PARKING STRUCTURES

PLANNING, DESIGN, CONSTRUCTION, MAINTENANCE AND REPAIR

Second Edition

To our colleagues at Walker Parking Consultants/Engineers, Inc.,
all of whom have helped make this book possible.

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Anthony P. Chrest
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Sam Bhuyan

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CONTENTS

PREFACE

This second edition is written eight years after we began the first. Eight more years of experience from each of the authors, plus our firm's experience gained from 1500 more parking-related projects, are brought to this work. The ten chapters in the first edition have been revised and expanded. Five new chapters—on the Americans with Disabilities Act (ADA), lighting, graphics, seismic design, and designing for maintenance—have been added. Our intention is to ensure that *Parking Structures* continues as the leader in its field, because it can be put to immediate good use by owners, designers, and builders.

Anthony P. Chrest

ACKNOWLEDGMENTS

Our heartfelt thanks to all our colleagues at Walker Parking Consultants/Engineers, Inc., all of whom have helped make this book possible, but especially to Mike Albers, Tom Butcher, Jim Kopencey, Don Monahan, Ken Terry, Steve Totten, and Dave Vander Wal for their reviews and advice; to Val Meyer, Diane Erikson, Cindy McCully, Debi McGee, and Janet Zange for manuscript preparation; to Scott Duff, Paul Kruger, Jeff Rozeveld, Paul Tegtmeier, Sterry Vander Meer, and Kevin Wylie for many of the illustrations; and to Howard Linders and Frank Transue for their understanding and support. Finally, we are grateful to our production editor, Francesca Drago, for all her assisstance.

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CHAPTER

1

INTRODUCTION

Anthony P. Chrest

1.1 BACKGROUND

Parking structures are found all over North America. They serve office buildings, shopping centers, banks, universities, and hospitals, and are in both urban or suburban areas.

Parking structures have been designed and built for decades. Why, then, the need for this book?

Parking structure design is more difficult than is immediately apparent, which can lead to deficiencies in the finished building. Yet this need not be so. It is hoped that the direction and advice given in this book will raise awareness of the complexities of parking structures and lead to their improved design, construction, maintenance, and repair.

Parking structures may appear simple, but can be deceptively difficult to plan, design, and construct. Aside from consideration of the impact on traffic in the surrounding streets, attention must be given to entrances and exits, revenue control, internal traffic and pedestrian circulation, patron security, openness requirements, structure durability, maintainability, and other matters not usually encountered in urban buildings.

As a result, even experienced designers and builders can be caught by practices they have used before, but which will not work in parking structures. Owners, too, may make decisions based on their previous experience, but that experience may not be applicable to parking structures. Much of this advice will apply to surface parking lots as well.

1.2 PURPOSE

The purpose of this book is to explain some of the peculiarities of parking structures that set them apart from other building types, and to offer some advice on how to avoid or deal with these unique features.

1.3 PARKING STRUCTURE PECULIARITIES

It is important to know that building codes recognize two types of parking structures—open and closed. Open parking structures do not require mechanical ventilation or sprinklers in most cases, as do closed structures; therefore they are less expensive.

For a building code to admit a parking structure as open, it must meet specific requirements in that code. For instance, the Uniform Building Code states, in part,

> For the purpose of this section, an open parking garage is a structure of Type I or II construction which is open on two or more sides totalling not less than 40 percent of the building perimeter and which is used exclusively for parking or storage of private pleasure cars. For a side to be considered open, the total area of openings distributed along the side shall be not less than 50 percent of the exterior area of the side of each tier.

Other codes have similar requirements, differing only in degree. A parking structure not meeting the code requirements for openness will be considered closed. A closed parking structure carries more stringent requirements for ventilation and fire protection, especially if automobile service will be inside the structure. The term used in most building codes for parking structures that are not open is *garage*.

It is always important, then, in dealing with building departments and code authorities to identify your project properly. In this book, unless we specifically state otherwise, we are usually discussing *open* parking structures, though most of the material applies to garages and surface lots as well.

Chapter 2 deals with internal circulation. In years past, a 300 to 500-car parking structure was considered an average size project, and a 1000-car deck, huge. These days, structures of 1000–3000 cars are not uncommon, and decks large enough to hold 12,000 cars are being built. With the advent of larger-capacity structures, the old rules of thumb for determining the number of entrance and exit lanes, and internal circulation routes to permit traffic to flow smoothly, are no longer adequate. Further, parking-related dimensions—stall width and length, parking angle, and parking module (the clear dimension between opposite walls of a parking bay)—are often limited by local ordinance. The local rules may often be outdated, leading to uneconomical parking structures.

Parking-related dimensions will differ for different patron types. At one end of the spectrum is a deck used for office parking only. Since the office worker will tend to park in the same spot all day, and probably in the same spot or close to it every day, he or she will quickly become used to the circulation pattern within the structure. Also the office worker will not require a wide parking stall. At the other end of the spectrum is a deck used for shopping center parking. Shoppers may be unfamiliar with the structure, will park for shorter periods, and will need wider parking stalls to load and unload passengers and packages. Chapter 3 deals with access issues, such as revenue control systems and designing entrances and exits for peak activity levels. As parking facilities have grown, these issues have become more significant.

Parking structures have attracted vandals, muggers, and rapists in recent years. Courts have held owners, operators, and sometimes architects and engineers responsible for security features or their absence. No amount of retrofitting can replace good original design practices. Chapter 4 addresses security and safety.

Good lighting, an important part of security and safety in a parking structure, is addressed in Chapter 5. Wayfinding, also important to security and safety, as well as helping to make the facility more user friendly, is covered in Chapter 6. The requirements of the Americans with Disabilities Act (ADA) as they apply to parking structures are addressed in Chapter 7.

Chapter 8 deals with structural design and Chapter 9, seismic design. Parking structures have unusual proportions, compared to most buildings. A typical cast-in-place structure might have one-way posttensioned slabs spanning 18–24 ft, supported by posttensioned beams spanning 54–62 ft. A precast structure typically has double tees spanning the 54 to 62-foot dimension, supported by spandrel beams spanning 18–30 ft. The floors in adjacent bays slope, so the beams join the columns at staggered levels. The interior columns between sloped floors may be short and stiff because of the building proportions.

In plan, the structure is relatively large. Structures 200–300 ft long and 110–130 ft wide are common. Many structures are larger.

To this rigid framing system, add the combined effects of camber in the beams and floor elements due to prestressing, vertical and horizontal deflections due to car and people loads, the structure's own weight, wind, earthquake, and construction. To complicate matters further, next add in the effects of structure volume changes due to shortening from the prestressing forces, shrinkage, and creep. Finally, add in the effects of severe weather and climate fluctuations. Now we have a system with which many engineers are unfamiliar and that others understand only partially. Even engineers relatively experienced in parking structure design may not always avoid some of the complexities inherent in a particular structure under certain combinations of conditions.

Because the parking structure *is* open, yearly temperature extremes can affect the floor elements, beams, columns, and walls. These elements are accessible in varying degrees to rain, snow, and sun. In climates where pavements are salted to control snow and ice, the salt will increase the number of freeze-thaw cycles and lead to corrosion of the steel reinforcement in floors and the lower parts of walls and columns.

Other than bridges, no other structure type has to resist such a variety of attack by corrosive environments and deteriorating forces. Unlike most buildings, parking structures have no protective envelope. Unlike most bridges, which rain can wash clean, only the roof of a parking structure is entirely open to rain. Designing a parking structure according to highway bridge codes will make it cost more than it should; however, if you design the structure according to some building codes, without special attention to its unique exposure, use, and requirements for durability, it will not perform well. Chapter 10 addresses design for durability.

A parking structure is a street in the sky. Like a street, it has signs, lighting, traffic controls, and parking spaces. Like a street, it's expected to last and requires periodic maintenance.

In a parking structure there are no carpets, ceilings, or wall finishes to conceal mistakes in forming or finishing. Extra care must be taken, then, to construct the building properly. There is also less leeway with respect to quality control of the concrete and reinforcement to achieve a durable structure. Finishing and curing require more care. These concerns are addressed in Chapter 11 on specifications and 12 on construction.

Parking structures require at least as much attention to maintenance as any other building—perhaps more. Though there may be only bare concrete to maintain, that concrete is exposed to severe weather fluctuations. Chapters 13, 14, and 15 address maintenance and repair.

1.4 ORGANIZATION OF THE BOOK

We hope that the three major parts of this book will help you deal successfully with the problem areas described in Section 1.3.

No matter how well the structural framing is designed, and no matter how durable it is, drivers must be able to enter and exit the structure, circulate and park with safety and convenience. Patrons, whether driving or walking, should feel safe and secure. The first part's following six chapters address these matters by dealing with functional planning, parking space layout, parking efficiency, entrance and exit planning and control, security, safety, the Americans with Disabilities Act (ADA), lighting, and graphics.

Having dealt with first things first, the book's second part, in six chapters, expands on the subjects of structural design, construction materials and durability, specifications and construction.

To complete the subject matter, the third part's three chapters treat maintenance and repair. If you are not familiar with parking structure terminology, you will find a Glossary following Chapter 15.

CHAPTER
2

FUNCTIONAL DESIGN

Mary S. Smith

2.1 INTRODUCTION

Parking structures have many things in common with buildings, but also have some unique differences. A very elemental one is that there must be some circulation system that provides access from one *floor* to the next; cars cannot use the elevators and stairs that provide circulation for pedestrians. The circulation system can be quite complex and difficult for a lay person to understand when looking at drawings. Just because it is complex does not mean that it will be confusing to the parker; on the other hand, some systems **are** confusing to the unfamiliar user. It is important, therefore, that the owner have a basic understanding of the issues in order to intelligently review and approve designs. An owner is going to have to live with the functional system on a day-to-day basis, and will quickly find out if the *functional design* is not successful.

Many factors affect the selection of the best functional design for a particular parking facility:

type(s) of users
pedestrian needs
wayfinding
floor-to-floor height
dimensions of site
parking *geometrics*
peak-hour volumes
flow capacity

This chapter provides guidelines for the functional design. If these guidelines are followed, the most frequent pitfalls can be avoided. It should be noted, however, that the guidelines do not cover all the minute details that must be considered in the preparation of documents for construction; only experience can teach all the little tricks that maximize user acceptance while minimizing cost.

2.2 THE LEVEL OF SERVICE APPROACH

Over the years parking designers have developed quite a number of "rules of thumb" for elements of functional design. These rules prescribe, for example, the maximum number of turns or spaces passed in the path of travel.[1] Professional judgment is still required to apply the rules to a specific situation; some rules are more important than others with some types of users. For example, it is desirable to route unfamiliar users past as many spaces as possible in a small to moderate-size facility. However, if most users park in the facility every day, it is desirable to get them in and out as fast as possible, which usually means minimizing the number of spaces passed; thus, no one set of design standards is suitable for all situations.

Traffic engineers have similar problems in designing streets and intersections; the degree of congestion that is acceptable to users and the community varies substantially. To overcome this problem, traffic engineers developed a system of classifying conditions by *levels of service* (LOS). For traffic at signalized intersections, conditions of virtually free flow and no delays are LOS A, the highest level of service. As congestion increases, the level of service decreases. The lowest LOS, F, is popularly (or unpopularly to those caught in one) called "gridlock." LOS E is the maximum flow of cars that can be accommodated before conditions begin to totally jam. The LOS system is used to reflect the acceptability of a parameter to the users or a community. Most roadways that are new or are being improved are designed to attain an LOS of C or better in the peak hours. LOS D is tolerated by commuters in our major urban centers, and efforts to mitigate the conditions would not be initiated unless the LOS drops to E or even F. In a small town, however, a street condition of LOS B may generate an outcry for traffic improvements.

Therefore, issues related specifically to the user can be addressed by selecting a level of service appropriate to the circumstance. Table 2-1 relates level of service criteria to the needs/concerns of users. A major factor in selecting LOS is the familiarity of the user. The *turnover* rate in a facility also plays a role; when arriving and departing vehicle activity is sustained at high levels throughout most of the day, a better level of service should be provided than if there is

TABLE 2-1. Level of Service Criteria

Design Consideration	Chief Factor	Acceptable Level of Service D	C	B	A
Turning radii, ramp slopes, etc.	Freedom to maneuver	Employees			Visitors
Travel distance, number of turns, etc.	Travel time	Visitors			Employees
Geometrics	Freedom to maneuver	Employees			Visitors
Flow capacity	*v/c* Ratio	Employees			Visitors
Entry/exits	Average wait	Visitors			Employees

one rush period of a half-hour in the morning and another short one in the evening. If employees represent the end of the scale with high familiarity/low turnover, visitors usually represent the converse situation of low familiarity/high turnover. There are, of course, exceptions; the multiday parker at the airport can be unfamiliar with the system. Finally, the more urban and congested the setting of the facility, the more tolerant users are of lower levels of service. LOS D is generally only used in the core areas of the largest cities (New York, Los Angeles, Chicago, and San Francisco) where land values and parking fees are at a premium level.

As seen in Table 2-1, most criteria dictate a higher level of service for visitors than for employees. However, certain criteria, generally those concerned with travel time and average wait, can result in reversal—i.e., providing a higher level of service for employees than visitors.

There also may be competing objectives that require compromising one criterion for the sake of another. For example, increasing the *floor-to-floor height* improves LOS but may increase the ramp slopes, which would lower the LOS of that criterion.

In many cases the specific type of user plays a major role, even within the same *land use* type. Is the user a family going to a theme park (loaded down with strollers and diaper bags) or a group of adult friends going to a football game? Is it an elderly couple meeting the family at the airport or is it a business traveler?

Are there choices/alternatives for the user? Is the user a shopper who has a number of choices or a visitor who comes to the site for a reason that will not be heavily influenced by parking convenience, such as to visit a specific doctor? Is it the only parking choice for the person, such as in the suburban office building, or is there a variety of parking options at various prices and walking distances such as in a central business district?

How long is the person going to stay—a few minutes, a few days? How often does the user park in the facility? Will the person park there every day or once a year? Is it a "stressful" situation such as hurrying to the airport or going to the hospital versus a more routine commute or shopping trip?

What are the users' expectations? Is the location suburban or urban? Is it the lot in front of a convenience center or an overflow lot used at the regional shopping center only at Christmas season? Is it a suburban office park where convenience is part of the marketing of the building to tenants or a special event where congestion and long walking distances are anticipated? Is it a corporate headquarters where the image of the corporation is an issue, or a "spec" office building?

In each of the above paired questions, a better level of service should be afforded to the former than the latter type of user.

It is also critically important to understand that a system could be quite consciously designed with LOS A for most parameters but with LOS D for one or more components. For example, airport parking structures are typically designed to LOS A, except for queuing at the toll plaza, which might fall to LOS C or even D on busy days. This generally relates to the fact that activity at the toll plaza is highly variable. It simply is not feasible to staff enough booths to keep queuing to LOS A at peak periods because they would be grossly underutilized the rest of the shift. Also airport users, even frequent travelers, tolerate (if not expect) some queuing in peak hours. Another example might be an urban parking structure. While users expect more congestion and a lower level of service than they would in a suburban setting, security considerations might dictate that certain parameters be designed to LOS A even though others are designed to LOS D.

The same parameters might also be designed to different levels of service at different points within the system. For example, we consider that the parking used on average or typical days at shopping centers should be designed for LOS A. For busy Saturdays LOS B should be maintained, and the parking that is only used for a few hours on the busiest days of the year might be designed for LOS C.

The level of service approach is applicable to a number of design considerations in parking facilities, including entry/exits, geometrics, *flow capacity*, travel distance and spaces passed, *turning radii*, and floor slopes. The old rules of thumb have thus been transformed into levels of service for these areas, as will be discussed in this chapter on functional design and in the next on *access design*.

2.3 CIRCULATION SYSTEMS

2.3.1 The Building Blocks

Four very basic building blocks are used in any parking facility design: "level" *parking bays*, "level" drive aisles without parking, "sloped" parking bays, and "sloped" drive aisles without parking. (See the Glossary for definition of level and sloped floors in parking connotations.) Sloped drive aisles without parking are also called ramps. There are three ramp subtypes: *circular* or *express helixes, express ramps,* and *speed ramps* (Figure 2-1).

Almost all functional systems are composed of the four basic building blocks assembled in one of two forms of a *helix* for circulation through the facility (Figure 2-2).

The basic forms of the helix are the single-threaded helix which *rises* one *tier* (usually 10 to 12 ft) with every 360 degrees of revolution, and the double-threaded helix that rises two tiers with every 360 degrees of revolution. The reason the latter is called a double-threaded helix is that because, by rising 20 ft per revolution, two "threads" may be intertwined on the same *footprint*. A double-threaded helix thus allows a vehicle to circulate from the bottom to the top (or the top to the bottom) of a facility with roughly half the number of turns and driving distance. Express helixes can be either single or double threaded, as can *parking bays*.

There is also a triple-threaded helix but it is seldom used. The triple threaded helix rises three levels with each 360 degrees of revolution and has three threads intertwined.

