost heave and helps distribute the imposed loads, allowing for a slightly thinner base course of asphalt concrete or asphalt-aggregate mixture than is necessary in full-depth design. Untreated aggregate base and subbase should be compacted at or near optimum moisture levels (refer to Section 810: Soils and Aggregates for further information on compaction).

Expected Pavement Life:

Asphalt concrete pavements when properly constructed typically requires surface maintenance or resurfacing overlays about every 20 years. The durability of the pavement depends upon many factors, including traffic volume, quality of construction, frequency of maintenance, severity of climate, and the quality of the materials involved.

6.0 THICKNESS DESIGN OF ASPHALT PAVEMENTS

6.1 Roads

Design Factors:

The thickness of asphalt concrete for roads depends on three factors:

1. Traffic weight and number of vehicles: the heavier and/or more numer-

Table 820-8. QUANTITIES OF ASPHALT AND AGGREGATE FOR SINGLE SURFACE TREATMENTS AND SEAL COATS*

Line	Nominal size of aggregate	Quantity of aggregate kg/m²(lb/yd²)†‡	Quantity of asphalt, L/m²(gal/yd²)†¶	Type and grade of asphalt
1	19.0–9.5 mm (¾–⅜ in)	22–27 (40–50)	1.6–2.0 (0.35–0.45) 1.8–2.3 (0.40–0.50)	Asphalt cement§ RS-2, CRS-2
2	12.5–4.75 mm (½ in–No. 4)	14–16 (25–30)	0.9–1.4 (0.20–0.30) 1.4–2.0 (0.30–0.45)	Asphalt cement§ RS-1, RS-2, CRS-1, CRS-2
3	9.5–2.36 mm (⅜ in–No. 8)	11–14 (20–25)	0.7–1.1 (0.15–0.25) 0.9–1.6 (0.20–0.35)	Asphalt cement§ RS-1, RS-2, CRS-1, CRS-2
4	6.3–1.18 mm (¼ in–No. 16)	8–11 (15–20)	0.7–0.9 (0.15–0.20)	RS-1, MS-1, CRS-1, HFMS-1
5	Sand	5–8 (10–15)	0.5–0.7 (0.10–0.15)	RS-1, CRS-1, MS-1, HFMS-1

* These quantities of asphalt cover the average range of conditions that include primed granular bases and old pavement surfaces. The quantities and types of materials may be varied according to local conditions and experience.

† The lower application rates of asphalt shown in the above table should be used for aggregate having gradations on the fine side of the specified limits. The higher application rates should be used for aggregate having gradations on the coarse side of the specified limits.

‡ The weight of aggregate shown in the table is based on aggregate with a specific gravity of 2.65. In case the specific gravity of the aggregate used is lower than 2.55 or higher than 2.75, the amount shown in the table above should be multiplied by the ratio that the bulk specific gravity of the aggregate used bears to 2.65.

§ AC-2.5, AC-5; AR-1000, AR-2000; 200/300 pen., 120/150 pen. (Note: In some areas persistent difficulty in retaining aggregate has been experienced with 200–300 penetration asphalt cements. Where this has occurred, the use of 200–300 penetration asphalt is not recommended.)

¶ It is important to adjust the asphalt content for the condition of the road, increasing it if the road is absorbent, badly cracked, or coarse, and decreasing it if the road is "fat" with flushed asphalt.

Corrections for Surface Conditions

Texture	*Gal/yd²*
Black, flushed asphalt	−0.01 to −0.06
Smooth, nonporous	0.00
Absorbent	
Slightly porous, oxidized	+0.03
Slightly pocked, porous, oxidized	+0.06
Badly pocked, porous, oxidized	+0.09

Table 820-9. QUANTITIES OF ASPHALT AND AGGREGATE FOR SINGLE SURFACE TREATMENTS AND SEAL COATS*

Sieve size (square opening)	Nominal size square openings †				
	3/4 to 3/8	1/2 to No.4	3/8 to No. 8	1/4 to No. 16	Sand
	Percentage passing by weight				
1	100				
¾	90–100	100			
½	20–55	90–100	100		
⅜	0–15	40–70	85–100	100	100
¼				90–100	
No. 4	0–5	0–15	10–30	60–85	95–100
No. 8		0–5	0–10	0–25	
No. 16			0–5	0–5	45–70
No. 50					5–25
No. 100					0–10
No. 200				0–2	0–2

* Refer to Table 820-8 for information on aggregate gradations used in surface treatments.

† In inches unless otherwise indicated.

Source: The Asphalt Institute, *Asphalt Surface Treatments—Specifications*, ES-11, February, 1982.

ous the load, the thicker the pavement required.

2. Subgrade support: weaker subgrades require stronger pavement design. The use of a strong aggregate subbase to achieve desired strength is recommended rather than thicker and/or more layers of asphalt concrete.

3. Materials in the pavement structure: hot-mix asphalt concrete gives more strength and the aggregate base distributes loads better than a full-depth design.

Thickness Design Procedure:

The following design procedure is recommended for roads in the United States by

Table 820-10. RECOMMENDED THICKNESS OF ASPHALT BLOCKS FOR TYPICAL APPLICATIONS*

Typical applications	Thickness of unit recommended, in
Traffic aisles and loading platforms	1½ or 2
Piers and docks	1½ or 2
Roof decks—parking or storage	1½
Roof decks and balconies—recreational	1¼ or 1½
Airport, hangars, runways, aprons	1½, 2, or 2½
Ramps and bridge approaches	2½ or 3
Streets, roads, bridges, viaducts	2½ or 3
Waterproofing protection courses	1¼
Estate, residential, and institutional driveways	2, hexagonal or rectangular
Walks, courts, plazas, and terraces	2, hexagonal or rectangular

* Check local practices and standards, manufacturers' specifications, or a civil engineer to more accurately determine proper thickness for particular jobs.

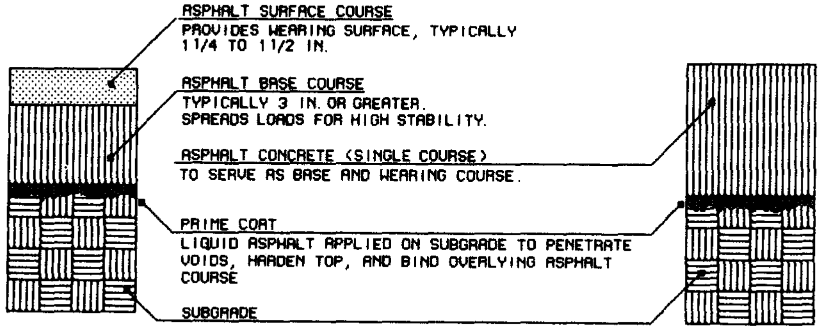
Source: Adapted from The Asphalt Institute, *The Asphalt Handbook,* 1965.

Table 820-11. LESS COMMON ASPHALT PAVING MIXTURES

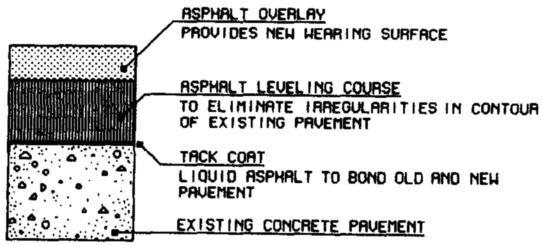
Asphalt mixture type	Intended use	Constituent materials†	Remarks
Cold laid plant mixes Cold mixes Emulsified asphalt Emulsified sand asphalt Emulsified sheet asphalt	For immediate patching or stockpiling. Use on sites far-removed from asphalt concrete plant, base, or surface courses.	Different mix designations available composed of liquid asphalts and various aggregate gradations in a plant-prepared mixture. Aggregate options include open and dense-graded gradations. A prepared and compacted subgrade	Placed by paving machines at ambient temperatures and compacted. Requires a period of time for water or solvents to evaporate. Care is needed to ensure proper curing for desired strength. Fully cured strength 20 to 30% less than asphalt concrete. Deficiencies in strength typically remedied by using thicker layers.
Road mixes mixed in place Cold laid road mixes	For base and surface courses. Immediate patching or stockpiling. Use on surfaces far-removed from hot-mix plant.	Liquid asphalt or asphalt cement, open or dense-graded aggregate, sand or sandy soil	Mixed in traveling plant or by graders manipulating layers of asphalt material and aggregate. Not as precise as plant mixing. Additional surface treatments may be added to seal surface or provide wearing coat.
Open-graded mixes	Typically as an overlay or nonskid surface (sometimes called friction course) on continuous flow, high-speed highway traffic surfaces	Asphalt cements or emulsified asphalts. Open-graded aggregate, often tougher than other aggregate mixes; high degree of interlocking necessary	As an overlay, has coarse appearance and temporarily absorbs water from light rains in pavement's porous structure. Better resists transferral of reflection cracks of pavement underneath than other mixes. Typically, not used for residential streets and parking lots.
Penetration macadam	Base courses or surface courses of roads	Macadam aggregate nominally sized at 1½ to 2½ in; asphalt cement or emulsified asphalt, seal coat, and compacted and prepared subgrade	Larger aggregate compacted onto prepared subgrade covered with asphalt material that seeps and penetrates into aggregate. Covered by smaller aggregate and then entire material compacted. Seal coat applied to surface. Application requires experienced labor to produce smooth riding surface. Rarely used today.

* Consult local practices and state specifications or an engineer for materials and application guidelines.

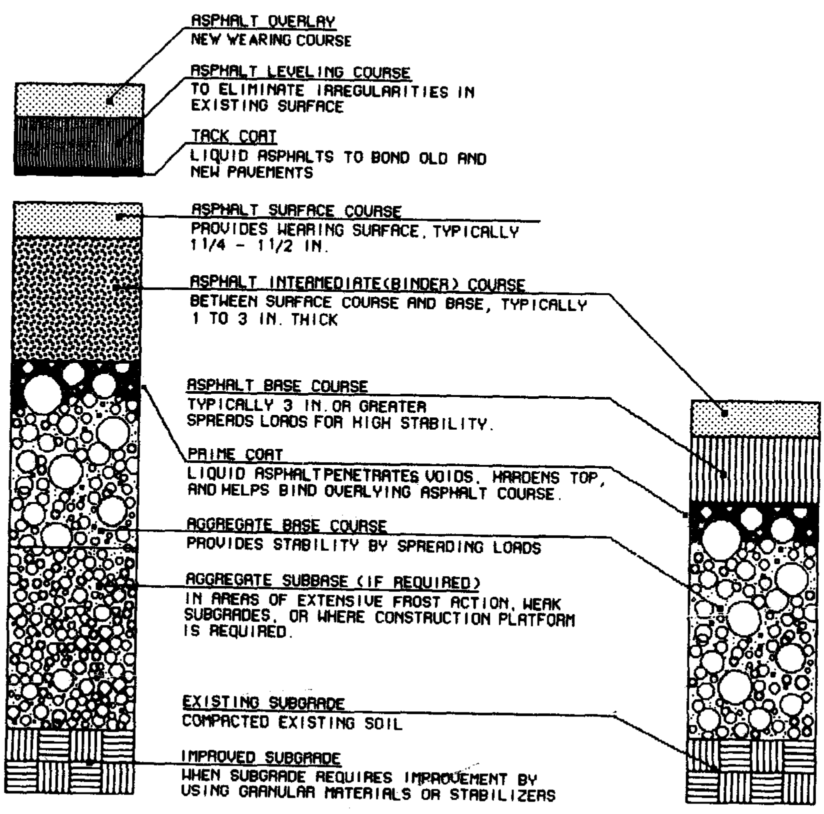
† See Table 820-3 for specific asphalt types of these mixtures.



TYPICAL FULL-DEPTH ASPHALT PAVEMENTS

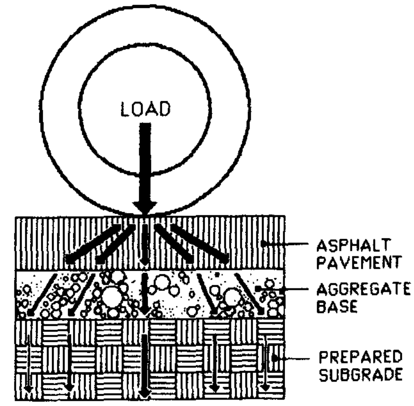


TYPICAL ASPHALT PAVEMENT OVER EXISTING PAVEMENT

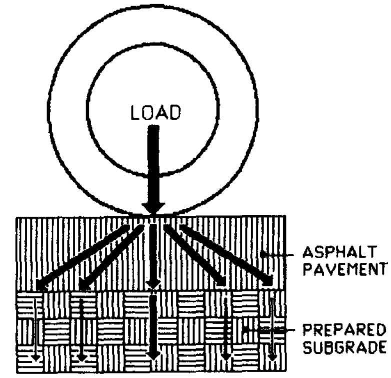


TYPICAL ASPHALT PAVEMENTS OVER UNTREATED AGGREGATE BASE

Figure 820-3. Typical asphalt pavement sections. *These sections show various courses of materials typically used in asphalt pavement construction. The actual pavement design used, including dimensional specifications, will depend on load, subgrade, materials, climate, and local practices. Prime coats are generally not used on pavements thicker than 3 to 4 in (75 to 100 mm) over aggregate, and are rarely used in full-depth pavements. Asphalt pavements over existing concrete, brick, or stone require special overlay construction techniques not covered in this handbook.*



PATTERN OF LOAD DISTRIBUTION IN ASPHALT PAVEMENT ON UNTREATED AGGREGATE BASE OVER PREPARED SUBGRADE



PATTERN OF LOAD DISTRIBUTION IN FULL-DEPTH ASPHALT PAVEMENT OVER PREPARED SUBGRADE

Figure 820-4. Load distribution in asphalt pavements. *Stronger materials spread loads more widely than do weaker materials. Pavement and aggregate thicknesses depend on the strength of the subgrade. Subgrades that are less likely to fail under load requires less thickness in overlying pavement.*

820 Asphalt

The Asphalt Institute. Local practices and standards should be investigated, as local conditions may suggest modification.

1. Classify the traffic: select the appropriate traffic classification shown in Table 820-12.
2. Classify the subgrade: determine the proper subgrade based on the criteria in Table 820-13. Consult a civil engineer to confirm the proper classification.
3. Determine the optimum asphalt concrete specifications: use the specifications of the local governing authority responsible for asphalt pavement specifications. If these are not available, determine the optimum asphalt cement and aggregate combination, considering the proposed load and subgrade.

   Any untreated aggregate incorporated in the design should comply with Graded Aggregate Material for Bases and Subbases for Highways and Airports (ASTM D2940). The aggregate should meet those requirements listed in Table 820-14.

   The subgrade should be compacted at or near optimum moisture content to achieve maximum density. The bases and subbases should also be compacted at optimum moisture content to achieve a minimum density of 100 percent maximum laboratory density.
4. **Determine the thickness:** Table 820-15 lists the thickness requirements for a full-depth asphalt concrete pavement. Tables 820-16 through 820-18 show thickness requirements for an asphalt concrete pavement over an untreated aggregate base.

Design Examples:

Two design examples are included here to clarify the procedure given above.

Example A: (rural minor collector road):

1. **Classify the Traffic:** A rural minor collector road is expected to average 10 heavy trucks per day over a 20-year design period. The total number of heavy trucks will be 10 x 365 x 20 = 73,000. Traffic Class III is indicated (Table 820-12).
2. **Classify the Subgrade:** From past experience and CBR test data, the subgrade is expected to have a CBR between 8 and 10. A medium subgrade soil classification is indicated (Table 820-13). Confirm the findings with an engineering study.
3. **Determine the Optimum** Asphalt Concrete Specifications: Two alternative pavements are considered: full-depth asphalt concrete (Table 820-15) and asphalt concrete over a 150-mm (6-in) untreated aggregate base (Table 820-17).
4. **Determine the Thickness:** The final thicknesses for each pavement type are computed below:

Pavement layer	Full-depth design	Asphalt concrete on untreated aggregate base
Asphalt concrete surface	40 mm (1.5 in)	40 mm (1.5 in)
Asphalt concrete base	85 mm (3.5 in)	60 mm (2.5 in)
Untreated aggregate base		150 mm (6.0 in)
Total thickness	125 mm (5.0 in)	250 mm (10.0 in)

Example B: (interpolation between traffic classifications):

1. **Classify the Traffic:** A minor arterial street is estimated to average 70 heavy trucks per day over a 20-year period. The total number of heavy trucks will be 70 x 365 x 20 = 511,000. This falls between Traffic Classes III and IV (Table 820-12).
2. **Classify the Subgrade:** Old soil-test records indicate that the design CBR value in the area was 7. This falls in the medium subgrade soil classification (Table 820-13). Confirm the findings with an engineering study.
3. **Determine the Optimum Asphalt Concrete Specifications:** Full-depth asphalt concrete has been selected for the pavement structure (Table 820-15).

Table 820-12. TRAFFIC CLASSIFICATIONS FOR ROADS

Traffic class	Type of street or highway	Approximate range—number of heavy trucks expected during design period*†	EAL ‡
I	▪ Parking lots, driveways ▪ Light traffic, residential streets ▪ Light traffic, farm roads	≤7000	5×10^3
II	▪ Residential streets ▪ Rural farm and residential roads	7000–15,000¶	10^4
III	▪ Urban minor collector streets ▪ Rural minor collector roads	70,000–150,000¶	10^5
IV§	▪ Urban minor arterial and light industrial streets ▪ Rural major collector and minor arterial highways	700,000–1,500,000	10^6
V§	▪ Urban freeways, expressways, and other principal arterial highways ▪ Rural interstate and other principal arterial highways ▪ Urban interstate highways ▪ Some industrial roads	>2,000,000	3×10^6

* "Heavy trucks" refers to two-axle, six-tire trucks or larger, as well as to trucks with heavy-duty, wide-based tires.

† "Design period" refers to the number of years from the initial application of traffic to the first planned major resurfacing or overlay.

‡ "EAL" is the equivalent number of 80k N (18,000 lb) single-axle loads. The equivalent is the effect on the pavement of any combination of axle loads of varying magnitude that equals 18,000 lb (80 k N).

§ Thickness determination with increasing loads becomes very complex. Whenever possible, consult the Asphalt Institute's manual MS-1, *Thickness Design—Asphalt Pavements for Highways and Streets,* to determine proper procedures and recommendations for classes IV and higher. For reasons of complexity, pavement thicknesses of class V will not be discussed. In these cases, consult with a civil engineer.

¶ When the value of truck use is between two class values, proportionately alter the thickness of the finished pavement (see Design Example B in the text).

Source: Adapted from The Asphalt Institute, *Asphalt Pavement Thickness and Design,* IS-181, November 1981.

4. **Determine the Thickness:** Because the total number of heavy trucks (511,000) falls between Traffic Classes III and IV, a total thickness between 125 mm (5.0 in) and 200 mm (8.0 in) must be determined by interpolation.

Interpolation (from Table 820-17):

Traffic Class IV = 200 mm (8.0 in) total thickness

Traffic Class III = 125 mm (5.0 in) total thickness

Difference = 75 mm (3.0 in)

Let x equal that amount of thickness needed to be added to 125 mm (5 in) to produce a total adequate thickness for 511,000 trucks. The number 511,000 falls between 150,000 (Class III) and 700,000 (Class IV). Thus,

$$\frac{x}{75} = \frac{511{,}000 - 150{,}000}{700{,}000 - 150{,}000}$$

$$\frac{x}{75} = \frac{361{,}000}{550{,}000}$$

$$x = 50 \text{ mm } (2.0 \text{ in})$$

Therefore, the total design thickness necessary will be:

50 mm (2.0 in) + 125 mm (5.0 in) = 175 mm (7.0 in)

This additional thickness should be added to the asphalt concrete base course rather than in the surface course. The thickness of the asphalt concrete surface course in cases of interpolation between traffic classifications should be the thicker value of the two traffic classes (i.e., 50 mm instead of 40 mm in Table 820-15). In the case of interpolation for the design of pavements on aggregate subbase, the thickness of the aggregate should also be the thicker value of the two traffic classes.

Final thickness design: Therefore, the thickness design should be:

Asphalt concrete surface = 50 mm (2.0 in)

Asphalt concrete base = 125 mm (5.0 in)

Total thickness = 175 mm (7.0 in)

6.2 Driveways and Parking Areas

Dolly wheels of a parked truck trailer will indent asphalt surfaces unless planks are placed under each wheel or a concrete pad installed.

Table 820-13. SUBGRADE CLASSIFICATIONS FOR ROADS

Subgrade class	CBR*†	Resilient modulus, MPa (psi)*†	R-value*†	Remarks
Poor	3	30 (4500)	6	Poor subgrade soils become quite soft and plastic when wet. Included are those soils having appreciable amounts of clay and fine silt. The coarser silts and sandy loams also may exhibit poor bearing properties in areas where frost penetration into the subgrade is a factor.
Medium	8	80 (12,000)	20	Medium subgrade soils retain a moderate degree of firmness under adverse moisture conditions. Included are such soils as loams, silty sands, and sand gravels containing moderate amounts of clay and fine silt.
Good to excellent	17	170 (25,000)	43	Good subgrade soils retain a substantial amount of their load-supporting capacity when wet. Included are the clean sands and sand gravels and soils free of detrimental amounts of plastic materials. Excellent subgrade soils are unaffected by moisture or frost. They include clean and sharp sands and gravels, particularly those that are well-graded.

* The following are specifications for the soil-testing procedures used. California Bearing Ratio (CBR): ASTM Method D 1883 (AASHTO Method T 193), compact samples according to ASTM Method D 155 T (AASHTO Method T 180), Method B or D. Resistance value (R-value): ASTM Method D 2844 (AASHTO Method T 190). Resilient modulus: approximately computed from CBR by equation

$$Mr(MPa) = 10.342 \text{ CBR or}$$
$$Mr(psi) = 1500 \text{ CBR}$$

or from R-value by equation

$$Mr(MPa) = 7.963 + 3.826 \text{ (R-value) or}$$
$$Mr(psi) = 1155 + 555 \text{ (R-value)}$$

Resilient modulus is approximated by these equations when the expected figure is 207 MPa (30,000 psi) or less. Such an approximation is useful in soils classified as CL, CH, ML, SC, SM, and SP (Unified Soil Classification, ASTM D 2487). With other soils, resilient modulus needs to be determined by laboratory testing. The resilient modulus used here and these approximations are not the same as the dynamic modulus test now being used by some agencies. The latter tends to give lower *Mr* results. For a more complete discussion, consult with a civil engineer or refer to the Asphalt Institute's *Soils Manual* (MS-10).

† The designer is cautioned to determine that estimated soil strength is accurate and conforms to the above specifications before utilizing the table.

Source: Adapted from The Asphalt Institute, *Asphalt Pavement Thickness and Design,* IS-181, November 1981.

Table 820-14. UNTREATED AGGREGATE BASE AND SUBBASE QUALITY REQUIREMENTS FOR ASPHALT ROADS*†

Test	Test requirements‡	
	Subbase	Base
CBR, minimum or	20	80
R-value, minimum	55	78
Liquid limit, maximum	25	25
Plasticity index, maximum, or	6	Nonplastic
Sand equivalent, minimum	25	35
Passing No. 200 sieve, maximum	12	7

* All bases and subbases should be compacted at optimum moisture content, plus or minus 1.5 percentage points, to achieve a minimum of 100% maximum laboratory density as established by ASTM Method Test D 1557, Method D (or AASHTO Method T 180).

† These requirements apply to all untreated aggregate used in this pavement design. Such aggregate should comply with *Graded Aggregate Material for Bases or Subbase for Highways and Airports,* ASTM specification D2940.

‡ The upper 6 in (150 mm) of untreated aggregate should meet the requirements for base material. Material below this may meet subbase requirements.

Source: Adapted from The Asphalt Institute, *Asphalt Pavement Thickness and Design,* IS-181, November 1981.

Table 820-15. ASPHALT CONCRETE THICKNESS FOR ROADS— FULL DEPTH DESIGN[a,b,c]

class[d]	Pavement section	Full-depth asphalt concrete, in (mm)			
Poor	Asphalt concrete surface	1.0 (25)	1.0 (25)	1.5 (40)	2.0 (50)
	Asphalt concrete base	3.5 (85)	4.0 (95)	5.5 (140)	8.0 (205)
	Total:	4.5 (110)	5.0 (120)	7.0 (180)	10.0 (255)
Medium	Asphalt concrete surface[f]	1.0 (25)	1.0 (25)	1.5 (40)	2.0 (50)
	Asphalt concrete base	3.0 (75)	3.0 (75)	3.5 (85)	6.0 (155)
	Total:	4.0 (100)[g]	4.0 (100)[g]	5.0 (125)	8.0 (205)
Good to excellent	Asphalt concrete surface[f]	1.0 (25)	1.0 (25)	1.5 (40)	2.0 (50)
	Asphalt concrete base	3.0 (75)	3.0 (75)	2.5 (60)	4.0 (105)
	Total:	4.0 (100)[g]	4.0 (100)[g]	4.0 (100)[g]	6.0 (155)

[a] Consult local standards and practices for all pavements. Such specifications supercede those mentioned here.

[b] See Table 820-13 for typical asphalt mixtures. The thickness of any asphalt concrete layer should be at least twice either the nominal maximum size mix designation or the maximum particle size of the mix (whichever term is used).

[c] Use full-depth pavements where highly frost-susceptible soils or heavy frost is not a problem. Otherwise, use asphalt concrete over an aggregate base.

[d] See Table 820-13.

[e] See Table 820-12.

[f] Minimum recommended thickness of asphalt concrete surface.

[g] Minimum recommended design.

Source: Adapted from The Asphalt Institute, *Asphalt Pavement Thickness and Design,* 1S-181, November 1981.

Table 820-16. PAVEMENT THICKNESS FOR ROADS OVER POOR SUBGRADES—ASPHALT CONCRETE ON AGGREGATE

Pavement section/various aggregate base thicknesses	Traffic classification[a] I	II	III	IV
	Thickness in inches (mm)			
4-in				
Asphalt concrete surface	1.0 (25)	1.0 (25)	1.5 (40)	2.0 (50)
Asphalt concrete base	2.5 (65)	3.0 (80)	5.0 (120)	8.0 (200)
Untreated aggregate base[e]	4.0 (100)	4.0 (100)	4.0 (100)	4.0 (100)
Total:	7.5 (190)	8.0 (205)	10.5 (260)	14.0 (350)
6-in				
Asphalt concrete surface	1.0 (25)	1.0 (25)	1.5 (40)	2.0 (50)
Asphalt concrete base	2.0 (55)	3.0 (75)	4.5 (120)	7.5 (190)
Untreated aggregate base[e]	6.0 (150)	6.0 (150)	6.0 (150)	6.0 (150)
Total:	9.0 (230)	10.0 (250)[f]	12.0 (310)	15.5 (390)
8-in				
Asphalt concrete surface	1.0 (25)	1.0 (25)	1.5 (40)	2.0 (50)
Asphalt concrete base	2.0 (50)	3.0 (75)	4.0 (105)	7.0 (185)
Untreated aggregate base[e]	8.0 (200)	8.0 (200)	8.0 (200)	8.0 (200)
Total:	11.0 (275)[f]	12.0 (300)[f]	13.5 (345)	17.0 (435)
10-in				
Asphalt concrete surface	1.0 (25)	1.0 (25)	1.5 (40)	2.0 (50)
Asphalt concrete base	2.0 (50)	3.0 (75)	3.5 (90)	7.0 (175)
Untreated aggregate base[e]	10.0 (250)	10.0 (250)	10.0 (250)	10.0 (250)
Total:	13.0 (325)[f]	14.0 (350)[f]	15.0 (380)	19.0 (475)
12-in				
Asphalt concrete surface	1.0 (25)	1.0 (25)	1.5 (40)	2.0 (50)
Asphalt concrete base	2.0 (50)	3.0 (75)	3.0 (85)	6.0 (160)
Untreated aggregate base[e]	12.0 (300)	12.0 (300)	12.0 (300)	12.0 (300)
Total:	15.0 (375)[f]	16.0 (400)[f]	16.5 (425)	20.0 (510)
18-in				
Asphalt concrete surface	1.0 (25)	1.0 (25)	1.5 (40)	2.0 (50)
Asphalt concrete base	2.0 (50)	3.0 (75)	2.5 (60)	5.5 (135)
Untreated aggregate base[e]	18.0 (450)	18.0 (450)	18.0 (450)	18.0 (450)
Total:	21.0 (525)[f]	22.0 (550)[f]	22.0 (550)[f]	25.5 (635)

[a] See Table 820-12.

[b] Depth of untreated aggregate base is dependent upon depth necessary to mitigate frost action. Local practice typically defines required depths. For aggregate bases greater than 18 in, consult with a civil engineer.

[c] Refer to Table 820-11 for typical asphalt mixtures. The thickness of any asphalt concrete layer should be at least twice either the nominal maximum size mix designation or the maximum particle size (whichever term is used).

[d] Consult local standards and practices for all pavements. Such specifications may supercede those mentioned herein if they provide the same service life of these designs.

[e] The top 6 in of untreated aggregate should meet base course quality requirements. Subbase quality requirements may be used below 6 in.

[f] Minimum thicknesses of asphalt concrete over untreated aggregate base and subbase apply to these designs as follows: for traffic class I, 3.0 in (75 mm); for traffic class II, 4.0 in (100 mm); for traffic class III, 4.0 in (100 mm); and for traffic class IV, 5.0 in (125 mm).

Source: Adapted from The Asphalt Institute, *Asphalt Pavement Thickness and Design,* 1S-181, November 1981.

Table 820-17. PAVEMENT THICKNESS FOR ROADS OVER MEDIUM SUBGRADES—ASPHALT CONCRETE ON AGGREGATE

Pavement section/various aggregate base thicknesses	Traffic classification[a]			
	I	II	III	IV
	Thickness in inches (mm)			
4 in				
Asphalt concrete surface	1.0 (25)	1.0 (25)	1.5 (40)	2.0 (50)
Asphalt concrete base	2.0 (50)	3.0 (75)	2.5 (60)	5.0 (130)
Untreated aggregate base[e]	4.0 (100)	4.0 (100)	4.0 (100)	4.0 (100)
Total:	7.0 (175)	8.0 (200)[f]	8.0 (200)[f]	11.0 (280)
6 in				
Asphalt concrete surface	1.0 (25)	1.0 (25)	1.5 (40)	2.0 (50)
Asphalt concrete base	2.0 (50)	3.0 (75)	2.5 (60)	4.5 (115)
Untreated aggregate base[e]	6.0 (150)	6.0 (150)	6.0 (150)	6.0 (150)
Total:	9.0 (225)[f]	10.0 (250)[f]	10.0 (250)[f]	12.5 (315)
8 in				
Asphalt concrete surface	1.0 (25)	1.0 (25)	1.5 (40)	2.0 (50)
Asphalt concrete base	2.0 (50)	3.0 (75)	2.5 (60)	4.0 (110)
Untreated aggregate base[e]	8.0 (200)	8.0 (200)	8.0 (200)	8.0 (200)
Total:	11.0 (275)[f]	12.0 (300)[f]	12.0 (300)[f]	14.0 (360)
10 in				
Asphalt concrete surface	1.0 (25)	1.0 (25)	1.5 (40)	2.0 (50)
Asphalt concrete base	2.0 (50)	3.0 (75)	2.5 (60)	3.5 (95)
Untreated aggregate base[e]	10.0 (250)	10.0 (250)	10.0 (250)	10.0 (250)
Total:	13.0 (325)[f]	14.0 (350)[f]	14.0 (350)[f]	15.5 (395)
12 in				
Asphalt concrete surface	1.0 (25)	1.0 (25)	1.5 (40)	2.0 (50)
Asphalt concrete base	2.0 (50)	3.0 (75)	2.5 (60)	3.5 (90)
Untreated aggregate base[e]	12.0 (300)	12.0 (300)	12.0 (300)	12.0 (300)
Total:	15.0 (375)[f]	16.0 (400)[f]	16.0 (400)[f]	17.5 (440)
18 in				
Asphalt concrete surface	1.0 (25)	1.0 (25)	1.5 (40)	2.0 (50)
Asphalt concrete base	2.0 (50)	3.0 (75)	2.5 (60)	3.0 (85)
Untreated aggregate base[e]	18.0 (450)	18.0 (450)	18.0 (450)	18.0 (450)
Total:	21.0 (525)[f]	22.0 (550)[f]	22.0 (550)[f]	23.0 (585)

[a] See Table 820-12.

[b] Depth of untreated aggregate base is dependent upon depth necessary to mitigate frost action. Local practice typically defines required depth. For aggregate bases greater than 18 in, consult with a civil engineer.

[c] Refer to Table 820-11 for typical asphalt mixtures. The thickness of any asphalt concrete layer should be at least twice either the nominal maximum size mix designation or the maximum particle size (whichever term is used).

[d] Consult local standards and practices for all pavements. Such specifications supercede those mentioned here.

[e] The top 6 in of untreated aggregate should meet base course quality requirements. Subbase quality requirements may be used below 6 in.

[f] Minimum recommended thicknesses of asphalt concrete over untreated aggregate base and subbase apply to these designs as follows: for traffic class I, 3.0 in (75 mm); for traffic class II, 4.0 in (100 mm); for traffic class III, 4.0 in (100 mm); and for traffic class IV, 5.0 in (125 mm).

Source: Adapted from The Asphalt Institute, *Asphalt Pavement Thickness and Design,* 1S-181, November 1981.

Table 820-18. PAVEMENT THICKNESS FOR ROADS OVER GOOD TO EXCELLENT SUBGRADES—ASPHALT CONCRETE ON AGGREGATE BASE[a,b,c,d]

Pavement section/various aggregate base thicknesses	Traffic classification[a] I	II	III	IV
	Thickness in inches (mm)			
4 in				
Asphalt concrete surface	1.0 (25)	1.0 (25)	1.5 (40)	2.0 (50)
Asphalt concrete base	2.0 (50)	3.0 (75)	2.5 (60)	3.0 (75)
Untreated aggregate base	4.0 (100)	4.0 (100)	4.0 (100)	4.0 (100)
Total:	7.0 (175)[f]	8.0 (200)[f]	8.0 (200)[f]	9.0 (225)[f]
6 in				
Asphalt concrete surface	1.0 (25)	1.0 (25)	1.5 (40)	2.0 (50)
Asphalt concrete base	2.0 (50)	3.0 (75)	2.5 (60)	3.0 (75)
Untreated aggregate base	6.0 (150)	6.0 (150)	6.0 (150)	6.0 (150)
Total:	9.0 (225)[f]	10.0 (250)[f]	10.0 (250)[f]	11.0 (275)[f]
8 in				
Asphalt concrete surface	1.0 (25)	1.0 (25)	1.5 (40)	2.0 (50)
Asphalt concrete base	2.0 (50)	3.0 (75)	2.5 (60)	3.0 (75)
Untreated aggregate base	8.0 (200)	8.0 (200)	8.0 (200)	8.0 (200)
Total:	11.0 (275)[f]	12.0 (300)[f]	12.0 (300)[f]	13.0 (325)[f]
10 in				
Asphalt concrete surface	1.0 (25)	1.0 (25)	1.5 (40)	2.0 (50)
Asphalt concrete base	2.0 (50)	3.0 (75)	2.5 (60)	3.0 (75)
Untreated aggregate base	10.0 (250)	10.0 (250)	10.0 (250)	10.0 (250)
Total:	13.0 (325)[f]	14.0 (350)[f]	14.0 (350)[f]	15.0 (375)[f]
12 in				
Asphalt concrete surface	1.0 (25)	1.0 (25)	1.5 (40)	2.0 (50)
Asphalt concrete base	2.0 (50)	3.0 (75)	2.5 (60)	3.0 (75)
Untreated aggregate base	12.0 (300)	12.0 (300)	12.0 (300)	12.0 (300)
Total:	15.0 (375)[f]	16.0 (400)[f]	16.0 (400)[f]	17.0 (425)[f]
18 in				
Asphalt concrete surface	1.0 (25)	1.0 (25)	1.5 (40)	2.0 (50)
Asphalt concrete base	2.0 (50)	3.0 (75)	2.5 (60)	3.0 (75)
Untreated aggregate base	18.0 (450)	18.0 (450)	18.0 (450)	18.0 (450)
Total:	21.0 (525)[f]	22.0 (550)[f]	22.0 (550)[f]	23.0 (575)[f]

[a] See Table 820-12.

[b] Depth of untreated aggregate base is dependent upon depth necessary to mitigate frost action. Local practice typically defines required depth. For aggregate bases greater than 18 in, consult with a civil engineer.

[c] Refer to Table 820-11 for typical asphalt mixtures. The thickness of any asphalt concrete layer should be at least twice either the nominal maximum size mix designation or the maximum particle size (whichever term is used).

[d] Consult local standards and practices for all pavements. Such specifications supercede those mentioned here.

[e] The top 6 in of untreated aggregate should meet base course quality requirements. Subbase quality requirements may be used below 6 in.

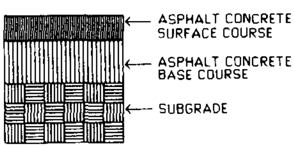
[f] Minimum recommended thicknesses of asphalt concrete over untreated aggregate base and subbase apply to these designs as follows: for traffic class I, 3.0 in (75 mm); for traffic class II, 4.0 in (100 mm); for traffic class III, 4.0 in (100 mm); and for traffic class IV, 5.0 in (125 mm).

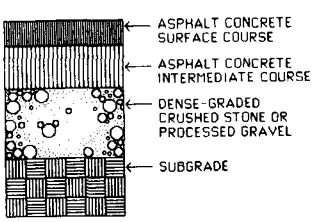
Source: Adapted from The Asphalt Institute, *Asphalt Pavement Thickness and Design,* 1S-181, November 1981.

Key Points - Asphalt Pavement Design

1. Refer to Section 440: Surfacing and Paving for additional information on pavement design.
2. The aggregate of pavement layers supports the loads imposed on it while the asphalt cement waterproofs and helps to bind everything together.
3. Precise thickness for paving surfaces, bases and subbases, should be based upon local practice and standards, wherever possible.
4. Full-depth pavement design is commonly used in regions without frost, or on subgrades that are not susceptible to frost action. Aggregate Base design is most appropriate in regions of heavy frost, or on frost-susceptible subgrades.
5. The use of a strong aggregate subbase to achieve desired pavement strength is recommended rather than thicker and/or more layers of asphalt concrete.
6. Asphalt concrete pavements, properly constructed, typically require surface maintenance or resurfacing overlays about every 20 years.
7. Intensity of use, subgrade support, and pavement structure dictate the thickness of asphalt concrete pavements (see Thickness Design Procedure in Subsection 6.1 Roads).
8. Bikepaths and walkways typically utilize a total asphalt concrete thickness of 75 to 100 mm (3 to 4 in) in a full-depth or untreated aggregate base design (Figure 820-5).
9. Golf cart paths require a softer surface to minimize golf shoe spike wear. The surface course should be a sand-asphalt mixture with an asphalt content slightly higher than for normal highway paving, or an open-graded mix.
10. Tennis courts require a sand-asphalt surface course or proprietary surfacing to maximize smoothness and minimize irregularities.

Table 820-19. THICKNESS DESIGN FOR DRIVEWAYS AND PASSENGER CAR PARKING AREAS (NO TRUCKS)





	Soft clay soils, plastic when wet	Average clay loam soils, not plastic	Gravel or sandy soils, well-drained
Full-depth asphalt concrete*			
Surface course, in	1	1	1
Base course, in	4–5†	3–4†	2–3†
Total thickness, in	5–6	4–5	3–4
Asphalt concrete and aggregate base*‡			
Surface course, in	1	1	1
Intermediate course, in	2	2	2
Gravel, in	6–8§	4–6§	2–4§
Total thickness, in	9–11	7–9	5–7

* See Table 820-6 for typical mixture specifications. The thickness of any asphalt concrete layer should be at least twice either the nominal maximum size mix designation or the maximum particle size of the mix. Local standards and practices supercede those mentioned here and should be consulted for all pavements.

† Where ranges in asphalt concrete thicknesses are shown, consult local practice and standards for a precise value. If such knowledge is not available, assume the higher value and consult a civil engineer.

‡ Utilize full-depth pavements where frost-susceptible soils or heavy frost is not a problem.

§ Aggregate base course depth varies depending on strength of subgrade soil and depth of frost. Check with local practices for safety and applicable standards.

Source: Adapted from The Asphalt Institute, The *Asphalt Handbook,* March 1970.

Table 820-19 can be used to determine pavement thickness for driveways and passenger car parking areas (no trucks), and Table 820-20 can be used to determine pavement thickness for heavy truck parking areas. For parking areas used by higher volumes of heavy trucks, such as truck stops or truck terminals, the design recommendations outlined in 6.1 Roads of this section can be used.

6.3 Bicycle, Pedestrian, and Golf Cart Paths

Bikepaths and Walkways. These utilize a total asphalt concrete thickness of 75 to 100 mm (3 to 4 in) in a full-depth or untreated aggregate base design (Figure 820-5). Local practices should be followed where applicable.

Golf Cart Paths. These require a softer surface to minimize golf shoe spike wear. Although the overall construction is similar to bikepaths and walkways, the surface course should be a sand-asphalt mixture with an asphalt content slightly higher than for normal highway paving (Table 820-3). Alternatively, an open-graded mix may be used as a surface course. Local practices should be followed where applicable.

6.4 Tennis Courts

Tennis court surfaces require a high degree of smoothness with a maximum irregularity of 3 mm (1/8 in) over a 3-m (10-ft) distance. This can be achieved with an asphalt concrete base of 20 mm (3/4 in) of nominal maximum size designation covered either with sand-asphalt for the surface course or with proprietary surfacing (Figure 820-6). The base course is 75 mm (3 in) and the surface course is 25 mm (1 in), creating a minimal total thickness of 100 mm (4 in). For more specific thickness design information, especially under various soil and environmental conditions, refer to Table 820-19. If a proprietary mixture is used, follow the manufacturer's recom-

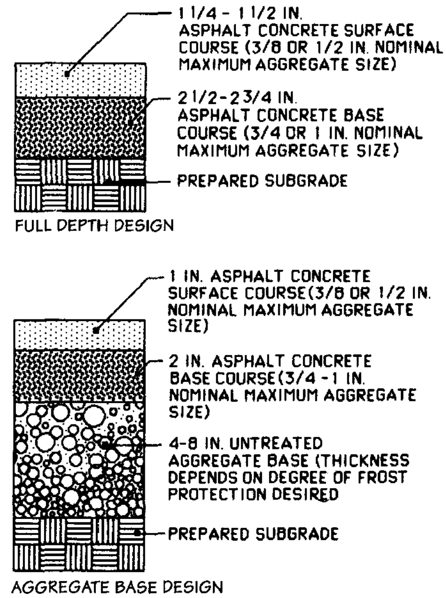
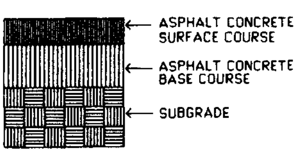
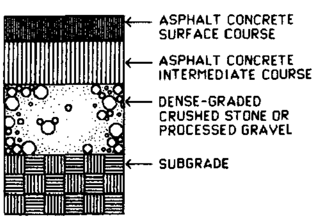


Figure 820-5. Typical design for walkways, bicycle trails, and golf cart paths. *Golf cart paths require a surface course of a sand-asphalt mixture with an asphalt content slightly higher than for normal roadway pavements. Refer to Table 820-6 for information on asphalt-concrete mixtures.*

Table 820-20. THICKNESS DESIGN FOR PARKING AREAS FOR HEAVY TRUCKS AND SERVICE STATIONS*





	Soft clay soils, plastic when wet	Average clay loam soils, not plastic	Gravel or sandy soils, well-drained
Full-depth asphalt concrete†			
Surface course, in	1.5	1.5	1.5
Base course, in	6–8‡	5–6‡	3–6‡
Total thickness, in	7.5–9.5	6.5–7.5	4.5–6.5
Asphalt concrete and aggregate base †·§			
Surface course, in	1.5	1.5	1.5
Intermediate course, in	3	3	3
Gravel, in	6–10¶	5–8¶	3–6¶
Total thickness, in	10.5–14.5	9.5–12.5	7.5–10.5

* For areas affected by higher volumes of heavy trucks (such as terminals), the recommendations outlines in 6.1 of this section should be followed.

† See Table 820-6 for typical mixture specifications. The thickness of any asphalt concrete layer should be at least twice either the nominal maximum size mix designation or the maximum particle size of the mix. Local standards and practices supercede those mentioned here and should be consulted for all pavements.

‡ Where ranges in asphalt concrete thicknesses are shown, consult local practice and standards for a precise value. If such knowledge is not available, assume the higher value and consult a civil engineer.

§ Utilize full-depth pavements where frost-susceptible soils or heavy frost is not a problem.

¶ Aggregate base course depth varies depending on strength of subgrade soil and depth of frost. Check with local practices for safety and applicable standards.

Source: Adapted from The Asphalt Institute, The *Asphalt Handbook,* March 1970.

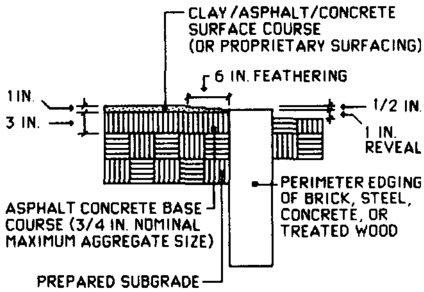


Figure 820-6. Tennis courts and perimeter edging. *Consult manufacturer's specifications for information on pavement construction and detailing when using proprietary surfaces. Refer to Table 820-6 for information on asphalt-concrete mixtures. Refer to Division 900: Details and Devices, for additional edging details.*

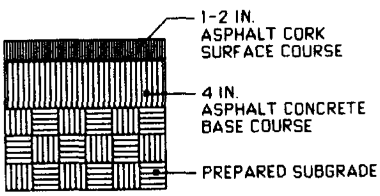


Figure 820-7. Typical asphalt cork surface course. *Recreational asphalt pavement courses often consist of proprietary products. Consult manufacturer's specifications for information on construction details.*

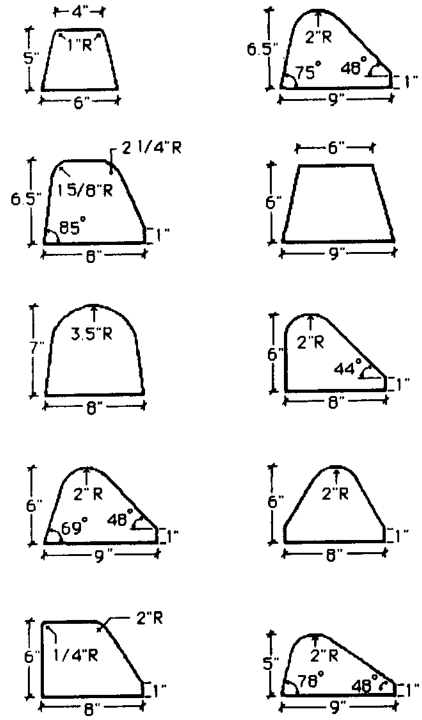


Figure 820-8. Typical shape for asphalt curbs.

mendation for the surface course and, if mentioned, for the base course as well. Perimeter edging is usually necessary to prevent edge failures.

If sand-asphalt is used, a latex paint of minimum thickness should be used no sooner than 30 days after construction. If a color finish has been applied, lines should be painted with a compatible material. Traffic, oil, alkyd, or solvent-vehicle-type paints should not be used.

6.5 Playgrounds and Recreational Areas

Thickness designs for playgrounds and other recreational areas should be the same as those used for tennis courts (see Figure 820-6).

Asphalt concrete can serve as a base for proprietary products such as sealers, color coats, resilient surface coatings, and artificial turf. The asphalt concrete base can be molded on a prepared subgrade to produce any desired gradient. Erosional undermining of pavement edges should be prevented. If proprietary surfacing materials are used, consult the manufacturer's recommendations for pavement specifications.

Combining a small percentage of cork with asphalt cement, sharp coarse sand, and limestone dust produces a resilient playground surface (Figure 820-7); the cork granules should have a maximum diameter size of 5 mm (¼ in). Other ingredients may also be used, such as vermiculite and ground rubber from old tires. Many such surfaces are proprietary products, and the manufacturer's specifications should be carefully followed.

7.0 MISCELLANEOUS

7.1 Asphalt Curbs and Gutters

Asphalt Curbs. These are available in various shapes (Figure 820-8). Although not affected by snow- and ice-melting chemicals, asphalt curbs can be sheared off or deformed when struck by heavy loads. Curbs should be back-filled with a solid granular material or well-compacted soil. Asphalt curbs are set by a curbing machine at an average rate of 610 m (2000 ft) per day. They must be installed on top of a solid, impervious pavement that will not erode or fail (Figure 820-9). Curbs are made of specially proportioned asphalt-aggregate mixtures (Table 820-21).

Asphalt concrete berms are an alternative to asphalt curbs (Figure 820-10).

Divisions 900: includes data on asphalt curb construction details.

Asphalt Gutters. These can be formed in a variety of cross sections. They are placed mostly by hand or on occasion (for special large projects) by a small paving machine, specially adapted to fit a particular job (Figure 820-11).

KEY POINTS: Curbs, Underlayments, Coloring & Recycled Pavement

1. Asphalt curbs should be back-filled with a solid granular material or well-compacted soil and must be installed on top of a solid, impervious pavement that will not erode or fail (Figure 820-9).
2. When using asphalt as an underlayment, the manufacturer's specifications for the surface product should be consulted to ascertain the strength of the material and thus determine the appropriate design.
3. Over time, the pavement will weather to a grayish tone and may reveal the color of the aggregate.
4. Only paints designed for use on asphalt pavements should be used.
5. Asphalt block pavements with exposed colored aggregate are commercially available.
6. Asphalt pavement can be recycled for use as base courses in pavement design by being ground into granular material.

7.2 Asphalt Underlayments

Asphalt concrete is often used as an underlayment for surface courses, including brick, stone block, and proprietary products. In principle, the surface material can provide a good wearing surface but may or may not contribute to the overall pavement strength that is necessary to distribute the loads. The underlayment must therefore fulfill the remaining strength requirements. Consequently, the manufacturer's specifications for the surface product should be consulted to ascertain the strength of the material and thus determine the appropriate design for an underlayment.

7.3 Colored Asphalt Pavements

Over time asphalt pavement will weather to a grayish tone and in some cases will reveal the color of the aggregate, especially if these are large particles. Asphalt mixtures with higher amounts of finer sand and filler produce darker-tones. The dark color helps hide grease drippings, accelerates melting of snow, and provides a good background for line striping.

Additional color can be added through a variety of methods. These include the following:

1. Paints and applied coatings are typically used on tennis courts, pools, playgrounds, and bikeways. Only paints designed for use on asphalt pavements should be used. These are typically sprayed on. The paint and proprietary surface manufacturer's recommendations should be followed. Oil-based paints should not be used.

Table 820-21. CURB MIXTURE SPECIFICATION

Sieve size	Passing, percent by weight*‡
19 mm (¾ in)	100
12.5 mm (½ in)	85–100
4.75 mm (No. 4)	65–80
2.36 mm (No. 8)	50–65
300 μm (No. 50)	18–30
75 μm (No. 200)	5–15
Asphalt content:	6.0–9.0 percent by weight of total mix†
AC-20 (AR-8000, 60–70 pen)	

* Mineral aggregate should be crushed stone, crushed gravel, crushed slag, natural or manufactured sand, or a combination of these materials. At least 50% by weight of the combined aggregate, other than naturally occurring rough-textured aggregate, should consist of crushed pieces.

† The asphalt content range includes a 0.5–1.0% increase over surface paving mix of same gradation to facilitate compaction and increase durability. The upper limit may need to be raised when slag or other absorptive aggregates are used.

‡ Other gradings may be used if they have a history of satisfactory performance. Consult local standards and practices.

Source: Adapted from The Asphalt Institute, *Construction Specifications for Asphalt Curbs and Gutters*, 4th ed., SS-3, March 1978.

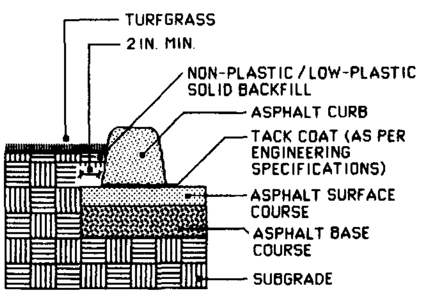


Figure 820-9. Typical bituminous curb and parking lot edge.

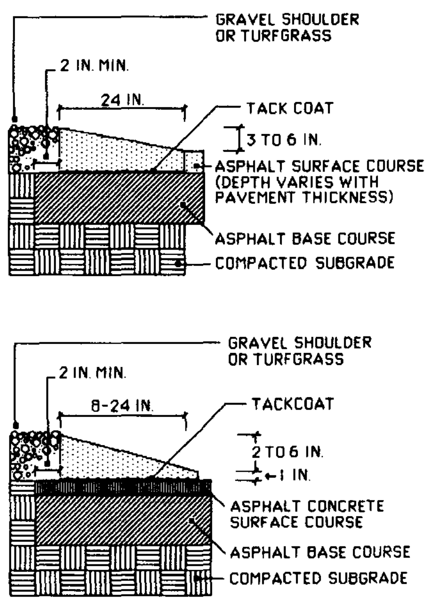


Figure 820-10. Typical asphalt concrete berms. *Widths, slopes, and overall dimensions vary. Increasing speeds and higher traffic volumes typically use wider berms and flatter slopes.*

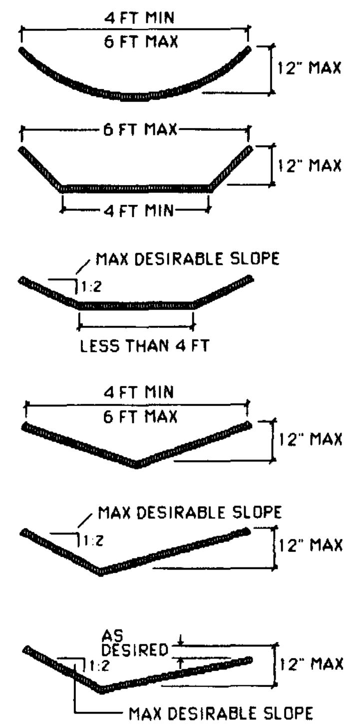


Figure 820-11. Typical shapes of asphalt gutters.

2. Colored stone chips can be embedded in a single or a multiple surface treatment procedure. This procedure may require much handwork and should only be done by competent specialists. Precautionary measures are necessary to protect nearby objects from the splatter of the spray applicator. This method provides a very coarse surface texture.

3. Asphalt concrete can be composed of selected colored aggregate and when the asphalt film wears off, there will be exposed the color of the aggregate. Smaller size stones [3/8 in (10 mm)] are standard.

4. Asphalt block pavements with exposed colored aggregate are commercially available.

7.4 Recycled Asphalt Granular Base Courses

Asphalt pavement can be recycled for use as base courses in pavement design. The used asphalt pavement is ground into granular material by either an on-site grinder or at a recycling facility and trucked to the site. Its use is similar to crushed rock.

AGENCIES AND ORGANIZATIONS

The Asphalt Institute.
(Regional offices throughout the United States and in some other countries)

U. S. Federal Highway Administration,
Department of Transportation.
Washington, DC, USA

National Asphalt Pavement Association.
(In the United States, many affiliated state pavement associations also exist.)

State Highway Departments
for each State in USA

REFERENCES

Oglesby, Clarkson H., and R. Gary Hicks. Highway Engineering, 4th ed., *Wiley, New York, 1982.*

Asphalt Institute Publications. *It has a number of documents on many aspects and uses of asphalt paving, including:*

Asphalt in Pavement Maintenance *(MS-16).*

Asphalt Overlays for Highway and Street Rehabilitation *(MS-17).*

Model Construction Specifications for Asphalt Concrete and Other Plant-Mix Types *(SS-1).*

Soils Manual *(MS-10).*

Thickness Design — Asphalt Pavements for Highways and Streets *(MS-1).*

Concrete

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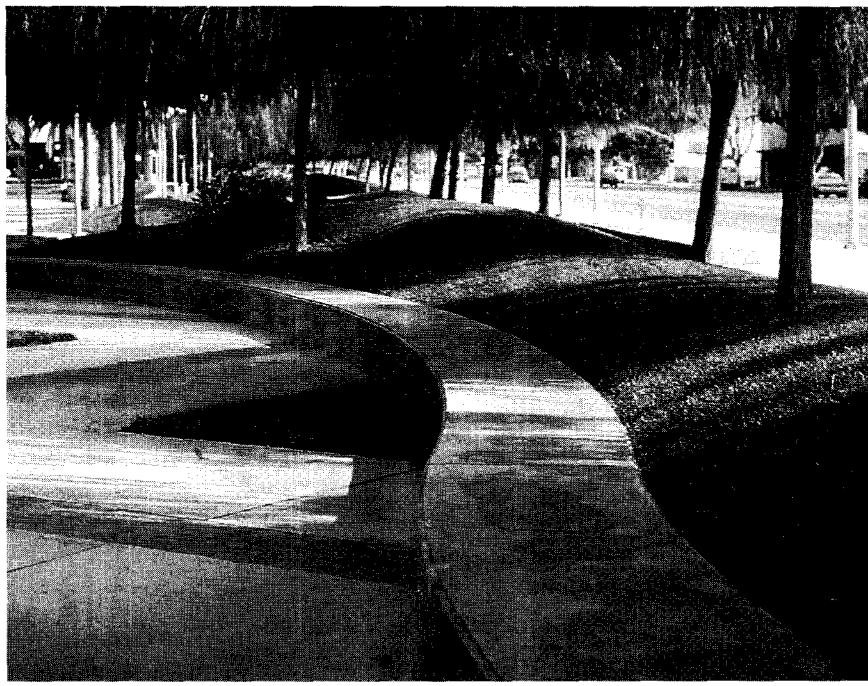

N. Dines

CONTENTS

1.0 INTRODUCTION

1.1 General

Concrete is a mixture of aggregate, portland cement, water, and sometimes special admixtures. Its most outstanding qualities are strength, durability, stability, availability, adaptability, and, in most cases, its relatively low cost in terms of construction and lifetime maintenance.

1.2 Properties of Concrete

The properties of concrete are determined by any one of the following several factors: (1) the quality of all constituents, including the type of cement used, the soundness of the aggregates used, the relative proportion of coarse and fine aggregate, the ratio of water to cement, and the type and amount of any chemicals, admixtures, and other compounds added to the mix; and (2) the skills used in placing, consolidating, finishing, and curing the concrete.

Five major properties to consider when producing finished concrete are described below.

Strength:

Strength is usually the first consideration for all concrete's except for lightweight or insulating concretes. The relative strength of concrete is a function of the type of cement and aggregate selected. Full strength is reached after about 28 days, however the strength may continue to increase past this date if sufficient moisture is available.

Resistance to Freeze/Thaw and Deicing Chemicals:

Resistance to freeze/thaw and deicing chemicals can be increased by the use of an air-entraining agent (i.e., an air-entraining admixture). Admixtures may reduce, or enhance somewhat, the potential strength of the concrete mix. (Refer to 5.0 Admixtures for Concrete in this section for more information.)

Resistance to Abrasion and Wear:

Resistance to abrasion and wear can be increased if the concrete mix contains well-graded strong aggregate and is well-consolidated when placed. For some purposes, special aggregate and finishes may be required. Finishing procedures are extremely critical for achieving abrasion resistance.

Reduction of Water Penetration:

Reduction of water penetration can be achieved by four means: (1) by keeping the water/cement ratio to less than 0.50 by weight, (2) by carefully treating all joints and cracks to prevent leaks, (3) by adding chemicals and admixtures to the concrete mix to reduce water penetration, and (4) by applying a waterproof surface seal or compound. Adding certain chemicals and admixtures to reduce water penetration often requires adding more mixing water, which may increase the permeability of the concrete.

Control of Setting Time for Concrete:

Control of the setting time for concrete is often needed in order to (1) reduce the setting time when temperatures are low enough to cause the water in the mix to freeze, (2) to increase the time for working concrete during very hot weather, and (3) to control bleeding, or the movement of water to the surface of freshly placed concrete. Also, normal bleeding will be a problem if finishing (floating, troweling, etc.) is performed while bleed water is on the surface

1.3 Methods of Placement

Three basic methods for placing concrete include:

1. Formed and molded (cast in place or precast)
2. Sprayed or air-blown (shotcrete)
3. Mixed in place (such as soil cement or dry-casting)

The most common technique for placement is the formed and molded method. The other methods offer distinct advantages only in certain situations.

Sprayed concrete can be applied to very complex horizontal and vertical surfaces, including hyperbolic forms. It can also be applied in relatively thin cross sections and will attain a very high density and strength. Sprayed concrete is widely used for constructing swimming pools and other sculptured elements within the landscape and for repairing deteriorating structures.

Mixed-in-place or soil concrete has been used for a long time to create low-cost stabilized surfaces. This typically involves mixing dry cement into the existing soil or surface materials, adding water, and then remixing and compacting.

This section covers only formed and molded concrete in detail.

1.4 Types of Concrete

There are many types of concrete that can be mixed for various applications. The most

KEY POINTS: Concrete Mixtures

1. Full strength of concrete is reached after about 28 days, however the strength may continue to increase past this age if sufficient moisture is available.
2. Resistance to abrasion and wear can be increased if the concrete mix contains well-graded strong aggregate and is well-consolidated when placed.
3. Reduction of water penetration can be achieved by four means:
   (a) by keeping the water/cement ratio to less than 0.50 by weight.
   (b) by carefully treating all joints and cracks to prevent leaks.
   (c) by adding chemicals and admixtures to the concrete mix to reduce water penetration.
   (d) by applying a waterproof surface seal or compound.
4. Control of the setting time for concrete is often needed to
   (a) reduce the setting time when temperatures are below freezing.
   (b) to increase the time for working concrete during very hot weather.
   (c) to control bleeding, or the movement of water to the surface of freshly placed concrete.
5. Air-entrained concrete should be used under all conditions involving severe exposure to frost/thaw temperatures.
6. Potable water is typically satisfactory for use in concrete. Water containing sulfates, salts or deleterious substances should be avoided.
7. Water to cement ratios should be selected on the basis of strength and workability requirements. Minimum cement content should not be less than 470 lb/yd^3.

frequently used types and their common uses are listed in Table 830-1.

2.0 CEMENT

2.1 Properties of Cement

Process of Hydration:

When cements are mixed with water, a chemical reaction called hydration occurs which results in hardening of the cement paste.

Heat of Hydration:

Heat is released during the hydration process between the cement and water. The amount of heat released increases with the type of cement, the mass of the concrete, and/or higher ambient temperatures. Heat should be retained in cold weather and dissipated in hot weather to maintain ideal curing temperatures.

2.2 Types of Cement

All portland cements are made from lime, silica, alumina, and gypsum. Gypsum is used to slow the setting time of the concrete. Five major types of portland cement are commonly used and classified both in the United States and Canada. In the United States, all cement should meet the American Society for Testing and Materials (ASTM) standards for portland cement, and in Canada the cements should meet the Canadian Standards Association (CSA) standards. These are listed and briefly described in Table 830-2. Additional types of cement are specially formulated for certain purposes.

3.0 AGGREGATE FOR CONCRETE

The aggregate used to make concrete performs several different functions. It typically constitutes 60 to 75 percent of the volume of most types of normal concrete. The most common types of aggregate used in making concrete are sand, gravel, and crushed stone. Aggregate is classified as fine if the particles are smaller than 5 mm (1/4 in), or coarse if larger than 5 mm (1/4 in) in diameter. Both the quality and the cost of the concrete are affected by the type of aggregate used in the mixture. Often, the choice of an aggregate is based on its local availability. This can give a special indigenous quality to the concrete mix if the aggregate is exposed in the final finishing process.

3.1 Types of Aggregate

Various types of igneous, sedimentary, and metamorphic aggregate are used in con-

Table 830-1. TYPES OF CONCRETE

Type	Description	Typical Uses
Normal weight	Weight of coarse aggregate used determines type; weight of aggregate: 135–165 lb/ft^3	
Lightweight—Structural	Weight of coarse aggregate used determines type; weight of aggregate: 85–115 lb/ft^3	Loadbearing and exterior walls, structural floors, prestressed concrete
Lightweight—Insulating	Weight of coarse aggregate used determines type; weight of aggregate: 15–90 lb/ft^3	Partitions and panel walls, decks, casing of structural steel, roof fill
Heavyweight	Weight of coarse aggregate determines type; weight of aggregate: 130–290 lb/ft^3	Walls of spaces containing radioactive materials; sometimes as counterweight
Cellular	Air or gas bubbles, suspended in mortar, characterize type; small amounts or no coarse aggregate provided	Where top insulating properties are required
Gap-graded	Omission of intermediate sizes of coarse aggregate characterizes type	Where aggregate is to be exposed; as insulating concrete, especially when lightweight aggregate and/or sand is not available or desirable; as inexpensive concrete for foundations
Shotcrete or gunite	Method of placement characterizes type; pneumatic equipment, using dry or wet method employed	Wherever construction without formwork is very desirable, as in complex forms (shells, domes, swimming pools)
Preplaced	Method of Placement characterizes type; coarse aggregate is placed dry, then mortar is pumped into it	Special forms and surfaces; e.g., exposed aggregate finishes on cast-in-place concrete columns
Pumped	Method of conveying plastic concrete for placement characterizes type	When concrete is to be placed high above grade or in formwork of complex shape
Ferrocement	Mix, method of placement, and reinforcement provided characterize type; mortar with large amount of light gauge reinforcing is used	Containers; e.g., bins, boat hulls, and other thin, complex shapes
Fiber	Addition of short fibers to mix characterizes type; where prevention of cracking is important; e.g., in highways and bridges, especially for pavement overlays	
Nailing	Nail-holding strength characterizes type; has high insulating value	

Source: Sweet's Selection Data: Cement and Concrete, McGraw-Hill, New York.

Table 830-2. APPROXIMATE RELATIVE STRENGTH OF CONCRETE AS AFFECTED BY TYPE OF CEMENT

Type of Portland Cement		Compression Strength; Percent of Strength of Type I or Normal Portland Cement Concrete			
ASTM	CSA	1 Day	7 Days	28 Days	3 Months
I	Normal	100	100	100	100
II	Moderate	75	85	90	100
III	High-early-strength	190	120	110	100
IV	Low-heat	55	55	75	100
V	Sulfate-resisting	65	75	85	100

Source: Portland Cement Association, *Design and Control of Concrete Mixtures,* 11th ed., Skokie, Ill., 1968.

crete construction, depending on availability and intended use. (Refer to Section 810: Soils and Aggregates, for a general discussion of aggregate.)

3.2 Selection of Aggregate

Selection of an aggregate should be based on the following criteria:

1. Resistance to abrasion if in a wearing surface
2. Performance record under conditions of similar use
3. Resistance to pop-outs or spalls caused by freezing or chemicals
4. Range of aggregate sizes needed for the required mix
5. Unit weight of the aggregate when used for lightweight concrete on rooftop gardens, plazas, decks, etc.

In addition, both the size and shape of the aggregate used in a concrete mixture are major variables affecting concrete properties. The following rules of thumb should be considered:

1. The size of aggregate should not exceed: (a) one-fifth the dimension of nonreinforced elements, (b) three-fourths the clear spacing between reinforcing bars and/or forms, and (c) one-third the depth of slabs. Use of the largest-size aggregate practical will generally reduce shrinkage and cracking of concrete.
2. Use of a proper mix of both large (coarse) and small (fine) aggregates will reduce the amount of necessary water in the mix.
3. Rough angular-shaped aggregate (such as crushed stone) will provide a better bond for the cement paste. Rough angular aggregates will not however necessarily result in a concrete of greater tensile and compressive strength than smooth, rounded aggregate (e.g., pebbles) because the angular aggregate requires more water in concrete and thereby somewhat reduces the ultimate strength of the concrete.
4. Elongated or flat aggregate should be avoided or limited to no more than 15 percent of the total aggregate by weight.

Table 830-3. TYPES OF ADMIXTURES

Types	Description
Air-entraining	Improves the concrete's resistance to freeze and thaw damage as well as to scaling due to deicing chemicals.
Water-reducing	Reduces the amount of water required for a given consistency of mix, and may affect the setting time. Some will increase drying shrinkage. May entrain some air.
Set-accelerating	Used to accelerate the set of concrete resulting in higher early strength. Some will increase dry shrinkage of the concrete during curing.
Set-retarding	Used to decelerate the set of concrete which results in lower early strength.
Pozzolans	Used to reduce the amount of cement required in a concrete mix. Improves workability. Strength is enhanced at later ages; heat of hydration is reduced.
Superplasticizers	Allows use of a much lower water to cement ratio in a concrete mixture. Can produce a more flowable concrete so that it can be pumped to the area of placement.

KEY POINTS: Aggregate for Concrete

1. The choice of an aggregate is usually based on its local availability. This can give a special indigenous quality to the concrete mix if the aggregate is exposed in the final finishing process.
2. The size of aggregate should not exceed:
   (a) one-fifth the dimension of nonreinforced elements.
   (b) three-fourths the clear spacing between reinforcing bars and/or forms.
   (c) one-third the depth of slabs. Use of the largest-size aggregate practical will generally reduce shrinkage and cracking of concrete.
3. Use of a proper mix of both large (coarse) and small (fine) aggregates will reduce the amount of necessary water in the mix.
4. Rough angular-shaped aggregate (such as crushed stone) will provide a better bond for the cement paste. Rough angular aggregates will not however necessarily result in a concrete of greater tensile and compressive strength.
5. Elongated or flat aggregate should be avoided or limited to no more than 15 percent of the total aggregate by weight.

4.0 ADMIXTURES FOR CONCRETE

4.1 Purposes of Admixtures

All substances that are added before or during the mixing of the concrete are referred to as admixtures. They are used to enhance one or more properties of the resulting concrete. Admixtures are often used for the following reasons:

1. To improve the workability of the concrete mixture by minimizing the separation of coarse and fine aggregate while it is being cast and/or worked
2. To reduce the water requirement of concrete significantly and thereby increase its strength
3. To entrain air in the mixture and thereby improve the concrete's durability and resistance to freeze/thaw damage, and its resistance to scaling caused by deicing chemicals
4. To accelerate or retard the hardening or setting of concrete
5. To increase the flowability of concrete to aid in placement

4.2 Selection Criteria for Admixtures

Before specifying an admixture, it must be determined:

1) whether the admixture will be compatible with the cement, aggregate, and any other admixtures that may be used.

2) whether the admixture will affect the workability, setting time, shrinkage,

strength, and/or permeability of the concrete.

3) whether the admixture will actually produce the desired results.

4.3 Types of Admixtures

Some of the more-common types of admixtures used in concrete and their effect on the concrete are listed in Table 830-3.

5.0 WATER

5.1 Water Quality

The water used to make concrete should be clean and free of oils, alkali's, acids, organic materials, and other deleterious substances. Water containing high concentrations of sulfates or salts should also be avoided. Potable water is typically satisfactory for use in concrete.

5.2 Water Quantity

The quantity of water needed for a mixture is always measured in relative proportion to the amount of cement used. An increase in the amount of water to cement will always result in concrete with less strength. For protection against frost damage, air entrained concrete should have a maximum water to cement ratio of 0.45. For protection of reinforcing steel against corrosion, the water to cement ratio should be no more than 0.40.

6.0 PREPARATION AND PLACEMENT OF CONCRETE

6.1 Mixing Testing and Site Preparation for Concrete

Mixing Concrete:

If ready-mixed concrete is available from local suppliers, then on-site mixing is seldom justified except on exceptionally large projects. Ready-mixed concrete should be delivered and placed within 90 minutes after cement has been added to the mixture. If concrete is less than 90 minutes old and has started to stiffen or dry out before it has been placed, it may still be used but only if it can be completely consolidated into forms. Adding water to the concrete to make the mixture more workable (retempering) is not considered ideal, but ASTM C94 (standard for ready-mixed concrete) does allow one retempering to bring the mix up to design slump requirements.

Testing Concrete:

A number of control tests are performed on concrete by inspection personnel, some of which are conducted while the concrete is fresh, and others while the concrete is in a hardened state. Some government authorities require certification by inspection personnel. Three common tests are the slump, air content, and cylinder tests.

Slump Test: The slump test determines the relative consistency among batches of concrete of the same design by measuring the amount of slump for a given-size cone of concrete (Figure 830-1 and Table 830-4). Changes in slump typically reflect changes in the amount of water in the mix, but they may also indicate changes in air content, sand content, aggregate gradation, temperature or hydration, and setting.

Air Contest Test: The air-content test determines the air entrainment at the time of use, thereby allowing an opportunity to adjust the mixture, if necessary, by adding more air entraining agent. An insufficient amount of air results in a concrete with poor resistance to freeze/thaw damage, and too much air results in a lower-strength concrete. The air content should be 5-8% to protect concrete frost and deicer damage.

Cylinder Test: The cylinder test is used to determine the compressive strength of cured concrete (Figure 830-2). This test involves

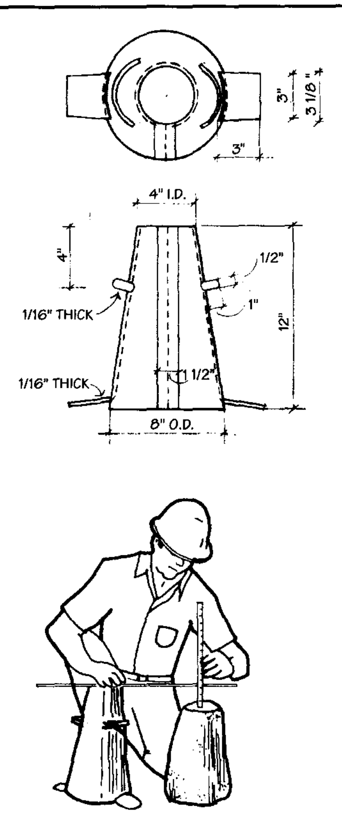


Figure 830-1. Slump test (ASTM C143). *Slump cones are made of metal and are 12 in. high, with a 4-in.-diameter opening at the top and a 8-in.-diameter opening at the bottom. The cone is filled with concrete in three layers of equal volume, and each layer is rodded 25 times with a steel tamping rod. After the cone is filled and the top surface is smoothed, the slump cone is slowly lifted vertically and the subsidence (slump) is measured.*

Figure 830-2. Cylinder test (ASTM C31). *Cardboard or steel molds are filled with fresh concrete in three equal layers, and each layer is rodded 25 times with a ⅝-in.-diameter tamping rod. Cylinders are lazeled and covered with a plate or plastic bag.*

Table 830-4. RECOMMENDED SLUMPS FOR VARIOUS TYPES OF CONCRETE CONSTRUCTION

Concrete Construction	Slump, in Maximum*	Slump, in Minimum
Reinforced foundation walls and footings	3	1
Plain footings, caissons, and substructure walls	3	1
Beams and reinforced walls	4	1
Building columns	4	1
Pavements and slabs	3	1
Mass concrete	2	1

* May be increased 1 in for consolidation by hand methods such as rodding and spading.

Source: C. G. Ramsey and H. R. Sleeper, *Architectural Graphic Standards*, 9th ed. , John R. Hoke (ed.), Wiley, New York, 1994.

Table 830-5. TYPES AND USES OF FORMWORK

Type	Uses	Remarks
Lumber	Form framing, form facing, shoring and bracing, edge forms (columns, beams, etc.)	
Plywood	Form facing	
Hardboard	Form facing	
Steel	Form framing, form facing, shoring and bracing, prefabricated forms, edge forms (columns, beams, etc.)	Patented prefabricated forms available, such as waffle slabs, joists, columns
Aluminum	Form framing, form facing, edge forms (columns, beams, etc.)	Light weight; facilitates handling
Fiberglass	Form facing, form liners, prefabricated forms	May be bonded to plywood or other form facings for a smoother patterned surface
Laminated fiber	Column forms, voids in concrete	Created to reduce weight of structure and provide passage for ductwork, raceways, etc.
Corrugated paper	Voids in slabs	See note
Metal decks	Floor framing, roof framing	May provide raceways for power and telephone; may be selected for composite action with concrete

Note: Form liners: (1) sandblasted Douglas fir or long-leaf yellow pine dressed one side away from the concrete surface; (2) flexible steel strip formwork adapted to curbed surfaces (Schwellmer System); (3) resin-coated, striated, or sandblasted plywood; (4) rubber mats; (5) thermoplastic sheets with high glass or texture laid over stone, for example; (6) formed plastics; (7) plaster of Paris molds for sculptured work; (8) clay (sculpturing and staining concrete); (9) hardboard (screen side); (10) standard steel forms; (11) wood boarding and reversed battens; (12) square-edged lumber dressed on one side; (13) resawn wood boards. Release agents: (1) oils, petroleum-based, used on wood, concrete, and steel forms; (2) soft scrubs; (3) talcum; (4) whitewash used on wood with tannin in conjunction with oils; (5) calcium stearate powder; (6) silicones used on steel forms; (7) plastics used on wood forms; (8) lacquers used on plywood and plaster forms; (9) resins used on plywood forms; (10) sodium silicate; (11) membrane used over any form; (12) grease used on plaster forms; (13) epoxy resin plastic used on plywood.

Source: Adapted from *Sweet's Selection Data: Cement and Concrete*, McGraw-Hill, New York ; also C. G. Ramsey and H. R. Sleeper, *Architectural Graphic Standards*, 9th ed., John R. Hoke (ed.), Wiley, New York, 1994.

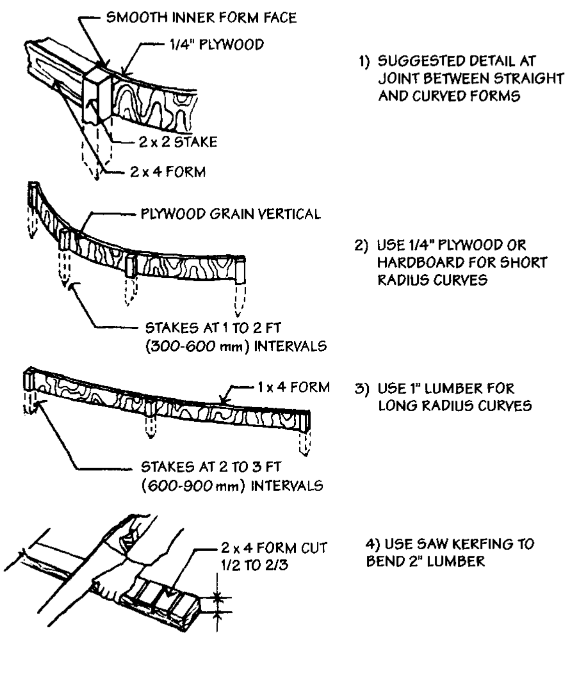


Figure 830-3. Details for making curved formwork.

putting concrete into a cylindrical mold 152 mm (6 in) in diameter and 300 mm (12 in) high. After the concrete has cured, the concrete cylinder is prepared and put into a special testing machine and subjected to increasing pressure until it fails. The point of failure is recorded as the concrete's strength in megapascals or pounds per square inch . Typically, cylinder tests are conducted at 7 days and 28 days following placement.

Site Preparation for Use of Concrete:

Except in extremely dry, very stable soils, most landscape-related uses of concrete require construction of an appropriate granular subbase over a prepared (compacted) subgrade. Construction details involving the use of concrete are shown in several sections of this handbook, including Division 900: Details and Devices.

The subgrade should be uniformly compacted, moist, and free of organic matter and expansive clays. Soft or muddy areas should be excavated, filled with soil similar to the abutting subgrade (or with a granular material such as sand, gravel, or crushed stone) and then compacted to the required density.

The subbase material between the subgrade and the concrete can be composed of a variety of granular materials as long as it is free-draining, durable, and capable of being compacted. (Refer to Section 810: Soils and Aggregates, for more information on soils and the use of various types of aggregate in landscape construction.)

6.2 Formwork for Concrete

Basic Function:

Formwork for concrete provides a container and supports the concrete when it is being placed and while it is setting. Typically, a designer will determine the configuration of a completed work, while a contractor or builder will be responsible for the actual strength design of the forms.

Formwork may be used only once or reused many times, depending on the type of formwork. In some cases the formwork is left in place as either a concealed or exposed part of the final design, referred to as a deadform). Table 830-5 describes types and uses of formwork .

Curved formwork for the construction of walks, drives, walls, etc., can be made from thin plywood [6 to 13 mm (1/4 to 1/2 in)], hardboard, sheet metal, or thicker lumber that is saw-kerfed (Figure 830-3).

Slip forms are used where continuous placing is an advantage, especially for

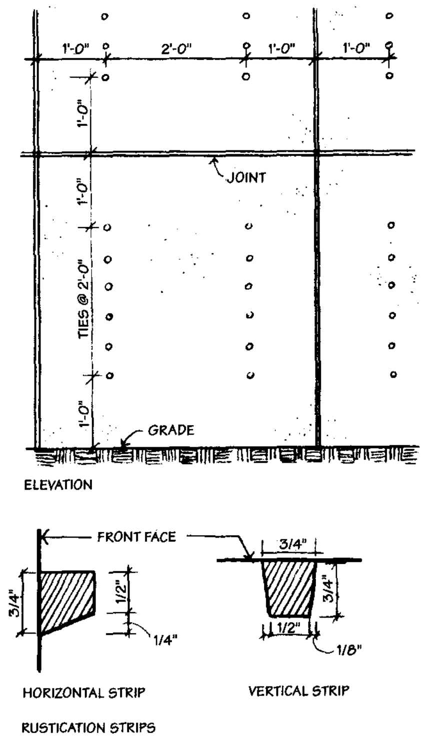


Figure 830-4. Exposed concrete with rustication strips. *Tie holes should be placed in a systematic pattern for aesthetic reasons.*

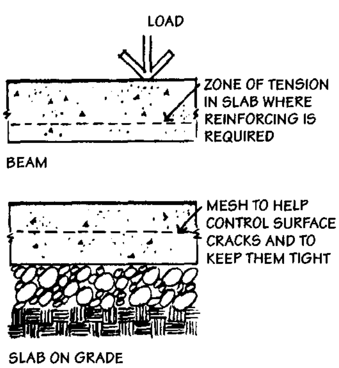


Figure 830-5. Typical reinforcement for beams and slab on-grade.

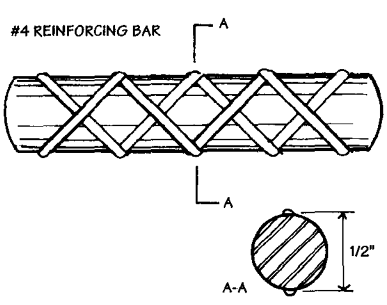


Figure 830-6. Reinforcing bars.

KEY POINTS: Preparation and Placement

1. Ready-mixed concrete should be delivered and placed within 90 minutes after cement has been added to the mixture.

2. Adding water to the concrete to make the mixture more workable (retempering) is not considered ideal, but ASTM C94 (standard for ready-mixed concrete) does allow one retempering to bring the mix up to design slump requirements.

3. Steel bars and welded wire fabric provide reinforcement for concrete structures and slabs. Tensile strength required will determine the size of bar or wire designated (Table 830-6).

4. Plastic, glass and steel fibers can be added to a concrete mix prior to pouring to create three-dimensional secondary reinforcement and to act as moderate inhibitors of cracks.

5. Prior to pouring, the subgrade and all forms must be moistened to prevent extraction of water from the concrete. Forms should also be treated with a nonstaining release agent for easier removal.

6. In slab construction, the placement of fresh concrete should begin along the perimeter of one end, with each successive batch placed against previously placed concrete.

7. In wall construction, the placement should begin at both ends and then progress from each end toward the center. The concrete should be placed in horizontal layers of uniform thickness, with each layer thoroughly consolidated before placement of the next layer.

8. Concrete should not be moved into position horizontally, for segregation between the mortar and coarse aggregate will result.

9. Concrete mixes (slumps) that will be consolidated by vibration should be considerably stiffer than those intended for consolidation by hand tools. The proportion of fine aggregate used in a concrete mix can also be reduced significantly if vibrators are used.

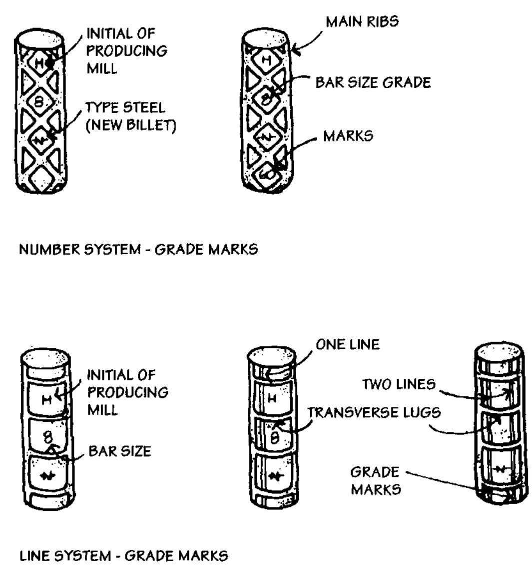


Figure 830-7. Reinforcing bar identification.

Slip forms are used where continuous placing is an advantage, especially for paving, curb and gutter operations.

Pattern Making:

Various patterns can be created in the surface of finished concrete by adding wood or plastic strips, special plastic liners, or small cones or other shapes to the faces of forms (Figure 830-4). Form liners made of plastic, rubber, or other materials can be placed between the form's face and the concrete to provide special finishes, textures, and patterns (Refer to 6.6 Finishing Concrete, in this section and to Table 830-9 for more information.).

Table 830-6. ASTM STANDARD REINFORCEING BARS SIZES—NOMINAL DIAMETER

Bar Size Designation	Weight per Foot		Diameter		Cross-Sectional Area Squared	
	lb	kg	in	cm	in	cm
3	0.376	0.171	0.375	0.953	0.11	0.71
4	0.668	0.303	0.500	1.270	0.20	1.29
5	1.043	0.473	0.625	1.588	0.31	2.00
6	1.502	0.681	0.750	1.905	0.44	2.84
7	2.044	0.927	0.875	2.223	0.60	3.87
8	2.670	1.211	1.000	2.540	0.79	5.10
9	3.400	1.542	1.128	2.865	1.00	6.45
10	4.303	1.952	1.270	3.226	1.27	8.19
11	5.313	2.410	1.410	3.581	1.56	10.07
14	7.650	3.470	1.693	4.300	2.25	14.52
18	13.600	6.169	2.257	5.733	4.00	25.81

Source: C. G. Ramsey and H. R. Sleeper, *Architectural Graphic Standards,* 9th ed., John R. Hoke (ed.), Wiley, New York, 1994.

6.3 Reinforcement of Concrete

Placement of Reinforcement:

Reinforcement is used to give concrete structures and slabs greater tensile strength and also to control cracking. Figure 830-5 shows the typical placement of steel or wire mesh reinforcement within a concrete slab or beam.

Types of Reinforcement:

Two types of reinforcement commonly used in landscape-related concrete are welded wire fabric and reinforcing bars. Plastic, glass, or steel fibers are also used as secondary reinforcement in concrete mixes.