2.3.2 Wayfinding and Pedestrian Concerns

Wayfinding is the ability to understand where you are and to find where you want to go in a building and then to recollect the path of travel when departing. Wayfinding design involves the total planning of the functional design to enhance this ability. It is much more than signage or graphics. In fact, if signage is critical to wayfinding, a parking facility, in particular, is in trouble. When Jerry Seinfeld devotes an entire episode of his television show to getting lost in a parking structure, it is obvious that wayfinding is a major concern to users and owners alike. A key goal of wayfinding should be that the people know where they

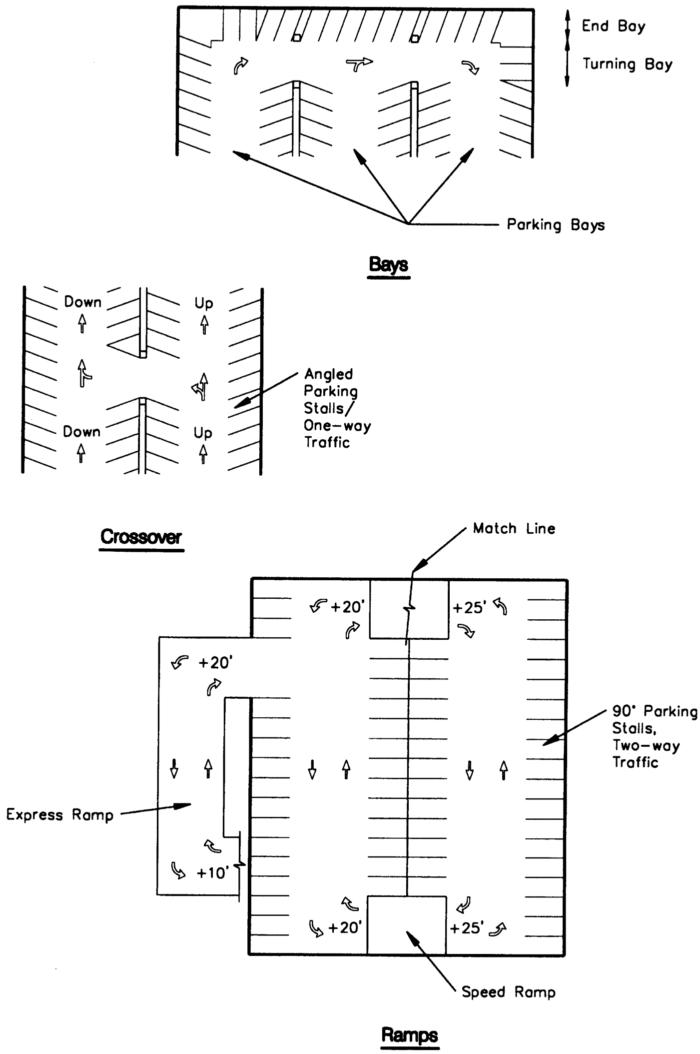


Figure 2-1. Some basic parking terms.

are and where they want to go with a minimum of *signs*. Therefore, wayfinding is discussed in this chapter on functional design rather than in Chapter 6, Signage and Graphics.

Although wayfinding is a relatively new buzzword in the design industry, the individual concepts or components have long been known. Indeed, many are simply common sense. However, wayfinding design

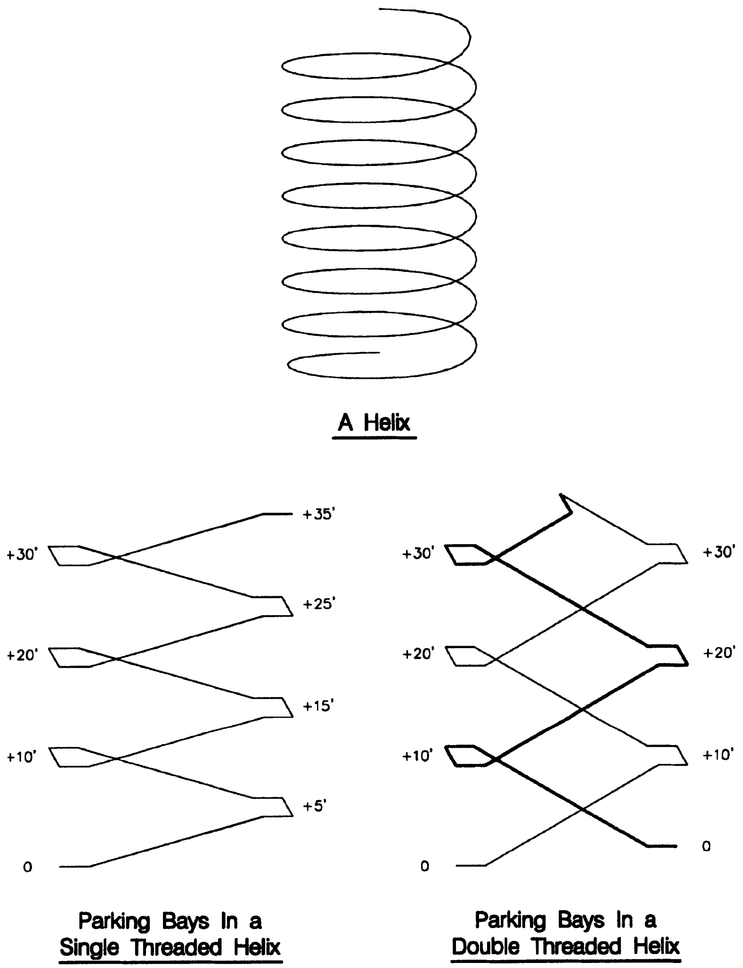


Figure 2-2. Helixes are used to provide floor-to-floor circulation in parking facilities.

provides a framework to draw all of these individual considerations into a cohesive, single focus. It also reflects the much higher emphasis on designing for the specific needs of the users that exists today. Table 2-2 from the first edition of this text, which presented level-of-service criteria for various design parameters, has been expanded to provide more guidance in the area of wayfinding. This necessitated breaking the table into two components, wayfinding and pedestrian considerations (Table 2-2) and vehicular circulation (Table 2-3.)

Obviously, wayfinding is not a major concern for a use that predomi-

TABLE 2-2. Recommended Design Parameters for Wayfinding

Design Standard For:	LOS D	LOS C	LOS B	LOS A
Maximum walking distance				
Within parking facilities				
Surface lot	1400′	1050′	700′	350′
Structure	1200′	900′	600′	300′
Front parking to destination				
Climate controlled	5200′	3800′	2400′	1000′
Outdoors, covered	2000′	1500′	1000′	500′
Outdoors, uncovered	1600′	1200′	800′	400′
Floor-to-floor height[1]				
Long span, posttensioned[2]	9′6″	10′6″	11′6″	12′6″
Long span, precast	10′6″	11′6″	12′6″	13′6″
% spaces on flat floors	0%	30%	60%	90%
Parking ramp slope	6.5%	6%	5.5%	5%
360-degree turns to top	7	5.5	4	2.5
Short circuit in long run[3]	400′	350′	300′	250′
Travel distance to crossover[4]	750′	600′	450′	300′
Spaces searched or compartment size[5]				
Angled	1600	1200	800	400
Perpendicular	1000	750	500	250

[1] Minimum vertical clearance for van accessibility is 8′2″, which requires minimum floor-to-floor heights per LOS C.
[2] LOS D clearance for P/T design set by minimum 6′8″ overhead clearance; some codes required 7′0″.
[3] To shorten exit path of travel.
[4] In one-way designs it is necessary to continue on the inbound path of travel before connection to the outbound path.
[5] Spaces passed on primary search path; or spaces per floor in express ramp design.

nantly generates regular users. For example, more than 90% of the parking spaces at office uses (excluding medical and certain consumer service offices) are used by employees of the tenant(s). It is generally not necessary to place a high priority on wayfinding, especially if a convenient parking area is reserved for visitors. However, many of the features that enhance wayfinding also enhance *passive security*, and thus some of the same design features might be a priority for parking facilities where wayfinding is not a high priority.

In parking facility design, wayfinding is necessary for both drivers and pedestrians. The following discussion will follow the progress of the typical user through the parking facility.

First, the driver must find and recognize the building as a parking facility. While it is appropriate to make the parking facility's architecture compatible with that in the area, hiding or camouflaging the structure should not be the goal. The well-known architect Stanley Tigerman

TABLE 2-3. Recommended Design Parameters for Vehicular Circulation

Design Standard for:	LOS D	LOS C	LOS B	LOS A
Nonparking Roadways and Express Ramps				
Lane width, straight				
One lane[1]	10′0″	10′6″	11′0″	11′6″
Multiple lanes	9′0″	9′6″	10′0″	10′6″
Clearance to obstructions[2]	0′6″	1′0″	1′6″	2′0″
Radius, turning (outside front wheel)[3,4]	24′0″	30′0″	36′0″	42′0″
Lane width, turning[5,6]				
One lane	13′6″	13′6″	13′6″	13′6″
Ea add'l lane	12′0″	12′0″	12′0″	12′0″
Circular helix[4,7]				
Single-threaded[8]				
Outside diameter	60′0″	74′0″	88′0″	102′0″
Inside diameter[9]	24′0″	36′0″	48′0″	60′0″
Double-threaded[10]				
Outside diameter	80′0″	95′0″	110′0″	125′0″
Inside diameter[9]	44′0″	57′0″	70′0″	83′0″
Express ramp slope	16%	14%	12%	10%
Transition length	10′0″	11′0″	12′0″	13′0″
Parking Areas				
Radius, turning[3,4]	24′0″	26′0″	28′0″	30′0″
Turning bays, clear between columns[11]				
One lane	14′6″	15′9″	17′0″	18′3″
Two lanes, concentric[12]	26′6″	28′0″	29′6″	31′0″
Two lanes, nonconcentric	29′0″	31″6″	34′0″	36′6″
PARC lane width[13]	8′9″	9′0″	9′3″	9′6″

[1] Use 15′ lane to pass breakdown, all LOS.
[2] From edge of lane to wall, column, parked vehicle, or other obstruction, per AASHTO 1990 Figure 111-25.
[3] LOS D per AASHTO 1990 Figure 11-1.
[4] Left turns at radius are LOS ( )+; right turns are LOS ( )–.
[5] LOS D per AASHTO 1990 Figures 111-23, except c is reduced to 2′ per Figure 111-25.
[6] Use 20′ lane to pass breakdown, all LOS, per AASHTO 1990 Figure 111-23.
[7] Helix diameter is out-to-out walls (6″ walls assumed).
[8] Turning radii/lane width increased 3′ due to multiple turns.
[9] Decrease 3′-6″ to provide 20′ lane to pass breakdown.
[10] Ramp slope, minimum lane width, and clearance to walls control dimensions for double-threaded helix.
[11] Clear between face of columns; check clearance at back of parking stalls with turning template.
[12] If flow predominantly one-way, can reduce by 3′.
[13] Assumes straight approach to lane; check turns into lanes with template.

took the opposite tack and designed the facade of a parking structure in downtown Chicago to look like the front grille of a car! Whimsy aside, the most important thing is to make sure the vehicle entrance is clearly identifiable to a driver who may be dealing with many visual distractions. Canopies or portals are often valuable in this effort.

Upon turning into the facility, the entrance area must be welcoming and well lighted. The parking control equipment, if any, should be placed to allow the patron to recognize its presence. Where exit or restricted lanes are provided in the same area as the visitor entrance lanes, the driver must have adequate sight distance to determine which lane to enter.

It is often desirable to not give the driver any choices immediately after passing through the entry lane. Driving the length of the structure before any further decisions are required will often help the driver become acclimated to the facility.

A primary element of wayfinding design is to provide visual cues. A simple, easily understood traffic pattern that is repeated on every floor greatly eases wayfinding. It is desirable to route unfamiliar drivers past visual anchors such as the main stair/elevator tower shortly after reaching each floor. This begins to orient the parker for the pedestrian mode. Certainly, turning traffic away from the tower and requiring a circuitous route back to it should be avoided. In larger facilities, light wells and other architectural features may also serve as visual anchors.

Visibility across the parking floor to the destination is another key to wayfinding. Why is it that shoppers will accept relatively long walking distances at the suburban shopping center but complain about parking around the corner downtown? Because the shopper can see the shopping center entrance from the moment he or she leaves the car. While one might think that this primarily affects pedestrian wayfinding, visibility while driving is equally beneficial.

Both security and wayfinding have caused a shift in the parking industry away from complicated sloping parking floor designs to ones that maximize the number of spaces on flat floors. In parallel, there has been a shift toward maximizing the slope of parking ramps. Where the site is long, the tendency is to keep the sloping portion to a minimum, with the remainder flat, instead of using a long, more gentle slope.

Another issue affecting visibility is the floor-to-floor height as well as the structural system. It is generally recognized that a *cast-in-place posttensioned* (CIP P/T) parking structure has a higher perceived ceiling height than other systems. This structural configuration also enhances other functional/wayfinding issues: signage is more visible; lighting more uniform. CIP P/T construction also tends to result in more openness along bumper walls both at interior sloping ramps and exterior walls. When precast is the preferred structural system, the same level of service can be achieved by increasing the floor-to-floor height (see Table 2-2 and Section 2.3.3 for further discussion of floor-to-floor heights). Because signing and lighting flat slab, waffle, and other conventionally reinforced structural systems is even more difficult, floor-to-floor heights must be carefully considered with those systems.

Minimizing the number of turns (in terms of 360 degree revolutions) in the path of travel has long been a priority of parking designers. There is a tendency for the driver to become disoriented, almost dizzy, when there are too many turns in the path of travel. It is also important to minimize the number of decision and/or conflict points. While having spaces off the main path of travel helps flow capacity (as will be discussed later in this chapter), it greatly complicates wayfinding for the unfamiliar user. Therefore, it is desirable to select a parking circulation system that naturally leads parkers past all the spaces once and only once. Conversely, when a driver is in the exit mode, short circuits that minimize the travel distance are equally desirable.

There is a point at which the number of spaces that must be searched to find an available one becomes excessive. In a larger facility, it is desirable to break the system into smaller "compartments" with express ramping systems to speed users to a floor with available spaces and return them to the street. The system becomes a series of "parking lots" stacked vertically. The driver then should only have to search a limited area of stalls for a vacant parking space. Another option is to simply break the structure into two (or more) structures with independent circulation systems.

Once the driver has found a space and parked the car, pedestrian considerations come into play. The first issue is helping the parker remember where the car is parked. Here signage **is** critical, and it is explored in Chapter 6.

Wayfinding for the pedestrian is greatly enhanced by *visibility* across the parking floor, as previously discussed. Acceptable walking distances and visibility are closely related. Fruin[2] stated:

> There are indications that the tolerable limit of human walking distance is more situation-related than energy related. . . . The tolerable walking distance for a given design situation is related to such factors as the trip purpose of the individual, the available time and the walking environment. We would expand Fruin's list of variables affecting acceptable walking distance to include the type of users, frequency of occurrence or use, the familiarity of the user with the facility, expectations/concerns of the user (including security), line of sight to destination, the degree of weather protection along the path of travel, the perception or absence of barriers or conflicts along the path of travel, and cost of alternatives to walking, if any. Many of these elements are directly associated with wayfinding.

Table 2-2 presents guidelines for acceptable walking distances. For further information on the development and application of these guidelines, see Smith and Butcher, 1994.[3]

The walking path of travel is also a consideration. It is generally desirable to orient parking aisles toward the pedestrian destination. In a freestanding parking facility, that will usually be the main stair/elevator tower. When bays are oriented transverse to this path, pedestrians will cut through between parked vehicles, which at best is not very user-friendly and at worst can cause security and safety concerns. If it is necessary or appropriate, it may be desirable to have cross aisles aligned with the stair/elevator tower or, in the case of direct connection to the ultimate destination, the building entrance(s). However, our experience is that pedestrians will always take the perceived shortest path, including cutting between cars.

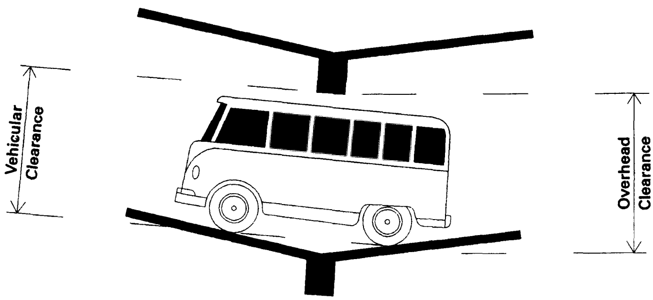
Proper location of stair/elevator towers in the overall path of travel to the ultimate destination is also important. Just as the pedestrian wants to see the tower from within the structure, so does the tower serve as a beacon for the pedestrian returning to the parking facility. Circuitous routes to, into, and out of these towers must be avoided.

Once the parker has retraced the route to the parking stall, wayfinding returns to a vehicular mode. The exit route should be equally simple and understandable. Keeping the exit route to the shortest path of travel is often a high priority, as previously mentioned.

2.3.3 Dimensions of Site

The floor-to-floor heights and slope of the elements are factors that affect the way in which our building blocks are assembled on a particular site. Floor-to-floor heights generally are dependent on the depth of the structural system used (for beams and floor elements) and the desired clearance. It is generally advisable to limit vehicles entering a parking facility to two to four inches less than the actual *overhead clearance* because the *vehicular clearance* is impacted by sloping floors (Figure 2-3). In general, the minimum floor-to-floor height in *posttensioned* parking facilities is 9′6″, which provides overhead clearances of 6′8″ to 6′10″. Such a facility would be signed with 6′6″ vehicular clearance. Some *short-span* designs get by with floor-to-floor heights less than 9′6″. Vehicular clearances must also include allowances for light fixtures, signage, and piping. Lights usually are tucked up between beams and/or stems in long-span, prestressed structural systems and thus do not affect clearance considerations. However, it is usually desirable to hang signs below tee stems, as discussed in Chapter 6.

It is a little-known fact that model building codes originally specified a 7′0″ **maximum** overhead clearance for parking facilities because this would keep out motor homes, heavier trucks, and other vehicles that weigh more than the design loads required elsewhere in the code. Some



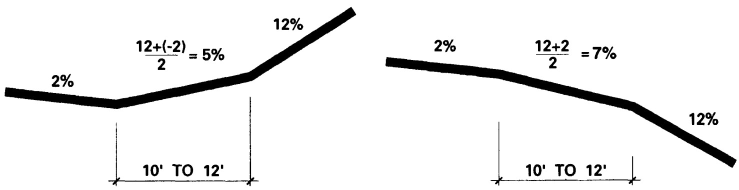


Figure 2-3. Transition slopes and clearances in parking facilities.

communities and even some committees revising national codes did not realize the connection with design loads and have altered the requirement to 7′0″ **minimum** to allow vans and other taller vehicles access. However, all standard production vans sold in America are 6′10″ in height or less and can be accommodated in facilities with 7′0″ vehicular clearance. Vans modified with "pop tops" or flashing lights, or sometimes just special antennas, may not be able to traverse a structure with 7′0″ vehicular clearance. The Americans with Disabilities Act requires that 8′2″ vertical clearance be provided for the path of travel to/from van-accessible spaces, which generally requires increasing the floor-to-floor height to 11′2″ to 11′4″. It is only necessary to provide this clearance along the path of travel to and from the required van-accessible stalls. This standard will still exclude *paratransit* and camper vehicles, which are simply too heavy compared to the design loads employed for parking facilities.

TABLE 2-4. Structure Length Parameters

Traffic Flow Rise	Required Site Length			
	LOS D	LOS C	LOS B	LOS A
One-way				
½-floor rise	107′	124′	144′	167′
1-floor rise	180′	212′	248′	292′
Two-way				
½-floor rise	131′	149′	169′	192′
1-floor rise	204′	236′	273′	317′

Once the clearance and floor-to-floor height are established, the slope of floor elements providing circulation between floors will influence the design. LOS classifications for slopes (as well as for other design features) are shown in Table 2-2. To determine the minimum length of a site for a structure with parking bays of LOS D slope, one must add the *turning bay* dimensions shown in Table 2-3 to the minimum *runs* necessary to achieve the desired rise and slope. Structural dimensions such as exterior walls must also be added to determine the length of a structure. Turning bays are usually kept level or slightly super-elevated. *Crossovers* can be sloped at the same rate as parking bays if the crossover is centered at the crossing point of the "X" formed by the two bays (see Table 2-4).

Thus, in a single-threaded configuration that rises one-half tier along each parking bay, the length of the structure must be at least 131 ft for two-way traffic and LOS D design; LOS A requires a structure length of 192 ft. A single-threaded system with a straight run that goes up a full floor must have a site at least 180 ft long for one-way traffic (204 ft for two-way traffic) at LOS D. To meet LOS A parameters, the structure length increases to 292 ft for one-way designs and 317 ft for two-way designs. For a double-threaded helix, the same structure lengths apply (see Figure 2-4).

If a sloping parking bay is desired but the structure length must be less than the dimensions needed to rise the desired run, speed ramps must be used at the turning bays to make up the difference. As long as the slope of the speed ramp does not exceed the slope used for parking bays, *end-bay* parking can be used. Therefore if the speed ramp is 36 ft long and LOS D slopes are being used for parking areas, a rise of more than 2′4″ ft in the speed ramp will necessitate the elimination of end-bay parking (36′ * .065′ = 2.34′).

Any discussion of slope must include the *breakover effect*; when there is a difference in slope of 10% or more between two sections of

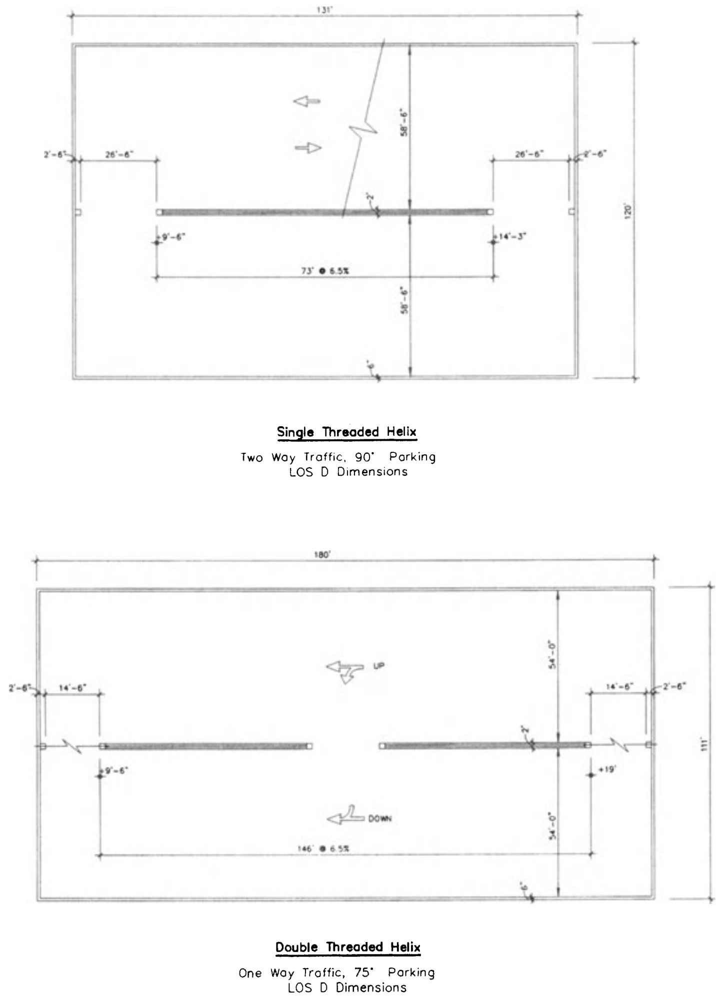


Figure 2-4. To determine structure dimensions, *structural clearances,* turning bay dimensions, module widths, and rise/run must all be included.

floor slab, a *transition* slope is required to prevent the vehicle from "bottoming out" (Figure 2-3). In general, the transition area should have one half the slope of the differential slope. Length of the transition slope is presented in Table 2-3.

Speed ramps are limited to rises of 5 ft or so, and even then they must be extended somewhat into the aisle because the overall ramp length, including transitions, must be 41.25 ft to achieve LOS D design (10′ * 8% + 21.25′ * 16% + 10′ * 8% = 5.0′).

In sum, the length of the site impacts the type of system used; speed ramps, however, can be used when the site is short.

The width of the site also impacts the selection of a system as it determines the number and *module* width of parking bays that can be placed on the site. The out-to-out width of the structure includes not only the wall-to-wall dimension necessary to achieve the module, but also the structural dimensions of the walls, etc. One of the chief factors influencing structure width is whether one-way or two-way traffic flow is employed.

2.3.4 One-Way or Two-Way Traffic Flow?

Is one-way traffic flow with *angled* parking better than two-way traffic flow with perpendicular parking? Or vice versa?

Among the chief advantages of two-way design are benefits created by its wider aisles, including a better angle of visibility when searching for a space, and the ability to pass another driver who has stopped to wait for a space about to be vacated. The wider aisles are also safer for pedestrians.

Also, two-way traffic flow follows its own pattern rather than one that is forced or regimented; thus a driver can't make a mistake and turn the wrong way down a one-way aisle.

Adherents of perpendicular parking claim it is more efficient than angled, especially as compared to flatter angles, such as 60 degrees. However, this is often an overstated benefit. While a 90-degree layout makes more efficient use of parking aisles, the larger turning bays required for two-way traffic often result in no greater *efficiency* and sometimes less.

In a structure with a big footprint, five bays of 75-degree angled parking will provide more spaces than four bays of 90-degree stalls in approximately the same overall width, thereby increasing *capacity* and/or reducing the height and mass of the facility. The result: greater efficiency for real cost advantage.

In addition, one-way design with angled parking makes it easier for drivers to enter/exit stalls. By contrast, getting properly aligned in a two-way design's perpendicular stalls can require some maneuvering.

Our own field studies of how well cars were parked in stalls of various angles shed light on this. We observed that at 90 degrees, fewer cars were parked at the intended angle than at 60 degrees. We also found that cars were more likely to be centered in angled stalls.

With many two-way designs, drivers pass all stalls on the way both in and out of a parking structure. With one-way design, which separates inbound and outbound traffic, drivers can be routed past half the stalls entering and half leaving; thus the number of times a driver must stop and wait for a car to park/unpark is, on average, halved.

Even when alternative one-way and two-way designs each have adequate flow capacity, the two-way system will usually have more congestion.

Other benefits of one-way design/angled parking accrue in lots as well as structures. Conflicts between two vehicles approaching an open stall from opposite directions do not occur. When backing out, angled parking provides better visibility. The potential for accidents is also reduced, because there are fewer decisions to be made and fewer conflict points with everyone driving in one direction.

Only one-way design allows the angle of parking to be altered to accommodate changes in car sizes. If sizes get smaller, the angle can be swung closer to 90 degrees; if bigger, the angle can swing the other way. If a parking facility is to be in service for several decades, such flexibility is quite beneficial.

In general, each project has its own particular requirements that will result in some of the advantages of a particular traffic system being more important than others. Two key considerations in determining which system is better are size and flow capacity.

In a surface parking lot, flow capacity is usually not a critical factor, as there are generally not a great many vehicles in motion at any one time, even with high turnover. The previously discussed benefits of two-way design may make it the best choice.

In a multilevel parking structure, a single parking aisle may need to accommodate peak-hour volumes associated with 1000 or more spaces. If so, most of the advantages of one-way design come to the fore, making it the system of choice.

There are, of course, alternative systems that provide significant flow capacity, such as the exterior express ramps commonly seen in airport parking structures. Such a structure is then equivalent to a series of parking lots stacked vertically.

Our own design solutions illustrate a pragmatic approach. For example, a 6000-space, seven-level retail parking structure was designed with two-way traffic because of its advantageous search pattern, while a 7500-space airport parking structure with a like number of levels was designed with one-way traffic.

A last word of advice is this: if you think about how the average

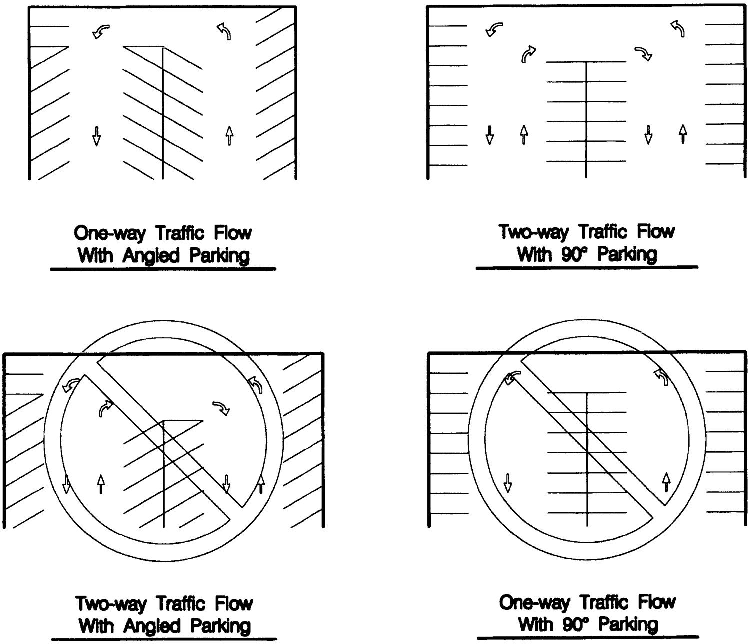


Figure 2-5. One-way traffic flow systems should have angled parking. Two-way traffic flow systems should have 90-degree parking.

driver will find an available space and later exit the facility, and also how peak-hour volumes are accommodated, the best design will probably become clear.

If one-way flow is desired, it is strongly recommended that angled parking stalls (not perpendicular to the driving aisle) be used (Figure 2-5). This allows the intended traffic flow to be self-enforcing. With perpendicular or 90-degree parking, one user who ignores the signs and proceeds the wrong way will cause problems for other drivers who are following the intended circulation pattern, especially if the turning bays are designed for one-way traffic. Therefore, if 90-degree parking is employed, design the system to accommodate two-way traffic.

Conversely, if you want two-way traffic, do not use angled parking. The latter combination causes problems when a driver coming from one direction sees a space intended for the opposite approach and attempts several maneuvers to enter the stall. In addition to delaying traffic flow, this driver is very likely to park improperly, encroaching on an adjacent stall.

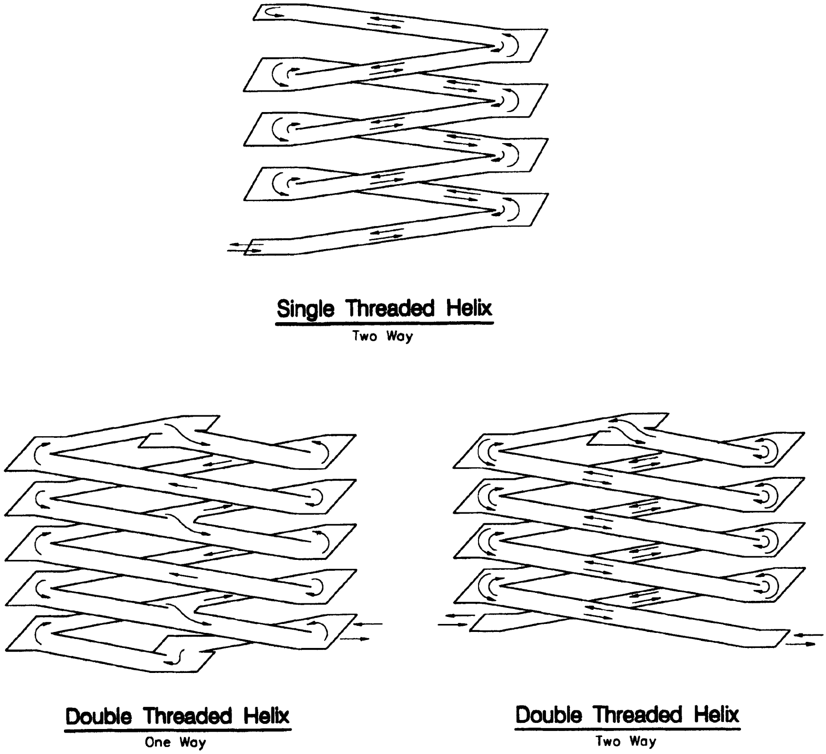


Figure 2-6. When only two parking bays are provided, a single-threaded helix must have one-way traffic, while a double-threaded helix can have either one-way or two-way flow.

2.3.5 Selection of Circulation System

Most of the common circulation systems used in parking structure design have been given names that in general relate to the pattern of traffic flow and the number of parking bays.

A two bay single-threaded helix must have two-way traffic unless a circular helix or an express ramp provides a way down (Figure 2-6). Obviously, what goes up must come down. Single-threaded helixes may, however, be provided in combinations known as side-by-side helixes or end-to-end helixes to achieve one-way traffic flow (Figure 2-7). Note that three-bay side-by-side helixes must have 90-degree parking and two-way traffic flow in the middle bay. Another type of single-threaded helix is the split level (Figure 2-8). In this system, the level parking bays are stepped at half-tier intervals, with speed ramps making up the difference in elevation between the parking bays.

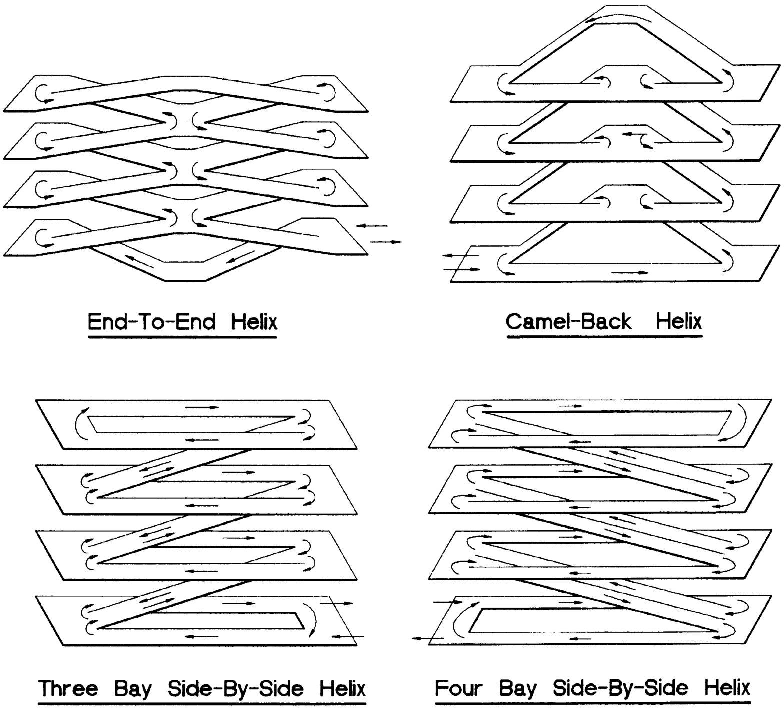
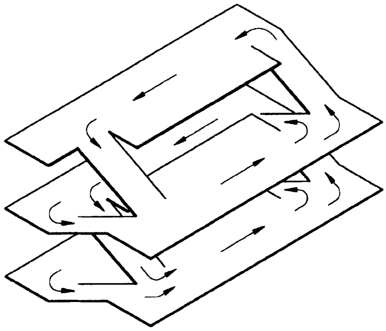


Figure 2-7. Combinations of single-threaded helixes.

Single-threaded helixes are very repetitive and easy to understand for the user. In the split-level and the side-by-side with either three or four bays, much of the floor area is level. Side-by-side single threads also tend to have the best visibility across the structure of any sloping parking bay design, thereby enhancing passive security (which is discussed in Chapter 4). Most architects prefer to work with level façade elements, although a creative architect can either hide or emphasize a sloping parking bay on the exterior.

A negative aspect of any single-thread design is the number of revolutions required to go from bottom to top or from top to bottom. Table 2-3 shows guidelines regarding the LOS for the number of turns. Double-threaded systems (shown in Figure 2-6), which by definition go two tiers per revolution, thus become progressively more desirable as the number of floors increases.

One-way traffic flow can be provided in the two-bay configuration of a double-threaded helix. One thread goes up while the other thread goes down. To get from the inbound "up" thread to the outbound



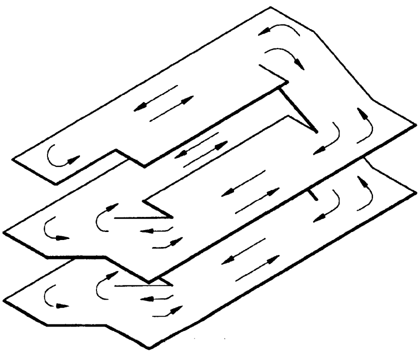
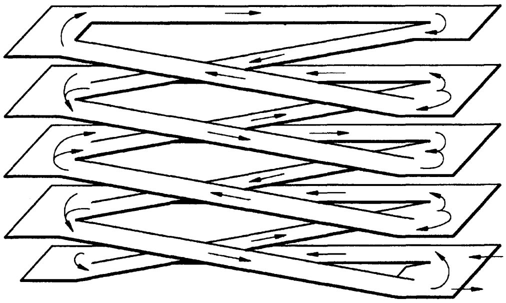


Figure 2-8. Split levels may have either one-way or two-way traffic flows.

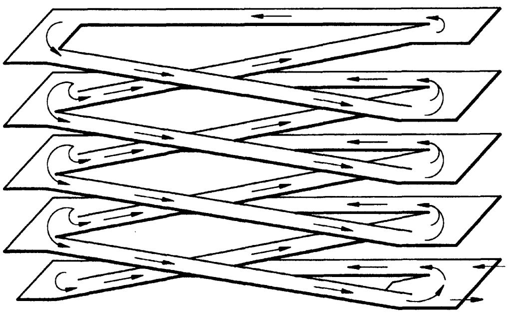
"down" thread (presuming the structure rises above street level), a crossover is provided. This is physically possible where the two sloping bays cross each other in the center of the structure. Depending on the type of user, crossovers are often provided only at every other tier. (See the guidelines for travel distance "up" to a crossover in Table 2-3.)