Welded Wire Fabric (WWF): Welded wire fabric, also called mesh, consists of electrically welded grids of steel wire with or without galvanized coating or epoxy treatment. Mesh is typically available from manufacturers in rolls or flat sheets. Various gauges of wire and grid spacing are available. WWF sizes are referred to by a system of four numbers, such as: 6 x 6 x W1.4 x W1.4. The first number is the longitudinal spacing of the wires, and the second number is the transverse spacing. The third and fourth numbers indicate the respective wire sizes.

Reinforcing Bars: Reinforcing bars have irregularities or embossments called deformations which keep the bars from slipping within the concrete (Figure 830-6). The bar size is indicated by a number which, when multiplied by 3 mm (1/8 in), gives the nominal diameter of the bar in inches; for example, a No. 4 bar has an area equal to a bar of 13-mm (1/2-in) diameter (See Table 830-6.).

Figure 830-7 shows reinforcing bar identification. The minimum thickness of concrete needed to cover metal reinforcement for corrosion protection is shown in Table 830-7.

Steel reinforcing can be galvanized or coated with paints, plastic, or epoxy coatings, etc. Some type of coating is essential where high corrosion is a factor, such as for bridges, waterfront seawalls, docks, and similar structures.

Secondary Reinforcement: Plastic fibers can be added to a concrete mix prior to pouring to create three-dimensional secondary reinforcement and to act as moderate inhibitors of plastic shrinkage cracks. They are lightweight, noncorrosive, and inert to alkali attack. They can be used for precast as well as cast-in-place concrete. Manufacturers of this product have slightly different requirements for use, however most specifications call for 0.884 kg of fiber per cubic meter (1-1/2 lb/yd^3) of concrete. Some manufacturers make their fiber in lengths from 20 to 65 mm (3/4 to 2-1/2 in) to meet the needs of concrete with different sizes of aggregate. Steel fibers are also available for use when the concrete will not be exposed to the elements.

6.4 Placing and Consolidating Concrete

Once the subgrade is compacted and moistened, the forms erected, and the reinforcing steel set in place, the concrete can be placed. The subgrade and all forms must be moistened to prevent extraction of water from the concrete. Forms should be treated with a release agent for easier removal.

In slab construction, the placement of fresh concrete should begin along the perimeter of one end, with each successive batch placed against previously placed concrete. Concrete should not be moved into position horizontally, for segregation between the mortar and coarse aggregate will result.

In wall construction, the placement should begin at both ends and then progress from each end toward the center. The concrete should be placed in horizontal layers of uniform thickness, with each layer thoroughly consolidated before placement of the next layer. The layers should be 150 to 500 mm (6 to 20 in) thick for reinforced members, and 380 to 500 mm (15 to 20 in) thick for mass work. Concrete moved horizontally into position should be kept to an absolute minimum to prevent segregation of mortar and coarse aggregate.

The consolidation of concrete is accomplished either by hand tools or by vibrators. Concrete mixes (slumps) that will be consolidated by vibration can be considerably stiffer than those intended for consolidation by hand tools. The proportion of fine aggregate used in a concrete mix can also be reduced significantly if vibrators are used. Various types of vibrators include immersion-type (internal) vibrators, form vibrators, and vibrating screeds. Hand methods include the use of spades or puddling sticks or of various types of tampers.

6.5 Joints, Locations, and Fillers

Purpose of Joints:

Joints are needed in most types of concrete construction to minimize or control the possibly damaging effects of expansion and contraction in the concrete due to temperature variations and the presence of moisture. Concrete contracts after the curing period as a result of drying, and it will also expand or contract with variations in temperature. Contraction is most dramatic dur-

Table 830-7. MINIMUM CONCRETE COVER FOR REINFORCEMENT. *Minimum concrete cover for reinforcement (except for extremely corrosive atmospheres, other severe exposures, or fire protection) shall be as follows:*

	Min. cover (inches)
Slabs and joints	
Top and bottom bars for dry conditions	
#11 bars and smaller	3/4 in.
#14 and #18 bars	1 1/2 in.
Formed concrete surfaces exposed to earth, water or weather; in contact with sewage and for bottoms bearing on work mats or slabs supporting earth cover:	
#5 Bars and smaller	1 1/2 in.
#6 through #18 bars	2 in.
Bars and columns (formed)	
For dry conditions:	
Stirrups and ties	1 1/2 on.
Principal reinforcement	2 in.
Exposed earth, water, sewage or weather:	
Stirrups and ties	2 in.
Principal reinforcement	2 1/2 in.
Walls	
For dry conditions:	
#11 bars and smaller	3/4 in.
#14 and #18 bars	1 1/2 in.
Footings and base slabs	
Formed surfaces and bottoms bearing on concrete work mats.	2 in.
Preformed surfaces and bottoms in (3 in.) contact with the earth	
Over top of piles	2 in.

Source: ACI #301

KEY POINTS: Joints and Fillers

1. Isolation, or expansion joints extend the full depth of the concrete and provide for lateral movement between slabs or other fixed structures.
2. Control, or contraction joints are designed to restrict the cracking of the concrete to predetermined locations.
3. Control joints should be tooled or sawed to a depth of at least 1/4 to 1/3 the thickness of the concrete. If tooled, this is done during the finishing of the concrete surface. If sawed, this is done when the surface of the concrete is firm enough not to be damaged by the sawing process, normally 12 to 24 hours after finishing.
4. Construction joints provide places where casting of concrete can be stopped. They may contain tie bars, slip dowels, and/or keyways for load transfer.
5. Spacing of isolation or control joints in pavements should form square panels where possible (See Table 830-8 for spacing requirements).
6. All Joints except control joints should be filled with fiber, wood, metal, or other materials to provide a smooth and safe wearing surface.
7. In climates where freezing and thawing occurs, it is desirable to caulk or seal control joints in concrete slabs, especially if they have been saw-cut.

ing the first few months, but it may continue for a year or more.

Types of Joints:

Three types of joints typically used in concrete construction include:

1. **Isolation, or expansion, joints.** These joints extend the full depth of the concrete and provide for lateral movement between slabs or other fixed structures, such as buildings or retaining walls, steps, and posts.
2. **Control, or contraction, joints.** These joints are designed to restrict the cracking of the concrete to predetermined locations. Joints should be tooled or sawn to a depth of at least one-fourth to one-third the thickness of the concrete. If tooled, this is done during the finishing of the concrete surface. If sawn, this is done when the surface of the concrete is firm enough not to be damaged by the sawing process, normally 12 to 24 hours after finishing. If sawing is delayed too long, the concrete may crack before it is sawn or may start cracking just ahead of the saw. Saw cutting is ineffective unless all of the reinforcing is also cut.
3. **Construction joints:** these joints provide places where casting of concrete can be stopped. They may contain tie bars, slip dowels, and/or keyways for load transfer.

Figures 830-8 through 830-10 show different types all three kinds of joints.

Location of Joints:

Locations of joints in concrete walks, drives, large paved terraces, etc., are shown in Figure 830-11. For walks and drives, the control joints should be spaced at intervals about equal to their widths. Ideally, concrete slabs 100 mm (4 in) thick or more should have control joints about 2400-3000 mm (8 to 10 ft) apart, but never more than 6000 mm (20 ft) apart in any direction. Where possible, these panels should be approximately square. If spaced wider than 3000-3600 mm (10 to 12 ft), then control joints down the center of the panel should be used. Panels with acute-angled corners should be avoided, as these corners tend to break off and initiate cracking.

Control joints should be continuous, not staggered or offset. The spacing of control joints is a function of the slab's thickness and the expected shrinkage of the concrete. Shrinkage is influenced by wetness of the mix and the maximum size of the aggregate. Table 830-8 lists suggested spacing of control joints.

Joint Fillers:

Typically, all joints except control joints are filled with some special material and sealed. Such materials may be manufactured and preformed, ready to install prior to the placing of the concrete. Others may be installed or applied after the concrete has been placed. Three of the most common types of joint fillers are:

1. **Fiber filler:** these are boards or strips made with or without asphalt impregnation. Those without asphalt normally require a joint sealant to keep out moisture.
2. **Wood dividers:** these are made of pressure-treated or decay-resistant wood left in the concrete after it has been cast.
3. **Plastics, rubber, cork, or metal:** These materials are also used to fill and seal joints. They are available in a wide variety of forms, from simple strips to complex shapes.

Several other types of materials can be used as joint fillers, including closed cell polyurethane, sponge or regular rubber, cork, special plastics, and metal expansion-joint systems.

Joint sealants are used to prevent filler material from bleeding or being squeezed

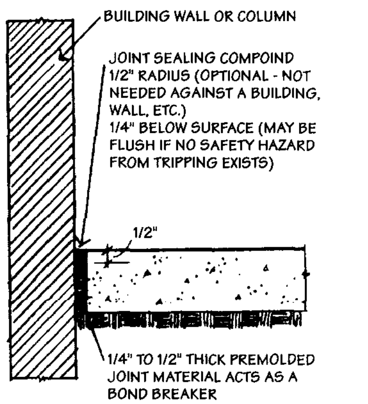


Figure 830-8. Isolation joints.

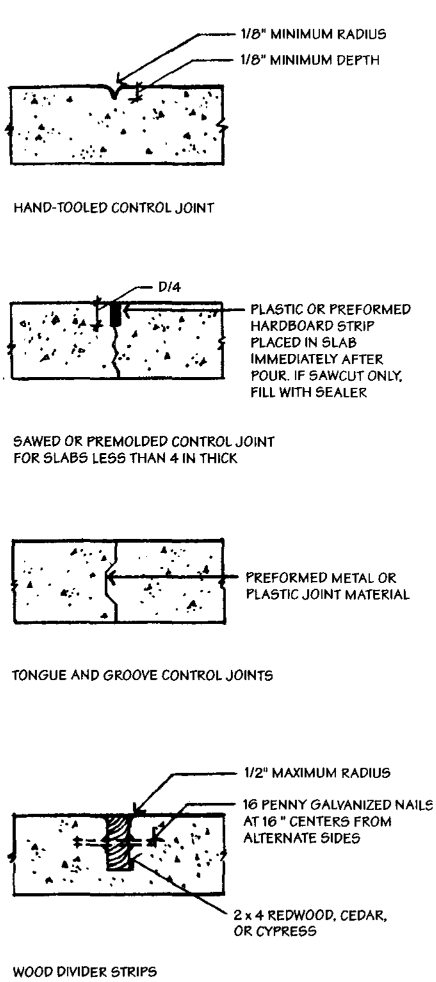


Figure 830-9. Types of control joints.

up, to keep out sand and other debris, and to help keep water out of the joints in climates where freezing occurs. The sealant must be compatible with the joint filler material, the concrete, and other materials in contact. Joint sealants are available in a variety of colors. Bacher rods or bond breaking materials may be recommended between the joint filler and sealant to prevent three-sided adhesion of sealant.

In climates where freezing and thawing occurs, it is desirable to caulk or seal control joints in concrete slabs, especially if they have been saw-cut.

6.6 Finishing Concrete

Surface Finishing:

Floating and troweling can begin as soon as the concrete starts to stiffen. The time required for concrete to stiffen depends on the wind, temperature, relative humidity, and type of concrete used. Finishing should not begin until bleed water (which is often present on the surface of the new concrete) has evaporated.

The formwork can be used to give different patterns to the surfaces of precast elements or vertical structures, such as the exposed faces of retaining or freestanding concrete walls. Strips of wood, metal, plastic or rubber liners can be used to achieve different effects. For horizontal surfaces, such as paved walks, there are a number of different ways to finish the concrete. Table 830-9 shows several common types of concrete finishes.

Two of the most common types of concrete finishes are: Floated finish is used when concrete has been placed, consolidated, struck off, leveled, and when the water sheen has disappeared and the surface has stiffened enough to permit floating. Floating can be done with a hand float, power trowel equipped with float shoes, or with a powered trowel disc float. During and after the first floating, the evenness of the surface should be checked with a 10-ft straight-edge applied to no less than two different angles. When the surface has met the desired slope tolerance, the slab should be refloated immediately to a uniform sandy texture.

Troweled finish may be used after the surface has been float finished as described above. Typically, the surface is first power troweled to make it smooth. Then, when it has hardened enough to cause a ringing sound when the trowel is moved over the surface, a hand trowel is used to make the surface free of trowel marks and uniform in texture and appearance. Troweled finishes should not be used outdoors because they are too slippery.

KEY POINTS: Finishes

1. Finishing should not begin until bleed water (which is often present on the surface of the new concrete) has been reabsorbed by the concrete.

2. Various casting, abrasive, chemical, and mechanical processes can be used to create finish concrete (Table 830-9). Different tools will yield dramatically different finishes (Table 830-11).

3. Coloring is typically achieved through color pigments integrated into the concrete mix, the dry-shake method of sprinkling pigments onto the surface, or through stains and paints used on hardened or existing surfaces.

4. Exposed aggregate finishes are usually achieved by hosing or acid washing and brushing the surface after it begins to set. The seeding method offers an alternative to this technique, where aggregate is sprinkled over freshly placed concrete and pounded into the surface.

5. Nonslip finishes can be achieved by hand-tooling with floats, trowels, or brooms, or by dry-shaking abrasive grains onto the surface.

6. Patterned or stamped finishes can be produced on freshly placed concrete surfaces through the use of special imprinting tools (Figure 830-12). A range of typical patterns is shown in Figure 830-13.

7. If retarder is used for exposed aggregate finishes, then edging is not feasible because the retarder will not allow a smooth edge to be created.

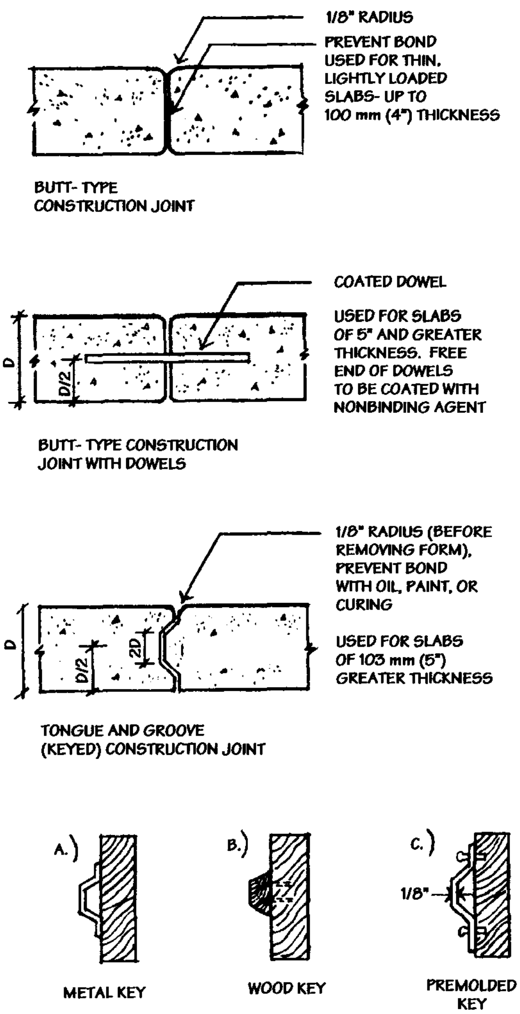


Figure 830-10. Types of construction joints.

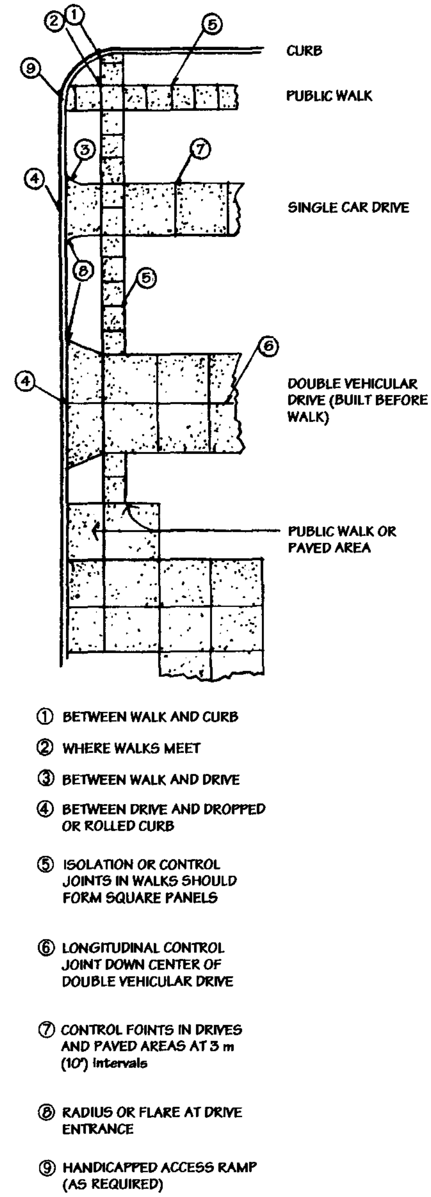


Figure 830-11. Location of joints.

Colored Concrete:

Coloring is typically achieved in three different ways.

1. Color pigments can be added to the concrete by either a one- or two-course method. The one-course method involves mixing special pigments into the concrete mix before it is placed. White cement is best for the lightest colors, but common Type I buff cement is used most frequently. The two-course method involves a first course of regular concrete, whose surface is left rough, and then a top or finish course of 12 to 25 mm (1/2 to 1 in) of colored concrete.

2. The dry-shake method consists of sprinkling special dry pigments on the surface of the newly cast concrete after it has had a preliminary floating, edging, and grooving. This technique requires the skill of a professional cement finisher to achieve uniform colors. Special effects can be achieved by adding color pigment to the mix, and then using the dry-shake method after the concrete is placed. The dry-shake method allows a wide range of dark and intense colors.

3. Stains and paints are typically used only when an existing slab of concrete has to be colored. Paints wear off and have to be reapplied over time, whereas stains or dyes penetrate into the surface. It is difficult to achieve uniform colors with some stains, and most stains eventually fade in sunlight.

The selection of a proper curing method is important when curing colored concrete. Waterproof paper or plastic sheets should not be used because they will cause discoloration. In most cases, a better solution involves the application of a wax-based curing compound that is clear or the exact same color as the colorant. It is difficult to steel-trowel the surface of colored concrete without causing variations or discolorations.

Table 830-10 lists the range of colors and agents used to make colored concrete.

Exposed Aggregate Finishes:

Exposed aggregate finishes are widely used because they offer a wide range of colors and textures as well as provide resistance to slipping and heavy wear. Three common methods used to create an exposed aggregate finish include the one-course, two-course, and seeding methods.

1. The one-course, or integral, method involves a single cast of concrete. The mix must contain a very high proportion of coarse to fine aggregate. The coarse aggregate to be left exposed should be of uniform size, specially selected for durability, and of contrasting color to the concrete paste. The concrete is finished in the usual way via floating, etc., until it begins to set; then the aggregate is ready for exposure by hosing or acid washing and brushing (or later by grinding, as with terrazzo). A surface retarding agent is sometimes applied, to control the time of exposure.

2. The two-course method involves a base course of conventional concrete, over which is promptly placed a 12- to 25-mm (1/2- to 1-in) concrete topping with special aggregate. The same technique of finishing and exposing the aggregate is used in the two-course method as is used in the one-course method.

3. The seeding method involves sprinkling specially selected aggregate over a freshly placed and rough-finished or screeded concrete base and pounding it into the surface while floating the concrete. This method requires much more working time, but a special retardant can be used to provide the extra time needed to perform this method. This method requires skilled labor to achieve uniformity of appearance.

The use of ground or polished terrazzo for exterior paving is not recommended because of the danger of pedestrians slipping when it becomes wet. A rustic terrazzo, similar to exposed aggregate concrete, is available from terrazzo contractors.

Table 830-8. SPACING OF CONTROL JOINTS

Slab Thickness, in	Less Than 3/4" Aggregate Spacing, ft	Larger Than 3/4" Aggregate Spacing, ft	Slump Less Than 4" Spacing, ft
5	10	13	15
6	12	15	18
7	14	18	21
8	16	20	24
9	18	23	27
10	20	25	30

* Given spacings also apply to the distance from control joints to parallel isolation joints or parallel construction joints. Spacings greater than 15 ft (5 m) show a marked loss in effectiveness of aggregate interlock to provide load transfer across the joint.

Source: Portland Cement Association, *Concrete Floors on Ground,* 2d ed., Skokie, Ill., 1983.

Special Non-Slip Finishes:

Non-slip finishes can be achieved by hand-tooling with floats, trowels, or brooms, or by dry-shaking abrasive grains onto the surface. The two most widely used abrasives are silicon carbide and aluminum oxide. Such abrasives are applied in the same way as the dry-shake method for coloring concrete.

Patterned or Stamped Finishes:

These finishes can be produced on freshly placed concrete surfaces through the use of special imprinting tools (Figure 830-12). Typically, these methods are used for horizontal surfaces, but they can be used for precast tilt-up walls, etc. These patterns can be achieved on the surface of any fresh concrete, whether that of a monolithic slab or a thin topcoat of concrete [with a minimum thickness of 12 to 75 mm (1/2 to 3 in)] over an existing slab of concrete. The fresh concrete is screeded to the proper grade, wood-floated, colored (if not premixed with color), and then imprinted with tools used to create the desired patterns.

Several companies make imprinting tools, and a few have developed trademarked techniques for installation. The imprinting tools are either open-faced, with only the pattern part touching the concrete, or solid-faced, with total contact made with the fresh concrete. Rubber-faced steel rollers are also used for texturing concrete surfaces. A range of typical patterns is shown in Figure 830-13.

Finishing Tools:

To achieve a desired finish on concrete, a designer will often indicate which tool should be used. Table 830-11 describes typical concrete finishing tools.

Edging:

Edging the concrete provides rounded edges that prevent chipping or other damage when forms are removed. Also, edging helps compact and harden the surface concrete next to the form, where floats and trowels are normally less effective. Edging may have to be done several times during the finishing operation to produce a clean, smooth, uniform edge.

KEY POINTS: Curing

1. The most common methods for retaining the moisture in concrete for proper curing are wet covering, waterproof paper or plastic sheets, sprinkling or ponding of water, and curing compounds.

2. Favorable temperatures for curing are those above 10° C (50° F) and below 29° C (85° F)

3. Concrete should be protected from freezing weather during installation, and for a period of 7 days to 2 weeks after placement unless special mixes such as Type III (High Early Strength Cement), a low water/cement ratio, or accelerator admixtures are used.

4. Waterproof paper or plastic sheets should not be used during the curing process on colored concrete because they will cause discoloration. A wax-based curing compound that is clear or the exact same color as the colorant should be used.

6.7 Curing

The durability of concrete continues to improve significantly up to 28 days and for several months beyond, as long as (1) moisture is present and (2) temperatures are favorable. Concrete should be protected from rapid drying and from freezing temperatures particularly during the first week after it is placed and finished. Several methods and materials are used to achieve proper curing (Table 830-12).

Moisture Control:

Four of the most common methods for retaining the moisture in concrete for prop-

Table 830-9. TYPES OF CONCRETE FINISHES

Category	Finish	Color	Forms	Critical Details
		Casting Processes		
	Remains as is after form removal[1]	Cement first influence, fine aggregate second influence	Wide range of options[1]	Slump = 2½–3½ in; joinery of forms; proper release agent; point form joints to avoid marks
		Abrasive Processes		
Brush blast	Uniform scour cleaning	Cement and fine aggregate have equal influence	All smooth	Scouring after 7 days; slump = 2½–3½ in
Light blast[2]	Sandblast to expose fine and some coarse aggregate	Fine aggregate primary, coarse aggregate and cement secondary	All smooth	10% more coarse aggregate; slump = 2½–3½ in; blasting between 7 and 45 days
Medium exposed aggregate[2]	Sandblasted to expose coarse aggregate	Coarse aggregate	All smooth	Higher than normal coarse aggregate; slump = 2–3 in; blast before 7 days
Heavy exposed aggregate[2]	Sandblasted to expose coarse aggregate; 80% viable	Coarse aggregate	All smooth	Special mix coarse aggregate; slump = 0–2 in; blast within 24 hr; use high frequency vibrator
		Chemical Processes		
Retardation of surface set	Chemicals expose aggregate	Coarse aggregate and cement	Glass fiber best and all smooth	Grade of chemical determines depth of etch; Stripping scheduled to prevent long drying period between stripping and washoff
Hardeners and coatings[3]	Aggregate can be adhered to surface			
		Mechanical Processes		
Surface fracturing, scaling, bush hammering, jack hammering, tooling[4]	Varied	Cement; fine and coarse aggregate	Textured	Aggregate particles ⅜ in for scaling and tooling; aggregate particles
		Combination Processes		
	Striated/abrasive blasted/ irregular pattern; corrugated/abrasive; vertical rusticated/abrasive blasted; reeded and bush hammered; reeded and hammered	The shallower the surface, the more influence aggregate fines and cement have	Wood or rubber strips, corrugated sheet metal, glass fiber, or asbestos cement	Depends on type of finish desired; wood flute kerfed and nailed loosely

[1] Form liners—rubber mats, plastic panels, wood boards (unfinished sheathing lumber or tongue-and-groove lumber), plywood, wood siding, and wood strips: used for walls and wall panels; secured to surfaces, either horizontal or vertical, against which concrete is poured; joints between plastic panels may have to be specially treated (Among other ways, the grain of the wood in plywood can be exposed by wire-brushing or sandblasting or in other ways)

Form liners—plaster-of-paris forms, wood forms, molded fiberglass forms: also used for walls and panels; repetitive elements used to allow multiple use of formwork. Wood forms may be protected with sprayed-on fiberglass

Dimpled: used for wall panels; size of aggregate bed against which concrete is cast and thickness of plastic film covering will influence pattern

[2] Exposed aggregate—marble chips, crushed rock, glass fragments, flagstone, gravel: Used for walls and wall panels, walks and terraces; large-size aggregates and flagstone are generally used when panels are cast exposed face down; aggregate transfer is used in vertically cast wall panels

Exposed aggregate—ground or polished: used for floors, floor tile, and stair treads, and for wall-facing panels; a surface sealer is recommended for floors, floor tile, and stair treads, not recommended for outdoor paving if pavement can become wet from rainfall or other sources of water

[3] Hardeners include liquid ones for sealing surfaces of poorly finished concrete paving in order to prevent dusting. Penetrating surface coatings are for waterproofing vertical surfaces. Film-forming and clear or pigmented surface coatings are for waterproofing and sealing horizontal and vertical surfaces.

[4] Types of mechanical processes include:
- Rubbing, grinding, acid etching, soundblasting, and bushhammering for removing imperfections on exposed concrete surfaces after forms are stripped. Surface texture will be changed to varying degrees depending on process used.
- Screeding or strike-off for surfaces not exposed to weather, wear, or view, e.g., footings and top surfaces of base course in two-course construction. May be floated to correct irregularities and level the surface.
- Float, trowel, or broomed swirl for horizontal surfaces, such as walks, ramps, and terraces, where slip-resistance is required and appearance is important.
- Burlap drag for large surfaces, such as pavements and driveways, where slip-resistance is required and appearance is of secondary importance.
- Steel-troweled for horizontal surfaces exposed to wear, such as residential, commercial, and light industrial floors.
- Shake-on aggregate steel-troweled for horizontal surfaces, such as heavy industrial and warehouse floors, that are exposed to severe wear.
- Travertine for walks and terraces. The finish coat is of white cement and yellow pigment is generally added.
- Rock salt for walks and terraces; not recommended in freeze-thaw climates.
- Stamped pattern for walks and terraces; many varieties of stamping tools are available.

Source: C. G. Ramsey and H. R. Sleeper, *Architectural Graphic Standards*, 9th ed., John R. Hoke (ed.), Wiley, New York, 1994.

Table 830-10. COLORING AGENTS FOR CONCRETE

Color	Ingredients
White	White portland cement, white sand
Buff	Buff portland cement, small quantity of black iron oxide, magnesium black, Germantown lampblack
Brown	Burnt umber, brown iron oxide, yellow oxide of iron to obtair modification
Yellow	Yellow oxide of iron
Buff	Yellow ochre, yellow oxide of iron, red oxide of iron may be used in small quantity
Cream	Small quantity of yellow oxide of iron
Pink	Small quantity of red oxide of iron
Rose	Red oxide of iron
Green	Chromium oxide, yellow oxide of iron may be added
Blue	Phthalocyanine blue
Black	Powdered carbon black

Source: Adapted from American Concrete Institute, *Slabs on Concrete,*Detroit, 1982.

er curing are wet covering, waterproof paper or plastic sheets, sprinkling or ponding of water, and curing compounds.

1. **Wet covering:** involves placing burlap or other moisture-retaining fabric over the wet concrete and keeping it wet. The use of coverings that may stain the concrete surface should be avoided.
2. **Waterproof paper or plastic sheets:** these can be used to prevent rapid loss of moisture from the concrete. The edges of materials must be lapped or sealed, and if exposed to wind, secured in place. Surfaces should be wetted before being covered.
3. **Sprinkling or ponding of water:** this is very effective but often expensive and difficult to supervise. Ponding requires sand or earth berms which have to be removed later and may leave stains.
4. **Curing compounds:** these can be used to help sustain curing after removal of the forms or protective coverings. Some curing compounds should not be used when waterproofing, sealers, glaziers, or other thin set type coatings are to be added later because they are not compatible with coating compounds. Both materials should be compatible, or an acid solution should be used to remove the curing compound before applying the waterproofing or coating compound.

Temperature Control:

Favorable temperatures for curing are those above 10°C (50° F) and below 29° C (85° F). Temperature affects the rate of setting. Higher temperatures cause quicker setting.

At low temperatures, slightly less water is needed to create a workable mix. Concrete should be protected from freezing weather during installation, and for a period of 7 days to 2 weeks after placement to maintain test strength. This can be accomplished by covering the concrete with plastic sheets and using portable heaters or insulating blankets, by steam curing, or by using special mixes such as Type III (high early strength cement), a low water/cement ratio, or accelerator-type admixtures.

6.8 Sealers and Glaziers

Special compounds are sometimes used to seal or glaze concrete. They are typically used on new or old concrete to provide a waterproof sealer which prevents or reduces moisture and chloride penetration. Some are also used to bring out natural colors in the aggregate or the colors of the concrete.

Various manufacturers have their own types and associated trade names for these sealers and glaziers. Three common types include:

1. Sealer and curing compound: this compound is suitable for use on concrete surfaces. It can be applied on damp concrete or used on fresh concrete as a nonfugitive curing compound that will provide continuous protection.
2. Glazer-sealer: this is a compound that brings out the natural color of slate, brick, stone, and concrete. It is recommended for exterior paved surfaces and walls.
3. Deck coating: this is a two-coat sealer for concrete slabs and decks which reportedly allows water vapor to evaporate but blocks penetration of moisture and chlorides. The first coat of oligomeric alkoxysilane chemically bonds to the substrate, penetrating the concrete surface about 6 mm (1/4 in). The second coat cures to a breathing film that reduces water absorption but permits escape of water vapor. It is resistant to deterioration from ultraviolet light and will not turn a yellow color. It should not be applied until the concrete has thoroughly dried.

6.9 Weathering Indexes in the United States

Figure 830-14 shows weathering indexes for the United States, that are determined by the product of the average number of freezing-cycle days and the average annual amount of winter rainfall, defined as follows:

A freezing-cycle day is any day during which the air temperature passes either above or below 0° C (32° F). The average number of freezing-cycle days in a year may be taken to equal the difference between the mean number of days during which the minimum temperature was 0° C (32° F) or below and the mean number of days during which the maximum temperature was 0° C (32° F) or above.

Winter rainfall is the sum, in centimeters (or inches), of the mean monthly corrected

Key Points - Sealants

1. Sealer and curing compound can be applied on damp concrete or used on fresh concrete as a nonfugitive curing compound that will provide continuous protection from moisture.
2. Glazier-sealer is a compound that brings out the natural color of slate, brick, stone, and concrete while providing moisture and chloride protection.
3. Deck coating allows water vapor to evaporate but blocks penetration of moisture and chlorides. It is resistant to deterioration from ultraviolet light and will not turn a yellow color. It should not be applied until the concrete has thoroughly dried.

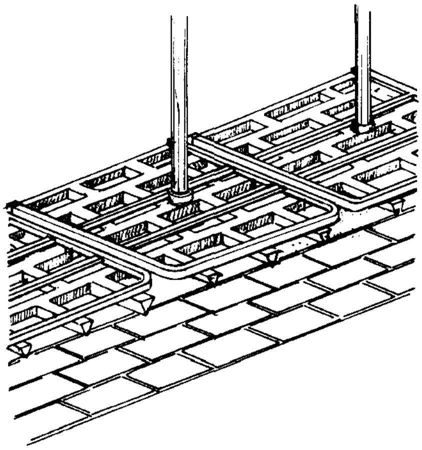


Figure 830-12. Imprinting or Pattern Stamping Tool. *Laborers step from pad to pad, stamping the design to a depth of about 1 in. (25mm).*

precipitation (rainfall) occurring during the period between, and including, the normal date of the first killing frost in the fall and the normal date of the last killing frost in the spring. The winter rainfall for any period is equal to the total precipitation less one-tenth of the total fall of snow, sleet, and hail. Rainfall for a portion of a month is prorated.

The weathering index shows general areas where concrete is subject to weathering.

6.10 Restoration and Repair of Concrete

Restoration and repair of concrete involves the following procedure:

1. Removal of all damaged and spalling concrete and cleaning of existing concrete to remove loose material and dust.
2. Concrete or grout is mixed in small amounts.
3. After cleaning, the damaged area is saturated with water and a neat cement slurry or bonding agent is applied to the entire base. Grout mix should comprise 1 to 1.5 parts of cement to concrete sand by weight or volume and be mixed damp (crumbly dry) to the touch.
4. The new concrete is finished to match the existing adjacent surfaces.
5. The concrete is moisture-cured to prevent shrinkage and cracking.

GLOSSARY

Accelerator. An admixture added to concrete to hasten its set and increase the rate of strength gain (the opposite of retarder).

Admixture. A material (other than portland cement, water or aggregate) added to concrete to alter its properties (i.e., accelerators, retarders, air entraining agents).

Aggregate. Normally, a hard, inert material mixed with cement and water to form concrete.

Bag (of cement). A quantity of cement that weighs 94 lb in the United States, 40 kg in Canada, and 50 kg in most other countries using the metric system.

Bleeding. Appearance of excess water rising to the surface shortly after the placing of concrete.

Cement. A binding agent (i.e., glue) capable of uniting dissimilar materials into a composite whole.

Concrete. A composite material made of cement, water, aggregates, and sometimes special admixtures.

Consistency. Uniformity of mixes or batches as measured by the slump test.

Crazing. Numerous fine hair cracks in the surface of a newly hardened slab.

Dusting. Appearance of a powdery material at the surface of a hardened concrete slab, probably caused by improper curing.

Formwork Structure erected to temporarily contain the concrete during its placing and initial hardening.

Graded aggregate. Aggregate containing graduated particle sizes from the finest fine aggregate size to the maximum size of coarse aggregate.

Graded sand. Sand containing uniformly graduated particle sizes from very fine up to 6 mm (1/4 in).

Grout. A fluid mixture of cement, water and sand of casting consistency.

Heat of hydration. Heat created during the hardening process of concrete.

Hydration. The chemical reaction of water and cement that produces a hardened concrete.

Hydraulic cement. A cement that can set or harden while under water.

Inert. Having inactive chemical properties.

Monolithic concrete. Concrete placed in one continuous cast without joints.

Neat cement. A mixture of cement and water (no aggregate).

Placing. The act of putting concrete in position (sometimes incorrectly referred to as pouring).

Plastic concrete. Easily molded concrete that will change its form slowly only if the mold is removed.

Precast concrete. Concrete components which are cast and cured off-site or in a factory before being placed into their final position.

Prestressed concrete. Concrete subjected to compressive forces by the prestretching (or stressing) of reinforcing bars or cables within, thereby developing greater strength, stiffness, and crack resistance in the concrete.

Puddling. Compacting concrete with a spade, rod, or other tool.

Ready-mixed concrete. Concrete mixed at a central plant or in trucks enroute to the job and delivered ready to be placed.

Reinforcing. Steel placed in concrete to take tensile stresses.

Retarder. An admixture added to concrete to retard the speed of its set.

Scaling. Breaking away of the hardened concrete surface of a slab [to a depth of about 1.6 to 4.8 mm (1/16 to 3/16 in)], usually occurring at an early age of the slab.

Scoring. Partial cutting of concrete to control shrinkage and cracking. Also used to denote the roughening of a base slab to develop a stronger mechanical bond with a finish slab, etc.

Segregation. Separation of heavier coarse aggregates from the mortar or of the water from the other ingredients of a concrete mix during handling or placing.

Shrinkage. Decrease in the initial volume due to the removal of moisture from fresh concrete. Also, it may refer to a decrease in volume due to subsequent decreases in temperature or moisture content.

Spalls. Fragments of concrete dislodged from the surface of concrete.

Subbase. A layer of material, aggregate, or coarse-graded concrete between the subgrade (soil, etc.) and the top course of the paving.

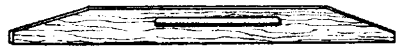
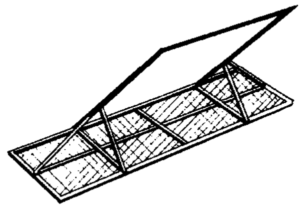
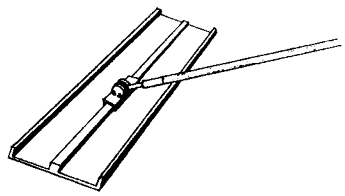
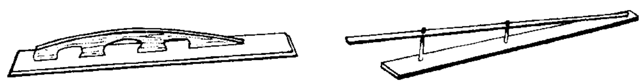
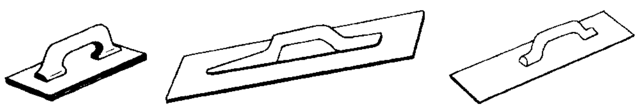
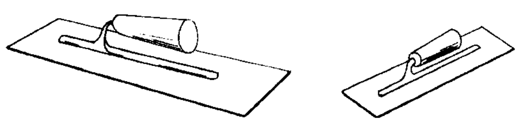
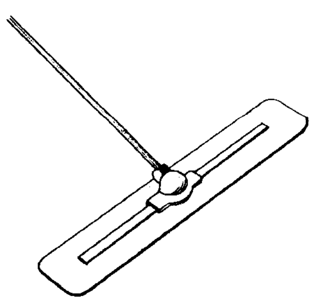
Subgrade. Compacted fill or earth surface upon which subbase is placed.

Swale. A low, flat depression to drain away storm water.

Water/cement ratio. The amount of water (liters or gallons) used per unit of cement in making concrete, often expressed as a pure number ratio, such as pound of water per pound of cement. It is an index to strength, durability, watertightness, and workability.

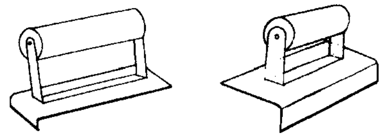
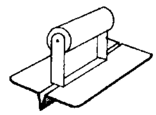
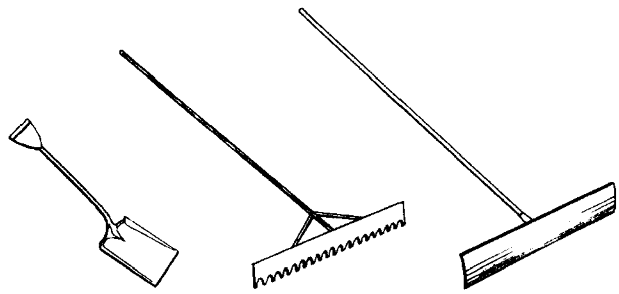
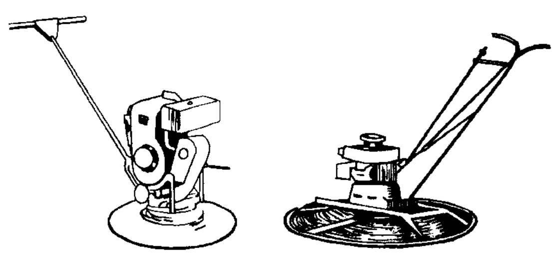
Workability. Relative ease or difficulty with which concrete can be placed and worked into its final position within forms, around reinforcing, etc.

Table 830-11. CONCRETE FINISHING TOOLS.

Tool	Description	Illustration
Straight-edge (screeds): Wood (6–16 ft long) Magnesium (6–14 ft long) Vibrating straightedges (up to 80-ft spans)	Used to strike off concrete to the required elevation	
Tampers (jitterbug): Flat grill Roller grill Power compactors (subgrades and subbases)	Used to push down coarse aggregates to just below the surface. Used only on very stiff concrete mixtures immediately after striking off the surface (straightedging)	
Bull floats: Wood (42–60 in wide) Magnesium (42–60 in wide)	Used to smooth the surface following straightedging (to get rid of high and low spots). Generally, wood bull floats perform better except on air-entrained and lightweight concretes	
Darbies: Short darbies (wood or magnesium) Long-handled darbies (wood or magnesium)	Used for the same purpose as bull floats (to get rid of high and low spots)	 (a) (b) (a) *Short-handled, and* (b) *long-handled darbies.*
Floats: Wood Magnesium Power floats (rotary)	Used to make surfaces true. Wood floats are best for non-air-entrained concrete and for high-slump concrete. Magnesium is used for low-slump, air-entrained, and lightweight concretes	 (a) (b) (c) (a) *Small wood float;* (b) *large magnesium float;* (c) *small magnesium float.*
Trowels: Spring steel (various sizes) Power trowelers (rotary)	Makes the surface hard and dense. Done after floating	
Fresno: Spring steel	A long-handled trowel, used as a trowel, not a bull float, where speed of troweling is important	

Source: American Concrete Association, *Slabs on Grade*, Detroit, 1982.

Table 830-11. CONCRETE FINISHING TOOLS.

Tool	Description	Illustration
Edging Tools: Short edgers Long edgers Corner tools Walking edgers	Used to round off edges so they are less likely to chip. Done after the slab has been bull floated and darbied	 (a) (b) *A shorter edger (a) is used on curves, while the longer edger (b) is used on straight runs.*
Jointers (Groovers):	Used to make contraction joints in slabs, about one-fourth the thickness of the slab	
Special tools: Tools to spread concrete: Square-nose shovel Concrete rake Come-along Tools to texture the surface: Wire comb texture broom (for nonslip surfaces, 3–5 ft wide) Shallow groovers ("cheaters")		 (a) (b) (c) (a) *A no. 2 square-nose shovel gives good leverage for moving concrete;* (b) *a concrete rake (not a garden rake) can be used with stiff concrete;* (c) *a come-along is wide enough to minimize segregation of the aggregates from the paste.*
Vibrators: Internal vibrators External vibrators Form vibrators Surface vibrators (vibrating screeds)	Used to consolidate concrete.	
Power Floats and Trowels: "Pony" trowels Heavy disk-type floats ("Kelly float") Large riding machines	Used for both floating and troweling. Kelly floats are used to compact and float heavy-duty floor toppings made with very low-slump concrete.	

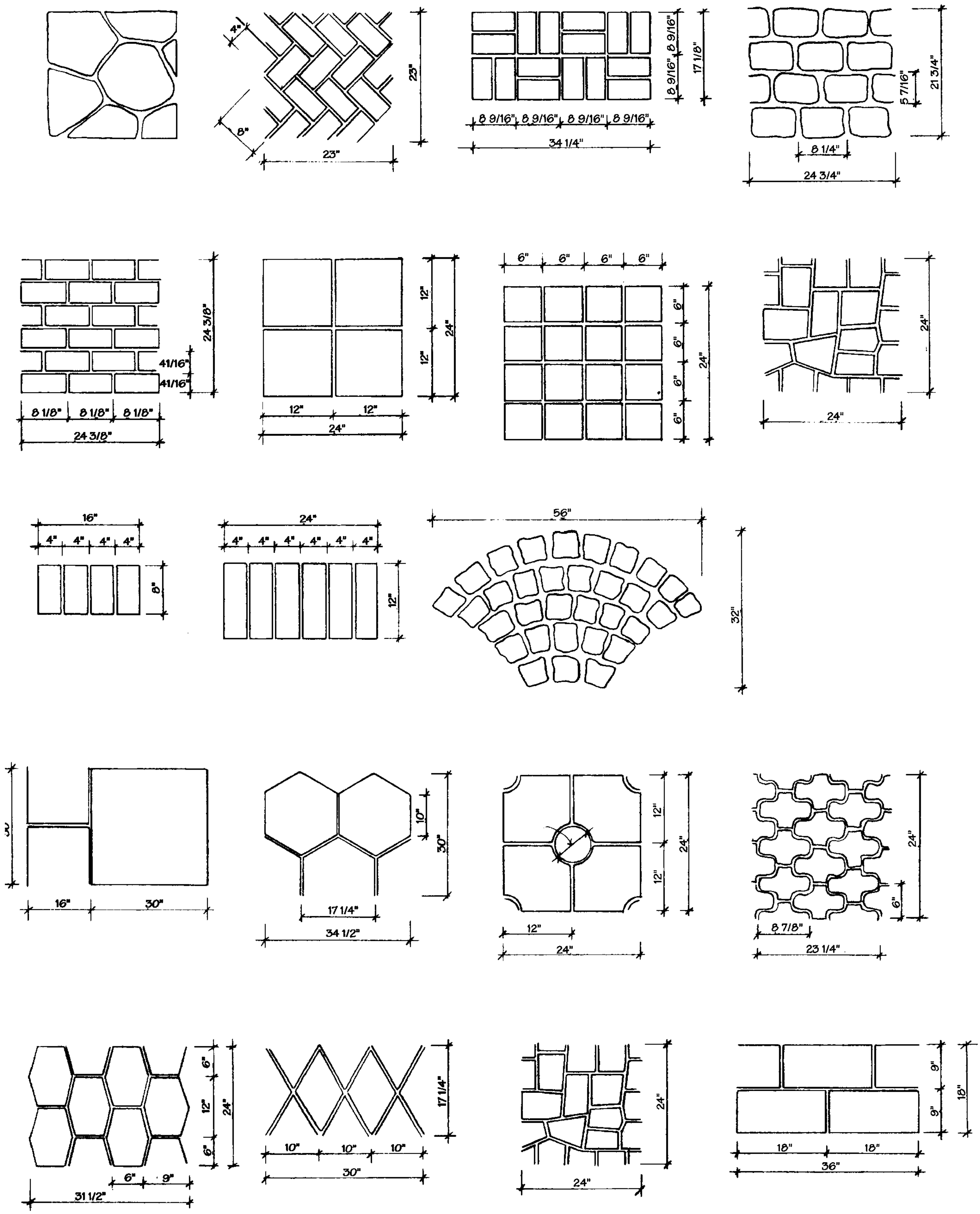


Figure 830-13. Typical stamped pattern for concrete. *Crack control and an attractive appearance are obtained by orienting bond lines across the short dimension of the pavement for cobblestone and all running bond patterns. Dimensions are centerline to centerline. Drawings are not in scale with each other.*

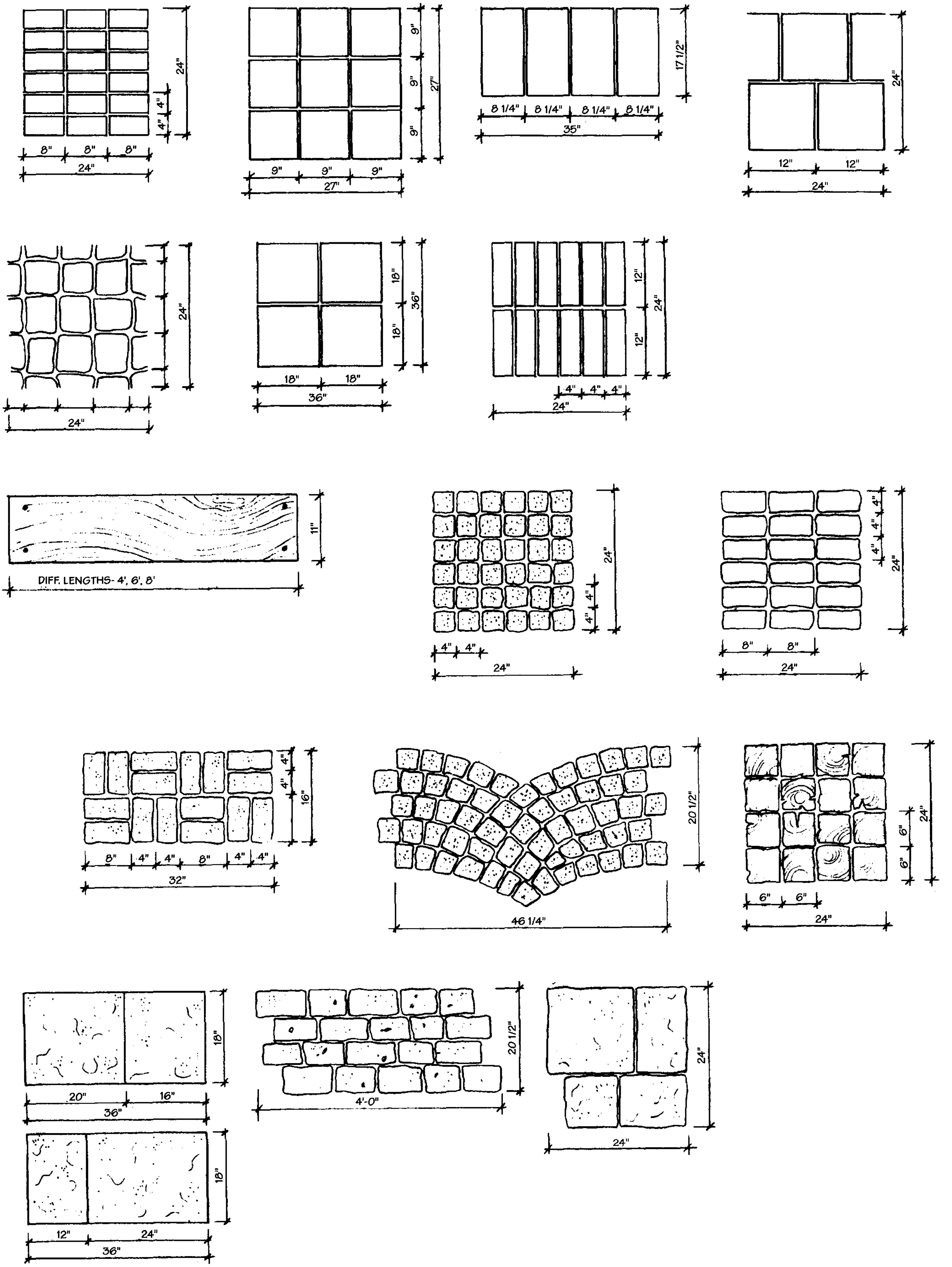

8"
8"
8"
24"
4"
4"
24"
9"
9"
9"
27"
9"
9"
9"
27"
8 1/4"
8 1/4"
8 1/4"
8 1/4"
35"
17 1/2"
12"
12"
24"
24"
24"
24"
18"
18"
36"
18"
18"
36"
4"
4"
4"
24"
12"
12"
24"
DIFF. LENGTHS- 4', 6', 8'
11"
4"
4"
24"
4"
4"
24"
8"
8"
24"
4"
4"
4"
24"
8"
4"
4"
8"
4"
4"
32"
4"
4"
16"
46 1/4"
20 1/2"
6"
6"
24"
6"
6"
24"
20"
16"
36"
18"
12"
24"
36"
18"
4'-0"
20 1/2"
24"
24"

Table 830-12. CURING TABLES AND TECHNIQUES.

Type	Uses	Remarks
Water ponding: with sand or earth dykes to contain water	For all horizontal surfaces, such as: pavements, walks, floors, horizontally cast panels	This will also maintain uniform temperature in concrete.
Continuous sprinkling	For horizontal and vertical surfaces: pavements, walks, floors, walls, cement plaster, stucco	Use fine spray through nozzles or soil-soaker hose.
Wet coverings: burlap, cotton mats	For horizontal and curved surfaces: pavements, walks, floors, shell roofs, horizontally cast panels	Wet sand, earth, straw, or hay could also be used.
Waterproof paper	For horizontal surfaces: pavements, walks, floors, horizontally cast panels	Should conform to ASTM C171.
Plastic sheets	For horizontal surfaces and complex shapes: pavements, walks, floors, shell roofs, horizontally cast panels	Should conform to ASTM C171.
Forms left in place	For vertical surfaces	Must be kep wet using spray or soil soaker hose.
Steam curing	For: cast-in-place, plant cast units	Enclosure for items to be cured is required.
Curing compounds: clear, white pigmented, light-gray pigmented, black	For all horizontal and vertical surfaces	Should conform to ASTM C 309.

Source: Sweet's Selection Data: Cement and Concrete, McGraw-Hill, New York.

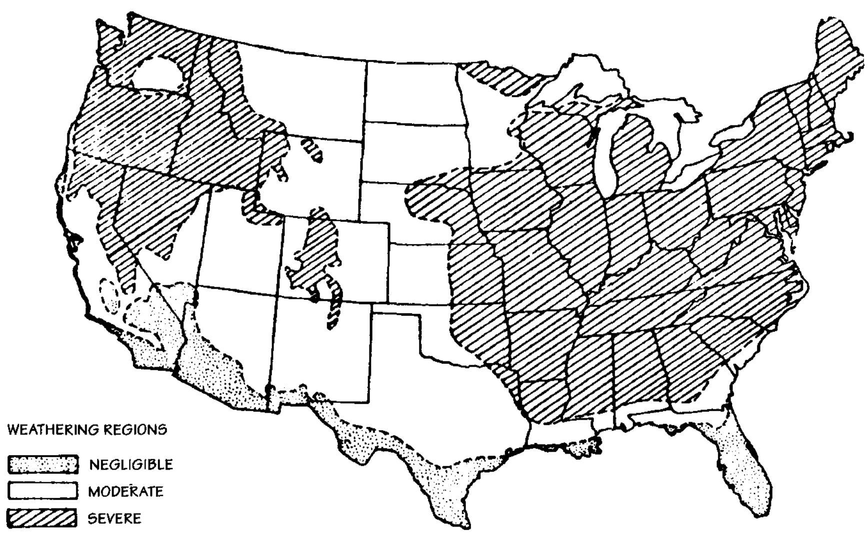


Figure 830-14. Weathering indexes in the United States. *This index shows general areas where concrete is subject to severe, moderate, and negligible weathering. Data needed to determine the weathering index for any locality in the United States may be found or estimated from tables of local climatological data, published by the U.S. Weather Bureau, U.S. Department of Commerce, Washington, D.C.*

AGENCIES AND ORGANIZATIONS

Industry Associations in the United States

American Concrete Institute (ACI)
Farmington Hills, Michigan

Concrete Reinforcing Steel Institute (CRSI)
National Headquarters
Schaumburg, Illinois

Concrete Sawing and Drilling Association (CSDA)
Dublin, Ohio

National Precast Concrete Association (NPCA)
Indianapolis, Indiana

National Ready-Mixed Concrete Association (NRMCA)
Silver Spring, Maryland

National Aggregates Association
Silver Spring, Maryland

Portland Cement Association (PCA)
Skokie, Illinois

Wire Reinforcement Institute (WRI)
Findlay, Ohio

Institutes and Agencies

Construction Specifications Institute (CSI)
Washington, D.C.

National Bureau of Standards (NBS)
U.S. Department of Commerce
Washington, D.C.

National Institute of Building Sciences (NIBS)
Washington, D.C.

National Technical Information Service (NTIS)
U.S. Department of Commerce
Springfield, Virginia

U.S. Department of Energy (DOE)
Energy Research and Development Administration
Washington, D.C.

REFERENCES

General

McGraw-Hill Information Systems. Sweet's Selection Data: Cement and Concrete, *McGraw-Hill, New York, annual.*

Olin, Harold, John L. Schmidt, and Walter H. Lewis. Construction: Principles, Materials and Methods, 3d ed. *The Institute of Financial Education, Chicago, IL1983.*

International Conference of Building Officials, Whittier, CA 1997.

Waddell, Joseph J. Concrete Construction Handbook, 2d ed., *McGraw-Hill, New York, 1974.*

Publications by Trade Associations

American Concrete Institute (ACI)
Manual of Concrete Practice

Concrete Sawing and Drilling Association (CSDA):
Concrete Sawing—What Choice Joints

Portland Cement Association (PCA):
Design and Control of Concrete Mixtures
Color and Texture in Architectural Concrete

Finishing Concrete Slabs with Color and Texture

Concrete Floors on Ground
Cement Mason's Guide

Wire Reinforcement Institute (WRI)
Welded Wire Fabric

SECTION 840

Masonry

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CONTENTS

1.0 INTRODUCTION

Clay, concrete, and stone masonry products are used extensively in landscape construction for a variety of purposes. Their modular characteristics, texture, and color, as well as their properties of durability, compressive strength, and resistance to moisture, allow them to be used in a wide range of applications.

Several other sections of this handbook contain more technical data and standards showing how one or more of these masonry materials can be used for variety of specific purposes. For instance, see Sections: 410: Retaining Walls and Devices, 440: Surfacing and Paving, 450: Fences, Screens and Walls, and 530: Pools and Fountains. Also, manufactures for each type of masonry material or product should be consulted to seek their suggestions on how to use one or more of their materials or standard, new or custom products. Typically, they offer data on the range of shapes, sizes, finishes, product and installation specifications, etc.

2.0 CLAY MASONRY

2.1 General Classification and Properties:

Clay masonry is typically classified into three groups: solid masonry units, hollow masonry units, and architectural terracotta. Individual products within these groups are further classified by size, grade, type, color, and texture. When in doubt or when the material is is be obtained and used outside of the USA, then the manufacturers for the types of clay materials or products being considered should be consulted to seek their suggestions on how to use one or more of their standard, new or custom made products. Typically, they offer data on the range of shapes, sizes, finishes, product and installation specifications, etc.

Solid Masonry Units (Brick):

A masonry unit is classified as solid if the void area does not exceed 25 percent of the total cross-sectional area of the unit. Solid masonry units typically include building brick (ASTM C62), facing brick (ASTM C216), ceramic glazed facing brick (ASTM C126), hollow brick (ASTM C652), and paving brick (ASTM C902).

Properties of Clay Masonry Units:

The characteristics of the raw clay material as well as the manufacturing process itself determine the properties of finished clay masonry units. Table 840-1 lists these basic properties.

Compressive Strength: Measured by the amount of stress placed perpendicularly to the loading plane. Bricks can be classified by compressive strength when such values are above those used in the graded classification. (Table 840-1)

Table 840-1. BASIC PROPERTIES OF CLAY MASONRY

	Properties and Test Methods*				
	Compressive Strength, psi	Modulus of Rupture, psi†	Water Absorption, %	Density, pcf	Material Specifications
Clay - Solid Masonry Units (Brick)‡					
Building and facing					ASTM C62-84 (building brick)
Grade SW	3000		17		ASTM C216-84 (facing brick)
Grade MW	2500		22		
Grade NW	1500				
Glazed facing	3000				ASTM C126-82
Paving					ASTM (902-79a)
Grade SX	8000		8		
Grade MX	3000		14		
Grade NX	3000		no limit		
Hollow					ASTM C652-81
Grade SW	3000		17		
Grade MW	2500		22		
Hollow Masonry Units (Tile)					
Load-bearing wall tile					ASTM C34-62 (reapproved 1975)
Type LBX	1400		18	52	
Type LB	1000		25	52	
Facing tile					ASTM C212-60 (reapproved 1981)
Standard	1400		7	48	
Special duty	2500		13	48	
Sand lime brick					ASTM C73-75
Grade SW	4500	650	7-10		
Grade MW	2500	450	7-10		

* For methods of testing clay brick, see ASTM C67-83.

† Modulus of rupture is a measure of flexural strength.

‡ Density, pcf = 103-145.

Source: Sweet's Selection Data: Stone and Masonry, McGraw-Hill, New York.

Water Absorption: The initial rate of absorption (IRA) or suction affects the bond between brick and mortar. (Table 840-1) Units with rates greater than 110 lpm/760 mm^2 (30 gpm/30 in^2) have too rapid an IRA and should be wetted thoroughly 3 to 24 hours before placement. The absorption (percent) is the amount of water absorbed by the unit. A lower percentage indicates less water absorption and contributes to better weathering characteristics in exposed, exterior conditions.

Durability: The combined factors of compressive strength and absorption constitute a measure of durability. Durability is also reflected in susceptibility to weathering, which is expressed by various grades. Weathering, primarily caused by alternate freezing and thawing in the presence of moisture, varies by climatic regions (Figure 840-1). Resistance to abrasion and staining, particularly important when using paving brick, is demonstrated by the denser hard-burned brick that exhibits low absorption. Local practices should be investigated to ascertain the impact of weathering on various grades of brick.

Texture, Colors, and Finishes: Commonly specified brick textures include smooth, matte, rugs, barks, stippled, sandmold, waterstruck, and sandstruck. Commonly available clay masonry colors include buff, cream, purple, maroon, black, pearl gray, and various shades of red. Use of glazes or special kiln techniques can produce an infinite range of color options. Finishes commonly applied to clay masonry units include:

1. **Smooth finish:** formed by the die in manufacturing

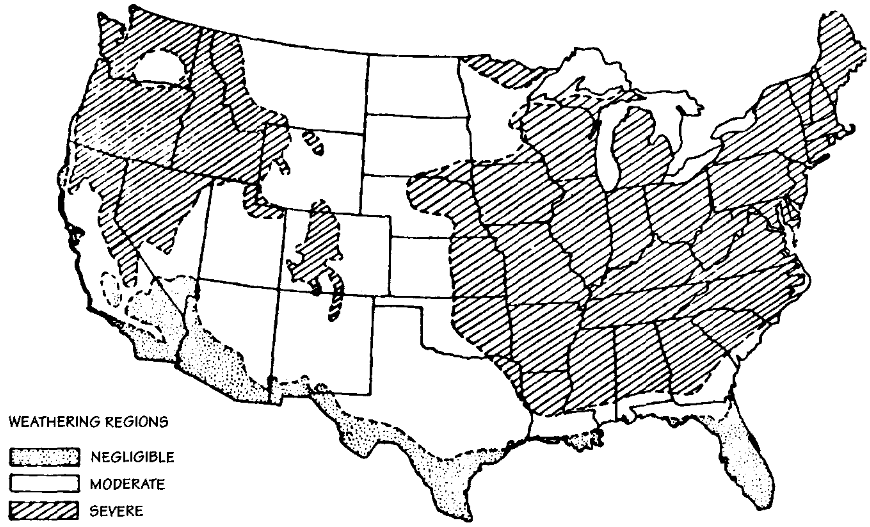


Figure 840-1. Regions of weathering in the United States.

2. **Scored finish:** grooved as it comes from the die in order to increase bonding
3. **Combed finish:** altered by parallel grooving after manufacture for texture or to increase bonding
4. **Roughened finish:** surface entirely roughened by wire cutting or other means for texture or to increase bonding
5. **Clear glaze:** transparent coating fused to surface
6. **Nonlustrous glaze:** transparent coating with a matte finish
7. **Ceramic color glaze:** solid or mottled with gloss or matte finish; wide range of colors
8. **Polychrome finish:** two or more colors applied and burned separately

Size Variation: Shrinkage in clays varies from 4.5 to 15 percent during the process of drying and firing and increases with higher temperatures. Some variation between dark and light units is inevitable. Therefore, industry specifications include tolerances in size and color.

2.2 Brick

Over centuries and in different parts of the world brick sizes have varied . More recently there has begun to develop some common nomenclature and dimensions for various parts of the world. For instance, since 1993 brick manufactures in the USA have adopted standard nomenclature for brick to cover roughly 90 percent of all sizes currently manufactured in the USA. These are shown in Table 840-2. Users of brick outside of the USA should seek information on what are the local standards and nomenclature for brick and other clay products.

Building Brick (ASTM C62):

Building (common) brick is the standard clay masonry unit used in brick masonry construction. Most sizes conform to a module based upon 100 mm (4 in) (Table 840-2).

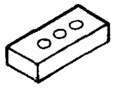
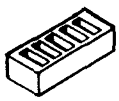
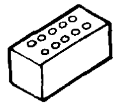
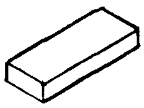
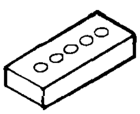
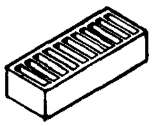
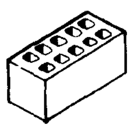
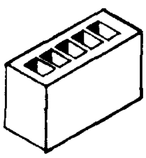
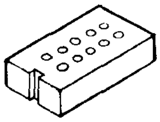
Facing Brick (ASTM C216):

Facing brick is manufactured with stringent tolerances for size, warpage, chippage, and color and is used where an exposed brick face is desired. The dimensions of facing brick are the same as for building brick (see Table 840-2).

KEY POINTS: Clay Masonry

1. Bricks are graded based on their susceptibility to weathering. Local practices should be investigated to ascertain the impact of weathering on specific grades of brick.
2. Building (common) brick is the standard clay masonry unit used in construction, and most sizes conform to a module based upon 100 mm (4 in) (Table 840-2).
3. Facing brick is used where an exposed brick face is desired. The dimensions of facing brick are the same as for building brick (see Table 840-2).
4. Paving brick is manufactured with high compressive strength and low absorption, thereby constituting a durable brick material suitable for paving. Paving bricks are available in a variety of sizes, grades and colors (Table 840-3 and Table 840-4.
5. Joints should be compressed and tooled to force the mortar tightly into the joint and ensure impermeability. Joints should not allow for the collection of water.

Table 840-2. SIZES OF MODULAR BRICK

Unit Designation		Nominal Dimensions, in (cm)‡ T	Nominal Dimensions, in (cm)‡ H	Nominal Dimensions, in (cm)‡ L	Joint Thickness, in (cm)	Manufactured Dimensions, in (cm) T	Manufactured Dimensions, in (cm) H	Manufactured Dimensions, in (cm) L	Modular Coursing, in (cm)
Standard modular		4 (10.16)	2⅔ (6.77)	8 (20.32)	⅜ (0.95) ½ (1.27)	3⅝ (9.21) 3½ (8.89)	2¼ (5.72) 2¼ (5.72)	7⅝ (19.37) 7½ (19.05)	3C = 8 (20.32)
Engineer modular		4 (10.16)	3⅕ (8.13)	8 (20.32)	⅜ (0.95) ½ (1.27)	3⅝ (9.21) 3½ (8.89)	2 13/16 (7.15) 2 11/16 (6.83)	7⅝ (19.37) 7½ (19.05)	5C = 16 (40.64)
Closure modular		4 (10.16)	4 (10.16)	8 (20.32)	⅜ (0.95) ½ (1.27)	3⅝ (9.21) 3½ (8.89)	3⅝ (9.21) 3½ (8.89)	7⅝ (19.37) 7½ (19.05)	1C = 4 (10.16)
Roman		4 (10.16)	2 (5.08)	12 (30.50)	⅜ (0.95) ½ (1.27)	3⅝ (9.21) 3½ (8.89)	1⅝ (4.13) 1½ (3.81)	11⅝ (29.55) 11½ (29.23)	2C = 4 (10.16)
Norman		4 (10.16)	2⅔ (6.77)	12 (30.50)	⅜ (0.95) ½ (1.27)	3⅝ (9.21) 3½ (8.89)	2¼ (5.72) 2¼ (5.72)	11⅝ (29.55) 11½ (29.23)	3C = 8 (20.32)
Norwegian or Engineer Norman		4 (10.16)	3⅕ (8.13)	12 (30.50)	⅜ (0.95) ½ (1.27)	3⅝ (9.21) 3½ (8.89)	2 13/16 (7.15) 2 11/16 (6.83)	11⅝ (29.55) 11½ (29.23)	5C = 16 (40.64)
Economy 12 or jumbo utility		4 (10.16)	4 (10.16)	12 (30.50)	⅜ (0.95) ½ (1.27)	3⅝ (9.21) 3½ (8.89)	3⅝ (9.21) 3½ (8.89)	11⅝ (29.55) 11½ (29.23)	1C = 4 (10.16)
Triple		4 (10.16)	5⅓ (13.55)	12 (30.50)	⅜ (0.95) ½ (1.27)	3⅝ (9.21) 3½ (8.89)	4 15/16 (12.55) 4 13/16 (12.23)	11⅝ (29.55) 11½ (29.23)	3C = 16 (40.64)
SCR brick§		6 (15.24)	2⅔ (6.77)	12 (30.50)	⅜ (0.95) ½ (1.27)	5⅝ (14.29) 5½ (13.97)	2¼ (5.72) 2¼ (5.72)	11⅝ (29.55) 11½ (29.23)	3C = 8 (20.32)

* Although the coring types shown are typical for solid units, they do not necessarily apply to the specific types of units with which they are shown above. Types will vary between manufacturers. Values shown in parentheses are metric dimensions.

† 1" = 2.54 cm
1' = 0.3 m

‡ Nominal dimensions refer to the manufactured width of a unit plus the width of a mortared joint.

§ Reg. U.S. Patent Office, SCPI (BIA).

Source: Modified from data provided by the Brick Institute of America, Reston, VA.

Table 840-3. SIZES BRICK PAVER UNITS*

Face Dimensions (Actual Size) Width, in	Face Dimensions (Actual Size) Length, in	Thickness, in	Paver Face Area, (in^2)	Paver Units, per ft^2
4	8	The unit thickness of brick pavers varies. The most popular thicknesses are 2¼ and 1⅝. The range of thickness is generally from ¾–2½.	32.0	4.5
3¾	8		30.0	4.8
3⅝	7⅝		27.6	5.2
3⅞	8¼		32.0	4.5
3⅞	7¾		30.0	4.8
3¾	7½		28.2	5.1
3¾	7¾		29.1	5.0
3⅝	11⅝		42.1	3.4
3⅝	8		29.0	5.0
3⅝	11¾		42.6	3.4
3 9/16	8		28.5	5.1
3½	7¾		27.1	5.3
3½	7½		26.3	5.5
3⅜	7½		25.3	5.7
4	4		16.0	9.0
6	6		36.0	4.0
7⅝	7⅝		58.1	2.5
7¾	7¾		60.1	2.4
8	8		64.0	2.3
8	16		128.0	1.1
12	12		144.0	1.0
16	16		256.0	0.6
6	6 hexagon		31.2	4.6
8	8 hexagon		55.4	2.6
12	12 hexagon		124.7	1.2

* This table does not include provisions for waste. Allow at least 5% for waste and breakage. Also, it is not a complete list but does provide those sizes most commonly available. Consult manufacturers for availability of sizes and colors.

Source: Brick Institute of America, "Brick Floors and Pavements, Part II," Technical Note 14A, 1975.

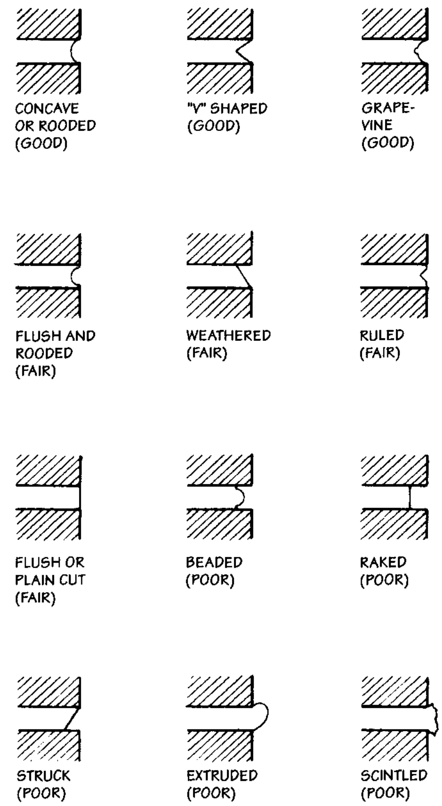


Figure 840-3. Types of joints (and weatherability).

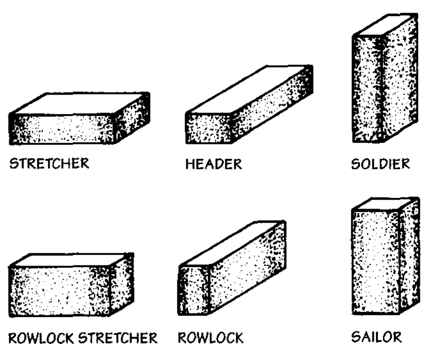


Figure 840-2. Terms applied to brick unit positions.

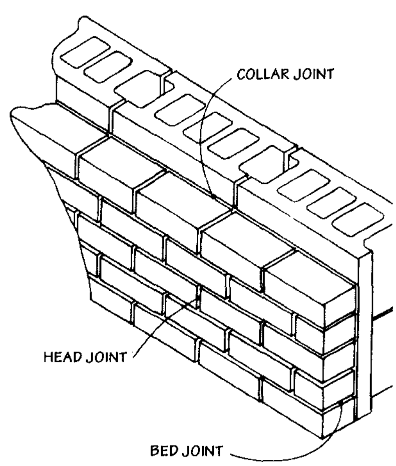


Figure 840-4. Terms applied to mortar joints in wall construction.

Table 840-4. GRADES AND TYPES OF PAVING BRICK (ASTM C902-79a)

Grade*	Use
Sx	For use where brick is expected to be frozen while saturated with water
Mx	For exterior use where resistance to freezing is not a factor
Nx	For interior use and when a sealer or coating will be applied to prevent infiltration of dirt
Type†	**Use**
I	For use when exposed to extensive abrasion, such as in driveways and entranceways
II	For use when intermediate levels of traffic are expected, such as in walkways, etc.
III	For use when low levels of traffic are expected, such as in patios, terraces, etc.

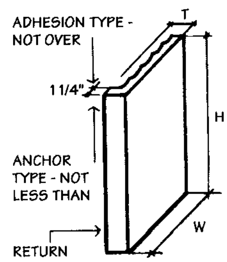
* Based on durability.

† Based on traffic.

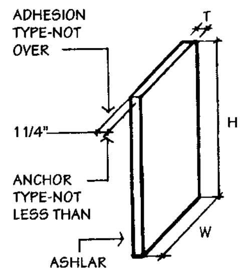
Source: Adapted from ASTM, Designation C902, Philadelphia, Pa., as reprinted in Brick Institute of America, "ASTM Standard Specifications for Brick and Applicable Testing Methods for Units and BIA Standard Specification for Portland Cement—Lime Mortar for Brick Masonry, BIA Designation MI-72," July 1981.

Table 840-5. STANDARD SHAPES AND SIZES OF ARCHITECTURAL TERRA-

Machine-Made Extruded Terra-Cotta

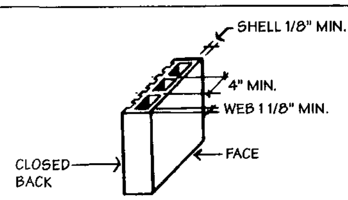


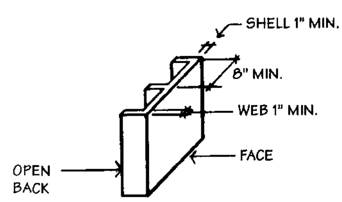
Width	Height	Thickness
5¾ in	2 ft 0 in	3½ in
7¾ in	2 ft 0 in	3½ in
11¾ in	2 ft 0 in	3½ in
1 ft 2¾ in	2 ft 2 in	3½ in
1 ft 3¾ in	2 ft 2 in	3½ in
1 ft 5¾ in	2 ft 2 in	3½ in

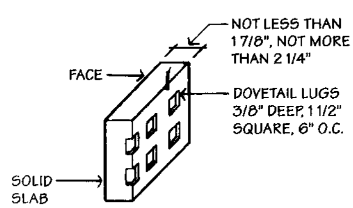


Width	Height	Thickness
5¾ in	2 ft 0 in	1¼ in
7¾ in	2 ft 0 in	1¼ in
11¾ in	2 ft 0 in	1¼ in
1 ft 2¾ in	2 ft 2 in	1¼ in
1 ft 3¾ in	2 ft 2 in	1¼ in
1 ft 5¾ in	2 ft 2 in	1¼ in

Handmade Terra-Cotta Thickness and Web Dimensions







* In adhesion types any one dimension is not to be greater than 30 in, and maximum outer face area is limited to 540 in^2. Anchor type veneers can possess larger dimensions and superficial area.

Source: Caleb Hornbostel, *Construction Materials,* Wiley, New York, 1981.

840 Masonry

Unfired "green" brick that can be obtained from the brick manufacturer and used to create bas-reliefs on walls, paved surfaces or free-standing sculptures. The carving is done on the unfired "green" brick which may be of any standard or special size. Some brick companies have developed special clay units for creating such sculptures. After the carving is done, each brick is numbered on the back and then put through the regular brick drying and firing processes. The finished products are then packaged to be taken to the site for installation.

Paving Brick (ASTM C902) and Paving Tile for Pedestrian and Light Traffic :

Paving brick and paving tile are manufactured with high compressive strength and low absorption, making them a durable material suitable for variety of types and patterns of paving. Some of the standard formats and dimensions for paving brick and tile are given in Table 840-3. Table 840-4 shows the grading system used for paving brick and tile.

2.3 Architectural Terra-Cotta (Ceramic Veneer)

Terra-cotta is used as an exterior veneer. Modern ceramic veneer refers to a machine-made product shaped by extruding plastic clay through dies (Table 840-5). Handmade terra-cotta is molded or pressed. Both are custom-made products, available in a wide variety of colors and manufactured to conform to job specifications. Table 840-5 shows both handmade and machine-made shapes and sizes of architectural terra-cotta.

2.4 Brick Unit Positions

Specific terms are given to brick units, depending on their position in a wall structure (Figure 840-2).

2.5 Jointing

Joints that exhibit the highest degree of watertightness are those that are compressed and tooled, thereby forcing the mortar tightly into the joint. Joints that are made with a small shelf on the lower edge or with protruding mortar should be avoided because they tend to collect water and are more permeable (Figure 840-3). Figure 840-4 illustrates the various terms applied to joints in the construction of brick walls.

3.0 CONCRETE MASONRY

3.1 General Classification and Properties:

Molded concrete masonry units are typically classified into three groups: concrete brick (solid), concrete block (solid and hollow), and special units. Manufacturers for each type of concrete material or product should be consulted to seek their suggestions on how to use one or more of their materials or standard, new or custom products. Typically, they offer data on the range of shapes, sizes, finishes, product and installation specifications, etc.

Grades: All load-bearing concrete masonry units are classified into one of two grades (ASTM). Units classified as grade N are suitable for general use, such as exterior walls, for below- or aboveground work that may be exposed to moisture penetration or weathering, and for interior and backup walls. Units classified as grade S are limited to use above-grade, in exterior walls with weather protective coatings, and in walls not exposed to the weather. Grades are further classified by type.

Types: Type refers to load-bearing and non-load-bearing units manufactured to ASTM specified limits of moisture content. Type I units are restrictive in terms of maximum moisture content and potential shrinkage. Units not restricted to moisture content are designated type II.

The physical properties of concrete masonry units are determined by the hardened cement paste and the type and gradation of aggregate used in their manufacture.

Compressive Strength: Measured by the amount of stress placed perpendicularly to

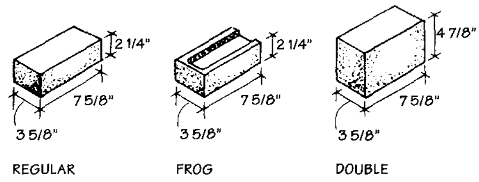


Figure 840-5. Standard sizes and shapes of concrete building brick.

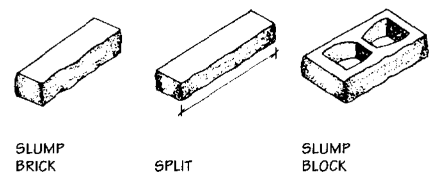


Figure 840-6. Standard shapes and sizes of slump brick and block..

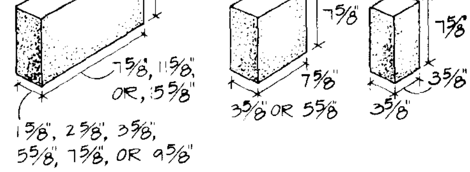
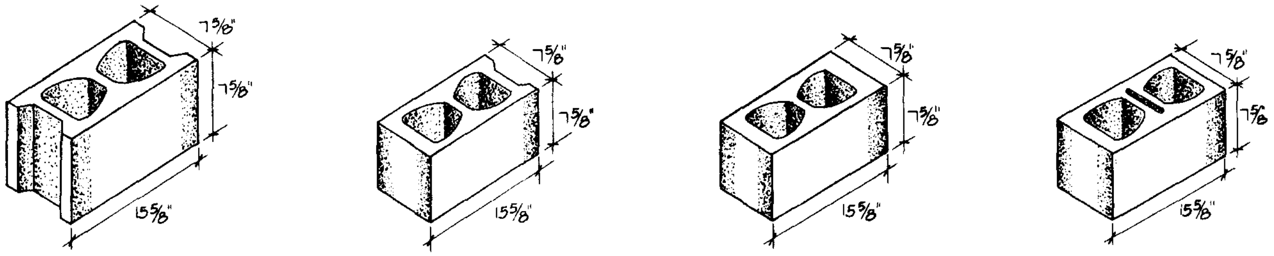


Figure 840-7. Standard shapes and sizes of solid load-bearing concrete masonry units.

KEY POINTS: Concrete Masonry

1. Molded concrete masonry units are classified into ASTM grades based on their resistance to weathering, and types based on moisture content and potential shrinkage.
2. All units intended for exposed, exterior walls should have low water absorption properties, and mortar joints should be tooled for watertightness.
3. Concrete building brick (ASTM C55) is manufactured as a solid unit, often with a frog to provide a stronger bond with the mortar.
4. Concrete block is available as load-bearing units (solid or hollow) and non-load-bearing units (hollow).
5. Special units, such as split-face blocks, faced blocks, and decorative blocks are available to provide attractive surfacing for concrete masonry structures.
6. Concrete pavers are available in a variety of colors, shapes and sizes, and include interlocking and turfblock pavers (Figure 840-12 and Figure 840-13).
7. Joints should be compressed and tooled to force the mortar tightly into the joint and ensure impermeability. Joints should not allow for the collection of water.

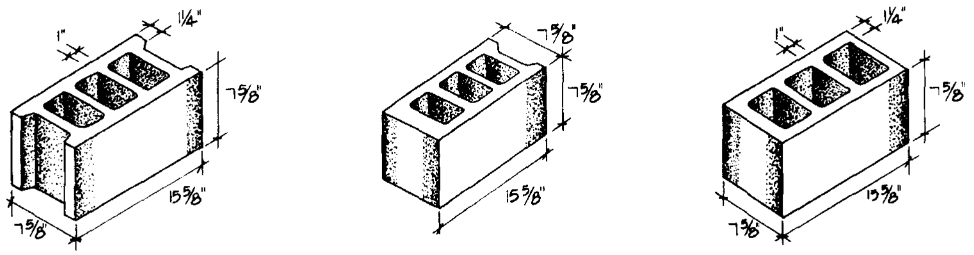


REGULAR STRETCHER

ONE PLAIN END
(SINGLE CORNER)

BOTH ENDS PLAIN
(DOUBLE CORNER OR PIER)

TWO-CORE 8x8x16" UNITS

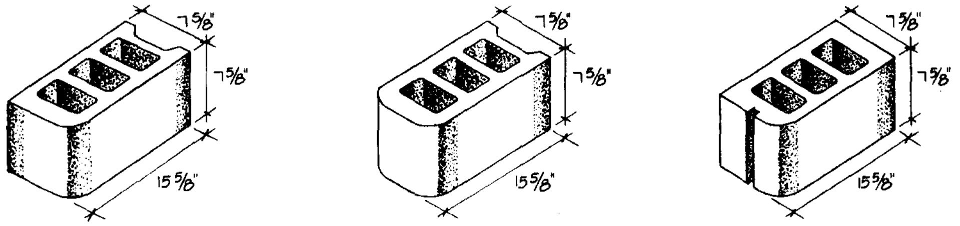


REGULAR STRETCHER

ONE PLAIN END
(SINGLE CORNER)

BOTH ENDS PLAIN
(DOUBLE CORNER OR PIER)

THREE-CORE 8x8x16" UNITS

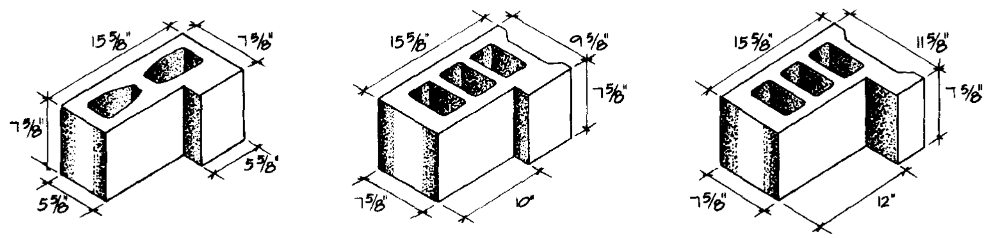


SINGLE

DOUBLE

SINGLE WITH SASH CORNER

BULLNOSE UNITS (RADIUS VARIES 1 TO 3 IN)

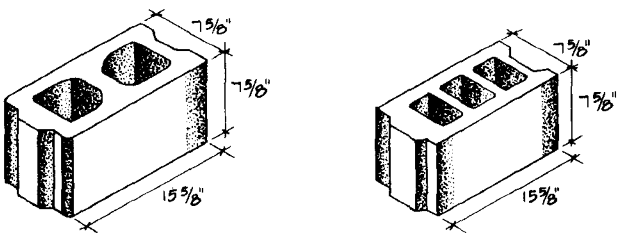


SIX INCH

TEN INCH

TWELVE INCH

RETURN OR CORNER ANGLE UNITS



CONTROL JOINT UNITS

Figure 840-8. Standard shapes and sizes of hollow concrete block

the loading plane, based on gross bearing area, including core spaces.

Water Absorption: A measure of the density (pores and pore structure) of concrete. All units intended for exposed, exterior walls should have low water absorption properties, and mortar joints should be tooled for watertightness.

Volume Changes (Thermal Expansion Coefficient): Volume changes are often due to changes in moisture (i.e., units expand when wet and contract when dry). This problem arises when improperly cured units are used, but it can be reduced by using high-pressure steam curing in the manufacturing process and by adjusting the moisture content of the unit in response to the relative humidity at the job site. Volume changes are also due in part to changes in temperature, which primarily affects the aggregate used.

Texture: Textures range from very smooth to rough and uneven. Open surface textures help to absorb sound.

Color: A wide range of colors is possible by mixing pure mineral oxide pigments with the concrete before molding it into various units.

3.2 Concrete Brick (Solid)

Concrete building brick (ASTM C55) is manufactured as a solid unit with or without a shallow depression called a frog (Figure 840-5). The frog reduces the weight of the brick and produces a better mechanical bond when laid in mortar. Modular dimensions typically are 100 mm (4 in) in width and 200 mm (8 in) in length, allowing for 9.5-mm (3/8-in) mortar joints.

Slump bricks and blocks are irregularly faced units which vary considerably in height, surface texture, and general appearance (Figure 840-6). A unique irregular wall surface is attained by using these units.

3.3 Concrete Block

Concrete block is manufactured in three classes: solid load-bearing units, hollow load-bearing units, and hollow non-load-bearing units.

Solid Load-Bearing Units: (ASTM C145) refer to those units with at least 75 percent net area in cross section. Figure 840-7 gives formats and dimensions of solid load-bearing masonry units.

Hollow Load-Bearing Units: (ASTM C90) refer to hollow units whose face shell and web thickness conform to specific dimensions. A nominal modular dimension of 200 mm x 200 mm x 400 mm (8 in x 8 in x 16 in) is produced with 9.5-mm (3/8-in) mortar joints. Half-length and half-height units are also available. Figure 840-8 shows standard formats and dimensions of hollow load-bearing concrete units.

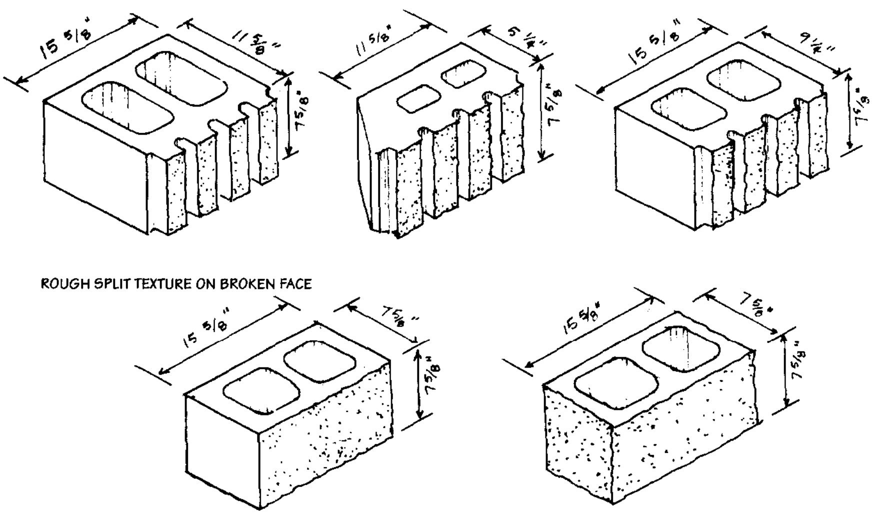


Figure 840-9. Standard shapes and sizes of split-face blocks.

3.4 Special Units

Split-face blocks are solid or hollow units that are split lengthwise to produce a rough texture. Units are laid with the split face exposed. Figure 840-9 shows standard formats and dimensions of split-face blocks.

Faced blocks are units with ceramic glazed, plastic, polished, or ground faces. The facing is produced during a separate operation after the blocks are produced.

Decorative blocks are manufactured in different forms with beveled face-shell recesses that produce decorative effects on wall surfaces (Figure 840-10). Figure 840-11 shows various types of screen wall units.

3.5 Concrete Pavers

Concrete pavers are units of various shapes and sizes used for paving (Figure 840-12). These pavers possess low absorption and high compressive strength characteristics in order to resist breakage from freeze/thaw cycles and to withstand loading from pedestrian and light vehicular traffic (Table 840-6). Dimensional tolerances in units of the same pattern must fall within 1.6 mm (1/16 in) of the approved unit pattern standard because a proper fit is necessary for the proper transfer of loads through a pavement surface.

Commonly used colors of concrete pavers are gray, red and brown. Other colors include blues, greens, and other bright colors, but these tend to fade with age. Beveled edges help to hide irregularities in surface and to prevent sucking of sand from joints.

Figure 840-12 shows typical formats and dimensions of concrete pavers, some of which are referred to as interlocking pavers. Figure 840-13 shows two types of grid paving that allow vegetative growth to occur in the interstitial spaces.

3.6 Jointing

The typical joints and weathertightness of brick masonry is applicable to joints used in concrete masonry construction.

3.7 Typical Uses of Concrete Masonry Units

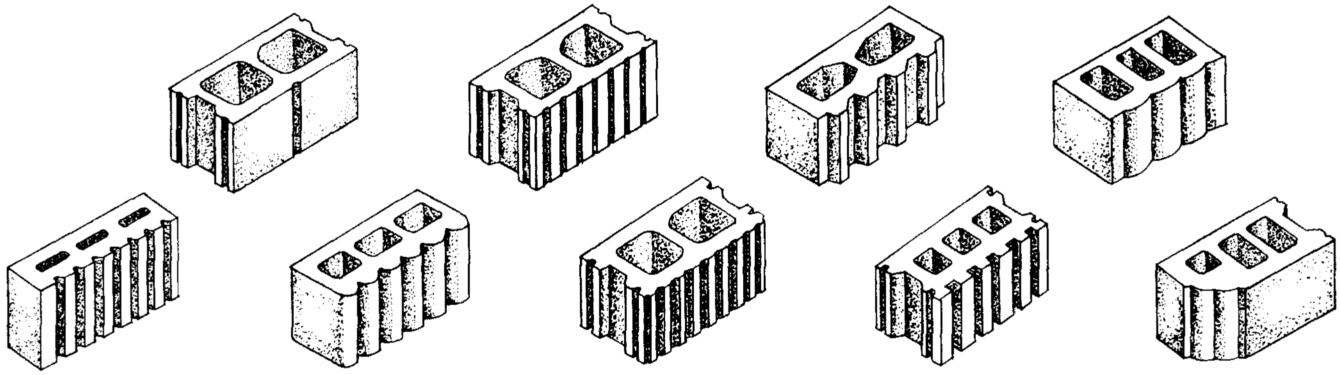
Typical uses for concrete masonry units are outlined in Table 840-7.

4.0 STONE MASONRY

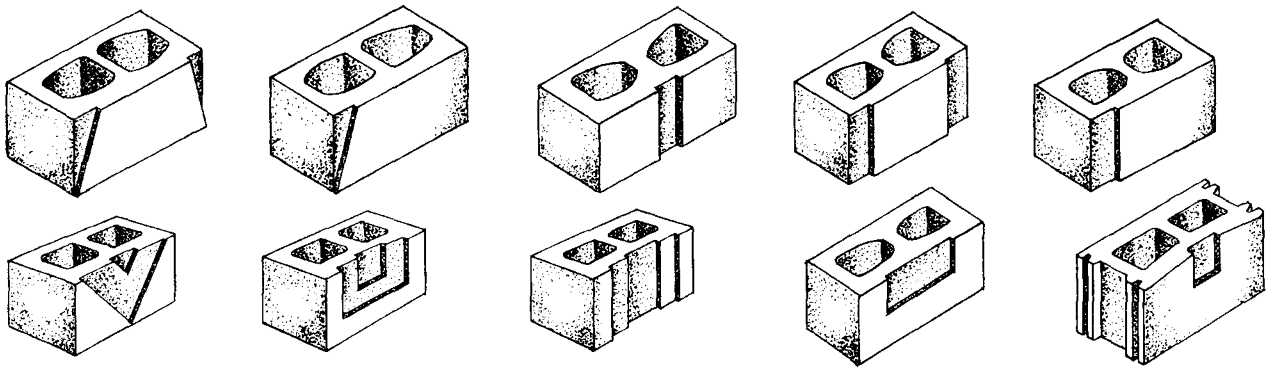
4.1 General Classification and Properties:

Stone is commonly classified into a number of categories based on appearance and use:

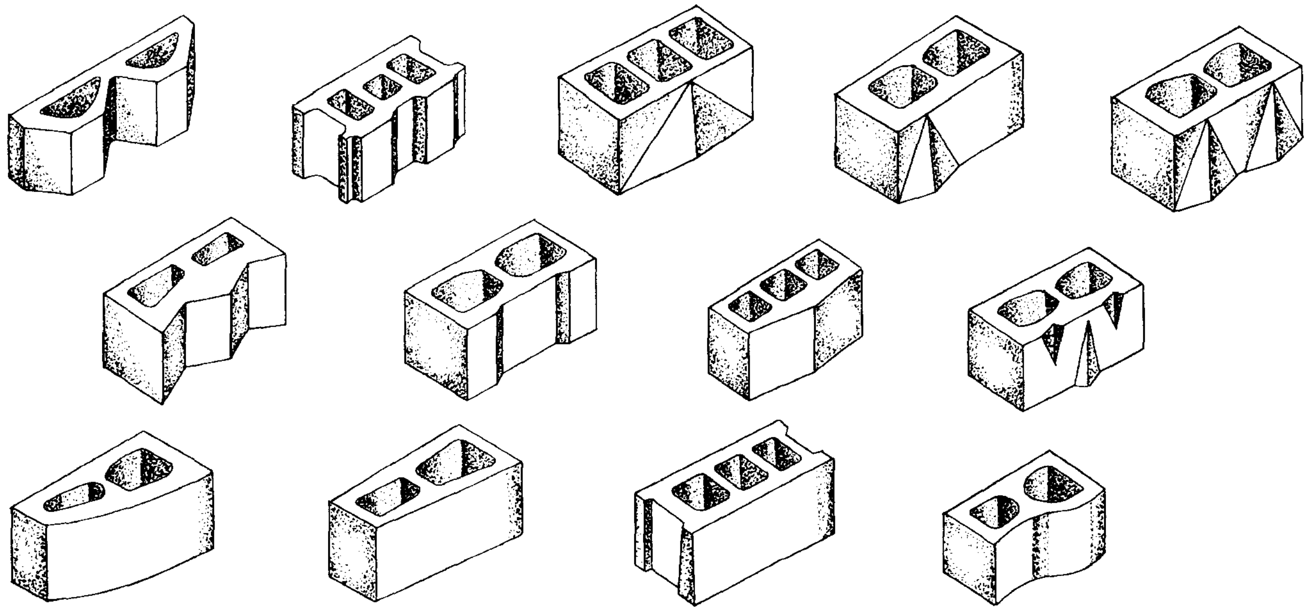
1. **Fieldstone:** naturally fractured and weathered masses of varying shapes and sizes.



SCORED, RIBBED, AND FLUTED FACES



RECESSED FACES



BASKET WEAVE TAPER BLOCK BEVEL SIDING SERPENTINE

ANGULAR AND CURVED FACES

Figure 840-10. Standard shapes of decorative blocks.

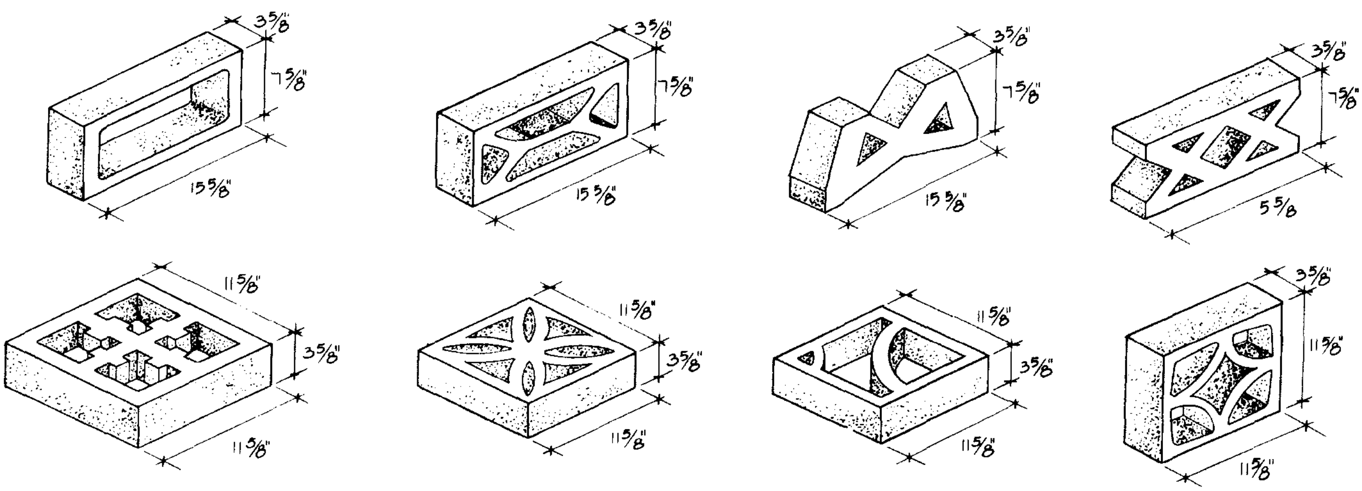


Figure 840-11. Standard shapes and sizes of screen wall units.

2. **Rubble stone:** irregular stone fragments with at least one good face, from quarrying operations. Usually within dimensions of 300 mm x 600 mm (1 ft x 2 ft).

3. **Dimension stone:** (cut stone, ashlar): cut at the quarry or mill to specified dimensions and finished. Ashlar is a smaller rectangular dimension stone with flat faces and sawn edges.

4. **Monumental stone:** either rough or finished; used for monuments, gravestones, etc.

5. **Flagstone:** flat thin stones [25 to 50 mm (1 to 2 in) thick], irregular or cut to dimension. Commonly used for paving.

6. **Crushed and broken stone (graded and sized):** Crushed stone usually varies from 6 to 54 mm (1/4 to 2-1/4 in) in diameter and consists of one type of rock. Used alone or as an aggregate in concrete or asphalt.

KEY POINTS: Stone Masonry

1. Granite is difficult to finish and relatively expensive. Typical uses include building veneer, pavers, curbing, crushed stone, and granite dust.

2. Limestone is chemically reactive and should not be used in areas of industrial fumes, smoke, acids, areas where hard impacts may occur, or in places where oil and grease may contact and readily be absorbed by the limestone. It should be waterproofed or isolated by a waterproof membrane if it touches the ground to prevent staining. Typical uses include building veneer, ashlar or flagstone walls, pavers, crushed aggregate, and limestone dust.

3. Marble is available in four quality grades, based on flaws and working difficulties. It is chemically reactive and should not be used in areas of industrial fumes, acids, or air pollution or where severe weather can be expected. Typical uses include veneer, monuments, and crushed aggregate.

4. Sandstone serves well as a nonslip walking surface. Typical uses include veneer, pavers, cut stone, and rubble.

5. Slate is strong and durable, with high tensile strength, and is typically available in colors of red, purple, green, black, and gray. Typical uses are flagstones for paving or walls, and roofing slate.

6. Fine or polished stone surfaces may be slick in wet conditions if used as a paving material.

7. Joints should be compressed and tooled to force the mortar tightly into the joint and ensure impermeability. Joints should not allow for the collection of water.

7. **Stone dust or powder:** graded particles from a crushing process [less than 6 mm (1/4 in) in diameter]. Commonly used as a surfacing or as a bedding material for pavers, etc.

Properties of Stone Masonry Units:

The physical properties of common types of stone are outlined in Table 840-8.

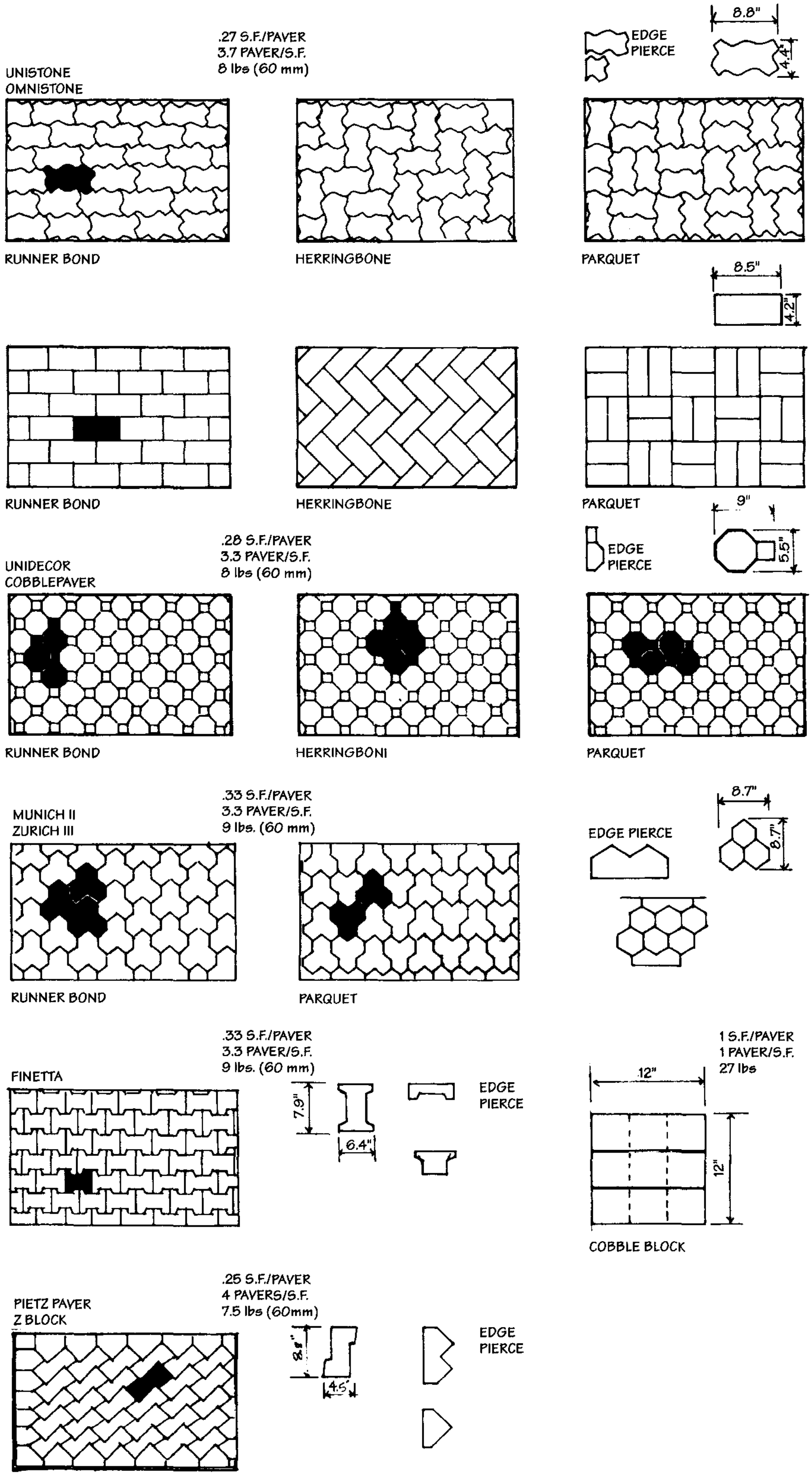
4.2 Common Types of Stone

Table 840-9 lists various types of stone commonly used in construction and their characteristics. Manufacturers or suppliers for each type of stone material or product should be consulted to seek their suggestions on how to use one or more of their materials or standard, new or custom products. Typically, they offer data on the range of shapes, sizes, finishes, product and installation specifications, etc.

Standard formats, dimensions, grades, and typical finishes for each type are described below.

Granite. It is a hard, strong, durable, impervious, igneous rock with a fine-, medium-, or coarse-grained appearance. Granite is very difficult to finish and the costs can be high. Typical uses include building veneer, pavers, curbing, crushed stone, and granite dust. Grades and dimensions of granite masonry units are given in Table 840-10.

Limestone. The properties of limestone are highly variable, depending on the type of cementing agent. Limestone is chemically reactive and should not be used in areas of industrial fumes, smoke, or acids, in areas where hard impacts may occur, or in places



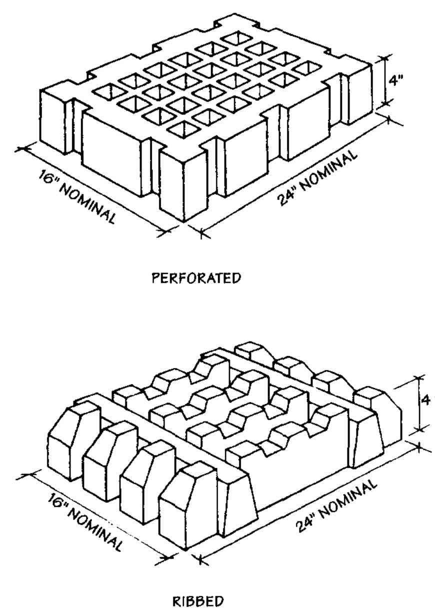


Figure 840-13. Grid or grass-filled blocks.

Figure 840-12. Typical concrete pavers. *Typical thicknesses include 2⅔ in. 3⅛ in. and 4 in. Manufacturers should be consulted for other shapes and sizes, specifications for installation, and product specifications.*

Table 840-6. SPECIFICATIONS FOR CONCRETE PAVERS (ASTM 938-82)

Average Compressive Strength, psi	Minimum Compressive Strength of Individual Unit, psi	Average Absorption (Increase in Block Weight After Immersion)	Absorption of Individual Unit (Increase in Block Weight After Immersion)
8000	7200	Not greater than 5%	Not greater than 7%

Source: American Society for Testing and Materials, *Annual Book of ASTM Standards,* Philadelphia, Pennsylvania.

Table 840-7. TYPICAL USES OF CONCRETE MASONRY UNITS

	Function of Walls				
Concrete	Retaining	Foundation	Reinforced	Load-Bearing	Non-Load-Bearing
Brick					
Common	•	•	•	•	•
Face	•		•	•	•
Block					
Solid	•	•	•	•	
Hollow load-bearing	•	•	•	•	
Hollow non-load-bearing					•
Screen					•
Glazed			•	•	•
Prefab panels				•	•

Source: Sweet's Selection Data: Stone and Masonry, McGraw-Hill, New York.

Table 840-8. IMPORTANT PROPERTIES OF COMMON STONE TYPES

	Properties						
	Absorption by Weight, Maximum, %[a]	Density, Minimum lb/ft^3[a]	Compressive Strength, Minimum, psi[b]	Compressive Strength, Minimum, psi[c]	Modulus of Rupture, Minimum, psi[d]	Abrasion Resistance, Minimum, Ha[e,f]	ASTM Specifications
Granite, all grades	0.4	160	19,000	20,000–36,000	1500	NA[g]	ASTM C615-80 Standard Specification for Granite Building Stone
Limestone							
Category I—low density	12	110	1,800	2,600	400		ASTM C568-79 Standard Specification for Limestone Building Stone
Category II—medium density	7.5	135	4,000	to	500	10	
Category III—high density	3	160	8,000	20,000	1000		
Marble							
Group A	0.75	144		8,000		10	ASTM C503-79 Standard Specification
		to	7,500	to	1000		for Marble Building Stone
Groups B, C, and D		175		23,000			
Sandstone							
Standard—sandstone	20	140	2,000	3,000	300		ASTM C616-80 Standard Specification for Sandstone Building Stone
Quartzite—quartzitic sandstone	3	150	10,000	to	1000	8	
Bluestone—quartzite	1	160	20,000	20,000	2000		
Slate—structural							
Exterior	0.25			10,000	9000		ASTM C629-80 Standard Specification
		NA		to	across grain	8	for Slate Building Stone
Interior	0.45			15,000	7200 along grain		

[a] When tested in accordance with ASTM C97.

[b] Range when tested in accordance with ASTM C170.

[c] Common range of available stones.

[d] Range when tested in accordance with ASTM C99, except for slate, which is tested in accordance with ASTM C120.

[e] Ha refers to the abrasive hardness value which is the reciprocal of the volume of material abraded multiplied by 10.

[f] When tested in accordance with ASTM C241.

[g] Not available or not established in cited ASTM Standard Specifications.

Source: Sweet's Selection Data: Stone and Masonry, McGraw-Hill, New York.

Table 840-9. TYPES OF STONE USED IN CONSTRUCTION

Common Name	Type of Stone	Characteristics: Texture	Characteristics: Appearance	Characteristics: Color
Black granite (traprock)	Igneous	Fine to coarse-grained, polished	Generally uniform	Black
Bluestone	Sedimentary	Smooth to rough	Uniform	Blue-gray
Granite	Igneous	Fine to coarse-grained, polished	Generally uniform; some colors have spots, veins, and variations in grain	Wide range of colors; white and black
Limestone	Sedimentary	Fine-grained	Uniform in color	Buff-gray
Marble	Metamorphic	Fine-grained, polished	Uniform or with wide variations of veining and colors	Wide range of colors; white and black
Sandstone	Sedimentary	Rough	Generally uniform	White, gray, yellow, brown, red
Slate	Metamorphic	Smooth to rough	Generally uniform	Blue, gray, green, reddish
Soapstone	Metamorphic	Smooth to rough	Generally uniform	Gray, green, blue
Travertine	Sedimentary	Smooth to rough, also polished	Irregularly shaped pores	Gray, white, buff

Source: Caleb Hornbostel, *Construction Materials,* John Wiley & Sons, New York, 1981.

Table 840-10. GRADES AND DIMENSIONS OF STONE MASONRY UNITS

	Rubble, Chunk		Ashlar			Panels*		Flags, Pavers*	
	Thickness Range, in	Face Dimensions (S.F.) Average Range	Thickness Range, in	Face Dimensions Range	Rise Range, in	Thickness Range, in	Face Dimensions, Common Limits, ft†	Thickness Range, in	Maximum Face Area (S.F.) Range
Granite, all grades	¼–1½	½–2	4–12	½–10 ft^2	4–13, 1½ in increments	1¼–4 and over	4 × 10	1¾–3	4–16
Limestone Category I—low density Category II—medium density Category III—high density	½–4	1–5	3½–6	Length: 10–36 in	2 9/16 4⅞ 7½ 11½ 2¼ 5 7¾	⅞ 2¼ 3	5 × 14	1¾ 2½	1–6
Marble Group A‡ Groups B, C, and D§	¼–3	½–4	½–2		2½ 5 7¾	½–2	6 × 7	⅞ to 1	1–2
Sandstone Standard—sandstone	1½–5		4	Height: ¾–14 in		2¼–4		1½–3	1–4
Quartzite—quartzitic sandstone		1–4		Length: 8–48 in			4 × 10		
Bluestone—quartzite	1–4		4–12		2¼, 5, 7¾	1½–2		⅝–2	1–10
Slate—structural Exterior and interior						1–1½	4 × 8	¼–2	Over 4

* Sizes and thicknesses shown are only indicative of some of the sizes and thicknesses generally used and do not imply size and/or thickness limitations. Intended use and size will generally dictate minimum thickness. In all instances consult industry associations or individual manufacturers before making final decisions.

† Larger sizes may be available.

‡ Uniform and good working quality; exterior or interior use.

§ Grades with increasing amounts of faults and more uncertain working quality; mainly for interior use.

Source: Sweet's Selection Data: Stone and Masonry, McGraw-Hill, New York.

where oil and grease may contact and readily soil the limestone. Typical uses include building veneer, ashlar or flagstone walls, pavers, crushed aggregate, and limestone dust. Grades and dimensions of limestone masonry units are given in Table 840-10.

Marble: It is a metamorphosed limestone that can be polished and is relatively expensive. Grades range from a uniform material with a minimal number of defects and variations (grade A) to grades with increasing numbers of flaws and working difficulties (grades B, C, and D). Despite the flaws, grade D often has the most beautiful colors. Marble is chemically reactive and should not be used in areas of industrial fumes, acids, or air pollution or where severe weather can be expected. Typical uses include veneer, monuments, and crushed aggregate. Grades and dimensions of marble masonry units are given in Table 840-10.

Sandstone: It is composed of sand that has been naturally cemented together. Strength and workability characteristics vary, depending on the cementing agent. The gritty surface of sandstone serves well as a nonslip walking surface. Typical uses include veneer, pavers, cut stone, and rubble. Grades and dimensions of sandstone masonry units are given in Table 840-10.

Slate: It is metamorphosed shale that cleaves easily into thin slabs. The material is strong and durable, with high tensile strength, and is typically available in colors of red, purple, green, black, and gray. Typical uses are flagstones for paving or walls, and roofing slate. Grades and dimensions of slate masonry units are given in Table 840-10.

4.3 Common Finishes for Stone Masonry Units

Table 840-11 describes typical finishes and their general availability for various stone masonry units. Fine or polished stone surfaces may be slick in wet conditions. Table 840-12 lists the colors of various building stones commonly available.

4.4 Jointing

The typical joints and weathertightness principles of brick masonry jointing are also applicable to joints used in stone masonry construction. (See 2.5 Jointing in this section)

4.5 Typical Uses of Stone Masonry Units

Typical uses for various stone types are outlined in Table 840-13.

KEY POINTS: Mortar and Reinforcement

1. Mortars are produced in various types, each composed of a unique combination of ingredients and used for a specific masonry task (see Table 840-14).

2. Bond strength is the most important property of hardened mortar and is affected as follows:
   a) As the air content is increased, the bond strength decreases.
   b) As the flow increases, the bond strength increases.
   c) As the lapsed time between the spreading of mortar and the laying of units increases, the bond strength decreases.

3. Mortar is colored either by the use of colored aggregate or by pigments. Organic colors, such as Prussian blue, cadmium, lithopone, zinc chromate, and lead chromate should be avoided because of their potential toxicity.

4. The maximum permissible quantities of metallic oxide pigments are typically 10 to 15 percent of the cement content by weight. Carbon black should be limited to 2 to 3 percent of the cement content by weight.

5. A number of types of reinforcement are available in both ladder and truss configurations (see Table 840-16). The spacing and sizes of the masonry units need to be determined in order to select the proper reinforcement.

6. See Section 830: Concrete for a discussion of reinforcing bars.

5.0 MORTAR AND REINFORCEMENT

5.1 Mortar

Mortar is produced by mixing cementitious materials, clean well-graded sand, and water. Basic functions of mortar are to:

1. Bonds units together and keeps out rain
2. Compensates for size variation in masonry units (depending on the thickness of joints)
3. Allow use of metal ties and reinforcing as an integral part of the wall
4. Provide color or texture for aesthetic reasons

Mortars are produced in various types, each composed of a unique combination of ingredients and used for a specific masonry task. Table 840-14 lists types of mortar and their common uses.

Sand Gradation Limits for Mortar:

Sand must be mixed according to specific gradation requirements to produce a mortar with smooth workability and proper strength (Table 840-15).

Plastic Properties:

While wet, mortar possesses the following plastic properties:

1. **Workability:** a uniform, cohesive, and usable consistency; resistant to segregation
2. **Water retention:** prevents loss of plasticity and bleeding
3. **Initial flow:** indicates the flow of mortar and is required to be 130 to 150 percent of the flow after suction
4. **Flow after suction:** indicates the flow of mortar after loss of water due to contact with an absorbent masonry unit

Hardened Properties:

Once hardened, mortar should possess the following properties to provide a strong, watertight, durable wall:

1. **Bond strength:** this is the most important property of hardened mortar and is affected as follows:
   a. As the air content is increased, the bond strength decreases.
   b. As the flow increases, the bond-strength increases.
   c. As the lapsed time between the spreading of mortar and the laying of units increases, the bond strength decreases.
2. **Compressive strength:** depends upon the amount of portland cement in the mix.

Table 840-11. TYPES AND AVAILABILITY OF STONE FINISHES

Types of Stone Finishes

Type of Finish	How Made	Appearance	Major Use
Broached	Produced by planing; the planer cuts out smooth valleys with a rough surface between valleys	Rough-ribbed texture with smooth valleys	Cut stone, panels, and preassembled units
Carborundum	Cut by Carborundum-type planer	Very smooth finish	Cut stone, molded stone surfaces, and preassembled units
Chat-sawed	By using a coarse abrasive during gang sawing	A coarse, pebbled surface	Cut stone, panels, preassembled units, and ashlar
Hand-tooled	By hand with various types of tools	Various types of finishes having handmade appearance	Confined to small, important areas because of cost
Honed	Machine-rubbed with find sand and water	Superfine, smooth finish	Cut stone, molded stone surfaces, and preassembled units
Machine-tooled or tooled	Cut by machine in only one direction, by hand in the other direction	Two, four, six, and eight parallel concave or convex grooves to the inch (25.4 mm)	Types of ashlar only
Plucked	By rough-planing the surface and breaking or plucking out small particles	Rough texture	Cut stone, molded stone surfaces, and preassembled units
Rock-faced	Sawed top and bottom; exposed face, a natural split dressed by machine	Rough, irregular texture	Types of ashlar only
Rusticated	Rustication done by machine, but surfaces that cannot be made by machine are done by hand	Extra deep joint effect	Types of ashlar; cut stone, and preassembled units
Sand-sawed	Gang saw only; no other finishing work	Granular surface containing saw marks, moderately smooth	Types of ashlar only
Shot-sawed	Gang saw, using steel shot for abrasive	Medium-rough pebbled surface to a surface with irregular, rough, parallel lines; brown tones obtained from rust stains from ground steel shot	Types of ashlar only
Smooth machine	By planers	Relatively smooth with a certain amount of texture	Cut stone, molded stone, and preassembled units
Split-faced	Sawed top and bottom; exposed face a natural split when stone is broken	Rough, irregular texture	Types of ashlar only
Textured Light	Cut by machine	Light textures, varying from slight texture to various vertical ribbing, minimum thickness 3½ in (63.5 mm)	Cut stone, panels, and preassembled units
Medium	Cut by machine in one direction	Various types and combinations of vertical ribbing, minimum thickness 3½ in (63.5 mm)	Cut stone, panels, and preassembled units
Rough	Cut by machine in one direction	Various types and combinations of vertical ribbing, minimum thickness 4 in (101.6 mm)	Cut stone, panels, and preassembled units
Thermal	Flame covers surface	Varies depending on grain of stone	Cut stone, panels, paving
Wet-rubbed	Machine-rubbed with fine sand and water	Smooth finish	Cut stone, molded stone, and preassembled units

Availability of Finishes

Type of Stone	Honed	Polished	Rubbed	Sand-Blasted	Sawed	Split-Face	Textured	Thermal	Tooled
Granite									
Building	•	•	•	•	•	•	•		•
Veneer	•	•	•	•	•		•	•	•
Masonry					•	•	•		•
Limestone*									
Oolitic									
Select	•		•	•	•	•	•		•
Standard	•		•	•	•	•	•		•
Rustic				•	•	•	•		•
Variegated					•	•	•		•
Dolomitic	•		•	•	•	•	•		•
Travertine	•	•	•						
Marble									
Group A	•	•	•						
Group B	•	•	•						
Group C	•	•							
Group D	•	•							
Sandstone†									
Standard					•	•			•
Quartzitic			•		•	•			
Quartzite			•		•	•			
Bluestone	•		•		•	•		•	
Slate									
Structural	•	•	•			•			
Roofing						•			
Specialty stones									
Serpentine	•	•		•	•				
Soapstone	•				•	•			
Expanded stone									
Reconstituted stone	•	•							
Simulated stone‡	•								

* Select, standard, and rustic come in colors of buff or gray and vary depending on grain coarseness. Variegated contains mixture of buff and gray colors as well as grain sizes.

† Certain OSHA regulations have limited the types of finishes available for sandstone; check local availability.

‡ Commonly imitates appearance of variegated rubble stone walls.

Source: Adapted from Caleb Hornbostel, *Construction Materials*, Wiley, New York, 1981; and *Sweet's Selection Data: Stone and Masonry*, McGraw-Hill, New York.

Table 840-12. COLORS OF BUILDING STONE

	Color Ranges																	
	White	Cream	Gray			Black	Red			Pink	Yellow	Brown			Green	Blue	Blue-grey	Purple
			Light	Medium	Dark		Light	Medium	Dark			Light	Medium	Dark				
Granite																		
Building	•	•	•	•		•	•	•	•	•		•	•	•	•	•	•	
Veneer	•	•	•	•		•	•	•	•	•		•	•	•	•	•	•	
Masonry	•	•	•	•		•	•	•	•	•		•	•	•	•	•	•	
Limestone																		
Oolitic[b]																		
Select	•	•	•									•	•					
Standard	•	•	•									•	•					
Rustic	•	•	•									•	•					
Variegated[c]				•	•												•	
Dolomitic	•	•	•		•					•		•	•	•			•	
Travertine[d]	•	•										•						
Marble																		
Group A[e]	•	•	•	•	•	•				•		•					•	
Group B[f]		•					•	•		•	•	•					•	
Group C							•	•	•	•				•	•		•	
Group D						•			•	•		•	•	•	•			
Sandstone[g]																		
Standard	•	•				•				•		•	•	•			•	•
Quartzitic	•	•				•				•		•	•				•	
Quartzite	•	•	•	•	•	•				•		•	•		•	•	•	
Bluestone					•											•	•	
Slate																		
Structural					•	•			•						•	•	•	•
Roofing					•	•			•						•	•	•	•
Specialty stones																		
Serpentine					•				•	•		•	•	•	•			
Soapstone			•	•	•												•	
Expanded stone		•	•	•	•	•						•						
Reconstituted stone	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Simulated stone[h]	•																	

[a] Color classifications are generalized and may not be identical for all stone types. Colors are dependent on mineral deposits at quarries; not all are available at all quarries.

[b] Appearance grades for oolitic limestone obtained from Indiana Limestone Institute. Oolitic limestone available also from other sources.

[c] Travertine.

[d] Travertine is also classified as marble.

[e] Only group A marble suitable for exterior use.

[f] The most colorful and interesting marbles are in groups B, C, and D.

[g] Certain OSHA regulations have limited the types of finishes available for sandstone; check local availability.

[h] Commonly imitates appearance of variegated rubble stone walls; colors of simulated stone depend on choice of aggregate and epoxy matrix.

Source: Sweet's Selection Data: Stone and Masonry, McGraw-Hill, New York.

Table 840-13. TYPICAL USES OF STONE MASONRY UNITS

	Walls				Paving and Floors							Miscellaneous					
	Retaining	Other Landscape	Building	Exterior-Facing	Chips, Roofs, and Landscape	Pebble Paving	Blocks	Flags	Slabs	Treads, Platforms	Curbs, Coping	Aggregate	Worktops	Ecclesiastical	Sculpture	Hearths	Standard Reference Specifications
Granite																	
Building	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	ASTM C615
Veneer	•	•	•	•				•	•	•	•		•	•		•	
Masonry	•			•			•				•						
Limestone																	
Oolitic																	
Category I (low density)			•	•	•	•		•	•	•		•		•	•		ASTM C568
Category II (medium density)		•	•	•	•	•	•		•	•	•	•		•	•		
Category III (high density)	•	•	•	•	•	•	•	•	•	•	•	•		•			
Dolomitic																	
Category I (low density)		•	•	•	•	•				•		•		•	•		
Category II (medium density)		•	•	•	•	•	•	•	•	•	•	•		•	•		
Category III (high density)	•	•	•	•	•	•	•	•	•	•	•	•		•			
Travertine			•	•					•	•				•			
Marble																	
Group A	•	•	•	•					•	•			•	•	•	•	ASTM C503
Group B, C and D			•		•				•	•			•	•	•	•	
Sandstone																	
Standard					•			•									
Quartzitic		•		•													
Quartzite				•				•	•	•		•					
Bluestone		•		•			•	•	•	•	•		•			•	
Slate																	
Structural			•	•				•	•	•			•	•		•	ASTM C629, structural slate
Roofing																	ASTM C406, roofing slate
Specialty stones																	
Serpentine				•					•	•			•			•	
Soapstone									•				•			•	
Lava				•	•	•										•	
Expanded stone																	
Shale					•							•					
Slate					•							•					
Obsidian		•	•	•													
Reconstituted		•	•	•				•		•			•				
Simulated		•		•													

Source: Sweet's Selection Data: Stone & Masonry, McGraw-Hill, New York.

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Table 840-14. TYPES OF MOTAR AND THEIR USES

Type of Mortar	Variations	Proportions of Constituents (Parts): Cement, Portland Cement, or Blast Furnace Slag Cement	Masonry Cement	Hydrated Lime	Lime Putty	Sand as Aggregate	Major Uses
M	(1) (2)	1 1	1 —	¼ —		Not less than 2¼ and not more than 3 times the sum of the volume of cement and lime used	Heavy-loaded and below-grade masonry subjected to rigorous exposure. Best for durability and compressive strength
S	(1) (2)	½ 1	1 —	— Over ¼ to ½			Load-bearing partitions and above-grade masonry subjected to severe exposure. Good for tensile bond and lateral strength
N	(1) (2)	— 1	1 —	— Over ½ to 1¼			Load-bearing partitions and above-grade masonry subjected to less severe exposure
O	(1) (2)	— 1	1 —	— Over 1½ to 2½			Interior masonry and above-grade, lightly loaded bearing masonry subjected to exposure in mild climate (above freezing temperature)
Lime		—	—	1 of either hydrated lime or lime putty		3	Interior non-load-bearing work where shrinkage is not important
Nonstaining cement		Nonstaining Portland, 1	—	⅕ of the cement and sand	—	3	Limestone, marble, ceramic veneer, glazed brick, and block masonry work
Nonstaining cement lime		Nonstaining Portland, ½	—	½	—	3	Cut stone and marble, and where nonstaining mortar is required
Nonstaining waterproof cement		Nonstaining waterproof Portland, 1	—	⅕	—	3	Where waterproofing is required (caps, copings, sills, etc.)
Gypsum		Neat-setting unfibered gypsum (retarded 4-hr set), 1	—	—	—	3	Gypsum blocks, decking, etc.
Pointing	(1)	Nonstaining Portland, 1	—	Sufficient amount to make as stiff a mixture as can be worked		2 white	Stonework facing
	(2)	White nonstaining	—	—	1	3	Stonework facing
Grout	(1)	Portland nonstaining, 1; Portland, 1	—	—	—	1	Stone or brick facing; setting bearing plates and railings
	(2)	Portland cement or blended cement, 1	—	0–⅒	—	2¼ to 3 times the sum of the volumes of cementitious materials	
Coarse grout	(3)	Portland cement or blended cement, 1	—	0–⅒	—	Coarse aggregate 1 to 2 times the sum of the volumes of cementitious materials. Note: coarse aggregate contains fine aggregate plus coarse aggregate	

Source: Adapted from Caleb Hornbostel, *Construction Materials,* Wiley, New York, 1981.

Table 840-15. RECOMMENDED SAND GRADATION LIMITS OF AGGREGATE FOR MASONRY MORTAR

	Percent Passing	
Sieve Size	Natural Sand	Manufactured Sand
No. 4	100	100
No. 8	95–100	95–100
No. 16	70–100	70–100
No. 30	40–75	40–75
No. 50	10–35	20–40
No. 100	2–15	10–25
No. 200	—	0–10

Source: Adapted from Jot Carpenter (ed.), *Handbook of Landscape Architectural Construction,* The Landscape Architectural Foundation, McLean, Virginia, 1976; and The American Society for Testing and Materials, *Annual Book of ASTM Standards,* Philadelphia, Pennsylvania, 1983.

3. **Volume change:** influences the amount of water penetration through walls and is dependent upon good materials, workmanship, and design.
4. **Rate of hardening:** the speed at which mortar develops resistance to indentation and crushing. A consistent rate of hardening allows tooling of the joints at the same degree of hardness to obtain uniform joint finishes.

Color Additives:

Mortar is colored either by the use of colored aggregate or by pigments. Pigments must be fine enough to disperse thoroughly, impart the desired color, and not react with other mortar ingredients. Iron, manganese oxides, chromium oxides, carbon black, and ultramarine blue may be used. Organic colors, such as Prussian blue, cadmium, lithopone, zinc chromate, and lead chromate should be avoided because of their potential toxicity. The maximum permissible quantities of metallic oxide pigments are typically 10 to 15 percent of the cement content by weight. Carbon black should be limited to 2 to 3 percent of the cement content by weight.

5.2 Reinforcement

The types of reinforcement used in masonry construction include wire reinforcement, wall ties, anchors, dowels, and reinforcing bars. Table 840-16 shows typical configurations of wire reinforcement. (Reinforcing bars are described in Section 830: Concrete.) For masonry construction, the spacing and sizes of the masonry units need to be determined in order to select the proper reinforcement.

Reinforcement should be corrosion-resistant to avoid deterioration and staining. Heavily galvanized or asphalt-coated steel as well as stainless-steel devices are available. Care must be exercised when selecting metals for anchors so as to avoid galvanic action.

6.0 CLEANING MASONRY

Table 840-17 lists common cleaning materials for masonry. The nature of particular stains can warrant the use of specific cleaning processes as outlined in Table 840-18. Sandblasting subjects masonry to rapid deterioration and should never be used for cleaning.

GLOSSARY

Backup: The part of the masonry wall behind the exterior facing.

Batter: The process of recessing or sloping a wall back in successive courses; the opposite of corbel.

Bond: Structural bond refers to tying a masonry wall together by lapping units one over another or by connecting them with metal ties. Tensile bond refers to adhesion between the mortar and masonry units or their reinforcement. Pattern bond refers to patterns formed by the exposed faces of units.

Corbel: A shelf or ledge formed by projecting successive courses of masonry out from the face of the wall.

Efflorescence: A white powdery substance composed of soluble salts carried to the wall surface by the movement and consequent evaporation of water.

"Green" brick: Unfired clay brick or other clay products which can be scultpted before they are dried and fired.

Parging: The application of mortar to the face or back of a masonry, sometimes called back-plastering.

Pointing: Troweling mortar into a joint after the masonry unit is laid.

Toothing: Projecting brick or block in alternate courses to provide for a bond with the adjoining masonry that will be laid later.

Tuck pointing: Involves refilling mortar joints that have been cut or have fallen out of existing masonry.

INDUSTRY ASSOCIATIONS AND AGENCIES

Associations

Association for Preservation Technology (APT)
Ottawa, Ontario, Canada

Brick Institute of America (BIA)
1140 Commerce Park Dr.
Reston, Virginia 22091 USA

Building Stone Institute (BSI)
New York, New York USA

International Masonry Institute (IMI)
Washington, DC, USA

National Concrete Masonry Association (NCMA)
Herndon, Virginia, USA

National Crushed Stone Association (NCSA)
Washington, DC, USA

National Sand and Gravel Association (NSGA)
Silver Spring, Maryland USA

National Terrazzo and Mosaic Association (NTMA)
Leesburg, Virginia USA

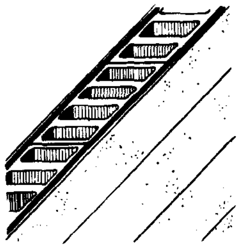
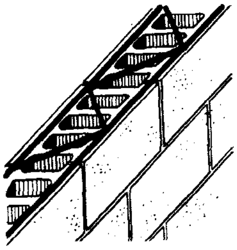
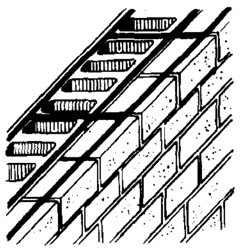
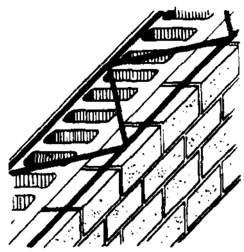
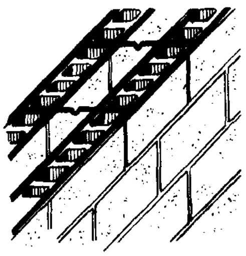
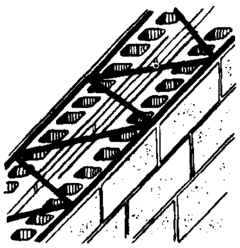
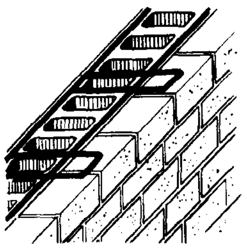
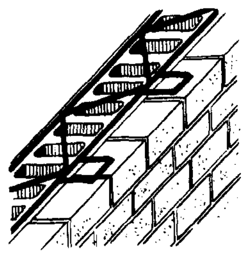
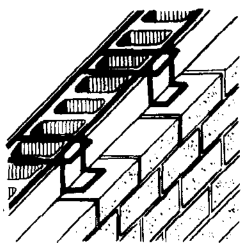
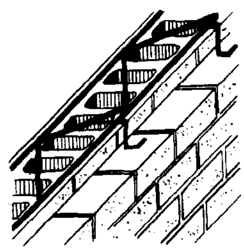
Portland Cement Association
Skokie, Illinois USA

Institutes and Agencies
American National Standards Institute (ANSI)
New York, New York USA

Construction Specifications Institute (CSI)
Washington, DC, USA.

National Institute of Standards and Technologies (NIST)
Washington, DC, USA

Table 840-16. TYPES OF WIRE REINFORCEMENT

Type and Use	Ladder Configurations	Truss Configurations
Two-wire ▪ Horizontal reinforcement of single wythe wall ▪ Continuous rigid tie for composite or cavity walls ▪ Reinforcement of stacked bond walls		
Three-wire ▪ Horizontal reinforcement of one wythe of composite or cavity wall where rigid anchorage of second wythe is required ▪ Continuous rigid tie system for cavity and/or composite walls		
Four-wire ▪ Horizontal reinforcement of each wythe of a composite or cavity wall where rigid anchorage of second wythe is required ▪ Reinforced masonry walls in heavy seismic zones		
Tab ▪ Horizontal reinforcement of one wythe of composite or cavity wall where flexible anchorage of second wythe is required		
Adjustable ▪ Horizontal reinforcement of one wythe of a composite or cavity wall where adjustment of tie to second wythe is required		

Notes: 1. Actual width of joint reinforcing is 2 in less than nominal wall width. 2. Different designs are available from various manufacturers. 3. Reinforcing is typically available for wall thicknesses of 3, 4, 6, 8, 10, 12, 13, 14 and 16 in.

Source: Sweet's Selection Data: Stone and Masonry, McGraw-Hill, New York.

Table 840-17. COMMON MATERIALS USED FOR CLEANING MASONRY

	Surfaces								Problems				Environmental Hazard			Application Notes	Remarks
	Porous	Hard	Soft	Decorated/Carved	Rough	Smooth	Polished	Light Colored	Dark Colored	Erosion and Abrasion	Cause Other Stains	Damage Other Materials	Low	Medium	High		■ Mortar and joints should be in good condition. ■ Cleaning should occur only after all restoration is complete. ■ Make sample cleaning tests. ■ Protect against possible damage to adjacent materials, environment.
Water																	
Low pressure		•	•			•	•	•	•		•	•				■ Gentle, safe to surface ■ Not effective for heavy staining	■ Generally safest and least expensive type of method ■ Do not use in cold weather.
Medium-high pressure		•				•	•	•	•		•			•		■ Pressure can cause damage ■ Generates large volume of water	■ Chemical salts present in masonry may react with water and form stains. ■ Provide for disposal of water.
Steam		•	•	•	•	•	•	•	•					•		■ Generally cleans most structures. Especially good on rough surfaces and buildings with varied surfaces.	
Chemical																	
Acids		•				•			•		•	•			•	■ Don't use on high-lime-content stones and mortars, or on lightcolored, glazed, or polished masonry.	■ Generally contain water in base mixture and in rinse ■ Can create all of the problems of plain water as well as: Discoloration Damage to plant and animal life Damage to adjacent materials, e.g., metals, glass
Cleansers, detergents	•				•	•			•		•			•		■ Many common household cleansers can be used.	
Proprietary compounds		•	•													■ Consult manufacturer's literature for specific product recommended for various masonry types.	
Steam and chemicals		•	•	•	•	•	•	•	•			•		•		■ Takes off heavy applied stains that simple steam cleaning won't remove	
Mechanical																	
Sand blasting		•			•			•	•	•		•			•	■ Don't use on polished surfaces or detailed carvings. ■ Choice available as to type of abrasive and amount of pressure	■ Generally better for heavier staining ■ Potentially damaging due to: Dust Surface erosion and need to preserve or weatherproof masonry Abrasion of adjacent surfaces
Sanding discs, grinders		•			•					•		•			•	■ Removes outer surface. Don't use on polished or carved surfaces.	
Wet sand		•								•		•				■ Less abrasive than blasting or grinding ■ Eliminates dust	
Wet aggregate		•	•		•	•		•	•			•		•		■ Contains a silica-free friable aggregate to lessen abrasion	

Source: Sweet's Selection Data: Stone and Masonry, McGraw-Hill, New York.

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Table 840-18. STANDARD METHODS OF STAIN REMOVAL

	Water			Chemical				Mechanical				Hand		Remarks
	Low Pressure	High Pressure	Steam	Acid	Detergents, Cleaners	Proprietary Compounds	Chemicals With Steam	Sanding Discs, Grinders	Wet Sand	Wet Aggregate	Sand Blasting	Dry Brush	Chisel	▪ Test masonry before cleaning. ▪ Chemical methods use H_2O often in mixture and always in rinse. ▪ With acid, do entire surface to keep color uniform.
Dirt, smoke Pollutants	•	•	•	•	•	•	•	•	•	•	•			▪ See chart on general cleaning for evaluation
Oil, tar					•	•	•							
Efflorescence (Bloom)	•			•	•	•						•		▪ Dilute HCL acid used. Rinse with H_2O. Do not use on light-colored, soft, sandy brick.
Green stains Vanadium	•				•	•								▪ May appear after cleaning with acid to remove efflorescence
Brown stains Manganese				•		•								
White bleed $CaCo_3$		•				•			•					
Rust				•	•	•								
Paint Graffiti						•	•	•	•	•	•	•		▪ Fresh paint removed with prop. compound. Old paint requires mechanical method or steam with chemicals.
Organic stains Plant growth, foods, etc.				•	•	•	•							▪ Most removed with bleach or oxalic acid. See NCMA-43.
Mortar spatter												•	•	
Unknown stains				•										▪ Test for organic material with sulfuric acid.

Source: Sweet's Selection Data: Stone and Masonry, McGraw-Hill, New York.

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SECTION **850**

Wood

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CONTENTS

1.0 INTRODUCTION

1.1 General

This section provides basic information on lumber and the proper use of wood in outdoor environments. In a world where there is a growing concern to promote use of renewal and sustainable resources, wood products typically fall within this area of concern. Rare woods which are harvested in ways that destroy ancient forests and their larger eco-systems and upset other natural systems (increase water runoff and water pollution, etc.) are to be discouraged and avoided if at all possible. There is a growing international effort (such as the "Smart Woods Program") which is promoting the creation of plantations where once rare timber trees (such as teak, etc.) can be grown and harvested for their wood.

Also, there is emerging a wider use of wood substitutes, such as "post-consumer" plastics which are being made into "lumber-like" products. See Section 870: Plastics and Glass for more information. This Section focuses primarily on softwoods as a construction material, their properties and characteristics that effect their use in design and construction. It does not include information on techniques of wood construction. These aspects and the hardware used in wood construction are covered in separate sections throughout the handbook, including: Section 470: Pedestrian Bridges, Section 460: Wood Decks and Boardwalks, Section 870: Plastics and Glass, and Section 860: Metals.

1.2 Important Properties of Wood

Moisture Content:

Moisture Content: (MC) refers to the amount of water contained in wood which is usually expressed as a percentage relative to the weight of oven-dried wood ("x" percent MC). Unseasoned (i.e., green or fresh-cut wood) has a very high moisture content. The level of moisture in newly cut wood can be lowered by different processes and are described as follows:

Unseasoned lumber: is the wood immediately after it has been cut.

Common Lumber: typically has a moisture content of 15 to 19 percentage. This improves the strength of the wood, reduces shrinkage and warping, etc.

Air-dried lumber: typically contains 12-15 percent moisture. It has been dried simply by exposure to the atmosphere. Most lumber is air-dried, although complete air drying of large timbers is usually impractical.

Kiln-dried lumber: typically has a moisture content as low as 6% to as high as 19%. This wood has been dried in a kiln under controlled heat and temperature to achieve a desired moisture content. It is primarily done for "appearance grades" or "finished lumber where dimensional stability and appearances are important. Kiln-dried stamped on individual wood members is always accompanied by a moisture content percentage.

Equilibrium moisture content: refers to the moisture content that a wood member will attain in service as affected by local temperatures and humidity. Specification of moisture content in lumber stock should be as near as possible to the moisture content the lumber will attain in service. (see Table 850-1).

Weight:

The unit weight of various woods depends both on the species and moisture content of the individual piece. The unit weight of wood is a rough indicator of its relative strength, with higher values implying greater strengths. Refer to Table 850-2 for the specific values of various species.

Strength:

The ability of a wood member to resist loading depends on the strength of the wood species, its orientation in the structure, and the cross-sectional dimension of the member. The inherent strength of a wood is expressed in a number of ways as described below. Design values for various softwood species are given in Tables 850-3.

Tensile strength (F_t): refers to the ability of a wood member to resist stretching or stresses imposed parallel to the grain. Tensile strength is reduced by the presence of knots, splits, and checks in the member. The tensile strength of wood perpendicular to the grain is very low.

Compressive strength: refers to the ability of a wood member to resist loads that are crushing the wood member. Compressive strengths parallel to the grain

Table 850-1. EQUILIBRIUM MOISTURE CONTENTS FOR WOOD IN VARIOUS ENVIRONMENTS

Temperature (Dry Bulb) °F	Relative Humidity, %																			
	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	98
30	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.4	13.5	14.9	16.5	18.5	21.0	24.3	26.9
40	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.3	13.5	14.9	16.5	18.5	21.0	24.3	26.9
50	1.4	2.6	3.6	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.3	11.2	12.3	13.4	14.8	16.4	18.4	20.9	24.3	26.9
60	1.3	2.5	3.6	4.6	5.4	6.2	7.0	7.8	8.6	9.4	10.2	11.1	12.1	13.3	14.6	16.2	18.2	20.7	24.1	26.8
70	1.3	2.5	3.5	4.5	5.4	6.2	6.9	7.7	8.5	9.2	10.1	11.0	12.0	13.1	14.4	16.0	17.9	20.5	23.9	26.6
80	1.3	2.4	3.5	4.4	5.3	6.1	6.8	7.6	8.3	9.1	9.9	10.8	11.7	12.9	14.2	15.7	17.7	20.2	23.6	26.3
90	1.2	2.3	3.4	4.3	5.1	5.9	6.7	7.4	8.1	8.9	9.7	10.5	11.5	12.6	13.9	15.4	17.3	19.8	23.3	26.0
100	1.2	2.3	3.3	4.2	5.0	5.8	6.5	7.2	7.9	8.7	9.5	10.3	11.2	12.3	13.6	15.1	17.0	19.5	22.9	25.6
110	1.1	2.2	3.2	4.0	4.9	5.6	6.3	7.0	7.7	8.4	9.2	10.0	11.0	12.0	13.2	14.7	16.6	19.1	22.4	25.2
120	1.1	2.1	3.0	3.9	4.7	5.4	6.1	6.8	7.5	8.2	8.9	9.7	10.6	11.7	12.9	14.4	16.2	18.6	22.0	24.7
130	1.0	2.0	2.9	3.7	4.5	5.2	5.9	6.6	7.2	7.9	8.7	9.4	10.3	11.3	12.5	14.0	15.8	18.2	21.5	24.2
140	.9	1.9	2.8	3.6	4.3	5.0	5.7	6.3	7.0	7.7	8.4	9.1	10.0	11.0	12.1	13.6	15.3	17.7	21.0	23.7
150	.9	1.8	2.6	3.4	4.1	4.8	5.5	6.1	6.7	7.4	8.1	8.8	9.7	10.6	11.8	13.1	14.9	17.2	20.4	23.1
160	.8	1.6	2.4	3.2	3.9	4.6	5.2	5.8	6.4	7.1	7.8	8.5	9.3	10.3	11.4	12.7	14.4	16.7	19.9	22.5
170	.7	1.5	2.3	3.0	3.7	4.3	4.9	5.6	6.2	6.8	7.4	8.2	9.0	9.9	11.0	12.3	14.0	16.2	19.3	21.9
180	.7	1.4	2.1	2.8	3.5	4.1	4.7	5.3	5.9	6.5	7.1	7.8	8.6	9.5	10.5	11.8	13.5	15.7	18.7	21.3
190	.6	1.3	1.9	2.6	3.2	3.8	4.4	5.0	5.5	6.1	6.8	7.5	8.2	9.1	10.1	11.4	13.0	15.1	18.1	20.7
200	.5	1.1	1.7	2.4	3.0	3.5	4.1	4.6	5.2	5.8	6.4	7.1	7.8	8.7	9.7	10.9	12.5	14.6	17.5	20.0
210	.5	1.0	1.6	2.1	2.7	3.2	3.8	4.3	4.9	5.4	6.0	6.7	7.4	8.3	9.2	10.4	12.0	14.0	16.9	19.3

Source: U.S. Forest Products Laboratory, *Wood Engineering Handbook*, Prentice-Hall, Englewood Cliffs, New Jersey,

(F_c) are 2 to 5 times greater than compressive forces perpendicular to the grain ($F_c \perp$). The former is applicable to vertical load-bearing members, while the latter is applicable to horizontal load-bearing members.

Extreme fiber stress in bending (F_b): refers to the ability of a horizontal load-bearing member to carry maximum load in bending without causing the fibers at the utmost top of the member (those most in compressive action) or those at the utmost bottom of the member (those most in tension) to fail. Single-member F_b values refer to loads borne by an individual member, while repetitive F_b values refer to instances where three or more load-bearing members, spaced no more than 600 mm (24 in) apart, are joined by load distributing elements. F_b values are used in load-bearing calculations to determine the sizing of horizontal members.

Modulus of elasticity (E): is a measure of stiffness in a wood member; it refers to the ability of the member to resist deflection. E is a ratio of the amount by which a material will deflect in proportion to an applied load. E values are used in load-bearing calculations to determine the sizing of horizontal members, based on deflection.

Horizontal shear strength: refers to the ability of wood fibers at the top half of a bending member (that part in compression) to resist shearing horizontally from the fibers in the bottom half of a bending member (that part in tension). Horizontal shear is most likely to occur along the neutral axis of a member (i.e., the horizontal plane running the length of a member approximately two-thirds of the way down from the top of the member). The installation of bolts should be avoided along this plane.

Appearance:

Color, figure patterns, grain, and defects in the wood influence the aesthetic value of a piece of lumber. In most landscape construction, wood is either allowed to weather naturally or is preserved, thereby changing its natural appearance from the time of installation.

Color: typically refers to the color of the heartwood in a species, since the sapwood of all species is light in color (virtually white). Heartwood is darker than sapwood and ranges in color from nearly white to deep reddish brown, depending on the species. Table 850-4 provides a description of several wood species.

Table 850-2. UNIT WEIGHTS OF VARIOUS SOFTWOODS

	Weight			
	Moisture Content, 15%		Moisture Content, 8%	
Softwoods	**lb/ft³**	**kg/m³**	**lb/ft³**	**kg/m³**
Cedar, Alaska	31.6	506.23	30.4	487.01
Cypress, bald	32.6	522.25	31.4	503.03
Fir, Douglas	30.5–34.3	488.61–549.49	29.2–33.1	467.78–530.26
Fir, true eastern	26.9	430.94	26.4	422.93
Fir, true western	26.7–28.3	427.73–453.37	25.8–27.2	413.32–435.74
Hemlock, eastern	29.0	464.58	28.0	448.56
Hemlock, western	29.6	474.19	28.7	459.77
Cedar, incense	25.5	408.51	24.2	387.68
Larch, western	39.4	613.19	38.2	611.96
Pine, eastern white	25.4	406.91	24.2	387.68
Pine, lodgepole (knotty pine)	29.2	467.78	28.2	451.76
Pine, pitch	34.9	551.09	33.8	541.48
Pine, pond	38.7	619.97	37.5	600.75
Pine, ponderosa	28.6	618.37	27.5	440.55
Pine, red	31.4	503.03	30.4	487.01
Pine, southern yellow	41.6–43.9	666.43–703.28	40.3–42.6	645.61–682.45
	35.7–36.3	571.91–581.53	34.6–25.3	554.29–565.51
Pine, sugar	26.0	416.52	24.0	384.48
Pine, western white	28.0	448.56	27.1	434.14
Cedar, Port Orford	30.1	482.20	28.9	462.98
Cedar, red eastern	33.5	536.67	32.2	515.84
Cedar, red western	23.4	347.87	22.4	358.85
Redwood	28.6	458.17	27.4	438.94
Spruce, eastern	29.4–28.4	470.99–459.97	28.7–27.2	459.77–435.74
Spruce, Engelmann	24.1	386.08	23.2	371.66
Spruce, Sitka	28.1	450.16	27.1	434.14
Tamarack	37.6	602.35	36.3	480.53

Source: Adapted from U.S. Forest Products Laboratory, *Wood Engineering Handbook*, Prentice-Hall, Englewood Cliffs, New Jersey.

KEY POINTS - Wood Properties

1. Common yard lumber is typically seasoned to a moisture content of about 15 to 19 percent. Typical industry standards are 6 to 12 percent for finish lumber.
2. The use of wood in arid regions may require lumber with slightly lower moisture contents to prevent further drying and warpage of the wood in service.
3. The unit weight of wood is a rough indicator of its relative strength, with higher values implying greater strengths (see Table 850-2 for values of various species).
4. The inherent strength of a wood is expressed in terms of tensile strength, compressive strength, extreme fiber stress in bending, modulus of elasticity, and horizontal shear strength (see Table 850-3 for design values of various species).
5. Any cross-grain in a piece of lumber adversely affects the strength of the member, and should be carefully examined before being used in a load-bearing situation.
6. Coarse-grained woods (widely-spaced rings) accept stains and other preservatives and hold paints and surface sealers better than woods with close grains or closely-spaced rings.

Table 850-3. DESIGN VALUES FOR MACHINE STRESS-RATED STRUCTURAL LUMBER [a,b]

Grade Designation	Grading Rules Agency (See Notes h-j)	Size Classification	Design Values (lb/in²)[c] Extreme Fiber in Bending, F_b[d] Single Member Uses	Repetitive Member Uses	Tension Parallel to Grain, F_t	Compression Parallel to Grain, F_c	Modulus of Elasticity, E
900f-1.0E	j	Machine-rated lumber, 2-in thick or less, all widths	900	1050	350	725	1,000,000
1200f-1.2E	h,i,j		1200	1400	650	950	1,200,000
1350f-1.3E	i		1350	1550	750	1100	1,300,000
1450f-1.3E	h,j		1450	1650	800	1150	1,300,000
1500f-1.4E	h,i,j		1500	1750	900	1200	1,400,000
1650f-1.5E	h,i,j		1650	1900	1020	1320	1,500,000
1800f-1.6E	h,i,j		1800	2050	1175	1450	1,600,000
1950f-1.7E	h,i		1950	2250	1375	1550	1,700,000
2100f-1.8E	h,i,j		2100	2400	1575	1700	1,800,000
2250f-1.9E	h,i		2250	2600	1750	1800	1,900,000
2400f-2.0E	h,i,j		2400	2750	1925	1925	2,000,000
2550f-2.1E	h,i		2550	2950	2050	2050	2,100,000
2700f-2.2E	h,i,j		2700	3100	2150	2150	2,200,000
2850f-2.3E	i		2850	3300	2300	2300	2,300,000
3000f-2.4E	h,i		3000	3450	2400	2400	2,400,000
3150f-2.5E	i		3150	3600	2500	2500	2,500,000
3300f-2.6E	i		3300	3800	2650	2650	2,600,000
900f-1.0E	h,i,j	See note j	900	1050	350	725	1,000,000
900f-1.2E	h,i,j		900	1050	350	725	1,200,000
1200f-1.5E	h,i,j		1200	1400	600	950	1,500,000
1350f-1.8E	h,i		1350	1550	750	1075	1,800,000
1500f-1.8E	j		1500	1750	900	1200	1,800,000
1800f-2.1E	h,i,j		1800	2050	1175	1450	2,100,000

[a] Stresses apply at 19% maximum moisture content.

[b] Design values listed are for normal loading conditions (see notes below) and other provisions in the national design specification. For adjustments of tabulated values, see Note d.

[c] Design values for horizontal shear F_v (DRY) and compression perpendicular to grain $F_{c\perp}$ (DRY) are:

Cedar (WWPA/ WCLIB)*	*Douglas fir, larch (WWPA/ WCLIB/ NLGA)*	*Douglas fir, south (WWPA)*	*Engelmann spruce (WWPA)*	*Hemlock, fir (WWPA/WCLIB/ NLGA)*	*Mixed species (WCLIB)*	*Pine (WWPA)*	*Southern pine (SPIB)*	*Spruce, pine, fir (NLGA)*	*Western hemlock (WWPA/WCLIB)*
Horizontal shear F_v (DRY)									
75	95	90	70	75	70	70	90	70	90
Compression perpendicular to grain $F_{c\perp}$ (DRY)									
265	385	335	195	245	190	190	405	265	280

* Cedar includes incense or western red cedar. Pine includes Idaho white pine, lodgepole pine, ponderosa pine, or sugar pine.

Figure: refers to the pattern of tree ring growth as a consequence of sawing the log. Depending on whether the log is plain-sawed or quartersawn, various species exhibit either conspicuous or inconspicuous growth rings. Table 850-4 describes the figure in various species as a consequence of both sawing methods.

Grain: refers to the density of wood growth in a piece of lumber. Annual rings that are close together (with small pores) are referred to as being close-grained, whereas widely spaced rings (with large pores) are referred to as being coarse-grained. Coarse-grained woods accept stains and other preservatives and hold paints and surface sealers better than close-grained woods.

The term grain is also used to refer to the direction of fibers in a piece of lumber, this direction being a consequence either of the tree's natural growth or of sawing the log. For maximum strength, the fibers in a piece of lumber should be parallel (or nearly so) to the edge of the member. Any cross-grain in a piece of lumber adversely affects the strength of the member, and should be carefully examined before being used in a load-bearing situation.

Defects: in a piece of lumber affect both the strength of the member and its appearance. Defects are caused either by natural growth in the tree or by manufacturing (i.e., sawing and surfacing) operations. Figures 850-1 through 850-5 illustrate various types of defects in lumber.

Table 850-3. (cont.)

[d] Tabulated extreme fiber values in bending values F_b are applicable to lumber loaded on edge. When loaded flat, these values may be increased by multiplying by the following factors:

Nominal width (in)	3	4	5	6	8	10	12	14
Factor	1.06	1.10	1.12	1.15	1.19	1.22	1.25	1.28

[e] Grading rules agencies listed include the following:
Northeastern Lumber Manufacturers Association, Incorporated (NELMA)
Northern Hardwood and Pine Manufacturers Association, Incorporated (NHPMA)
National Lumber Grades Authority (Canada) (NLGA)
Redwood Inspection Service (RIS)
Southern Pine Inspection Bureau (SPIB)
West Coast Lumber Inspection Bureau (WCLIB)
Western Wood Products Association (WWPA)
The design values are applicable to lumber that will be used under dry conditions. For 2- to 4-in thick lumber, the DRY surfaced size should be used in member design.
The design values for surfaced dry or surfaced green lumber may be multiplied by the following factors (for southern pine use tabulated design values without adjustment:

Thickness of lumber	*Moisture content (MC)*	*Extreme fiber in bending in F_b*	*Tension parallel to grain F_t*	*Horizontal shear F_v*	*Compression perpendicular to grain F_c*	*Compression parallel to grain F_c*	*Modulus of elasticity E*
2-4 in	15% maximum	1.08	1.08	1.05	1.00	1.17	1.05
2-4 in	19% and above	0.86	0.84	0.97	0.67	0.70	0.97
5 in	19% and above	1.00	1.00	1.00	0.67	0.91	1.00

[f] National Lumber Grades Authority grading rules.

[g] Southern Pine Inspection Bureau grading rules.

[h] West Coast Lumber Inspection Bureau grading rules.

[i] Western Wood Products Association grading rules.

[j] Size classifications for these grades are:
NLGA—machine rated lumber; 2-in thick or less; all widths
SPIB—machine rated lumber; 2-in thick or less; all widths
WCLIB—machine rated joists; 2-in thick or less; 6 inches and wider
WWPA—machine rated lumber; 2-in thick or less; all widths

Source: Adapted from C. G. Ramsey and H. R. Sleeper, *Architectural Graphic Standards,* 7th ed., John T. Packard (ed.), Wiley, New York, 1981, as prepared by the National Forest Products Association, *Design Values for Wood Construction,* Washington, D.C.

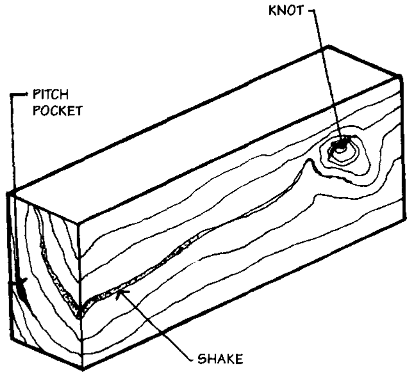

Figure 850-1. Natural defects. Pitch pockets *are openings containing resin. Their number, size, and location do not significantly affect strength if kept within established guidelines.* Shakes *are separations along the grain which can affect shear strength if they are significant.* Knots *refer to the growth of tree limbs and can affect both the appearance of a wood member and its strength. Reduction in strength is found acceptable within certain established limits.*

Insect and Decay Resistance:

A variety of insect species can degrade wood. Termites are by far the most destructive. The range of termite infestation in the United States is shown in Figure 850-6. Termites require moist soil conditions. Anti-termite construction techniques, termite shields, chemically treated soils and timbers, and termite-resistant wood species can minimize the problem. Termite-resistant wood species include redwood, bald cypress (tidewater red), and eastern red cedar.

Table 850-4. COLOR AND FIGURE CHARACTERISTICS OF VARIOUS SOFTWOODS

Species	Color of Dry Heartwood	Type of Figure in: Plain-Sawed Lumber or Rotary-Cut Veneer	Type of Figure in: Quartersawed Lumber or Quarter-Sliced Veneer
Bald cypress	Light yellowish brown to reddish brown	Conspicuous irregular growth ring	Distinct, not conspicuous, growth-ring stripe
Cedar:			
Alaska	Yellow	Faint growth ring	None
Atlantic white	Light brown with reddish tinge	Distinct, not conspicuous, growth ring	None
Eastern red	Brick red to deep reddish brown	Occasionally streaks of white sapwood alternating with heartwood	Occasionally streaks of white sapwood alternating with heartwood
Incense	Reddish brown	Faint growth ring	Faint growth-ring stripe
Northern white	Light to dark brown	Faint growth ring	Faint growth-ring stripe
Port Orford	Light yellow to pale brown	Faint growth ring	None
Western red	Reddish brown	Distinct, not conspicuous, growth ring	Faint growth-ring stripe
Douglas fir	Orange red to red; sometimes yellow	Conspicuous growth ring	Distinct, not conspicuous, growth-ring stripe
Fir:			
Balsam	Nearly white	Distinct, not conspicuous, growth ring	Faint growth-ring stripe
White	Nearly white to pale reddish brown	Conspicuous growth ring	Distinct, not conspicuous, growth-ring stripe
Hemlock:			
Eastern	Light reddish brown	Distinct, not conspicuous, growth ring	Faint growth-ring stripe
Western	Light reddish brown	Distinct, not conspicuous, growth ring	Faint growth-ring stripe
Larch, western	Russet to reddish brown	Conspicuous growth ring	Distinct, not conspicuous, growth-ring stripe
Pine:			
Eastern white	Cream to light reddish brown	Faint growth ring	None
Lodgepole	Light reddish brown	Distinct, not conspicuous, growth ring; faint pocked appearance	None
Ponderosa	Orange to reddish brown	Distinct, not conspicuous, growth ring	Faint growth-ring stripe
Red	Orange to reddish brown	Distinct, not conspicuous, growth ring	Faint growth-ring stripe
Southern:			
longleaf, loblolly, shortleaf, and slash	Orange to reddish brown	Conspicuous growth ring	Distinct, not conspicuous, growth-ring stripe
Sugar	Light creamy brown	Faint growth ring	None
Western white	Cream to light reddish brown	Faint growth ring	None
Redwood	Cherry to deep reddish brown	Distinct, not conspicuous, growth ring; occasionally wavy and burl	Faint growth-ring stripe; occasionally wavy and burl
Spruce:			
Black, Engelmann, Red, White	Nearly white	Faint growth ring	None
Sitka	Light reddish brown	Distinct, not conspicuous, growth ring	Faint growth-ring stripe
Tamarack	Russet brown	Conspicuous growth ring	Distinct, not conspicuous, growt ring

* The sapwood of all species is light in color or virtually white unless discolored by fungus or chemical stains.

Source: Adapted from U.S. Forest Products Laboratory, *Wood Engineering Handbook*, Prentice-Hall, Englewood Cliffs, New Jersey.

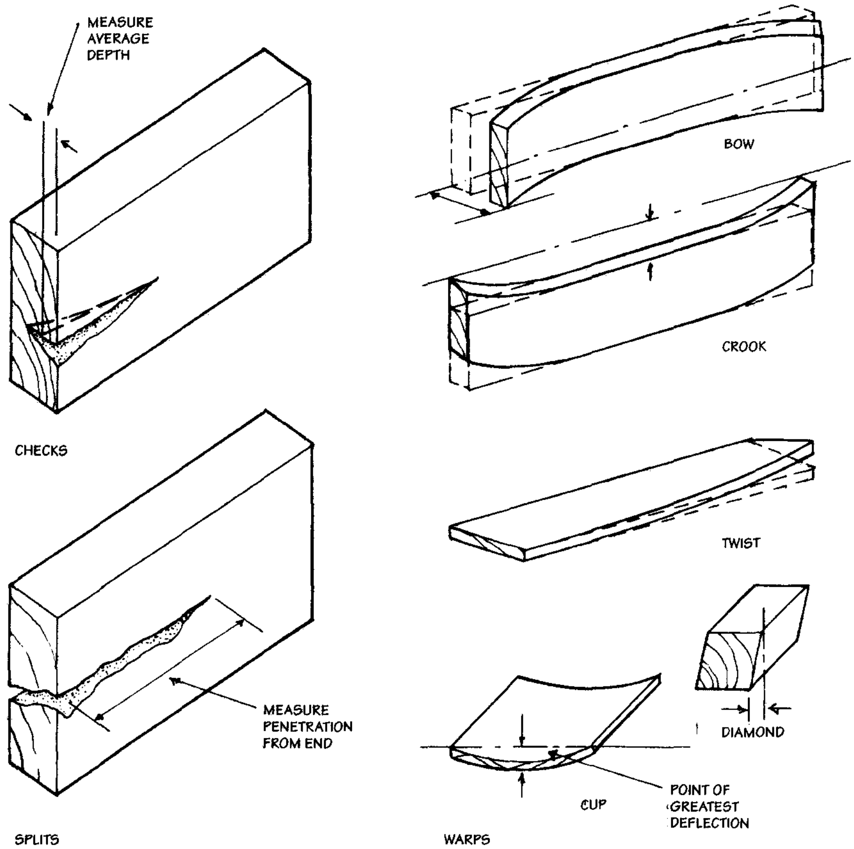

Figure 850-2. Defects due to seasoning. *Checks are separations across the grain due to seasoning. Splits are lengthwise separations through the entire piece. Warp is any deviation from a true or plane surface, including bowing, crooking, twisting, cupping, or combinations of each.*

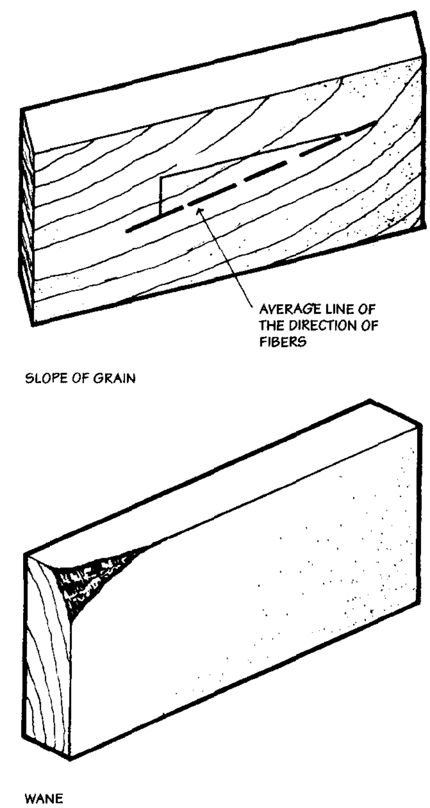

Figure 850-3. Defects due to sawing. *Slope of grain refers to the angle of the grain relative to the member's edge. The greater the slope, the weaker the member. Wane refers to an absence of wood, or the presence of bark.*

Table 850-5. RELATIVE DECAY RESISTANCE OF VARIOUS SOFTWOODS

Resistant or very resistant	Moderately Resistant	Slightly or nonresistant
• Bald cypress, old growth* • Cedars • Cypress, Arizona • Junipers • Locust, black† • Osage orange† • Redwood • Sassafras • Yew, Pacific‡	• Bald cypress, young growth* • Douglas fir • Honey locust ‡ • Larch, western • Pine, eastern white* • Southern pine: Longleaf* Slash* • Tamarack	• Pines (other than long leaf, slash, and eastern white)‡ • Spruces • True firs, western and eastern • Yellow poplar

* The southern and eastern pines and bald cypress are now largely second growth with a large proportion of sapwood. Consequently, substantial quantities of heartwood lumber of these species are not available.

† These woods have exceptionally high decay resistance.

‡ These species or certain species within the group have higher decay resistance than most woods in this grouping.

Source: Adapted from U.S. Forest Products Laboratory, *Wood Engineering Handbook*, Prentice-Hall, Englewood Cliffs, New Jersey, 1974.

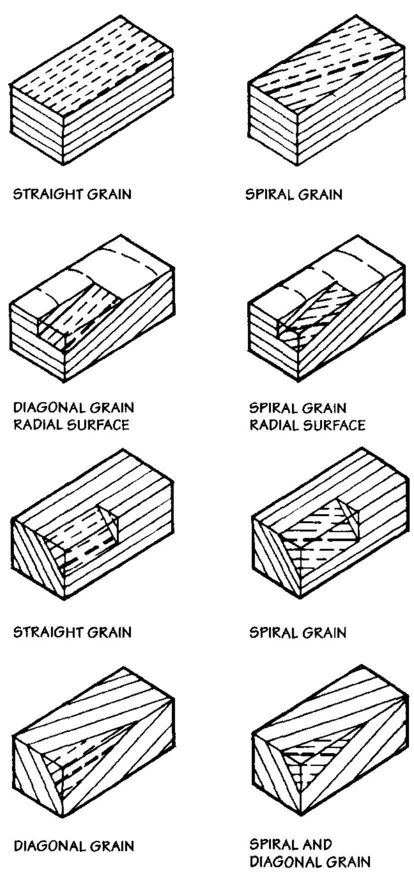

Figure 850-4. Defects due to cross-grain. *Cross-grain is a slope of grain defect caused by aberrant growth of the tree or by improper sawing, and results in a weaker piece of lumber than straight grain. Straight-grained lumber is strongest and has fibers oriented parallel to the longitudinal axis of the piece (shown with bold dashed line).*

Fungi—in the form of mold, stains, dry rot, and soft rot—also can seriously degrade wood (Table 850-5). Resistance to decay from most fungi is improved by restricting the moisture content of wood to 20 percent or less. Dry rot can be avoided if moisture contents are kept to 30 percent or less. Wood that is completely and continuously submerged in water will not rot.

Some softwood species are inherently resistant to attack from insects and fungi (Table 850-5). The heartwood of any species is typically more resistant than its sapwood. Maximum resistance to attack from insects and fungi, without chemical preservation, can be achieved by specifying all heartwood lumber from a resistant species like California redwood (*Sequoia sempervirens*) or bald cypress (*Taxodium distichum*).

Pressure-treated wood should be used where a member will be embedded in moist ground, especially when used for the support of permanent structures. Paints and stains can provide increased insect and decay resistance. Table 850-5 provides additional information on decay-resistant species.

Construction plans should detail how to join wood members so as to minimize the trapping of moisture.

Weatherability:

Weathering refers to the ability of wood to resist cupping, warping, and checking, as well as the visual effects of weathering on the wood's color. Checking is most evident in coarse-grained woods and plain-sawed boards. Warping is most evident in plain-sawed boards. Cupping is most evident in dense woods and in boards that are much wider than they are thick. To minimize cupping, the width of boards should be no more than 8 times their thickness, and boards used as a decking material should be laid bark-side up.

Exposed (i.e., untreated) woods characteristically turn various shades of gray with various degrees of sheen, depending on the species. Weathered appearances are predictable, and can be arrested at any stage in the process by the application of sealers or other types of preservative. Tables 850-6 and 850-7 provide information on the weathering characteristics of various softwood species.

1.3 Characteristics of Various Softwoods

The characteristics of various softwoods, including decay resistance, weathering, ease of keeping painted, color, and figure, are described in Tables 850-4 through 850-8.

2.0 LUMBER CLASSIFICATION

2.1 Regional Production and Grading Authorities

Figure 850-7 and Table 850-9 identify various wood species produced in different regions of the United States. A number of regional grading authorities have established standards of sizes, properties, and design stress values for woods grown in their jurisdiction. These standards are based on guidelines established by the American Lumber Standards Committee (PS 20-70 American Softwood Lumber Standards). The terminology of sizes and their associated grading hierarchies is generally consistent from one authority to another, although slight variations do occur. Softwood species in the United States and the respective grading authorities are shown in Table 850-10.

2.2 Sawing and Surfacing

Sawing:

The method used to saw lumber affects the appearance and wearability of the wood. Two types of sawed lumber are plain-sawed (producing flat-grained boards) and quartersawn (producing edge- or vertical-grained boards).

Plain-sawed lumber: is made by sawing directly across the entire log (Figure 850-8). Members are produced that are relatively inexpensive, have conspicuous growth rings and figure patterns, and whose strength is less affected by knots. Shrinkage and swelling are more evident in the width of the member than in its thickness, and plain-sawed boards tend to easily develop checks and surface splits during seasoning.

Quartersawn lumber: is cut from a quarter section of log (Figure 850-8). Members are more expensive than plain-sawed lumber, figure patterns peculiar to the radial pattern are conspicuously displayed, and shrinkage and swelling occurs less in width of the board than in its thickness. Edge-grained lumber wears more evenly, is less susceptible to twisting and cupping, and is less likely to develop surface checks and splits during seasoning and use.

Surfacing:

The surfacing or finishing of a wood member influences its appearance and determines its actual cross-sectional dimensions.

Rough lumber: refers to lumber that has been sawed, edged, and trimmed but not surfaced by planing. Dressed or surfaced lumber refers to wood that has been planed to achieve smooth surfaces and uniform dimensions. Figure 850-9 illustrates various combinations of dressed faces.