Two-way traffic is sometimes used on a double-threaded helix. In that case, the driver can travel back down the same thread, and crossover between threads is not required. Interconnection between the threads can occur only at the top and the bottom of the structure. Two-way traffic on a double-threaded helix results in two up threads and two down threads. This may or may not be advantageous, as will be discussed later.

Like single-threaded helixes, double-threaded helixes may also be provided end-to-end or side-by-side when a structure is very large (generally over 1500 spaces). In such a case, the facility is usually treated



Three Bay Double Threaded Helix



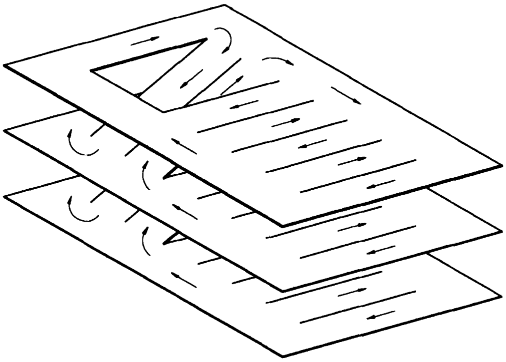
Three Bay Interlocked Helix
(Single Threaded)

Figure 2-9. Sometimes traffic may be routed in either a double-threaded or single-threaded pattern on the same configuration of parking bays.

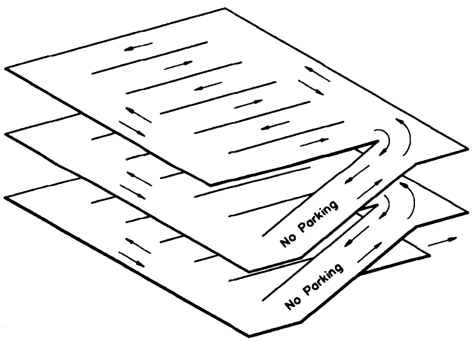
as two separate structures, with crossover from one helix to the other allowed but not encouraged. With one-way traffic there will be two up and two down threads; with two-way traffic there would be four ups and four downs. This type of facility tends to be very confusing to the user, and "lost cars" are a frequent problem. Therefore, unless there is a capacity problem which requires more than one circulation route (to be discussed in Section 2.5), multiple double-threaded helixes are usually avoided.

Several common systems provide double-threaded helixes in two bays with additional level bays off the primary circulation patterns. In such a case the level bay may provide the crossover from the up circuit to the down circuit. Single-threaded helixes likewise may have "level" bays off the circulation route. In some cases the same sloping parking bay configuration can have different traffic flow, resulting in either a single- or double-threaded helix circulation pattern (Figure 2-9).

A structure with a very large footprint may also have just one or two



Large Footprint
Single Threaded
Parking Bays



Single Threaded
Exterior Express Ramps

Figure 2-10. Adding level bays off the primary circulation route results in more decisions for the driver.

bays sloping with the remainder level. In general the larger the number of level parking bays, the better the visibility for wayfinding, patron comfort, and security. Express ramps are often employed when there is a goal to have all parking on level floors. Sloping parking bays or express ramps are usually combined with flat parking bays to achieve a single-threaded helix configuration (Figure 2-10). However, double-threaded systems can also be used when height and number of turns are considerations.

In general, concerns for patron comfort, visibility, and ease of orientation all encourage the use of single-threaded schemes for facilities that will serve large numbers of infrequent users. If the users are present every day, however, they will get to know the system and become frustrated by long search routes and circuitous exit routes. Therefore, sloping parking bays in double-threaded patterns are generally preferred for office parking and other situations with predominantly everyday users.

2.4 PARKING GEOMETRICS

An important step in functional design is selection of the parking geometrics. The most critical dimensions are the stall width and the parking module. Parking designers consider the module dimension to be more important than the aisle dimension because the aisle is merely the space left when vehicles are parked opposite each other. The aisle is theoretical; the module is the dimension needed for construction.

The first major concern is the door opening dimension. For *long-term* parking (3 hours or more), studies[4] have shown that a door opening clearance of 20 in. between parked vehicles is acceptable. For high turnover parking, a door opening clearance of 24 in. provides a better level of convenience for the more frequent movements.

The second major concern is vehicle movement into the stall. As the angle of parking moves farther from 90 degrees (toward 45 degrees), the parking module may be reduced while providing similar maneuverability (i.e., one turning movement) into the stall. The module width is dependent to some extent on the stall width. A narrower stall requires a wider module to achieve the same comfort as a wider stall with a narrower module. Stall widths greater than the minimum provide higher levels of comfort for turning movement and door opening. Increasing stall width is generally a more economical method for increasing comfort than increasing the module.[5]

2.4.1 The Impact of Downsizing

The trend to smaller cars began after the oil shortages of the early 1970s when the U.S. Government fuel efficiency standards (Corporate Average Fuel Economy, CAFE) were adopted. At the same time smaller, more economical Japanese vehicles became popular. These two factors combined to force American automobile manufacturers to substantially reduce vehicle sizes.[6]

The first reaction to downsizing was to permit a certain percentage of the stalls in a parking facility to be designed for "small cars only."

Because manufacturers use "compact" and "standard" to designate certain groups of vehicles of similar size, most parking consultants use the terms "small-car" stalls and "large-car" stalls.

During the late 1970s, when small car sales were steadily increasing, many sources in the automobile and parking industries predicted that small-car sales would continue to rise and that as many as 80% of all vehicles (on the road) would be small cars by 1990. This prediction, however, has not come true.

Small-car/large-car sales have been charted in each calendar year since 1970.[3,5] Small-car sales rose slowly from 14% to 25% from 1973 to 1978, as shown in Figure 2-11. A steady rise in small-car sales occurred through 1981; then it stabilized and hovered around 50% small cars sold each year from 1983 to 1990.

Since 1990, however, the percentage of small cars sold has dropped back to below 40%. This is believed to be primarily due to the fact that manufacturers have been able to substantially improve fuel efficiency, allowing them to build larger cars and still meet CAFE rules.

Given the pattern of car sales for the last ten years, approximately 50% of the vehicles on the road as of 1995 are small cars. It appears, however, that the percentage may move downward if the trend to lower small-car sales continues. There are, of course, definite regional variations. In many cases it is desirable to conduct a "vehicle mix survey" at the project site or at a similar land use in the same community to determine the expected small-car/large-car ratio for the project.

An even more important trend is that auto sales have clustered around the small-car/large-car boundary in recent years. A 1989 Parking Consultants Council study[7] looked at automobile sales by class since 1980. These data have been updated through calendar year 1993. The PCC uses a classification system based on the area of the vehicle in square meters.[5] Classes 5 through 7 are considered small cars; classes 8 through 11 are large cars (Figure 2-12).

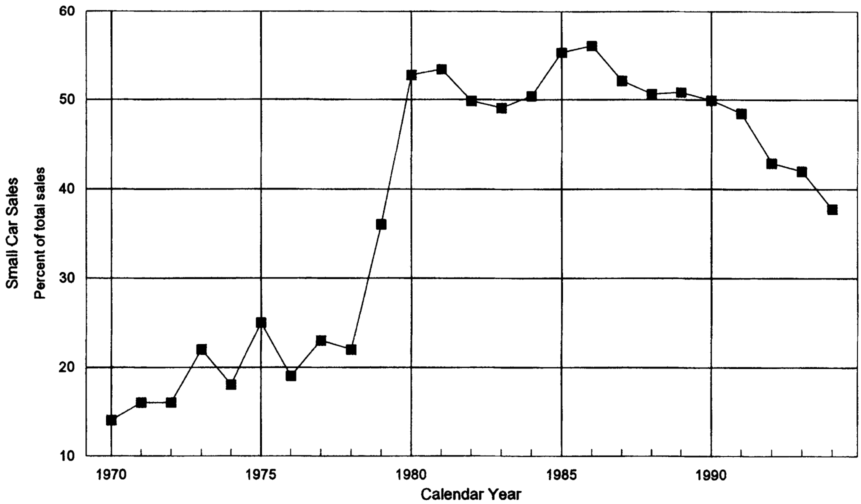
The popular Ford Tempo and Taurus models are excellent examples of this clustering phenomenon. The Tempo is among the largest of the cars in the small-car classes; the Taurus is among the smallest of the large-car classes. In 1980 39% of all vehicles sold were in classes 7 and 8, the border between large and small. This figure has been steadily rising so that since 1989 more than 70% of all vehicles sold were in classes 7 and 8. Therefore, the percentage of vehicles in classes 7 and 8 on the road has been increasing, as older cars, which are more polarized in size, have been retired from service.[7]

The pendulum does seem to be swinging back toward larger cars; however, two things are important in this trend. The lengths have only

Annual Auto Sales by Class

	Small-Car Classes				Large-Car Classes					
Year	5	6	7	Small-Car Subtotal	8	9	10	11	Large-Car Subtotal	TOTAL
1980	33,201	2,372,860	2,556,835	4,962,896	1,015,406	2,316,629	1,086,576	31,553	4,450,164	9,413,060
	0.4%	25.2%	27.2%	52.7%	10.8%	24.6%	11.5%	0.3%	47.3%	
1981	56,174	2,481,352	2,105,792	4,643,318	1,144,123	1,839,188	986,817	87,513	4,057,641	8,700,959
	0.6%	28.5%	24.2%	53.4%	13.1%	21.1%	11.3%	1.0%	46.6%	
1982	56,879	1,941,307	1,942,424	3,940,610	1,383,807	1,448,222	1,036,090	105,381	3,973,500	7,914,110
	0.7%	24.5%	24.5%	49.8%	17.5%	18.3%	13.1%	1.3%	50.2%	
1983	27,756	1,942,859	2,522,645	4,493,260	1,617,857	1,751,531	1,240,607	59,626	4,669,621	9,162,881
	0.3%	21.2%	27.5%	49.0%	17.7%	19.1%	13.5%	0.7%	51.0%	
1984	58,631	1,711,450	3,447,243	5,217,324	1,864,253	2,129,082	1,057,727	90,869	5,141,731	10,359,055
	0.6%	16.5%	33.3%	50.4%	18.0%	20.6%	10.2%	0.9%	49.6%	
1985	88,023	1,275,036	4,728,474	6,091,533	2,138,597	2,060,844	613,521	117,606	4,930,568	11,022,101
	0.8%	11.6%	42.9%	55.3%	19.4%	18.7%	5.6%	1.1%	44.7%	
1986	151,012	1,513,428	4,744,133	6,408,573	2,495,661	1,852,244	546,513	133,175	5,027,593	11,436,166
	1.3%	13.2%	41.5%	56.0%	21.8%	16.2%	4.8%	1.2%	44.0%	
1987	149,161	1,153,907	4,020,479	5,323,547	3,060,943	1,284,030	411,860	139,893	4,896,726	10,220,273
	1.5%	11.3%	39.3%	52.1%	29.9%	12.6%	4.0%	1.4%	47.9%	
1988	187,796	923,879	3,854,820	4,966,495	2,764,226	1,418,369	332,176	341,158	4,855,929	9,822,424
	1.9%	9.4%	39.2%	50.6%	28.1%	14.4%	3.4%	3.5%	49.4%	
1989	104,121	554,993	4,295,608	4,954,722	2,790,792	1,484,841	409,557	119,254	4,804,444	9,759,166
	1.1%	5.7%	44.0%	50.8%	28.6%	15.2%	4.2%	1.2%	49.2%	
1990	83,237	553,676	3,921,449	4,558,362	2,633,404	1,381,215	264,836	302,756	4,582,211	9,140,573
	0.9%	6.1%	42.9%	49.9%	28.8%	15.1%	2.9%	3.3%	50.1%	
1991	58,115	536,870	3,384,412	3,979,397	2,712,992	1,047,431	195,189	277,725	4,233,337	8,212,734
	0.7%	6.5%	41.2%	48.5%	33.0%	12.8%	2.4%	3.4%	51.5%	
1992	43,244	486,990	2,991,177	3,521,411	2,946,394	1,278,002	201,829	260,454	4,686,679	8,208,090
	0.5%	5.9%	36.4%	42.9%	35.9%	15.6%	2.5%	3.2%	57.1%	
1993	34,797	371,457	3,169,929	3,576,183	2,986,425	1,388,393	311,861	252,260	4,938,939	8,515,122
	0.4%	4.4%	37.2%	42.0%	35.1%	16.3%	3.7%	3.0%	58.0%	
1994	3,732	421,719	2,844,098	3,269,549	3,265,568	1,478,812	527,043	119,950	5,391,373	8,660,922
	0.0%	4.9%	32.8%	37.8%	37.7%	17.1%	6 .1%	1.4%	62.2%	

Figure 2-11. Automobile sales by class since 1980.



Source: Compiled by Walker Parking Consultants from Automotive News "Market Data Issue".

Figure 2.12 Small-car sales since 1970.

gone up to 18′0″ to 18′6″, not all the way back to 20′ as existed in the early 1970s. Furthermore the market share of these vehicles—whether they are 17′, 18′, or 20′ in length—is still relatively small. The total sales of vehicles in classes 10 and 11 accounted for 7% or less of all vehicles sold. Even if the market share returns to that which existed prior to the downsizing of standard vehicles, only 12% of auto sales would be in classes 10 and 11. In an interview at the 1989 Chicago Auto Show,[8] GM chairman Roger Smith stated that "there's no question" that some models were downsized too much; however, he went on to say that the "dinosaurs of the past are gone forever."

Another trend is toward more light trucks, vans, and utility (LTVU) vehicles. As seen in Figure 2-13, LTVU sales comprised 31% of total vehicles sold in 1987; in 1993 they comprised 38.5%.

Clearly, downsizing has had an impact; 43% of LTVU vehicles sold in calendar year 1987 are in the small-car classes. In 1993, this figure declined back to 17.3%. When LTVU vehicles are added to the 1987 passenger auto sales discussed previously, the percentage of small vehicles is reduced only by 3%. However, in 1993, the addition of LTVU vehicles pulls the overall percent of small vehicles sold down 10%. A major contributor to this significant change is that many of the class 7 pickups, minivans, and sport utility vehicles were replaced

Comparison of Car and LTVU Sales 1993 vs 1987

	5	6	7	Subtotal		8	9	10	11	Subtotal		Total
1987												
Cars	149,161	1,153,907	4,020,479	5,323,547	52.1%	3,060,943	1,284,030	411,860	139,893	4,896,726	47.9%	10,220,273
LTVU	83,334	171,157	1,745,097	1,999,588	42.7%	800,478	1,612,550	236,780	33,878	2,683,686	57.3%	4,683,274
Total	232,495	1,325,064	5,765,576	7,323,135		3,861,421	2,896,580	648,640	173,771	7,580,412	50.9%	14,903,547
	1.6%	8.9%	38.7%	49.1%		25.9%	19.4%	4.4%	1.2%	50.9%		100.0
1993												
Cars	34,797	371,457	3,169,929	3,576,183	42.0%	2,986,425	1,388,393	311,861	252,260	4,938,939	58.0%	8,515,122
LTVU	43,443	83,704	804,938	932,085	17.3%	3,098,544	921,101	421,943	19,207	4,460,795	82.7%	5,392,880
Total	78,240	455,161	3,974,867	4,508,268	32.4%	6,084,969	2,309,494	733,804	271,467	9,399,734	67.6%	13,908,002
	0.6%	3.3%	28.6%	32.4%		43.8%	16.6%	5.3%	2.0%	67.6%		100.0%

	1987	1993
Percent in Classes 7 and 8		
Cars	69.3%	72.3%
LTVU	54.4%	72.4%
Total	64.6%	72.3%

Figure 2-13. Sales of light trucks, vans, and utility vehicles are increasingly significant in parking design.

by class 8 models. There has been some migration from class 9 to class 8 as well.

Clustering is also a very strong phenomenon in LTVU sales; in 1987 54.4% of LTVUs were in classes 7 and 8; in 1993 72.4% were in 7 and 8. This reflects the popularity of minivans, sport utility vehicles, and small pickups as personal vehicles, which means they are likely to be parked in a parking facility. In fact 60% of 1993 LTVU sales were minivans or sport utility vehicles. The minivan (usually class 8) has largely replaced the old "family station wagon" that accounted for a substantial number of class 11 vehicles in the 1970s.[7] Most of the larger pickups and a good portion of the vans are sold as commercial vehicles and therefore would not have as big an impact.

The impact of the downsizing of the automobile on parking dimensions has been pronounced; the change in vehicle length not only affects stall size but also reduces the aisle required for turning into the stall. Regulatory agencies such as local zoning boards, however, have been slow to respond. After experimentation with a small-car-only stall proved successful, many localities modified their ordinances to permit a certain percentage of small-car spaces. Design standards for the large-car stalls remained the same. Since then, however, nearly all intermediate and standard models have been reduced in size. (Exceptions are the Cadillac Fleetwood Brougham and the Lincoln Town Car, which retain their 1970s length of 18′5″ and 18′3″, respectively, and a few full-size station wagons.)

While many parking consultants promoted smaller, "one-size-fits-all" parking spaces, most zoning ordinances continue to permit large-car/small-car standards. This has the impact of encouraging separate large-car/small-car stalls, which are difficult to enforce and frequently abused. Some small-car owners will routinely choose to park in the more generous large-car stalls, often leaving large-car drivers no choice but to park in small-car stalls. One response has been to place the small-car stalls in the "best" locations in the parking facility; intermediate and even large cars then try to use the small-car stalls. In effect, the level of comfort for all users is reduced below that which the local officials desire.[7]

The clustering of vehicles around the large-car/small-car boundary only increases the confusion and/or abuse of small-car-only stalls. The PCC[7] therefore revamped its standards for parking design, and strongly recommends that one-size-fits-all stalls be used. In the absence of an updated ordinance, owners should apply for variances. Two concepts have been developed to facilitate this process—the *design vehicle*,[5] and the level of service approach to parking dimensions.[9] Using these tools, many consultants have been successful in gaining ordinance changes and/or zoning variances.

2.4.2 The Design Vehicle

In 1983 Walker Parking Consultants performed an extensive study of parking dimensions. It was found helpful to select a theoretical vehicle size and then determine stall and module dimensions to accommodate the needs of this "design vehicle." To maintain the recommended level of comfort for users the design vehicle is selected as the 85th-percentile vehicle among the vehicles present.