2.3 Lumber Grading Methods

The grading rules established by each of the regional grading authorities are based on quality-reducing characteristics (defects) that adversely affect the appear-

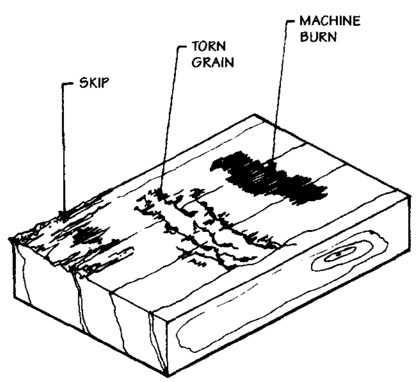

Figure 850-5. Defects due to surfacing. *Machine burn is the darkening of wood due to overheating by machine knives or rollers when pieces are stopped by the machine. Torn grain is a roughened area caused by the machine tearing out bits of wood in the dressing. Skip is an area on a piece that fails to surface smoothly as it passes through the planer.*

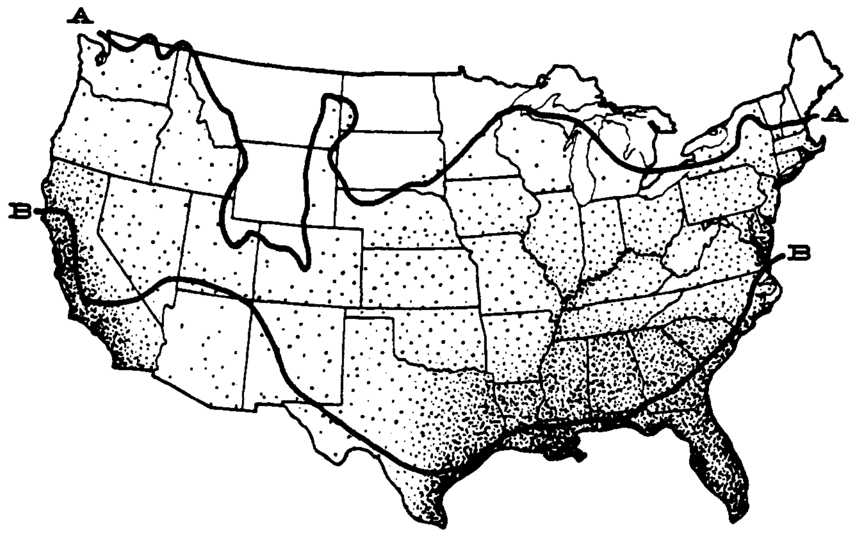

Figure 850-6. Extent of termite infestation in the United States. *Zones illustrate general relative hazard of termite infestation. Subterranean termites have been found as far north as line A-A. Line B-B shows the northern limit of non-subterranean termites.*

KEY POINTS - Lumber Classification and Sizes

1. Terminology of sizes and their associated grading hierarchies are often developed by trade associations or a regional or national authority. Often there are slight variations from place to place.
2. Plain-sawed lumber is relatively inexpensive and has conspicuous figure patterns. It may develop checks and surface splits during seasoning.
3. Quartersawn lumber is more expensive than plain-sawed lumber, and its radial figure patterns are conspicuous. It will wear more evenly, is less susceptible to twisting and cupping, and is less likely to develop surface checks and splits during seasoning and use.
4. Most lumber is visually graded by trained inspectors who classify the pieces according to slope of grain, natural and manufacturing defects, and the number, tightness, and location of knots.
5. Cross-sectional lumber specifications typically refer to the nominal size of a piece rather than the actual size. Actual dressed dimensions are smaller than nominal dimensions due to shrinkage and planing. Dimensions of length are nearly exact.

Table 850-6. EFFECTS OF WEATHERING ON VARIOUS SOFTWOODS

Woods (Softwoods)	Weathering: Resistance to Cupping*	Weathering: Conspicuousness of Checking†
Cedar:		
Alaska	1	1
California incense	—	—
Port Orford	—	1
Western red cedar	1	1
White	1	—
Cypress	1	1
Redwood	1	1
Pine:		
Eastern white	2	2
Sugar	2	2
Western white	2	2
Ponderosa	2	2
Fir, commercial white	2	2
Hemlock	2	2
Spruce	2	2
Douglas fir (lumber and plywood)	2	2
Larch	2	2
Lauan (plywood)	2	2
Pine:		
Norway	2	2
Southern (lumber and plywood)	2	2
Tamarack	2	2

* 1 = best, 4 = worst. † 1 = least, 2 = most.

Source: Adapted from U.S. Forest Products Laboratory, *Wood Engineering Handbook*, Prentice-Hall, Englewood Cliffs, New Jersey.

Table 850-7. COLOR EFFECTS OF WEATHERING ON VARIOUS SOFTWOODS

Type of Wood	Changes to Light Gray Color With Silvery Sheen	Changes to Light Gray Color With Moderate Sheen	Changes to Dark Gray Color With Little or No Sheen
Evergreen (softwood)	Bald cypress	Hemlock:	Douglas fir
	Cedar:	Eastern	Fir:
	Alaska	Western	Commercial
	Port Orford	Pine:	White
		Eastern white	Larch:
		Ponderosa	Western
		Sugar	Pine:
		Western white	Southern yellow
		Spruce:	Cedar:
		Eastern	Western red
		Sitka	Redwood

Source: Adapted from Caleb Hornbostel, *Construction Materials*, John Wiley, New York.

ance, strength, durability, or utility of the wood.

Visually Graded Lumber:

Most lumber is visually graded by trained inspectors who classify the pieces according to specific criteria. These criteria include slope of grain, natural and manufacturing defects, and the number, tightness and location of knots.

Natural defects: are processes in timber growth that adversely affect the appearance or strength and consequent grading of the wood member (Figure 850-1).

Manufacturing defects: are faults due to improper seasoning, sawing, and surfacing operations that adversely affect the appearance or strength and consequent grading of the wood member (Figures 850-2 through 850-5).

Improper sawing may produce cross-grain that diminishes the strength of a wood member. This occurs when either the fibers and/or the grain in a piece of wood are not parallel to the edges (Figure 850-4). Cross-grained lumber should be avoided because it is more susceptible to warpage, end shrinkage, rough faces, torn or lifted grain, and structural weakness.

Table 850-8. CHARACTERISTICS OF WOODS FOR PAINTING

Softwoods	Suitability for Paint*
Cedar:	
Alaska	I
California incense	I
Port Orford	I
Western red cedar	I
White	I
Cypress	I
Redwood	I
Products overlaid with resin-treated paper	I
Pine:	
Eastern white	II
Sugar	II
Western white	II
Ponderosa	III
Fir, commercial white	III
Hemlock	III
Spruce	III
Douglas fir (lumber and plywood)	IV
Larch	IV
Lauan (plywood)	IV
Pine:	
Norway	IV
Southern (lumber and plywood)	IV
Tamarack	IV

* I = easiest to maintain; V = most exacting.

Source: Adapted from U.S. Forest Products Laboratory, *Wood Engineering Handbook*, Prentice-Hall, Englewood Cliffs, New Jersey.

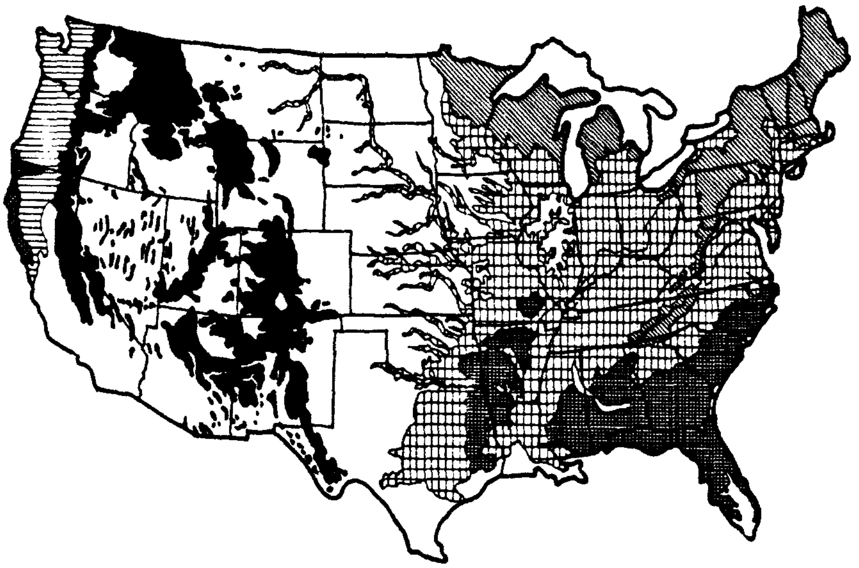

Figure 850-7. Areas of timber growth in the United States.

Table 850-9. LUMBER AND LOCATIONS OF GROWTH

Type of Wood and Location
Cypress, bald From Delaware to Florida along the Atlantic coastal plain, along the Gulf coast, and up the Mississippi Valley to Indiana
Fir, Douglas From the Rocky Mountains to the Pacific coast and from Mexico to central British Columbia
Fir, true eastern New England, New York, Pennsylvania, and the Great Lakes states
Fir, true western From the Rocky Mountains to the Pacific coast
Hemlock, eastern From New England along the Appalachian Mountains to Alabama and Georgia and the Great Lakes states
Hemlock, western Pacific coast of Oregon and Washington, Rocky Mountains north to Canada and Alaska
Cedar, incense California, Oregon, and Nevada
Larch, western Montana, Idaho, Oregon, and Washington
Pine, eastern white From Maine along the Appalachian Mountains to Georgia and the Great Lakes states
Pine, lodge pole (knotty) Rocky Mountains and Pacific coast to Alaska
Pine, pitch Maine and northern New York, south to Tennessee and Georgia
Pine, pond New Jersey to Florida
Pine, ponderosa From Arizona and New Mexico to South Dakota and westward to the Pacific coast mountains
Pine, red New England states, New York, Pennsylvania, and the Great Lakes states
Pine, southern yellow New York and New Jersey, southward to Florida, westward to Texas and Oklahoma, and north to the Ohio Valley and Missouri
Pine, sugar From the Pacific coast and Cascade Mountains of Oregon along coast ranges and Sierra Nevada of California
Pine, western white Western Montana, northern Idaho, Washington, Oregon, and California
Cedar, Port Orford Pacific coast from Coos Bay, Oregon, south to California; extends only 40 miles inland
Cedar, red, eastern Eastern half of the United States except Maine, Florida, and small area along Gulf coast
Cedar, red, western Pacific coast north to Alaska; also in Idaho and Montana
Redwood In the Sierra Nevada of California
Spruce, eastern Great Lakes states, New England and the Appalachian Mountains
Spruce, Engelmann High elevations of the Rocky Mountains
Spruce, Sitka Northwestern coast of the United States from California to Alaska
Tamarack From Maine to Minnesota

Source: Adapted from Caleb Hornbostel, *Construction Materials*, Wiley, New York.

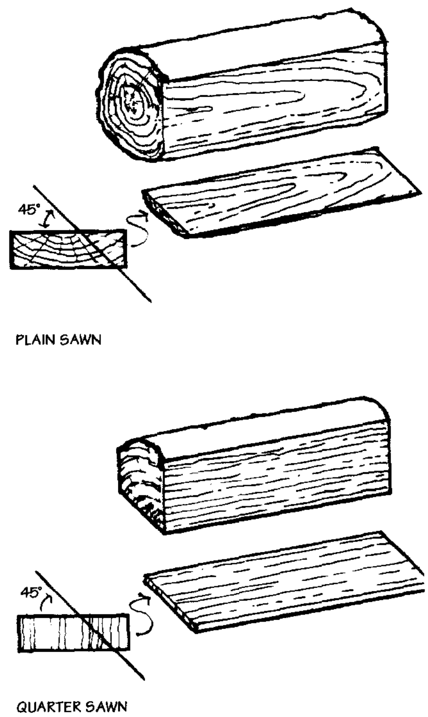

Figure 850-8. Methods of sawing. *Lumber sawed so that the annual rings form an angle of 45 degrees or less with the wide face of the piece is called plain-sawed or flat-grained lumber. Quartersawn, edge-grained, or vertical-grained lumber refers to boards in which the annual rings are at an angle of 45 degrees or more.*

Table 850-10. REGIONAL CLASSIFICATIONS AND ORGANIZATIONS

Species Covered by Grading Rules	Name of Grading Authority
Bald cypress, eastern red cedar	National Hardwood Lumber Association (NHLA) Memphis, Tennessee
Balsam fir, eastern white pine, red pine, eastern hemlock, black spruce, white spruce, red spruce, pitch pine, tamarack, jack pine, northern white cedar	Northeastern Lumber Manufacturer's Association Falmouth, Maine
Bigtooth aspen, quaking aspen, eastern white pine, red pine, jack pine, black spruce, white spruce, red spruce, balsam fir, eastern hemlock, tamarack	Northern Hardwood and Pine Manufacturers' Association (NHPMA) Green Bay, Wisconsin
Western red cedar (shingles and shakes)	Red Cedar Shingle and Handsplit Shake Bureau (RCSHSB) Bellevue, Washington
Redwood	Redwood Inspection Service Mill Valley, California
Bald cypress	Southern Cypress Manufacturers' Association (SCMA) Memphis, Tennessee
Longleaf pine, slash pine, shortleaf pine, loblolly pine, Virginia pine, pond pine, pitch pine	Southern Pine Inspection Bureau (SPIB) Pensacola, Florida
Douglas fir, western hemlock, western red cedar, incense cedar, Port Orford cedar, Alaska cedar, western true firs, mountain hemlock, Sitka spruce	West Coast Lumber Inspection Bureau (WCLIB) Portland, Oregon
Ponderosa pine, western white pine, Douglas fir, sugar pine, western true firs, western larch, Englemann spruce, incense cedar, western hemlock, lodgepole pine, western red cedar, mountain hemlock, red alder	Western Wood Products Association (WWPA) Portland, Oregon
Coast Sitka spruce, Douglas fir, Larch (north), eastern white pine (north), western white pine	National Lumber Grades Authority (NLGA) Vancouver, British Colombia, Canada

Source: U.S. Forest Products Laboratory, *Wood Engineering Handbook*, Prentice-Hall, Englewood Cliffs, New Jersey.

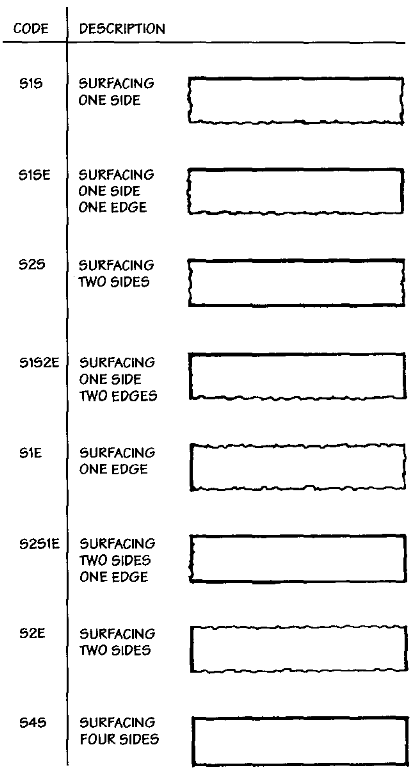

Figure 850-9. Surface Finishing.

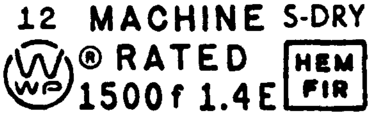

Figure 850-10. Stamp for machine stress-graded lumber.

Grading systems correspond with standard stock sizes of lumber (see Table 850-11). Structural grades in a few species (e.g., Douglas fir and southern pine) have additional requirements based on density and growth ring count.

Machine Stress-Rated Lumber:

Lumber 50 mm (2 in) thick or less may be machine stress-rated at the sawmill in order to standardize and guarantee the load-bearing capacity of each piece. As the piece leaves the machine, a stamped impression is made which specifies values for fiber stress in bending (stamped as f) and modulus of elasticity (stamped as E) (Figure 850-10). Design values for machine-graded lumber are given in Table 850-3.

3.0 STANDARD LUMBER DIMENSIONS

3.1 Nominal Sizing

Cross-sectional lumber specifications typically refer to the nominal size of a piece, or the size before shrinkage and planing, rather than the actual size. Actual dressed dimensions are smaller than nominal dimensions. Dimensions of length are nearly exact because shrinkage longitudinal to the grain is negligible.

3.2 Yard Lumber Sizes and Grading

Yard lumber refers to standard construction lumber, as opposed to worked lumber and special wood products. All yard lumber is classified into one of three categories. Boards are typically 25 mm (1 in) thick and 50 mm (2 in) wide or greater. Dimension lumber is generally 50 - 100 mm (2 - 4 in) thick and 50 mm (2 in) wide or greater. Timbers are usually greater than 125 mm (5 in) thick and 125 mm (5 in) wide. Table 850-3 lists common yard lumber sizes and grading. The nomenclature and sizing for this classification system are fairly standard and are recognized by most regional grading authorities, although minor variations may occur.

3.3 Methods for Specifying Sizes and Quantities of Lumber

There are four common methods for specifying size and quantity of lumber:

1. Board measure or board feet measure (BDM or BD FT) refers to volumes of lumber of a stock of nominal thickness and width. Board measure is typically used when specifying boards (Figure 850-11).
2. Lineal Meter (Feet): Boards may be ordered by the lineal meter or foot (or running foot) (Lm, Lf or Lft) of a stock of nominal thickness and width.
3. Nominal size and length: yard stock is often ordered by numbers of specific pieces. Lengths of yard lumber typically range from 2 to 4 m (6 to 24 ft) in 0.6 m (2-ft) increments. Some lumber mills will cut lengths to exact specifications upon request.
4. Areas to be covered: shakes and shingles are ordered according to an area to be covered. One square unit covers 9.3 m^2 (100 ft^2) of area when laid with a normally exposed coursing width.

4.0 SPECIAL PRODUCTS

4.1 Plywood

Plywood refers to sheet lumber that is manufactured by bonding together several layers of wood veneer under high pressure with a waterproof or water-resistant adhesive (Figure 850-12). A solid lumber or fire-resistant mineral core may also be incorporated. Plywood is manufactured for both indoor and outdoor applications and is typically available in 1.2 m x 2.5 m (4 x 8 ft) sheets. Only exterior grade plywood is discussed in this section.

Plywood panels are manufactured from a variety of wood species and may consist of more than one kind of wood. Species that make up the various veneers are classified according to stiffness and strength into one of the five groups, as established by the National Bureau of Standards (Product Standard PS 1). Group 1 species produce panels with the least strength and stiffness.

Construction plywood can be used in exterior applications. It is manufactured primarily from softwoods, although hardwoods are sometimes used. Decorative construction and industrial hardwood are types of plywood that are used primarily in interior applications only.

Properties:

Apart from the characteristics of the veneer, the most important properties of plywood are the result of its cross-laminated construction, such as durability, bending strength and stiffness, and shear resistance.

Durability: refers to the ability of a plywood to remain intact over time. The glueline used to bond veneers is as durable as the wood itself, enabling the material to be

Table 850-11. YARD LUMBER SIZES AND GRADING

	Common Sizes*						Common Stock			
	Thicknesses			Face Widths						
		Minimum Dressed			Minimum Dressed					
Type of Yard Lumber	Nominal	Dry	Green	Nominal	Dry	Green	Sprecific Stock	Nominal Thickness	Nominal Width	Available Grades and Comments
Boards:				2	1 1/2	1 9/16	Sheathing,	1 in	2 in or	Select: good appearance; Common: for general
generally 1-				3	2 1/2	2 9/16	siding,		more	used where natural or construction and
in thick,				4	3 1/2	3 9/16	flooring,			painted finish is utility
greater than				5	4 1/2	4 5/8	paneling			desired
or equal to	1	3/4	25/32	6	5 1/2	5 5/8	Siding	Thickness expressed		■ B & B (B and better): ■ No. 1 Common
2-in wide				7	6 1/2	6 5/8		as dimensions of		highest grade for exterior (highest common
	1 1/4	1	1 1/32	8	7 1/4	7 1/2		butt edge		finish, trim, paneling, grade)
				9	8 1/4	8 1/2				siding, flooring, and ■ No. 2 Common
	1 1/2	1 1/4	1 9/32	10	9 1/4	9 1/2	Moulding and	Thickness expressed		moulding ■ No. 3 Common
				11	10 1/4	10 1/2	trim	as size at thickest		■ C Select: less quality ■ No. 4 Common
				12	11 1/4	11 1/2		and widest points		and cost than B & B ■ No. 5 Common
				14	13 1/4	13 1/2				■ D Select: less quality (lowest grade)
				16	15 1/4	15 1/2				and cost than C Select
Dimension:				2	1 1/2	1 9/16	Light framing	2–4 in	2–4 in	For uses not demanding high strength, such as
2–4 in				3	2 1/2	2 9/16	(not stress-			blocking and plates
thick,				4	3 1/2	3 9/16	graded)			
greater	2	1 1/2	1 9/16	5	4 1/2	4 5/8				■ Construction: low in bending strength
than or	2 1/2	2	2 1/16	6	5 1/2	5 5/8				■ Standard: less strength than construction grade
equal to	3	2 1/2	2 9/16	8	7 1/4	7 1/2				■ Utility: very low in bending strength
2-in wide	3 1/2	3	3 1/16	10	9 1/4	9 1/2				
				12	11 1/4	11 1/2				
				14	13 1/4	13 1/2	Structural light	2–4 in	2–4 in	For engineering uses, especially when greater
				16	15 1/4	15 1/2	framing			strength in bending is needed
				2	1 1/2	1 9/16				■ Select Structural: highest bending strength†
				3	2 1/2	2 9/16				■ No. 1: less strength than select structural grade
				4	3 1/2	3 9/16				■ No. 2: less strength than No. 1 grade
				5	4 1/2	4 5/8				■ No. 3: lowest bending strength of structural light
	4	3 1/2	3 9/16	6	5 1/2	5 5/8				framing pieces
	4 1/2	4	4 1/16	8	7 1/4	7 1/2				
				10	9 1/4	9 1/2				
				12	11 1/4	11 1/4				
				14		13 1/2	Studs (always	2–4 in	2–6 in	For use in walls

* Nominal and minimum dressed sizes of lumber products are shown in inches.

† Select means high quality, not necessarily guaranteed to be a good surface for painting and finishing.

‡ Timbers are sawn and surfaced in green condition.

Source: Adapted from Caleb Hornbostel, *Construction Materials*, Wiley, New York.

Table 850-11. (cont.)

Type of Yard Lumber	Common Sizes* Thicknesses Nominal	Thicknesses Minimum Dressed Dry	Thicknesses Minimum Dressed Green	Face Widths Nominal	Face Widths Minimum Dressed Dry	Face Widths Minimum Dressed Green	Common Stock Specific Stock	Common Stock Nominal Thickness	Common Stock Nominal Width	Available Grades and Comments
				16		15½	in lengths of 10 ft or less			■ Studs: only one grade available, comparable to structural light framing No. 3
							Structural joists and planks	2-4 in	5 in and wider	Joists are loaded on narrow edge; planks are loaded on wide side. Structural joists and planks are stress-graded for engineering purposes. ■ Select Structural: highest bending strength† ■ No. 1: less bending strength than Select ■ No. 2: less bending strength than No. 1 ■ No. 3: lowest bending strength of structural joists and planks
							Appearance framing	2-4 in	4-12 in	For use as light framing, joist, or plank-measured pieces where moderately high strength and good appearance are desired. ■ Appearance grade: only grade offered
							Decking	2-4 in	4-12 in	For decking or planking. Moisture typically limited to 15% MC (moisture content). Members typically used with tongue-and-groove pattern. Faces finished to provide plain, grooved, or striated surfaces and rounded or V edges. ■ Select decking: greater strength than commercial decking† ■ Commercial decking: less strength than select decking
Timbers: greater than 5-in thick and greater than 5-in wide‡	5 6 8 10 12 14 16	4½ 5½ 7¼ 9¼ 11½ 13¼ 15¼	4⅝ 5⅝ 7½ 9½ 11½ 13½ 15½	5 6 8 10 12 14 16	4½ 5½ 7¼ 9¼ 11¼ 13¼ 14¼	4⅝ 5⅝ 7½ 9½ 11½ 11½ 15½	Post and timbers Beams and stringers	5 in and thicker	5 in and wider but not more than 2 in greater than thickness	For posts; lower bending strengths than beams. ■ Select structural: greater strength than No. 1† ■ No. 1: less strength than select structural grade. For beams and stringers; slightly higher bending strength than posts. ■ Select structural: greater strength than No. 1.† ■ No. 1: less strength than Select Structural grade.

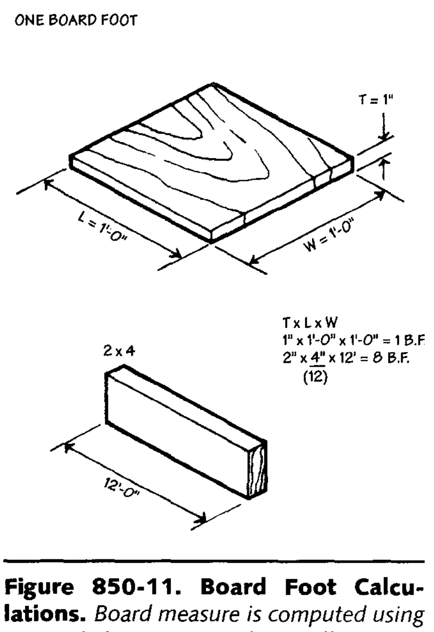

Figure 850-11. Board Foot Calculations. *Board measure is computed using nominal dimensions. The smallest value used in computations is 1 in.*

exposed out-of-doors without delaminating. Checking occurs less in plywood than in common lumber. Paints or stains can protect against weathering or chalking. Preservatives are required in areas of high decay or termite hazard.

Bending strength and stiffness: refers to the strength and stiffness of plywood in its plane, a property that makes it suitable as a bracing material. The grain of the face should be placed perpendicularly to the support members. The minimum recommended thickness for a bracing support is 10 mm (5/16 in).

Shear resistance: refers to the ability of plywood to distribute loads applied perpendicularly to its face without shearing. Plywood has a great ability to bear loads from nails and can be securely nailed as near as 5 mm (1/4 in) to its edge.

KEY POINTS - Plywood

1. Construction plywood is used in exterior applications. It is manufactured primarily from softwoods, although hardwoods are sometimes used.

2. The glue used to bond wood veneers is as durable as the wood itself, enabling the material to be exposed out-of-doors without delaminating. Checking occurs less in plywood than in common lumber.

3. Plywood is categorized into appearance grades based mainly on visual characteristics and engineered grades based mainly on strength (see Table 850-12).

Grades:

Plywood is categorized into: (1) appearance grades, which are based mainly on the appearance of the outer plies, and (2) engineered grades, which are based mainly on properties of strength. Exterior grades for both categories are described in Table 850-12. Exterior (waterproof) types incorporate Grade C veneer or better throughout the panel. They retain their glue bond when repeatedly wetted and dried and are manufactured for permanent outdoor exposure.

Appearance Grades: The grade designation is based primarily on the appearance and quality of the facing veneer as well as on the species groups of the component layers. The grade of a plywood is indicated on the piece by two letters describing the face and the back veneer (Table 850-13). Panels are sanded smooth on both sides for appearance and balanced construction. Decorative surfaces are also available.

Engineered Grades: These grades are developed for wall sheathing, roof sheathing, subflooring, and underlayment to ensure a suitable base for overlaying materials (Table 850-14). Engineered plywood requires stiffness and strength, nail holding ability, durability, dimensional stability, and resistance to puncture and impact. Identification index numbers or span ratings are based on the species group, thickness, bending strength, and stiffness of the face and back plies of the panel (Table 850-15).

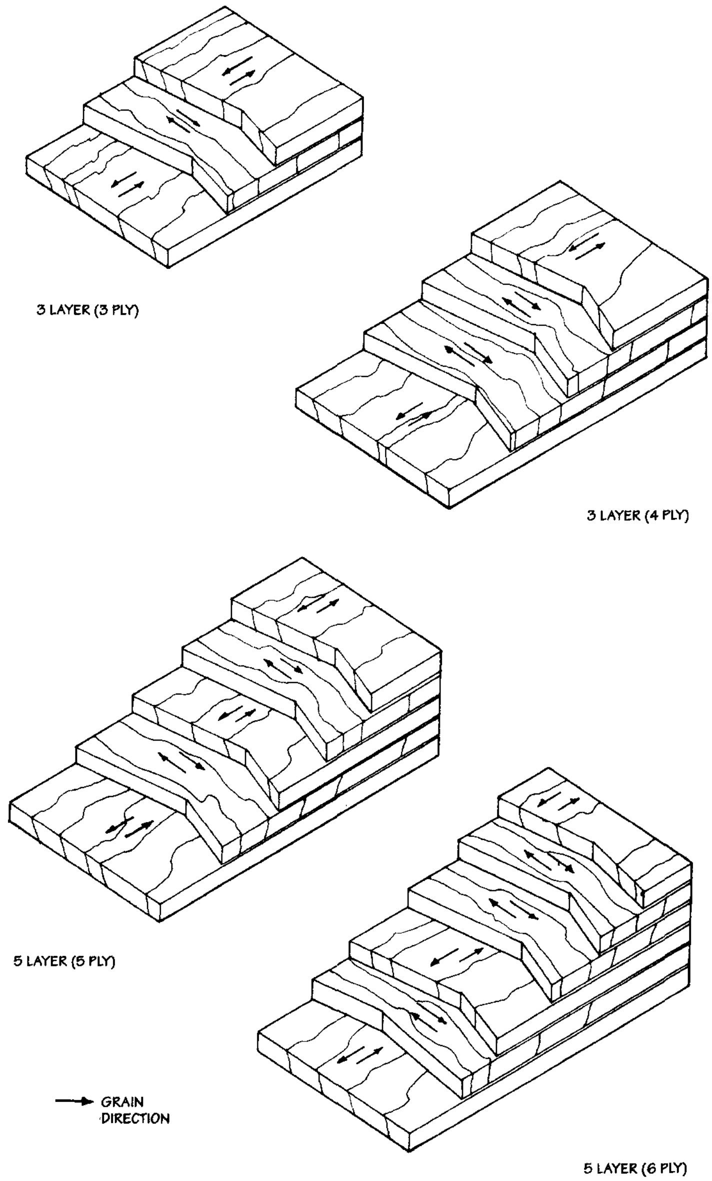

Figure 850-12. Plywood construction. *Typical three- and five-layer construction with parallel-laminated crossbands in the 4- and 6-ply panels.*

4.2 Particleboard

Particleboard is sheet lumber consisting of wood chips or sawdust glued together under heat and pressure to form 1.2 m x 2.5 m (4 x 8 ft) panels. Waferboard is composed of wafers of wood that measure several millimeters square, that have been glued, heated, and pressed into 1.2 m x 2.5 m (4 x 8 ft) panels.

Particleboard is a uniform material produced with various uniform surface textures, some of which can easily be painted or finished. The binder and additives chosen determine the strength, abrasion resistance, fire resistance, and durability of the panel. Particleboard is weak in tension perpendicularly to the face. The screw or nail holding ability may be poor in some particleboard's.

Particleboard is dimensionally stable and warp-resistant. Its stability depends upon the density of the compressed particles and the type of glues used. Common uses of particleboard include sheathing, underlayment, and siding. Grades of particleboard suitable for exterior use are shown in Table 850-16. The thicknesses range from 3 to 50 mm (1/8 to 2 in).

4.3 Wood Shingles and Shakes

Shingles:

Most wood shingles are produced from red cedar growing in the Western USA, although eastern white cedar, tidewater cypress, and California redwood are also available. Shingles are sawn from blocks of wood to produce smooth faces. Surfaces can be sawn smooth or later grooved (striated by machine). Special shapes are sometimes available (Figure 850-13).

Available Sizes: Shingles are produced in random or specified widths (i.e., dimension shingles). Random widths range from a minimum of 75 mm (3 in) to a maximum of 350 mm (14 in), and dimension shingles are either 125 or 150 mm (5 or 6 in) wide. All are available in three standard lengths (Table 850-17). Standard thicknesses of shingles are described as 4/2, 5/2-1/4, and 5/2 (four shingles to 2 in of butt thickness, five shingles to 2-1/4 of butt thickness, and five shingles to 2 in of butt thickness).

Table 850-12. TYPICAL EXTERIOR GRADES AND USES OF PLYWOOD

Grade[b]	Common Uses	Veneer[a]			Thickness, in										
		Face	Middle	Back	1/4	5/16	11/32	3/8	15/32	1/2	19/32	5/8	23/32	3/4	1 1/8
	Appearance[b, c, d]														
A-A EXT-APA[f]	Use where both sides are visible	A	C	A	o		o	o	o	o	o	o	o	o	
A-B EXT-APA[f]	Use where view of one side is less important	A	C	B	o		o	o	o	o	o	o	o	o	
A-C EXT-APA[f]	Use where only one side is visible	A	C	C	o		o	o	o	o	o	o	o	o	
B-B EXT-APA[f]	Utility panel with two solid faces	B	C	B	o		o	o	o	o	o	o	o	o	
B-C EXT-APA[f]	Utility panel. Also used as base for exterior coatings on walls and roofs	B	C	C	o		o	o	o	o	o	o	o	o	
HDO-EXT-APA[f]	High density overlay plywood has a hard, semiopaque resin fiber overlay on both faces. Abrasion resistant. Use for concrete forms, cabinets, and counter tops	A B	C C plugged	A B		o		o		o		o		o	
MDO-EXT-APA[f]	Medium-density overlay with smooth resin fiber overlay on one or two faces. Recommended for siding and other outdoor applications. Ideal base for paint	B	C	B C		o	o	o	o	o	o	o	o	o	
303 Siding EXT-APA[h]	Special surface treatment such as V-groove, channel groove, striated, brushed, rough sawn	[g]	C	C			o	o	o	o	o	o			
Marine EXT-APA	Made only with Douglas fir or Western larch. Special solid-jointed core construction. Subject to special limitations on core gaps and number of face repairs. Also available with HDO or MDO faces.	A B	B	A B	o			o		o		o		o	
	Engineered[d]														
C-C EXT-APA[i]	Unsanded grade with waterproof bond	C	C	C		o		o	o	o	o	o	o	o	o
Structural I C-C EXT-APA	For engineered applications in construction and industry where full exterior type panels are required. Unsanded. See Note f for species group requirement	C	C	C		o		o	o	o	o	o	o	o	o
B-B Plyform Class I and Class II EXT-APA[e]	Concrete form grades with high reuse factor. Sanded on both sides. Mill oiled unless otherwise specified. Special restrictions on species. Also available in HDO.	B	C	B				o		o	o	o	o	o	o

[a] 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 × 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, and parallel to grain, permitted. May be used for natural finish in less demanding applications.

B = solid surface. Shims, circular repair plugs, and tight knots to 1 in across grain permitted. Some minor splits permitted.

C plugged = improved C veneer with splits limited to ⅛-in width and knotholes and borer holes limited to ¼ × ½ in. Admits some broken grain. Synthetic repairs permitted.

C = tight knots to 1½ in. Knotholes to 1 in across grain and some to 1½ 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 2½ in width across grain and ½ in larger within specified limits. Limited splits are permitted. Stitching permitted. Limited to interior grades of plywood.

[b] Available in group 1, 2, 3, 4, or 5 unless otherwise noted.

[c] Sanded on both sides except where decorative or other surfaces specified.

[d] Standard 4 × 8 panel sizes; other sizes available.

[e] Also available in Structural I.

[f] Also available in Structural I (all plies limited to group 1 species) and Structural II (all plies limited to group 1, 2, or 3 species).

[g] C or better for five plies; C plugged or better for three-ply panels.

[h] Stud spacing is shown on trademark stamp.

[i] Made only in woods of certain species to conform to APA specifications.

[i] Made in many different species combinations. Specify by span rating.

Source: Adapted from the American Plywood Association, *Guide to Grades and Specifications*, Tacoma, Washington.

Table 850-13. APPEARANCE GRADES OF PLYWOOD (EXTERIOR TYPE)

Grade Designation[b]	Description and Most Common Uses	Veneer Grade: Face	Veneer Grade: Back	Veneer Grade: Inner Plies	Most Common Thicknesses, in[c]									
A-A EXT-APA	Use where appearance of both sides is important. Fences, built-ins, signs, boats, cabinets, commercial refrigerators, shipping containers, tote boxes, tanks, and ducts.[d]	A	A	C	1/4		11/32	3/8	15/32	1/2	19/32	5/8	23/32	3/4
A-B EXT-APA	Use where the appearance of one side is less important.[d]	A	B	C	1/4		11/32	3/8	15/32	1/2	19/32	5/8	23/32	3/4
A-C EXT-APA	Use where the appearance of only one side is important. Soffits, fences, structural uses, boxcar and truck lining, farm buildings, tanks, trays, and commercial refrigerators.[d]	A	C	C	1/4		11/32	3/8	15/32	1/2	19/32	5/8	23/32	3/4
B-B EXT-APA	Utility panel with solid faces.[d]	B	B	C	1/4		11/32	3/8	15/32	1/2	19/32	5/8	23/32	3/4
B-C EXT-APA	Utility panel for farm service and work buildings, boxcar and truck lining, containers, tanks, agricultural equipment. Also as base for exterior coatings for walls, roofs.[d]	B	C	C	1/4		11/32	3/8	15/32	1/2	19/32	5/8	23/32	3/4
HDO EXT-APA	High density overlay (HDO) plywood. Has a hard, semiopaque resin-fiber overlay, both faces. Abrasion-resistant. For concrete forms, cabinets, counter tops, signs and tanks.[d]	A or B	A or B	C or C (plugged)				3/8		1/2		5/8		3/4
MDO EXT-APA	Medium density overlay (MDO) with smooth, opaque, resin-fiber overlay, one or both panel faces. Highly recommended for siding and other outdoor applications, built-ins, signs, and displays. Ideal base for paint.[d]	B	B or C	C		5/16		3/8	15/32	1/2	19/32	5/8	23/32	3/4
303 Siding EXT-APA	Proprietary plywood products for exterior siding, fencing, etc. Special surface treatment such as V-groove, channel groove, striated, brushed, rough-sawn. 4-ft × 9-ft and 4-ft × 10-ft panels available.	[e]	C	C			11/32	3/8		1/2	19/32	5/8		
T 1-11 EXT-APA	Special 303 panel having grooves 1/4 in deep, 3/8 in wide, spaced 4 in or 8 in o.c. Other spacing optional. Edges shiplapped. Available unsanded, textured, and MDO. 4-ft × 9-ft and 4-ft × 10-ft panels available	C or btr.	C	C							19/32	5/8		
MARINE EXT-APA	Ideal for boat hulls. Made only with Douglas fir or western larch. Special solid jointed core construction. Subject to special limitations on core gaps and number of face repairs. Also available with HDO or MDO faces.	A or B	A or B	B	1/4			3/8		1/2		5/8		3/4

[a] Sanded both sides except where decorative or other surfaces specified.

[b] Available in Group 1, 2, 3, 4, or 5 unless otherwise noted.

[c] Sandard 4 × 8 panel sizes, other sizes available.

[d] Also available in Structural I (all plies limited to Group 1 species) and Structural II (all plies limited to Group 1, 2, or 3 species)

[e] C or better for 5 plies. C plugged or better for 3-ply panels.

[f] For strength properties of appearance grades, refer to "Plywood Design Specification," form Y510, American Plywood Association.

Source: American Plywood Association, *Guide to Grades and Specifications,* Tacoma, Washington.

Table 850-14. ENGINEERED GRADES OF EXTERIOR PLYWOOD

Grade Designation	Description and Most Common Uses	Veneer Grade			Most Common Thicknesses, in								
		Face	Back	Inner Plies									
Structural I C-C EXT-APA and Structural II C-C EXT-APA	For engineered applications in construction and industry where full exterior type panels are required. Unsanded. See a for species group requirements.	C	C	C	5/16	3/8	7/16	15/32	1/2	19/32	5/8	23/32	3/4
B-B Plyform Class I and Class II EXT-APA	Concrete form grades with high reuse factor. Sanded on both sides. Mill-oiled unless otherwise specified. Special restrictions on species. Also available in HDO.[b]	B	B	C						19/32	5/8	23/32	3/4

[a] Also available in Structural I (all plies limited to Group 1 species) and Structural II (all plies limited to Group 1, 2, or 3 species).

[b] Also available in Structural I.

Source: American Plywood Association, *Guide to Grades and Specifications,* Tacoma, Washington.

Grades: Grades for western red cedar shingles are shown in Table 850-17. Grades for northern white cedar are Extra, Clear, 2nd Clear, Clear Wall, and Utility. Grades for bald cypress are No. 1, Bests, Primas, Economy, and Clippers. Grades for redwood shingles are No. 1, No. 2 VG, and No. 2 MG.

The No. 1 grade for all species of wood is all clear, all heartwood, and all quartersawn. The lower grades are quartersawn or plain-sawn, have heartwood and sapwood, and have increasing degrees of imperfections.

Shakes:

Shakes refer to hand-split shingles; they have rough, split faces and either sawed or split backs (Figure 850-14). Most shakes are split by machine. All shakes are manufactured from western red cedar.

Three common types of shakes are:

1. **Taper-split:** These shakes have a uniform texture and 100 percent edge-grain. Preferred for siding.
2. **Straight-split:** These shakes have a uniform texture and 100 percent edge-grain. Preferred for siding.
3. **Hand-split and resawed:** These shakes have heavy butt lines, a rugged appearance, and 50 to 100 percent edge-grain. Preferred for roofing.

Available Sizes: Shakes are manufactured in random widths [minimum of 100 mm (4 in)] and in lengths of 450 mm (18

Table 850-15. GUIDE TO SPAN RATINGS FOR ENGINEERED GRADES OF PLYWOOD

Thickness, in	C-D INT-APA C-C EXT-APA		
	Group 1 and Structural I	Group 2† or 3 and Structural II†,§	Group 4‡
5/16	20/0	16/0	12/0
3/8	24/0	20/0	16/0
1/2	32/16	24/0	24/0
5/8	40/20	32/16	30/12§
3/4	48/24	40/20	32/16§
7/8	—	48/24	40/20

* "Span rating" is designated by two numbers separated by a slash, where the first number represents the maximum recommended support spacing when the sheet is used as roof sheathing, and the second number represents the maximum recommended support spacing when the sheet is used as subflooring.

† Panels with Group 2 outer plies and special thickness and construction requirements or Structural II panels with Group 1 faces may carry the span rating numbers shown for Group 1 panels.

‡ Panels made with Group 4 outer plies may carry the span rating numbers shown for Group 3 panels when they conform to special thickness and construction requirements detailed in PS 1.

§ Check local availability.

Source: American Plywood Association, *Guide to Grades and Specifications,* Tacoma, Washington.

KEY POINTS - Wood Shingles and Shakes

1. Most wood shingles are produced from western red cedar, although eastern white cedar, tidewater cypress, and California redwood are also available.
2. The No. 1 grade for all species of wood is all clear, all heartwood, and all quartersawn. The lower grades are quartersawn or plain-sawed, have heartwood and sapwood, and have increasing degrees of imperfections.
3. All shakes are manufactured from western red cedar (graded No. 1 and 100 percent heartwood) and are used primarily for siding or roofing
4. Shingles and shakes can be used in the landscape for railings on decks and bridges, and for free-standing fences, walls and screens.

in), 600 mm (24 in), and less frequently 800 mm (32-in). A starter-finish course of 375 mm (15 in) is also available. Shake thicknesses range from 10 to 30 mm (3/8 to 1-1/4 in). Table 850-18 lists common types and sizes of red cedar shakes.

Grades: All cedar shakes are graded No. 1 and are 100 percent heartwood, free of both bark and sapwood (Table 850-18).

4.4 Glue-Laminated Beams

Glue-laminated beams (glulams) are large structural members composed of pieces of lumber that have been placed with the grain running longitudinally, glued with adhesive, laminated, and, if specified, bent into various shapes (Figure 850-15). "Glulams" are adaptable to construction needs and offer a variety of shapes, sizes, and strengths.

Their strengths are greater than lumber due to their increasing member size as well as to selectively using strong laminates on the outer layers where the stress is greatest.

Lumber species commonly used in the manufacture of glue-laminated beams include Douglas fir, larch, hemlock, fir, redwood, and southern yellow pine.

Glue-laminated beams for exterior applications require certain adhesives and preservative impregnation. If the site is particularly humid, all-heartwood construction may be warranted.

Commercially available sizes of glue-laminated beams are indicated in Table 850-19, although other sizes are available. Heights can vary, typically up to 3 m (10 ft). Lengths vary as the task demands, typically up to 40 m (130 ft).

5.0 PROTECTIVE TREATMENTS

Figure 850-16 shows regions in the United States where precautions against decay are necessary.

5.1 Types of Preservatives

Wood preservatives are classified as either oilborne or waterborne preservatives. Creosote is an oilborne preservative with widespread use in the past. However, it has been proved to be a carcinogenic substance that is now restricted in several states and municipalities. Its use should be avoided.

Oilborne preservatives: the most commonly used of which is pentachlorophenol, are not quite as effective as creosote compounds but are suitable for all but the most demanding situations (Table 850-20). Their disadvantages include toxicity and discoloration of wood (turning it brown), but they are relatively odor-free and can be painted over if they are applied using liquefied petroleum gas (LPG) rather than a heavier oil as a base. Water-repellent preservatives are used to treat wood prior to painting. The use of oilborne toxic preservatives should be limited to situations dictating extreme protection.

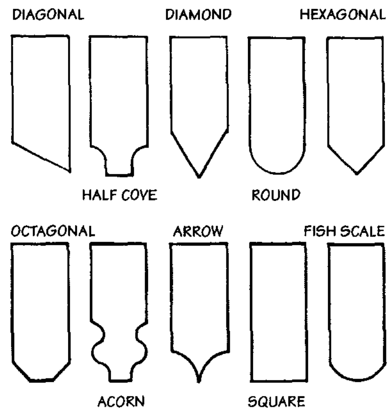

Figure 850-13. Fancy butt red cedar shingles. *Fancy butt shingles are 125 mm (5 in) wide and 190 mm (7½ in) long, custom produced to individual orders.*

Waterborne preservatives: are salts which have the advantage of being clean, odorless, and can be painted (Table 850-21). Treated wood are typically stained a light tint of green.

5.2 Fire Retardents

Fire hazards related to wood can be reduced some by use for fire retardants which are produced for both indoor and outdoor use for safety or insurance reasons. Wood is easily painted after treatment.

Table 850-16. EXTERIOR GRADE PARTICLEBOARDS

Grade	Density, lb/ft³
2-H-1	High: 50 and over
2-H-2	High: 50 and over
2-M-1	Medium: 37-50
2-M-2	Medium: 37-50
2-M-3	Medium: 37-50
2-M-W*	Medium: 37-50
2-M-F†	Medium: 37-50

* W indicates that this product is made from wafers.

† F indicates that this product is made from flakes.

Source: National Particleboard Association, *Particleboard, the Versatile Product of the 1980s.*

5.3 Methods of Application

The effectiveness of a particular preservative often depends on the manner in which it is applied to the wood. Penetration by pressure treatments will be complete in sapwoods but only partial in heartwoods due to the higher density of the wood. The best pressure treatments can protect wood for 30 to 60 years. The six most used methods of application are:

Brushing or Spraying: a preservative on wood relies on capillary action for penetration and is effective to depths of a few millimeters into the wood. The process is adequate for many situations.

Dipping: wood members into a solution for approximately 3 minutes also relies on capillary action for penetration. Dipping is more effective than brushing or spraying because checks and cracks are completely filled with preservative.

KEY POINTS - Protective Treatments

1. Wood preservatives are classified as either oilborne or waterborne preservatives. Oilborne preservatives are inherently toxic and should not be used if waterborne preservatives are a viable alternative.
2. Creosote, an oilborne preservative, has been proven to be carcinogenic and should not be used. Other oilborne preservatives such as pentachlorophenol, are not quite as effective but are suitable for most situations dictating extreme protection.
3. Waterborne preservatives are salts which have the advantage of being clean, odorless, and can be painted. Pressured-treated wood is typically stained a light tint of green.

Table 850-17. GRADES, TYPES, AND SIZES OF RED CEDAR SHINGLES*

Grade	Type, in	Bundles or Cartons per Square† No.	Weight, lb	Description
No. 1, Blue label	24 (Royals)	4 bundles	192	Premium grade of shingles for roofs and walls. These are 100% heartwood, clear, and edge-grain.
	18 (Perfections)	4 bundles	158	
	16 (XXXXX)	4 bundles	144	
No. 2, Red label	24 (Royals)	4 bundles	192	A good grade for most applications. Not less than 10 in clear on 16-in shingles, 11 in clear on 18-in shingles, and 16 in clear on 24-in shingles. Flat grain and limited sapwood are permitted.
	18 (Perfections)	4 bundles	158	
	16 (XXXXX)	4 bundles	144	
No. 3, Black label	24 (Royals)	4 bundles	192	A utility grade for economy applications and secondary buildings. Guaranteed 6 in clear on 16-in and 18-in shingles, 10 in clear on 24-in shingles.
	18 (Perfections)	4 bundles	158	
	16 (XXXXX)	4 bundles	144	
No. 4, Undercoursing	18 (Perfections)	2 bundles	60	A low grade for undercoursing on double-coursed sidewall applications.
	16 (XXXXX)	2 bundles	60	
No. 1 or No. 2, Rebutted-and-rejointed	18 (Perfections)	1 carton	60	Same specifications as No. 1 and No. 2 grades above but machine-trimmed for exactly parallel edges with butts sawn at precise right angles. Used for sidewall application where tightly fitting joints between shingles are desired. Also available with smooth sanded face.
	16 (XXXXX)	1 carton	60	
No. 1, Machine-grooved	18 (Perfections)	1 carton	60	Same specifications as No. 1 and No. 2 grades above; these shingles are used at maximum weather exposures and are always applied as the outer course of double-coursed sidewalls.
	16 (XXXXX)	1 carton	60	
No. 1 or No. 2, Dimension	24 (Royals)	4 bundles	192	Same specifications as No. 1 and No. 2 grades above, except they are cut to specific uniform widths and may have butts trimmed to special shapes.
	18 (Perfections)	4 bundles	158	
	16 (XXXXX)	4 bundles	144	
No. 1 or No. 2, Hip-and-ridge	18 (Perfections)			Same specifications as No. 1 and No. 2 grades above; factory-cut, mitered, and assembled units produced for a 6-in-12 slope and adjust to fit slopes between 4 in 12 and 8 in 12.
	16 (XXXXX)			

* Redwood, white cedar, and cypress shingles are also available. Grades and types will vary.

† Nearly all manufacturers pack four bundles to cover 100 ft². When used at maximum exposures, undercoursing, rebutted-and-rejointed, and machine-grooved shingles typically are packed to cover 100 ft² when used at maximum exposure.

Source: Adapted with permission from Harold B. Olin, John L. Schmidt, and Walter H. Lewis, *Construction: Principles, Materials, and Methods,* U.S. League of Savings Institutions, Chicago.

Table 850-18. TYPES AND SIZES OF RED CEDAR SHAKES

Grade	Length and Thickness, in	Bundles per Square*	Weight, lb per Square	Description
No. 1, Hand-split and resawn	18 × ½ to ¾	4	220	These shakes have split faces and sawn backs. Cedar blanks or boards are split from logs and then run diagonally through a bandsaw to produce two tapered shakes from each.
	18 × ¾ to 1¼	5	250	
	24 × ⅜	4	260	
	24 × ½ to ¾	4	280	
	24 × ¾ to 1¼	5	350	
	32 × ¾ to 1¼	6	450	
No. 1, Tapersplit	24 × ½ to ⅝	4	260	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-split (barn)	18 × ⅜ (true edge)	4	200	Produced in the same manner as taper-split shakes except that by splitting from the same end of the block, the shapes acquire the same thickness throughout.
	18 × ⅜	5	200	
	24 × ⅜	5	260	
No. 1, Starter finish	15 × ½ to 1¼	—	—	These shakes are used as the starting or underlay course at the eaves and as the final course at the ridge.
No. 1, Hip and ridge	18 × ½ to 1¼	—	—	Factory cut, mitered, and assembled units are produced for a 6 in 12 slope; they adjust to fit slopes between 4 in 12 and 8 in 12.
	24 × ½ to 1¼			

* Generally represents the number of bundles required to cover 100 ft² when used for roof construction at the maximum recommended weather exposure.

Source: Adapted with permission from Harold B. Olin, John L. Schmidt, and Walter H. Lewis, *Construction: Principles, Materials, and Methods,* U.S. League of Savings Institutions, Chicago.

Table 850-19. TYPICAL SIZES OF GLUE-LAMINATED BEAMS*†

Nominal, in	Net Finished, in (mm)
3	2 ¼ (57)
4	3 ⅛ (79)
6	5 ⅛ (130)
8	6 ¾ (171)
10	8 ¾ (222)
12	10 ¾ (273)
14	12 ¼ (311)
16	14 ¼ (362)

* Special widths are available for particular jobs. Depths and spans vary in size as constructed to match the needs of a particular job.

† Standard widths.

Source: C. G. Ramsey and H. R. Sleeper, *Architectural Graphic Standards*, 9th ed., John R. Hoke ed., New York, Wiley 1994.

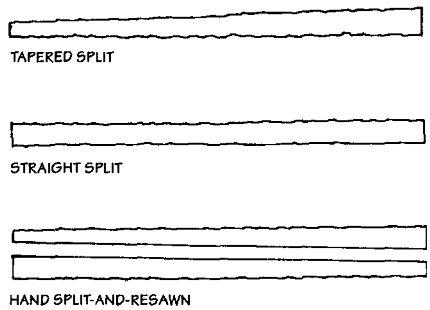

Figure 850-14. Types of wood shakes.

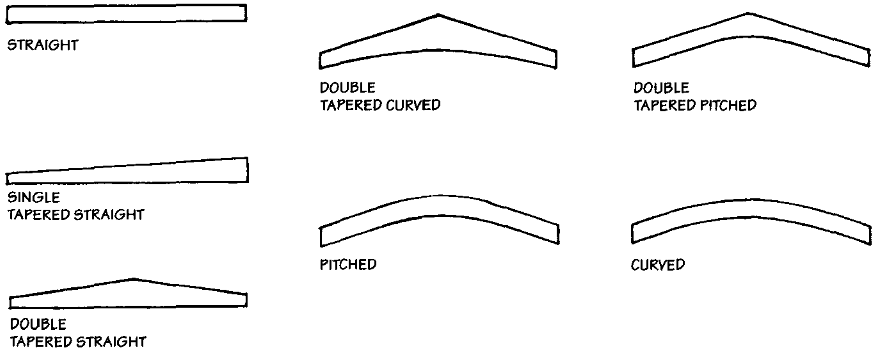

Figure 850-15. Typical shapes of glue-laminated beams.

Soaking: refers to dipping for up to 1 day in a preservative bath, while steeping refers to immersion for more than 1 day in a waterborne preservative. Soaking, and especially steeping, are very effective means of protection.

Double-diffusion: refers to the steeping of a wood member in one bath for a few days and then a second bath for an additional period of a few days, resulting in considerable penetration of the preservative.

Thermal Processes: achieves greater penetration and retention of a wood preservative if the wood members are immersed into a hot chemical bath followed by a cold chemical bath. This process is warranted in instances where dipping alone would be inadequate.

Pressure Treatments: relies on differences in atmospheric pressure to force preservatives into wood tissue deeper than would otherwise be possible. The full-cell process involves the vacuum removal of air out of the wood member, followed by forced entry of preservative into the tissue, resulting in high levels of penetration. This process is often used for wood that will be in contact with moist ground and for members used in marine environments.

Empty-cell process: involves the forced entry of preservative into the wood tissue without prior vacuum air removal. Penetration is uniform and deep and leaves the wood surface drier than the full-cell process. The empty-cell process is suitable for the application of oilborne preservatives.

5.4 Selection Criteria

The proper selection of a preservative and the means of application depends on the specific situation where the wood is to be used. Table 850-22 summarizes common wood preservatives and applications for various situations.

AGENCIES AND ORGANIZATIONS

National Technical Information Service (NTIS), U.S. Department of Commerce, Springfield, Virginia, USA

American Institute of Timber Construction (AITC), Englewood, Colorado, USA

American Plywood Association (APA), Tacoma, Washington, USA

American Wood Preservers Institute (AWPI), McLean, Virginia, USA

National Hardwood Lumber Association (NHLA), Memphis, Tennessee, USA

National Lumber Grades Authority (NLGA), Vancouver, British Columbia, Canada

Northeastern Lumber Manufacturer's Association, Inc. (NELMA), Falmouth, Maine, USA

Northern Hardwood and Pine Manufacturers Association (NHPMA), Green Bay, Wisconsin, USA

Red Cedar Shingle and Handsplit Shake Bureau (RCSHSB), Bellevue, Washington, USA

Southern Cypress Manufacturers Association (SCMA), Memphis, Tennessee, USA

Southern Pine Inspection Bureau (SPIB), Pensacola, Florida, USA

Western Wood Products Association (WWPA), Portland, Oregon, USA

REFERENCES

American Institute of Timber Construction Timber Construction Manual , *4th Ed. Wiley, New York, USA 1994*

American Lumber Standards Committee, National Bureau of Standards. PS 20-70 American Softwood Lumber Standards *U.S. Government Printing Office, Washington, District of Columbia, USA , (See latest edition).*

American Plywood Association. PS 1-74 Construction and Industrial Plywood *Tacoma, Washington, USA (See latest edition).*

Breyer, Donald E. Design of Wood Structures, *3rd. Ed. McGraw-Hill, Inc. New York, USA 1993*

Canada Standards Association. Standard Grading Rules for Canadian Lumber *National Lumber Grades Authority, Vancouver, British Columbia (See latest edition).*

U.S. Forest Products Laboratory Wood Engineering Handbook *Prentice-Hall, Englewood Cliffs, New Jersey, USA (See latest edition).*

Table 850-20. OILBORNE PRESERVATIVES

Type of Preservative	Composition	Advantages	Disadvantages
Pentachlorophenol	Mixture of petroleum oils and 5% of pentachlorophenol, also 2% penta in creosote Pena mixture comes mixed with either light oil, heavy oil, or liquified petroleum, gas (LPG). Mixtures penetrate into wood leaving penta deeply inbedded. LPG evaporates rapidly after applying and leaves wood clean to touch.	High protection against decay fungi and termites; can be painted; no unpleasant odor; less easily ignited than coal-tar creosotes (fire hazard compares to that of untreated wood if volatile solvents are used and allowed to evaporate)	May alter color if dark-colored petroleum oils are used; provides less protection against marine borers
Copper naphthenate	Mixture of petroleum oils and 0.3-0.5% copper metal equivalent (5-30% copper naphthenate)		Gives wood greenish or dark color and provides less protection against marine borers than creosote
Water-repellent preservatives†	Mineral spirits and 10-25% maximum of nonvolative matter including the preservatives; preservatives shall be not less than 5% pentachlorophenol; copper naphthenate varies from 1-2%	Retards moisture changes in wood; good protection against decay and insects	Cannot be used in contact with ground or areas where continual dampness can occur unless preservative is thoroughly applied (water repellent has little value)

* Some of the above wood preservatives may be hazardous to human health if exposure is not limited or prevented.

† Not less than 0.045% copper 8 quinolinolate for areas where foodstuffs will be in contact with treated woods.

Source: Caleb Hornbostel, *Construction Materials*, Wiley, New York.

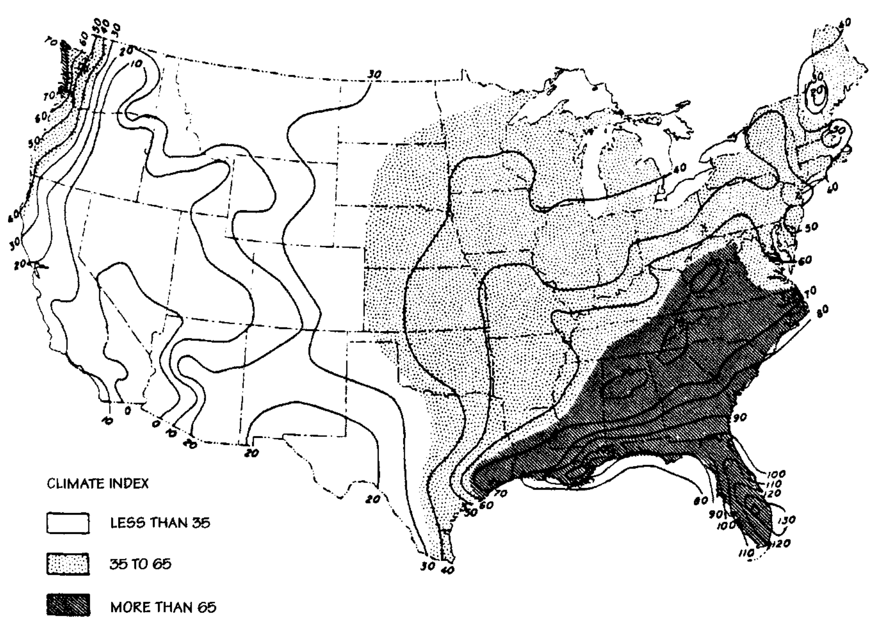

Figure 850-16. Levels of decay potential in the United States. *Zones illustrate levels of decay potential for wood in aboveground service. Darker tones indicate increased potential for decay. Regions are determined based on rainfall and temperature data.*

Table 850-21. WATERBORNE WOOD PRESERVATIVES

Type of Preservative	Composition			Advantages	Disadvantages
Acid copper chromate† (Celcure)	31.8% copper oxide and 68.2% chromic acid; copper sulfate, potassium dichromate, or sodium dichromate may be substituted for copper oxide			Good protection against insects and decay; can be painted; no objectionable odor; impregnated with 0.5 lb/ft^3 (8.10 kg/m^3); resistant to marine borer attack	Wood can be in contact with ground or water, but degree of impregnation depends on use of wood
	Parts by weight				
Chromated copper arsenate:	Chromium trioxide	Copper oxide	Arsenic pentoxide		
Type I† (Erdalith, Greensalt, Tanalith, and CCA)	61	17	22	Excellent protection against decay, fungi, and termites; good resistance to marine borer attack when only *Limnoria* and *Terdeo* borers are present	Wood can be in contact with ground; used in salt water when only *Limnoria* and *Terdeo* borers are present
Type II† (Boliden, K33)	35.3	19.6	45.1	Good protection against decay and insect attack; can be painted; no objectionable odor	Can be in contact with ground or water
Type III† (Wolman, CCA)	47	19	34		
	The following substitutions are permitted: sodium or potassium dichromate for chromium trioxide; copper sulfate, basic copper carbonate, or copper trioxide for copper oxide; and arsenic acid or sodium arsenate for arsenic pentoxide				
Chromated zinc chloride	80% zinc oxide and 20% chromium trioxide; the following substitutions are permitted: zinc chloride for zinc oxide and sodium dichromate for chromium trioxide			Moderately effective in contact with ground; good protection under somewhat drier conditions	Should not be used in contact with ground or water because it has some leaching action
Chromated zinc chloride (FR)‡	80% chromated zinc chloride, 10% boric acid, and 10% ammonium sulfate			Retention of 1½–3 lb/ft^3 (24.03–48.06 kg/m^3) provides protection from decay and insect attack and has good fire-retardant characteristics	
Ammonical copper arsenite† (Chemonite)	49.8% copper oxide, 50.2% arsenic pentoxide, 1.7% acetic acid; the following substitutions are permitted: copper hydroxide for copper oxide, and arsenic trioxide for arsenic pentoxide			Good protection against decay and termite attack; protection against marine environment, provided pholad-type borers are not present	Wood can be in contact with ground or water, but degree of impregnation and high retention of preservatives depend on end use of wood
Chromated zinc arsenate†	20% arsenic acid, 21% sodium arsenate, 10% sodium dichromate, and 43% zinc sulfate			Good protection against decay and termites; can be painted; no objectionable odor	Wood can be in contact with ground but not water
Fluor chrome Arsenate phenol† (Wolman salts. Osmosalts)	22% fluoride, 37% chromium trioxide, 25% arsenic pentoxide, and 10% dinitrophenol; the following substitutions are permitted: sodium pentachlorophenate for dinitrophenol; sodium or potassium fluoride for fluoride, sodium chromate or dichromate for chromium trioxide, and sodium arsenate for arsenic pentoxide			Good protection against decay, fungi, and insects in above-ground wood construction, and moderate protection when in contact with ground	Wood cannot be used in contact with ground or water when good protection is required
Zinc metal arsenite	60 parts arsenious acid and 40 parts zinc oxide with sufficient acetic acid to maintain preservations in solution			Good protection against decay and insects; can be painted; no objectionable odor	Wood can be used in contact with ground but generally not recommended for contact with water

* Some of these wood preservatives may be hazardous to human health if exposure is not limited or prevented.

† Many of these preservatives are trademark products covered by patents and should not be used without the specific consent of the patentee.

‡ Designation for fire retardant.

Source: Caleb Hornbostel, *Construction Materials,* Wiley, New York.

Table 850-22. SUMMARY OF WOOD PRESERVATIVE TREATMENTS

Industry Standard	Uses	Description
	Pressure Treatment: Waterborne Solutions	
AWPB LP-2—Softwood lumber, timber, and plywood, pressure-treated with waterborne preservatives for aboveground use	All construction uses (framing lumber, sheathing, siding, and trim) where wood should be protected from moderate decay hazard and insect attack.	
AWPB LP-22—Softwood lumber, timber, and plywood, pressure-treated with waterborne preservative for ground-contact use	All construction uses when exposed to severe insect attack and decay hazard. Also where wood is used in contact with the ground such as fence posts, steps, decks, etc.	Treated wood is clean, bright, and odorless; it is readily painted and glued with most adhesives.
AWPB-FDN—Softwood lumber, timber and plywood, pressure-treated with waterborne preservatives for ground-contact use	All parts of wood foundation systems for residential and light construction placed directly in the ground	The preservative is permanently fixed in the wood and will not leach out when exposed to weather.
AWPA C-23 Residential and commercial building poles, pressure-treated with waterborne preservatives	Poles for use in ground contact as a building foundation and column support against both lateral and vertical forces	
	Pressure Treatment: Oilborne Solutions (Pentachlorophenol)	
AWPB LP-3—Softwood lumber, timber, and plywood, pressure-treated with light petroleum solvent-penta solution for aboveground use	All construction uses (framing lumber, sheathing, siding, and trim) where wood should be protected from moderate decay hazard and insect attack	
AWPB LP-33—Softwood lumber, timber, and plywood, pressure-treated with light petroleum solvent-penta solution for ground-contact use	All construction uses where exposed to severe insect attack and decay hazard. Also where wood is used in contact with the ground such as fence posts, steps, decks, etc.	Treated wood is clean, bright, and relatively odorless; it is paintable and can be glued with special adhesives.
AWPB LP-4—Softwood lumber, timber, and plywood, pressure-treated with volatile petroleum solvent (LPG)-penta solution for aboveground use	All construction uses (framing lumber, sheathing, siding, and trim) where wood should be protected from moderate decay hazard and insect attack.	Suitable for indoor and outdoor use.
AWPB LP-44—Softwood lumber, timber and plywood, pressure-treated with volatile petroleum solvent (LPG)-penta solution for ground-contact use	All construction uses where exposed to severe insect attack and decay hazard. Also where wood is used in contact with the ground such as fence posts, steps, decks, etc.	All petroleum solvent must be evaporated before painting and to eliminate odor.
AWPB CP-33—Residential and commercial building poles, pressure-treated with pentachlorophenol in light hydrocarbon solvent	Poles for use in ground contact as a building foundation and column support against both lateral and vertical forces	
AWPB CP-44—Residential and commercial building poles, pressure-treated with pentachlorophenol in volatile petroleum solvent (LPG)	Poles for use in ground contact as a building foundation and column support against both lateral and vertical forces	
AWPA LP-7—Softwood lumber, timber, and plywood, pressure-treated with solvent-penta for aboveground use	Farm buildings, fences, bridges, etc. Good for outdoor applications because of good weathering characteristics	
AWPA C-23—Softwood lumber, timber, and plywood, pressure-treated with solvent-penta for ground use	All construction uses where exposed to severe insect attack and decay hazard. Also where wood is used in contact with the ground as in fence posts, steps, decks, etc.	Treated wood varies from light to dark brown, surface slightly oily; odor of oil and penta remain for several months after treatment.[d]
AWPA C-23—Residential and commercial building poles, pressure-treated with pentachlorophenol	Poles for use in ground contact as a building foundation and column support against both lateral and vertical forces	
AWPA C-23—Residential and commercial building poles, pressure-treated with creosote and creosote solutions	Creosote poles are widely used for pole-platform construction. They are suitable for residential pole-frame construction, but their use should be generally limited to those exterior poles that do not pass through enclosed, living space.	Creosoted poles range from dark brown to black, blending well with earth colors and natural surroundings. Because their surfaces are oily, painting is difficult at best and a characteristic smoky odor is detectable for some time following treatment.
	Non-Pressure Treatment: Oilborne, Water-Repellent Preservative Solution	
NWMA IS-4—Water-repellent preservative, nonpressure treatment for millwork	Exterior millwork: precut window, door, and trim components	Clear, odorless, and easily painted[e]

[a] Some of the above wood preservatives may be hazardous to human health if exposure is not limited or prevented.

[b] Treated wood can be painted and glued, after redrying; not recommended for hardwoods.

[c] Suitable for treatment of hardwoods as well as softwoods; not recommended for marine use.

[d] Generally not paintable; should not be used for subflooring or in contact with materials subject to staining (plaster, wallboard, etc.); retains odor for a long period when enclosed in a structure.

[e] Should not be used in contact with the ground or for conditions of severe insect attack and decay hazard.

Source: Adapted with permission from Harold B. Olin, John L. Schmidt, and Walter H. Lewis, *Construction: Principles, Materials, and Methods,* U.S. League of Savings Institutions, Chicago, 1983.

SECTION 860

Metals

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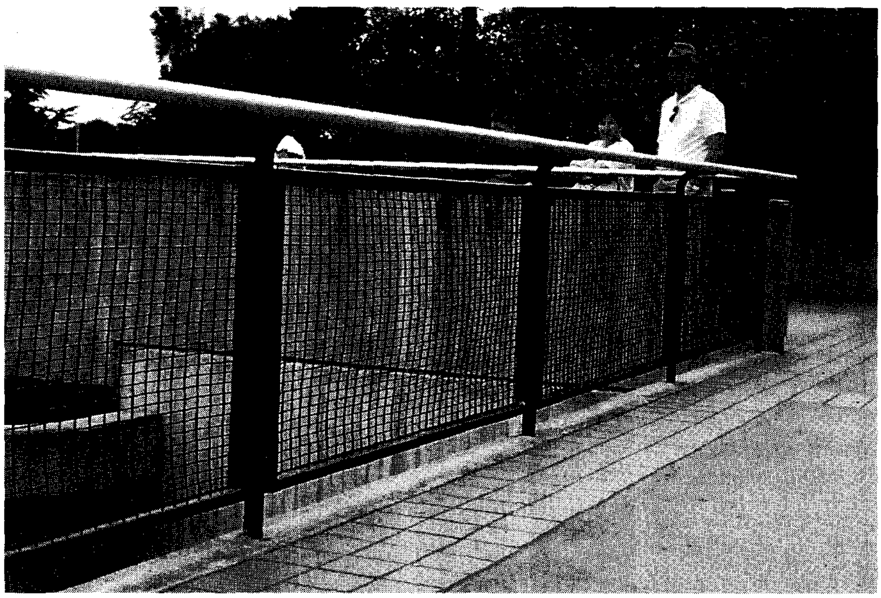
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CONTENTS

1.0 INTRODUCTION

1.1 General

Metal technology is complex, and consultation with a structural engineer is important whenever issues of bearing strength, durability, codes, or issues of safety are involved.

1.2 Basic Properties of Metal

When using any metals related to outdoor construction there are five generic criteria that should be evaluated and, if appropriate, factored into your recommendations for use of a particular metal. These are discussed here in brief, to remind users of this handbook of their importance and the possible need to consult more technical sources of data and/or a structural engineer.

Galvanic corrosion is a process that occurs when two different metals are in physical contact with one another. The more anodic of the two metals corrodes, and its material is deposited on the more cathodic (more "noble") metal when a solution (such as water) is present. The solution conducts electricity between the two metals.

Typically, the solution is water in the form of moisture condensation, and contaminants within the water act as the electrolyte. The corrosion potential increases in industrial, non-arid and seacoast areas because of increased contaminants and/or moisture. The galvanic predisposition of several metals and metal alloys is shown in Table 860-1.

Galvanic corrosion is controlled by:

1. Using similar metals in the galvanic series
2. Using sacrificial anode coatings which corrode and form a protective layer.
3. Providing a barrier to inhibit exposure to moisture such as paint or a bituminous coating.
4. Installing a surface metal cladding (with galvanic potential similar to the expected conditions) onto a base metal that, if exposed, would otherwise be anodic or cathodic.
5. Applying a paint or primer that either chemically changes the surface of the metal or includes an alkaline chemical that greatly reduces the rate of galvanic action to an acceptable level.

Chemical corrosion refers to the dissolving of a metal by some type of chemical reaction caused by a gas or acid. Because each type of metal reacts differently to various chemicals found in the environment it is very important to make the proper selection according to specific site conditions.

Finishes:

Metal products can be finished to provide a variety of colors, textures, patterns, and degrees of reflectivity as well as to provide greater protection against abrasion and corrosion. Metal finishes are categorized according to the basic process by which they are applied. Certain finishing processes are suitable only for certain kinds of metals. Basic finishes for metals include:

TABLE 860-1. GALVANIC SERIES OF METALS*

1. Aluminum
2. Zinc
3. Steel
4. Iron
5. Nickel
6. Tin
7. Lead
8. Copper
9. Stainless steel

* When any two metals on the list are in contact with one another in the presence of moisture, the lower one will be corroded. The further apart on the list, the more rapid and extensive will be the galvanic corrosion. This series is meant only as a guide to illustrate relative susceptibilities to galvanic corrosion.

1. Mechanical finishes, include grinding, polishing, buffing, rubbing, or sandblasting.
2. Chemical finishes, refer to the reaction of a chemical to a metal surface to produce colors, textures, and/or corrosion resistance.
3. Anodized finishes, which are produced by placing a metal into an acid solution and passing an electric current through it. This alters the outer surface of the metal to create an integral corrosion-resistant layer. Clear, translucent, or opaque finishes in a variety of colors are available. Anodized finishes are used almost exclusively on aluminum.
4. Applied coatings, which refer to the process of adding materials to the surface of a metal to provide color, corrosion resistance, and/or protection against abrasion. Such coatings include paints, enamels, plastic films, galvanizing, and cladding. Some plastic coatings are proprietary products not covered by established standards of performance.

Manufacturing and Fastening:

Metals are formulated in a mill and then undergo fabrication to produce objects in desired shapes. Fabrication processes include rolling, extruding, casting, drawing, and forging. Thermal treatments are applied to metals to alter their strength, hardness, machinability, ductility, and cold-forming characteristics. Many types of thermal treatments are available, the most common of which are tempering, quenching, and annealing.

KEY POINTS: Basic Metal Properties

1. Metal technology is complex, and consultation with a structural engineer is important whenever issues of bearing strength, durability, codes, or issues of safety are involved.
2. The galvanic corrosion potential of metal increases in industrial, non-arid, and seacoast areas because of increased contaminants and/or moisture in the atmosphere.
3. Galvanic corrosion is controlled by:
   a) Using similar metals in the galvanic series (Table 860-1).
   b) Using coatings that purposely corrode, thereby leaving the desired surface untouched and protected.
   c) Applying paint or a bituminous coating, to inhibit exposure to moisture.
   d) Installing a surface metal cladding.
   e) Applying paint or primer that either chemically changes the surface of the metal.
4. Metal can be finished by mechanical, chemical, or anodized methods, or by applying coatings such as paints or enamels.
5. Finishes on certain metals may be limited to particular fastening techniques if marring of the surface is a concern. Specialists should be consulted when fastening metals in order to determine the suitability of a fastening technique.

Metals that have been fabricated, formed, and finished may need additional work when they are fastened on-site. Typical techniques for fastening include welding, brazing, soldering, riveting, bolting, and screwing. Specialists should be consulted when fastening metals in order to determine the suitability of a fastening technique.

Environmental Issues.

Due to potential toxicity to animals and humans, the methods of manufacture, fabrication , disposal and reuse of metal products are subject to environmental regulations. It is advisable to seek information and assistance from a material specialist to understand the environmental implications of their use. Certain metals useful to site construction are well suited to recycling technologies and should be considered for their resource conservation value.

2.0 METALS USED IN CONSTRUCTION

2.1 Aluminum

Aluminum is a lightweight, corrosion-resistant metal (one-third the weight of iron) that can be manufactured in a wide variety of shapes. Corrosion is controlled by an oxide that naturally forms on the surface of the metal, thereby preventing further oxidation of the metal beneath. Aluminum is subject to chemical attack from alkalis, hydrochloric acid, and to a lesser degree, diluted acids. Corrosion occurs when it is used with lime mortar, high alkaline concrete, masonry, green or damp wood. This can be prevented or corrected by applying bituminous or zinc chromate prime on metal, or paint on the wood, or using preservative treated woods.

Aluminum Alloys:

Pure aluminum is soft and highly corrosion-resistant. The addition of one or more alloying elements can enhance strength, machinability, impact resistance, and malleability, but it typically lessens resistance to corrosion. In the United States, a nomen-

TABLE 860-2. COMMON ALUMINUM ALLOYS

Casting nomenclature and product	Wrought nomenclature and product	Major alloying element	Remarks and typical uses
1xx.x	1xxx	Aluminum (at least 99% pure)	Corrosion resistance and workability are excellent. Used in small quantities. Slight amounts of silicon and iron increase strength but decrease corrosion resistance. Non-heat-treatable alloy
	1100-H16		Sheet, ducts
2xx.x	2xxx	Copper	Series displays strength and hardness but ductility and workability are decreased. Corrosion resistance often less; thus typically clad. Heat-treatable alloy
214			Fittings and railings
	2014-T6		Structural members
	2017-T4		Screws
	2024-T4		Screws and rivets
3xx.x	3xxx	Manganese	Series for general purposes as alloy displays moderate strength with ductility, workability, corrosion resistance, and brightness almost that of pure aluminum. Commercial 3003 anodizes very well. Non-heat-treatable alloy
356.0-T6			Hardware, railings, supports
	3003-O		Concealed and exposed flashing
	3003-H18		Hardware
4xxx.x	4xxx	Silicon	Series exhibits best corrosion resistance of the aluminum alloys. Good for marine, heavily weathered, and heavy chemical environments. Non-heat-treatable alloy
B443.0-F			Casting or sand casting. Used for panels, hardware, lettering, grilles, posts, sculpure
5xx.x	5xxx	Magnesium	Series displays higher tensile strengths and resistance to fatigue. Have excellent corrosion resistance in many environments, including seacoast atmospheres and saltwater. Does not cut or work as clean as other alloys. Non-heat-treatable alloy
514.0-F			Lettering, posts
	5050-O		Hardware
6xx.x	6xxx	Magnesium-silicon	Somewhat less strength than 2xxx series, but displays better corrosion resistance and workability. Heat-treatable alloy.
	6061-T13		Pipe railings. Excellent fusion weldability properties
	6061-T6		Structural member, gratings, treads, steps, floor, and angle flanges. Excellent fusion weldability characteristics
	6061-T913		Nails
	6063-T4		Poles for flagpoles or lamps
	6063-T42		Exposed flashing
	6063-T5		Door and window frames, railings, thresholds, exposed flashing, hardware bars, rods, tubes
	6063-T6		Structural members, nails, corrugated sheets
7xx.x	7xxx	Magnesium-zinc	Series displays strongest properties of aluminum alloys. Highest yield strength. More difficult to work with and more expensive. Heat-treatable alloy
	7075-T6		Structural members

TABLE 860-3. FINISHES FOR ALUMINUM

Type of finish	Designation*	Description	Remarks
		Mechanical	
As fabricated	M10 M11 M12 M1X	Unspecified Specular as fabricated (bright finish) Nonspecular as fabricated (dull finish) Other	Used where appearance is not important; can be discolored when welded
Buffed	M20 M21 M22 M2X	Unspecified Smooth specular (mirrorlike finish) Specular Other	Used where bright finish is desired (entrance doors and hardware); avoid using on broad flat surfaces where "oil canning" is objectionable
Directional textured	M30 M31 M32 M33 M34 M35 M3X	Unspecified Fine satin Medium satin Coarse satin Hand-rubbed Brushed Other	Use where smooth satin sheen of limited reflectivity is desired; easy to restore after welding
Nondirectional textured	M40 M41 M42 M43 M44 M45 M46 M47 M4X	Unspecified Extra fine matte Fine matte Medium matte Coarse matte Fine shot blast Medium shot blast Coarse shot blast Other	Used primarily for castings in architectural use; produced by blasting (sand, beads, shot, etc.)
Patterned		Embossed and coined patterns and textures	Available in light gauge sheet; patterns can be highlighted by polishing.
		Chemical	
Nonetched cleaned	C10 C11 C12 C1X	Unspecified Degreased Inhibited chemical cleaned Other	Used to clean in preparation for other finishes
Etched	C20 C21 C22 C23 C2X	Unspecified Fine matte Medium matte Coarse matte Other	Typically used for surfaces to be anodized, although finish can be clear lacquer; can be used to produce patterns in the metal surface

* The complete designation must be preceded by AA—signifying Aluminum Association.

† *Impregnated* color coatings are available in many colors. Not all colors are suitable for exterior use. Gold is the most colorfast.

Integral color coatings offer a range of colors from bronze to gray to black. Some colors can be obtained only with certain alloys. Colorfastness is excellent. Typically, these colors are applied by a proprietary process.

clature system devised by the Aluminum Association categorizes casting and wrought aluminum and their alloys. This is indicated by the first digit of the aluminum numeric (Table 860-2). Other countries use different nomenclature systems to describe the same alloys.

Casting alloys are those that are cast in their intended form. Wrought alloys are those produced by mechanically shaping cast aluminum ingots. Aluminum alloys are often tempered to improve their strength, stability, and/or workability.

Finishes:

Exposed aluminum will naturally form an oxide layer that inhibits further corrosion. Applied finishes may improve the corrosion or abrasion resistance, alter the surface texture or color, or prepare a surface for a subsequent finish coating (Table 860-3).

Mechanical Finishes: Mechanical finishes should not be applied to aluminum-clad surfaces because such finishes will damage the integrity of the cladding (Table 860-3).

Chemical Finishes: Chemical finishes are used for surface cleaning, to produce a matte texture or a bright finish, or to prepare the surface for another finish such as painting (Table 860-3).

Anodized Finishes: Anodized coatings require a sealer to provide resistance to staining and to ensure greater durability of color. Acid materials should be avoided when cleaning or maintaining anodized surfaces. The anodizing process (a proprietary product) is performed during manufacturing. (Table 860-3).

Applied Coatings: Plastic films are durable, fade-resistant and demonstrate

TABLE 860-3. CONTINUED

Type of finish	Designation*	Description	Remarks
		Chemical	
Brightened	C30	Unspecified	Limited architectural use; avoid use in large surfaces (fascias, spandrel panels, etc.); appropriate for window frames
	C31	Highly specular (mirror bright)	
	C32	Diffuse bright	
	C3X	Other	
Chemical conversion coatings†	C40	Unspecified	Used to improve adhesion of surfaces for painting, and can be used as final finish; most methods are proprietary.
	C41	Acid chromate-fluoride (clear to yellowish color)	
	C42	Acid chromate-fluoride-phosphate (clear to greenish color)	
	C43	Alkaline chromate (gray color)	
	C4X	Other	
		Anodized	
Architectural class II (0.4 to 0.7 mil coating)	A31	Clear (natural) coating	Thickness of coating ranges from 0.4 to 0.7 mils. For interiors not subject to excessive wear and for exteriors that are regularly maintained. Sulfuric acid (clear) process: thick-thin coats
	A32	Coating with integral color	
	A33	Coating with impregnated color	
	A34	Coating with electrolytically deposited color	
	A3X	Other	
Architectural class I (0.7 mil and greater anodic coating)	A41	Clear (natural) coating	Thickness of coating must be at least 0.7 mils. For interiors with normal wear and exteriors receiving no regular maintenance
	A42	Coating with integral color	
	A43	Coating with impregnated color	
	A44	Coating with electrolytically deposited color	
	A4X	Other	
		Applied coatings	
Laminated: three types of plastic films		Polyvinyl chloride: range of colors Polyvinyl fluoride:: limited color range, medium gloss, smooth surface Acrylic: clear by nature but can be pigmented	Resistant to thermal expansion; highly durable; excellent color retention and weatherability; can be applied in one operation; recommended for interiors and exterior metal work

Electrolytically deposited color coatings are available in a range of colors from light bronze to black. Of all anodized coatings, colors that are electrolytically deposited are the least susceptible to sunlight and other types of weathering.

Source: Adapted from *Sweet's Selection Data: Metals*, McGraw-Hill, New York, 1978; and adapted with permission from Harold B. Olin, John L. Schmidt, and Walter H. Lewis, *Construction: Principles, Materials, and Methods*, U.S. League of Savings Institutions, Chicago, 1983.

excellent weatherability (Table 860-3). Typical films include polyvinyl chloride (wide range of colors), polyvinyl fluoride (smooth surface, medium gloss, but limited color range), and acrylics (clear and colored).

2.2 Copper and Alloys

Copper and many of its alloys are resistant to corrosion and easily welded, brazed, or soldered. Natural oxidation of copper causes a bluish-green patina on the surface of the material. Copper is susceptible to

KEY POINTS: Aluminum

1. Pure aluminum is soft and highly corrosion-resistant. The addition of one or more alloying elements can enhance strength, machinability, impact resistance, and malleability, but it typically lessens resistance to corrosion.
2. Typical corrosive situations occur when aluminum is used with lime mortar, high alkaline concrete, or masonry where wet conditions are expected. These situations can be corrected by applying bituminous or zinc chromate prime on metal.
3. Corrosion can also occur when using aluminum with green or damp wood. This can be corrected by applying paint or using wood treated with preservatives not containing acid.

TABLE 860-4. COPPER AND COPPER ALLOYS

Alloys	Remarks	Color: Unexposed	Color: Initial weathering	Color: Final weathered	Typical uses	Fabrication: Machinability*	Fabrication: Brazenability†	Fabrication: Solderability†	Weldability: Oxyacetylene†	Weldability: Gas shielded arc†	Weldability: Coated metal arc†	Weldability: Resistance (spot)†	Weldability: Resistance (seam)†
Wrought alloys													
Copper													
110 99.99 copper	Copper (110) and high copper alloy (122) are corrosion resistant and best for wire.	Salmon-red	Reddish brown	Gray-green patina	Gutters, flashing, screens, nails, tacks	20	B	A	D	C	D	D	D
122 99.99 copper		Salmon-red	Reddish brown	Gray-green patina	Tube, sheet, plate, welding	20	A	A	B	A	D	D	D
Architectural bronze and common brasses													
220 Commercial bronze	Plain brasses have a high percentage of zinc, hardened by cold-working; less expensive than high copper alloys. Red brass is excellent to resist corrosion. Cartridge brass has good combination of strength and durability.	Red-gold	Brown	Gray-green patina	Grills, screws, rivets, hardware	20	A	A	B	B	D	D	D
230 Red brass		Reddish yellow	Chocolate brown	Gray-green patina	Trim, weatherstripping, fasteners	30	A	A	B	B	C	D	D
260 Cartridge brass		Yellow	Usually protected from weathering to preserve color		Grills, rivets, screws, miscellaneous hardware	30	A	A	B	C	B	D	D
280 Muntz metal		Reddish yellow	Red brown	Gray brown	Sheet and stripping trim large nuts and bolts	40	A	A	B	C	B	D	D
314 Leaded commercial bronze					Screws and miscellaneous rough hardware	80	B	A	D	D	D	D	D
320* Leaded red brass	Leaded brass has improved machinability but cannot be cold-worked as easily.	Reddish yellow	Chocolate brown	Gray-green patina		30	A	A	B	B	C	D	D
350 Medium leaded brass					Finish hardware	70	B	A	D	D	D	D	D
377 Forging brass		Reddish yellow	Russet brown	Dark brown	Forging	80	B	A	D	D	D	D	D
385 Architectural bronze		Reddish yellow	Russet brown	Dark brown	Architectural extrusions and hardware	90	B	A	D	D	D	D	D
Nickel silver and silicon bronze													
651 Silicon bronze	Silicon bronzes have higher tensile strength and good corrosion resistance.	Reddish old gold	Russet brown	Finely mottled dark gray-brown	Hardware	30	A	A	B	A	C	A	B
655 Silicon bronze		Reddish old gold	Russet brown	Finely mottled dark gray-brown	Hardware	30	A	B	B	A	C	A	A
745 Nickel-silver	Nickel-silvers: copper-zinc-nickel formulations. Lead, if added, improves machinability. Easily hot-worked and fabricated into intricate parts	Warm silver	Gray-brown	Finely mottled gray-green	Rivets, screws, fasteners, hardware	20	A	A	B	C	D	B	C
774 Nickel-silver		Warm silver	Gray-brown	Finely mottled gray-green	Typically for extrusions	—	—	—	—	—	—	—	—
796 Leaded nickel silver		Warm silver	Gray-brown	Finely mottled gray-green	Typically for extrusions	50	A	A	B	D	D	B	B
Cast alloys													
Architectural bronze and common brasses													
834 Similar to 220	See appropriate remarks above.	Red-gold	Brown	Gray-green patina		60	A	A	C	C	D	—	—
836 Similar to 230		Reddish yellow	Chocolate brown	Gray-green patina		84	B	A	D	D	C	—	—
852 Similar to 260		Yellow	Usually protected from weathering to preserve color			80	C	A	C	D	D	—	—
853 Similar to 260		Yellow				30	A	A	B	B	D	—	—
855 Similar to 260		Yellow				80	C	B	D	D	D	—	—
857 Similar to 260		Yellow				80	C	B	D	D	D	—	—
875 Similar to 651 and 635		Reddish old gold	Russet brown	Finely mottled gray-green		50	C	C	C	C	D	—	—
Nickel-silver													
973 Composition similar to nickel-silver		Warm silver	Gray-brown	Finely mottled gray-green		70	A	A	D	D	D	—	—

* 0-100 scale of increasing ease.

† A = excellent; B = good; C = fair; D = not recommended.

Source: Adapted from *Sweet's Selection Data: Metals*, McGraw-Hill, New York.

TABLE 860-5. FINISHES FOR COPPER

Finishes	Appearance, pattern, and color	Remarks
	Mechanical	
"As fabricated"—originally imparted by a rolling, extrusion, or casting process	Hot-rolled and heat-treated products have dull finish. Cold-rolled surfaces have brighter finish	Do not use where appearance is important.
Buffed	Available in specular and smooth specular finish	Used mostly for hardware; high reflectivity; avoid use on wide, flat surfaces.
Directional textured	Satin sheen in fine, medium, or coarse texture (also in hand-rubbed or brushed finishes)	Limited reflectivity
Nondirectional textured	Available in fine, medium, or coarse matte finishes	Primarily used for hardware, castings; "se" is restricted to metal at least ¼ in thick.
Patterned	Embossed and coined patterns and textures	Minimal marring in service; elimination of distorted reflections; pattern can be highlighted by polishing; increased sheet stiffness
	Chemical	
Nonetch cleaning	Removes oil, grease, soil, etc., from the surface of the metal	Used to clean surfaces in preparation for other finishes via degreasing or chemical cleaning
Matte finishes	Matte, textured surface	Tend not to be used on copper alloys; used mainly on bronzes
Bright-dipped	Smooth, bright	Limited architectural uses; used mostly as a surface preparation for plating or painting
Conversion coating	Statuary bronze finishes can be toned, which will vary from a light golden color to black. Sulfide treatments produce statuary brown colors. Selenide treatments provide deep colors.	Most important finish for copper alloys; used primarily to alter color and provide final finish; duplicates weathering effects from 1–12 yr; types include treatments which produce (a) patinas or verde antiques, (b) statuary or oxidized colors; statuary treatment has better color uniformity; statuary finish is difficult to produce and maintain and requires periodic rubbing with oil.
	Applied	
Laminated coatings	Clear film (bonded polyvinyl fluoride)	Chemically inert; mechanically strong; resists impact, abrasion, weathering
Oils and waxes	Rich luster and depth of color	Primarily used for maintenance purposes on site

Source: Adapted from *Sweet's Selection Data: Metals*, McGraw-Hill, New York.

attack from alkalis and most acids, especially in areas where sulfur is present.

Copper Alloys:

In the United States, the Copper Development Association has established a nomenclature system for copper and copper alloys such as brass, bronze, etc. (Table 860-4).

Finishes:

Coppers, brasses, bronzes, nickel silvers, and silicon bronzes have integral colors, patinas, and surface textures that can be altered by mechanical or chemical means in a variety of ways (Table 860-5).

Mechanical Finishes: These finishes for copper produce surfaces ranging from natural colors to a bright or reflective appearance (Table 860-5). Marring is more noticeable on mirror-like finishes

Chemical Finishes: Chemicals are used on coppers to clean the surface, to provide a matte or smooth bright finish, to age the surface artificially, or to preserve surface color (Table 860-5).

Applied Coatings: Applied coatings (clear films) are often used on copper to protect the copper from abrasion and to preserve its color (Table 860-5).

2.3 Iron

Pure iron is a tough, malleable metal that readily oxidizes in air. Iron is the base metal of cast iron.

Cast Iron:

Cast iron is distinguished from wrought iron or steel by containing more than 2 percent carbon. A major advantage of cast iron is that it can be poured into forms of various shapes to produce specific objects. Cast iron exhibits good compressive strength and is relatively inexpensive, but has poor tensile strength. Corrosion of cast iron can be minimized by adding a corrosion-resistant alloy or be prevented by adding a galvanized, plated, or asphalt surface coating.

Typical uses of cast iron include piping and fittings, pavement opening frames and covers, gratings, ornamental ironwork, custom-made objects, and hardware. Cast iron is more difficult to join by welding than other iron or metal alloys. The two types of

TABLE 860-6. TYPES OF IRON USED IN CONSTRUCTION

Types	Remarks
Gray cast iron	Gray color when broken; soft and tough; easily machinable
Malleable cast iron	Light gray color when broken, strong and tough, easily machined; more ductile with increased breakage resistance as compared to gray cast iron
Wrought iron	Soft, resistant to corrosion and fatigue, easily machined and worked; resistant to progressive corrosion

Source: Adapted from Caleb Hornbostel, *Construction Materials,* Wiley, New York.

TABLE 860-7. CARBON STEEL (A) CLASSES, (B) COMMON DESIGNATED STEELS

Class	Percentage of carbon
Soft	0.20
Mild	0.15-0.25
Medium	0.25-0.45
Hard	0.45-0.85
Spring	0.85-1.15

(a)

Common designated steels	
ASTM	AISI
ASTM A373	
	10XX
A283	
	11XX
Merchant quality: A 663 bars	
	12XX
A 675 bars	
	15XX
ASTM A36	

(b)

Source: Adapted with permission from Harold B. Olin, John L. Schmidt, and Walter H. Lewis, *Construction: Principles, Materials, and Methods,* U.S. League of Savings Institutions, Chicago.

cast iron typically used in construction are gray and malleable (Table 860-6).

Wrought Iron:

Wrought iron is distinguished from cast iron by its smaller carbon content (less than 0.1 percent), which makes the material softer, more malleable, easily machined and welded, and resistant to continued corrosion (Table 860-6). Basic forms include bars, sheets, plates, pipes, and special shapes. Applications include ornamental ironwork, railings, fences, gates, furniture, grilles, and screens.

2.4 Steel

Steels are combinations of iron, carbon, and other alloys and characterized by it strength.

Carbon Steels:

The most common form of steel is carbon steel. Increasing the amounts of carbon improves the strength, reduces the ductility, and decreases the melting point of steel. Carbon steels exhibit poor corrosion resistance but can be improved by incorporating copper as an alloying element or by specifying a galvanized or other protective finish.

A number of nomenclature systems designate carbon steels. Table 860-7 compares these two classification systems. A Unified Numbering System (UNS) was established in 1975 as a comprehensive system that combines to two former systems.

Carbon steels are available as wrought, cast and extruded products.

Finishes for Carbon Steel: Chemical finishes are used to clean the surface without otherwise affecting it and to prepare the surface for applied coatings. Common finishes for carbon steel are described in Table 860-8.

High-Strength Low-Alloy Steels (Weathering Steels):

High-strength low-alloy steels contain less than 1 percent of any alloying element. It exhibits high strength, stiffness, ductility, and excellent resistance to corrosion. It is most useful where a high degree of strength with low weight and/or corrosion resistance is required (e.g., bridges, trellises, etc).

The use of weathering steels should be avoided in corrosive industrial atmospheres, marine environments, or situations where the metal may be in constant contact with or in water. It should be used only where it is fully exposed to the atmospher.

KEY POINTS: Iron and Steel

1. If corrosion is to be minimized, cast iron should be alloyed with a corrosion-resistant alloy or be protected by either a galvanized, plated, or asphalt surface coating.
2. Carbon steels exhibit poor corrosion resistance but can be improved by incorporating copper as an alloying element or by specifying a galvanized or other protective finish.
3. Due to high production costs, the use of alloy steels in architectural applications is limited.
4. High strength low alloy steels (weathering steels) are most useful where a high degree of strength with low weight and/or corrosion resistance is required (e.g., bridges).
5. Weathering steel surfaces must be fully exposed to atmospheric changes in moisture content, and not located under debris or submerged in water. During the oxide forming period, any moisture dripping from the steel will stain surrounding surfaces, especially porous ones.
6. The use of weathering steels should be avoided in corrosive industrial atmospheres, marine environments, and situations where the metal may be in constant contact with water.
7. Stainless steel will not corrode when placed in concrete masonry and its wash will not stain nearby materials. It can, however, be stained from the washes of other materials.
8. If welding of stainless steel is required, the manufacturer of the product should be contacted to determine which welding techniques are appropriate.
9. Given stainless steel's high rate of thermal expansion, expansion joints are often necessary to avoid a warping of panels.

TABLE 860-8. FINISHES FOR CARBON STEEL

Finishes	Appearance, pattern, and color	Remarks
	Mechanical	
As fabricated (mill finishes)	Hot-rolled: tight mill scale and rust powder	Improper preparation could prevent complete adhesion and provide focal points for corrosion. Mill scale and rust powder must be removed.
	Cold-rolled: may be extremely smooth; must be degreased before painting	Must be cleaned and possibly roughened for extremely smooth surfaces
Cleaning methods	Removal of mill scale, corrosion products, and dirt	Methods to remove mill scale, dirt, etc.: hand cleaning (for spot cleaning), power tool cleaning (for heavy stock), shot- and sand-blasting (provides most suitable surface for painting), flame cleaning (for heavy stock)
Pattern	Various embossed patterns	
	Chemical	
Cleaned only	Clean mill finish surface	Methods: pickling (removes dirt, rust, mill scale), vapor degreasing (removes oil and grease), alkaline cleaning (removes oil and grease)
Conversion coatings	Fine matte surface texture; usually slate gray	Acid phosphate solutions are generally used to prepare the surface for paint and other coatings; usually proprietary
	Applied	
Zinc (galvanizing) G90	Gray crystalline	For normal use, steel sheets use 0.90 oz/ft^2 of zinc coating
Lightweight	Gray crystalline; fine matte finish	Coatings less than 0.1 oz/ft^2 of sheet require painting.
After fabrication	Gray crystalline	Used with a variety of small and large fabricated shapes for critical exposures (aggressive industrial atmospheres). Standard galvanized coating, applied after fabrication, lasts up to 25 years.
		Zinc coatings will burn off during welding operations but can be restored. Heavier coatings last longer.
Aluminum (aluminizing) Type 2	Weathers like aluminum	Provides excellent corrosion resistance; not recommended for use at temperatures above 900°F; wide acceptance in many building applications
Porcelain enamel	Wide range of colors and textures, from low gloss (semimatte) to dull (full matte)	Color uniformity from part to part excellent; bonded by fusion at 800°F or higher; resists chemical stains; nonporous; highly durable
Laminated	Polyvinyl chloride plastic films (grained embossed); polyvinyl flouride plastic films (medium gloss, smooth surface); acrylic films (clear but usually pigmented)	Good resistance to thermal expansion; durable and weather-resistant for exterior use; can be applied in one operation; excellent color retention; recommended for exterior metal work

Source: Adapted from *Sweet's Selection Data: Metals,* McGraw-Hill, New York.

During the initial period when oxide is forming any moisture dripping from the steel will stain surrounding surfaces, especially porous ones.

Stainless Steels:

Stainless steels are ferrous steels with a chromium content of at least 12 percent and additional amounts of nickel, manganese, or molybdenum. (Table 860-9). Stainless steels exhibit a high degree of permanence, high resistance to corrosion, high strength, high rates of thermal expansion, low rates of thermal conductivity, and surfaces that are relatively bright. The initial costs are relatively high, but the long-term maintenance costs are minimal.

Stainless steels used in construction are first categorized by grain structure and subsequently according to the alloying elements (Table 860-9). Some types can be tempered for greater strength and hardness. If welding of stainless steel is required, the manufacturer of the product should be contacted to determine which welding techniques are appropriate. Stainless steel has a high rate of thermal expansion and needs expansion joints.

Finishes for Stainless Steels: Stainless can be achieved by mechanical or chemical means or by applied finishes (Table 860-10). Fabricators carry a wide variety of finish types.

2.5 Nickel

Nickel is a silvery metal that is strong, tough, and highly resistant to corrosion from both alkalis and acids, with the exception of nitric acid. Nickel can be welded, brazed, soldered, easily worked, and polished by a variety of methods. Nickel is typically too expensive except where low maintenance and/or aesthetics are major objectives.

Nickel plating can be applied to metals for a particular finish or for improved resistance to corrosion and galvanic actions.

TABLE 860-9. STAINLESS STEELS

Grain structure	Type	Corrosion resistance	Welding, combining	Remarks
Austentic (hardenable by cold-working; nonmagnetic, high ductility; with care, it can be fusion and resistance welded)	201	Excellent even at high temperatures. Compared to other stainless steels, more susceptible to deoxidizing by sulfur gases.	Fusion and resistance welding	Exterior work: same as 301 but stronger and harder
	202	Excellent even at high temperatures compared to other stainless steels, more susceptible to deoxidizing by sulphur gases.	Fusion and resistance welding	Exterior work: similar to 302
	301	Excellent except when in contact directly with salt spray or seawater	Fusion and resistance welding and good cold-forming	Exterior flashings: sometimes used as a structural member when cold-worked.
	302	Excellent except when in contact directly with salt spray or seawater	Fusion and resistance welding	Exterior work: often interchangable with 304
	304	Excellent except when in direct contact with salt spray or seawater	Fusion and resistance welding	Exterior work: often interchangable with 302; more machinable
	305	Excellent		Bolts, screws, nuts, and fasteners
	361	Best of stainless steels. Suitable in salt spray, seawater, and many chemical environments	Fusion and resistance welding	Exterior use, salt spray environments, and industrial areas
Ferritic (chromium content, at 12–27%; does not respond to heat treatment; can be welded but joint must not be subject to bending stress or shock)	430	Very good corrosion resistance	Fusion and resistance welded, but joint should not be exposed to shock or bending stress	Exterior use, sometimes for gutters, downspouts, trim, and column covers
Martinsitic (hardened by heat treatment; can be cold-formed or hot-forged and cooled slowly to prevent cracking)	410	Moderate. Avoid in industrial, marine, salt, and seawater environments.	Easily welded but needs to be followed by annealing or tempering to reestablish ductility	Bolts, screws, nuts, fasteners. Suitable where hardness, strength, and resistance to abrasion are necessary.

3.0 METAL STOCK

In addition to designations for type, shape, and size, many kinds of metal stock (whether in the form of sheets, strips, wire, tubing, rivets, or screws) are typically specified according to thickness. The term gauge refers to the thickness (or cross-sectional dimension) of a material, but references can be misleading because the exact dimensions for identical gauge sizes differ between various standard gauging systems (Table 860-11). Different industries and sometimes different products within a particular industry may use more than one gauging system. If precision is important then the products should be specified in millimeters or decimal of inches to clearly indicate the desired size.

The range of types, shapes, etc. of metal stock are shown in the Tables 860-12 through Table 860-37.

4.0 COMMON METAL PRODUCTS

The range of types, shapes, etc. are shown in Tables 860-32 through Table 860-37 and Figures 860-1 through 860-3. All fasteners and base metals should be checked for galvanic compatibility.

4.1 Nails, Screws, and Bolts

Nails:

Nails commonly used in construction are shown in Tables 860-32 and 860-33. Materials include zinc, brass, Monel, copper, aluminum, iron or steel, stainless steel, copper-bearing steel, and muntz metal. Coatings include tin, copper, cement, brass-plated, zinc, nickel, chrome, cadmium, acid-etched, and parkerized.

A nail's diameter, length, shape, and surface affect its holding power. Joint hanger nails are not equivalent to common nails because of their length and should not be considered a substitute unless the shorter length is specified in load tables.

Screws and Bolts:

Wood screws commonly used in construction are shown in Table 860-34. Wood screws are not often used in landscape construction but do find occasional application. They are never used in instances where bearing strength is an issue, but rather for decorative assemblies, small planter boxes, light trellises, etc. Wood screws should extend three-fourths of the way into the second piece of wood. Pilot holes are sometimes drilled to prevent splitting of the wood, especially near edges or with harder woods.

Metal screws are used primarily to fasten metals together, but they can be used in place of bolts to fasten small wood members together. If used to fasten wood members together, washers are typically used at both ends, unless the screw heads are of the flat or oval variety. If used to fasten metals, metal screws should be matched to

TABLE 860-10. FINISHES FOR STAINLESS STEELS

Finishes	Appearance, pattern, and color	Remarks
	Mechanical	
Standard mill finish	No. 1: dull	Used for concealed applications
Sheet-rolled	No. 2D: dull, nonreflective	Used when appearance is not important
	No. 2B: bright, moderately reflective finish	General purpose finish; used when appearance is not important
	Bright annealed: bright, highly reflective finish	Used when appearance is not important
Polished finish	No. 3: coarser than No. 4	Used as an intermediate, polished finish
	No. 4: bright machine-polished finish with grain	Most frequently used finish for architectural applications
	No. 6: dull, satin finish	Used when a high luster is undesirable and to contrast with brighter finishes
	No. 7: bright, highly reflective finish	Gaining acceptance in architectural work
	No. 8: Bright, "mirror" finish	Used for applications such as mirrors and reflectors
Patterned	Embossed and coined patterns and textures	Provides more stiffness to sheet; reduces optical distortion; available in light gauge sheet; patterns can be highlighted by polishing.
	Chemical	
Conversion coatings	Light to dark bronze; bluish hue to dark brown or brown-black	Acquired by controlled oxidation; excellent resistance to abrasion, humidity, corrosion, soiling, and oxidation; acquired by controlled heat-treating
	Applied	
Proprietary	Variety of forms	Used when appearance is not critical
Porcelain enamel	Essentially glass applied in translucent colors with metallic luster seen through glaze	Used at times for color and visual contrast; more durable but somewhat less elastic than organic coatings
Metallic	Copper and terne	

Notes: Most of the stainless steel used architecturally is in the form of sheet or strip. Unpolished No. 2D and 3B, proprietary finishes and bright rolled finishes cannot be matched in a fabricator shop. For fabricated products, use only if appearance is not critical. For large flat areas, use nonreflective matte, textured, patterned, or contoured finishes. For welded assemblies, use blendable finishes (No. 4).

Source: Adapted from *Sweet's Selection Data: Metals*, McGraw-Hill, New York

KEY POINTS: Fasteners

1. A nail's diameter, length, shape, and surface affect its holding power. Joint hanger nails are not equivalent to common nails because of their length and should not be considered a substitute unless the shorter length is specified in load tables.
2. Wood screws are not often used in landscape construction but do find occasional uses with decorative assemblies, small planter boxes, light trellises, etc. Wood screws should extend three-fourths of the way into the second piece of wood.
3. If used to fasten metals, metal screws should be matched to the metals being fastened in order to avoid galvanic corrosion.
4. Lag bolts are typically installed with a large washer under the head to prevent mashing of the wood and consequent loss of holding power.
5. To avoid the hazard of protruding ends, the length of screws and bolts should not exceed that which is necessary.

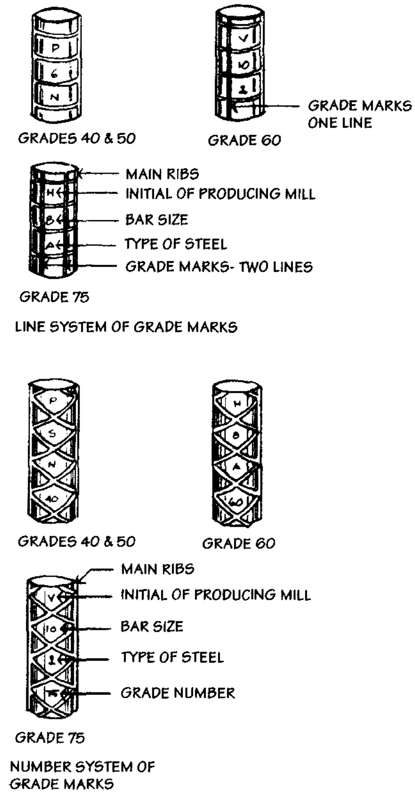


Figure 860-1. Reinforcement bar markings. *N refers to new billet, A refers to axle, and + refers to rail. Grade mark lines must be continued for at least five deformation spaces on the bar. Bar identifications and grade mark numbers may read horizontally (90 degrees to those shown above.)*

the metals being fastened in order to avoid galvanic corrosion.

Lag bolts are typically installed with a large washer under the head to prevent mashing of the wood and consequent loss of holding power. The center-hole diameters of washers should match the bolt or screw to ensure maximum strength of the fastening. Pilot holes are always drilled to facilitate easier installation of the bolt and to prevent splitting of the wood.

Machine bolts require a large washer under both head and nut if used to fasten wood members together. Carriage bolts require a square hole in a metal plate to prevent the bolt from turning. The round head has the advantage of being snag-free and provides a clean appearance.

Screws and bolts commonly used in landscape construction are shown in Table 860-35. To avoid the hazard of protruding

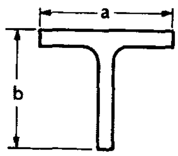
TABLE 860-11. STANDARD GAUGES

GAUGE NO.	US STD. REVISED — For hot and cold rolled steel sheets.		UNITED STATES STANDARD (USS) — For stainless steel and monel metal sheets.		AMERICAN STEEL WIRE OR WASHBURN & MOEN (W & M) — For iron and steel wire.		BROWN AND SHARP (B & S) OR AMERICAN WIRE (AW) — For aluminum, copper, brass, bronze, and nickel silver sheets, strips, and wire. Small sizes in copper and brass tubing.		BIRMINGHAM WIRE (BWG) OR STUBS IRON WIRE — For hot and cold rolled steel strips. Rivets, spring steel, and flat steel wire. Steel, aluminum, bronze, monel stainless, and large size copper and brass tubing.		MACHINE AND WOOD SCREWS — For machine screws and ferrous and non-ferrous wood screws.		GAUGE NO.
	DECIMAL	FRACTION	DECIMAL	FRACTION	DECIMAL	FRACTION	DECIMAL	FRACTION	DECIMAL		DECIMAL	FRACTION	
000	.3750"	3/8"	.3750"	3/8"	.3625"	23/64"	.4096"	13/32"+	.425"	27/64"+	GRAPHIC SIZES DO NOT APPLY TO THIS COLUMN		000
00	.3437"	11/32"	.3437"	11/32"	.3310"	21/64"+	.3648"	23/64"+	.380"	3/8"+			00
0	.3125"	5/16"	.3125"	5/16"	.3065"	5/16"-	.3249"	21/64"-	.340"	11/32"-	.060"	1/16"	0
1	.2812"	9/32"	.2812"	9/32"	.2830"	9/32"	.2893"	19/64"-	.300"	19/64"+	.073"	5/64"-	1
2	.2656"	17/64"	.2656"	17/64"	.2625"	17/64"-	.2576"	1/4"+	.284"	9/32"+	.086"	3/32"-	2
3	.2391"	15/64"+	.2500"	1/4"	.2437"	1/4"-	.2294"	15/64"-	.259"	17/64"-	.099"	3/32"+	3
4	.2242"	7/32"+	.2344"	15/64"	.2253"	7/32"+	.2043"	13/64"+	.238"	15/64"+	.112"	7/64"+	4
5	.2092"	13/64"+	.2187"	7/32"	.2070"	13/64"+	.1819"	3/16"-	.220"	7/32"+	.125"	1/8"	5
6	.1943"	3/16"+	.2031"	13/64"	.1920"	3/16"+	.1620"	5/32"+	.203"	13/64"	.138"	9/64"-	6
7	.1793"	11/64"+	.1875"	3/16"	.1770"	11/64"+	.1443"	9/64"+	.180"	3/16"-	.151"	5/32"-	7
8	.1644"	11/64"-	.1719"	11/64"	.1620"	5/32"+	.1285"	1/8"+	.165"	11/64"-	.164"	11/64"-	8
9	.1495"	5/32"-	.1562"	5/32"	.1483"	9/64"+	.1144"	7/64"+	.148"	9/64"+	.177"	11/64"+	9
10	.1345"	9/64"-	.1406"	9/64"	.1350"	9/64"-	.1019"	7/64"-	.134"	9/64"-	.190"	3/16"+	10
11	.1196"	1/8"-	.1250"	1/8"	.1205"	1/8"-	.0907"	3/32"-	.120"	1/8"-	.203"	13/64"	11
12	.1046"	7/64"-	.1094"	7/64"	.1055"	7/64"-	.0808"	5/64"+	.109"	7/64"	.216"	7/32"-	12
13	.0897"	3/32"-	.0938"	3/32"	.0915"	3/32"-	.0719"	5/64"-	.095"	3/32"+	–	–	13
14	.0747"	5/64"-	.0781"	5/64"	.0800"	5/64"+	.064"	1/16"+	.083"	5/64"+	.242"	1/4"-	14
15	.0673"	1/16"+	.0703"	5/64"-	.0720"	5/64"-	.0571"	1/16"-	.072"	5/64"-	–	–	15
16	.0598"	1/16"-	.0625"	1/16"	.0625"	1/16"	.0508"	3/64"+	.065"	1/16"+	.268"	17/64"+	16
17	.0538"	3/64"+	.0562"	1/16"-	.0540"	3/64"+	.0453"	3/64"-	.058"	1/16"-	–	–	17
18	.0478"	3/64"+	.0500"	3/64"+	.0475"	3/64"+	.0403"	3/64"-	.049"	3/64"+	.294"	19/64"	18
19	.0418"	3/64"-	.0437"	3/64"-	.0410"	3/64"-	.0359"	1/32"+	.042"	3/64"-	–	–	19
20	.0359"	1/32"+	.0375"	1/32"+	.0348"	1/32"+	.0320"	1/32"+	.035"	1/32"+	.320"	5/16"+	20
21	.0329"	1/32"+	.0344"	1/32"+	.0318"	1/32"+	.0285"	1/32"	.032"	1/32"+	–	–	21
22	.0299"	1/32"-	.0312"	1/32"	.0286"	1/32"-	.0253"	1/32"-	.028"	1/32"-	–	–	22
23	.0269"	1/32"-	.0281"	1/32"-	.0258"	1/32"-	.0226"	1/64"+	.025"	1/32"-	–	–	23
24	.0239"	1/32"-	.0250"	1/32"-	.0230"	1/64"+	.0201"	1/64"+	.022"	1/64"+	.372"	3/8"-	24
25	.0209"	1/64"+	.0219"	1/64"+	.0204"	1/64"+	.0179"	1/64"+	.020"	1/64"+	–	–	25
26	.0179"	1/64"+	.0187"	1/64"+	.0181"	1/64"+	.0159"	1/64"+	.018"	1/64"+	–	–	26
27	.0164"	1/64"+	.0172"	1/64"+	.0173"	1/64"+	.0142"	1/64"-	.016"	1/64"+	–	–	27
28	.0149"	1/64"-	.0156"	1/64"	.0162"	1/64"+	.0126"	1/64"-	.014"	1/64"-	–	–	28
29	.0135"	1/64"-	.0141"	1/64"-	.0150"	1/64"-	.0113"	1/64"-	.013"	1/64"-	–	–	29
30	.0120"	1/64"-	.0125"	1/64"-	.0140"	1/64"-	.0100"	1/64"-	.012"	1/64"-	.450"	29/64"	30

Note: Fractional data are provided for reference purposes. Thicknesses should be specified in decimal inches.

Source: Adapted from C. G. Ramsey and H. R. Sleeper, *Architectural Graphic Standards*, 9th ed., Wiley, New York.

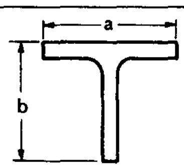
TABLE 860-12. ALUMINUM STRUCTURAL TEES

Shape	Size		
	Flange (a),in	Stem (b), in	Thickness (t), in
	1	1	⅛
	1½	1¼	⅛
	1½	1¼	3/16
	1½	1½	3/16
	1½	1½	¼
	1½	2	3/16
	2*	2	¼
	2	2	5/16
	2¼*	2¼	¼
	2½	1¼	3/16
	2½*	2½	5/16
	2½	3	5/16
	3	2½	5/16
	3*	3	⅜
	4	2	⅜
	4	3	5/16
	4*	4	⅜
	4	5	⅜
	4	5	½
	4½	3	5/16
	5	3	⅜

* Standard shapes normally available from warehouse stocks.

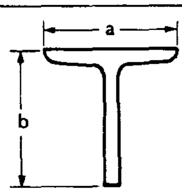
Source: The Aluminum Association, *Engineering Data for Aluminum Structures*, New York, 1986.

TABLE 860-13. STEEL STRUCTURAL TEES

Shape	Width (a),in	Depth(b), in
	3	2½
	3	3
	4	3
	4	4
	5	3½

Source: Adapted from American Institute of Steel Construction, *Manual on Steel Construction*, Chicago, 1980.

TABLE 860-14. STRUCTURAL STEEL TEES CUT FROM "S" SHAPES

Shape	Designation	Width (a),in	Depth(b), in
	ST6 X 17.5	5.078	6.00
	X 15.9	5.000	6.00
	ST5 X 17.5	4.944	5.00
	X 12.7	4.661	5.00
	ST4 X 11.5	4.171	4.00
	X 9.2	4.001	4.00

Source: Adapted from American Institute of Steel Construction, *Manual on Steel Construction*, Chicago, 1980.

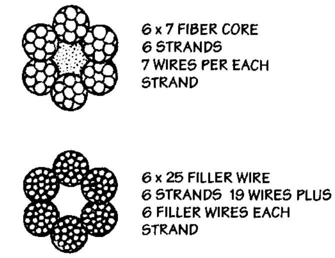


Figure 860-2. Cable (braided wire).

ends, the length should not exceed more than what is necessary.

4.2 Concrete Reinforcing Bars

Reinforcing bars are manufactured out of carbon steel (Figure 860-1 and Table 860-36). Bars can be specified to receive an epoxy coating for use under conditions of high corrosion potential. Refer to Section 830: Concrete for additional discussion of reinforcing bars.

4.3 Welded Wire Fabric

Welded wire fabric is manufactured from carbon steels. It is currently specified according to a revised means of designation (Table 860-37). Refer to Section 830: Concrete for additional discussion of welded wire fabric and its use as concrete reinforcement.

4.4 Cable (Braided Wire)

Specifications for cable refer to a size such as a x b (where a refers to the number of wires in a strand and b to the number of strands in a cable) (Figure 860-2). Table 860-38 shows nominal diameters commonly available. Zinc coatings are available to minimize corrosion. Class A coatings refer to normal protection against corrosion, Class B to intermediate protection, and Class C to highest protection.

Consultation with an engineer is advisable to ensure proper selection of cable whenever strength is an important consideration.

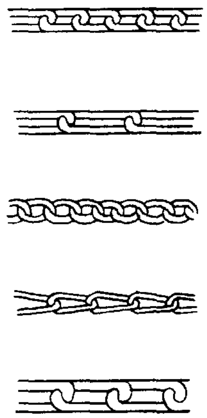
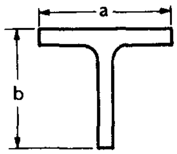


Figure 860-3. Common types of chain.

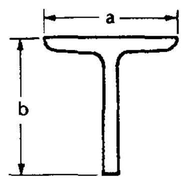
TABLE 860-15. STRUCTURAL STEEL TEES CUT FROM "W" SHAPES

Shape	Designation	Depth(b), in	Flange (a),in
	WT6 X 11	6.155	4.030
	X 9.5	6.080	4.005
	X 8	5.995	3.990
	X 7	5.955	3.970
	WT5 X 9.5	5.120	4.020
	X 8.5	5.055	4.010
	X 7.5	4.995	4.000
	X 6	4.935	3.960
	WT4 X 7.5	4.055	4.015
	X 6.5	3.995	4.000
	X 5	3.945	3.940

* Most commonly used sizes shown here.

Source: Adapted from American Institute of Steel Construction, *Manual on Steel Construction,* Chicago, 1980.

TABLE 860-16. STAINLESS STEEL TEES

	Size		
Shape	Flange (a),in	Stem (b), in	Thickness (t), in
	1¼	1¼	3/16
	1½	1½	3/16
	2	2	¼
	2½	2½	¼
	2½	2½	⅜
	1½	1	3/16
	1¼	2	3/16
	1½	2⅜	3/16
	1	1¼	¼
	2	1¼	¼
	2½	1½	¼
	1½	2	¼
	2½	3	⅜
	3½	4	5/16

Source: Caleb Hornbostel, *Construction Materials,* Wiley, New York, 1978.

4.5 Chain

Metal chain is produced in a variety of styles, sizes, and strengths (Figure 860-3). Chains intended for loading or safety situations should be carefully selected for adequate strength. Products are typically referred to by the number of links per meter (foot), weight per 30 m (100 ft), and tensile strength.

5.0 WELDED JOINTS AND SYMBOLS

Table 860-39 shows the standard symbols used in the USA for indicating the types of welded joints are desired for different types of metal construction that is needed.

AGENCIES AND ORGANIZATIONS

The Aluminum Association, Washington, DC, USA.

The American Society for Testing and Materials (ASTM), Philadelphia, Pennsylvania.

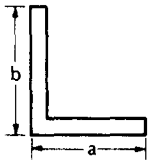
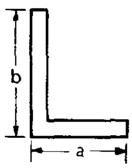
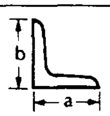
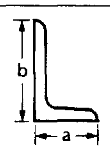
American Iron and Steel Institute (AISI), Washington, DC, USA.

American Welding Society (AWS), Miami, Florida,

The Copper Development Association, Inc., Greenwich, Connecticut, USA.

National Fire Protection Association, Quincy, Massachusetts, USA.

TABLE 860-17. ALUMINUM ANGLES

Shape	Size, in	Size, in	Size, in
	Equal legs, square corners		
	½	1⅛	2
	½	1¼	2
	⅝	1¼	2½
	¾	1½	3
	¾	1½	3
	1	1½	3½
	1	1¾	4
	1	2	
	Unequal legs, square corners		
	¾ × ⅝	2 × ¾	3½ × 2
	1 × ½	2 × 1	3½ × 2½
	1 × ¾	2 × 1	3½ × 3
	1¼ × ½	2 × 1½	4 × 2
	1½ × ½	2½ × 1	4 × 3
	1½ × ¾	2½ × 1½	5 × 3
	1½ × 1	2½ × 2	5 × 4
	1¾ × 1	3 × 1	5¼ × 2¼
	1¾ × 1½	3 × 2	
	2 × ½	3½ × 1¼	
	Equal legs, rounded corners		
	¾	2	5
	1	2½	6
	1¼	3	8
	1½	3½	
	1¾	4	
	Unequal legs, rounded corners		
	¾ × 1¼	2 × 2½	3 × 5
	¾ × 1½	2 × 3	3½ × 5
	1 × 1½	2½ × 3	3½ × 6
	1¼ × 1½	2½ × 3½	4 × 6
	1¼ × 1¾	3 × 3½	6 × 8
	1½ × 2	3 × 4	
	1½ × 2½	3½ × 4	

Source: Adapted from The Aluminum Association, *Engineering Data for Aluminum Structures,* New York, 1986.

REFERENCES

Aluminum Association. Aluminum Standards and Data, *Washington, DC, USA.*

American Iron and Steel Institute. Steel Products Limits, *Washington, DC, USA.*

American Society for Metals. Metals Handbook, *Metals Park, Ohio, USA.*

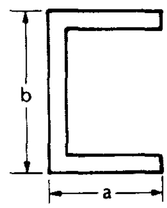
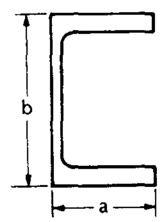
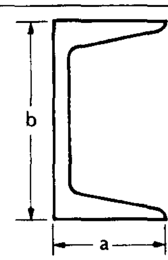
American Society for Testing and Materials. (ASTM) Standards *(published annually), Philadelphia, Pennsylvania, USA.*

American Welding Society. The Welding Handbook, Miami, Florida, USA.

Hornbostel, Caleb. Construction Materials, Types, Uses and Applications, John Wiley & Son, New York 1991.

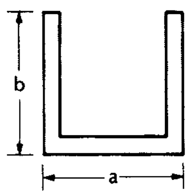
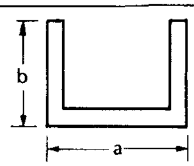
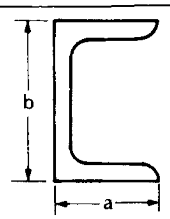
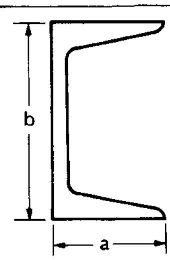
Zahner, L. William. Architectural Metals, A Guide to Selection, Specification and Performance, *John Wiley & Son. New York 1995.*

TABLE 860-18. ALUMINUM CHANNELS

Shape	Size, in	Size, in	Size, in
	Channels, square corners		
	⅜ × ⅜	1¼ × ¾	2½ × ¾
	½ × ⅜	1¼ × 1¼	2½ × 1½
	½ × ½	1½ × ½	2½ × 2½
	½ × ¾	1½ × ⅝	3 × ½
	⅝ × ⅝	1½ × ¾	3 × 1
	⅝ × 1	1½ × 1	3 × 2
	¾ × ⅜	1½ × 1½	3 × 3
	¾ × ½	1¾ × ½	4 × 1½
	¾ × ¾	1¾ × ¾	4½ × 2
	1 × 1½	1¾ × 1	5 × 2
	1 × ¾	2 × ½	
	1 × 1	2 × 1	
	1¼ × ½	2 × 2	
	1¼ × ⅝	2¼ × ⅞	
	Channels, rounded corners		
	2 × 1	5 × 2¾	9 × 3¼
	2 × 1¼	6 × 2½	9 × 4
	3 × 1½	6 × 3¼	10 × 3½
	3 × 1¾	7 × 2¾	10 × 4¼
	4 × 2	7 × 3½	12 × 4
	4 × 2¼	8 × 3	12 × 5
	5 × 2¼	8 × 3¾	
	Channels		
	3 × 1.410	6 × 1.945	9 × 2.430
	3 × 1.498	6 × 2.034	9 × 2.648
	3 × 1.596	6 × 2.157	10 × 2.600
	4 × 1.580	7 × 2.110	10 × 2.886
	4 × 1.647	7 × 2.194	12 × 2.960
	4 × 1.720	7 × 2.299	12 × 3.047
	5 × 1.750	8 × 2.290	12 × 3.170
	5 × 1.885	8 × 2.343	15 × 3.400
	5 × 2.032	8 × 2.435	15 × 3.716
	6 × 1.920	8 × 2.527	

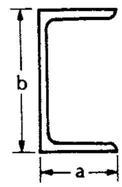
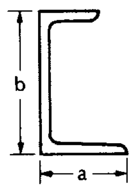
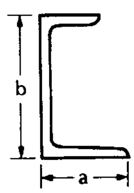
Source: Adapted from The Aluminum Association, *Engineering Data for Aluminum Structures,* New York, 1986.

TABLE 860-19. STEEL CHANNELS, COLD-ROLLED

Shape	Size, in	Size, in	Size, in
	Equal sides, square corners		
	½	1	1½
	¾	1¼	2
	Unequal sides, square corners		
	1 × 1½	1 × 2	
	1½ × 1¾	2 3/16 × 2⅜	
	Channels—bar size		
	¾ × 5/16	1¼ × ½	2 × 9/16
	¾ × ⅜	1½ × ½	2 × ⅝
	⅞ × ⅜	1½ × 9/16	2 × 1
	⅞ × 7/16	1½ × ¾	2½ × ⅝
	1 × ⅜	1½ × 1½	
	1 × ½	1¾ × ½	
	1⅛ × 9/16	2 × ½	
	Channels with designations		
	Designation	**(a)**	**(b)**
	C6 × 8.2	6	1⅞
	× 10.5	6	2
	× 13	6	2⅛
	C10 × 15.3	10	2⅝
	× 20	10	2¾
	× 25	10	2⅞
	× 30	10	3
	C12 × 20.7	12	3
	× 25	12	3
	× 30	12	3⅛

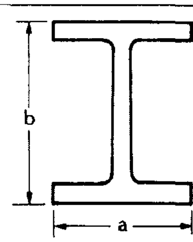
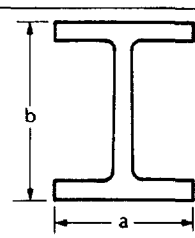
Source: Adapted from Theodore D. Walker, *Site Design and Construction Detailing,* 2nd ed., PDA Publishers, Mesa Arizona, 1986; and C. G. Ramsey and H.R. Sleeper, *Architectural Graphic Standards,* 9th ed., John R. Hoke, ed., Wiley, New York, 1994.

TABLE 860-20. STAINLESS STEEL CHANNELS

Shape	Size, in	Size, in	Size, in
	Equal sides, cold-rolled		
	½	1	1½
	¾	1¼	2
	Unequal sides, cold-rolled		
	⅝ × 5/16	1½ × 1	2 × 1
	¾ × ⅜	1¾ × 1⅛	2⅜ × 2 3/16
	Unequal sides, extruded		
	1 × ½	2 × ¾	4 × 1¾
	1¼ × 1	2½ × ⅝	
	1½ × ½	3 × 1⅜	

Source: Adapted from Caleb Hornbostel, *Construction Materials,* Wiley, New York, 1978.

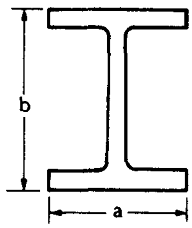
TABLE 860-21. ALUMINUM STRUCTURAL I-BEAMS*

Shape	I-Beam, in		
	American Standard		
	3 × 2.330	5 × 3.000	7 × 3.755
	3 × 2.509	5 × 3.284	8 × 4.000
	4 × 2.660	6 × 3.330	8 × 4.262
	4 × 2.796	6 × 3.443	10 × 4.660
			12 × 5.00
	Aluminum Association Standard		
	3 × 2½	6 × 4	9 × 5½
	4 × 3	7 × 4½	10 × 6
	5 × 3½	8 × 5	12 × 7

* Structural shapes in this table range in web thickness from 0.17 to 0.687 in; flange thickness from 0.257 to 0.653 in; unit weights from 1.96 to 17.28 lb/ft^2.

Source: Adapted from The Aluminum Association, *Engineering Data for Aluminum Structures,* 2d ed., New York, 1986.

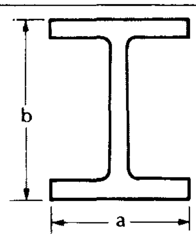
TABLE 860-22. ALUMINUM H-BEAMS, STRUCTURAL WIDE-FLANGE



Shape	Nominal dimensions (in)		
	2 × 2	6 × 4	8 × 8
	2½ × 2	6 × 6	10 × 5¾
	4 × 4	8 × 5¼	
	5 × 5	8 × 6½	

Source: Adapted from The Aluminum Association, *Engineering Data for Aluminum Structures,* 2d ed., New York, 1986.

TABLE 860-23. ALUMINUM ANGLES

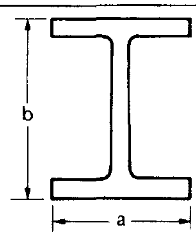


Shape	I-Beams from W shapes, in		
	Designation	Depth (b)	Width (a)
	W8 × 13	8	4
	W12 × 16	12	4
	W14 × 43	13⅝	8
	W14 × 53	13⅞	8
	W14 × 68	14	10
	W14 × 90	14	14½
	W14 × 159	15	15⅝
	W14 × 257	16⅜	16
	W14 × 500	19⅝	17
	W16 × 40	16	7

* Sizes shown here are those within the range typically used for structural columns.

Source: Adapted from American Institute of Steel Construction, *Manual on Steel Construction,* Chicago, 1980.

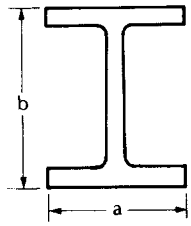
TABLE 860-24. STEEL "S" SHAPES



Shape	S shapes, in		
	Designation	Depth (b)	Width (a)
	S3 × 7.5	3	2½
	S4 × 9.5	4	2¾
	S5 × 14.75	5	3¼
	S6 × 17.25	6	3⅝
	S7 × 20.0	7	3⅞
	S8 × 23	8	4⅛
	S10 × 35	10	5
	S12 × 35	12	5½
	S12 × 50	12	5½
	S15 × 50	15	5⅝
	S18 × 70	18	6¼
	S20 × 75	20	6⅜
	S20 × 95	20	7¼
	S24 × 100	24	7¼
	S24 × 120	24	8

Source: Adapted from American Institute of Steel Construction, *Manual on Steel Construction,* Chicago,

TABLE 860-25. STEEL "M" SHAPES*

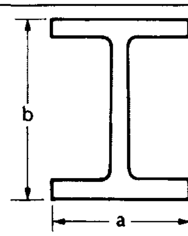


Shape	M shapes, in		
	Designation	Depth (b)	Width (a)
	M4 × 13	4	4
	M5 × 18.9	5	5
	M6 × 22.5	6	6
	M7 × 5.5	7	2⅛
	M8 × 32.6	8	8
	M10 × 9	10	2¾
	M12 × 11.8	12	3⅛
	M14 × 17.2	14	4

* Selected typical range.

Source: Adapted from American Institute of Steel Construction, *Manual on Steel Construction,* Chicago, 1980.

TABLE 860-26. STEEL "HP" SHAPES



Shape	HP shapes, in		
	Designation	Depth (b)	Width (a)
	HP8 × 36	8	8⅛
	HP10 × 57	10	10¼
	HP12 × 74	12⅛	12¼
	HP14 × 102	14	14¾

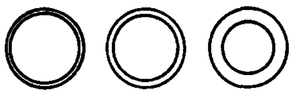
Source: Adapted from American Institute of Steel Construction, *Manual on Steel Construction,* Chicago, 1980.

TABLE 860-27. ALUMINUM PIPE

Shape	Size (diameter), in	Schedule number	Outside diameter, in
	1	5-160	1.315
	1¼	5-160	1.660
	1½	5-160	1.900
	2	5-160	2.375
	2½	5-160	2.875
	3	5-160	3.500
	3½	5-80	4.000
	4	5-160	4.500
	5	5-100	5.536
	6	5-160	6.625

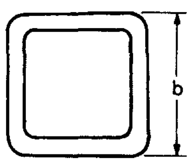
Source: Adapted from Caleb Hornbostel, *Construction Materials,* Wiley, New York, 1978.

TABLE 860-28. STEEL PIPE

Shape	Size (nominal inside diameter), in		
	Standard	Extra strong	Double extra strong
	2.067	1.939	1.503
	2.69	2.323	1.771
	3.068	2.900	2.300
	3.48	3.364	2.728
	4.026	3.826	3.152
	5.047	4.813	4.063
	6.065	5.761	4.897

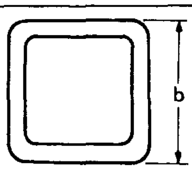
Source: Adapted from American Institute of Steel Construction, *Manual on Steel Construction*, Chicago, 1980.

TABLE 860-29. SQUARE ALUMINUM TUBING

Shape	Sizes, in	Sizes, in	Sizes, in
	½	1	1¾
	⅝	1¼	2
	¾	1½	2½
			3
			4

Source: Adapted from Theodore D. Walker, *Site Design and Construction Detailing*, 2d ed., PDA Publishers, Mesa, Arizona, 1986.

TABLE 860-30. SQUARE STEEL TUBING

Shape	Sizes, in	Sizes, in	Sizes, in
	1	2	4
	1⅛	2½	5
	1¼	3	6
	1½	3½	

Source: Adapted from Theodore D. Walker, *Site Design and Construction Detailing*, 2d ed., PDA Publishers, Mesa, Arizona, 1986.

TABLE 860-31. STAINLESS-STEEL WIRE*

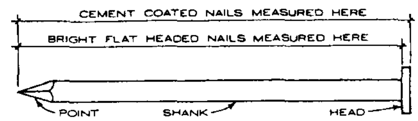
Type of wire	Type of stainless	Tensile strength, lb-ft/in²	Major uses
Cold-drawn	302, 430	90,000–100,000	Nuts, bolts, screws, rivets, and similar products
Weaving	302	70,000–150,000	Wire mesh and cloth
Rope	302	140,000–355,100	Tension members and wire rope

* When obtained in coils, typical sizes range from 0.003 to 0.5 in diameter. When obtained in straight or cut units, typical sizes include 0.03 in and greater.

Source: Adapted from Caleb Hornbostel, *Construction Materials,* Wiley, New York, 1978.

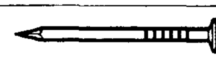
TABLE 860-32. COMMON AND JOIST HANGER NAILS

Common Nails



Length, in	Penny, d	Gauge, #	Diameter of head, in	Number per pound
1	2	15	11/64	847
1¼	3	14	13/64	543
1½	4	12½	¼	296
1¾	5	12½	¼	254
2	6	11½	17/64	167
2¼	7	11½	17/64	150
2½	8	10¼	9/32	101
2¾	9	10¼	9/32	92
3	10	9	5/16	66
3¼	12	9	5/16	66
3½	16	8	11/32	47
4	20	6	13/32	30
4½	30	5	7/16	23
5	40	4	15/32	17
5½	50	3	½	14
6	60	2	17/32	11

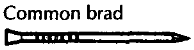
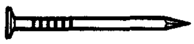
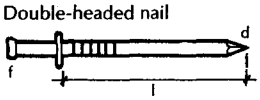
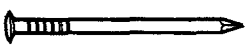
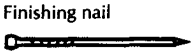
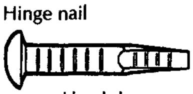
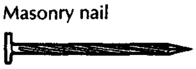
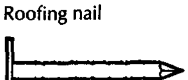
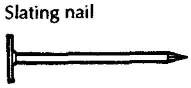
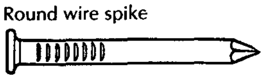
Joist hanger nails



Length, in	Penny, d	Gauge, #	Notes
1¼	8	11	Joist hanger nails are shorter than common nails of the same gauge or penny.
1½	10	9	
2½	16	8	
1¾	20	(0.192)	Annular ring
2½	⅛-in diameter	(0.250)	Annular ring
2⅛	20	(0.192)	Annular ring

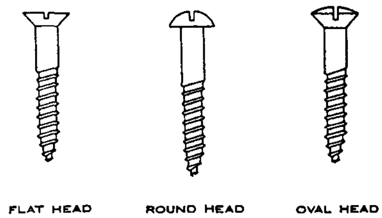
Source: Adapted from C. G. Ramsey and H.R. Sleeper, *Architectural Graphic Standards,* 9th ed., John R. Hoke, ed., Wiley, New York, 1994.

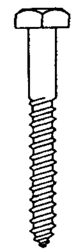
TABLE 860-33. MISCELLANEOUS NAILS

Nail types	Materials	Size: Length (l), in	Penny (d)	Gauge (#)
Cement or concrete nail 	Smooth, bright, oil-quenched	½–3	8–30	10–5
Common brad 	Bright or cement-coated; cupped head available	1–6	2–60	15–2
Common nail 	Steel, plain or zinc-coated	1–6	2–60	15–2
Double-headed nail 	Bright, cement-coated, and made in several designs	1¾–4½	6	11½
Fence nail 	Smooth, bright, cement-coated	1¾–4	8	10
Finishing nail 	Smooth wire; cupped head available	1–4	2–20	15
Hinge nail 	Smooth, bright, or annealed	1½–4 (3⁄16–¼)	—	—
Masonry nail 	High carbon steel, heated and tempered	½–4	10–18	9–7
Roofing nail 	Barbed, bright, or zinc-coated; neoprene washer optional	¾–2½	4–16	8–12
Shingle nail 	Smooth, bright, zinc; cement-coated; light and heavy aluminum	2½–3	4	12
Siding nail 	Steel, zinc-coated (used for fences, gates, etc.)	2½–3	6	11
Slating nail 	Zinc-coated, bright cement-coated, o. copper-clad	1–2	several	several
Round wire spike 	Smooth, bright, or zinc-coated (also in lengths up to 12–16 in)	3–6	(⅜″)–20	(⅜″)–6

Source: Adapted from C. G. Ramsey and H.R. Sleeper, *Architectural Graphic Standards*, 9th ed., John R. Hoke, ed., Wiley, New York, 1994.

TABLE 860-34. WOOD SCREWS AND LAG BOLTS*





Wood screws			Lag bolts		
Diameter	Decimal equivalent, in	Length, in	Diameter	Decimal equivalent, in	Length, in
0	0.063	¼–⅜	¼	0.250	1-6
1	0.073	¼–½	5/16	0.313	1-10
2	0.086	¼–¾	⅜	0.375	1-12
3	0.099	¼–1	7/16	0.438	1-12
4	0.112	¼–1½	½	0.500	1-12
5	0.125	⅜–1½	⅝	0.625	1½–16
6	0.138	⅜–2½	¾	0.750	1½–16
7	0.151	⅜–2½	⅞	0.875	2-16
8	0.164	⅜–3	1	1.000	2-16
9	0.177	½–3			
10	0.190	½–3½			
11	0.203	⅝–3½			
12	0.216	⅝–4			
14	0.242	¾–5			
16	0.268	1-5			
18	0.294	1¼–5			
20	0.320	1½–5			
24	0.372	3-5			

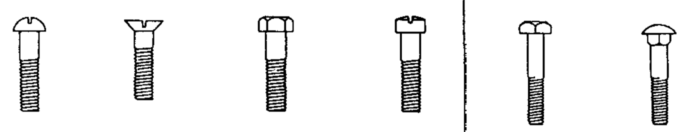
* American Standard sizes by the American Bolt, Nut, and Rivet Manufacturers. Many screws are available in aluminum, brass, copper, stainless steel, monel and bronze.

† Length intervals: 1/8-in increments up to 1 in, 1/4-in increments from 1 1/4 to 3 in and 1/2-in increments from 3 1/2 to 5 in.

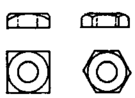
Source: Adapted from C. G. Ramsey and H.R. Sleeper, *Architectural Graphic Standards,* 9th ed., John R. Hoke, ed., Wiley, New York, 1994.

TABLE 860-35. WOOD SCREWS AND LAG BOLTS*

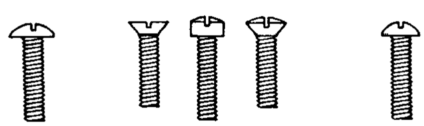
Cap screws: length in					Bolts: length in	
Screw Diameter	Button head	Flat head	Hexagon head	Fillister head	Machine bolt	Carriage bolt
¼	½-2¼	½-2¼	½-3½	¾-3	½-8	¾-8
5/16	½-2¾	½-2¾	½-3½	¾-3¾	½-8	¾-8
⅜	⅝-3	⅝-3	½-4	¾-3½	¾-12	¾-12
7/16	¾-3	¾-3	¾-4	¾-3¾	¾-12	1-12
½	¾-4	¾-4	¾-4½	¾-4	¾-24	1-20
9/16	1-4	1-4	1-4½	1-4	1-30	1-20
⅝	1-4	1-4	1-5	1¼-4½	1-30	1-20
¾	1-4	1-4	1¼-5	1½-4½	1-30	1-20
⅞	—	—	2-6	1¾-5	1½-30	—
1	—	—	2-6	2-5	1½-30	—



Nuts		Set screws			
Square nut	Hexagon nut	Square head diameter	Length	Headless diameter	Length
Nuts are available for all screws and bolts		¼-1	½-5	‡(4)-½	½-5



Machine screws and stove bolts: length, in				
Stove bolt diameter	Machine screw diameter	Round head	Flat head, fillister head, oval head	Oven head
—	2	⅛-⅞	⅛-⅞	—
—	3	⅛-⅞	⅛-⅞	—
—	4	⅛-1½	⅛-1½	—
—	4	⅛-1½	⅛-1½	⅛-¾
⅛	5	⅛-2	⅛-2	⅜-2
—	6	⅛-2	⅛-2	⅛-1
5/32	8	3/16-3	3/16-3	3/16-2
3/16	10	3/16-6	3/16-3	¼-6
—	12	¼-3	¼-3	
¼	¼	5/16-6	5/16-3	⅜-6
5/16	5/16	⅜-6	⅜-3	¾-6
⅜	⅜	½-5	½-3	¾-6
½	½	1-4	—	—



* Stove bolts have wider tolerances than machine screws.

† Length intervals: 1/16-in increments up to 1/2-in, 1/8-in increments from 5/8 to 1 1/4-in, and 1/4-in increments from 1 1/2 to 3 1/2-in, and 1/2-in increments from 3 1/2 to 5 in.

‡ Size 4 screw to 1/2-in diameter

Source: Adapted from C. G. Ramsey and H.R. Sleeper, *Architectural Graphic Standards,* 9th ed., John R. Hoke, ed., Wiley, New York, 1994.

TABLE 860-36. ASTM STANDARD STEEL REINFORCING BARS (NOMINAL DIAMETER)

Bar size designation*	Diameter, in	Weight, lb
#3	0.375	0.376
#4	0.500	0.668
#5	0.625	1.043
#6	0.750	1.502
#7	0.875	2.044
#8	1.000	2.670
#9	1.128	3.400
#10	1.270	4.303
#11	1.410	5.313
#14	1.693	7.650
#18	2.257	13.600

* Bar numbers are based on the number of ⅛ in included in the normal diameter of the bar.

Source: Adapted from Wire Reinforcement Institute, McLean, Virginia, 1963.

TABLE 860-37. WELDED WIRE FABRIC (COMMON STOCK)

New designation[1]	Old designation	Steel area/ft	
Spacing—cross sectional area, in—in²/100	Spacing—wire gauge, in—AS&W	Longitudinal, in	Transverse, in
	Rolls [2,3,4]		
6 × 6—W1.4 × W1.4[5]	6 × 6—10 × 10	0.028	0.028
6 × 6—W2.0 × W2.0[5]	6 × 6—8 × 8[6]	0.040	0.040
6 × 6—W2.9 × W2.9[5]	6 × 6—6 × 6	0.058	0.058
6 × 6—W4.0 × W4.0	6 × 6—4 × 4	0.080	0.080
4 × 4—W1.4 × W1.4	4 × 4—10 × 10	0.042	0.042
4 × 4—W2.0 × W2.0	4 × 4—8 × 8[6]	0.060	0.060
4 × 4—W2.9 × W2.9	4 × 4—6 × 6	0.087	0.087
4 × 4—W4.0 × W4.0	4 × 4—4 × 4	0.120	0.120
	Sheets [3,4]		
6 × 6—W2.9 × W2.9	6 × 6—6 × 6	0.058	0.058
6 × 6—W4.0 × W4.0	6 × 6—4 × 4	0.080	0.080
6 × 6—W5.5 × W5.5[7]	6 × 6—2 × 2[8]	0.110	0.110
4 × 4—W4.0 × W4.0	4 × 4—4 × 4	0.120	0.120

[1] Method of designating:

WWF 6 × 12 − W16 × W26
WWF 6 in = longitudinal wire spacing
12 in = transverse wire spacing
W16 = longitudinal wire size
W26 = transverse wire size

[2] Welded mesh comes in rolls: 150-, 200-, and 300-ft lengths.

[3] Widths vary from 56 to 72 inches in 2-inch increments and from 84 to 96 inches in 3- and 4-inch increments.

[4] Tensile strength: 70,000–80,000 psi.

[5] Most commonly used sizes.

[6] Exact W-number size for 8 gauge is W2.1.

[7] No. 2 gauge and larger comes only in sheets.

[8] Exact W-number size for 2 gauge is W5.4.

Source: Adapted from Wire Reinforcement Institute, McLean, Virginia, 1963.

TABLE 860-38. CABLE (BRAIDED WIRE)

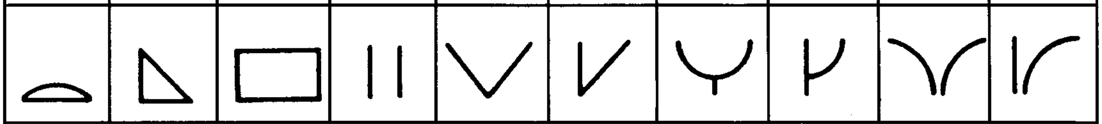
Nominal diameter, in	Weight, lb/ft	Nominal diameter, in	Weight, lb/ft				
3/8	0.24	1 1/2	3.82	13/16	1.10	2 3/4	12.74
7/16	0.32	1 5/8	4.51	7/8	1.28	3	15.11
1/2	0.42	1 3/4	5.24	15/16	1.47	3 1/4	18.00
9/16	0.53	1 7/8	6.03	1	1.67	3 1/2	21.00
5/8	0.65	2	6.85	1 1/8	2.11	3 3/4	24.00
11/16	0.79	2 1/4	8.66	1 1/4	2.64	4	27.00
3/4	0.95	2 1/2	10.60	1 3/8	3.21		

Source: Adapted from Caleb Hornbostel, *Construction Materials,* Wiley, New York, 1978.

TABLE 860-39. WELDED JOINTS (STANDARD SYMBOLS)

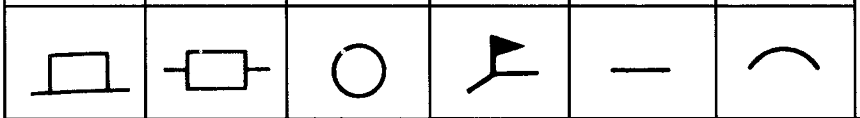
BASIC WELD SYMBOLS

BACK	FILLET	PLUG OR SLOT	GROOVE OR BUTT						
			SQUARE	V	BEVEL	U	J	FLARE V	FLARE BEVEL

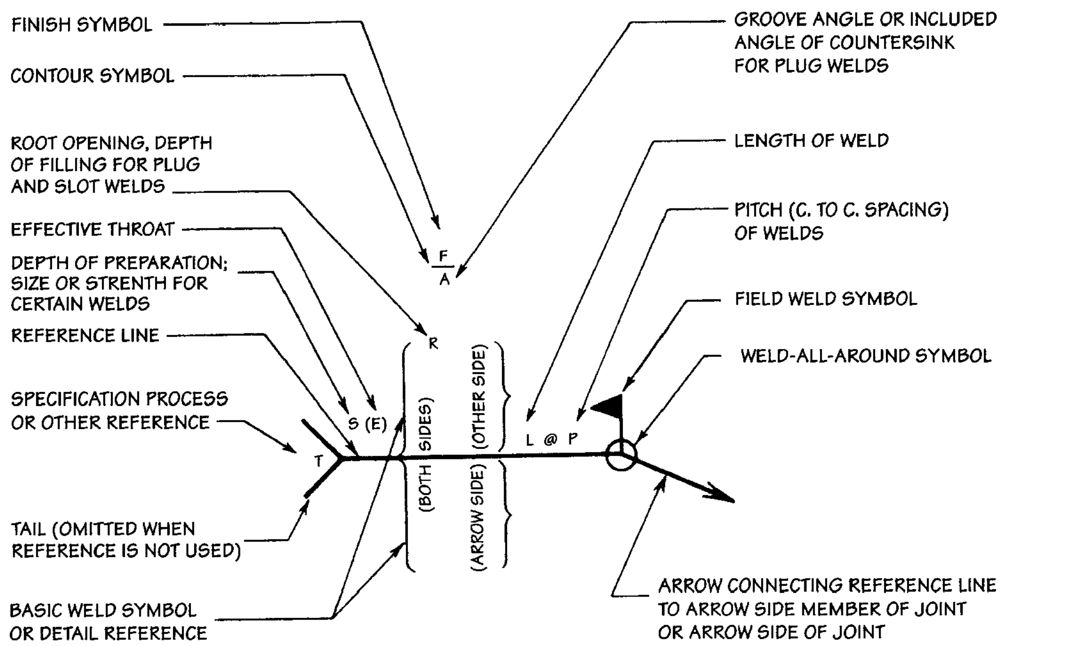


SUPPLEMENTARY WELD SYMBOLS

BACKING	SPACER	WELD ALL AROUND	FIELD WELD	CONTOUR		
				FLUSH	CONVEX	FOR OTHER BASIC AND SUPPLEMENTARY WELD SYMBOLS, SEE AWS A2.4-86

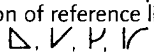


STANDARD LOCATION OF ELEMENTS OF A WELDING SYMBOL



Note:

Size, weld symbol, length of weld and spacing must read in that order from left to right along the reference line. Neither orientation of reference line nor location of the arrow alters this rule.

The perpendicular leg of  weld symbols must be at left.

Arrow and Other Side welds are of the same size unless otherwise shown. Dimensions of the fillet welds must be shown on both the Arrow Side and the Other Side Symbol.

Flag of field-weld symbol shall be placed above and at right angle to reference line of junction with the arrow.

Symbols apply between abrupt changes in direction of welding unless governed by the "all around" symbol or otherwise dimensioned.

These symbols do not explicitly provide for the case that frequently occurs in structural work, where duplicate material (such as stiffeners) occurs on the far side of a web or gusset plate. The fabricating industry has adopted this convention: that when the billing of the detail material discloses the existence 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.

Source: American Institute of Steel Construction

Plastics and Glass

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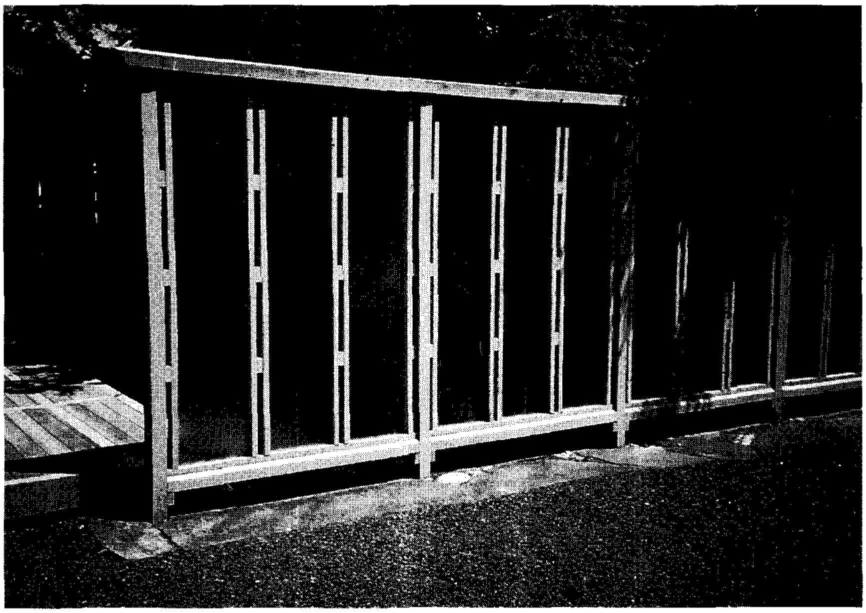


Kyle D. Brown

CONTENTS

1.0 INTRODUCTION

This section describes two groups of materials: plastics and glass. In the past use of these two materials in terms of landscape design and construction has been very limited. More recently, there has been a surge of interest and use of these materials. This is particularly true of products and devices made out of a variety of types of plastics or combinations (reinforced plastics with fiber glass) and laminates, etc. These uses overlap several topical sections such as Sections: 330, 450, 460, 510, 540, etc.) and a few sections of Divisions 800: Materials and 900: Details and Devices. Refer to Table 870-7 for more information on these overlaps.

Manufacturers of these materials and products made from them should be consulted for suggestions on how to use one or more of their materials and products. Typically, they offer data on the range of shapes, sizes, finishes, products, product and installation specifications.

2.0 PLASTICS

Plastic have become important material for both construction and manufacturing of special products used in the landscape primarily because of their moisture and corrosion resistance, toughness, malleability, and light weight.

Basically, plastic is a synthetic or man-made material made up of giant molecules built around a carbon or a silicon atom. There are many terms used to identify different types of plactic. Some of the better known terms are vinyls (such as polyvinyl choloride or PVC), acrylics , and polyesters (often reinforced by fiber glass). More simply they can be categorized into two basic groups as a function of how they are made and their response to heat:

Thermoplastics soften with exposure to heat and harden when cooled (like candle wax). This process can be repeated any number of times.

Thermosets are plastic materials which are heated, shaped and then they cool and harden into a permanent set. Repeated exposure to temperatures above the normal air temperatures will cause gradual chemical decomposition, brittleness, etc.

2.1 Properties of Plastics:

Tensile Strength: Most plastics are similar to wood in terms of tensile strength. Laminates and reinforced plastics offer greater strength, a few of which exceed the strength of steel, especially on a strength-to-weight basis (Table 870-1). Fiberglass-reinforced plastics (FRPs) have the highest tensile strengths.

Stiffness: In construction, stiffness is often more important than strength. Thermosets are slightly stiffer than thermoplastics, and reinforced plastics are the stiffest of all. Most are roughly comparable to wood, although the stiffness of some high-performance composites approaches that of aluminum or steel.

Toughness: Toughness is generally expressed in terms of the ability to resist impact. Plastics (and different formulations of the same plastic) can vary widely in impact resistance.

Hardness: Plastics scratch more easily than glass or steel, but some types of plastic may be more resistent to wear (e.g., as bearings) and may be superior to steel. Their resistance to indentation is usually better than that of commonly used wood species across the grain, but some soft plastics are easily indented.

Expansion and Contraction: Thermal expansion is characteristically high in plastics. Thermosets expand less than thermoplastics. Reinforced plastics and laminates expand the least and are nearly comparable to aluminum. Expansion joints are necessary when materials of widely different expansion rates are abutt or are joined.

Corrosion Resistance: Plastics vary in their resistance to attack by chemical reagents. Generally speaking, a plastic can be found to resist any common chemical. Fluorocarbons are the most inert and are susceptible to attack by only the most powerful reagents. Other plastics are susceptible to only selective action by particular chemicals.

2.2 Basic Types of Plastics

Many kinds of plastic materials are commercially available. Table 870-2 describes those commonly available and their typical uses.

2.3 Plastic Formats

Plastic is available in a variety of formats. Tables 870-3 through 870-6 give commonly available sizes and important characteristics.

Sheet Plastic: The availability of sheet plastics varies between manufacturers. Special orders are sometimes possible (Table 870-3).

Corrugated Plastic Sheets: These are made of fiberglass or non-reinforced plastic and are typically used for roofing applications although they can be used for other non-structural purposes such as panels for fences, screens or free-standing walls as in Sec. 450. These products are often rated for strength, fire resistance, and other characteristics (Table 870-4).

Rigid Plastic Pipe: These are made of polyvinyls and chloride (PVC) and when a stablizer is added it prevents or retards degradation of the plastic due to exposure to sunlight and other environmental conditions. Is commonly used in drainage, irrigation, pools and fountain applications (Table 870-5).

Flexible Tubing: This is commonly used to protect underground wires and in irrigation applications (Table 870-6).

2.4 Plastic Products.

870-7 shows the range of types of plastic products that are becoming available for a variety of purposes which overlap several other sections of this handbook. It is expected that many more will be developed and become widely used as the possibilities and benefits of using plastic become better understood.

Manufacturers of plastic materials and products should be consulted for suggestions on how to use one or more of their materials and products. Typically, they offer data on the range of shapes, sizes, finishes, products, product and installation specifications.

KEY POINTS: Plastics

1. Most plastics are similar to wood in terms of tensile strength and stiffness. Laminates and reinforced plastics offer greater strength, a few of which exceed the strength and stiffness of aluminum and steel, especially on a strength-to-weight basis
2. When two types of plastic, or plastic and another material are joined together, expansion joints are necessary if materials have widely different expansion rates.
3. Plastics scratch more easily than glass or steel, but some resist wear (e.g., plastic bearings) and may be superior to steel.

Table 870-1. SELECTED PROPERTIES OF PLASTICS

Plastic	Tensile strength lb/in²	Compressive strength lb/in²	Impact strength ft-lb/in notch	Resistance to heat, continuous, °F	Effect of sunlight	Clarity	Machining qualities
Acrylonitrile-butadiene-styrene (ABS)	4000–8000	7000–22,000	1.0–10	140–230	None to slight yellowing	Translucent to opaque	Good to excellent
Acrylic (PMMA)	7000–11,000	11,000–19,000	0.3–0.5	140–200	None	Excellent to opaque	Fair to excellent
Cellulosics, (CA, CAB, CAP, CN, CP, EC)	2000–9000	2000–36,000	0.4–8.5	115–220	Slight to discoloration, embrittlement	Transparent to opaque	Good to excellent
Epoxies (EP)	4000–30,000	1000–40,000	0.2–10	200–550	None to slight	Transparent to opaque	Poor to excellent
Fluoroplastics, (FEP, PCTFE, PTFE, PVF)	2000–7000	1700–10,000	3.0 to no break	300–550	None to slight bleaching	Transparent to opaque	Excellent
Melamine-formaldehyde (MF)	5000–13,000	20,000–45,000	0.24–6	210–400	Slight to darkening	Translucent to opaque	Fair to good
Nylon polyamide (PA)	7000–35,000	6700–24,000	1.0–5.5	175–400	Slight discoloration	Translucent to opaque	Fair to excellent
Phenol-formaldehyde/ phenolics (PF)	3000–18,000	10,000–70,000	0.2–18	200–550	Darkens	Transparent to opaque	Poor to good
Polycarbonate (PC)	8000–20,000	12,500–19,000	1.2–17.5	250–275	Slight color change	Transparent to opaque	Fair to excellent
Polyesters	800–50,000	12,000–50,000	0.2–16.0	250–450	None to slight yellowing, embrittlement	Transparent to opaque	Poor to excellent
Polyethylene (PE)	1000–5500	— to 5500	0.5–2.0 to no break	180–275	Unprotected crazes fast, weather resistance available	Transparent to opaque	Fair to excellent
Polypropylene (PP)	2900–9000	3700–8000	0.5–20.0	190–320	Unprotected crazes fast, weather resistance available	Transparent to opaque	Fair to good
Polystyrene (PS, SAN, SBP, SRP)	1500–20,000	4000–22,000	0.25–11.0	140–220	Slight yellowing	Excellent to opaque	Fair to good
Silicones (SI)	800–35,000	100–18,000	— to 15	400–>600	None to slight	Clear to opaque	Fair to good
Urea-formaldehyde (UF)	5500–13,000	25,000–45,000	0.25–0.40	170	Pastels, gray	Transparent to opaque	Fair
Urethanes (UP)	175–10,000	20,000	5 to flexible	190–250	None to yellowing	Clear to opaque	Fair to excellent
Vinyls (PVAc, PVAI, PVB, PVC, PVCAc, PVFM)	500–9000	1000–22,000	0.4–20 (impact strength varies with type and amount of plasticizer)	120–210	Slight	Transparent to opaque	Poor to excellent

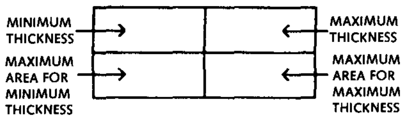
Source: Albert G. H. Dietz, *Plastics for Architects and Builders,* The MIT Press, Cambridge, Mass., 1969.

Table 870-2. TYPES OF PLASTICS

Thermoplastics	
Acrylics (PMMA)	Common trade names in the United States include Lucite and Plexiglas. They are transparent, break-resistant, and weather-resistant. They scratch easily and soften at 200°F (90°C). Uses include skylights and roof domes, glazing, lighting fixtures, clear or corrugated sheets for roofing, films or sheets bonded to wood or metal for exterior finishes, and molded pieces of hardware.
Acrylonitrile-Butadiene-Styrene (ABS)	Copolymers noted for toughness, chemical resistance, nonbrittleness at low temperatures, rigidity, and tensile strength. Typically used for piping and pipe fittings; water and gas supply lines for drain, waste, and vent systems.
Cellulosics (CA, CAB, CAP, CN, CP, EC)	Transparent (cellulose acetate) but optical properties are not as good as acrylics. Remarkably tough and withstand rough handling, but not all are suited for prolonged outdoor exposure. Primarily used in photographic film and recording tape, but also for piping and pipe fittings, outdoor-lighting fixtures, and handrailings.
Fluorocarbons (FEP, PCTFE, PTFE, PVF)	Very inert, high thermal stability (450 to 500°F) (230 to 260°C) and excellent resistance to chemical attack. Used in piping for highly corrosive chemicals at high temperatures; for low friction slider pads to permit movement in steam lines; and as nonstick linings for pots and pans (Teflon).
Nylon/polyamide (PA)	A common name for a group of plastics called polyamides. Molded nylons are tough, with high strength, good chemical resistance, and good shear resistance, but not good weather resistance. Nylon fabric uses include sails, parachutes, and air-supported structures.
Polyethylene (PE)	Waxy, chemically inert, flexible at low temperatures, and good water or vapor barrier, but untreated polyethylene deteriorates in sunlight. Used for vapor barriers in building construction, wire and cable insulation, and for certain types of piping (e.g., cold water, gas, and chemicals). Not suitable for conditions involving high temperatures or extremely corrosive chemicals.
Polystyrene (PS, SAN, SBP, SRP)	Brittle, weathers poorly, and begins to soften at about 212°F (100°C). It is transparent, has a wide range of colors, and is water-resistant. Used for lighting fixtures and various molded pieces of hardware. Expanded (foamed) polystyrene is used in construction for insulation, as well as for core material in the manufacture of doors and sandwich panels.
Vinyls (PVAc, PVA1, PVB, PVC, PVCAc, PVFM)	Have a wide range of properties ranging from flexible film to rigid pipe. Most possess good strength and toughness, fair chemical resistance, and low water absorption. They do not perform well at high temperatures, and some may soften at 130°F (55°C), but some are suitable for outdoor exposure (e.g., polyvinyl chloride). Used to produce sheet and tile flooring; gutters and downspouts; moldings; clapboards and siding; window frames; piping and drainage systems. In sheet form it is used for facings in sandwich construction and is bonded to wood or metal for exterior building finishes, doors, and window frames.
Thermosets	
Epoxy (EP)	Remarkable adhesive strength, chemical resistance, and water resistance. Used for bonding metal, glass, masonry, and other plastics; in coating compounds and adhesives; and as protective coatings. Also can be mixed with mineral aggregate or plastic chips to produce terrazzo.
Melamine-Formaldehyde/Urea-Formaldehyde (MF, UF)	Both are classified as amino plastics and have similar properties: hard, relatively dimensionally stable, and available in a wide color range. Melamine is mainly used in high-pressure laminates for countertops and cabinet finishes, as adhesives for plywood, and as a protective treatment for fabrics and paper.
Phenol-Formaldehyde/Phenolics (PF)	Low-cost plastic limited to dark colors, strong, and both electrical- and heat-resistant. Pure phenolics are brittle and hard, but mixing with fillers improves their impact resistance. In molded form, they are used for electrical parts and hardware items. As foamed insulation, they are used as the core for sandwich panels and around piping and ducts. Resins are used to form high-pressure laminations.
Silicones (SI)	Stable compounds of high corrosion resistance, electrical resistance, a wide service range of temperatures (−80 to 500°F) (−60 to 260°C), and resistance to weathering. Applied to masonry as a water-repellent, sealant, and retardant to weathering.
Urethane/Polyurethane (UP)	Used primarily as low-density foams for either soft, flexible, open-cell types or tough, rigid, closed-cell types. Resistant to heat, chemicals, and fire (when properly formulated, but smoke may be severe). Uses include building insulation and as the core material in sandwich panels. Flexible urethane foams are used for cushions, upholstery, and padding.
Composites	
	Simple one-component plastics sometimes do not have all the properties necessary for specific applications. Plastics are often combined with other materials to produce a product with properties not inherent in the individual materials themselves. Three principal types of composite plastic products include laminates, reinforced plastics, and sandwiches.

Table 870-3. SHEET PLASTIC TYPES AND SIZES *†

KEY:



Plastic type	Clear		Tinted		Reflective coated	Opaque ceramic frit	Patterned	
Acrylic, sheet	0.060	4½	Same as clear		Same as clear	Available in some colors		
	24 × 36	120 × 144						
Polycarbonate, sheet	3/32	½	0.06	¼		Available in some colors	0.125	0.250
	72 × 96	96 × 96	36 × 48	120 × 144				72 × 96
Acrylic polycarbonate, double-skin	⅛	58	Same as clear					
	48 × 96	48 × 144+						
Acrylic polycarbonate, laminates	1	1¼	Same as clear					
	48 × 96							
Reinforced	3/32	3/16	Same as clear					
	44 × 96							

* Maximum sizes are available from one or more manufacturers; larger sizes and/or additional material variants may be available on request. Larger sizes may be approved by UL on special request.

† Strength values given are average and for short-term loading; they may vary from manufacturer to manufacturer and from product to product; check with manufacturer also for long-term and cyclic loads.

Source: Sweet's Division, *Building Product Selection Data,* McGraw-Hill, New York, 1984.

Table 870-4. CORRUGATED PLASTIC SHEETING TYPES AND SIZES

Type		Slope, minimum, in/ft	Maximum span, in*	Width	Length	Weight or thickness, oz/ft²	Exposure or lap	General notes
Corrugated fiberglass, reinforced plastic	1¼-in corrugations, ¼-in deep	3	40–22	26 in (maximum 50 in)	4–39 ft	5, 6, 8	1, 1½, or 2 corrugation side lap. 6-in minimum end lap	Self-tapping screws, drive screws and nails. All with neoprene washers
	2½-in corrugations, ½-in deep		65–32	26 in (maximum 50 in)	4–39 ft	4, 5, 6, 8, 10, 12		(a) Weight: approximately 40 lb/ft²
	4.2-in corrugations, 1 1/16-in deep		72–50	42 in; 50⅝ in	4–39 ft	5–12		(b) Color and texture: many colors nslucent to opaque, smooth or pebble finish
	2.67-in corrugations, ⅞-in deep		70–42	50 in	4–39 ft	5–12		(c) Fastener: self-tapping screws. Drive screws and nails with neoprene washers
	5-V crimp, 1-in deep		65–32	26 in	4–39 ft	5–8		
	5.3-V crimp, 1-in deep		84–60	41⅝ in; 45 in	4–39 ft	5–12		
Corrugated plastic, nonreinforced plastic	2.67-in corrugations, 9/16-in deep	1	70–42	50½ in	8, 10, 12, 15, 20 ft	5–8	1 corrugation side lap. 8-in minimum end lap	

* For 15–40 lb/ft².

Source: C.G. Ramsey and H.R. Sleeper, *Architectural Graphic Standards, 9th ed.,* John R. Hoke ed., Wiley, New York, 1994.

Table 870-5. SCHEDULE 80 RIGID PVC PIPE SIZES

Nominal pipe size, in	½	¾	1	1¼	1½	2	2½	3	4
Actual inside diameter	.546	.742	.957	1.278	1.500	1.939	2.323	2.900	3.826
Actual outside diameter	.840	1.050	1.315	1.660	1.900	2.375	2.875	3.500	4.50

Source: Theodore D. Walker, *Site Design and Construction Detailing,* 2d ed., PDA Publishers, Mesa, Arizona, 1986.

3.0 GLASS

Glass is seldom used in any major way related to landscape design and construction. Depending on its proposed use, local and/or national codes may effect how it can be used. Before using any glass material it is important to determine whether and which codes apply? In the United States, the Consumer Product Safety Commission (CPSC) Standards and local building code regulations should be consulted. Glass products seem to incur higher rates of vandalism than most other materials.

3.1 Properties of Glass

Glass has several properties that permits it to be used fir a variety of purposes. Few of these are applicable to landscape design and construction. These properties are listed very briefly here. More technical information should be sought from the manufacturing associations or manufacturers of glass and glass-based products.

Table 870-6. 125 PSI FLEXIBLE POLYETHYLENE TUBING SIZES

Nominal pipe size, in	½	¾	1	1¼	1½	2
Actual inside diameter	.622	.824	1.049	1.380	1.610	2.067
Actual outside diameter	.711	.942	1.199	1.577	1.840	2.364

Source: Theodore D. Walker, *Site Design and Construction Detailing,* 2d ed., PDA Publishers, Mesa, Arizona, 1986.

Optical Properties. The transmission of visible light varies with the type or treatment of the glass or its surface.

Mechanical Properties. While standard sheet glass cannot withstand bending or impacts some special glass units, such as glass blocks, can resist high compression which makes it useful in a variety of applications related to outdoor uses.

Chemical Properties. Glass is inert, durable, nonporous, nonabsorptive, and resistant to weathering and corrosion. It can be acid-etched or sand blasted for greater obscurity for decorative purposes.

Thermo Properties. All types of glass expand and contract depending on their color and whether theyt reflect or absorb solar energy. When two types of glass or glass and another material are joined together, the expansion rates of each material must be closely matched to minimize stress and to avoid possible breakage.

Table 870-7. RANGE OF PLASTIC PRODUCTS AVAILABLE FOR LANDSCAPE DESIGN & CONSTRUCTION

Types of uses by sections in this book	Types of products	General comments
330: Stormwater Management	drain covers drain pipes	in lieu of cast metals, stone, etc. in lieu of clay or iron
450: Fences, Screens	panels & decorative elements structural elements	in lieu of wood,stone, etc. in lieu of wood,metal, etc.
460: Decks & Broadwalks	decking, railings, seats, etc.	in lieu of wood, metal, etc.
470: Pedestrian Bridges	decking and railings	in lieu of wood, metal, etc.
510: Site Furniture, etc.	signs, benches, lights, shelters	in lieu of wood, metal, etc.
530: Pools and Fountains	plumbing & fountain elements	in lieu of metal
540: Outdoor Lighting	Light fixtures, supports, etc.	in lieu of metal, etc.
550: Plants & Planting	Plant contains, tree grates, etc.	in lieu of clay, metal, wood
610: Roof & Deck Landscapes	decking, railings, seats, etc.	in lieu of wood, metal, etc.
620: Interior Landscapes	seating, plant contains, etc.	in lieu of wood, metal, etc.
850: Wood		(as an alternative to wood lumber, posts, panels, etc.)
860: Metals		(as an alternative to metal pipes, beams, posts, panels, etc.)
Div. 900: Details & Devices		(as an alternative to many materials shown in this Division.)