It is highly unlikely that three 100th percentile (i.e., absolutely largest) vehicles will be parked side by side with three 100th percentile vehicles across the aisle. Use of the 85th percentile is still conservative with respect to the average condition (which would be the 50th percentile) while realistically representing the probable worst condition of parked vehicles. This approach parallels the standard design principle for traffic in which a roadway is designed for the 85th percentile peak hour.

Parking dimensions were developed to comfortably accommodate the design vehicle in both its parked position and its turning path for a range of mixes of small and large cars, from 20% small/80% large, 30% small/70% large, and so on up to 80% small/20% large. Dimensions for designs with separate small- and large-car stalls were also provided, under the labels 100% small/0% large and 0% small/100% large. The recommendations were thus designed to allow parking dimensions to be tailored to the expected mix of small cars and large cars in any locality and to remain viable as the automobile population changes.

Several considerations were included in the determination of stall size, including the fact that vehicles often do not pull all the way to a wall, wheel stop, or other parking guide. It is also important to understand that the projection of the parked vehicles in stalls determines the width of the aisle available in any parking bay rather than the rotation of a stall to the angle desired.[5] Many ordinances that call for rotation of the stall end up requiring a wider bay for a one-way aisle serving angled parking spaces than is required for a two-way aisle serving perpendicular parking spaces!

In 1985, the PCC[6] also adopted a design vehicle approach based largely on the Walker research. Data on design vehicles from auto sales have recently been updated as follows:

Design Vehicles

	On the Road, 1983 Smith 1985	1987 Auto Sales PCC 1989	1994 Auto Sales
Small Cars	5′7″ × 14′8″	5′8″ × 14′8″	5′8″ × 14′8″
Large Cars	6′7″ × 18′4″	6′6″ × 18′0″	6′2″ × 17′2″
All Cars	6′3″ × 17′2″	6′2″ × 17′0″	6′3″ × 16′8″
% Small Cars	36%	52.1%	38%

The design vehicle for small cars sold since 1983 has remained quite stable, while the design vehicle for large cars has declined by 1′2″ in length. Therefore, the design vehicle length among those on the road has also reduced. It is extremely important to note that the design vehicle for the overall sales in 1994 declined compared to 1987 even as large-car sales have increased as a percent of sales. This is directly related to the fact that class 8 sales, the smallest of the large cars, is the market segment that has grown the most. In fact, in 1994, sales in Class 8 were equal to the total small car sales (Classes 5–7.)

The sales of LTVUs for commercial vehicles makes it difficult to calculate a design vehicle for the overall mix of personal vehicles. The design vehicle for LTVUs in 1993 was 6′7″ (somewhat wider than for cars) by 16′5″ (a little shorter than for cars). It is clear that the design vehicles based on all cars on the road in 1983 are still conservative compared to the design vehicle among personal vehicles on the road today. One thing we can conclude from over twenty years of auto sales analysis is that auto sizes will change. Therefore, we have chosen not to change the design vehicles, which in turn means that we will not change our recommendations for stall and aisle geometry.

2.4.3 Levels of Service for Parking Geometrics

The level-of-service approach provides assistance in tailoring a design for the users of the specific project. In parking design, there are virtually infinite combinations of stall width and module. LOS F designs result in extremely tight conditions where some parkers have to make several attempts to get into the stall. *Encroachment* into adjacent stalls may leave them unusable. The PCC 1989[7] dimensions are roughly LOS D, the minimum acceptable design. Since the design vehicle is the 85% vehicle in the mix, most users can turn into the stall in one movement. Larger vehicles may require a second movement, but should be able to align in the stall properly. Regular users will become accustomed to and will accept the design. These dimensions would not, however, be acceptable in high-turnover facilities or in areas where users are accustomed to very generous parking dimensions. (See Table 2-5 for the gradation of stall and module combinations from LOS D up to LOS A.)

Designers may reduce aisle (and consequently module) width 3 in. for each additional inch of stall width and maintain the same level of service. For example, in a 40% small-car/60% large-car mix, an 8′6″ stall and 51-ft module for 60-degree parking would be LOS C. Increasing aisle width and reducing stall width is not recommended.

For a more complete discussion of the details involved in laying out parking stalls the reader is referred to Smith[5] and/or the PCC.[7]

2.4.4 Parking Efficiency

In addition to achieving the correct traffic flow, the selection of the angle of parking will depend on several factors; often the most critical is the *efficiency*. In most cases, efficiency has a direct impact on the construction cost per parking stall. Obviously if one design requires less floor area per space, it will cost less. Because *modules* with angled parking are narrower than those for 90-degree parking, one can sometimes put more bays of angled parking onto a site. For example, a site that is 110 ft wide is too narrow for two *double-loaded* bays of 90-degree parking, but can comfortably accommodate two double-loaded bays of angled parking. More spaces can be accommodated on that site with angled parking than with 90-degree parking. It is a myth that 90-degree parking is **always** more efficient than angled parking. The case above, in which one bay in a 90-degree scheme would have to be *single loaded,* is one example. Unfair comparison you say? Then let's lay out two parking lots on a site 121 ft wide by 200 ft long. For simplicity's sake, ignore the need for parking equipment and assume that there are driveways at one end. As seen in Figure 2-14, one lot has 8′5″ stalls at 90 degrees on a module of 60′6″. This is classified as a level of service B for a vehicle population containing 40% small cars. For 75-degree parking, 8′5″ stalls require a module of 56′4″ for LOS B (40% small cars). Note that for 8′5″ stalls at 75 degrees, the dimension of the stall parallel to the aisle is about 8′9″. The turning bays at both ends are designed to provide LOS B, assuming turnover conditions. The two lots have the same number of cars, but the 75-degree design uses less floor area. The efficiency of the 75-degree layout is greater than the efficiency of the 90-degree layout. In addition to the money saved on paving, the angled design provides a little more space on the site for landscaping, storm water retention, and other design concerns.

TABLE 2-5. Recommended Stall and Module Widths

			LOS D		LOS C		LOS B		LOS A	
		Angle	Stall	Module	Stall	Module	Stall	Module	Stall	Module
0%	small car	45	8.25	49.58	8.50	50.58	8.75	51.58	9.00	52.58
100%	large car	60	8.25	54.67	8.50	55.67	8.75	56.67	9.00	57.67
		75	8.25	58.17	8.50	59.17	8.75	60.17	9.00	61.17
		90	8.25	61.00	8.50	62.00	8.75	63.00	9.00	64.00
30%	small car	45	8.00	46.92	8.25	47.92	8.50	48.92	8.75	49.92
70%	large car	60	8.00	51.83	8.25	52.83	8.50	53.83	8.75	54.83
		75	8.00	55.42	8.25	56.42	8.50	57.42	8.75	58.42
		90	8.00	59.83	8.25	60.83	8.50	61.83	8.75	62.83
40%	small car	45	7.92	46.08	8.17	47.08	8.42	48.08	8.67	49.08
60%	large car	60	7.92	50.75	8.17	51.75	8.42	52.75	8.67	53.75
		75	7.92	54.33	8.17	55.33	8.42	56.33	8.67	57.33
		90	7.92	58.5	8.17	59.50	8.42	60.50	8.67	61.50
50%	small car	45	7.83	45.58	8.08	46.58	8.33	47.58	8.58	48.58
50%	large car	60	7.83	50.17	8.08	51.17	8.33	52.17	8.58	53.17
		75	7.83	53.67	8.08	54.67	8.33	55.67	8.58	56.67
		90	7.83	57.67	8.08	58.67	8.33	59.67	8.58	60.67
60%	small car	45	7.67	44.58	7.92	45.58	8.17	46.58	8.42	47.58
40%	large car	60	7.67	49.17	7.92	50.17	8.17	51.17	8.42	52.17
		75	7.67	52.58	7.92	53.58	8.17	54.58	8.42	55.58
		90	7.67	56.50	7.92	57.50	8.17	58.50	8.42	59.50
100%	small car	45	7.25	41.33	7.50	42.33	7.75	43.33	8.00	44.33
0%	large car	60	7.25	45.17	7.50	46.17	7.75	47.17	8.00	48.17
		75	7.25	48.17	7.50	49.17	7.75	50.17	8.00	51.17
		90	7.25	50.00	7.50	52.00	7.75	54.00	8.00	56.00

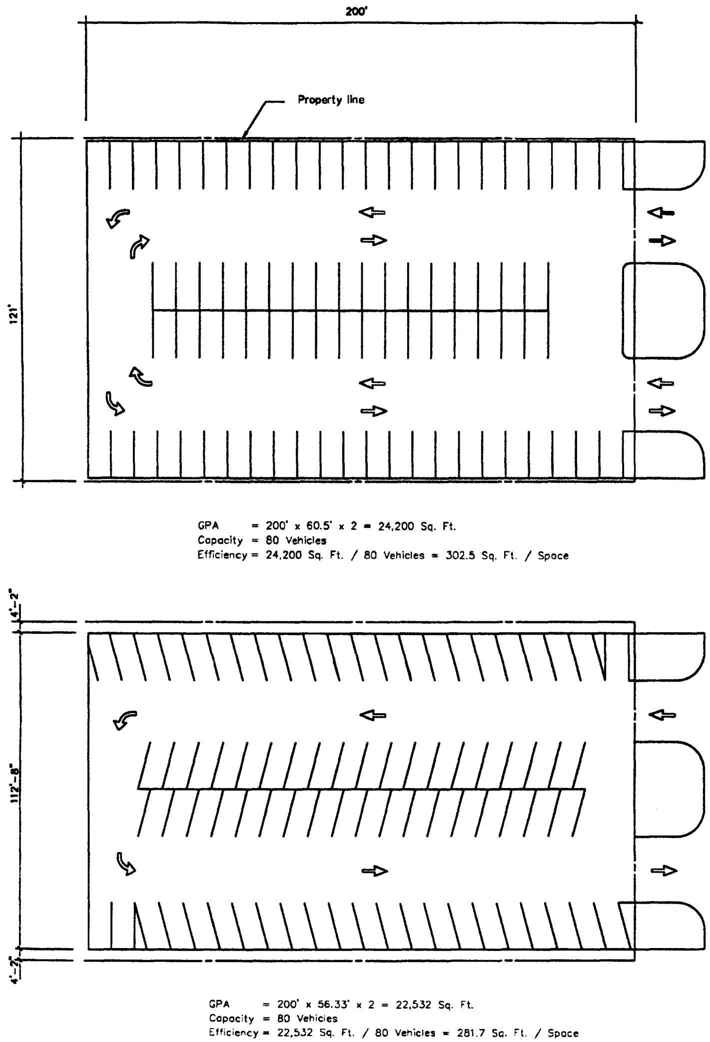


Figure 2-14. Angled parking can be more efficient than 90-degree parking.

While it is quite true that any 90-degree layout is more efficient in its use of the adjacent aisle, the larger turning bays required for two-way traffic in this particular layout counterbalance the efficiency advantage in the parking bays. Other design "tricks," such as parking along end bays, affect the efficiency of a design. Therefore, designers, always check several layouts before deciding which is the most efficient; owners, make sure your designers did it!

The actual efficiency figure depends to some degree on how it is calculated. Some designers make their efficiencies look better by removing interior columns, walls, and any openings between sloping bays to achieve a net floor area, but this is spurious at best. The best approach is to use the *gross parking area* (GPA) (outside-to-outside of exterior walls) because it most closely parallels the floor area dedicated to parking, which in turn determines the cost of building the parking space. Stair and elevator towers are removed from the gross parking area even if they are located *inboard*; the towers are present no matter what the efficiency of the parking area is, and the design of the stair/elevator towers (be it spartan or palatial) should not impact the assessment of parking efficiency. The GPA as defined herein is similar to the gross leasable area used for commercial buildings.

Using the stall and module dimensions recommended herein, efficiencies of 300 sq ft per car or less can often be achieved. Just using these dimensions is no guarantee. A critical factor in the overall efficiency is the length of a row of parking stalls between turning bays or crossovers. A structure 250 ft long will have better efficiency than one 150 ft long with the same geometrics. Therefore, it is generally more efficient to lay the parking bays along the long dimensions of the site.

Structures that have fewer turning bays will also be more efficient if other factors are equal. A single-threaded helix either alone or side-by-side (two turning bays per level) will usually be more efficient than a double-threaded helix (two turning bays plus a crossover). The latter is usually more efficient than an end-to-end or a split level (with one-way traffic), each of which has four turning bays. As noted previously, however, it is always best to look at several alternatives before deciding which is most efficient.

2.5 FLOW CAPACITY CONSIDERATIONS

In the past, the relatively small number of parking structures with more than 1500 parking spaces tended to be conservatively designed with multiple circulation paths or high-volume *circular helixes*. There were no standards for the flow capacity of a circulation route except an old rule of thumb that no more than 750 vehicles an hour should use a sloped parking bay. It becomes apparent to an experienced designer, however, that the type of traffic flow and the design of the system do have an impact on the flow capacity. Several other rules of thumb were developed, such as, it is better to use one-way traffic flow than two-way traffic flow. However, how much better? Where is the breaking point between acceptable and unacceptable?

Parking consultants generally agree that retail facilities with sloping parking bays should have one-way traffic flow because of the high volumes of vehicles arriving and departing at the same time. It is easier to get in and out of one-way stalls; therefore the delay to other users is less. Also, in two-way systems, departing vehicles have to wait for gaps in both departing and arriving traffic streams, often from two directions. Conflicts between two vehicles approaching an empty parking stall from different directions are eliminated. In most one-way systems, arriving and departing traffic are separated, and there is better visibility to watch for approaching vehicles when the car is parked at an angle. The more one direction of flow (either in or out) predominates, the more muddy the waters become. Many consultants argue that 90-degree parking and two-way traffic flow are perfectly acceptable for office parking, where most vehicles arrive in the morning and depart in the evening. In fact, a double-threaded helix with two-way traffic flow has twice the circulation routes (two up and two down) of a double-threaded helix with one-way flow. Under the old rule of thumb of 750 vehicles per hour per route, the flow capacity has been doubled. The two-way design eliminates the need for a crossover in a two-bay configuration, improving efficiency. End of argument, right? No. Other consultants argue that one-way traffic flow is still better.

In 1986, Walker initiated a study to find a better way to assess the flow capacity of parking circulation systems. The British equivalent of the Transportation Research Board (TRB), the Transport and Road Research Laboratory (TRRL) did extensive research in 1969[10] and again in 1984[11] on this issue. Unfortunately, it was never widely published in the United States. Also, the test parameters employed were appropriate for British driving conditions, including a much higher ratio (virtually 100%) of small cars. Therefore, the TRRL equations are not directly applicable to American conditions.

The TRRL equations were therefore reviewed, and modifications were made for American conditions. It should be noted that the results have not been field-tested in the same way that the TRRL equations were. However, the results seem reasonable and provide a good basis for an "apples-to-apples" comparison of two circulation systems.

The intent of this book is to acquaint the reader with important information regarding the design of parking facilities; in this case, the point is that there **is** an analytical approach to determining the flow capacity of a parking facility. The equations and guidelines for assumptions are provided herein; however, the methodology and research used to develop the methodology are not provided.

2.5.1 Peak-Hour Volumes

The most critical variable in determining the adequacy of any circulation system is the volume, *V*, of vehicles expected to arrive and/or depart in the peak hour. Some references have recommended that a parking structure should be able to fill or discharge completely in 1 hr, with an even faster fill/discharge rate of 30 min for special events.[12] This standard is, however, substantially higher than that employed for designing streets. In standard traffic engineering practice, "trips" are generated for peak hours based on the square footage of the generating land use, such as office, retail, etc.[13]When these figures are combined with the ratio of parking spaces required per 1000 sq ft, which have also been published,[14] a ratio of peak-hour volume as a percent of parking spaces can be determined for these land uses. Only in a very few cases do land uses generate peak-hour volumes equal to or in excess of the *static parking capacity* (denoted *N*) required for that use (Table 2-6). One exception is the special-event facility, which in most cases should be designed to fully "dump" in one hour or less. Convenience retail and consumer banking facilities also tend to turn over more than once an hour; however, the spaces associated with these uses are not normally a major component of demand for a multistory parking facility.

It must be noted that there is substantial variance from the ITE standards based on the specific characteristics of the land use served by the parking facility and/or the community in which it is located. In general, it is wise to estimate the peak-hour volume conservatively high. In addition to the peak hour of the *generator* as shown in the table, it is sometimes necessary to check volumes during the peak hour of street traffic, because the two may occur at different times. Also, the larger the facility, the more justification there is for doing a detailed study to more accurately determine the peak-hour volume for a particular case.

2.5.2 Flow Capacity

In most real conditions there are peaks and valleys in the flow during the course of the peak hour. To ensure that the flow is not unacceptably constrained in shorter periods, the flow capacity (in vehicles per hour) of a system should be somewhat more than the expected volume in the hour. Traffic engineers use *peak-hour factors* to upwardly adjust the

TABLE 2-6. Typical Peak-Hour Volumes

	Volume in 1 hr[1,2]			
	Peak A.M. Hour		Peak P.M. Hour	
Land Use	In	Out	In	Out
Residential	5–10%	30–50%	30–50%	10–30%
Hotel/motel	30–50%	50–80%	30–60%	10–30%
Office	40–70%	5–15%	5–20%	40–70%
General retail/restaurant	20–50%	30–60%	30–60%	30–60%
Convenience retail/ banking	80–150%	80–150%	80–150%	80–150%
Central business district[3]	20–60%	10–60%	10–50%	20–60%
Medical office	40–60%	50–80%	60–80%	60–90%
Hospital				
Visitor spaces	30–40%	40–50%	40–60%	50–75%
Employee spaces	60–75%	5–10%	10–15%	60–75%
Airport				
Short-term (0–3 hr)	50–75%	80–100%	90–100%	90–100%
Mid-term (3–24 hr)	10–30%	5–10%	10–30%	10–30%
Long-term (24+ hr)	5–10%	5–10%	5–10%	5–10%
Special event[4]	80–100%	85–200%		

[1] As a percentage of the static capacity of the parking facility.
[2] As a general rule, the larger the facility and/or the more diverse the tenants of the generated land uses, the lower the peak-hour volume as a percentage of the static capacity.
[3] It is generally more accurate to determine what portion of the spaces are allocated to retail, office, and other uses.
[4] If 100% of the capacity leaves in 30 min, the equivalent volume in a full hour is 200% of capacity.

volume of traffic. The peak-hour factor (PHF) is usually determined by measuring volumes in 15-min intervals within the hour (V_{15}), selecting the highest 15 min volume, and converting to an equivalent hourly *rate of flow*, v. Therefore, $v = 4 * V_{15}$ and PHF $= V/v$. A PHF of 0.85 has been found to be reasonable for most traffic situations in the absence of complete data. However, if a special-event facility is to "dump" in 30 minutes, the PHF would be quite different. One half of V would have to depart in 15 min, so $v = 4 * .5V = 2V$ and PHF $= V/2V = 0.5$. Also, a parking facility that serves a single employer with uniform starting and ending times can have a PHF as low as 0.5.

The ratio of flow rate to the maximum flow capacity, v/c, provides a good measure for assessing level of service for flow capacity considerations. Table 2-7 provides guidelines for v/c at each LOS. It is not recommended that an LOS D flow capacity be permitted in a parking facility, and therefore no value is provided.

TABLE 2-7. Flow Capacity of Circulation Elements

	Theoretical Maximum Flow Capacity, c[1] (vehicles per hour)			
Design Standard For:	LOS D	LOS C	LOS B	LOS A
Straight lane or drive ramp[2]				
One-way	1850	1853	1855	1858
Two-way	1845	1848	1850	1853
Circular Helix				
Single-threaded	1169	1473	1631	1715
Double-threaded	1589	1704	1761	1793
Turning bays[3]	936	1097	1233	1345
Design flow capacity[4]	NR	0.8	0.7	0.6

[1] Dimensions for each LOS per Table 2-3, capacity equation per TRRL 1969.
[2] Aisle with no parking along side.
[3] Turning radii per Table 2-3; no parking on end bay; no merging traffic.
[4] Ratio of expected flow rate to theoretical capacity, v/c.
NR, Not recommended.

2.5.3 Nonparking Circulation Components

Table 2-6 summarizes the capacities, c, of various nonparking circulation components as calculated using the TRRL equations[10] and the dimensions per Table 2-3. The typical flow capacity of straight express ramps and nonparking bays ranges from 1850 to 1860 vph. The difference in flow capacity between one-way and two-way roadways is negligible.

Capacity is decreased when vehicles flow through a turn or bend. In a parking facility, the most common bends are 90 degrees, 180 degrees, and 360 degrees (in a circular helix).

The flow capacity of a single-threaded circular helix with LOS D geometry is 1169 vph. Because larger radii are recommended for double-threaded circular helixes to reduce floor slope, the LOS D double-threaded helix has a flow capacity of 1589 vph. It should be noted that a circular helix at the geometry for LOS D is acceptable for one turn and/or slow speeds, but for greater heights, or speeds, LOS C or better should be provided. Note also that the flow capacity LOS still must be determined by calculating v/c. c will be increased with increasing radius; a single-threaded helix with LOS C geometry has 26% more capacity than one with LOS D geometry. One note regarding circular helixes—-they reduce travel distance and eliminate delays for the individual driver along the path of travel. Circular helixes therefore deliver the peak surges in activity to the exit area without the moderating effects of differing travel lengths. Systems with circular helixes thus require more careful design of the control lanes, stacking, and reservoir areas.

Also shown in Table 2-7 are c values for U-turns in turning bays based on TRRL[11] equations. It should be noted that the TRRL equation does not include any component for width of lane; given the negligible differences in capacity for straight aisles of varying widths, it seems reasonable to neglect width of lane for curve capacity. The flow capacities at turning bays generally exceed those of adjacent parking bays during outbound flows, as will be presented in Section 2.5.4, and thus do not create bottlenecks. The turning bay capacities are, quite reasonably, much lower than the capacities of straight aisles or roadways without parking and thus control the flow of vehicles in systems that combine straight nonparking ramps with 90- or 180-degree turns at the ends.

2.5.4 Capacity of Parking Bays

The TRRL procedures for determining capacity of parking bays are substantially more complicated. As noted previously the TRRL equations and procedures are not reproduced herein; it is felt that a user must have the complete study in order to properly modify the TRRL equations for American situations. The procedures have been adapted for American conditions, and modified for use by personnel not trained in traffic engineering. To do this a number of assumptions have been made based on our recommendations for such variables as stall width and aisle width. The reader is cautioned that the values presented are thus predicated on certain specific assumptions that may not match those used in a particular project. Further, it is recommended that the LOS of flow capacity be kept at C or better. Therefore, the ratio of v/c should not exceed 0.8.

The TRRL[11] equations for capacity of aisle/stall systems are based on field observations and measurements of situations where all the vehicles attempted to arrive or depart simultaneously. The term *tidal flow capacity* has been adopted for these conditions because, while waves of activity may occur, the volume is all inbound (or outbound) in the peak hour; c_{in} is the tidal flow capacity inbound, and c_{out} is the tidal flow capacity outbound.

The TRRL research found a clear relationship between stall and aisle dimensions and flow capacity. Quite logically, vehicles can arrive and depart in a very comfortable stall/aisle system more quickly than in a system with tighter dimensions. A minor variation in capacity is due to the angle of parking; with approximately equal comfort of turning movement into the stall, the capacity decreases as the angle goes from 70 degrees to 90 degrees. The percentage of vehicles backed into stalls also affects capacity, reducing c_{in} and increasing c_{out}. TRRL also found

TABLE 2-8. Tidal-Flow Capacity of Parking Bays

Geometric LOS	Tidal-Flow Capacity[1] (vehicles per hour) D		C		B		A	
Angle	c_{in}	c_{out}	c_{in}	c_{out}	c_{in}	c_{out}	c_{in}	c_{out}
60° one-way	1349	1011	1500	1037	1500	1065	1500	1095
70° one-way	1189	994	1421	1018	1500	1043	1500	1071
80° one-way	886	941	979	961	1130	983	1343	1006
90° one-way	693	704	764	716	853	728	970	741

[1] One hundred percent of static capacity arrives in 1 hr or departs in 1 hr. See Table 2-5, compact only, for stall and aisle dimensions. Percent reversed: 0% for angle less than 90 degrees, 5% for 90 degrees, c_{max} = 1500 vph.
Source: TRRL 1984.[11]

in the later[11] research that *short-span* column designs reduce capacity compared to long-span designs. With a typical 30′ × 30′ short-span grid system, inbound capacity is reduced by at least 30%, and outbound capacity by at least 15%. Standard statistical theory was used to develop equations reflecting these variables.

The TRRL found that the number of stalls in the system (or subsystem when there are multiple circulation routes) does not materially affect the flow capacity, except as it induces peak-hour volumes. That is, the flow capacity at a particular point in two facilities with the same stall and aisle dimensions and similar traffic flow is the same when one facility has 100 spaces and the other 1000 spaces. Of course, the 1000-space facility is more likely to produce a volume of vehicles that exceeds the flow capacity.

Tidal flow capacity has been calculated, both inbound and outbound, for a variety of angles, and the LOS of the geometrics is provided (Table 2-8). These figures do not include a peak hour factor. There is obviously an upper limit as to how much the degree of comfort of turn impacts the tidal flow capacity, but the TRRL apparently did not test dimensions generous enough to reach this upper limit. We have therefore arbitrarily set an upper limit on tidal flow capacity at 1500 vph.

The 1984 TRRL research was aimed at covering conditions during which spaces are turning over. The *turnover capacity*, c_t, was observed by dispatching vehicles at predetermined, pseudorandom intervals to enter the stall/aisle system and park; the driver was instructed to unpark and depart after one vehicle had passed. The TRRL then developed a procedure to calculate what maximum rate of turnover a facility with a certain number of spaces and a specific circulation system can handle in an hour.

We have chosen a second approach to the capacity problem, that being whether the expected peak-hour volumes will approach the facility's flow capacity, thus allowing classification of flow conditions by LOS.

There is an obvious relationship between c_{in} and c_{out} under turnover conditions; the higher the inflow, the lower the capacity for outflow, and vice versa. The TRRL found that it is important to look at the *mean inhibiting period* of each vehicle passing the point at which capacity is critical. In a constant stream of vehicles coming as close together as they possibly can, there is an average *headway* or spacing that can be expressed in either length (such as feet) or time (such as seconds.) In laymen's terms, each vehicle "uses" a certain amount of the available time. If c_{in} is 1000 vph, the average time used per vehicle at capacity flow is 60 min/1000 = .06 min = 3.6 sec. If the mean inhibiting period, *t*, is expressed in hours, it is the inverse of capacity, that is, t(hours)= $1/c$(vph); *t* is the average spacing (in time units) at capacity flow.

In a typical parking facility, some vehicles driving a primary circulation route may be searching for a stall, some vehicles may be unparking and exiting, and others may be passing through to or from an area off the circulation route. The TRRL found that the *t* components will be different for each of these four types of movements.

To check flow capacity in a particular situation, one adds up the mean inhibiting period (expressed in hours) of each vehicle in the stream passing by the critical point in a peak hour. The equation for Σt by the vehicles passing through at capacity flow is as follows:

$$\Sigma t = p * t_p + u * t_u + s * t_s + e * t_e$$

where

p is the number of vehicles parking on the circulation route, and t_p is the mean inhibiting period of those vehicles, which is $1/c_{in}$,

u is the number of vehicles unparking and departing from the route, and t_u is the mean inhibiting period for those vehicles, or $1/c_{out}$,

s is the number of vehicles seeking a stall but parking off the circulation route being studied, with a mean inhibiting period of t_s, and

e is the number of vehicles that pass through from another area on the way to an exit, with a *mean inhibiting period* of t_e.

Note that the *t* components must be expressed in hours. Based on our field observations of vehicle spacings at peak hours, a value of 1800 vehicles per hour is recommended for the flow rate of vehicles passing through on the way to an exit; therefore, t_e = 1/1800 or 0.00056 hr. Those searching for a stall but parking off the route are assumed to have t_e = 1/1500 or 0.00067 hr.

In a one-way system, there may be all or only one of these activities impacting the capacity at peak hours. In a two-way system, each of the two streams on the route will have its own Σt; however, the parking and unparking movements affect both streams. Another important consideration in applying this methodology is that the "subsystem" through which the vehicles pass may not be just one ramp or leaf of a series in a typical sloping ramp parking facility. If there is basically continuous flow from parking bay to parking bay, the subsystem for the outbound flow would be the entire series of parking bays along the outbound route followed by the vehicle that must drive the farthest from parking space to exit. When bays act in parallel rather than series, they would be separate subsystems. At most points at which traffic merges, the traffic from the minor leg is reflected in the e and s components. At points where traffic crosses, Σt for each stream is added to determine if the expected flows can be accommodated.

In the Appendix to this chapter is an example problem to facilitate use of this procedure.

2.5.5 Flow Capacity Level of Service

If Σt is less than 1, there is theoretically some time available for more vehicles to join the stream. Remember, however, that at capacity, one has presumed conditions of absolutely constant flow rather than the peaks and valleys that occur in real conditions. Although a more complicated formula is used now, the 1965 *Highway Capacity Manual*[15] employed the volume to capacity ratio, v/c, to determine the LOS. The t components represent V in time units; further, because we are looking at how much of the hour is used $V/c = \Sigma t/1 = \Sigma t$. The peak-hour factor and flow rate must also be considered before classifying the LOS. Since $v/c = V/(\text{PHF} * c)$, then $\Sigma t/\text{PHF}$ is equivalent to v/c. Σt for two of the most common PHFs is as follows:

		Σt	Σt
LOS	v/c	PHF = .85	PHF =.5
C	0.8	0.68	0.40
B	0.7	0.60	0.35
A	0.6	0.51	0.30

2.5.6 Benefits of Flow Capacity Analysis

The type of circulation therefore does affect the flow capacity. In using this methodology, we have found it to be of substantial value in several ways:

- Demonstrating that the LOS is quite good. Congestion for the user should be minimal and need not influence functional design.
- Identifying "borderline" situations. This border cannot be treated as a "Berlin Wall" between acceptable and unacceptable conditions. Rather, as Σt approaches 0.8, further study should be made in an attempt to improve circulation.
- Demonstrating that the system will clearly be overstressed and that additional circulation capacity is required.
- Comparing two alternatives to determine which is the best from a circulation capacity standpoint. The analysis can provide an order of magnitude for the differences, answering the frequently asked question: "How much better is alternative X?" Using this analysis, one can say that alternative X will have 25%, 50%, or 100% more capacity, with a corresponding decrease in congestion than alternative Y.

2.5.7 Functional System Capacities

When all components are included, virtually every different parking facility will have a different peak-hour flow capacity on its circulation routes. There is, however, some benefit to comparing circulation systems on an "apples-to-apples" basis; the general pattern of flow capacity can be observed and factors that influence flow capacity can be determined. To do this, the static capacity, $N_{\text{LOS C}}$, which produces a v/c ratio at LOS C has been calculated for many common functional systems under four scenarios:

Special events where the volume of vehicles arriving before the event and the volume departing after the event are each equal to 85% of the static capacity. There is, further, no departing flow during peak arrival periods, and vice versa (PHF = 0.5).

Retail usage with both arriving and departing volumes equal to 60% of the total number of parking spaces; these volumes occur simultaneously (PHF = 0.85).

Office usage where the volumes arriving in the morning or departing in the evening are each equal to 60% of the static capacity. The opposing flows (departing in the morning and arriving in the evening) are equal to 5% of the number of parking spaces (PHF = 0.85).

Airport parking conditions where both the volumes arriving and departing in a peak hour are equal to 30% of the total number of parking spaces; these volumes occur simultaneously (PHF = 0.85).

These percentages were selected to represent relatively high traffic volumes for those uses and thus would tend to be conservative. The

TABLE 2-9. Functional System Capacities
$N_{\text{LOS C}}$

Use:	Sp. Event		Retail		Office		Airport	
PHF:	0.5		0.85		0.85		0.85	
Arrival/Departure Rate:	85%–0%		60%–60%		60%–5%		30%–30%	
Angle:	70	90	70	90	70	90	70	90
Two-bay systems								
Single-threaded helix	N.A.	335	N.A.	420	N.A.	750	N.A.	840
Double-threaded helix	585	675	980	840	1360	1505	1960	1675
End-to-end helix	585	675	980	840	1360	1505	1960	1675
Split level	480	335	670	420	1090	750	1345	840
Three-bay systems								
Interlocking helix	545	505	850	625	1255	1125	1695	1250
Double-threaded helix	635	830	1160	1135	1490	1880	2325	2275
Side-by-side helix[2]	480	410	710	560	1100	930	1425	1125
Four-bay systems								
Side-by-side helix	585	675	980	840	1360	1505	1960	1675
Single-Threaded helix	585	465	980	680	1360	1065	1960	1360
Double-Threaded helix	655	930	1275	1360	1555	2125	2545	2720
Larger systems[3]								
5 Bays, Single-Threaded helix	615	505	1080	775	1430	1160	2160	1555
5 Bays, Double-Threaded helix	675	1010	1335	1550	1600	2320	2710	3110
6 Bays, Single-Threaded helix	635	535	1160	865	1485	1270	2325	1730
6 Bays, Double-Threaded helix	690	1070	1415	1730	1635	2540	2835	3460

N.A. = Not applicable.
[1] Static capacity which produces Σt/PHF = 0.8 or LOS C; geometrics also LOS C.
[2] 70-degree values account for two-way, 90-degree ramps.
[3] Level bays except for floor-to-floor circulation as follows: Single-Threaded: 90 degrees, one bay sloping and 70 degrees, two bays sloping. Double-Threaded: two bays sloping.

results are shown in Table 2-9. Isometric views of most of the circulation systems have been previously presented. These table values work only for designs with flow patterns exactly as shown in the isometrics.

The tables all assume geometrics at LOS C, and adjustment for other conditions may be made by adding approximately 50 spaces in static capacity per step. That is, an LOS D design would have a capacity of the table value minus 50, and LOS A would be the value plus 100. Long-span conditions are also assumed; if a short-span design is used, capacity will be reduced substantially.

Designers can use this table as a guide to selecting a design that will provide LOS C or better in terms of flow capacity. Because of the range of the scenarios, the tables may be interpolated for different arrival and departure rates. For example, if a single-threaded helix is expected to have simultaneous peak-hour arrivals and departures equaling 40% of capacity, one can interpolate between values in the retail and airport columns. ($N_{LOS\ C}$ = 420 + (840 – 420) * (0.4 – 0.3)/(0.6 – 0.3) = 560 spaces). It is important of course to check for the "weakest link in the chain," be it the parking aisles, a circular helix, or an express ramp.

When the size of the facility exceeds the static capacity that would produce a LOS C *v/c* ratio, alternatives or secondary routes should be developed. For example, if *N* is 800 compared with a table value which shows that a 700-space facility will be at LOS C, a different circulation system should be provided. The numbers are not so precise that exceeding the recommended static capacity by five to ten spaces will cause a major problem. The designer's judgment must always resolve "close calls."

2.5.8 General Implications

There are certain key considerations that maximize the ability to accommodate traffic. TRRL's research confirms in theory a number of rules for good design that many professional parking consultants have learned in practice. It is generally advantageous to provide separate, one-way, inbound and outbound routes even when there is little or no opposing flow. This is related directly to the fact that fewer spaces are located along the circulation route. For example, under office usage, $N_{LOS\ C}$ for 90-degree parking in a two-bay, single-threaded helix (in which the in route is retraced outbound) is 750 spaces compared to the 1360 space $N_{LOS\ C}$ of a 70-degree, one-way double-threaded helix which has separate in and out routes. The outbound vehicle encounters proportionately fewer delays from vehicles unparking along the outbound route in a double-threaded helix, and thus the total static capacity can be greater.

Similarly, the flow capacity of a one-way, angled parking layout is greater than a 90-degree, two-way design on the same system, if there are the same number of circulation routes. A one-way split level, for example, has 60% more capacity under retail use, and 45% more capacity under office use, than a two-way design. Therefore, although both designs may have adequate capacity, there will be less congestion and delay to users in the one-way system. When 90-degree parking and two-way circulation on the same ramping system increase the number of circulation routes (such as when two-way traffic is employed on a double-threaded helix), there is some increase in the capacity of the system when there is substantially one directional flow, and/or there are many spaces off the circulation routes. However, when there is opposing flow, one one-way system may have more capacity than two two-way systems. For example, when two-way flow with 90-degree parking is used instead of one-way 70-degree parking on a double-threaded helix, capacity under retail use reduces almost 15% ($N_{LOS\ C}$ is 840 versus 980). However, with office use, the two-way system increases flow capacity about 10% (1505 versus 1360). As spaces are added in bays off the circulation routes, the capacity benefit of one-way traffic flow is diminished. When a four-bay facility with a double-threaded helix plus two noncirculation bays is provided, the two-way system has 7% more flow capacity under retail use and 37% more capacity under office use than the one-way system.