3.2 Basic Types and Sizes

Flat Glass: Basic types of glass are flat, commercial glass include sheet, float, and plate. All of these are rarely used within landscape designs and construction.

Glass Block: This type of glass product allows light to pass through but not with a clear view. The images seen through glass blocks are normally beautifully distorted and repeated with slight variations from block to block. If the images are moving, such as a person walking by, it results in beautiful rythmic abstract patterns rippling along the length of the wall of glass blocks. Table 870-8 gives information on various types, sizes and construction properties of glass block. See Section 840: Masonry for additional information on masonry construction.

3.3 Special Types of Flat Glass

Patterned Glass: This is a glass that has a linear or geometric pattern pressed onto one or both sides of the glass to obscure vision. Acid etching or sandblasting will also create greater obscurity. Patterned glass is available in a wide range of textures and patterns, primarily in thicknesses of 3 mm (1/8 in) and 5 mm (7/32 in). Table 870-9 provides information on types and sizes.

Wired Glass: Is glass is made with wire mesh or parallel wires rolled into the center of the glass to hold the glass together under low levels of impact or excessive

Table 870-8. GLASS BLOCK

	Nominal sizes available*		Approximate weight (lb)	Compressive strength (psi)	Maximum recommended panel size	Light transmission, %	Remarks †
	4-in thick	3-in thick					
Single cavity							
Clear	6 × 6 8 × 8 12 × 12	6 × 6 3 × 6 8 × 8 4 × 8 12 × 12 4 × 12 6 × 8	Installed	400–600	Exterior: consult manufacturer	75	Corner pieces 6 × 6 size only. Consult manufacturer for minimum radius for curved construction.
Clear with reflective coating	8 × 8 12 × 12	Not available	20 psf (4 in)	400–600		5–20	Gold, bronze, or gray coating on one or both sides (for solar heat gain control).
Light-diffusing patterned	8 × 8 12 × 12	Not available	15 psf (3 in)	400–600	Interior: 144 ft² 25 ft high	39	Provides maximum quantity of diffused light (for glare control, privacy).
Decorative patterned (two-way fluted, semi-clear, etc.)	6 × 6 3 × 6 8 × 8 4 × 8 12 × 12 4 × 12	6 × 6 3 × 6 8 × 8 4 × 8 12 × 12 4 × 12 6 × 8	Consult manufacturer for individual block weights	400–600		20–75	Consult manufacturer for specific patterns.
Double cavity							
Light diffusing patterned	8 × 12 12 × 12	Not available	Same as single cavity	400–600	Same as single cavity	28	Double cavity formed by fibrous glass insert; white or colors (for glare and heat transmission control).
Decorative patterned (two-way fluted, semiclear, etc.)	6 × 6 3 × 6 8 × 8 4 × 8 12 × 12 4 × 12	Not available	Same as single cavity	400–600	Same as single cavity	43	Consult manufacturer for specific patterns (for heat transmission control).
Solid							
Clear	5 × 5 × 2⅝ 8 × 8 × 3 3 × 8 × 3¾ Round: 6½ diameter × 2		6 15 6 —	80,000	Consult manufacturer	80	Consult manufacturer for information concerning anchors, stiffeners, expansion strips, mortars, reinforcement, etc., for all block types.

* Check with manufacturers for exact dimensions, especially solid block.
† Mortar joints for glass block construction are typically ¼ in (6 mm).
Source: Sweet's *Building Product Selection Data,* McGraw-Hill, New York, 1984.

heat. Wired glass is generally produced in 6 mm (1/4 in) thickness only. Table 870-10 provides information on types and sizes.

3.4 Surface Finishes

Glass in any format can be given various surface treatments during manufacture or afterwards. The techniques for doing this require both a technical knowledge and artistic tastes. Listed below are the three most common finishes:

Etching: Certain acids can produce varying degrees of transparency in glass, from a semipolished, translucent quality to a nearly opaque, frosted appearance. Etching reduces the strength of sheet glass.

Sandblasting: This method usually gives a coarser appearance than acid etching and can reduce the strength of glass by as much as 50 percent.

Enameling: Glass can be coated with vitreous enamels in translucent and solid colors and then fired at high temperatures. The firing process partially tempers the glass and makes it stronger.

KEY POINTS: Glass

1. When two types of glass, or glass and another material are joined together, the expansion rates of the materials must be closely matched to minimize stress differentials and avoid possible breakage.
2. Table 870-8 gives information on various types, sizes, and construction properties of glass block. Refer to Section 840: Masonry for discussion of masonry construction.
3. Etching and sandblasting the surface finish can reduce the strength of the glass, while enameling strengthens the glass through partial tempering during the firing process.

AGENCIES AND ORGANIZATIONS

Government Agencies

Consumer Product Safety Commission (CPSC), Bethesda, Maryland (or nearest regional office)

National Bureau of Standards (NBS), U.S. Department of Commerce

Standards Development Services Section, Washington, D.C.

Table 870-9. PATTERNED GLASS TYPES AND SIZES

Product	Type	Thickness, in	Maximum area, in*	Weight, lb/ft²	Visible light transmission, %
Patterned glass	Floral				
	Hammered	⅛	60 × 132	1.60–2.10	80–90
	Stippled				
	Granular				
	Ribbed				
	Fluted	7/32	60 × 132	2.40–3.00	80–90
	Striped†				

* Maximum area varies according to producer; larger sizes may be available from some producers.

† These are just a few of the most common patterns available; many patterns are patented and made by one producer only.

Source: Adapted with permission from Harold B. Olin, J. L. Schmidt, and W. H. Lewis, *Construction: Principles, Materials, and Methods,* U.S. League of Savings Institutions, Chicago, 1983.

Table 870-10. WIRED GLASS TYPES AND SIZES

Product	Type	Thickness, in	Maximum area, in*	Weight, lb/ft²	Visible light transmission, %
Wired glass	Polished (square or diamond mesh)	¼	60 × 144	3.50	80–85
	Patterned (square or diamond mesh)	¼	60 × 144	3.50	80–85
	Parallel wired*	7/32	54 × 120	2.82	80–85
		¼	60 × 144	3.50	80–85
		⅜	60 × 144	4.45	80–85

* This type of wired glass does not carry Underwriter's Laboratory, Inc. fire-retardant rating; it is used mainly for decorative partitions.

Source: Adapted with permission from Harold B. Olin, J. L. Schmidt, and W. H. Lewis, *Construction: Principles, Materials, and Methods,* U.S. League of Savings Institutions, Chicago, 1983.

Private Institutes and Agencies

American National Standards Institute (ANSI), New York, New York

American Society for Testing and Materials (ASTM), Philadelphia, Pennsylvania

Construction Specifications Institute (CSI), Washington, D.C.

Glass

Building Officials and Code Administrators International (BOCA), Country Club Hills, Illinois

National Glass Association (NGA), McLean, Virginia, (21 regional groups)

Plastics

National Association of Plastic Fabricators (NAPF), Washington, D.C.

Society of the Plastics Industry (SPI), New York, New York

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SECTION 880

Geotextiles

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1.0 INTRODUCTION

Geotextiles and their associated products (geogrids, composite drains, geo-cells, and grid or fiber soil reinforcement) allow landscape architects to improve the basic properties of soils. With geotextiles one can increase bearing capacity, facilitate drainage, decrease erosion, and prevent the intermixing of different soil types. When selecting geotextiles, the key is to match the fabric, grid, etc., to the specific conditions that need to be modified.

2.0 BASIC FUNCTIONS OF GEOTEXTILES

The physical characteristics of a geotextile determine its value for an intended application. For example, some fabrics (or portions thereof) deteriorate over time, a trait desirable for short-term erosion control, while others resist deterioration, a trait desirable for soil separation and drainage applications. Common functions are described below.

2.1 Separation

A major use of geotextiles is to separate materials. Subsoil can be prevented from migrating into roadway base aggregate or railroad ballast, and different zones of material (i.e., clay, drain rock, etc.) can be kept separate in earth dams. Drain rock can be kept unclogged in planters, and retaining wall backfill can be kept separate from adjacent soil. The function of separation often coincides with other functions, such as filtration and reinforcement. Fabrics can be used as flexible concrete formwork. The fabric can be placed in difficult-to-get-at places and inflated with concrete or grout. The permeability of the fabric allows air or water to escape from the form as the concrete fills the cavity between the layers of fabric.

2.2 Reinforcement

Geotextiles can be used to reinforce soils to improve bearing capacity, extending the range of moisture that can be accommodated under a load. Fabrics can be used to bind soil areas together to act as a unit to support foundations or to secure structures horizontally as deadmen. Grids can reinforce soil, similar to steel or mesh in concrete, and fabrics or grids can be mixed into soil, similar to fiber reinforcement of concrete. They can also be used between layers of pavement to control reflected cracking and other failures. Geotextiles can be laid over soft, compressible subsoils and under an aggregate base for both drainage and added strength in roadways and other structures. Fabrics can also be used in turf to increase the durability of playing fields.

2.3 Filtration (Drainage)

Geotextiles can be used as a filter material in many drainage applications. Fabric is used to filter fine soil particles out of coarser stone drainage media in underdrains, at the base of planters, behind retaining walls, etc. They can also be used to wrap perforated pipe or other drainage media to prevent intrusion of fine soil particles into the drainage medium.

2.4 Surface Protection (Erosion Control)

Geotextiles can be used effectively to reduce soil erosion by reducing the velocity of surface runoff waters and securing surface soil particles in place. Fabrics for this purpose can be made of durable artificial fibers offering a long life, or natural or artificial fibers that deteriorate over time, or a combination of the two.

Erosion along coastlines or along waterways can be minimized by using a permeable fabric grid or containment web, covered by heavy aggregate (the fabric traps

Table 880-1. PROPERTIES OF VARIOUS GEOTEXTILE FIBERS

	Fibers					
Property	**Nylon 66**	**Nylon 6**	**Polyethylene**	**Polypropylene**	**Polyvinyl chloride**	**Jute**
Fiber properties:						
Tenacity, g/denier (approx.)	8	8	4.5	8	1.8	-
Extension at break, % (approx.)	15	17	25	18	25	-
Specific gravity	1.14	1.14	.94	.91	1.69	1.5
Melting point, °C	250	215	120	165	-	-
Maximum operating temperature, °C (approx.)	90	Below 65	55	90	-	Below 65
*Resistance to:**						
Fungus	3	3	4	3	3	1
Insects	2	2	4	2	3	1
Vermin	2	2	4	2	3	1
Mineral acids	2	2	4	4	3	1
Alkalis	3	3	4	4	3	1
Dry heat	2	2	2	2	2	2
Moist heat	3	3	2	2	2	2
Oxidizing Agents	2	2	1	3	-	-
Abrasion	4	4	3	3	4	3
Ultraviolet light	3	3	1	3	4	1

* Poor 1; fair 2; good 3; excellent 4.
Source: Extracted from a paper by E.W. Cannon, *Civil Engineering*, March 1976.

soil particles while allowing water to move through it).

Fabric fences can also be used as windbreaks to reduce wind erosion.

3.0 GEOTEXTILE MATERIALS

Geotextiles are composed of various fibers that are either woven or bonded together to form fabric. Related materials (grids, webs, composites) are formulated from plastics.

3.1 Fibers

Basic Types of Fibers:

The main fibers used in geotextiles are polypropylene, polyester, polyvinyl chloride, nylon, polyethylene, fiberglass, and natural fibers such as jute. The fibers can be recycled, or if natural fibers, are renewable.

Properties of Fibers:

The type of fiber used in the manufacture of a geotextile determines the fabric's overall strength and resistance to various environmental weathering agents (i.e., biological attack, chemical reaction, temperature, abrasion, and ultraviolet light) (Table 880-1).

Properties of Plastics:

Plastics provide a rigid framework in composite materials. The plastics can be either recycled or virgin material; they add strength under a variety of conditions or maintain voids within a composite.

3.2 Basic Types of Fabrics

Woven Fabrics:

Woven fibers are bound together into yarns, and the yarns are interlaced to form a weave (Figure 880-1). This rectangular structure gives woven fabrics their characteristic strength and extensibility (stretch). Parallel to the warp and weft, the fabric is the weakest and stretches the least, while it is the strongest and stretches the most at 45 degrees to the warp and weft (Figure 880-2).

The number of yarns per area is the count of the fabric, and the count helps determine the porosity, weight, thickness, and extensibility of the fabric. The finish (if any) applied to the surface of the fabric can modify its properties.

Nonwoven Fabrics:

Nonwoven fabrics consist of continuous filaments or cut fibers bound together in a random manner by mechanical entanglement, chemical bonding, or thermal bonding. Many geotextiles are then needle-punched to improve their permeability.

Nonwoven fabrics tend to be equally strong and extensible in all directions and to have an evenly distributed range of pore sizes over the entire fabric (Figure 880-2).

Table 880-2. RECOMMENDATIONS FOR FABRIC OVERLAP

CBR of soil	Overlap, %
20	10
15	12
10	14
8	15
6	18
4	22
2	25

Source: E.I duPont de Nemours, "A Method for Constructing Aggregate Bases Using 'Typer' Spunbonded Polypropylene," unpublished report, Wilmington, Delaware.

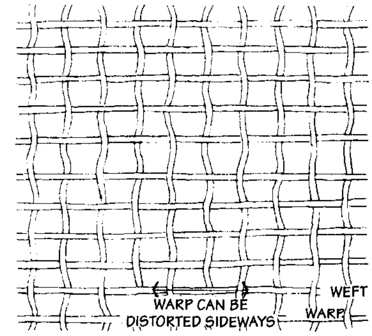
4.0 PROPERTIES OF GEOTEXTILES

4.1 Physical Properties

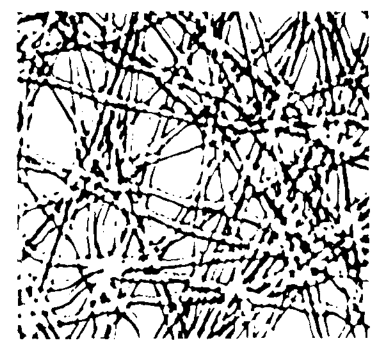
Thickness and porosity are the two physical properties of geotextiles most important in landscape applications.

Thickness:

As the thickness of a fabric increases (particularly a nonwoven fabric), the overall strength of the fabric increases, but it has proportionately less permeability. Thicker



WOVEN FABRIC



NON-WOVEN FABRIC

Figure 880-1. Basic Types of Fabrics. *Woven fabrics consist of yarns that have been woven together, whereas nonwoven fabrics consist of filaments randomly bound together by mechanical, chemical, or thermal means.*

KEY POINTS: Applications of Geotextiles

Geotextiles are available for a wide variety of applications. Their physical characteristics (i.e. permeability, pore size, tensile strength, durability, etc.) depend on their intended use.

1. A major use of geotextiles is to separate materials. Typical applications include roadways or earth dams, separating different zones of drainage materials. Geotextiles may also be used as formwork for concrete or grout.
2. Geotextiles may be used to improve the bearing capacity of soils. It is commonly applied to roadways to reduce the amount of aggregate required to handle heavy loading. Other applications include tiebacks for retaining walls, slope and turf reinforcement.
3. Geotextiles may be used as filter material for drainage devices, such as perforated pipe. It is generally recommended that the minimum permeability of a filter geotextile should be greater than or equal to the permeability of the soil. The opening size must be small enough to prevent piping and subsequent clogging of the drainage device.
4. Fabrics can be used to protect against erosion from runoff, either permanently or on a temporary basis. Biodegradable geotextiles are used in temporary control situations.

nonwoven fabrics (three-dimensional fabrics or felts) are much stronger than thinner fabrics (two-dimensional fabrics) but can become clogged internally by soil particles.

Porosity:

The permeability of a fabric is related to its porosity, the size of the openings in the fabric (Figure 880-3). Porosity is expressed as equivalent opening size (EOS) and corresponds to the closest U.S. standard sieve size (i.e., a fabric with an EOS of 200 has openings equivalent to a No. 200 sieve).

Roughness:

The roughness of a fabric surface relates to its ability to slow down moving water and "grab" the earth when used as a tie-back or deadman.

4.2 Mechanical Properties

Elongation, grab strength, and burst pressure are three mechanical properties of geotextiles most important in landscape applications.

Elongation:

Elongation is the percent increase in overall length the fabric attains when it is extended.

Grab Strength:

The grab strength is the measure of force in pounds (kilograms) required to pull a fabric apart.

Burst Pressure:

Burst pressure is the amount of pressure required to burst a section of fabric.

5.0 CRITERIA FOR SELECTION

The following characteristics of geotextiles are typically considered when assessing their value for a particular application:

1. The filtering and piping characteristics of a fabric (e.g., the ability of the fabric to filter without clogging).
2. The permeability K of a fabric (e.g., important in drainage applications).
3. The pore size (EOS) of a fabric (e.g., important in drainage and separation applications).
4. The moisture absorption properties of a fabric (e.g., important in erosion control applications. Natural fibers tend to absorb more water than synthetics).
5. The chemical resistance of a fabric (e.g., resistance to chemical fertilizers, organic soils, excessively alkaline soil and resistance to oil and asphalt).
6. The ultraviolet resistance of a fabric (e.g., important if fabric will be exposed to sunlight in part or in full).
7. The tensile strength and extensibility of a fabric (e.g., important if the fabric is to hold together or remain in place under the force of gravity on a steep slope, or to conform to uneven terrain).
8. The impact and abrasion resistance of a fabric (e.g., important if an aggregate will be installed over the fabric).
9. The thickness of a fabric (e.g., the thickness will affect the permeability and extensibility of the fabric).
10. The effect of on-site versus imported soils on a fabric (e.g., the soil beneath a fabric may be different both chemically and texturally from the soil above).
11. The soil holding ability of a fabric (e.g., important on steep slopes and areas subject to considerable runoff).
12. Connection details (horizontal seams must be secured by overlap, mechanical fasteners such as stakes or staples, heat welding or sewing. Top and bottoms of covered slopes need to be secured in a trench or secured mechanically.) See "Connection Details" illustration.

6.0 SITE APPLICATIONS

6.1 Separation

Roadway or Railroad Bed:

A geotextile placed between the subgrade and aggregate subbase will maintain the required design thickness of a bed by preventing the subgrade from migrating or pumping into the subbase (Figure 880-4).

Earth Dam Design:

Earth dam designs utilize many different zones of materials that are separated by geotextiles to maintain their individual functions (Figure 880-5).

Drainage Medium Separation in Planters:

The drainage medium can be kept separate from the planting soil by the use of a geotextile in planters or in planted areas over a structure (Figure 880-6).

Formwork:

Fabrics can be used as formwork in either mat or tube forms. Two sheets of fabric are

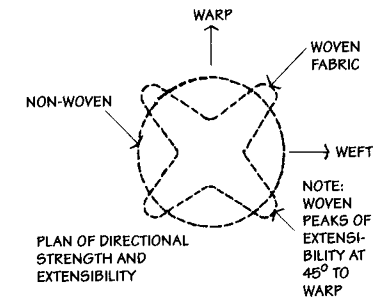


Figure 880-2. Strength and Extensibility of Fabrics. *Nonwoven fabrics are equally strong and extensible in all directions, whereas woven fabrics are strongest and most extensible at an angle of 45 degrees to the warp and weft.*

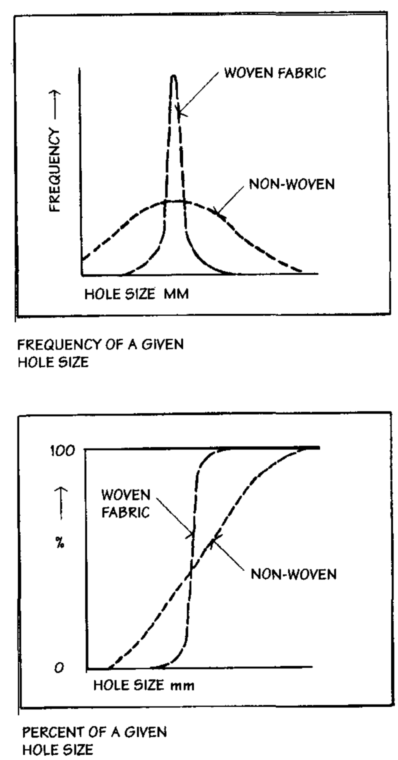


Figure 880-3. Porosity of fabrics. *Nonwoven fabrics have a variety of pore sizes, while woven fabrics have consistently sized pores.*

joined together at various points and then inflated with concrete or grout in a manner similar to inflating an air mattress. These concrete or grout mats are used to stabilize embankments and to fill in voids beneath large structures set on irregular surfaces (Figure 880-7). Tubes of fabric can be used to set concrete or grout in difficult-to-get-at places, such as when underpinning bridge supports (Figure 880-8) and encasing piers in concrete (Figure 880-9). The flexibility of the fabric allows for easy placement of the formwork and allows water and/or air to escape when the concrete or grout is injected into the tube.

Tubes or mats can also be filled with soil (rather like oversized sandbags) for inexpensive dams or retaining walls and/or shoreline protection.

6.2 Reinforcement

Paving:

Geotextiles can be used to prevent cracks in old pavements from being reflected in new pavement overlays. Fabrics are installed

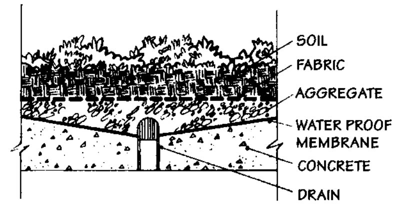


Figure 880-6. Fabric used in roof garden planter. *The geotextile keeps the drainage material separate from the planting soil.*

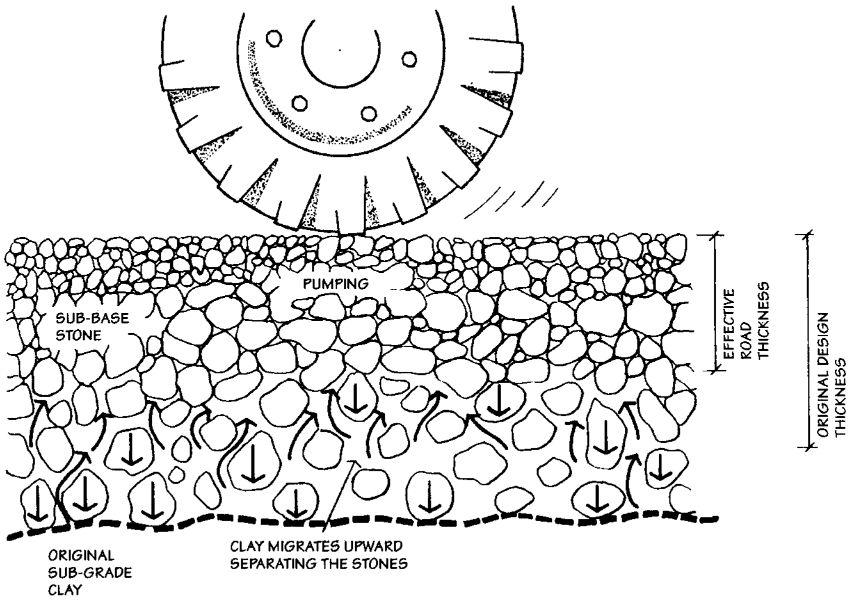


Figure 880-4. Fabric used in roadway or railroad bed. *The geotextile prevents the subgrade from pumping into the subbase.*

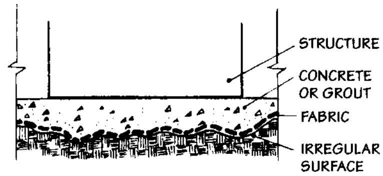


Figure 880-7. Fabric formwork for structures on irregular surfaces.

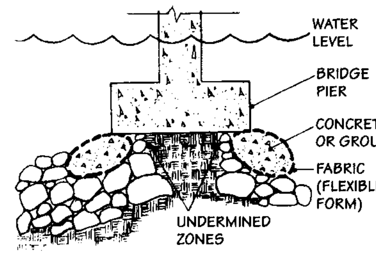


Figure 880-8. Fabric formwork used to install concrete under a bridge support to prevent undermining. *The fabric formwork is in the shape of a donut which, when filled with concrete, protects the foundation on all sides.*

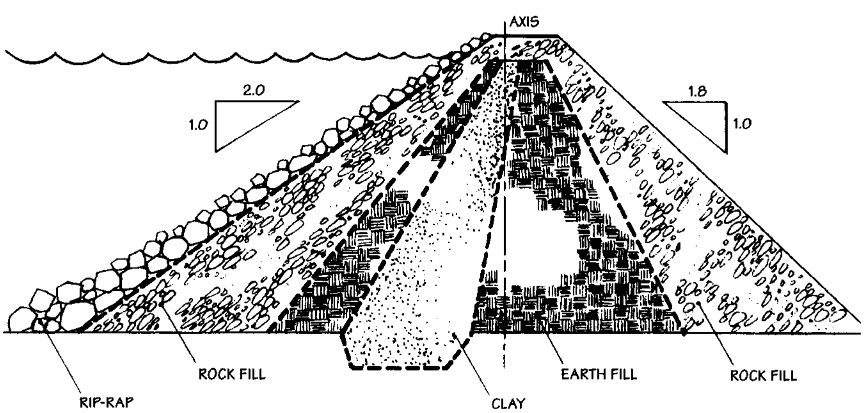


Figure 880-5. Fabric used in zoned earthfill dam. *Geotextiles are used to separate the various zones of materials, thereby improving their individual functions.*

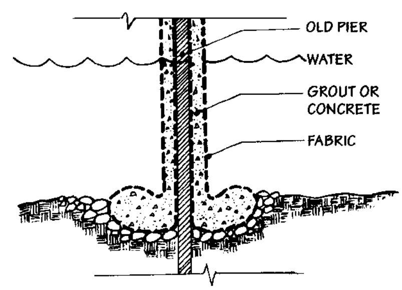


Figure 880-9. Fabric used for pier encasement. *The fabric is in the shape of a sleeve which, when filled with concrete, encases the deteriorating pier.*

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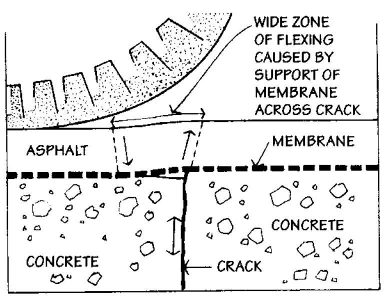


Figure 880-10. Fabric used to inhibit cracking of pavement. *The fabric bridges over cracks in the underlying pavement, thereby preventing the cracks from being reflected in the overlying surface course.*

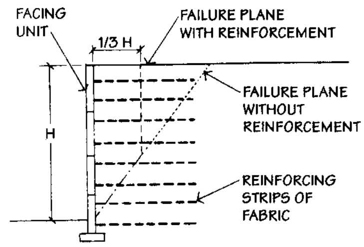


Figure 880-11. Fabric used as a deadman in a retaining wall. *Geotextiles function in the same way as other forms of deadmen to anchor the retaining wall into the hillside.*

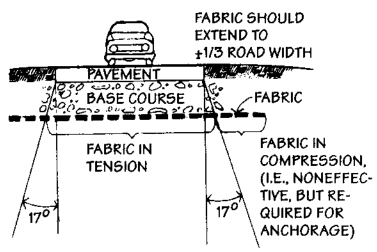


Figure 880-12. Fabric used in roadway construction. *The fabric separates the base course from the underlying subbase, thereby reducing the amount of base material required under the roadway. The fabric also helps maintain proper drainage of the base course.*

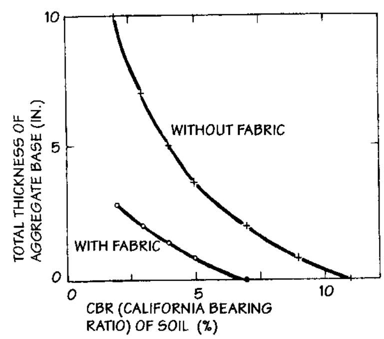


Figure 880-13. The effect of fabric on the bearing capacity of a road base. *Recent studies show that geotextiles can significantly improve the bearing capacity of soils with a low CBR, thereby reducing the necessary thickness of the base material.*

with a tack coat over the old pavement. The fabric bridges over the cracks and its strength supports the imposed loads, thereby protecting the overlying surface course (Figure 880-10).

Retaining Wall Support:

Geotextile tiebacks are used to anchor retaining wall facing units, utilizing the weight of the ground behind the wall to hold the wall's facing units (Figure 880-11).

Slope Reinforcement:

Slopes steeper than the natural angle of repose of the underlying soils are susceptible to failure by sloughing. Geotextiles or grids can be used with plant material into the slopes to prevent failure of the bank. Horizontal geotextiles or grids are installed horizontally approximately every 2 feet and soil is compacted in place over the fabric or grid.

Roadways:

Compressible fabrics can reduce the amount of aggregate base material needed in a roadway construction. The separation of materials also extends the life of a roadway by maintaining proper drainage (Figure 880-12).

The ability of soil to resist a load is measured by the California bearing ratio (CBR). By adding a fabric to the soil, the effective CBR can be functionally increased and the amount of aggregate required for a roadbed can be reduced (Figure 880-13).

Since rolls of fabric are available in limited widths, fabric must be overlapped, fused, or sewn together to function as a continuous mat. Typical overlaps range from 300 to 1 500 mm (12 to 60 in), depending on the nature of the soil, the fabric, the degree of loading, and the thickness of the cover material. Table 880-2 gives recommendations for overlap based on the CBR of the soil.

Turf Areas:

Three-dimensional geotextiles or meshes have been used to reinforce turf areas. Such fabrics have sufficient structural integrity to distribute the load of light vehicles or heavy play directly to the subgrade so that turfgrass can grow, free from problems of compaction or abrasion. Such geotextiles are installed either by spreading fine topsoil over the fabric, followed by seeding, or by spreading sod over the fabric and rolling the sod to ensure proper full contact with the earth. Turf areas can also be reinforced by mixing fibers or thin grid sections into the topsoil for a depth of 100 mm (4 in) or more to provide deeper resistance to compaction and sheer. In such a section the turf roots bind the fibers or meshes as they penetrate the soil and the turf protects the surface from erosion.

6.3 Filtration

Fabrics are used to prevent small soil particles from entering aggregate layers in a base. In a traditional french drain, filtering is accomplished by using layers of graded aggregate outside of a coarse aggregate zone. The key to a successful filter is for the filter to have openings that are large enough to allow movement of water and small enough to prevent piping (fine particles of soil passing through the fabric and entering the drainage zone). The physical properties of a soil determine the range of the filter sizes needed to achieve proper drainage.

Permeability:

The permeability K of a soil (i.e., K soil) is the factor which determines the minimum permeability of the geotextiles that can be used. In theory, a given fabric will not inhibit soil drainage if the following equation is satisfied:

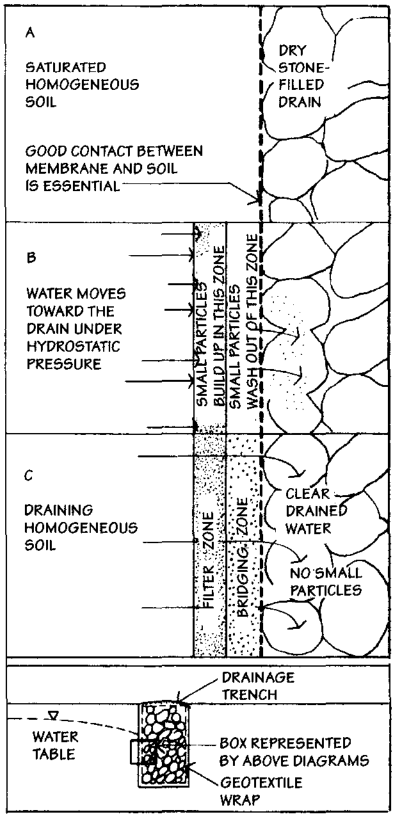
$$K \text{ (fabric)} > 0.1 \text{ (K soil)}$$

In other words, in theory, a fabric will not inhibit soil drainage if the fabric's permeability is greater than one-tenth the permeability of the soil with which it is used.

Practically speaking, however, it is generally recommended that the minimum permeability of a geotextile used should be greater than or equal to the permeability of the soil. The minimum can be up to 5 times the permeability of the soil if the fabric used retains fine particles of soil as a result of electrochemical forces.

Protection against Piping:

Piping refers to the process of fine particles of soil passing through a fabric rather than being retained. To prevent piping (and the consequent clogging of drainage media), the opening size of a fabric must be small enough to stop the passage of these fine soil particles (but still large enough to allow water to drain) (Figure 880-14).



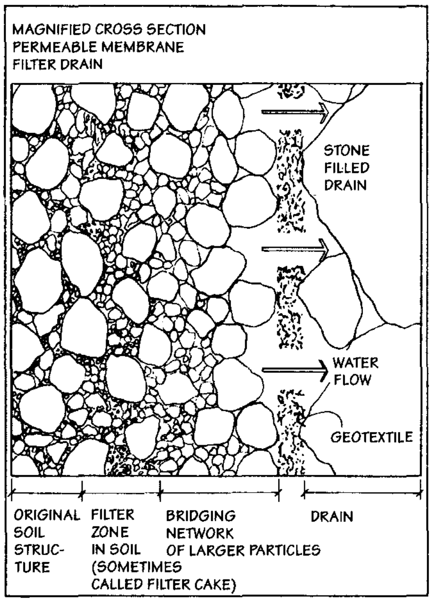


Figure 880-14. Fabric used to prevent clogging of drainage media. *This illustration shows the development of the cake of fine soil materials that builds up behind a fabric. This cake acts as the filtering mechanism that prevents piping of fine soil materials into a drainage medium.*

The maximum equivalent opening size (EOS) of a geotextile refers to the maximum opening size that a fabric can have and still prevent piping of fine soil particles (of a given size). To find out the maximum EOS appropriate for a given soil, the composition of the soil must be analyzed for the size distribution of the smallest soil particles.

The criterion established by the U.S. Corps of Engineers to determine the maximum EOS for a given situation states that if a fabric is to prevent piping, the EOS of the fabric must be less than twice the opening or sieve size that will allow 85 percent of the soil to pass through it (D85 soil). The following condition must be satisfied:

EOS fabric < 2

D85 soil

This formula was developed for granular soils containing 50 percent or less silt (No. 200 sieve size) by weight. For soils containing more than 50 percent silt, the U.S. Corps of Engineers recommends the following formula:

EOS fabric < 1

D85 soil

To reduce clogging, a minimum EOS of 100 or a minimum open area of 4 percent is recommended.

There has been a disagreement among professionals regarding minimum guidelines for the use of geotextiles in landscape applications. Few experimental installations exist where a fabric's performance has been measured, and comprehensive guidelines

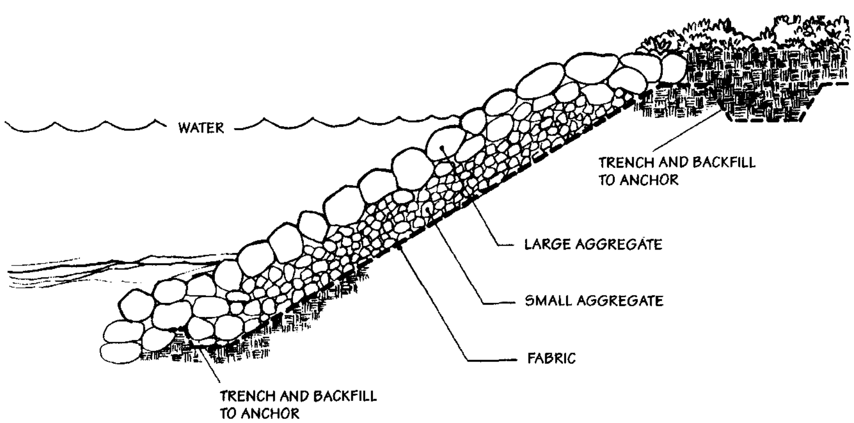


Figure 880-15. Fabric used for shoreline erosion control.

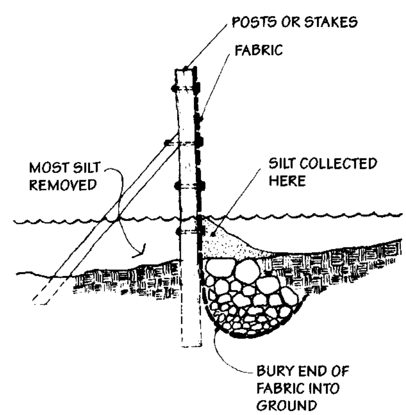


Figure 880-16. Fabric used to help control sediment in a stream.

have not been well developed. However, current research has shown that fabrics with differing EOS and K ratings can perform very similarly. This is because the fabric itself at some time after installation no longer functions as the primary filtering mechanism; rather, the cake of fine soil particles that builds up adjacent to the fabric assumes the role of the filtering mechanism. The fabric then merely acts as a permeable constraint (Figure 880-14).

6.4 Erosion Control

Protection against Water Erosion:

Fabrics can be used to protect soil against erosion from overland runoff, either permanently or temporarily, while still allowing vegetation to germinate and grow. When selecting a fabric, care should be taken to select materials that will be biodegradable for a vegetative solution, or if a permanent nonvegetative installation is desired, to select fabrics that are resistant to abrasion, ultraviolet rays, etc.

If a fabric is to be placed in a situation where an upward gradient may exist (i.e., upward movement of water through a fabric), care must be taken to specify a fabric that will not clog from upward movement of fine soil particles.

If aggregate or ballast is to be placed over a fabric, the fabric should be strong enough to withstand dumping of the aggregate from trucks without tearing the fabric. The fabric should be anchored in place by wire staples, the ends of the fabric buried, and/or the fabric covered with ballast.

If a fabric will frequently or constantly be exposed to water, a nonbiodegradable variety should be specified. At the toe of an embankment, for instance, a shallow trench should be dug and the fabric secured in it by use of staples, pins, or ballast (Figure 880-15). The fabric is then secured up the entire embankment. At the top of the embankment the fabric must be secured to prevent surface water from undermining the fabric. After the fabric is in place, a layer of fine aggregate is placed over the entire surface and then covered by coarser aggregate. This process helps protect the membrane from damage when the coarser aggregate is installed.

Protection against Wind Erosion:

Fabric fences, similar to those used for sediment traps (Figure 880-16), can be used to reduce wind-caused soil erosion.

Sediment Traps:

Preassembled fences (made of fabric with integral support and posts) can be used to trap sediment. These fences are located downslope from open excavations, etc., to trap waterborne silts and clays. They are installed by rolling out a fabric and driving posts into the ground. The bottom of the fence is buried in the ground to prevent runoff from undermining the fence (Figure 880-16). Similarly, these fences can be used to reduce water turbidity (cloudiness or pollution) when dredging or excavating waterbodies or shorelines.

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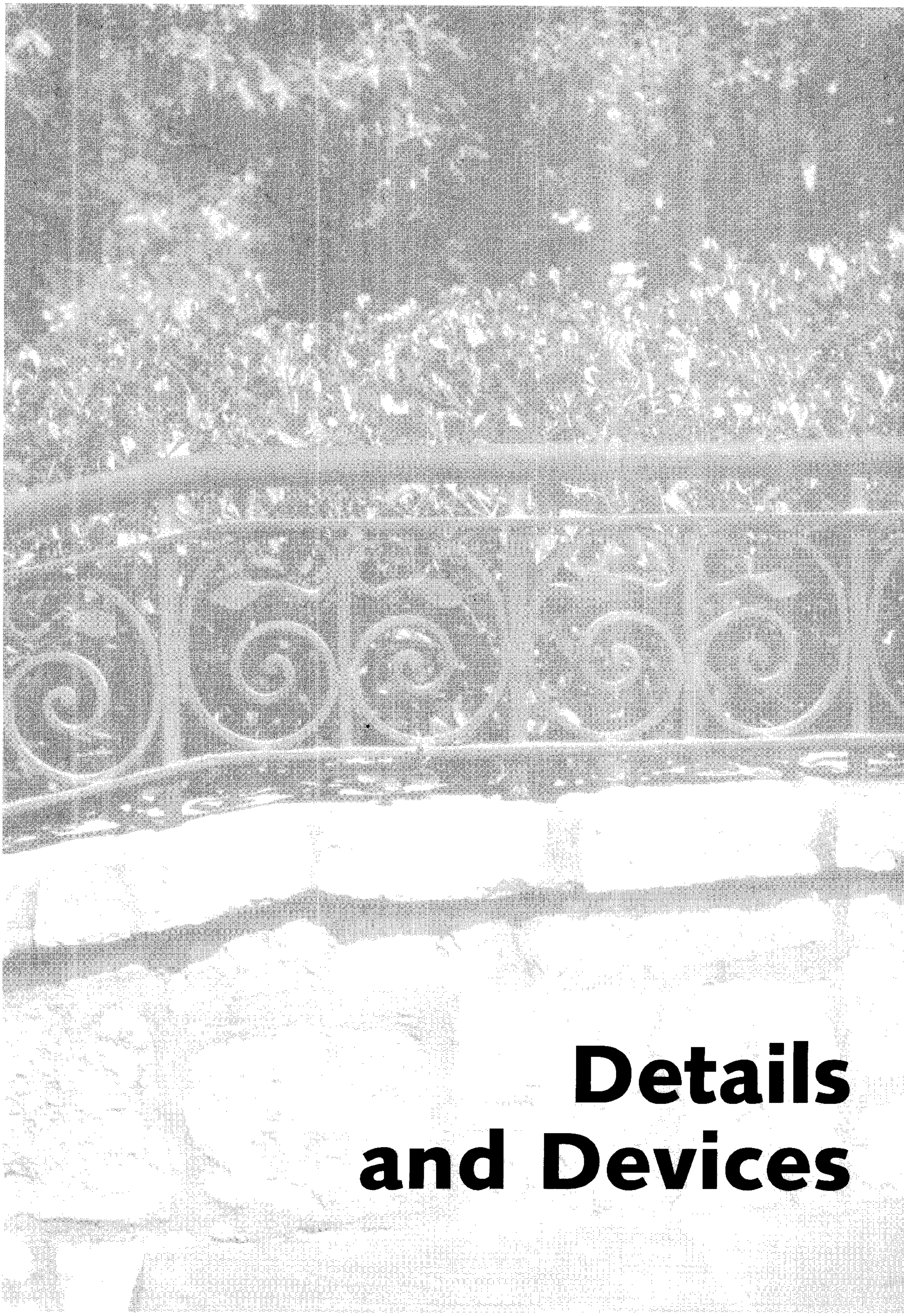

Details and Devices

DIVISION 900

Details and Devices

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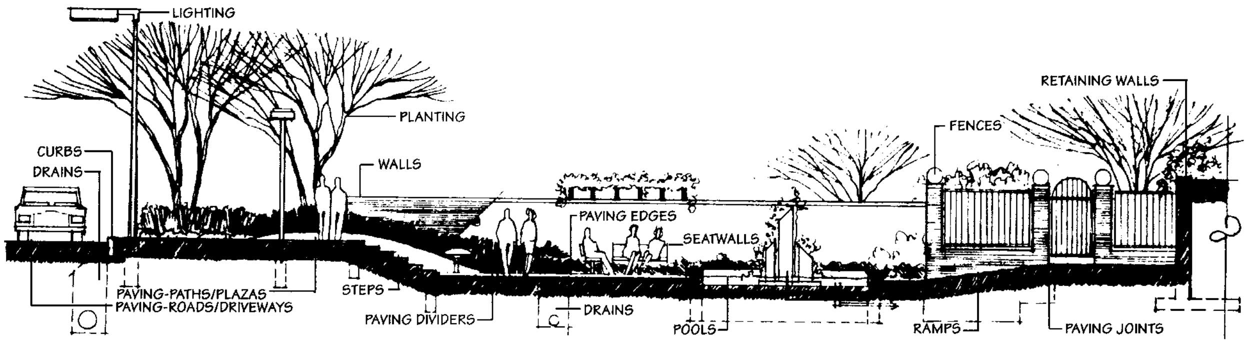


Figure 900-1. Public plaza design cross section. *A typical design section depicting various detail types which commonly occur in such a landscape setting. Each setting carries its own set of descriptive details related to the activities or structures associated with each setting.*

1.0 INTRODUCTION

Design details together with written specifications illustrate and describe how proposed site design elements are to be furnished, assembled, installed or placed on the site by the contractor. Details describe surface finishes and the structures required to support them. Generally, a construction detail is required to describe ground plane changes in elevation and material, or at architectural structure foundations or thresholds. Additionally, details are required to describe site system components such as, utilities, stormwater devices, and other site improvements, which may include proprietary or custom built elements. Figure 900-1 illustrates a typical design cross section depicting the range of detail types found in a public plaza. Each landscape type may require details common to all site construction as well as details unique to that particular type.

The details illustrated in this Division represent medium duty details designed for well drained soils, unless specifically noted. They are grouped by detail type, and represent a limited anthology to serve as a basis for further design development. Some common details are annotated to indicate how they may be modified to accommodate more intense loading or poorly drained soils. Each detail is dimensioned using dual metric and US units, and is subject to local variations, physical conditions, and cultural customs. These details are not to be used as construction documents, since any detail must be derived from the specific site requirements. All structural specifications must be approved by appropriate local authorities and licensed consultants.

2.0 DESIGN CRITERIA

Site construction details are typically designed to accommodate:

1. **Application requirements with regard to design loads or use intensity:** Loading or use are described as light, medium, or heavy duty. Each detail type possesses its own rating criteria for determining its duty of service. Pavements vary by design load which is expressed as finish material strength, and aggregate base thickness. Tree planting may vary by size and degree of environmental stress, while swale design may vary by volume and velocity of discharge.
2. **Soils and hydrology:** Common details require adaptation to colloidal or expansive clay soils subject to capillary moisture migration. This typically involves additional aggregate subbases, fabric separators, and strategically placed subdrain pipes. Eccentrically loaded structures may require wider footings at greater depth to resist lateral sheer.
3. **Climate:** Hot arid, hot humid, temperate, and cold climates affect footing and pipe trenching depths, expansion joint design, material porosity and absorption tolerances, color, slope, etc. In addition, long-term maintenance requirements may limit the palette of materials in particular climate zones.
4. **Regulatory specifications:** Local codes and Federal agency regulations may severely restrict the use of certain materials and design forms.

3.0 UNIT COST

The unit cost of a particular detail is determined by the cost of materials, labor, equipment, and contractor overhead and profit. The long-term cost of a particular installation is determined by its embodied energy value, its rated length of service, and its annual maintenance budget requirements. Prudent detail design requires that all of these factors be considered in the development of final details and construction specifications.

4.0 ENERGY AND RESOURCE CONSERVATION

It is highly recommended that long term embodied energy and maintenance costs be given a high priority in the final design development process. Recycled materials should be specified first from the local region, second from surrounding regions, and third from more distant sources. Newly processed short-lived materials made from non-renewable extracted resources should be avoided, along with processed materials requiring intercontinental importation. Materials with high embodied energy ratings should also have a long life expectancy, such as quarried igneous stone, stainless steel, etc., or should be made from recycled materials, such as aluminum extrusions made from recycled cans and scrap.

5.0 MAINTENANCE

Without proper maintenance, most pavements and structural site improvements will begin to show wear and deterioration within 10 to 15 years. Plantings typically mature during this same period. Proper maintenance involves periodic surface coatings, pointing, cleaning and sealing of joints, flushing and oxidizing of drains and infiltration devices, and pruning, transplanting, and dividing of plantings. Ideally, the designer should arrange to make periodic inspections as part of a site management contract agreement to insure that performance specifications be maintained during the design life-cycle.

Paving

1.0 INTRODUCTION

Pavement construction begins by properly grading and preparing the site subgrade to receive the designated aggregate subbase and base courses, which are topped with the finish pavement surface. Simple light-duty pavements may only require a single aggregate base course and a single wearing surface course. Pavements may be divided into rigid, flexible, unit, or monolithic types. Complex pavements designed for heavy duty use or poor subsoils may require multiple lifts of aggregate courses placed upon a fabric separator to prevent subgrade deformation. Wet conditions frequently require subdrains to be placed at low points to insure uniform moisture conditions of both subgrade and subbase material.

1.1 General Notes

The primary objective of proper pavement design is to create a stable uniform subgrade and aggregate base condition to guard against differential settlement over the pavement life. The second objective is to place the finish surface course in accordance with performance specifications to achieve the design goals. Aggregate and unit pavements require edge restraints to prevent lateral creep. Subbase aggregate should extend beyond the finish edge to provide structural support. Subbase and base thickness is determined by subgrade bearing capacity and permeability. For equal loads, rigid pavements require thinner aggregate bases than flexible pavements.

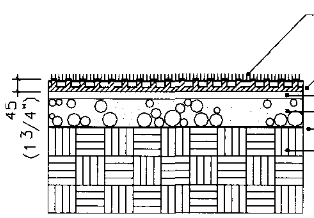


Figure 910-1. Plastic cellular turfgrid on aggregate base. *Useful for emergency access or overflow parking lot in warm to temperate zones.*

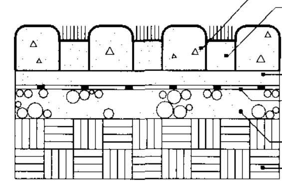


Figure 910-2. Concrete cellular turfgrid paving I. *Can serve as regular parking and service areas in all climates (heavy duty application).*

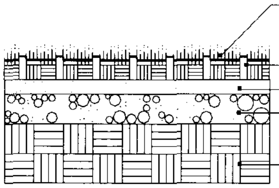


Figure 910-3. Concrete cellular turfgrid paving II. *Moderate duty applications for all climate zones.*

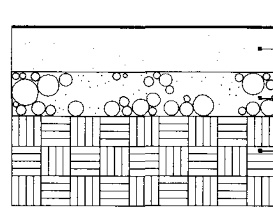


Figure 910-4. Skinned infield on aggregate base. *Typical softball or baseball infield. May use proprietary clay mixture.*

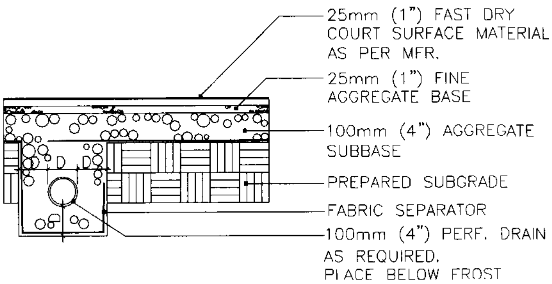


Figure 910-5. Clay tennis court. *Clay tennis court with proprietary finish top course.*

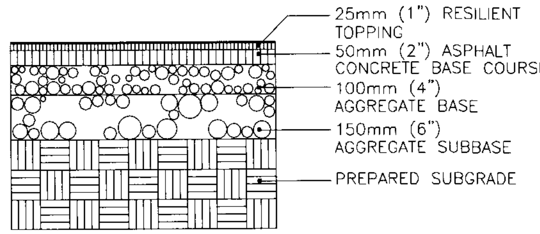


Figure 910-6. Resilient asphalt running track on aggregate base. *Typical built-up running track with resilient finish. Many surfaces available.*

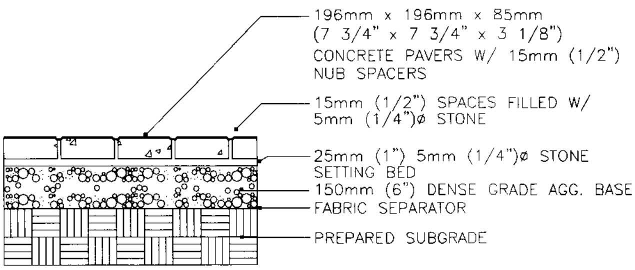


Figure 910-7. Concrete lawn pavers with drain joints. *Paving system with offset nubs for close or far spacing shown with close spacing.*

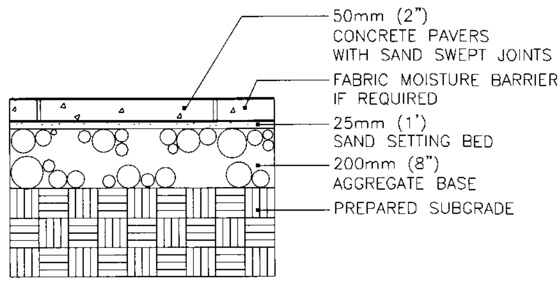


Figure 910-8. Concrete pavers on aggregate base. *Vehicular loading allowed with silica sand setting bed.*

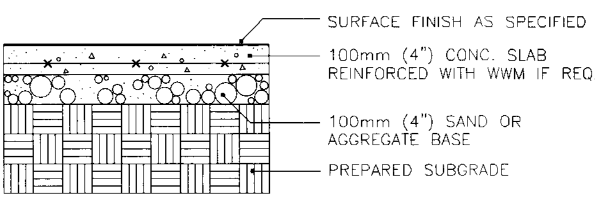


Figure 910-9. Concrete paving on aggregate base. *Basic concrete slab paving. Aggregate base is recommended for all applications.*

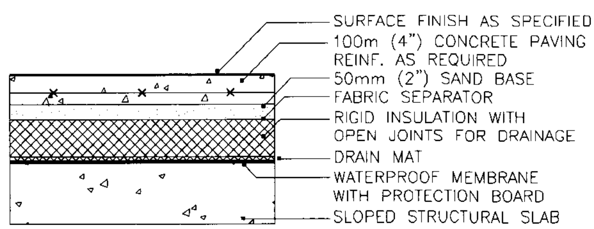


Figure 910-10. Concrete paving on structure. *Typical roof deck with concrete paving. Other finishes may be substituted.*

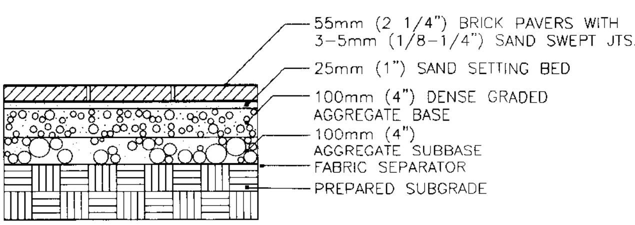


Figure 910-11. Brick pavers on aggregate base in clay soils. *Brick pavers require fabric and subbase due to low bearing and heaving potential of clay.*

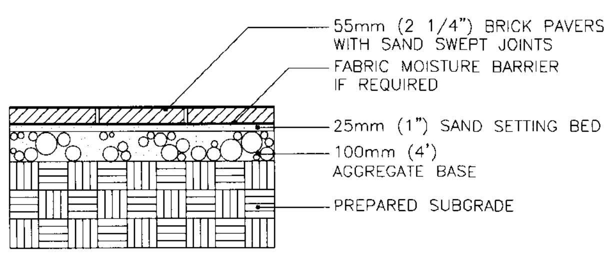


Figure 910-12. Brick pavers on aggregate base. *Aggregate base with thin sand setting bed provides better support for heavy foot traffic.*

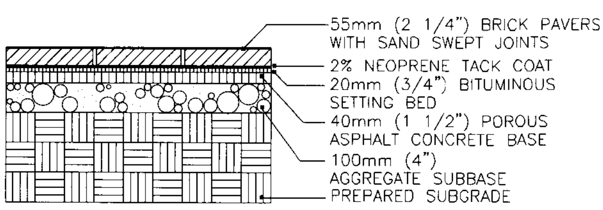


Figure 910-13. Brick pavers on asphalt base. *Good for cold climates to create uniform base conditions.*

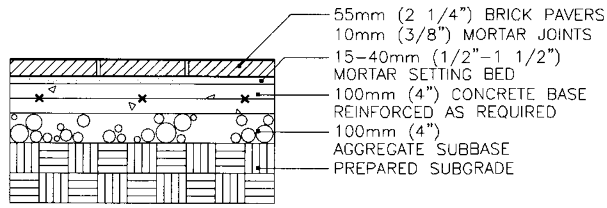


Figure 910-14. Brick pavers on concrete base. *Bricks are mortared onto reinforced concrete base.*

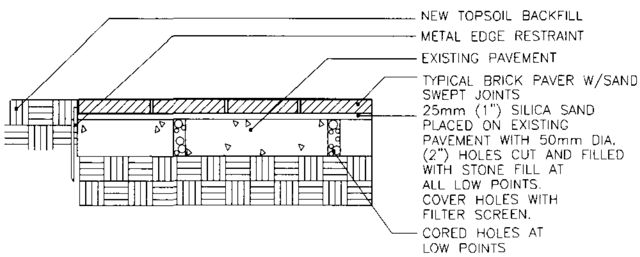


Figure 910-15. Brick pavers over existing concrete paving. *Existing pavement must be drilled to provide drainage for sand setting bed.*

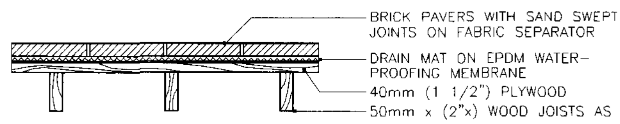


Figure 910-16. Brick pavers with sand swept joints on wood deck. *Light decking uses EPDM and drain mat to support brick with sand swept joints.*

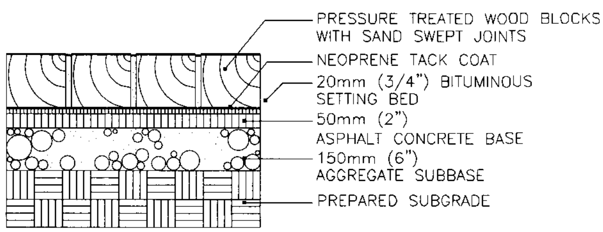


Figure 910-17. Wood pavers on asphalt base. *Used primarily in warm climates for pedestrian or industrial surfaces.*

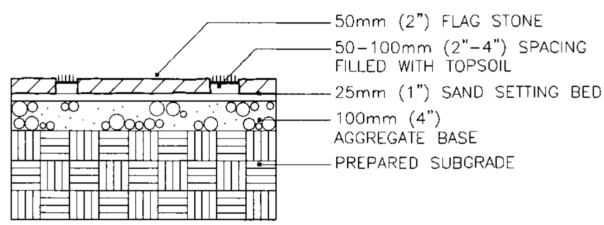


Figure 910-18. Flagstone pavers with topsoil joints on aggregate base. *Thicker stone provides more soil for grass to grow. Poor for arid zones.*

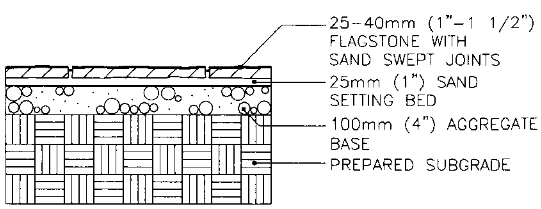


Figure 910-19. Flagstone pavers on aggregate base. *Patio scale use of thin flag stone pavers. Commercial uses require thicker stone and base.*

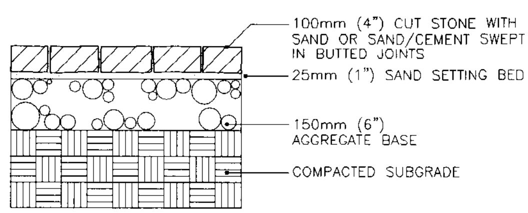


Figure 910-20. Cut stone pavers on aggregate base. *Classic cut granite sets in sand with aggregate base for medium duty applications.*

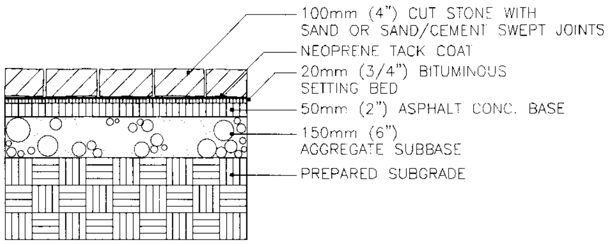


Figure 910-21. Cut stone pavers on asphalt base. *Useful in urban applications where firm base is required to support service vehicles.*

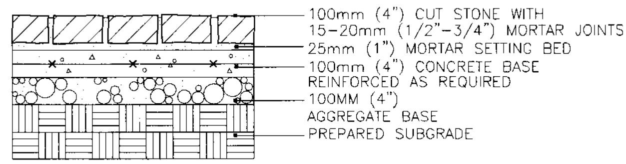


Figure 910-22. Cut stone pavers with mortar on concrete base. *Typical separator strip to differentiate pedestrian and vehicular zones.*

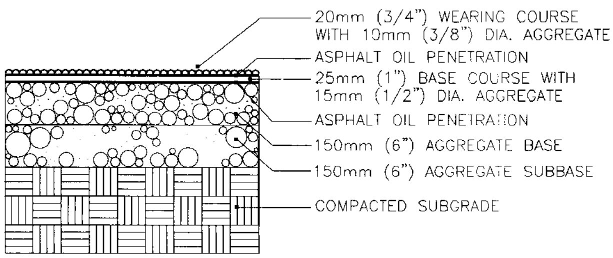


Figure 910-23. Stone and oil penetration on aggregate base. *Drives and medium duty roads use subbase for strength.*

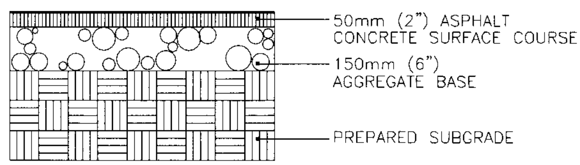


Figure 910-24. Asphalt paving on aggregate base. *Typical for pedestrian walks and light applications.*

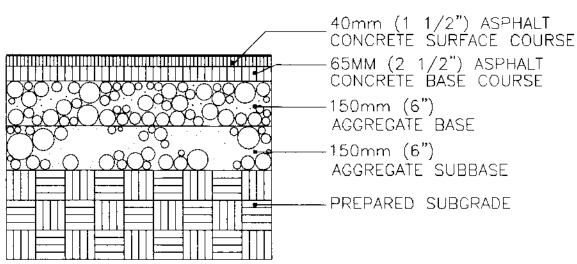


Figure 910-25. Asphalt paving on aggregate base and subbase. *Heavy duty application showing subbase layer.*

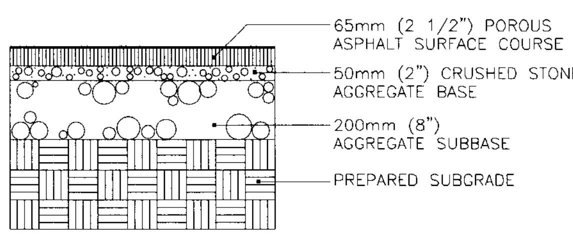


Figure 910-26. Porous asphalt paving on aggregate base. *Used for parking areas in warm climates for infiltration of runoff.*

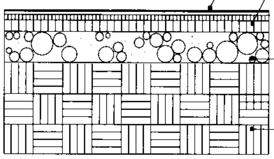


Figure 910-27. Porous rubber play surface on aggregate base. *Play rated surfacing placed using special binder and shredded rubber.*

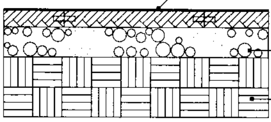


Figure 910-28. Resilient interlocking play surface on aggregate base. *Doweled rubber tiles are play rated and placed directly on dense graded aggregate.*

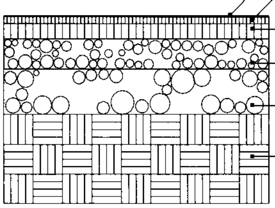


Figure 910-29. Asphalt tennis court on aggregate base. *Asphalt tennis court may require underdrain system in some wet soils.*

SECTION **911**

Edges

1.0 INTRODUCTION

Edge structures used in flexible pavement design serve to contain the pavement and prevent lateral creep. They also may provide additional support to prevent crushing due to loading at the edge. Rigid pavement edges are used primarily as reinforcement against edge loading. In both cases, edging may also serve to define a pavement and to separate two different materials. Selection of proper edging must consider site climate and maintenance practices. Details illustrate flexible and rigid pavement edges.

1.1 General Notes

Wood edges are temporary and require aggregate bases to prolong the life of the wood. Wood stakes securing wood edges will heave in clay soils and frost /thaw zones. Metal stakes may prevent excessive heaving. Edging between materials must be handicapped accessible in most cases. Concrete edging may act as a grade beam for flexible pavements and as a reinforcement for rigid pavements. Many precast units are available for edging applications. Care should be taken to assess material compatibility with regard to maintenance requirements and durability when joining two materials.

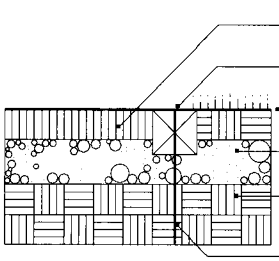


Figure 911-1. Wood edge with steel pins. *Extend aggregate beyond edge. Smaller edging may use steel stakes on outer edge.*

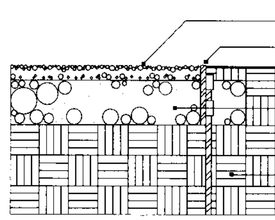


Figure 911-2. Aggregate paving with metal edge. *Superior method for edging loose material when inconspicuous edge is required.*

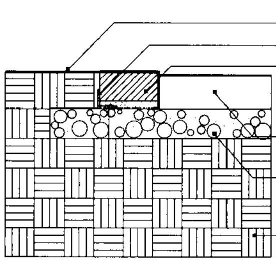


Figure 911-3. Cobblestone path with metal pins. *Stone edge rides on top of edging for secure retention. Metal is not visible.*

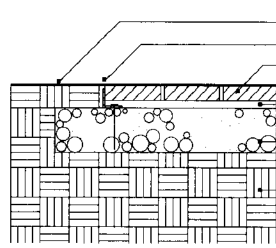


Figure 911-4. Brick pavers with metal "L" edge. *Brick setting bed rests on metal flange for even appearance. Good for planting edge.*

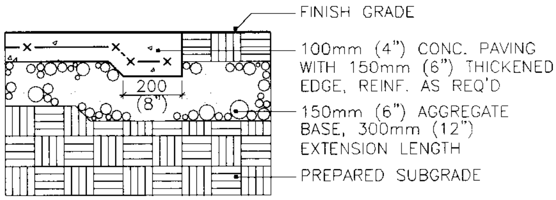


Figure 911-5. Concrete paving with thickened edge. *Used to protect slab edge from light service vehicle loading in parks and plazas.*

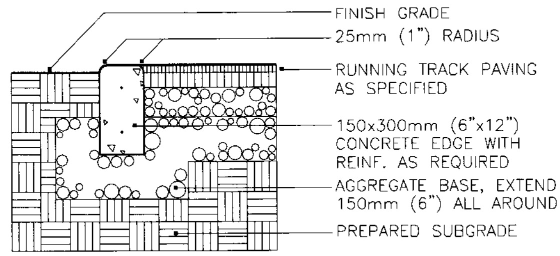


Figure 911-6. Concrete grade beam for running track. *Reinforced concrete track edge restraint. Aggregate needed due to track runoff.*

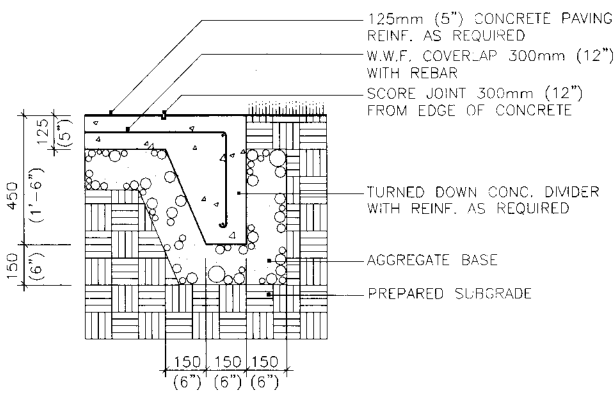


Figure 911-7. Turn-down concrete edge. *May also be used for small light duty curb detail for 100-150 mm (4-6 in) curbs.*

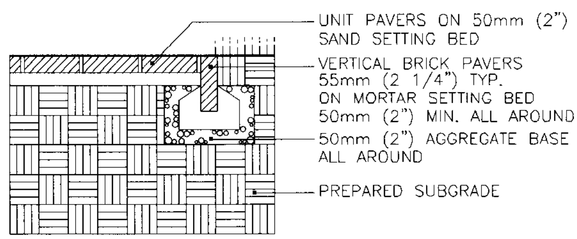


Figure 911-8. Brick paving edge on mortar setting bed. *Bricks mortared at edge joint. Mortar struck below pavement base. Not used in cold zones.*

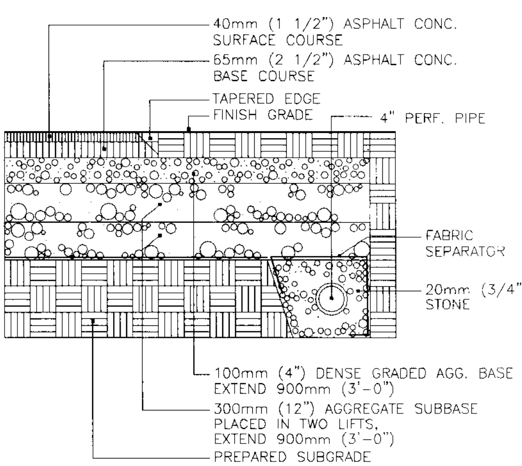


Figure 911-9. Asphalt paving with tapered edge on clay soil. *The same tapered edge may be used in well drained soils with single course base.*

SECTION 912

Joints

1.0 INTRODUCTION

Pavement joints allow for expansion and contraction in rigid pavements or join two different materials, or abutting slabs. The selected details illustrate a range of conditions and materials.

1.1 General Notes

Control joints in concrete are required to provide controlled break points in the event of swelling stresses. Expansion joints are typically required every 7 500 mm (25 ft) to allow for contraction and expansion due to temperature fluctuations. Expansion joints should be sealed in cold climates to prevent saturation and freezing within the joint. All joints should be periodically cleaned and resealed. Unit pavers mortared onto slabs require sealed expansion joints to be aligned with slab joints. Metal pins and sleeves may be used in heavy duty concrete joints with care being taken to thicken the slab around the sleeve and pins for strength. Slab ends may also be keyed using pre-formed expansion joint fillers in standard slab thicknesses.

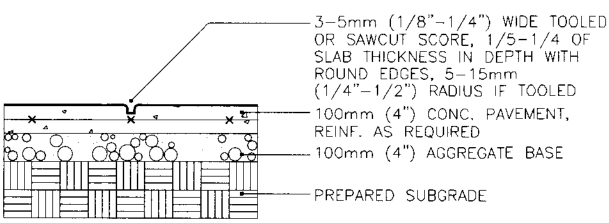


Figure 912-1. Concrete paving control joint. *Control joints may be scored in wet concrete, or sawn in cured concrete.*

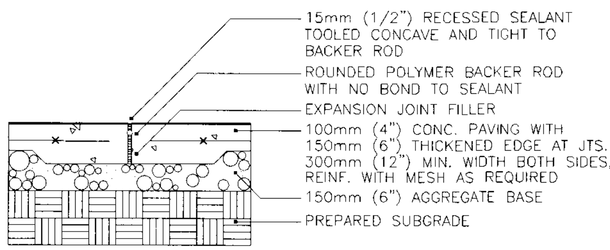


Figure 912-2. Concrete paving expansion joint with thickened edge. *Used when vehicular loading may require extra support.*

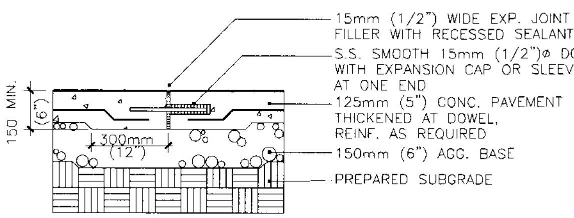


Figure 912-3. Concrete paving expansion joint with dowel. *Used to tie one slab to the next and still allow movement. May corrode in cold zones.*

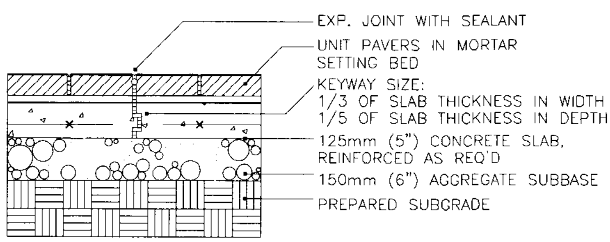


Figure 912-4. Keyed expansion joint in brick paving on concrete base. *Formed with pre-molded expansion joint filler. Seal joint from water infiltration.*

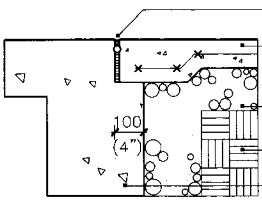


Figure 912-5. Concrete paving expansion joint with concrete sill at new structure. *Superior method of attaching a concrete slab to avoid settlement at a building sill.*

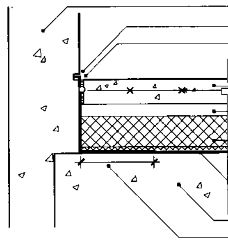


Figure 912-6. Concrete paving expansion joint at building on structure. *Expansion joint is crucial to avoid compressing membrane counter flashing.*

SECTION 913

Dividers

1.0 INTRODUCTION

Dividers to create visual or textural transitions from one paving material to another, or to emphasize a visual band in a large pavement system. Maintenance required for the divider should not adversely affect surrounding materials. Care should be taken to avoid differential settlement at junctions. The selected details illustrates various material combinations in a number of design circumstances.

1.1 General Notes

Decorative bands in pavements should create smooth joints with surrounding materials and in most instances should be subject to the same accessibility standards as the main pavement. Avoid large differences between divider thickness and adjacent pavement thickness to allow for even subgrade conditions. Rigid bands are typically set before flexible infill pavements.

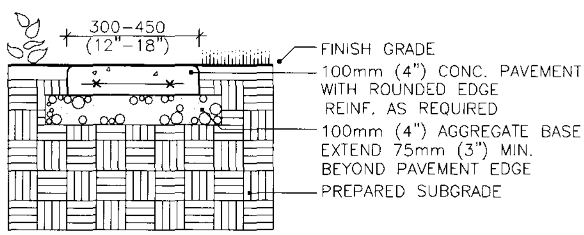


Figure 913-1. Concrete mowing strip. *Concrete strips may be tinted or textured to create neat trim for turf and garden areas.*

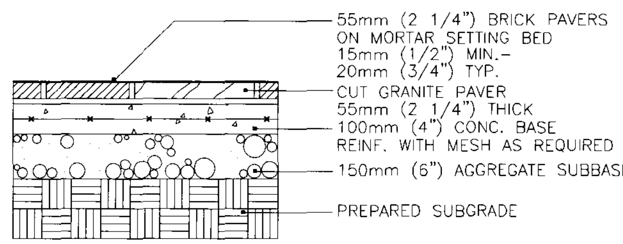


Figure 913-2. Granite band in brick paving. *Granite band should be no thicker than the brick paver. If less, shim with mortar.*

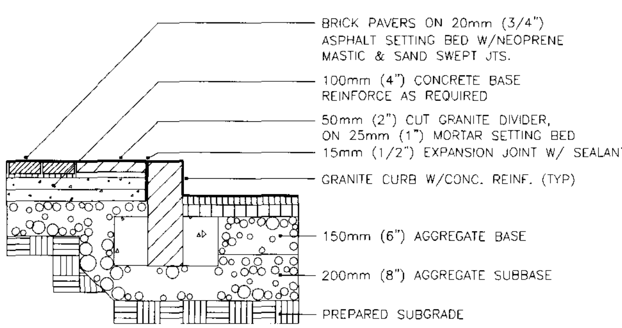


Figure 913-3. Granite band at granite curb. *Extend expansion joint to granite band and seal. If thin veneer, shim with mortar.*

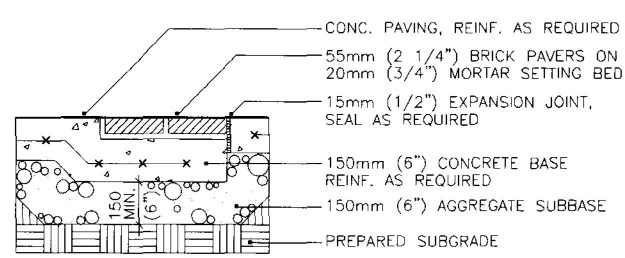


Figure 913-4. Brick band in concrete paving. *Slab requires inset to allow for modular brick on mortar bed. Light vehicular loading.*

Athletic and Game Surfaces

1.0 INTRODUCTION

Athletic and game surfaces typically include general field play, sanctioned games such as football, baseball, softball, and soccer, as well as specialized games such as lawn bowling, tennis, and croquet. The following details illustrate a sampling of reinforced natural turf and synthetic turf surfaces. All such surfaces require regular maintenance and grooming.

1.1 General Notes

All natural turf requires irrigation, and may be heated in cold climates for professional or collegiate play. Irrigation systems are often set within the growth horizon for direct root feeding. Heating tubes are commonly set below the soil horizon, and within the top layer of the aggregate base. Synthetic turf surfaces require minimal slope for outdoor installations. Modern practice uses a monolithic resilient porous pad under the synthetic surface to absorb impacts for greater player protection and better internal drainage. The goal of these details is to provide a smooth uniform playing surface capable of supporting light service vehicle loading. It is common practice to carefully screen and amend soil to secure the best combination of structural bearing, infiltration, and capillarity.

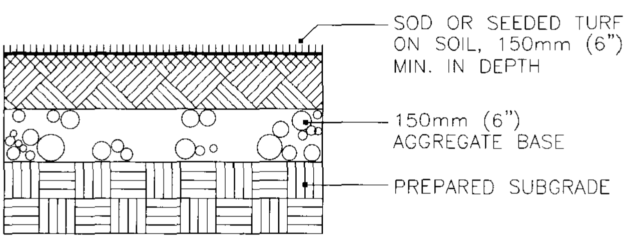


Figure 914-1. Game lawn on aggregate base. *Fine aggregate base allows light vehicular loading. A 200 mm (8") soil depth is preferred*

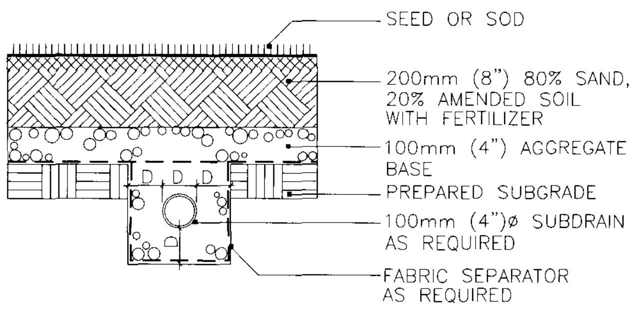


Figure 914-2. Natural turf athletic field. *Dense grade aggregate base placed on a fabric separator. Sand amendment for to drainage.*

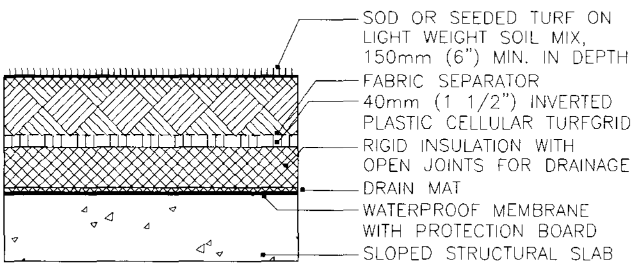


Figure 914-3. Game lawn with inverted cellular turfgrid on structure. *A 300 mm (12") lightweight soil depth is preferred. Requires a soil separator as shown.*

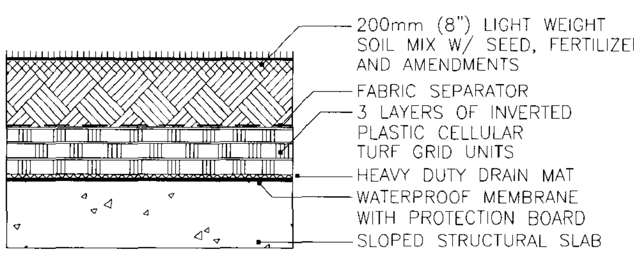


Figure 914-4. Natural turf athletic field- on structure. *Fabric separator is required. A 300 mm (12") lightweight soil depth is preferred.*

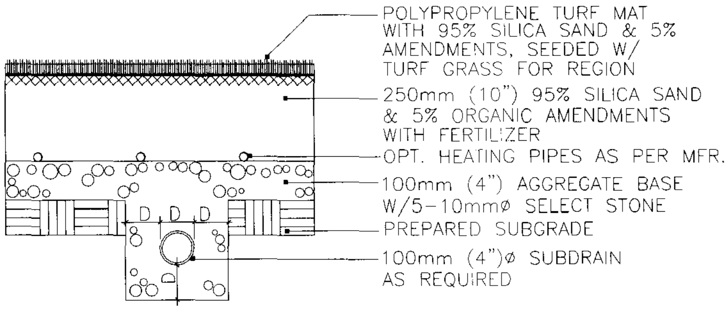


Figure 914-5. Polypropylene reinforced athletic field. *It is internally heated in cold climates. Subdrains placed under fabric separator.*

Curbs

1.0 INTRODUCTION

Pavement curbs allow road and path grades to be depressed and to act both as wheel barriers and stormwater runoff containment edges. Curbs are classified as vertical, sloped, mountable, or curb and gutter combination types. They range in height from 100-200 mm (4-8 in). Selected details illustrate a range of materials and curb configurations.

1.1 General Notes

Wood curbs should be used for informal or temporary conditions only. They require extended aggregate bases and periodic pins to secure them to the pavement base. Steel pins resist seasonal heaving and can be re-set easily. Brick and masonry curbs may serve as light duty curbs in pedestrian systems or light residential drives in warm climates. Stone curbs are more resistant to plowing and general maintenance. Concrete curbs come in standard profiles and may be custom formed to provide ramp access. Slip form curbs in cold climates are often placed using high strength concrete without reinforcing. Curb and gutter configurations allow for free aggregate base drainage.

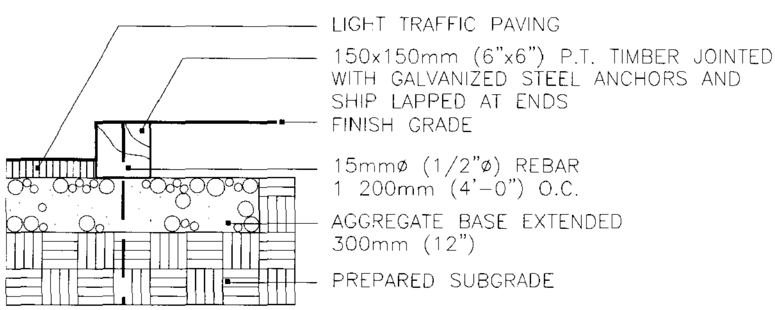


Figure 915-1. Wood curb with rebar pins at notched joint. *Informal edge or parking area curb stop. May also be placed on asphalt base course.*

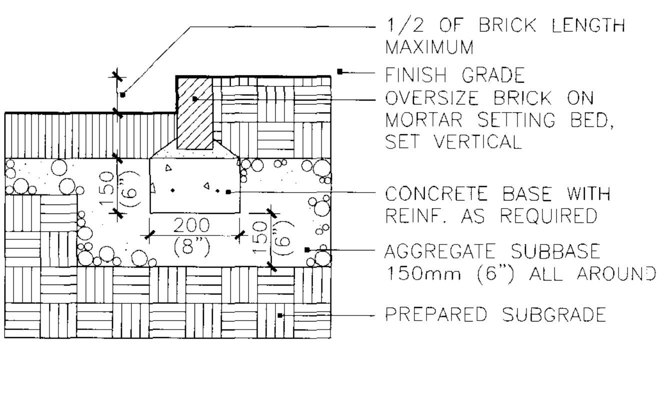


Figure 915-2. Vertical brick curb. *Brick has mortar joints and requires concrete grade beam. Not used in cold climates.*

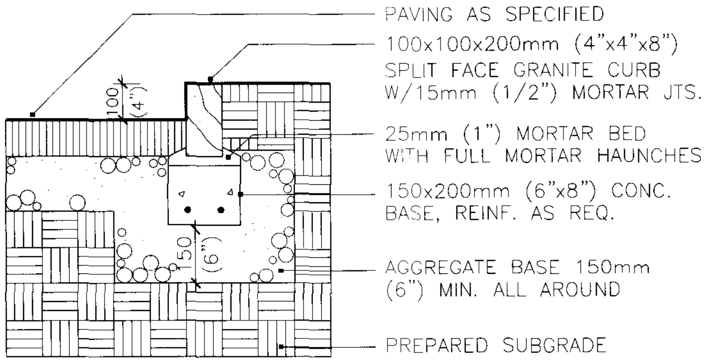


Figure 915-3. Granite block on concrete base. *Sturdy curb edge used in drives for all climates except cold. Mortar all joints.*

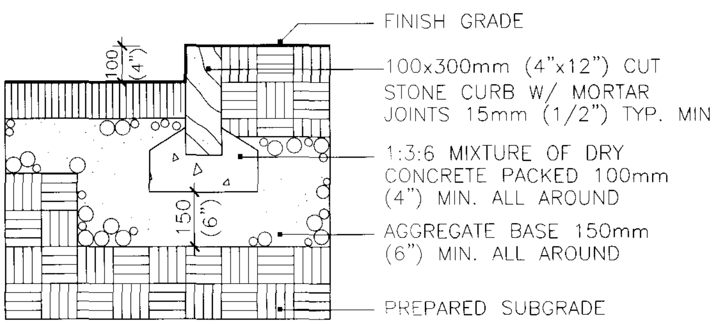


Figure 915-4. Vertical stone curb. *Parking lot curb used in all climate zones. May be re-set if required.*

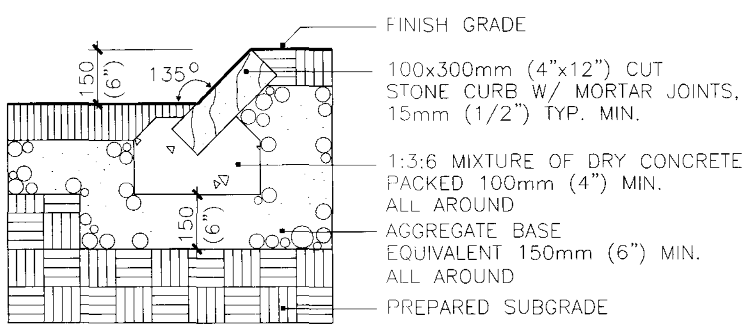


Figure 915-5. Sloped stone curb. *Typically used in radius returns and in parking lots using short or long segments.*

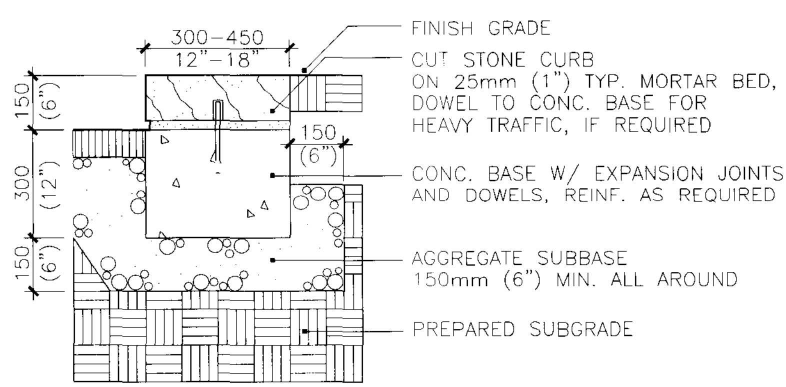


Figure 915-6. Cut stone curb on concrete base. *Used to accent curb edge using dowel to set cut and gauged stone on concrete grade beam.*

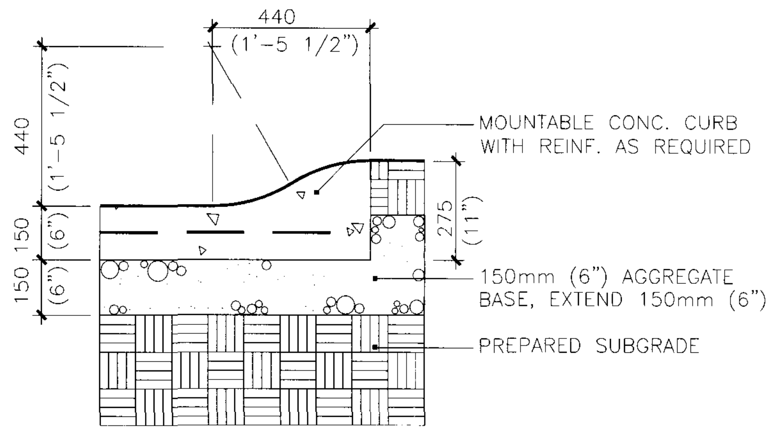


Figure 915-7. Mountable concrete curb and gutter. *Formed on-site for smooth access to upper pavement. May incorporate a gutter.*

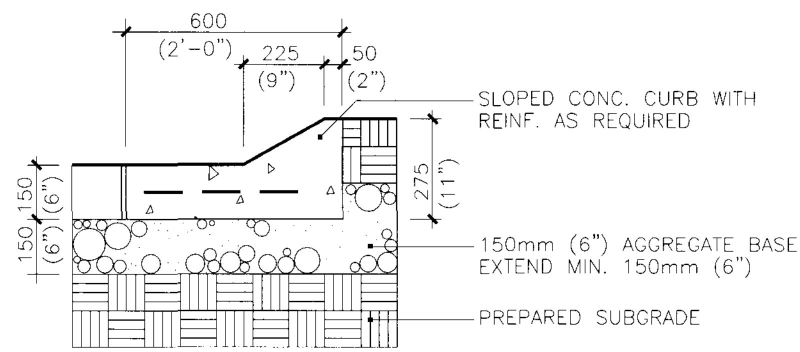


Figure 915-8. Sloped curb and gutter. *Standard cast-in-place curb profile. Allows ramp access.*

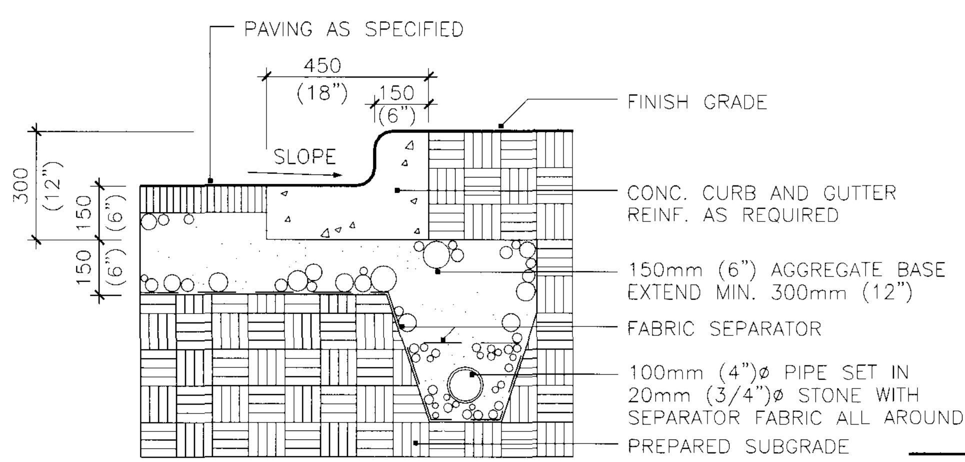


Figure 915-9. Concrete curb and gutter with drain. *Used in clay soils to prevent heaving, especially in cold zones. Pipe is in back of curb.*

Steps

1.0 INTRODUCTION

Steps and ramps (Section 917) allow vertical circulation within the site. It is common practice to eliminate steps where ever possible, especially at entrances to avoid dual ramp and stair construction. Steps should be proportioned to provide graceful exterior scale strides, typically at a flatter angle of attack than interior stairs. Climate and maintenance are important considerations in site design with regard to placement of steps. The selected details illustrate typical materials and construction techniques used to build steps.

1.1 General Notes

Ramp steps should be spaced in multiples of human strides, typically 675 mm (27 in) riser to riser. Exterior steps have shorter risers than do interior steps, typically 125-150 mm (5-6 in). All treads should slope 2% for positive drainage. Sheet runoff should not be allowed to cascade over steps from above, especially in cold climates. All expansion joints should be sealed to prevent moisture intrusion. Cheek walls must bear on frost- free soil in cold climates. Rigid pavement abutting top and bottom stairs should sit on footing sills to maintain alignment and finish elevation. Limit stair runs to multiples of eye-level for best human scale.

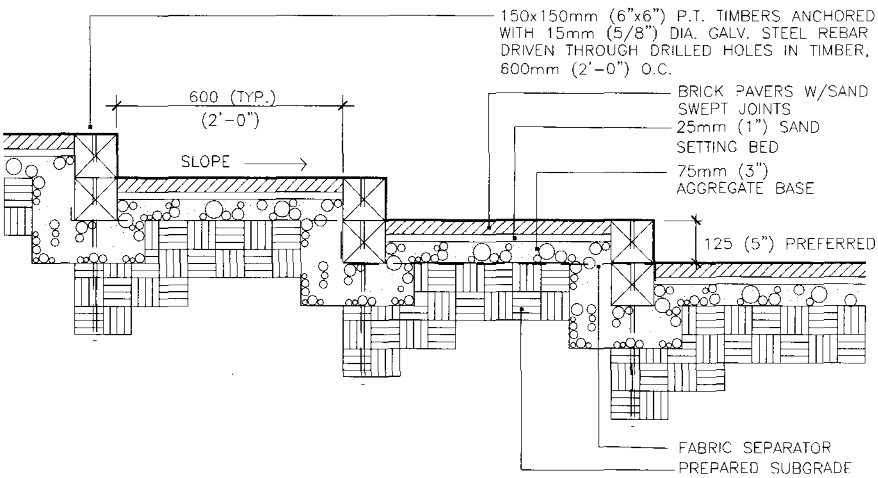


Figure 916-1. Wood/stone ramp steps. *Pins and fabric ties stabilize wood risers. Stone may be substituted.*

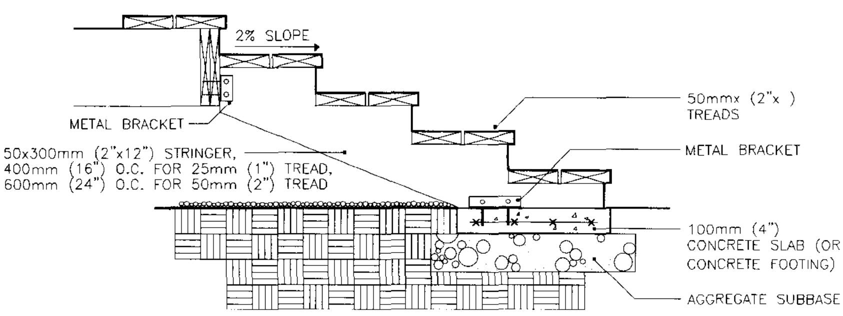


Figure 916-2. Wood steps with notched stringer. *Flanges secure stringers. Codes may require closed risers.*

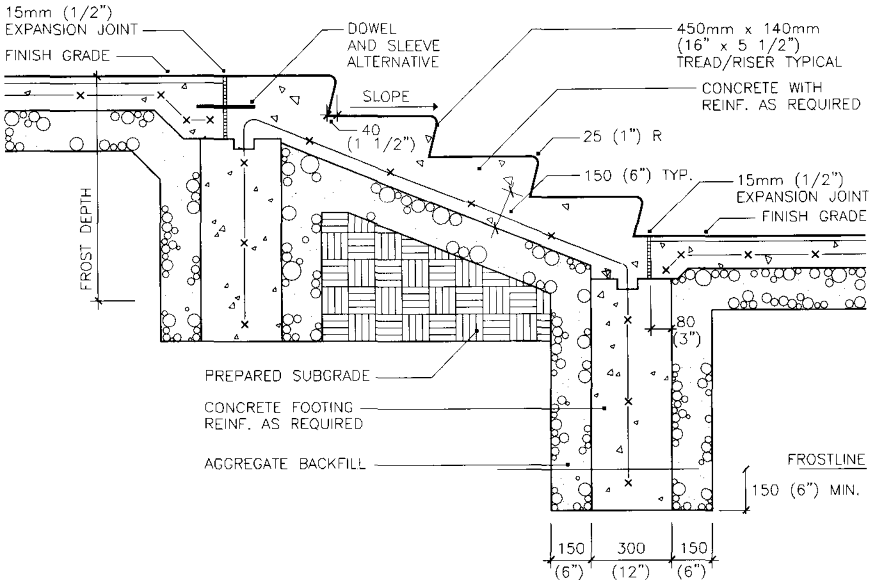


Figure 916-3. Concrete steps with footing and pavement sill. *Top and bottom footings used for long runs and to secure sills for pavement slabs.*

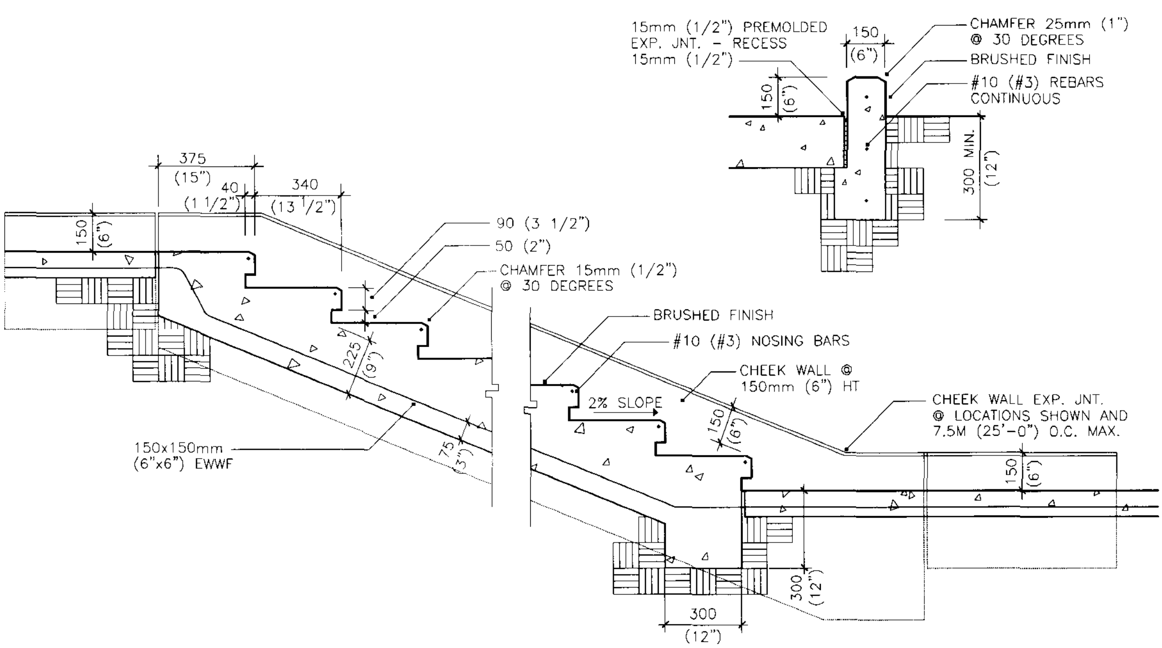


Figure 916-4. Concrete steps with cheek wall. *Used to maintain grade and create formal trim to step edge, often used with inset wash lights.*

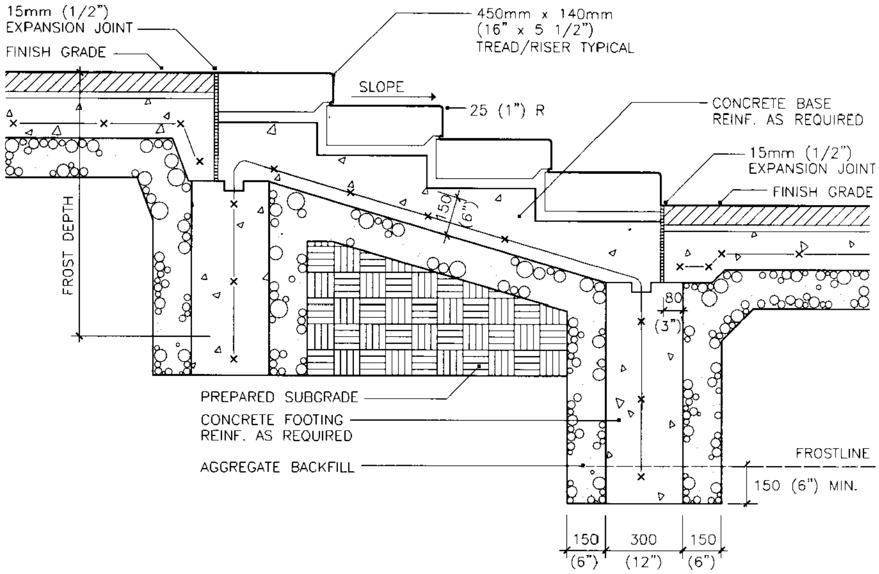


Figure 916-5. Granite steps with concrete base and pavement sill. *Many different systems available. Seal all joints. Long lasting surface.*

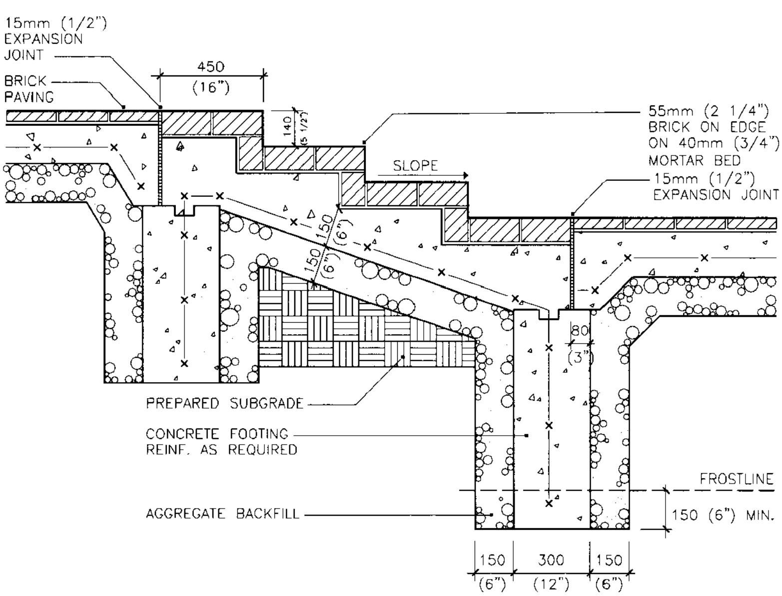


Figure 916-6. Brick veneered steps with footings and pavement sill. *Brick patterns change to accommodate tread/riser proportions. Many patterns are possible.*

Ramps

1.0 INTRODUCTION

Ramps are regulated by statute. The same restrictions that apply to steps apply to ramps (Refer to Section 916). Because of the necessity of entrance ramps, careful consideration should be given to site design and placement. Long ramps with landings should be adequately drained to avoid runoff accumulation at the lower end. Selected details illustrate various materials and configurations used in ramp construction.

1.1 General Notes

Conservative estimates of structural loading on ramps should be used to anticipate pedestrian crowding and periodic furniture delivery. Typically, commercial loading values should apply. Ramp surface should provide traction, especially in cold climates. If a unit paver surface is used, an interlocking pattern provides better results due to its resistance to creeping along the slope. A secure base grade beam or other restraining device is recommended. Wood ramps should be secured to concrete footings and threshold blocks for longer service and structural integrity.

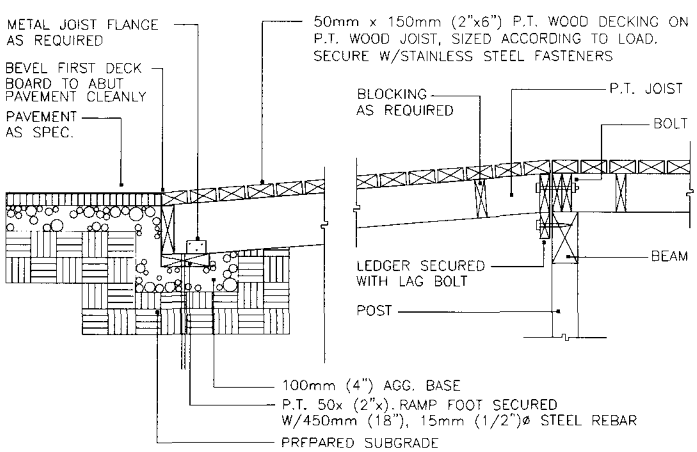


Figure 917-1. Wood ramp with flush pavement. *Simple informal treatment in warm climate and well drained soils.*

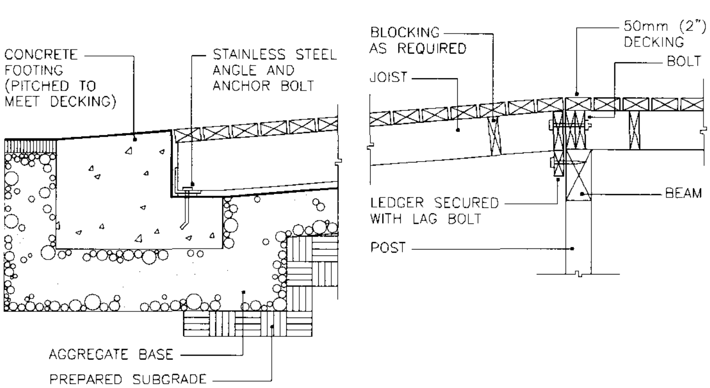


Figure 917-2. Wood pedestrian ramp with concrete apron. *Used in more formal settings and in cold climates to insure longer wood service.*

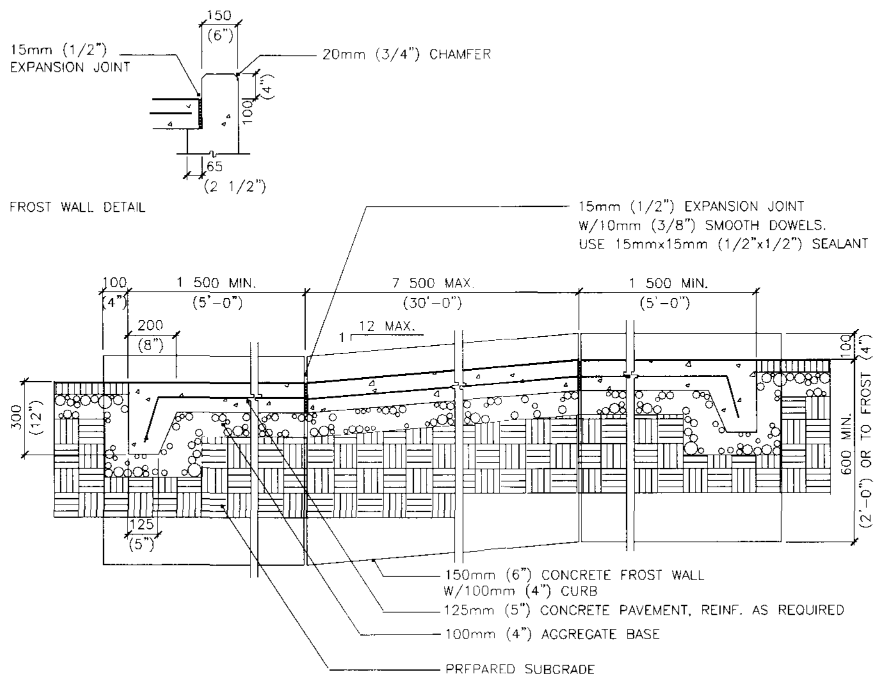
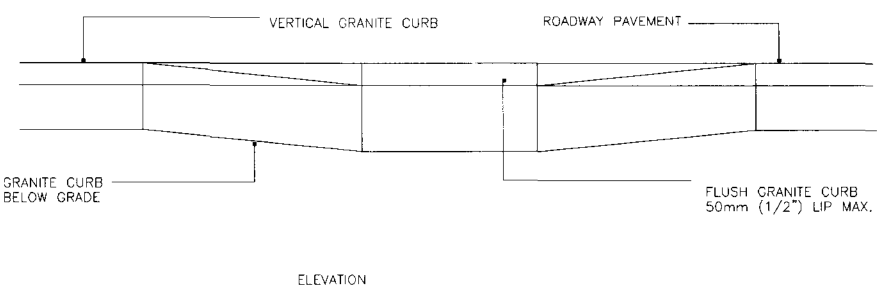


Figure 917-3. Concrete ramp. *Ramp showing optional frost wall if required. Ramp and landing length set by statute.*



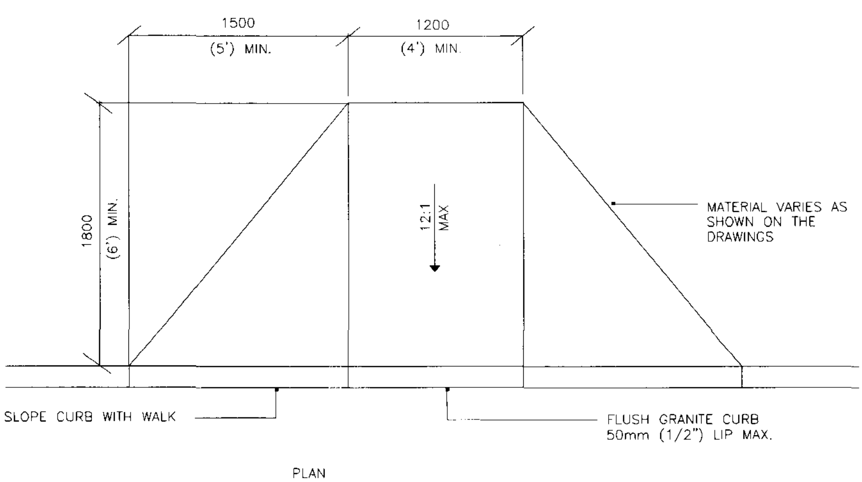


Figure 917-4. Concrete curb ramp. *Simple transition ramp for curb access at sidewalk and street edge. Unit pavers may abut.*

SECTION **918**

Fences

1.0 INTRODUCTION

Fences range in height from 900-2 400 mm (3-8 ft) and are constructed of wood, metal, plastics and combinations of each with masonry piers. Fences are characteristically composed of panels spanning between posts, and often contain gates and other associated structures. Structural design is determined by height and wind loads, and in the case of masonry pier, by soil bearing. The selected details illustrate a range of materials and applications.

1.1 General Notes

Simple wood fences may use direct burial posts which are either pressure treated or decay resistant wood. Long term fencing and commercial applications typically require concrete pier footings with metal attachment devices to secure posts to footings. Steel may be attached to the posts and set in set concrete, or steel may be set in concrete and attached to posts after the concrete cures. Steel may be routed into the wood for a more finished appearance. All exposed metal should be cleaned, primed, and coated prior to attachment. All wood surfaces should be milled to shed water for longer service. Iron fences attached to masonry piers are typically attached to metal flanges set into the masonry piers during their construction. Footing depths range from 600-900 mm (2-3 ft) depending on wind loads and frost depth..

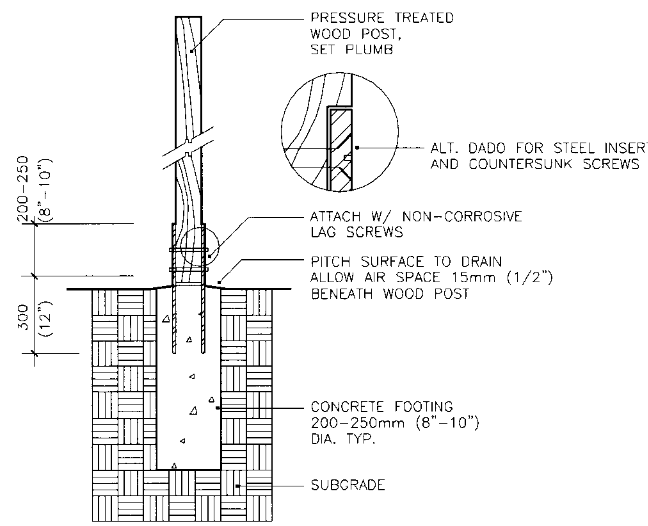


Figure 918-1. Wood fence post-metal anchor in concrete. *Preferred method of attachment for long service life and ease of repair.*

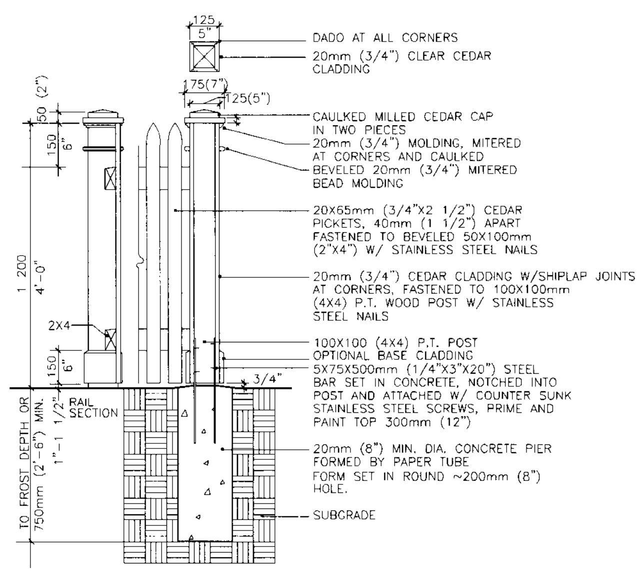


Figure 918-2. Wood clad picket fence with concrete pier. *Classic built-up post and wood trim. Requires periodic coating to retain integrity.*

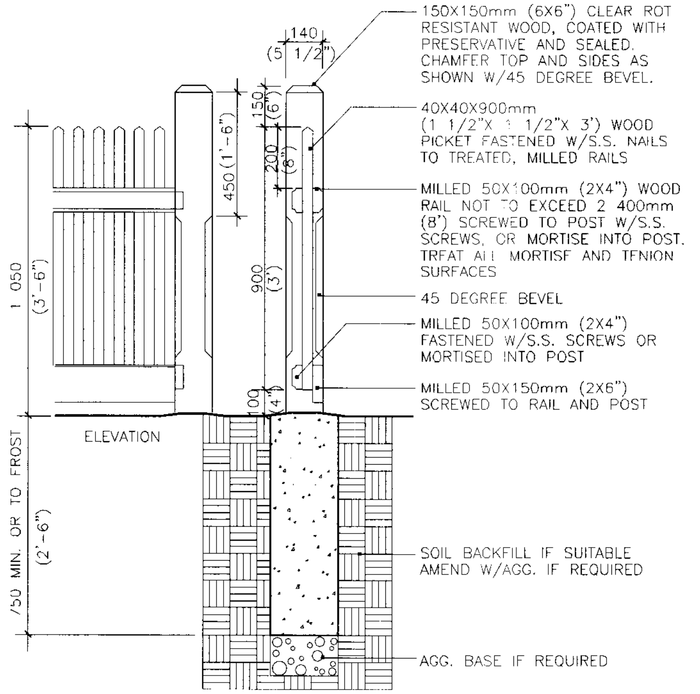


Figure 918-3. **Square picket wooden fence.** *Requires periodic post replacement due to rotting. Note mortise and tenon detail for rail.*

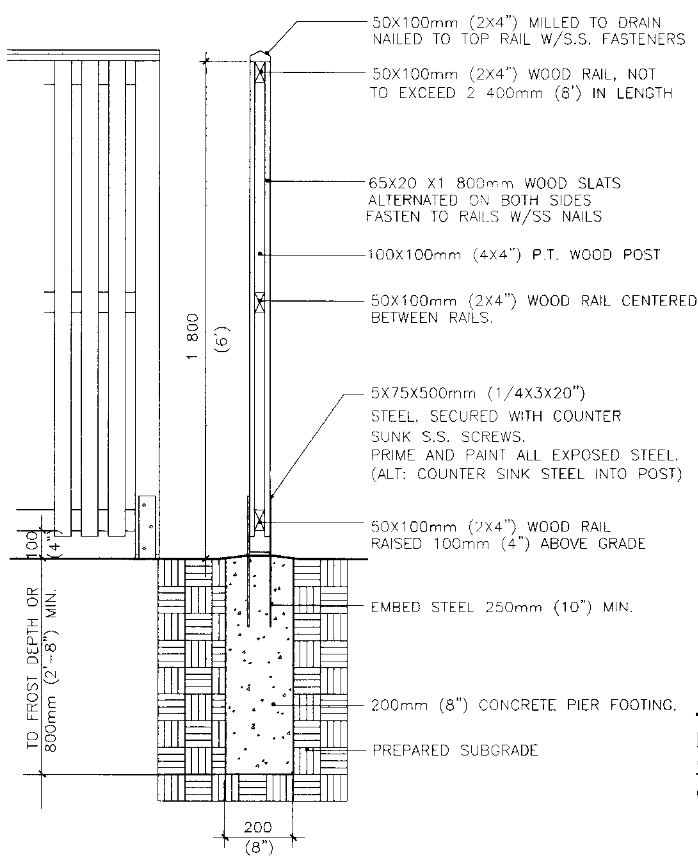


Figure 918-4. **Wood slat fence with alternating boards.** *Screen fence with flush metal attachment to pier. Best coated with sprayer.*

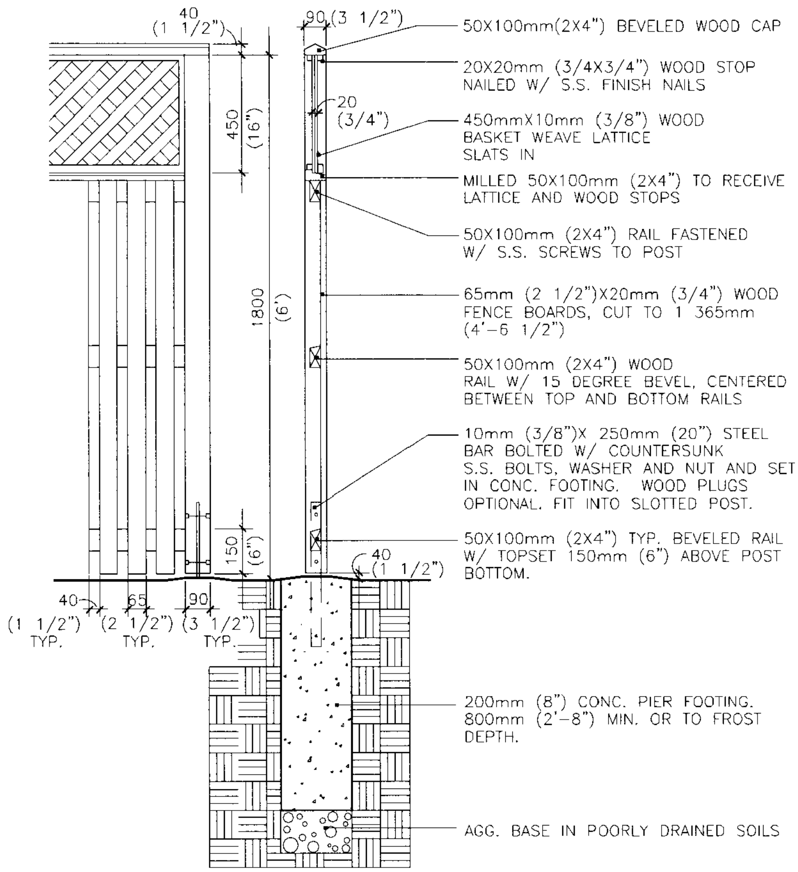


Figure 918-5. Wood slat fence with lattice. *Post show concealed slotted attachment to pier. All moldings are milled to drain.*

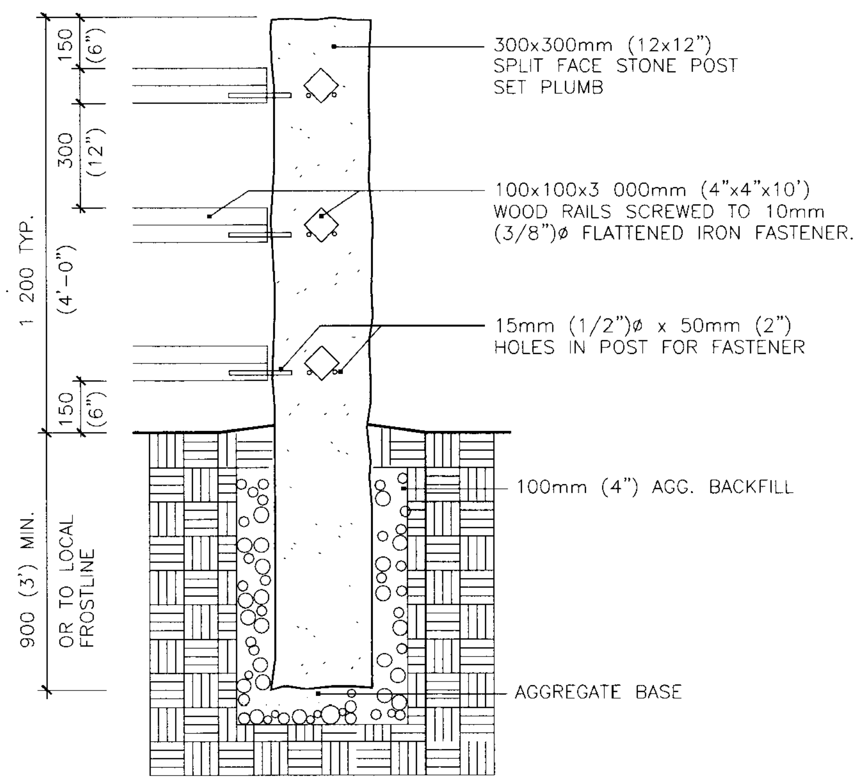


Figure 918-6. Stone post and rail fence. *Institutional barrier fence provides long life if rails and hardware are periodically coated.*

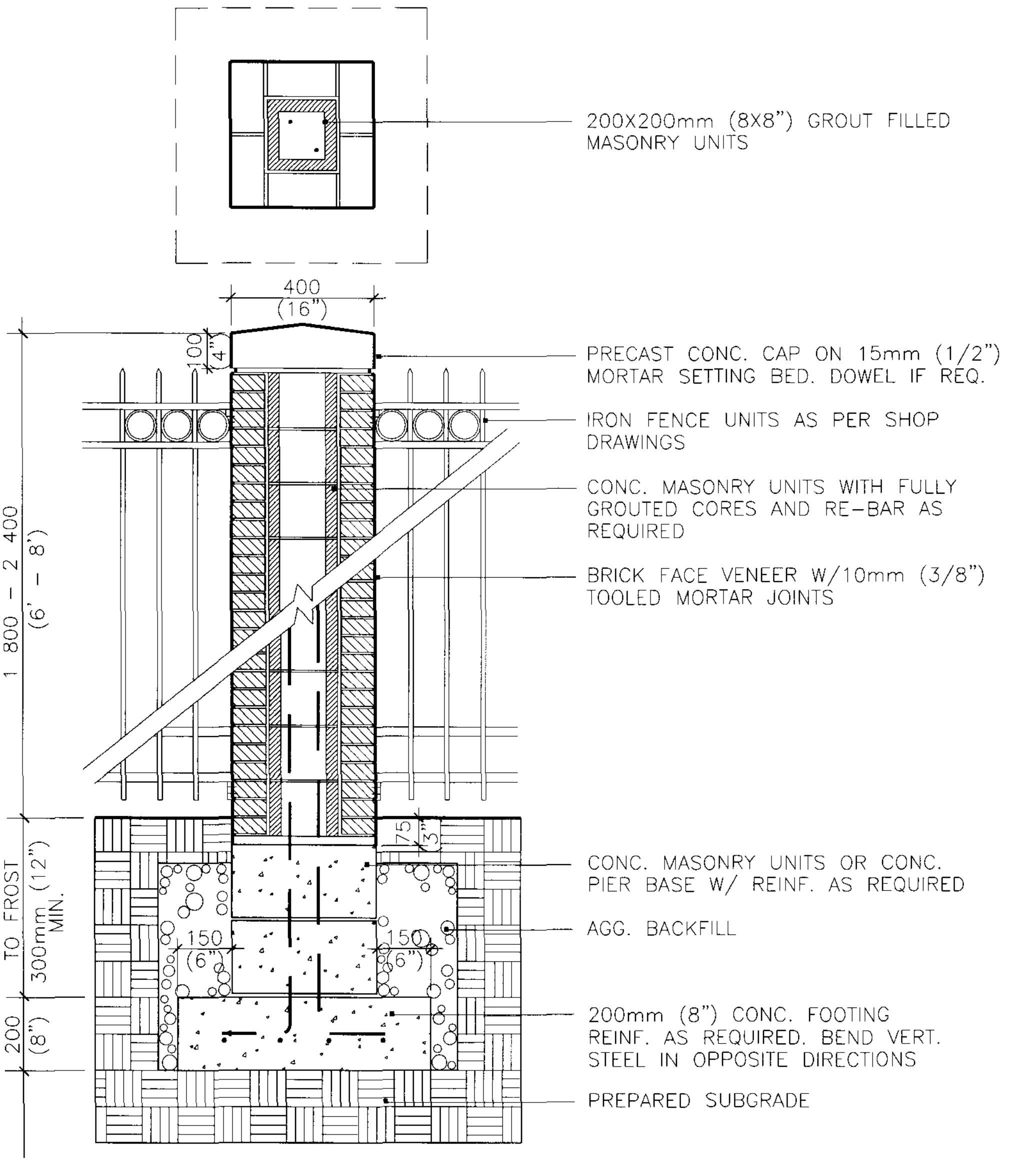


Figure 918-7 Brick fence pier with masonry core. *Classic masonry pier and iron fence. Piers may contain electrical conduit for lights.*

SECTION 919

Walls

1.0 INTRODUCTION

Free standing barrier walls may vary in height from 900-2 400 mm (3-8 ft). They are typically constructed from masonry, stone, or concrete. Design is governed by porosity and bearing capacity of site soils, and wind load conditions. With the exception of dry laid stone walls, all such barrier walls require footings and tensile reinforcement. Selected details illustrate typical applications of these walls and materials.

1.1 General Notes

Stone walls should be built of stones from the local region. Larger stones are typically laid in bottom courses. Periodic single course tie stones are useful for holding dry laid walls together, especially in cold climates. Mortared stone walls require footing below frost line in cold regions. Rake and tool all joints to avoid moisture penetration, especially at top of wall. Single width cap stone is preferred over small fitted pieces. Cap stone thickness is typically 50-100 mm (2-4 in) minimum. Avoid thin veneer caps. Small concrete walls may not require a spread footing. All walls subject to wind loads typically require a spread footing, with depth calculated for lateral sheer, or frost depth (which ever is greater). Masonry walls require steel reinforcing and fully grouted cavities, sealed with a cut cap stone or precast coping sloped to drain.

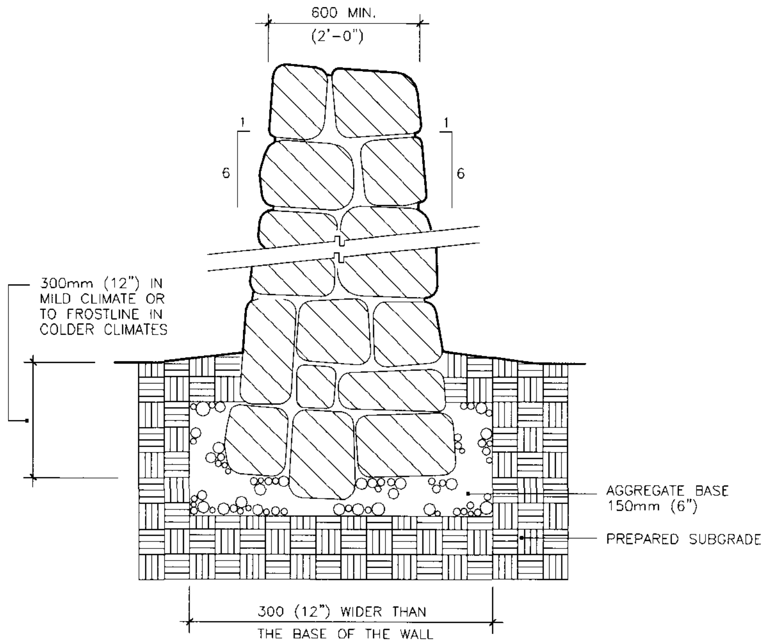


Figure 919-1. Dry laid stone wall. *Lay stone on aggregate base below frost in cold climates. Batter both sides.*

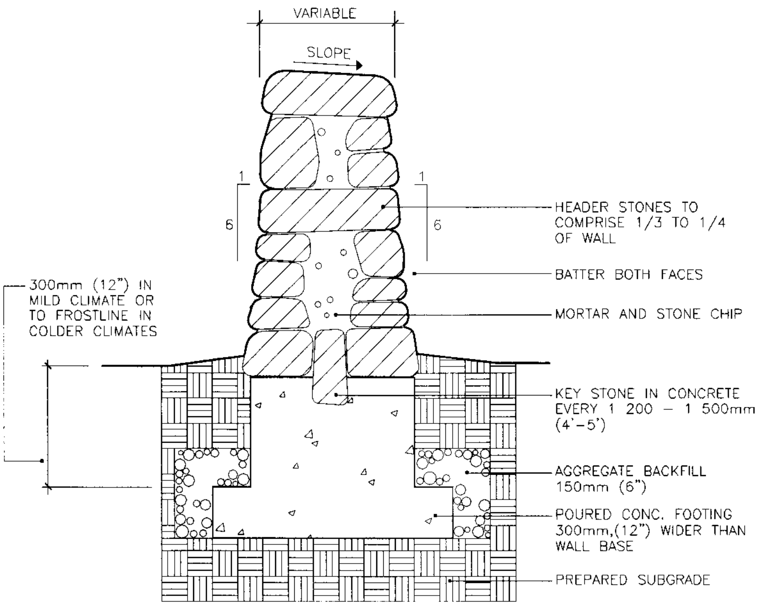


Figure 919-2. Double tier mortared stone wall on concrete footing. *Mortared stone and rubble grout core set on concrete footing base with cast key stone.*

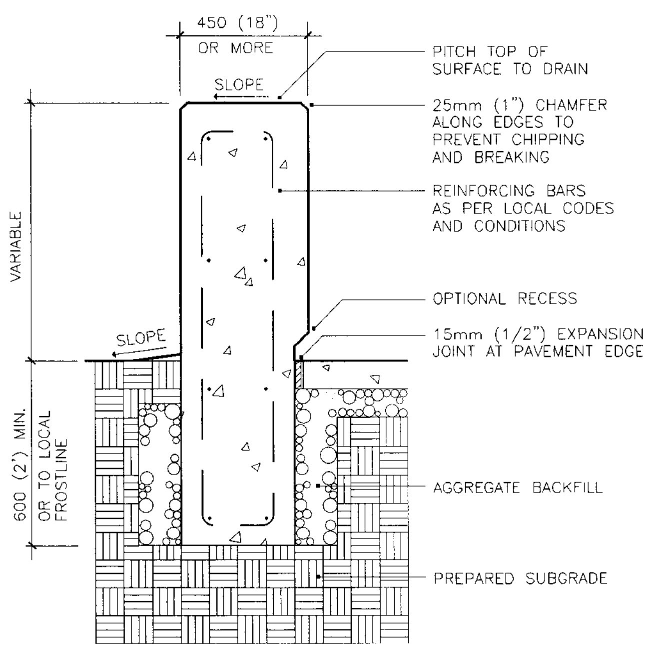


Figure 919-3. Poured concrete wall. *Short walls may not require spread footing in well drained soils. Reinforced with steel.*

919 Walls

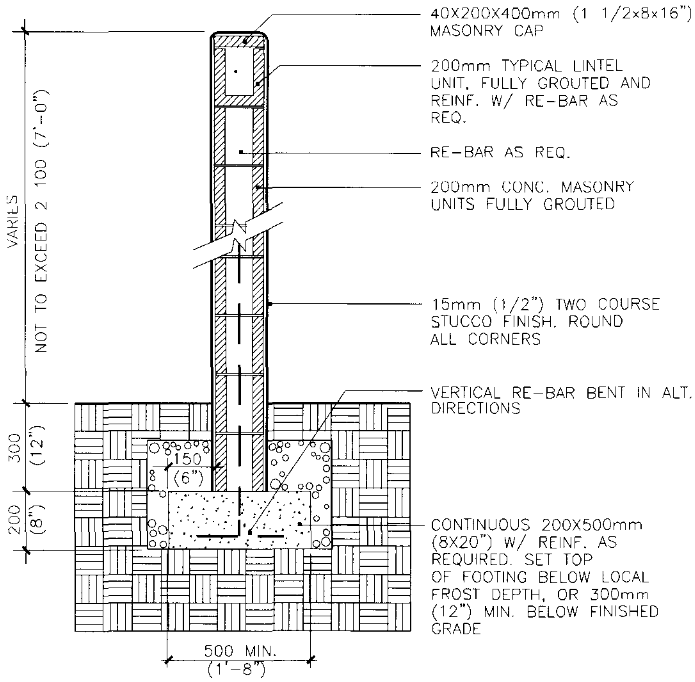


Figure 919-4. Concrete block wall with stucco finish. *Simple construction for warm climates. Steel calculated for wind loads. Full stucco.*

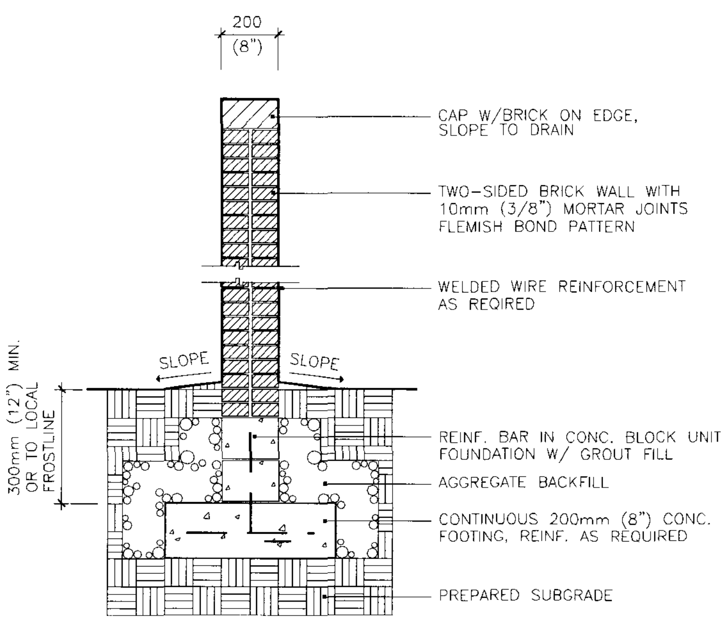


Figure 919-5. Two-sided brick masonry wall. *Typically set with Flemish bond to lock sides. Light steel bar imbedded in grout core.*

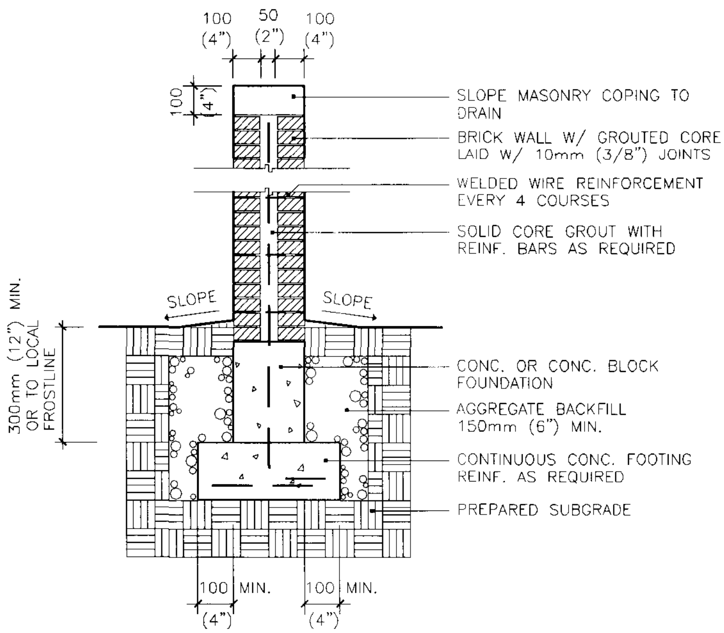


Figure 919-6. Two-sided brick masonry wall with grouted core. *Brick faces tied with wire reinforcing. Wide walls may use masonry block core.*

SECTION **920**

Retaining Walls

1.0 INTRODUCTION

Retaining walls and embankment stabilizing structures are designed to hold back vertical cuts and steep embankments required by designs in sloping terrain. The principle structural systems employ static equilibrium achieved through gravitational weight (gravity walls and rip-rap), tensile reinforcement and friction (Horizontal fabric and controlled aggregate lifts), and a combination of steel reinforcement and weight (reinforced concrete cantilevered wall). All systems are derived from soil mechanics of specific soil groups. Final proportions and dimensions are determined from such structural soil properties as cubic weight, bearing capacity, shearing or internal friction angle, friction coefficient, and permeability. Soils are divided into colloidal and granular types for the purpose of design. The selected details in this section display examples of these common structural systems.

1.1 General Notes

Embankments greater than 1:1.5 typically exceed the natural angle of repose of most soils. Bank reinforcement in such circumstances usually consists of aggregates, stone, or masonry units of sufficient weight to counteract the slope's tendency to slip along its shearing plane. The top of slope should be graded to prevent sheet flow runoff from washing across the slope. The toe of slope often requires a grade beam or stone reinforcement to withstand the accumulated embankment surface weight. Vegetative reinforcement may require irrigation. Dry soil plants are recommended. Gravity wall base is typically 0.45 to 0.60 H, depending on soil type. Stone walls typically require a 600 mm (2 ft) top width. Dry stone walls usually require no footings. Mortared or concrete gravity walls require footings below local frost depth. Most codes require at least a 300 mm (12 in) soil cover over top of footing in warm climates. Cantilevered walls and all rigid construction require weep hole and back drains to relieve hydrostatic pressure when applicable. Tops of walls should slope back away from the face to prevent staining. Some conditions may require an impermeable swale at top of wall to prevent infiltration in cold or colloidal soil conditions.

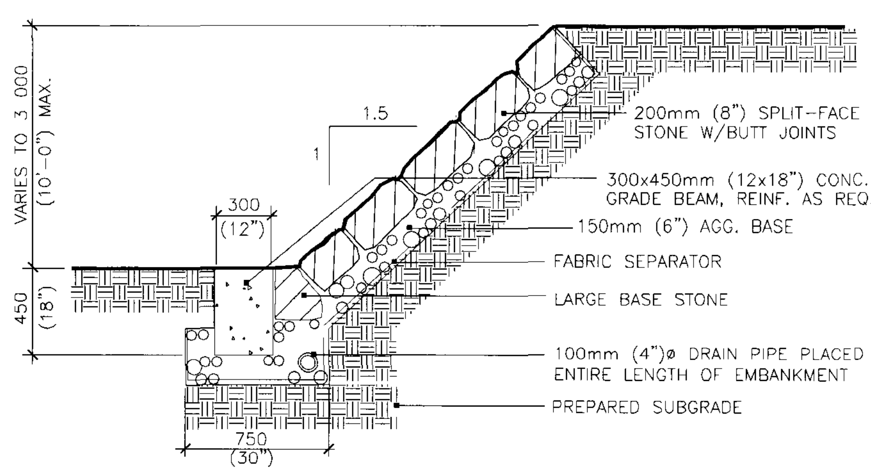


Figure 920-1. Stone retaining embankment. *Stone thickness and weight are determined by soil pressure. Non-porous stone preferred.*

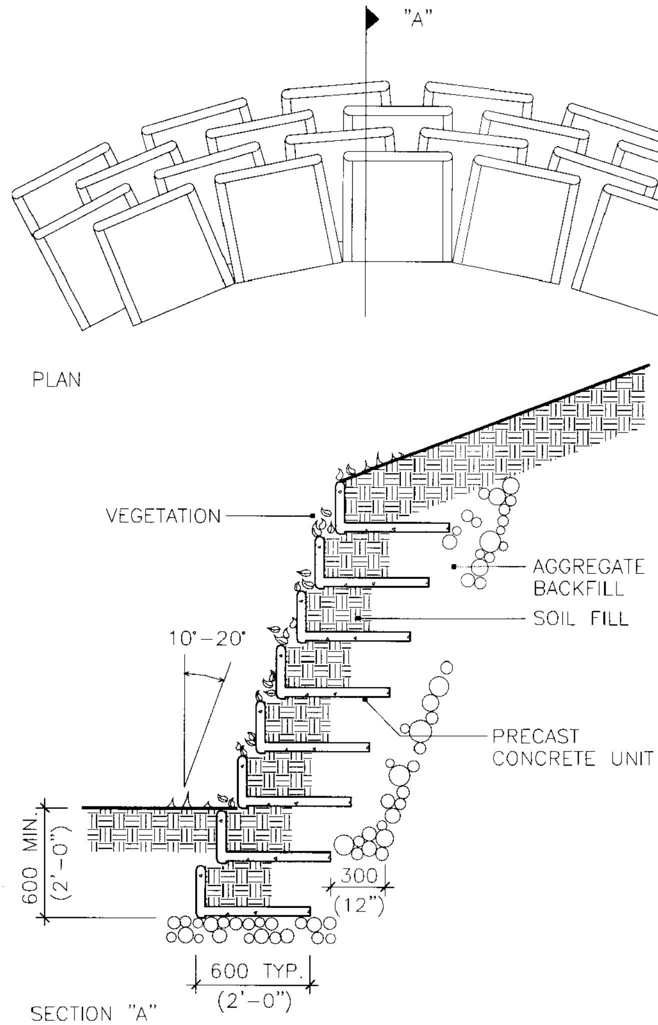


Figure 920-2. Vegetative retaining wall. *Wall units may create a curved face. Not recommended in wet clay soils.*

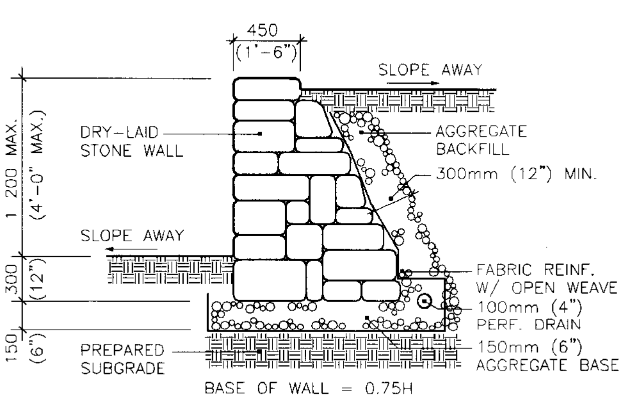


Figure 920-3. Dry-Laid Stone Retaining Wall. *Adaptation for clay soils with fabric separator, aggregate base, and subdrain locations.*

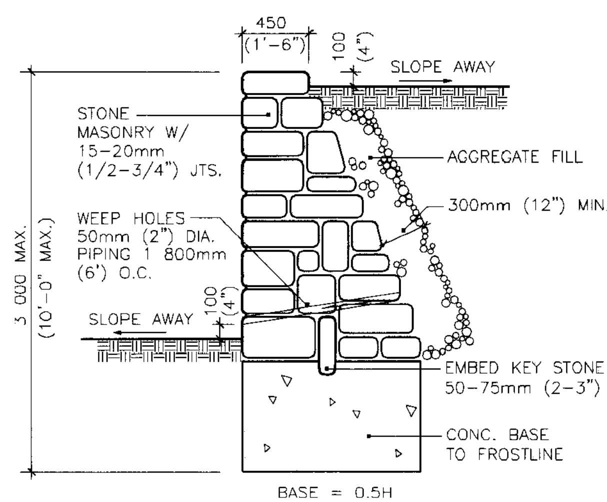


Figure 920-4. Mortared stone gravity retaining wall. *Cast keystone set in concrete base on prepared subgrade. Wall has deep-raked joints.*

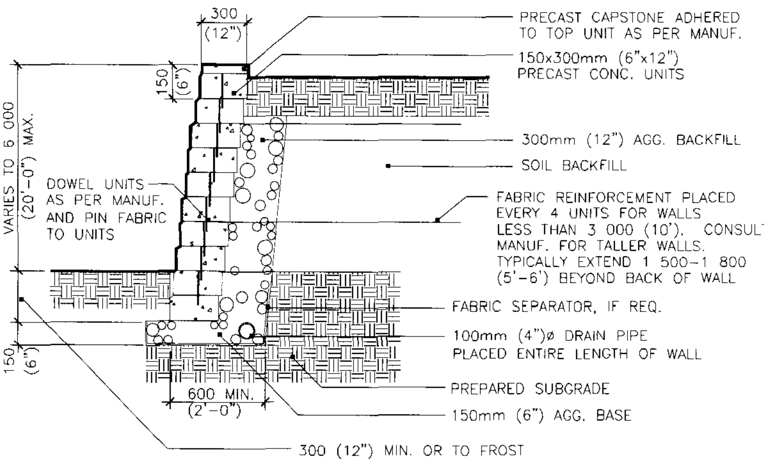


Figure 920-5. Concrete unit retaining wall. *Precast stack and pin system with fabric reinforcement in high walls.*

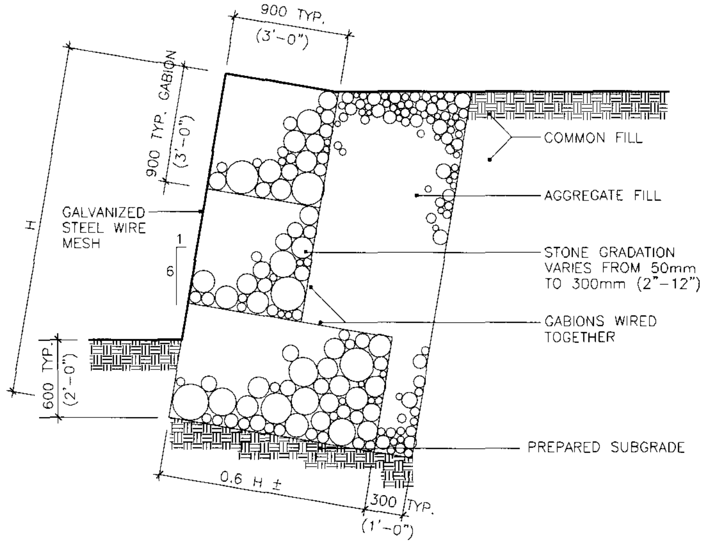


Figure 920-6. Gabion retaining wall. *Subgrade may require aggregate leveling course. Units are joined and pinned on-site.*

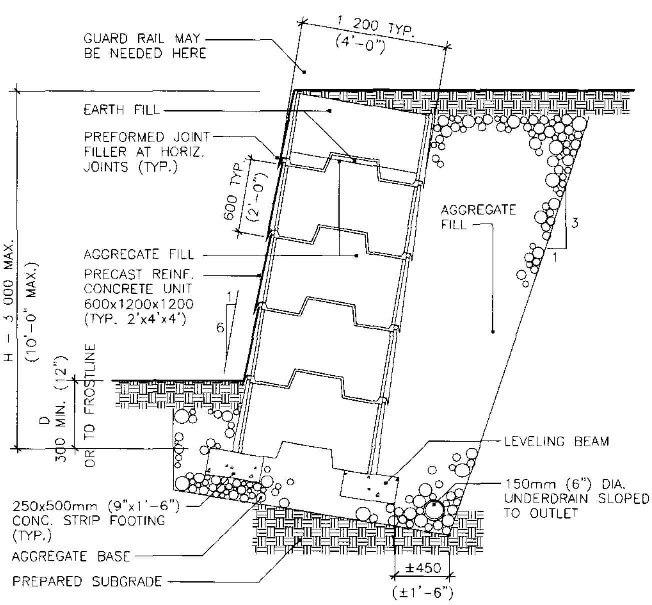


Figure 920-7. Concrete bin wall. *Use wider leveling beams for broader base bearing. Subdrain is essential.*

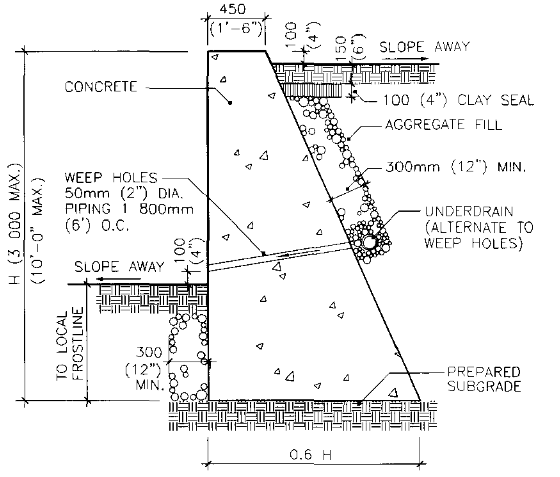


Figure 920-8. Concrete gravity retaining wall. *Typically placed on prepared subgrade. Clay soils may require aggregate and fabric.*

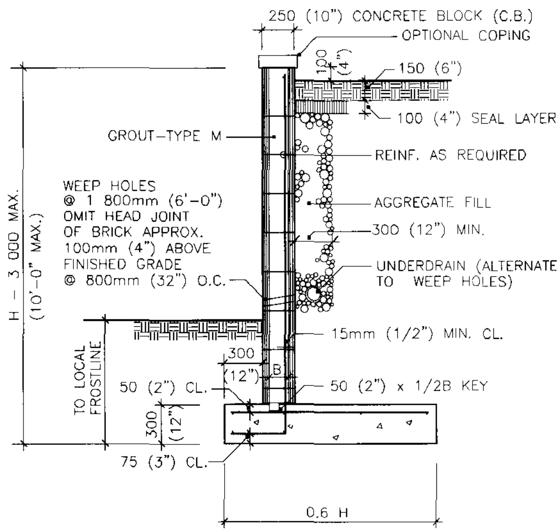


Figure 920-9. Concrete block cantilevered wall. *Best in well drained soils. Fully grouted and reinforced, may require damp-proofing.*

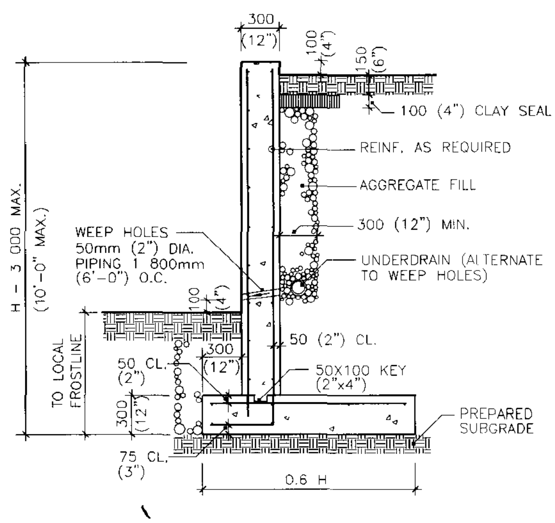


Figure 920-10. Reinforced concrete cantilevered wall. *Stem shown in front third of base. Stem may thicken at base in clay or surcharge loading.*

Seatwalls

1.0 INTRODUCTION

Seatwalls are typically integrated into a design and serve multiple purposes, such as containing plantings, acting as barriers, or providing transitional level changes. To act as seating walls, the height is restricted to a range of 400-600 mm (16-24 in) with 450 mm (18 in) preferred. Material finishes should respect the design vocabulary and the local climate. Seatwalls are high maintenance elements due to the continuous human contact. Surfaces should be smooth to avoid abrasions and snagging of clothing. Selected details illustrate design expressions using a range of finish materials.

1.1 General Notes

Except for informal garden walls, most seatwalls require footings and careful backfilling to account for dampness and drainage. Top of wall may range in width from 400-600 mm (16-24 in), but 600 mm (24 in) is more accommodating to a broader population of users. Slope top of wall back from face to drain for better appearance and anatomical fit. Damp proof masonry block walls if containing irrigated planting areas. Provide weep holes or back drains in poorly drained soils.

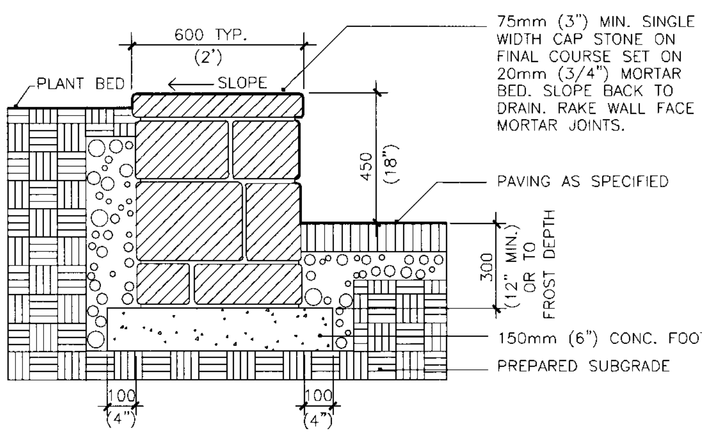


Figure 921-1. Mortared stone seatwall. *May be laid loose with no footing, but use gauged ground top stone with mortar shims.*

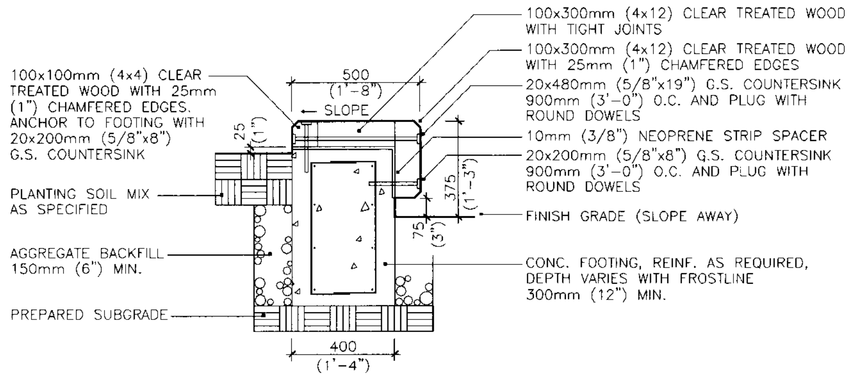


Figure 921-2. Wood veneered seatwall. *Built-up seat using treated planks. Use shims to separate wood from concrete base.*

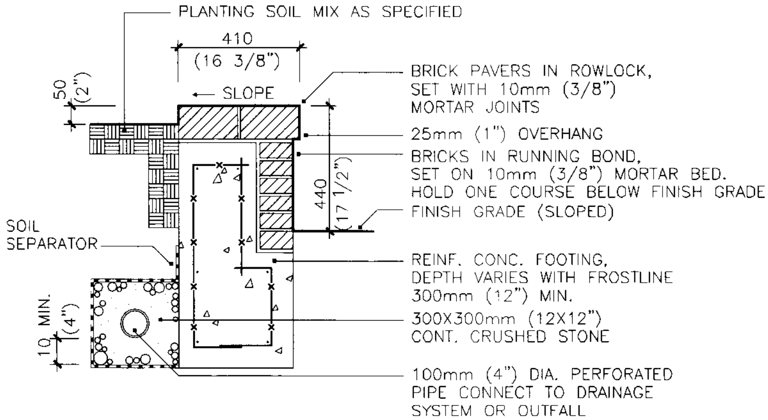


Figure 921-3. Brick veneered seat-wall with subdrain. *Classic brick veneer wall. May use concrete block core instead. Drain for poor soils.*

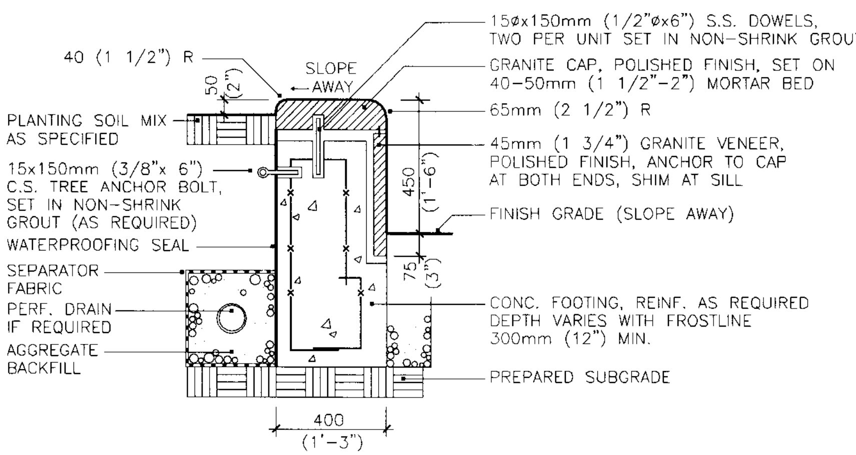


Figure 921-4. Granite veneered seat-wall. *Seal all mortar joints and damp proof back and veneer joint at soil line. Use channel pins.*

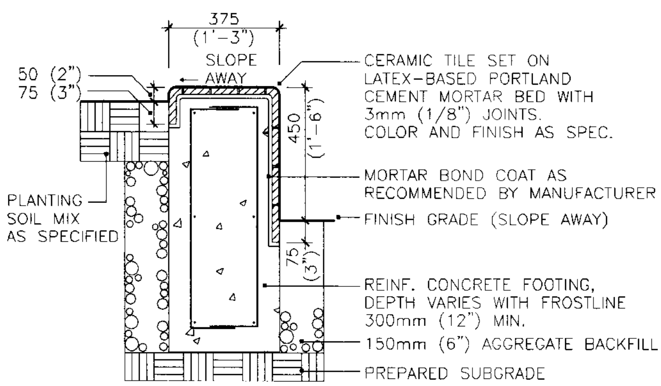


Figure 921-5. Ceramic tile seatwall. *Restricted to warm dry climates. Provide concrete inset to receive tile as shown.*

Lighting

1.0 INTRODUCTION

Site lighting includes accent ornamental lighting for plantings and buildings, pedestrian circulation lighting, vehicular lighting, and large area lighting associated with athletic events or major facilities and industrial plants. Site lighting requires organization of fixtures to create the specified coverage and light intensities, and organization of conduits to avoid conflicts with other utility systems. Fixture designs are specific for glare control and illumination pattern to comply with code restrictions and should be selected accordingly. Low voltage systems should be used whenever possible to reduce energy consumption. The following selected details illustrate examples from these categories.

1.1 General Notes

Small fixtures are typically direct burial systems. Commercial grade fixtures are typically mounted on a concrete pier with cast-in-place conduit feeds. Most conduits under paved surfaces require at least 600 mm (2 ft) of soil cover. Residential wiring may allow direct burial in non-paved areas. Conduits are recommended for high quality site work. Post and pole piers are typically 10% of the pole height plus 600 mm (2 ft) in depth. Clay soils and windy sites may require deeper and thicker piers. In cold climates, all pier footings are set below frost line to prevent heaving and to maintain plumb alignment.

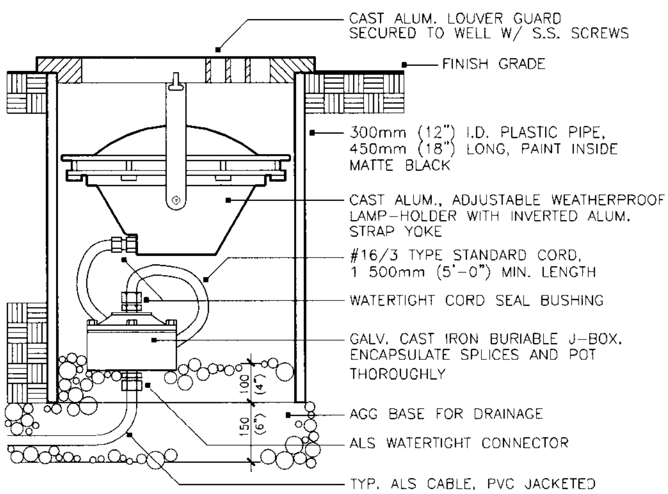


Figure 922-1. Up light-below grade in planting bed. *Pre-formed casings are set on aggregate base to house waterproof junction and fixture.*

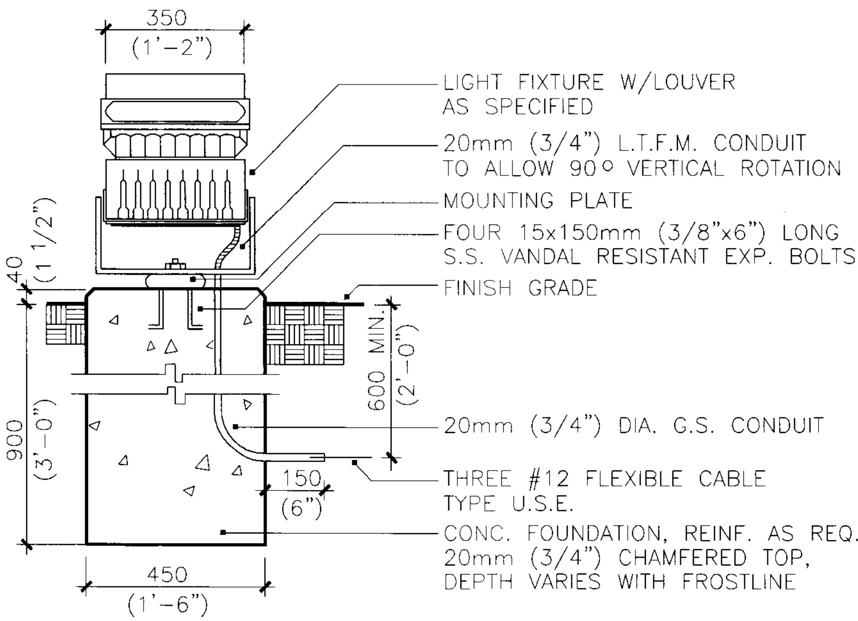


Figure 922-2. Up light-above grade. *Typical wall washer or up-light requires protection and baffle in traffic area.*

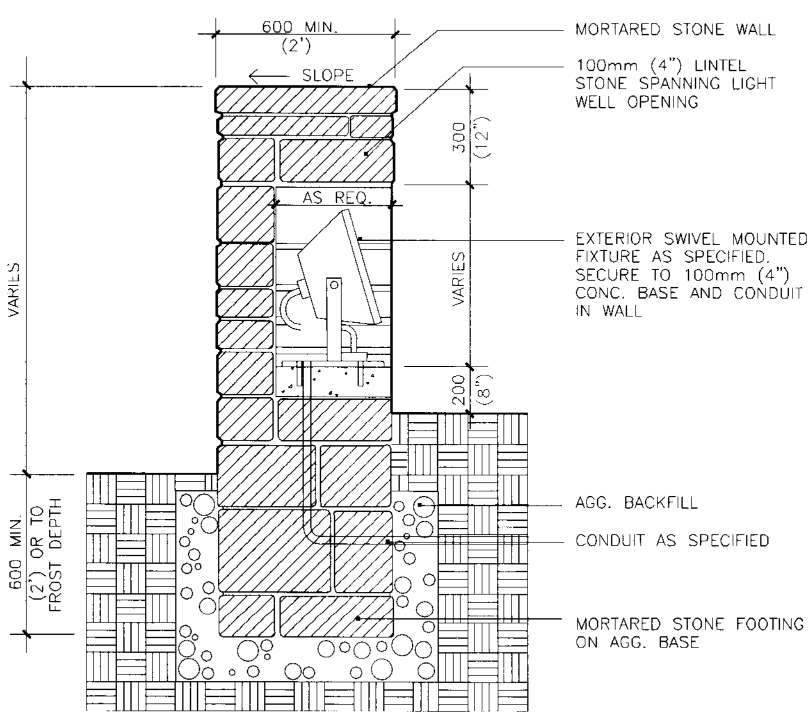


Figure 922-3. Wall wash light set in stone wall. *Stone wall used to conceal an architectural wall wash light and protect unit from traffic.*

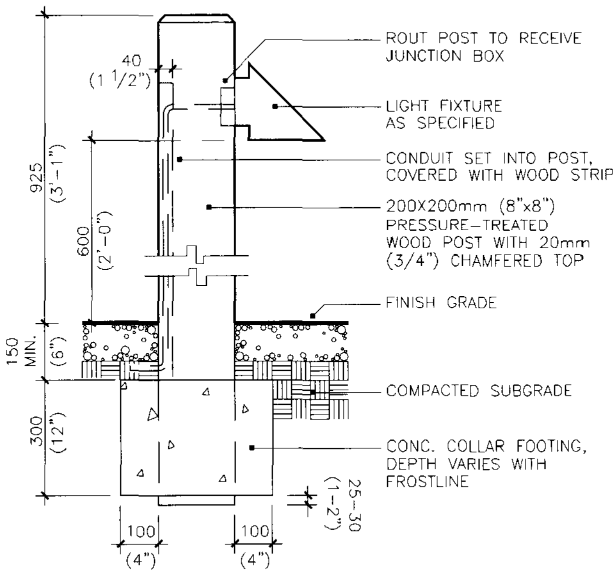


Figure 922-4. Wood bollard light. *Direct burial common, concrete collar may be placed at base, below conduit. Post is routed.*

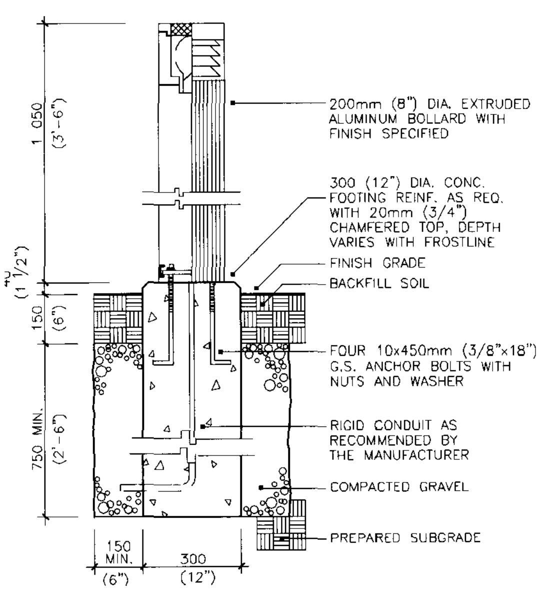


Figure 922-5. Metal bollard light. *Requires concrete pier footing with attachment bolt plate as per manufacturer.*

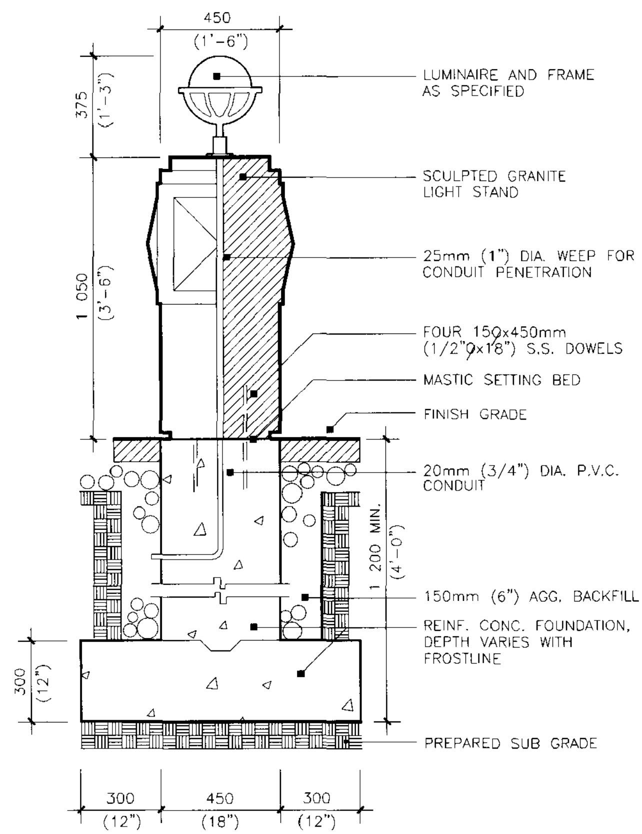


Figure 922-6. Light standard with sculptured granite stand. *Carved granite stand pinned to concrete pier and set with epoxy mastic and sealed.*

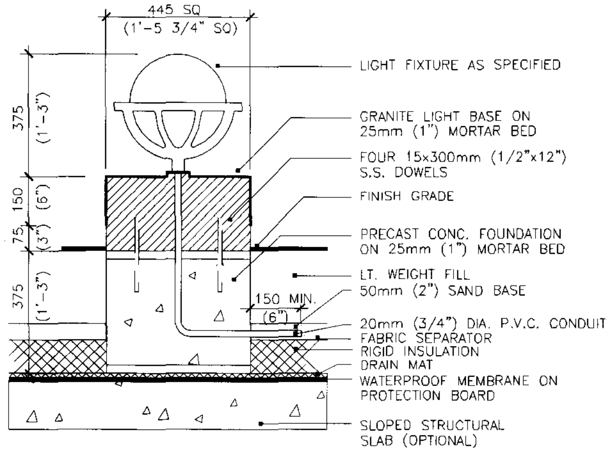


Figure 922-7. Granite stand area light-on structure. *Lightweight concrete or masonry base mortared onto drain mat. Fixture doweled to base.*

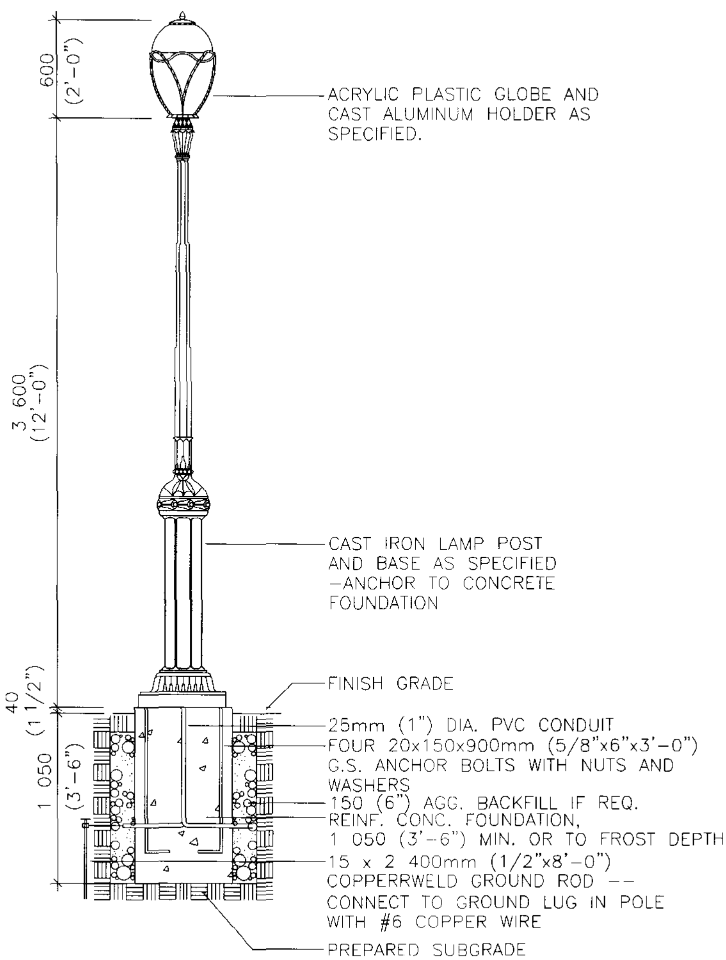


Figure 922-8. Historic walkway light. *Cast iron or polymer pole is bolted to concrete pier containing conduit and connection box.*

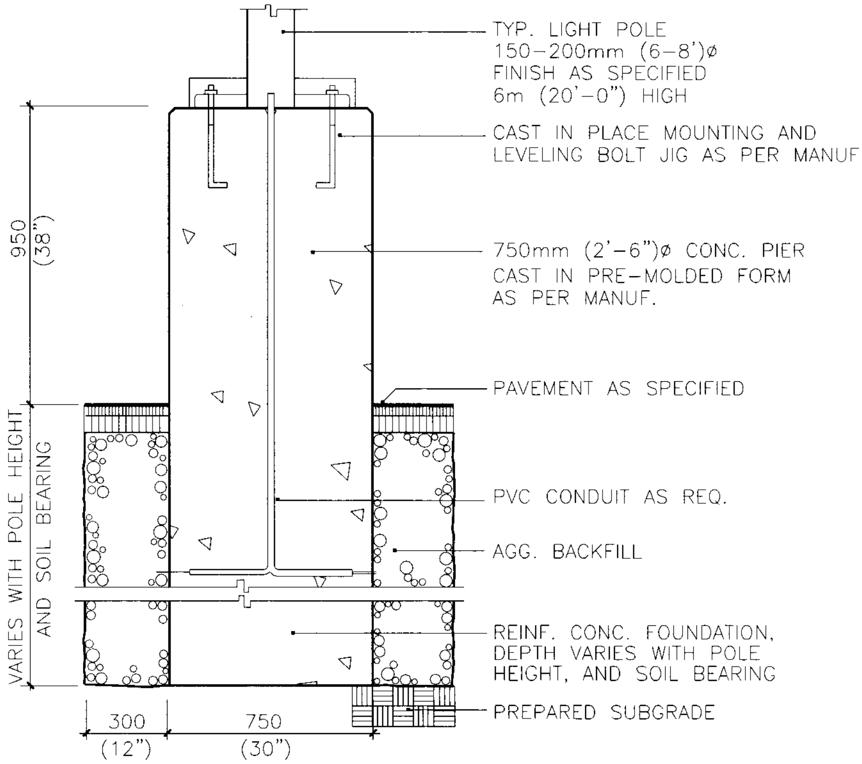


Figure 922-9. Vehicular light with raised footing. *Heavy duty pier for use in parking lots to protect fixture pole from damage.*

SECTION 923

Planting

1.0 INTRODUCTION

Planting typically encompasses large, medium, and small trees, shrubs, ground covers, grasses and turf, herbaceous perennials, bulbs, corms, and annuals. American practices are guided by the American Nurseryman's Association Standards with regard to plant material sizes and planting procedures. The planting details presented in this section refer to selected large trees and shrubs.