The rule of thumb that says "angled for retail, 90 degree for office" works well for some situations but not for others. In terms of flow capacity:

- Angled parking is "better" when there are equal numbers of circulation routes.
- Two two-way outbound paths are "better" than one one-way outbound path for office use.
- One one-way outbound path is "better" than two two-way outbound paths for retail use, if most spaces are on the paths of travel.
- Adding noncirculation bays increases flow capacity, especially under high-turnover conditions such as retail.

In summary, the TRRL analysis method permits the capacity and congestion issues to be reviewed on an objective rather than a subjective basis. Statements like "one-way traffic is better," or "two-way traffic providing more routes is better," can now be based on analysis rather than intuition. While the analysis procedure is still somewhat theoretical, it can be used to compare two circulation systems on an "apples-to-apples" basis.

2.6 PUTTING IT ALL TOGETHER

There are many subjective considerations in the selection of a circulation system, such as wayfinding, flow capacity, type of user, dimensions of the site, efficiency, spaces passed, and number of turns. For example, it may be desirable to route unfamiliar users past most of the spaces in a small to moderate-size facility, contrary to its effect on capacity. Side-by-side (with four bays), end-to-end, and double-threaded helixes with

Figure 2-15. With an express ramp and flat floors, a mega-structure becomes a series of parking lots stacked vertically. Courtesy of Walker Parking Consultants.

one-way traffic flow all route drivers past half the spaces on the way up and the other half on the way down. These systems are therefore good designs for retail with a capacity of up to almost 1000 spaces. The number of turns to the top, geometrics, and the size of the site would be other considerations in selecting among these circulation patterns. These systems are also excellent for airport and hospital uses. It should be noted, however, that while capacity restraints under airport peak-hour flow might permit these facilities to have as many as 2000 spaces, the search time for the available space is probably too long. While adding bays off the circulation route might increase capacity, the ability to find the available space is reduced.

In larger systems, flow capacity and wayfinding both point to the use of flat floors with express ramps (see Figure 2-15). The parker then need only search a compartment with a reasonable number of spaces. Today's sophisticated occupancy counting systems allow automatic direction of parkers to the floor with the most spaces available. The compartments can have either angled or 90-degree parking as appropriate to the design. Two-way systems tend to have more accidents (it is harder to see all approaching vehicles) and to have conflicts when two drivers coming from opposite directions want the same stall. One-way traffic patterns are thus "better" for turnover conditions. In general, if parkers can see across several bays to available spaces, two-way end bays should be provided whether or not the parking bays are two-way. Drivers then can get to the available spaces quickly and without frustration. If, however, parkers must be routed through an area a certain way, angled parking should be provided throughout the system. A second, internal ramping system may be desirable to allow circulation between floors, and may be critical if the express system must be closed for maintenance. The secondary system may have parking along the path of travel, and parking should be angled unless traffic flow on it will be minimal.

Such two-bay designs as a single-threaded helix or a split-level are very limited in application owing to restrictive flow capacity ($N_{\mathrm{LOS\ C}}$ is about 420 spaces for retail use and 750 spaces for office use with 90-degree parking). These systems are also considered less desirable by drivers than most other systems when the height exceeds three or four levels, owing to the number of turns and the frustration of knowing that one is passing the same spaces on the way down as on the way up. Therefore, a design that has fewer turns, passes fewer spaces, and has less congestion (by virtue of having a greater flow capacity) will be "better" whether or not the capacity is exceeded.

For regular users, a double-threaded helix as the principal traffic route (whether one- or two-way) is almost always considered preferable with four or more tiers because the exit path is substantially shorter. If the site permits, additional level bays of parking off the circulation routes are acceptable as they further reduce travel distance and congestion. Because most users are present every day, they will know where to find an available space at a particular time of day. It should be noted that a one-way system on a double-threaded helix is still preferable unless capacity problems require more than one up and one down route. Some additional capacity may be achieved by using two-way traffic on each of the routes in the double-threaded helix. Again, however, two one-way routes down will still be "better" than two two-way routes.

2.7 SUMMARY

The level of service approach to parking design provides a valuable tool for tailoring a design to the specific needs of the expected users. Guidelines using LOS have been provided for many design parameters in parking facilities—wayfinding, turning radii, ramp slopes, travel distance, geometrics, and flow capacity. Using these guidelines, a comfortable, well-functioning internal circulation system can be developed for each and every parking facility. The next chapter—Access Design—deals with an equally important element in design: getting the vehicles you want into the facility, keeping out those that you don't want, and collecting the established parking fee from each and every user.

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CASE STUDY

Suppose that a hospital parking facility is to have 650 parking spaces. A parking study was performed to determine the size of the facility; data from that study provide information for determining peak-hour volumes. Two thirds of the spaces will be used by employees, who will be provided cards for access. Seventy-five percent of those spaces are for the use of the employees who work the day shift; the remaining are for employees who work the evening shift. Overlap between the shifts occurs at 3:00 P.M. From data on time cards it has been determined that 75% of the day shift works from 7:00 A.M. to 3:00 P.M.; most of the other day shift employees work from 8:00 A.M. to 5:00 P.M. The remaining spaces will be used by visitors, who will pay for parking based on the length of stay. Field studies indicate that the average length of stay for visitors is 1.3 hr, and that the spaces allocated to visitors will be fully utilized from about 10:00 A.M. until 4:30 P.M., when occupancy will begin to drop off. A negligible number of the visitors will arrive before 7:00 A.M. Therefore:

The *static capacity*, N, consists of two components:

$$N = 650 \text{ spaces}$$
$$N_m = 650 * 0.67 = 436 \text{ spaces for } \textit{monthly parkers}$$
$$N_t = 650 * 0.33 = 214 \text{ spaces for visitors}$$

Peak morning arrivals are from 6:30 to 7:30 A.M. The volumes expected are:

$$V_m = 436 * 0.75 * 0.75 = 245 \text{ vehicles}$$
$$V_t = 214 * 0.05 = 11 \text{ vehicles}$$
$$V_{in} = 245 + 11 = 256 \text{ vehicles}$$

Peak afternoon departures are from 2:30 to 3:30 P.M. with these volumes:

$$V_m = 436 * 0.75 * 0.75 = 245 \text{ vehicles}$$
$$V_t = 214/1.3 = 165 \text{ vehicles}$$
$$V_{out} = 245 + 165 = 410 \text{ vehicles}$$

There will be some opposing flows. Morning exiting, 6:30 to 7:30 A.M.:

$$V'_m = \text{say } 50 \text{ vehicles}$$
$$V'_t = \text{say } 10 \text{ vehicles}$$
$$V'_{out} = 50 + 10 = 60 \text{ vehicles}$$

The monthly arrivals in the morning are concentrated over 30 min. Visitor arrivals and departures are at random throughout the day. Therefore, in the morning the total volume of vehicles in the peak 15 min is:

$$V_{15} = 245/2 + (11 + 60)/4 = 140 \text{ vehicles}$$
$$v = 140 \text{ x } 4 = 560 \text{ vph}$$
$$PHF_{A.M.} = (256 + 60)/560 = 0.54$$

The evening entering activity in the peak hour 2:30 to 3:30 P.M. is:

$$V'_m = 436 * 0.15 = 65 \text{ vehicles}$$
$$V'_t = 214/1.3 = 165 \text{ vehicles}$$
$$V'_{in} = 65 + 165 = 230 \text{ vehicles}$$

The monthly exiting in the evening does not occur in the same 15 min as the arrivals of the evening shift. Therefore:

$$V_{15} = 245/2 + (165 + 165)/4 = 205 \text{ vehicles}$$
$$v = 205 \times 4 = 820 \text{ vph}$$
$$PHF_{P.M.} = (410 + 230)/820 = 0.78$$

Three circulation systems are possible: a single-threaded helix with 90-degree parking and two-way traffic; a double-threaded helix with 70-degree angled

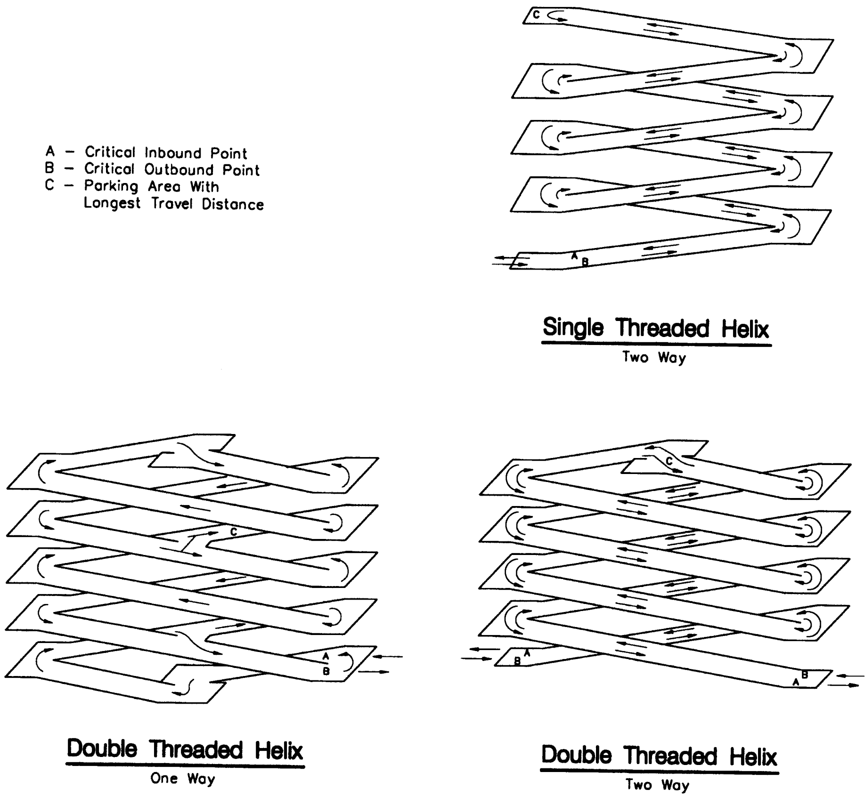

Figure 2-16. Isometrics for example problem.

parking and one-way traffic flow, and the double-threaded system but with 90-degree parking and two-way traffic (Figure 2-16). In the latter case there are essentially two routes up and two routes down. In the other two cases there is one route up and one route down. In the double-threaded helix, however, the routes are separated whereas in the single thread the up route is retraced on the way down. The parking stall geometrics will be LOS B. Which is the "best" system from a circulation standpoint?

The afternoon peak hour has the highest total volume of vehicles in motion, with the following rate of arrivals (P_a) and departure (P_d).

$$P_a = V'_{in}/N = 230/650 = 0.35$$
$$P_d = V_{out}/N = 410/650 = 0.63$$

In the single-threaded helix, the critical inbound point is at A, and the critical outbound point is B. There are no vehicles passing through this system to get to or from parking spaces off the system. *e* and *s* are therefore 0. While the vehicles in the A stream are not unparking, they will be delayed by the unparking vehicles, and vice versa for stream B. Therefore, the time used in each stream is:

$$c_{in} = 853 \text{ vph}$$
$$c_{out} = 728 \text{ vph}$$
$$p * t_p = V'_{in} * (1/c_{in}) = 230/835 = 0.275$$
$$u * t_u = V_{out} * (1/c\ ) = 410/728 = 0.563$$
$$\Sigma t = p * t_p + u * t_u = 0.275 + 0.563 = 0.838$$
$$\Sigma t/\text{PHF} = 0.838/0.78 = 1.07$$
$$\text{LOS} = \text{F}$$

As the LOS is well below D, the single-threaded helix should not be used. The double-threaded helix with two-way traffic is simply two separate single threads, each with half the total spaces. c_{in} and c_{out} are the same, but p and u are half of that above. Therefore $\Sigma t = 0.838/2 = 0.419$ and $t/\text{PHF} = 0.419/0.78 = 0.54$ and the LOS is A–.

In the double-threaded helix with one-way flow, a car unparking at a location just after the last crossover point C has the greatest distance to travel from parking space to exit. This vehicle will pass about 425 spaces. Along this route,

$$c_{in} = 1500 \text{ vph}$$
$$c_{out} = 1043$$
$$p * t_p = P_a * 425 * (1/c_{in}) = 0.35 * 425/1500 = 0.099$$
$$u * t_u = P_d * 425 * (1/c_{out}) = 0.63 * 425/1043 = 0.256$$

s is very small at the critical point and is neglected.

$$e * t_e = (V_{out}\text{-}u) * (1/1500) = (410–0.63 * 425)/1500 = 0.095$$
$$\Sigma t = 0.099 + 0.256 + 0.095 = 0.45$$
$$\Sigma t/\text{PHF} = 0.45/0.78 = 0.58$$
$$\text{LOS} = \text{A–}$$

The two double-threaded helixes have roughly the same capacity, which is adequate for the expected volumes. Note that providing a crossover at every floor will shorten the maximum travel distance and improve the v/c ratio, so the level of service of the one-way double-threaded helix would then be better than the two-way double-threaded helix (but the efficiency may be worse because of the crossovers).

CHAPTER

3

ACCESS DESIGN

Mary S. Smith

3.1 INTRODUCTION

The design of the entry/exit areas is critical to the ultimate acceptance and profitability of a parking facility. These areas provide the patron's first and last impressions of the facility. A positive or negative experience will be a very influential factor in decisions regarding future patronage.

To ensure good design a number of things must be considered:

What type of *parking access and revenue control* (PARC) system, if any, is to be provided?

How many lanes are required to handle peak and daily loads? Are there any special design requirements such as evening event parking?

What configuration of each lane is required to ensure that the PARC system works as intended?

How much space is required to accommodate the lanes required, as compared to the space available?

What are the requirements for auxiliary spaces such as parking management offices?

This chapter will provide the reader with a basic understanding of the above considerations in the approximate sequence listed. Before we proceed, however, we must dispense with the first and most obvious decision: Is a PARC system needed at all? A PARC system has one or both of two fundamental purposes—keeping unauthorized users out, and keeping revenues in. If neither of these is an issue, a PARC system is not required. This situation sometimes occurs at a self-contained development that will provide free parking. The access points will be "free flow," at least to the extent the surrounding street traffic system and the internal circulation design permits. If you know you aren't going to have a PARC system, you can skip this chapter altogether. Otherwise we'll proceed with determining what PARC system is right for the project at hand.

3.2 PARC SYSTEMS

3.2.1 Levels of Revenue Control

Before discussing specific systems, it is helpful to differentiate between the various levels of revenue control. The Parking Consultants Council Committee on Revenue Control, following on classifications originally developed by Donohue and Lathan,[1] has defined "levels of revenue control" as seen in Table 3-1.[2]

The first level of control is virtually all by hand and provides, in fact, very little "control"; hence the designation level "0." These controls may be found in special-event facilities where speed of transaction is critical, as well as in facilities that provide all-day parking at fairly low fees.

Level 1 controls include electromechanical devices, but have little to no *audit trail.* Most of these systems have been essentially replaced by the next generation of equipment and are little marketed if they are even still in production.

Level 2 devices add the first level of electronics, with an audit trail at each device but no centralized reporting. Some *memory* for data storage and automatic control of devices such as gates is provided.

Level 3 controls use *microprocessors* or other computer systems in individual devices. From the user perspective Level 3 controls generally are "bells and whistles" added to level 2, including machine readable tickets, online card controllers, and *pay-on-foot*[3] machines. However, there is still no centralized reporting of revenues at this level. To determine total revenue, the reports from the fee computers, card controller, and monthly payment ledger must be either hand copied and tabulated or entered into a separate computer program for reconciliation.

At Level 4, most if not all devices are online to a central computer which monitors activity in "real time"—i.e., as it happens. A manager can observe all transactions by one cashier, determine overall occupancy in the facility, or monitor the activity at any or all lanes. Customized reports are developed and then automatically issued, with *excep-*

TABLE 3-1. Levels of Control in PARC Systems

Level	Examples	Typical Applications	Audit Trail
Zero "hand"	"Cigar box" Hand-issued tickets Slot boxes Paper permits Hang tags Decals	Special-events very low fee or turnover very small lots (<50 spaces)	None
One "mechanical"	Meter (mechanical) Coin/token collector Zero + mech counters Cash register/out clock Nonprogrammable card reader	Small lots (<100 spaces low fees/ turnover	Limited and by hand
Two "electronic"	Fee computer Programmable card reader Electronic meter Electronic counters Electronic multispace meters	50–500 spaces	Machine tabulation and reports; compilation of multiple lanes by hand; ticket auditing still required
Three "time and revenue savers"	**Two +** Machine-read tickets License plate inventories Debit cards Credit cards Central pay stations Central cashiering Online cards Lane monitors	300 spaces and up	Same as level 2 but time requirement reduced
Four "Online, real-time" facility management	Facility management system Direct connection to central office accounting	Multifacility systems; high revenue	Fully automated; central control

Source: Parking Consultants Council Revenue Control Committee.

tion transactions (any occurrence that could be an indicator of theft/fraud) tabulated and highlighted.