1.1 General Notes

Successful tree planting begins with healthy plant material which has been protected from transportation stress. Tree pits should be at least twice the size of the container or tree ball, but three to four times the diameter is recommended where space permits. Large trees should be placed directly on prepared subgrade at the tree pit center to avoid settlement. Inorganic containers and wrappings should be removed, while the top third of cloth wraps should be cleanly cut and removed before back filling. Backfill soil should be screened and prepared to specification as per species requirements, and placed in controlled 150 mm (6 in) lifts to avoid air pockets and to anchor the rootball to prevent lateral shifting. Palms may require water jet saturation for proper seating. It is common practice to place the root crown level with, or slightly above finish grade. In all cases except pavement plantings, a tamped soil saucer rim should be formed around the tree pit surface to retain water. Mulching is recommended for lowering root temperature and preventing evaporation. Staking and guying are only recommended for windy sites. Trunk wrapping is not generally recommended.

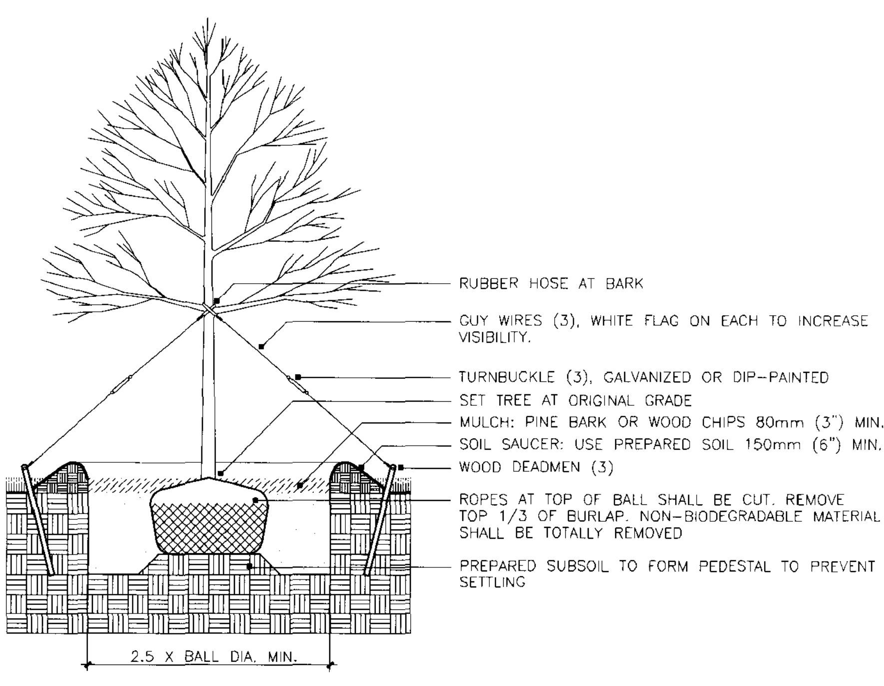


Figure 923-1. Deciduous tree planting. *Large tree staked and guyed for windy site.*

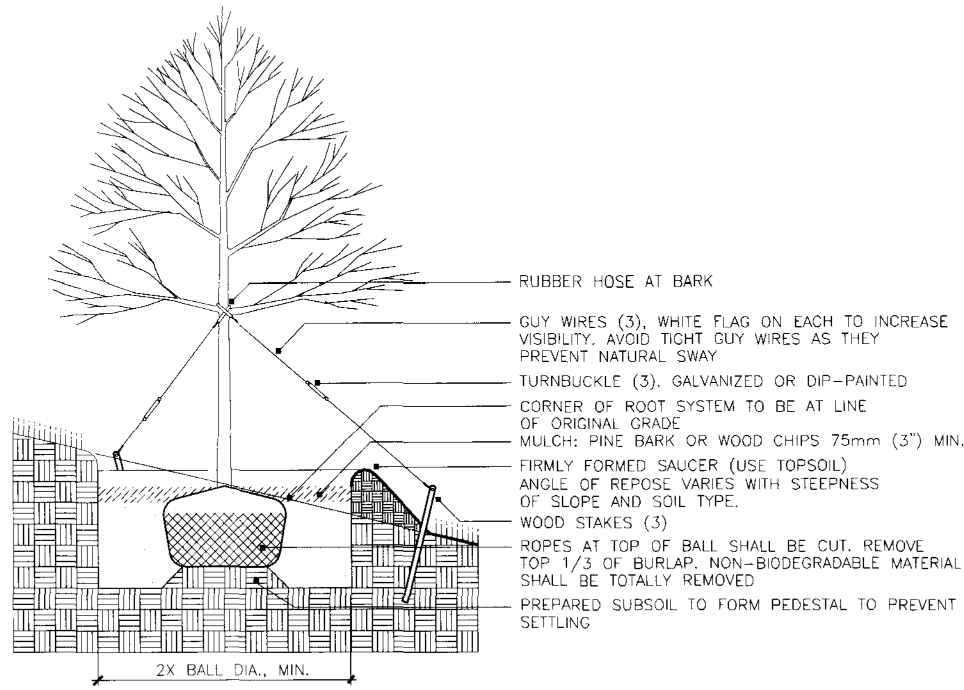


Figure 923-2. Deciduous tree planting on slope. *Set ball height at slope plane, and build large saucer with tamped earth. Guy if windy.*

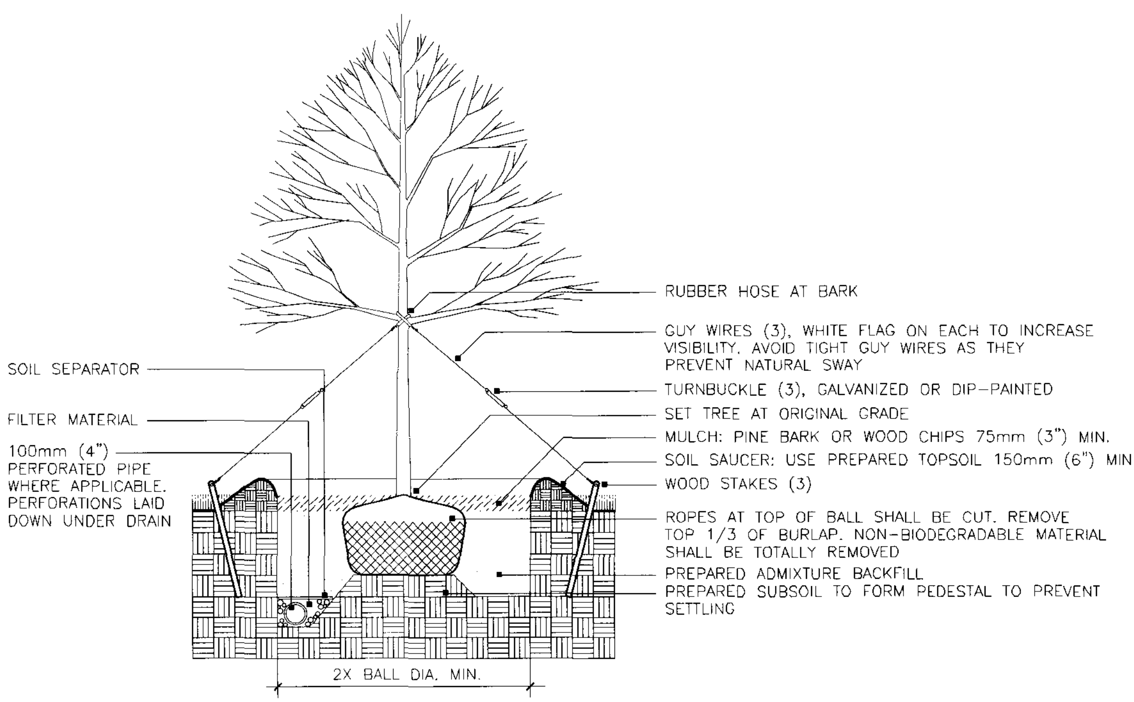


Figure 923-3. Deciduous tree planting with subdrain. *Set subdrain at edge of tree pit. Used for wet soils or excavated stratified rock.*

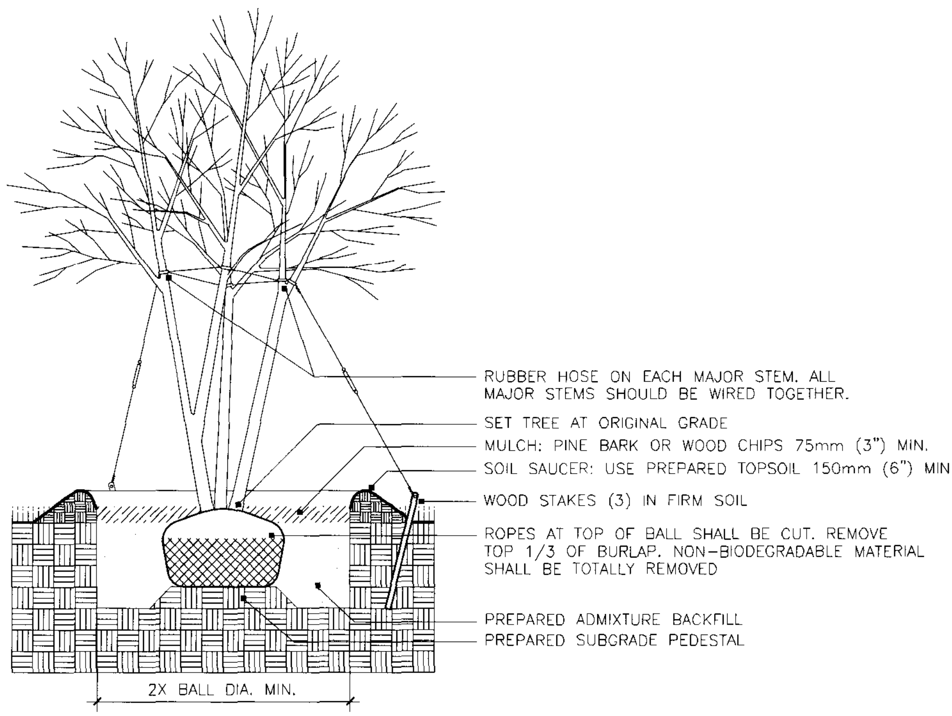


Figure 923-4. Multi-stem tree planting for windy sites. *Guy internal stems to limit branch movement on windy sites.*

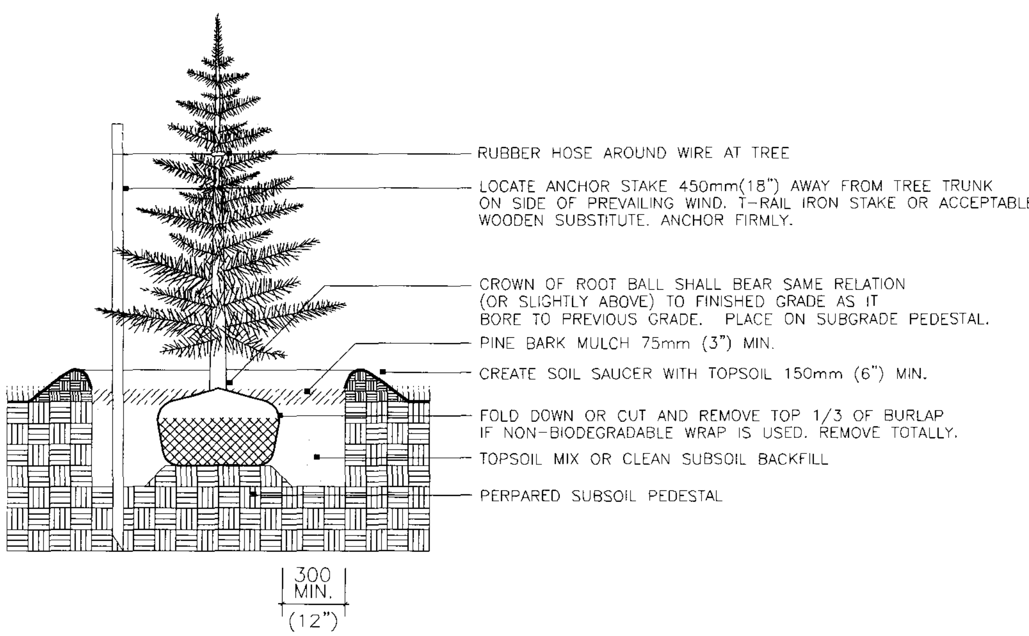


Figure 923-5. Coniferous tree planting. *Use single stake for prevailing winds, or three stakes for swirling winds.*

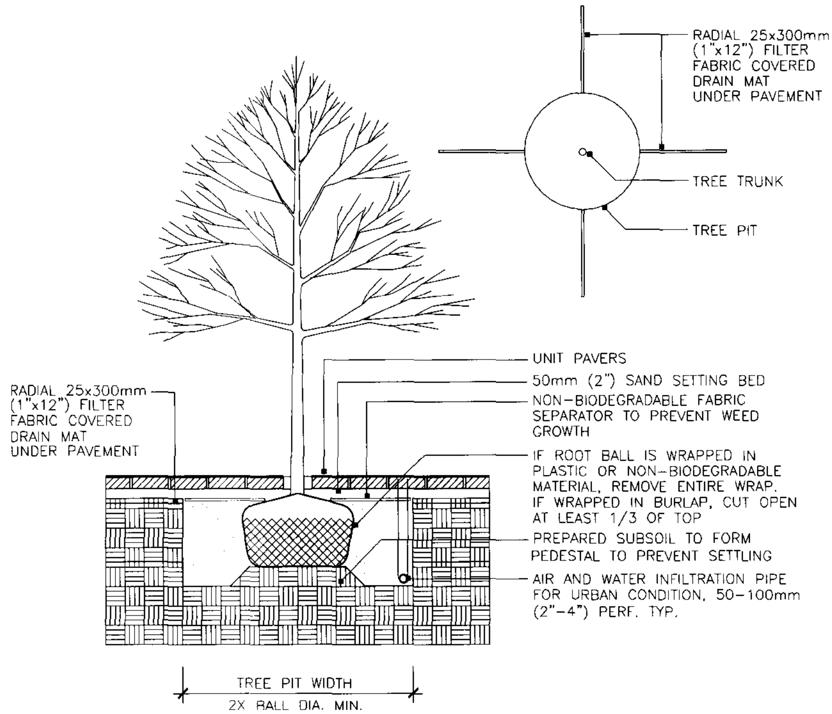


Figure 923-6. Deciduous tree planting in unit pavement. *Drain mat trenches radiate from tree pit. Aeration and feeder pipes connect other trees.*

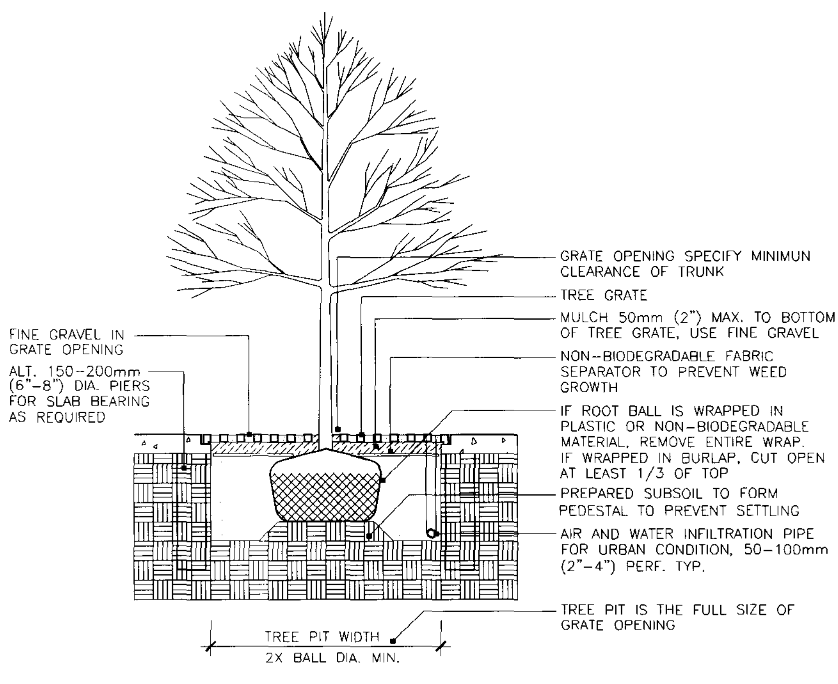


Figure 923-7. Deciduous tree in suspended pavement with metal grate. *Suspended pavement on concrete piers. Aeration and feeder pipes connect to other trees.*

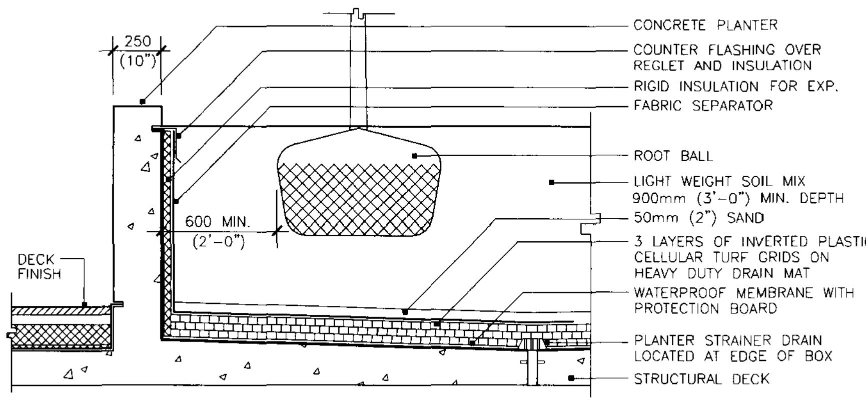


Figure 923-8. Deciduous tree in planter on structure. *Planting medium and tree ball rests on inverted plastic turfgrids. Drain at edge of planter.*

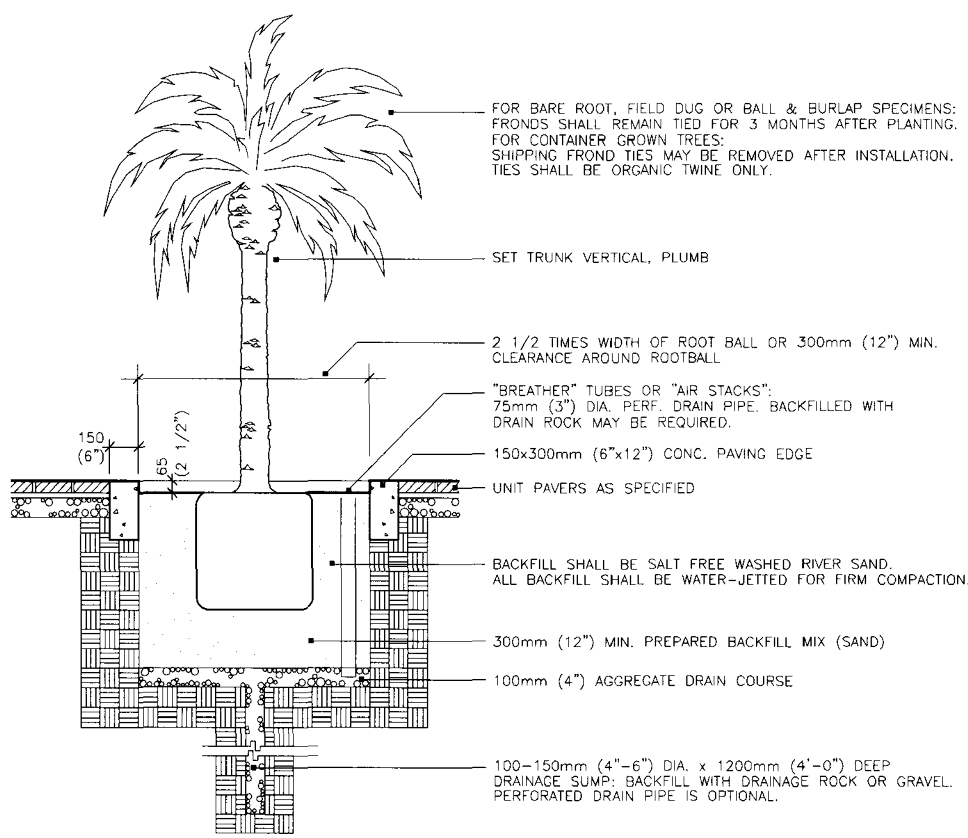


Figure 923-9. Palm tree planting in paving. *Amended backfill is hydro-slurried into pit. Pedestal supports tree prior to backfilling.*

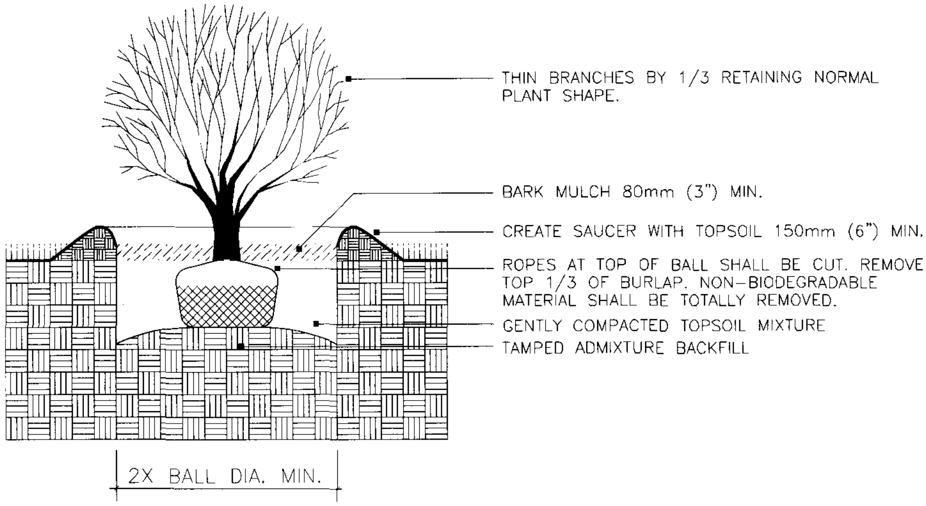


Figure 923-10. Shrub planting-ball and burlap. *Tamp mound at hole base to support ball. Soak generously to compact and settle.*

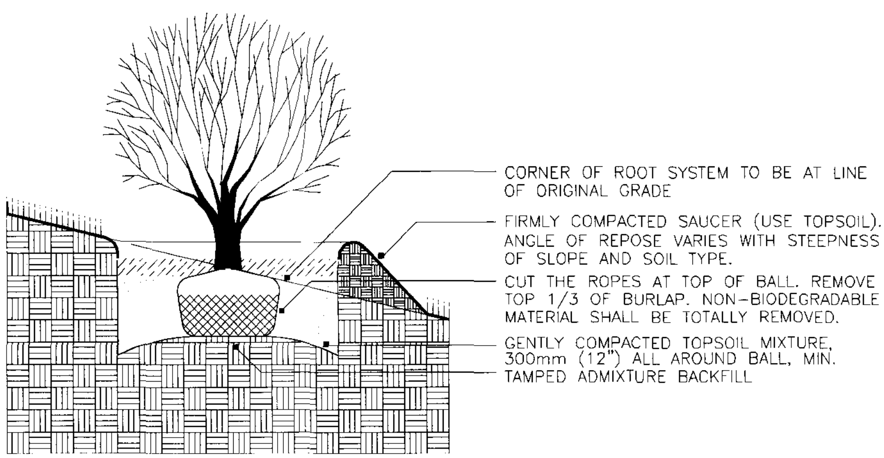


Figure 923-11. Shrub planting on slope- ball and burlap. *Place root crown at slope plane. Tamp saucer rim and add mulch to contain water.*

SECTION 924

Drains

1.0 INTRODUCTION

Site drains receive water at low points for infiltration, diversion, or disposal to site outfalls. Drain inlets should be durable and appropriate for the climate zone. Infiltration devices should only be used in sufficiently porous soils. Long term care requires periodic cleaning and sealing of joints and re-setting of grates and finish pavements or turf grades due to settlement or silting. Selected details illustrate a range of drain types for various applications.

1.1 General Notes

Locate drains at the edge of use areas. Drain pavements onto turf areas before collecting if possible. Avoid discharging sheet flow runoff from turf areas onto pavements to avoid silting and staining, especially in freeze/thaw regions. Allow 750 mm (2 ft-6 in) soil cover over pipes subject to vehicular loading. Set inlet footings below frost in cold regions. Plastic grates and frames should be confined to turf areas in cold regions. Warm regions may set drain pipes at shallow depths, but care should be taken to guard against crushing in pedestrian walking zones. When joining a small pipe to a large pipe, the crown of the small pipe can be set no lower than the crown of the large discharge pipe within a basin.

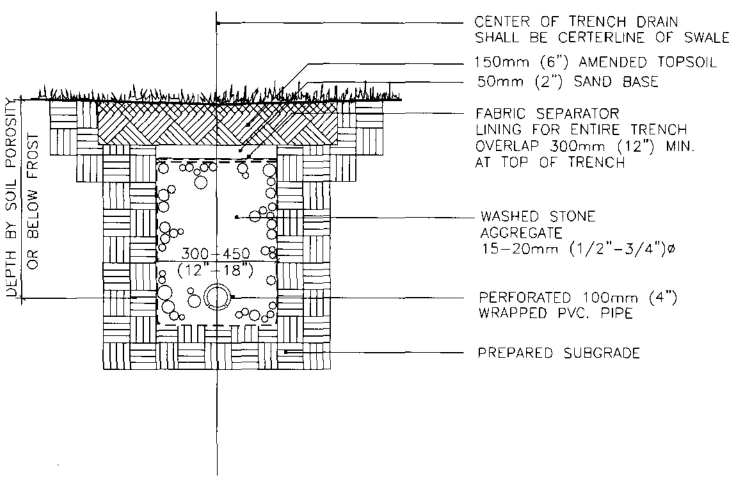


Figure 924-1. Perforated pipe curtain drain. *For infiltration and for draining moist soils. Sand filter required for fine soils.*

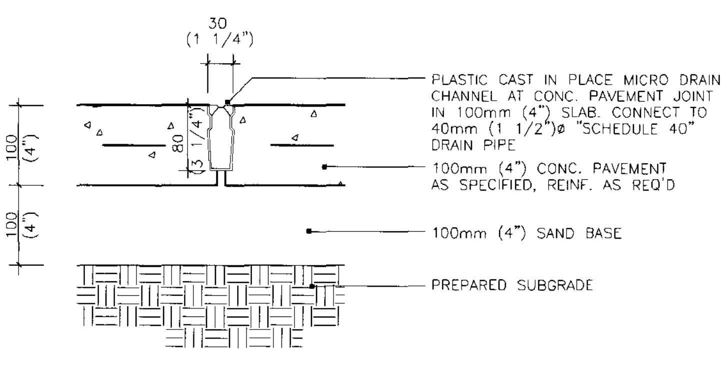


Figure 924-2. Polymer pavement strip drain. *Various sizes for cast slab applications available. Warm climates only.*

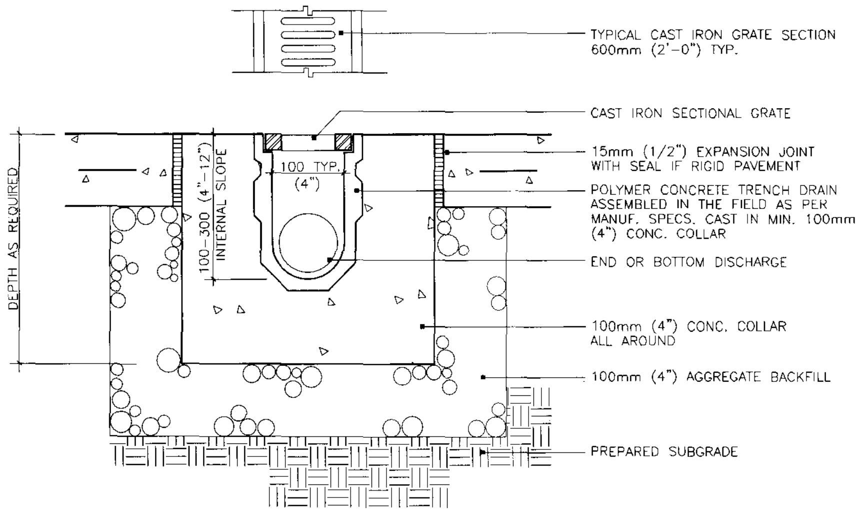


Figure 924-3. Polymer trench drain in concrete. *Segments lock together. Various grate types available. Warm to temperate zones.*

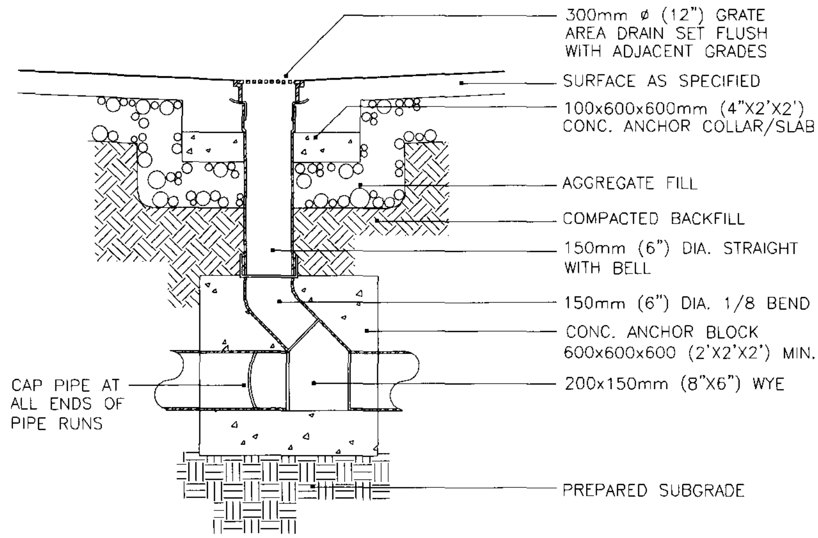


Figure 924-4. Small area drain. *Inexpensive grate and frame attached to pipe riser set in concrete collar. (Plastic and metal.)*

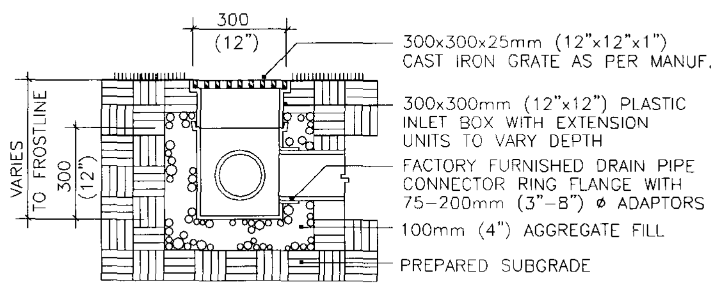


Figure 924-5. Plastic drain inlet in turf area. *Plastic inlets have modular depth rings and cleanout sumps. Warm to temperate zones.*

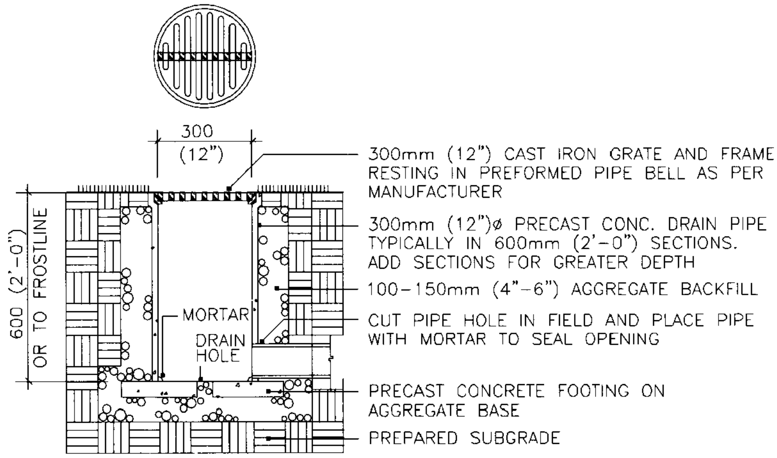


Figure 924-6. Precast concrete pipe drain inlet. *Standard pipe and grate units set on precast wedges for stability. Drain hole cut on-site.*

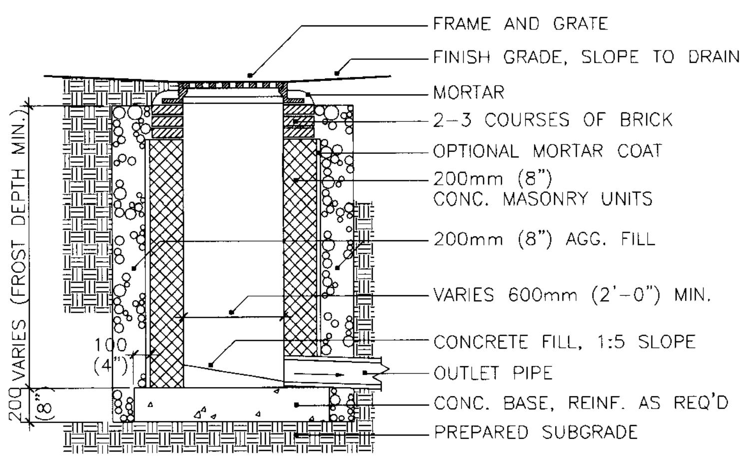


Figure 924-7. Concrete masonry drain inlet. *Concrete block or brick walls with standard frame and grate. Footing required.*

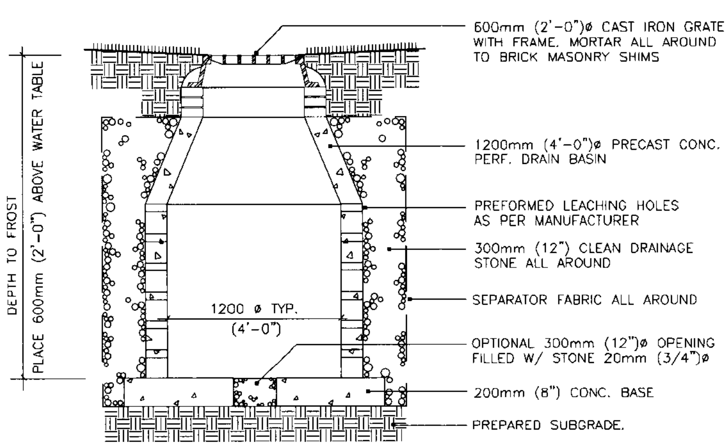


Figure 924-8. Precast concrete infiltration basin. *Precast stormwater infiltration basin. Requires well drained soils and fabric separator.*

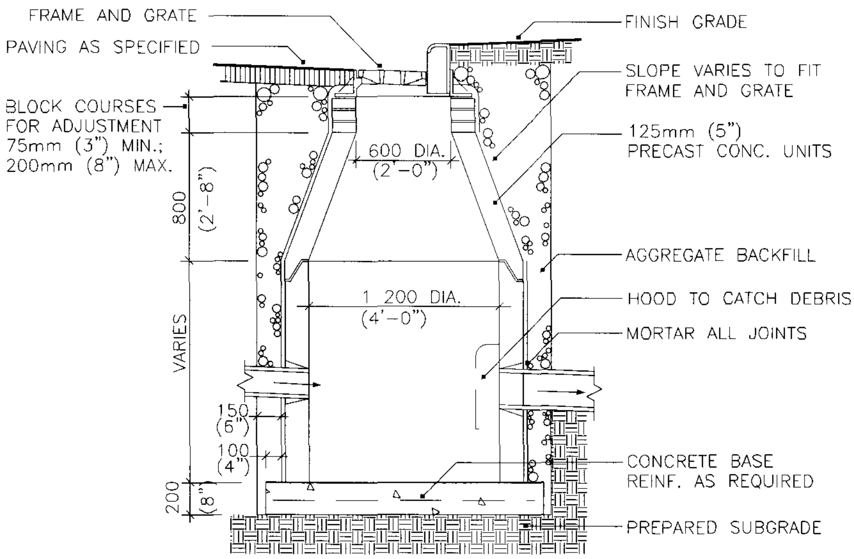


Figure 924-9. Precast concrete catch basin at curb. *Many standard shapes and sizes available for storm and sanitary sewer work.*

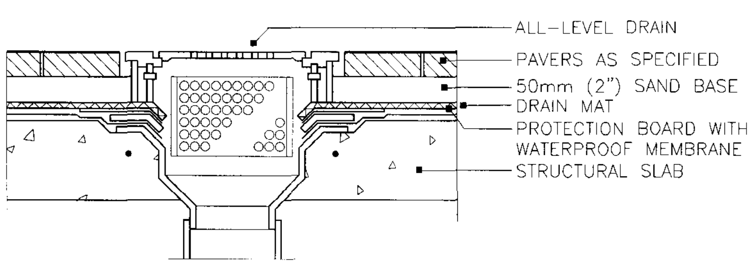


Figure 924-10. Surface drain on structure. *Typical roof drain fitted to accommodate pedestrian pavement in roof garden setting.*

SECTION **925**

Swales

1.0 INTRODUCTION

Drainage swales vary in design by lining type, cross section shape, volume, and velocity potential. It is a general practice to create broad low velocity swales with high infiltration capacity to reduce over-all runoff volume when ever possible. Some swales serve as channels to deposit large volumes of water into detention or retention ponds and require impermeable or erosion resistant linings. The details selected illustrate heavy duty applications using various lining and cross section strategies.

1.1 General Notes

A parabolic turf swale is ideal for achieving low velocity moderate volume runoff capacity. Generally, a swale velocity of a given slope, for a given volume may be reduced by broadening its cross section and reducing its full flowing depth. High velocity swales require durable lining to withstand the scouring potential of moving water. Deposition of fines occur at about .75 m/sec (2.5 ft/sec), and severe scouring of structural linings can occur at 3-4.5 m/sec (10-15 ft/sec). Maintain swale velocity approaching an outfall to prevent silt deposition. Infiltration swales usually require a fabric separator under stone to prevent upward migration of fines into the water stream when at full capacity. Fiber matting, hydro-seeding, or sodding help to hold the swale channel while seeding germinates.

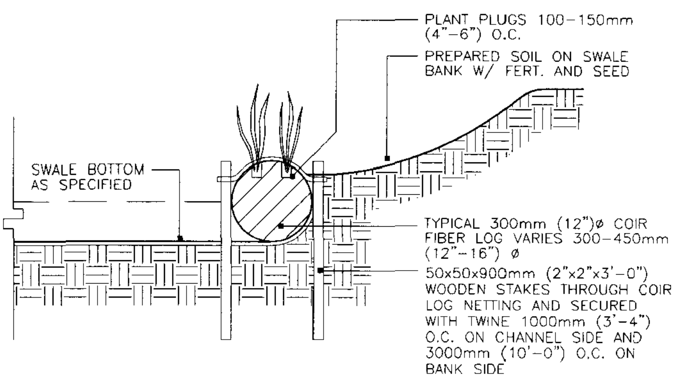


Figure 925-1. Swale with fiber-log channel edge. *Swale channel requires permanent pool level to support initial plant growth in fiber log.*

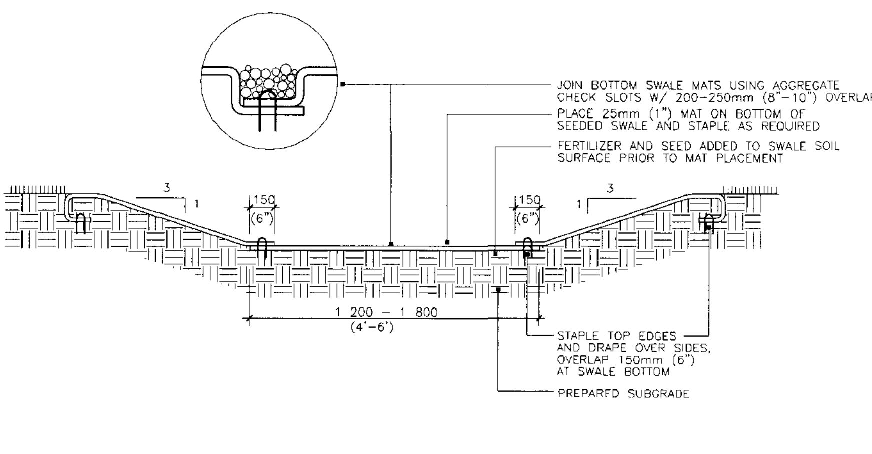


Figure 925-2. Fiber-mat swale reinforcing. *Used in highly erodable soils to protect swale banks during seed germination.*

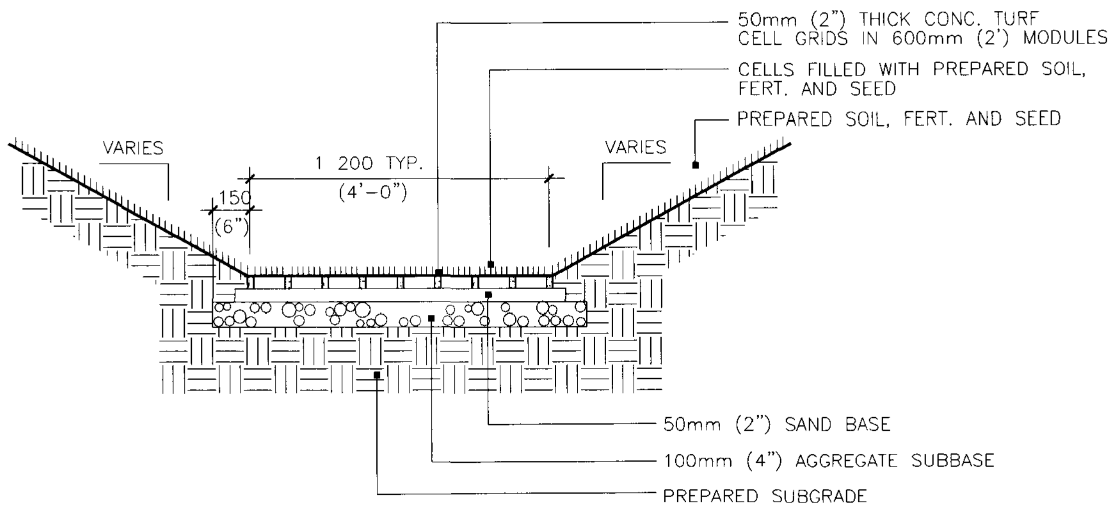


Figure 925-3. Concrete cellular turfgrid swale. *Used for heavy runoff and infiltration strategies. Requires well drained soils.*

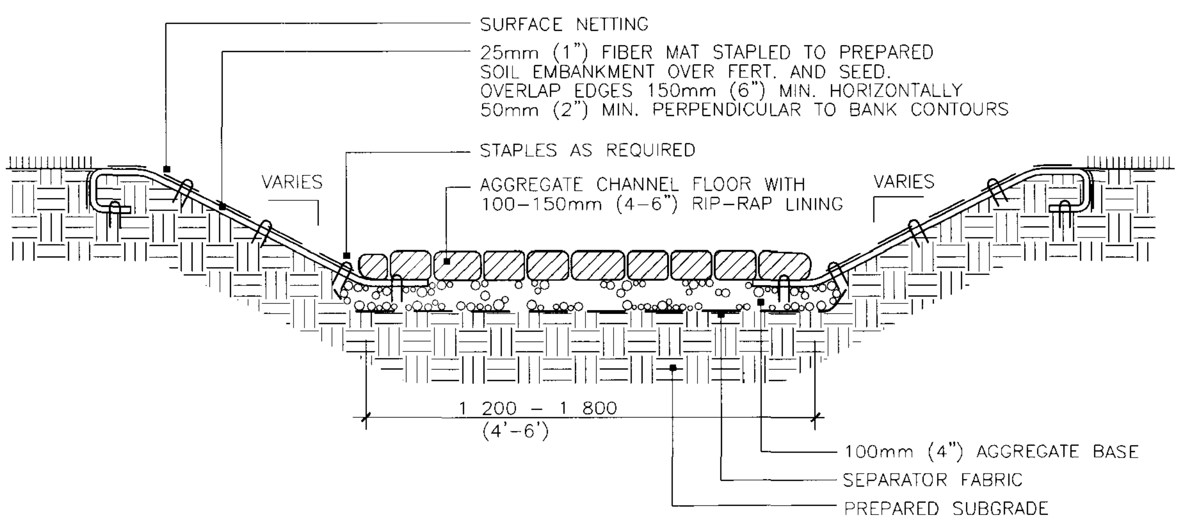


Figure 925-4. Fiber mat swale bank reinforcing. *Heavy duty infiltration swale for high volume runoff applications.*

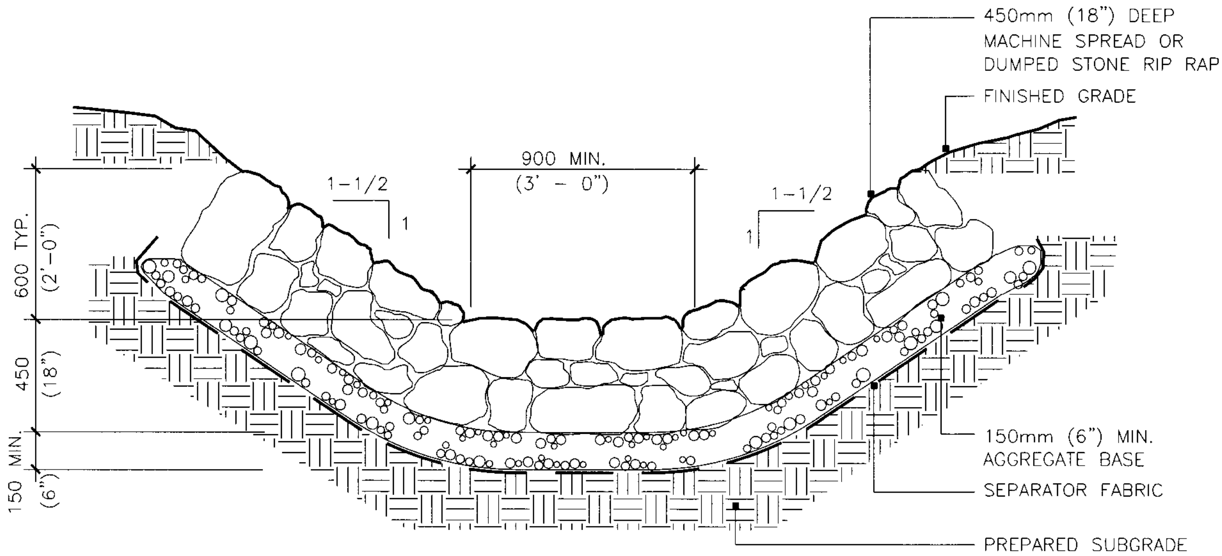


Figure 925-5. Stone rip-rap swale. *Primary discharge infiltration swale used to disperse pipe flow into channels or forest edge.*

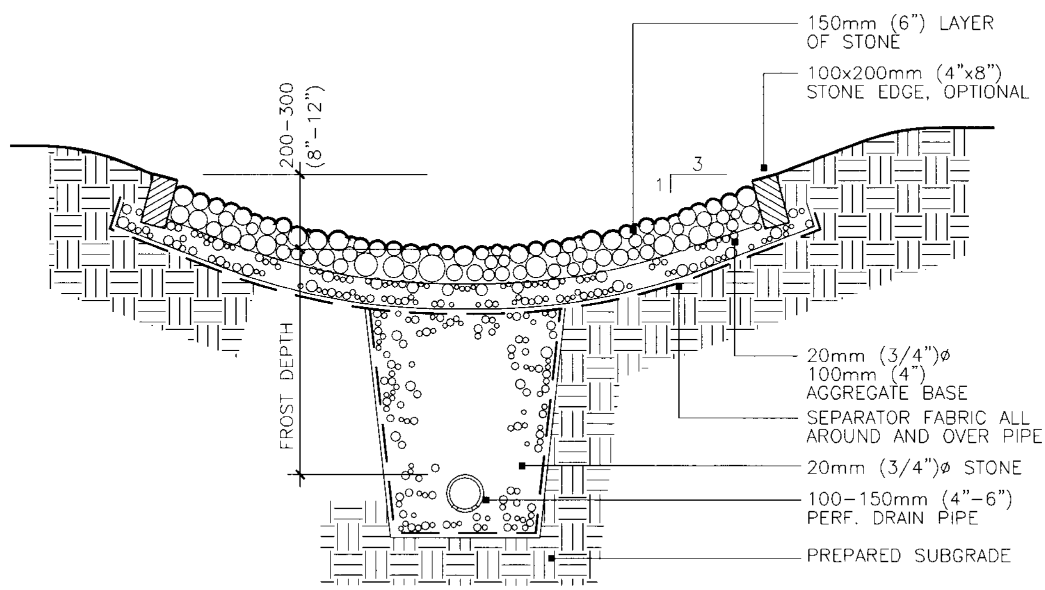


Figure 925-6. Stone lined swale with perforated drain. *Decorative infiltration swale with maintenance edges for mowing and containment.*

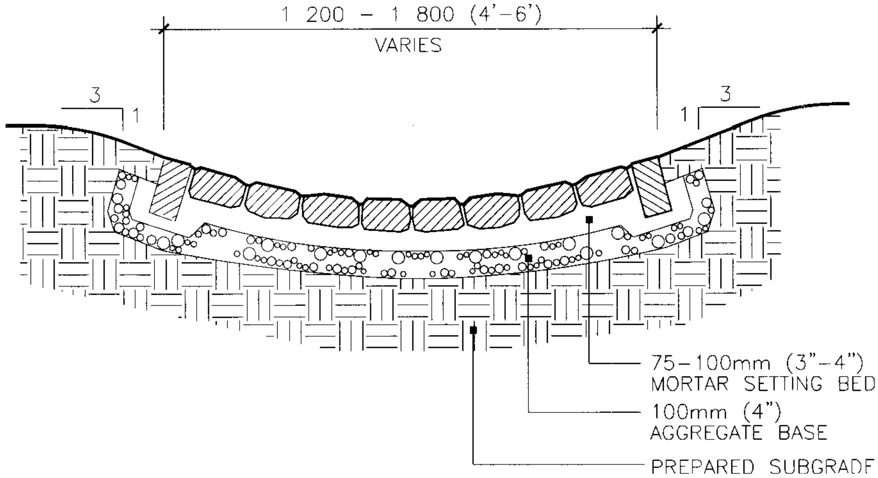


Figure 925-7. Mortared stone parabolic swale. *Typical steep gutter at edge of site road swale designed for short distances and low volume.*

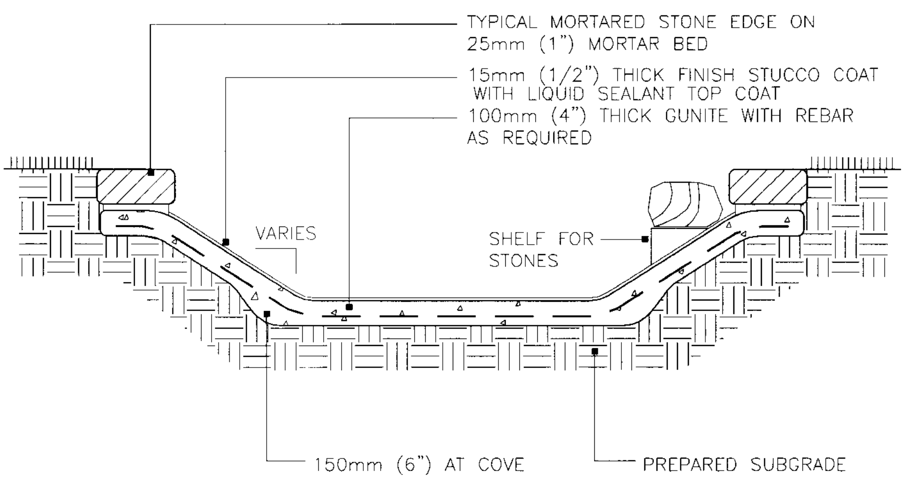


Figure 925-8. Gunite stream channel. *Often used to carry discharge to a pond, or as an ornamental channel.*

SECTION 926

Pools

1.0 INTRODUCTION

Pools typically require full filtration and circulatory systems to regulate particulate matter, pH, temperature, algae, and bacterial organisms. Pools may accommodate swimming, may be ornamental, or may support aquatic life. In each case they must be of water proof construction and be adapted to the local climate and soils. All types require provisions for periodic draining, cleaning, and sealing or coating to maintain structural integrity, appearance, and operation.

1.1 General Notes

Flexible liners may be used on-grade for temporary installations using submersible pumps and exposed pipes to protect the liner integrity. Stones placed on liners must rest on a drain mat or sand cushion . Heavy stones may require a sand base beneath the liner as well. Custom built liners may be used in conjunction with rigid structures to allow for circulation intake and drain hardware to be bonded on-site. Rigid construction requires provision for draining of aggregate base to relieve hydro-static soil pressure, especially during seasonal drawdown or cleaning periods. Footings must extend to undisturbed earth or below frost lines. If placed in segments, all joints must be fully keyed and gasketted. All reinforcing steel must be covered with at least 50 mm (2 in) of concrete. Waterlines are usually vertical surfaces finished with tile or polished stone for ease of cleaning.

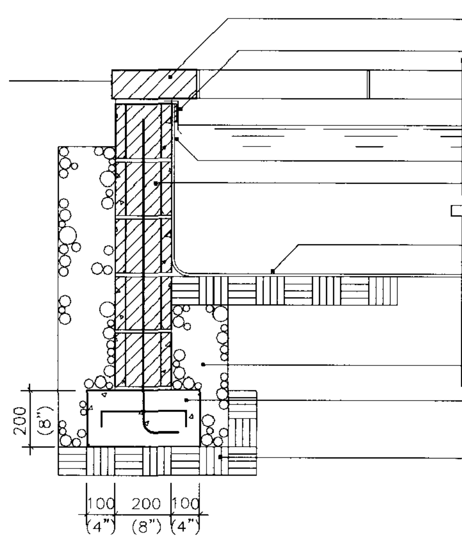


Figure 926-1. Concrete masonry garden pool. *Grouted reinforced concrete block walls. Membrane glued to top of wall at pressure bar.*

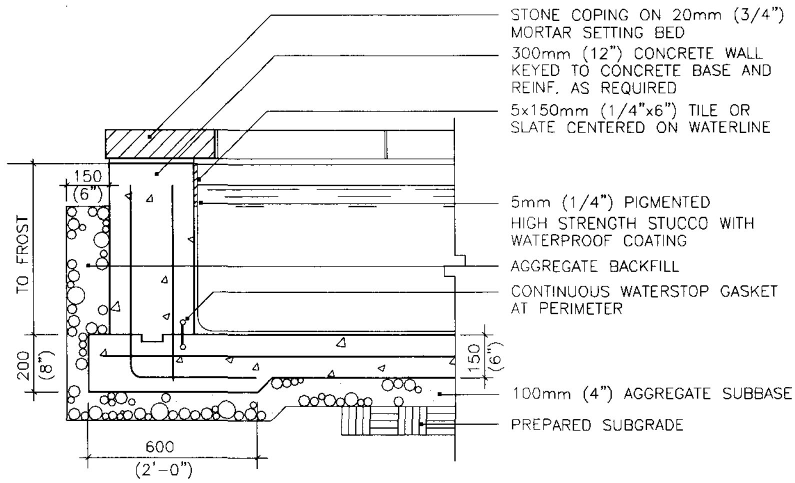


Figure 926-2. Concrete garden pool. *Connect wall and base with water stop gasket. Footing is set below frost line.*

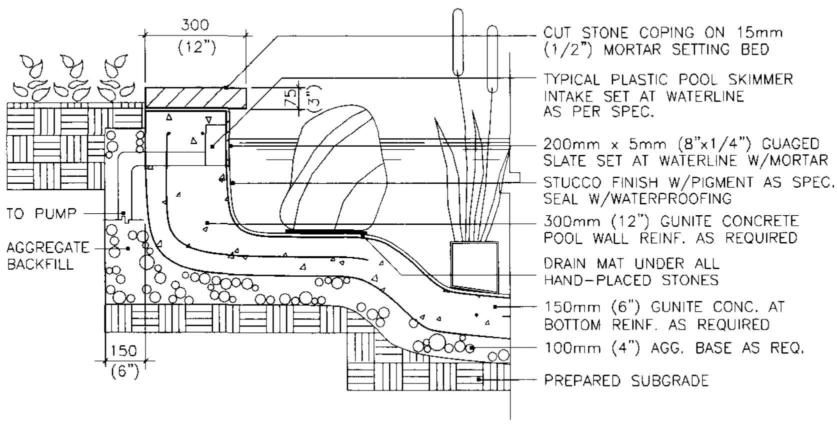


Figure 926-3. Gunite concrete garden pool. *Gunite is placed on hand shaped aggregate base shelves to receive plant boxes and stones.*

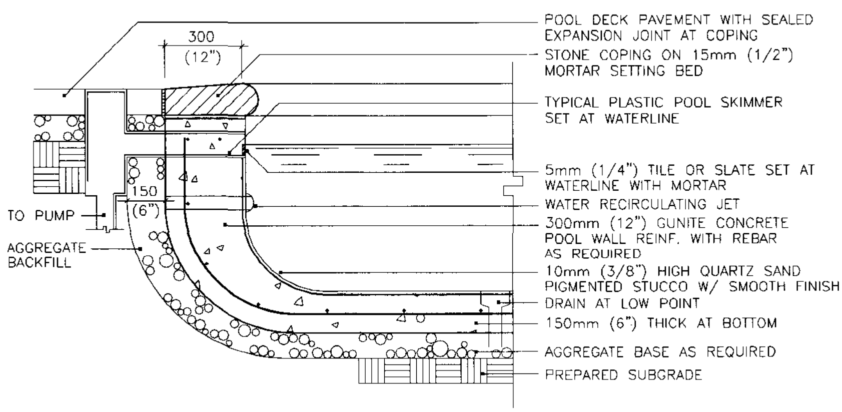


Figure 926-4. Gunite concrete pool on aggregate base. *Vertical wall is thickened for soil and temperature stresses. Openings are cast within shell.*

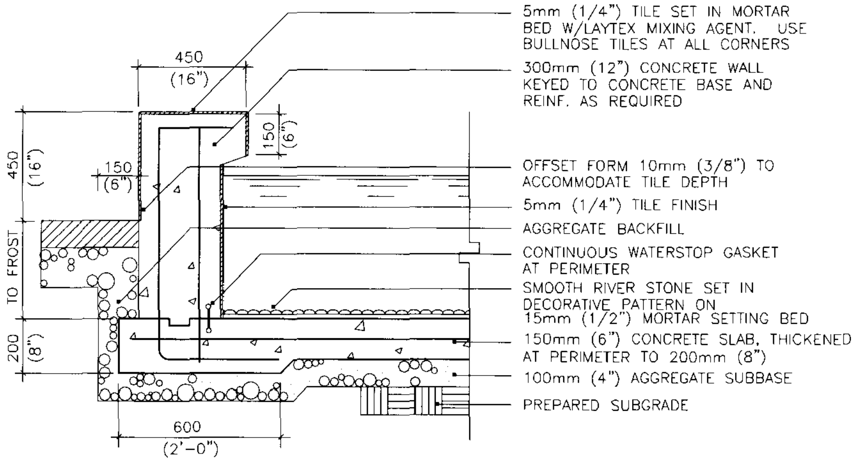


Figure 926-5. concrete pool with tile veneer. *Offset form to allow tile to be set with thin-set mortar and a flush finish at grade.*

Ponds

1.0 INTRODUCTION

Ponds refer to augmented or constructed wetlands designed to retain, detain, settle, or infiltrate site stormwater runoff. The selected details assembled below illustrate augmented wetland edges, selected liners for both retention and detention, and erosion protection edges for infiltration.

1.1 General Notes

All wetland plants have specific soil, moisture, and depth tolerances. Use local native species for best results. Cut embankments are commonly seeded and covered with protective matting. Planted waterline slopes are graded to a gradual depth of 450 mm (18 in) to receive cattail or other local aquatic plants. Infiltration ponds and clay lined retention ponds, typically use a fabric separator over subgrade before filtering, or ballast aggregates are placed to reduce turbidity during stormwater infusion. Single ply EPDM or other polymer liners may require a sand cushion prior to placement if subgrade is too course. A permanent pool depth of 2 100-3 000 mm (7-10 ft) is required to attain temperature stratification and support biological cycles. All such construction is subject to local and federal permitting processes, which may prescribe regionally specific construction procedures.

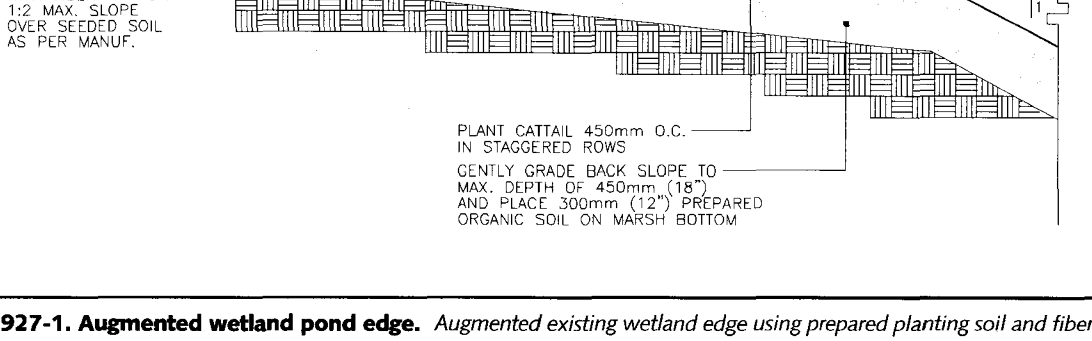


Figure 927-1. Augmented wetland pond edge. *Augmented existing wetland edge using prepared planting soil and fiber mat stabilization.*

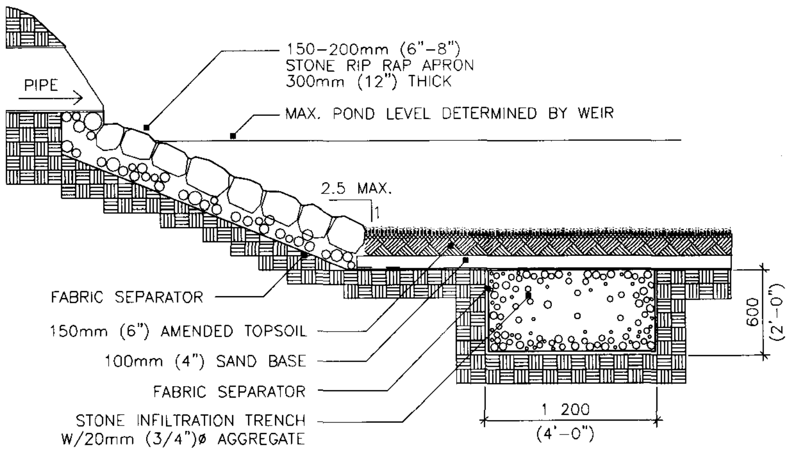


Figure 927-2. Infiltration detention pond. *A prepared stone dispersal trench with stone lined pipe discharge channel and turf basin.*

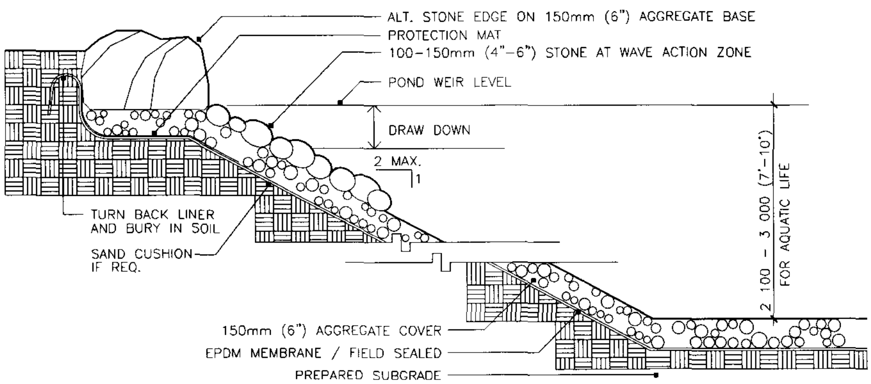


Figure 927-3. Stone pond edge at membrane liner. *Stone edge aggregate base rests on drain mat cushion to protect liner membrane.*

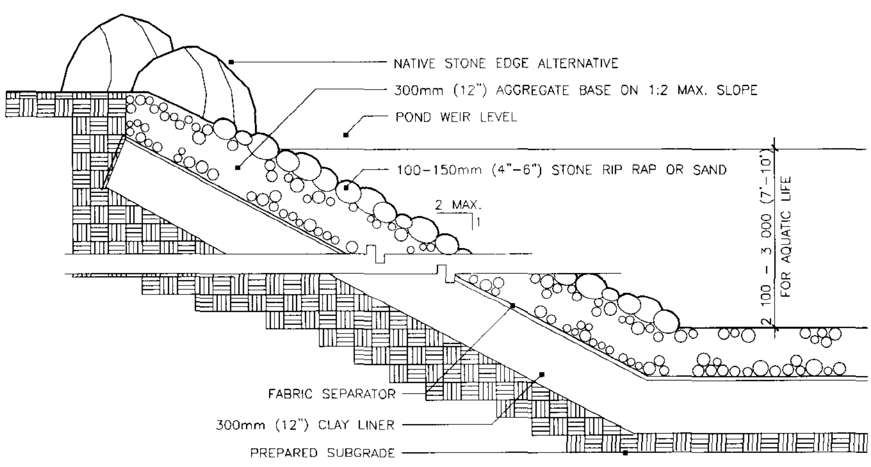


Figure 927-4. Clay-lined pond. *Clay lining and fabric must extend above waterline. Fabric contains fines at waterline.*

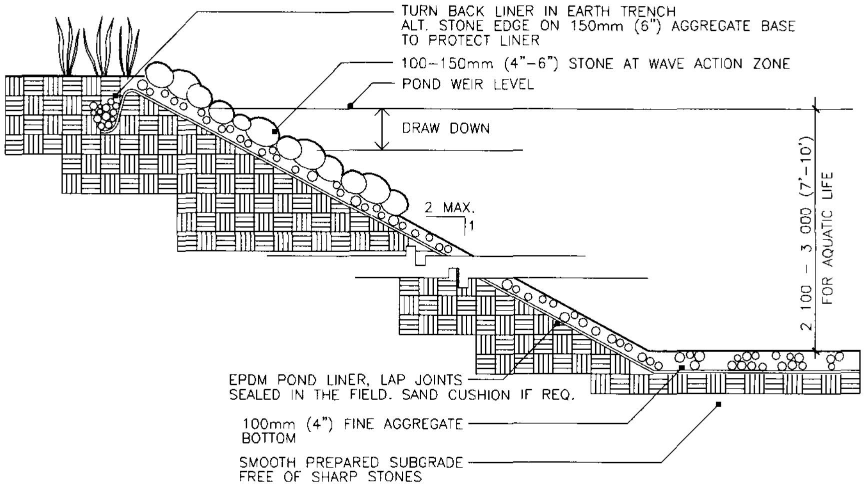


Figure 927-5. Polymer-membrane pond edge. *Turn back liner at top edge, and line with stone to protect against wave action erosion.*

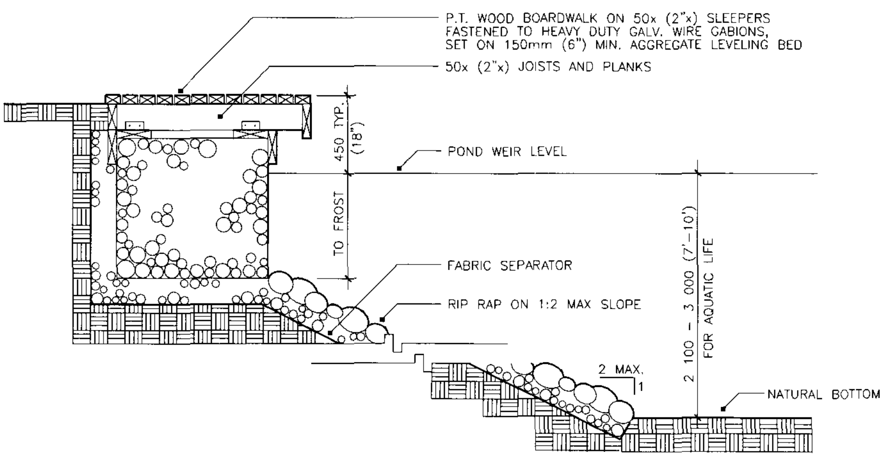


Figure 927-6. Board walk pond access on gabions. *Use radial gabion segment for curves. Sleepers may require mortar shims and steel pins.*

Appendix:
Metric Conversion Guidelines

THE METRIC CONVERSION ACT

The Metric Conversion Act of 1975, as amended by the Omnibus Trade and Competitiveness Act of 1988, establishes the modern metric system (System International or SI) as the preferred system of measurement in the United States. It requires that, to the extent feasible, the metric system be used in all federal procurement, grants, and business-related activities by September 30, 1992.

BASE UNITS

Quantity	Unit	Symbol
length	meter	m
mass[1]	kilogram	kg
time	second	s
electric current	ampere	A
temperature[2]	kelvin	K
luminous intensity	candela	cd

[1] "Weight" in common practice often is used to mean "mass."
[2] Celsius temperature (°C) is more commonly used than kelvin (K), but both have the same temperature gradients. Celsius temperature is 273.15 degrees warmer than kelvin, which begins at absolute zero.

METRIC PREFIXES

Only two decimal prefixes are commonly used with metric base units in design and construction:

Prefix	Symbol	Order of Magnitude	Expression
kilo	k	10^3	1000 (one thousand)
milli	m	10^{-3}	0.001 (one thousandth)

The prefixes mega (M) for one million (10^6), giga (G) for one billion (10^9), micro (M) for one millionth (10^{-6}), and nano (n) for one billionth (10^{-9}) are used in some engineering calculations.

PLANE AND SOLID ANGLES

The radian (rad) and steradian (sr) denote plane and solid angles. They are used in lighting work and in various engineering calculations. In surveying, the units degree (°), minute ('), and second (") continue in use.

DERIVED UNITS

Quantity	Name	Symbol	Expression
liquid volume	liter	L	L = .001 m^3
large areas (for surveying)	hectare	ha	ha = 10 000 m^2
large loads	metric ton	t	t = 1 000 kg
frequency	hertz	Hz	Hz = s^{-1}
force	newton	N	N = $kg{\cdot}m/s^2$
pressure, stress	pascal	Pa	Pa = N/m^2
energy, work, quantity of heat	joule	J	J = N·m
power, radiant flux	watt	W	W = J/s
electric charge, quantity	coulomb	C	C = A·s
electric potential	volt	V	V = W/A or J/C
capacitance	farad	F	F = C/V
electric resistance	ohm	Ω	Ω = V/A
electric conductance	siemens	S	S = A/V or Ω^{-1}
magnetic flux	weber	Wb	Wb = V·s
magnetic flux density	tesla	T	T = Wb/m^2
inductance	henry	H	H = Wb/m^2
luminous flux	lumen	lm	lm = cd · sr
illuminance	lux	lx	lx = lm/m^2

RULES FOR WRITING METRIC SYMBOLS AND NAMES

- Print unit symbols in upright type and in lower case except for liter (L) or unless the unit name is derived from a proper name.
- Print unit names in lower case, even those derived from a proper name.
- Print decimal prefixes in lower case for magnitudes 10^3 and lower (that is, k, μ, m, and n) and print the prefixes in upper case for magnitudes 10^6 and higher (that is, M and G).

- Leave a space between a numeral and a symbol (e.g. 45 kg not 45kg).
- Do not use a degree mark (°) with kelvin temperature (k).
- Do not leave a space between a unit symbol and its decimal prefix (e.g. kg, not k g).
- Do not use the plural of unit symbols (e.g. 45 kg, not 45 kgs), but do use the plural of written unit names (e.g. several kilograms).
- For technical writing, use symbols in conjunction with numerals (the area is 10 m^2); write out unit names if numerals are not used (carpet is measured in square meters). Numerals may be combined with written unit names in nontechnical writing (10 meters).
- Indicate the product of two or more units in symbolic form by using a dot positioned above the line ($kg{\cdot}m{\cdot}s^2$).
- Do not mix names and symbols (write N·m or newton meter, not N·meter).
- Do not use a period after a symbol except when it occurs at the end of a sentence (e.g. 12 g, not 12g.)..
- Always use decimals, not fractions (e.g. 0.75 g, not ¾ g).
- Use a zero before the value marker for values less than one.
- Use spaces instead of commas to separate blocks of three digits for any number over four digits (e.g. 45 138 kg or 0.004 46 kg, or 4371 kg).
- In the United States, the decimal marker is a period; in other countries, a comma is typically used.

CONVERSION AND ROUNDING

In a "soft" conversion, an exact U.S. unit measurement is converted to its exact (or near exact) metric equivalent. In a "hard" conversion, a new rounded, rationalized metric number is created that is convenient to work with and remember.

- Wherever possible, convert measurements to rounded, rationalized "hard" metric numbers. For instance, if anchor bolts are to be imbedded to a depth of 10 inches, the exact converted length of 254 mm might be rounded to either 250 mm (9.84 inches) or 260 mm (10.24 inches). The less critical the number, the "rounder" it can be, but ensure that allowable tolerances or safety factors are not exceeded. When in doubt, stick with the exact "soft" conversion.
- When converting numbers from U.S. units to metric, round the metric value to the same number of digits. In all cases, use professional rounding to determine the exact value.
- Round to "preferred" metric numbers. While the preferred numbers for the "1 foot 12 inches" system are, in order of preference, those divisible by 12, 6, 4, 3, 2 and 1, preferred metric numbers are, in order of preference, those divisible by 10, 5, 2 and 1 or decimal multiples thereof.

SPECIFICATIONS

Metric specifications should use "mm" for almost all measurements. The use of mm is consistent with the dimensions specified in major codes. Meters should be used only where large, round metric sizes are specified. Centimeters should not be used in specifications.

DRAWINGS

- Use only one unit of measure on a drawing. Except for large scale site or cartographic drawings, the unit should be the millimeter (mm).
- Delete unit symbols but provide an explanatory note ("All dimensions are shown in millimeters" or "All dimensions are shown in meters"). Whole numbers always indicate millimeters; decimal numbers taken to three places always indicate meters.
- Where modules are used, the recommended basic module is 100 mm, which is similar to the 4-inch module used in building construction (4 inches = 101.6 mm).

DRAWING SCALES

All scales are expressed as non-dimensional ratios.

Comparison of Drawing Scales

Inch-Foot Scales	Inch-Foot Ratio	Metric Scale
Full Size	1:1	1:1
Half Size	1:2	1:2*
4" = 1'-0"	1:3	
3" = 1'-0"	1:4	1:5
2" = 1'-0"	1:6	
1½" = 1'-0"	1:8	1:10
1" = 1'-0"	1:12	
¾" = 1'-0"	1:16	1:20
½" = 1'-0"	1:24	1:25*
¼" = 1'-0"	1:48	1:50
1" = 5'-0"	1:60	
⅛" = 1'-0"	1:96	1:100
1" = 10'-0"	1:120	
1/16" = 1'-0"	1:192	1:200
1" = 20'-0"	1:240	1:250*
1" = 30'-0"	1:360	
1/32" = 1'-0"	1:384	
1" = 40'-0"	1:480	1:500
1" = 50'-0"	1:600	
1" = 60'-0"	1:720	
1" = 80'-0"	1:960	1:1000

* Limited use as metric scales.

DRAWING SIZES

The ISO "A" series drawing sizes are preferred metric sizes for design drawings. There are five "A' series sizes:

Size	Sheet Size
A0	1189 x 841 mm (46.8 x 33.1 inches)
Al	841 x 594 mm (33.1 x 23.4 inches)
A2	594 x 420 mm (23.4 x 16.5 inches)
A3	420 x 297 mm (16.5 x 11.7 inches)
A4	297 x 210 mm (11.7 x 8.3 inches)

A0 is the base drawing size with an area of one square meter. Smaller sizes are obtained by halving the long dimension of the previous size. All A0 sizes have a height to width ratio of one to the square root of 2.

RULES FOR LINEAR MEASUREMENT (LENGTH)

- Use only the meter and millimeter in design and construction.
- Use the kilometer for long distances and the micrometer for precision measurements.
- Avoid use of the centimeter.
- For survey measurement, use the meter and the kilometer.

RULES FOR AREA

- The square meter is preferred.
- Very large areas may be expressed in square kilometers and very small areas, in square millimeters.
- Use the hectare (10 000 square meters) for land and water measurement only.
- Avoid use of the square centimeter.
- Linear dimensions such as 40 x 90 mm may be used; if so, indicate width first and height second.

RULES FOR VOLUME AND FLUID CAPACITY

- Cubic meter is preferred for volumes in construction and for large storage tanks.
- Use liter (L) and milliliter (mL) for fluid capacity (liquid volume).

RULES FOR ANGLES AND SLOPES

- Plane angles in surveying (cartography) will continue to be measured in degrees (either decimal degrees or degrees, minutes, and seconds) rather than the metric radian.
- Slope is expressed in nondimensional ratios. The vertical component is shown first and then the horizontal. The units that are compared should be the same (meters to meters, millimeters to millimeters). For slopes less than 45°, the vertical component should be unitary (for example, 1:20). For slopes over 45°, the horizontal component should be unitary (for example, 5:1).

RULES FOR STRUCTURAL CALCULATIONS

- There are separate units for mass and force. The kilogram (kg) is the base unit for mass, which is the unit quantity of matter independent of gravity. The newton (N) is the derived unit for force (mass times acceleration, or $kg \cdot m/s^2$). It replaces the unit "kilogram-force" (kgf), which should not be used.
- Do not use the joule to designate torque, which is always designated newton meter (N·m).
- The pascal (Pa) is the unit for pressure and stress ($Pa = N/m^2$) . The term "bar" is not a metric unit and should not be used.
- Structural calculations should be shown in MPa or kPa.

CONVERSION FACTORS

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
		mm	304.8
	inch	mm	25.4
Area	square mile	km²	2.590 00
	acre	m²	4 046.856
		ha	0.404 685 6
	square yard	m²	0.836 127 36
	square foot	m²	0.092 903 04
	square inch	mm²	645.16
Volume	acre foot	m³	1 233.49
	cubic yard	m³	0.764 555
	cubic foot	m³	0.028 316 8
		cm³	28 316.85
		L	28.316 85
	100 board feet	m³	0.235 974
	galllon	L	3.785 41
	cubic inch	cm³	16.387 064
		mm³	16 387.064
Mass	lb	kg	0.453 592
	kip (1000 lb)	metric ton	0.453 592
Mass/unit length	plf	kg/m	1.488 16
Mass/unit area	psf	kg/m²	4.882 43
Mass density	pcf	kg/m³	16.018 5
Force	lb	N	4.448 22
	kip	kN	4.448 22
Force/unit length	plf	N/m	14.593 9
	klf	kN/m	14.593 9
Pressure, stress, modulus of elasticity	psf	Pa	47.880 3
	ksf	kPa	47.880 3
	psi	kPa	6.894 76
	ksi	Mpa	6.894 76

Quantity	From Inch-Pound Units	To Metric Units	Multiply By:
Bending moment, torque, moment of force	ft-lb	N·m	1.355 82
	ft-kip	kN·m	1.355 82
Moment of mass	lb-ft	kg·m	0.138 255
Moment of inertia	lb-ft²	kg·m²	0.042 140 1
Second moment of area	in⁴	mm⁴	416 231
Section modulus	in³	mm³	16 387.064
Temperature	°F	K	5/9(°F-32) +273.15
		°C	5/9(° F-32)
Energy, work, quantity of heat	kWh	MJ	3.6
	Btu	J	1 055.056
	ft-lbf	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
Thermal resistance (R value)	ft²-h-°F/Btu	m²· K/W	0.176 110
Volume rate of flow	ft³/s	m³/s	1.028 316 8
	cfm	m³/s	0.000 471 947 4
		L/s	0.471 947 4
Velocity, speed	ft/s	m/s	0.3048
Luminous intensity	cd	cd	1 (same unit)
Luminance	lambert	kcd/m²	3.183 01
	cd/ft²	cd/m²	10.763 9
	footlambert	cd/m²	3.426 26
Luminous flux	lm	lm	1 (same unit)
Illuminance	footcandle	lux	10.763 9

SOURCES OF TECHNICAL INFORMATION AND ASSISTANCE

American Concrete Institute
P.O. Box 19150, Detroit, MI 48219

American Congress on Surveying and Mapping
5410 Grosvenor Lane, Suite 100
Bethesda, MD 20814

American Institute of Steel Construction
One East Wacker Drive, Suite 3100
Chicago, IL 60601-2001
American National Metric Council
Washington, D.C.

American National Standards Institute, Inc.
11 West 42nd St.
New York, NY 10036

American Society for Testing and Materials
1916 Race St.
Philadelphia, PA 19103

Building Officials and Code Administrators International
4051 W. Flossmoor Rd.
Country Club Hills, IL 60477-5795

Canadian Standards Organization
178 Rexdale Blvd.
Rexdale, Ontario M9W IR3

U.S. Metric Association
10245 Andasol Avenue
Northridge, CA 91325

CONSTRUCTION TRADES

The metric units used in the construction trades are as follows. The term "length" includes all linear measurements (that is, length, width, height, thickness, diameter, and circumference).

Trade	Quantity	Unit	Symbol
Surveying	length	kilometer, meter	km, m
	area	square kilometer	km^2
		hectare (10 000 m^2)	ha
		square meter	m^2
	plane angle	degree (non-metric)	°
		minute (non-metric)	'
		second (non-metric)	"
Excavating	length	meter, millimeter	m, mm
	volume	cubic meter	m^3
Trucking	distance	kilometer	km
	volume	cubic meter	m^3
	mass	metric ton (1000 kg)	t
Paving	length	meter, millimeter	m, mm
	area	square meter	m^2
Concrete	length	meter, millimeter	m, mm
	area	square meter	m^2
	volume	cubic meter	m^3
	temperature	degree Celsius	°C
	water capacity	liter (1000 cm3)	L
	mass (weight)	kilogram, gram	kg, g
	cross-sectional area	square millimeter	mm^2
Masonry	length	meter, millimeter	m, mm
	area	square meter	m^2
	mortar volume	cubic meter	m^3
Steel	length	meter, millimeter	m, mm
	mass	metric ton (1000 kg)	t
		kilogram, gram	kg, g
Carpentry	length	meter, millimeter	m, mm
Plastering	length	meter, millimeter	m, mm
	area	square meter	m^2
	water capacity	liter (1000 cm^3)	L
Glazing	length	meter, millimeter	m, mm
	area	square meter	m^2

Trade	Quantity	Unit	Symbol
Painting	length	meter, millimeter	m, mm
	area	square meter	m^2
	capacity	liter (1000 cm^3)	L
		Milliliter (cm^3)	mL
Roofing	length	meter, millimeter	m, mm
	area	square meter	m^2
	slope	millimeter/meter	mm/m
Plumbing	length	meter, millimeter	m, mm
	mass	kilogram, gram	kg, g
	capacity	liter (1000 cm^3)	L
	pressure	kilopascal	kPa
Drainage	length	meter, millimeter	m, mm
	area	hectare (10 000 M^2)	ha
		square meter	m^2
	volume	cubic meter	m^3
	slope	millimeter/meter	mm/m
HVAC	length	meter, millimeter	m, mm
	volume	cubic meter	m^3
	capacity	liter (1000 cm^3)	L
	airflow	meter/second	m/s
	volume flow	cubic meter/second	m^3/s
		liter/second	L/s
	temperature	degree Celsius	°C
	force	newton, kilonewton	N, kN
	pressure	kilopascal	kPa
	energy, work	kilojoule, megajoule	kJ, MJ
	rate of heat flow	watt, kilowatt	W, kW
Electrical	length	meter, millimeter	m, mm
	frequency	hertz	Hz
	power	watt, kilowatt	W, kW
	energy	megajoule	MJ
		kilowatt hour	kWh
	electric current	ampere	A
	electric potential	volt, kilovolt	V, kV
	resistance	ohm	Ω

REFERENCES

The metric units in this appendix are those adopted by the U.S. government (see the Federal Register of December 20, 1990; Federal Standard 376A, Preferred Metric Units for Use by the Federal Government; and PB 89-226922, Metric Handbook for Federal Officials).

ASTM E 62 1, Standard Practice for Use of Metric (SI) Units in Design and Construction,

ANSI/IEEE 268, American National Standard Metric Practice,

ASTM E 380, Standard Practice for the Use of the International System of Units (SI) -

American National Metric Council, Metric Editorial Guide and
U.S. Metric Association, Metric Units of Measure and Style Guide.

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Illustration Source Notes

Figure 130-3. Adapted from R. Scott Siddens, *Walker's Building Estimator's Reference Book, 23rd ed.*, Frank R. Walker Company, Lisle, IL, 1989.

Figure 130-4. Adapted from R. Scott Siddens, *Walker's Building Estimator's Reference Book, 23rd ed.*, Frank R. Walker Company, Lisle, IL, 1989.

Figure 130-5. Richard C. Ringwald, *Means Heavy Construction Handbook,* R.S. Means Company, Inc., Kingston, MA, 1993.

Figure 130-6. Richard C. Ringwald, *Means Heavy Construction Handbook,* R.S. Means Company, Inc., Kingston, MA, 1993.

Figure 130-7. S.W. Nunnally, *Construction Methods and Management,* Prentice-Hall, Inc., Englewood Cliffs, NJ, 1993.

Figure 130-8. Richard C. Ringwald, *Means Heavy Contruction Handbook,* R.S. Means Company, Inc., Kingston, MA, 1993.

Figure 130-9. S.W. Nunnally, *Construction Methods and Management,* Prentice-Hall, Inc., Englewood Cliffs, NJ, 1993.

Figure 130-12. Richard C. Ringwald, *Means Heavy Construction Handbook,* R.S. Means Company, Inc., Kingston, MA, 1993.

Figure 130-13. Richard C. Ringwald, *Means Heavy Construction Handbook,* R.S. Means Company, Inc., Kingston, MA, 1993.

Figure 130-14. Richard C. Ringwald, *Means Heavy Construction Handbook,* R.S. Means Company, Inc., Kingston, MA, 1993.

Figure 130-15. Sylvia Hollman Fee, *Means Landscape Estimating,* R.S. Means Company, Inc., Kingston, MA, 1987.

Figure 130-16. Sylvia Hollman Fee, *Means Landscape Estimating,* R.S. Means Company, Inc., Kingston, MA, 1987.

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About the Editors

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