The argument for computerizing parking equipment is the same as in any other industry: the information made available to management increases greatly while the time required of personnel at all levels is reduced. One of the primary audit tasks in any PARC system is to correlate tickets issued, vehicles present, and time parked with revenue generated. Computers can do this in seconds, not hours. On the other hand, far more information is generated by a state-of-the-art, computerized system than many users want or need. To determine the right PARC system for each situation, it is critical to assess what is expected from the controls. Some or all of the following may be concerns and priorities of a client:

- controlling cash revenues
- detecting theft by employees
- monitoring on-site managers/supervisors
- detecting fraud by customers
- totaling and auditing cash revenues from several cashier stations or several facilities
- maintaining an accurate count of spaces available
- providing activity counts for auditing purposes
- minimizing error
- controlling regular all-day parkers
- minimizing waiting time and/or delays
- providing *passive* or *active security* by cashier presence
- minimizing labor cost
- maximizing *turnover*, utilization, and revenues

As more Level 3 features are added, the "tighter" the controls become. The need for Level 4 controls generally increases as the fees and revenues increase; the incentive for patron cheating and/or fraud, of course, is directly proportional to the fees. Likewise, the more money a cashier handles, the more he or she is tempted to try to divert funds for personal use. Employee theft is generally an even bigger problem than patron fraud and if uncontrolled can severely impact revenues. An additional, less predictable variable in the equation is the "computer hacker" who tries to beat the system merely for the challenge of doing it. The worst cases of theft often involve a few employees and/or a supervisor working with a hacker who modifies the programming to hide individual, small thefts occurring day in, day out, over a long period of time. It is therefore critical for the owner to determine the priorities of the PARC system. Once the needs and expectations are known, the most cost-effective control system can be determined.

3.2.2 Nongated Systems

The parking *meter* was invented over 50 years ago to provide a means of keeping employees out of prime spaces intended for visitors and customers. The basic theory is that *short-term* users are willing to pay a nominal amount for convenient parking; employees are theoretically not able to keep the meter current by leaving work every two hours to "feed" it. The hourly rate of the meter is intended to cover the cost of collecting the fees and maintaining the meter; in some cases a much lower rate is charged at spaces intended for long-term parkers. When used as intended, meters are quite effective, especially with widely scattered spaces on streets and in small lots.

In practice, however, the meter is frequently misused. Local governments may trim enforcement and *maintenance* expenditures to lower than acceptable levels, while diverting meter revenues to bolster the general fund. Hourly rates have generally not kept pace with inflation. Area employees find that they can get away to feed the meter a couple times a day and are willing to pay the meter fee and an occasional ticket. Cheating meters is a "folk crime": everyone does it if they think they can get away with it. If the municipality does not pursue enforcement vigorously, "scofflaws" ignore tickets and may eventually accumulate hundreds of dollars in unpaid ticket fines. Owing to vandalism, poor maintenance, and time-consuming court appearances by enforcement personnel, a substantial number of tickets are thrown out of court. Thefts of the collected funds by both vandals and collection personnel are frequent problems. Under these conditions, the meter is an inefficient means of controlling parking.

Several variations on the meter have been developed. The second-generation *electronic meters* are in appearance quite similar to the old standard; however, the electronic workings require less maintenance and provide audit information to detect and document theft. The cost of these meters is only 25% more than conventional meters, which should be paid back in relatively short time. Optional features include solar power and acceptance of prepaid "frequent parker" cards. Enforcement and ticket collection problems, however, remain largely the same.

Another alternative to the conventional meter is the *slot box*. This usually consists of a box with numbered slots corresponding to each parking stall in the facility. It is nonelectrical, and has no moving parts. The patron inserts the posted fee in the slot. Collection personnel then check that the appropriate fee is present for each occupied space and issue tickets to those who have not paid the correct fee. Payment of these tickets is generally on an honor system. These boxes are most effective in perimeter all-day parking lots, where a flat rate is charged and revenues can be checked and collected just once a day.

Electronic meter boxes have likewise been developed in recent years. There are two basic types. Electronic "pay and display" units operate as follows: The patron parks the vehicle in a space, goes to the meter, pays a variable fee for a certain amount of time, and returns to the vehicle to place the voucher on the dashboard. The voucher is checked during enforcement procedures. Somewhat less convenient for the patron than individual meters, these units have been more widely employed in Europe.

The other type of electronic meter box, the multispace meter (MSM), represents a third-generation solution (see Figure 3-1). The parker is not required to return to the car with a voucher. Instead the spaces are numbered; the parker enters the space number before paying. The device has a microprocessor which prints out a list of the currently paid spaces for the use of the enforcement officer during ticket writing. While this system is more user friendly, users who paid the device after the officer pulled the list—but before the officer's route brought him to the space—can get ticketed. Therefore, the officer usually has to return to the device frequently for updated lists; in parking structures, this may require placing one device on each parking level.

With either type, a wider and more complex range of fee schedules is available, making electronic meter boxes applicable for short-term as well as long-term parking. Dollar bill acceptors and/or changers are provided to reduce coin storage requirements. *Monthly parkers'* cards can be accepted by the machine with nearly all the features discussed for "online" card systems later in this chapter.

Both types also have audit information to provide accountability for the revenue collected. One primary benefit to such a unit is that one enforcement officer can check several facilities on a frequent basis, eliminating full-time cashiering at each facility. The ability to accommodate large *volumes* of vehicles in *peak hours* is also greatly improved by the lack of gates and cashiering operations. When combined with card capability, the computerized meter box finds its best application in facilities that predominantly serve monthly parkers. Converting an

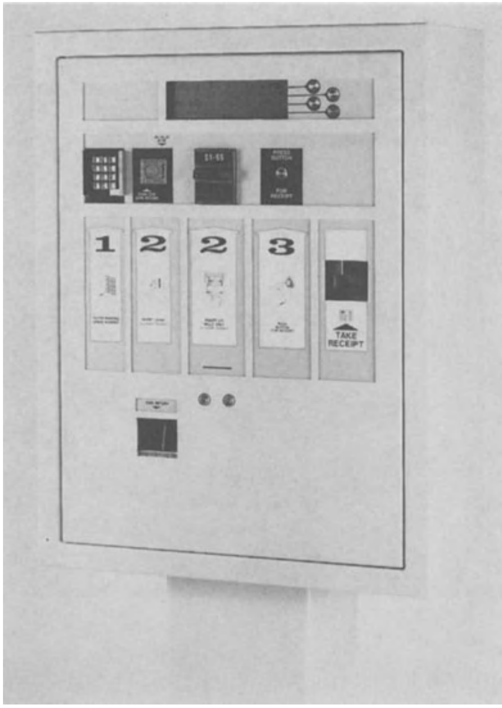

Figure 3-1. Electronic meter boxes can be used for both monthly and daily fee parking in large parking structures. Photo courtesy Traffic & Safety Control Systems, Inc.

underutilized cashier into a roving enforcement officer improves security as well.

There are also some interesting possibilities in locating several pay units throughout a mall, downtown area, or airport with the units interconnected to each parking facility. The patron who has exceeded a time limit has only to go to the nearest station, enter the space and facility numbers, and purchase more time.

The chief disadvantage to any form of meter is that all are essentially "honor" systems and introduce a punitive aspect to the parking experience. Scofflaws may ignore tickets if enforcement is insufficient, and private owners may lack legal remedy for collection. It was chiefly for this reason that the parking gate was invented (see Figure 3-2). The gate keeps unauthorized users out and authorized users in until they have paid the appropriate fee. Parkers can be charged based on the actual length of stay, rather than an estimate made at the time of arrival. Patrons thus do not have to worry about whether or not a meter has expired.

In general, a gated system will yield more patron revenue than an

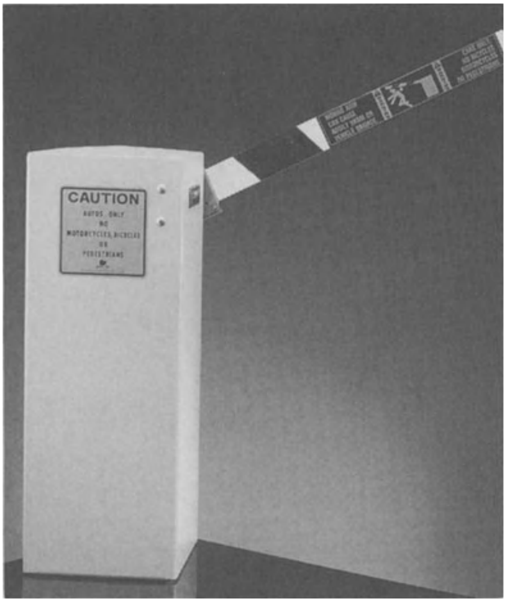

Figure 3-2. The parking gate was invented to keep unauthorized users out and revenues in. Photo courtesy Federal APD.

ungated system, which in most cases more than pays for the higher operational cost of the gated system. Most parking structures today with a fee for parking are gated.

3.2.3 Gated Systems

The typical gated PARC system consists of a cashier system for *daily fee parkers* and a system for regular parkers who prepay on a monthly basis. In the most primitive systems, cash is kept in a "cigar box," with no audit trail whatsoever. The monthly parkers are issued permits in paper or decal format. Gates, if provided, are opened manually or by command of the cashier. These systems provide almost no revenue control, and are really not "parking access and revenue control systems" at all.

In the first generation of true PARC systems, the gates are automatically opened by electrical signals sent by other devices in the lane such as *ticket dispensers* and *card readers*. In most cases, the gate is closed by a signal from a *vehicle detector* which monitors a *loop* in the pavement. For parkers who pay a daily fee, tickets are issued at the entry lanes (see Figure 3-3). At the exit an *out clock* stamps the ticket with the exit time. The cashier enters the fee in a standard commercial cash

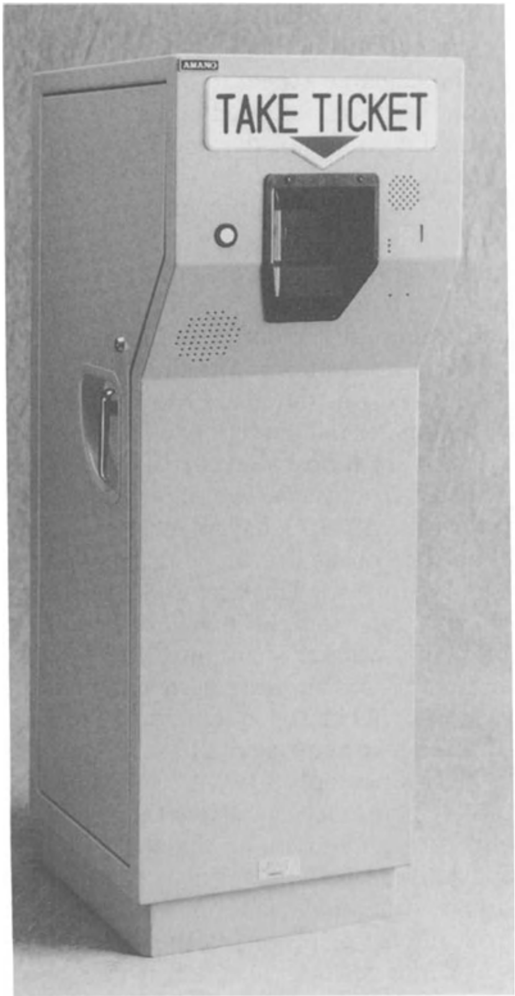

Figure 3-3. Gated systems generally have a ticket dispenser at the entry lanes for daily fee parkers. Photo courtesy Amano Cincinnati, Inc.

register and collects the fee due. Card readers are usually provided at both entry and exit for monthly parkers because the speed of the transaction is two to three times faster than if the cashier processes the monthly parker. Card systems therefore reduce the number of lanes and staffing requirements and are very cost-effective. *Antipassback* controls are provided by reversing a magnetic field in the card with each use at entry and exit. Once a card has been used at an entrance gate, it must be used at an exit gate before it will be accepted at an entrance again.

If passback problems are not expected, the system may be designed as "card in, free out."

The negative aspect to first-generation gated systems is that control is not very sophisticated and substantial management time is required to achieve most of the usual goals of PARC systems discussed previously. With a cash register, the only record of transactions is the *journal tape*. Substantial auditing time is required to find errors, theft, and fraud. Virtually every ticket must be hand-audited. To lock out one card user who is no longer authorized to use the facility, all cards must be collected, recoded, and reissued. If the coding is not changed, cards can remain in circulation for months or even years after the cardholder loses authorization to use the facility.

The next generation of PARC system reduces or eliminates all of these problems, at relatively low additional cost. In fact, second-generation systems are almost always cost-effective and should be used in virtually all cases. Today's *fee computer* systems automatically print out summaries of activity each day, report transactions by type, reconcile cash that should be in the drawer, and raise red flags for *exception transactions* (see Figure 3-4). Tracking exception transactions permits the manager to note, for example, that there are a lot of "lost tickets" when one particular cashier is on duty. The fee computer thus provides a better audit trail for auditing cash revenues than a standard cash register, especially when the system *software* is specially designed for parking. The fee computer also allows the transaction to be completed more quickly since only the "in" time and any *validations* are entered and the fee computer calculates the fee. Errors and some types of cashier and patron fraud are minimized. The fee computer has a *fee indicator* specially designed for *visibility* by the exiting driver. Presumably, the driver will notify management if the fee quoted by the cashier is different from the fee displayed by the fee computer.

A common misconception is that fee computers eliminate the need to audit activity on a daily basis. The tickets turned in at the end of each shift must still be checked to be sure that a cashier is not entering a false time or falsely recording validations. This check is more easily done if each ticket is printed with the transaction information processed by the fee computer. Daily, monthly, and annual reports for a facility, much less for a group of facilities, must also be prepared by manually totaling the paper reports from each lane.

The second generation of card systems allows owners to invalidate the cards of those who are no longer employed or haven't paid, even if the card has not been recovered from the individual. These systems also prevent employees from "losing" a card while actually giving it to

Figure 3-4. The fee computer provides an audit trail for control of cash revenues. Photo courtesy Parking Automation Corporation.

someone else. The card reader is "smart" in that it is microprocessor controlled. Periodically, management personnel can go to each card reader and, using a device similar to a hand-held calculator, program the reader not to accept specific cards (such as 113, 283, 139) and/or all cards in a certain block (such as 203–249). These card systems also have antipassback capability.

Another important component of the second-generation PARC system is a vehicle counting system. A *differential counter* maintains a count of the number of vehicles in the facility at all times. When occupancy reaches the preset "full" level, the unit automatically illuminates the *full sign* until occupancy drops off again. When card systems are used, it is generally desirable to set the "full" level a few spaces below actual *capacity*. The ticket dispenser is interconnected so that a ticket won't be issued until the occupancy drops below "full." However, the card readers continue to let card holders in, with the cushion of extra spaces between "full" and the actual capacity, ensuring that the monthly parkers will find a space. The vehicle counting system also should have nonresettable counters, two for each lane, that automatically record gate uses and card uses. By comparing the total of card uses and cash uses (the latter as reported by the fee computer) with the total of gate uses for each cashier's shift, the manager can determine if cash transactions are being performed by hand, with the revenue going into the cashier's pocket.

3.2.4 Upgrades to the Basic Card System

In situations with numerous gates and especially when there are several lots and facilities (such as at a campus or hospital), a centralized computer system should be used for cards. All the readers are hard-wired to a central microprocessing unit; therefore the generic name is an online card system. The central computer may be either a standard microcomputer, such as an IBM PC, or a unit with a *CPU, operating system,* and *memory* designed specifically for this application. There are two variations of the online card system: the "dummy" reader and the "smart" reader. In the former case, whenever a card is used at any gate in the system, the number of the card is transmitted to the central unit, which checks to see if it is valid. Authorization for every transaction is sent from the central unit. In the smart case, the wiring from reader to central computer is used to "download" changes in authorization, eliminating the need to go from reader to reader with the handheld device. The authorization decision is made at the reader itself. The smart systems tend to be more expensive (because, of course, each reader is more expensive) and may require more maintenance. However, all readers are not shut down when the master unit goes down, as is the case with the dummy reader (see Figure 3-5).

There is some disagreement in the industry over how tightly the antipassback controls should be applied. "Misreads" of card number are occasionally a cause of problems, often creating a chain reaction with other users. For example, if card number 301 is read at an entry lane as card number 311, the computer will not let card 301 out in the evening as it hasn't been considered "in." Meanwhile, card number 311 can't get in, because the computer thinks it already is "in." In some cases, the misread problem becomes progressively worse owing to *degradation* of the cards.

Almost all major manufacturers have reacted to this problem by designing the antipassback software to be used in either a *soft* or *firm* mode, as selected in the field by the owner/operator of the facility. The soft control accepts a card that is properly paid but is out of sync with

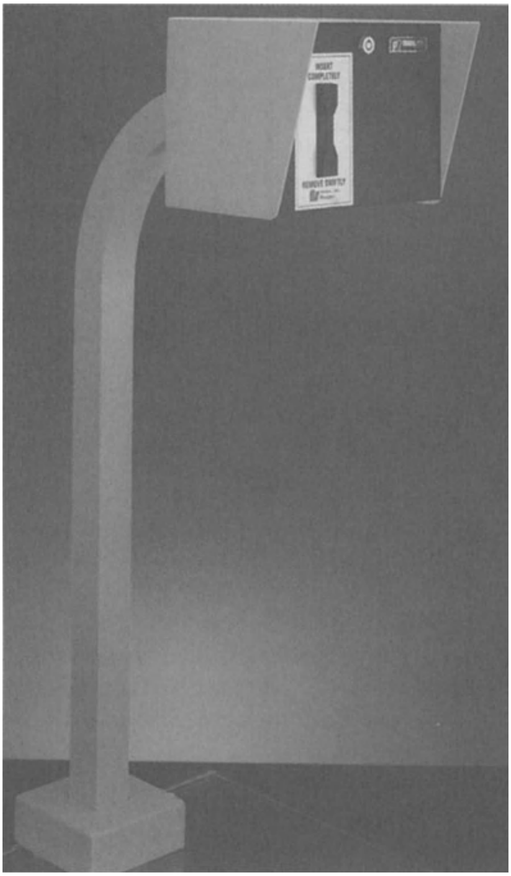

Figure 3-5. Card readers on-line to a central controller provide the best control of monthly parkers. Photo courtesy Federal APD.

respect to antipassback mode, printing an error message at the central controller for follow-up by the management. Follow-up and/or disciplinary action may only be taken for repeated offenders. The argument for soft control is that it eliminates backups, delays, and complaints at lanes when a "good" card is rejected. The proponents of firm-only controls, which reject the out-of-sync card, argue that the correction to misreads is to eliminate the misread problem rather than to accommodate it. Furthermore, soft systems tend to encourage "lazy" users, who pull a ticket on the way in when the card is not immediately at hand. The ticket is then discarded, and the card is used to exit, avoiding the usually longer line at the cashier. The discarded ticket throws off the daily cash revenue audit. When challenged about the antipassback violation, the lazy user plays dumb and blames "the computer" or shrugs his or her shoulders and confesses to being unable to find the card when entering. A similar problem occurs when gates are lifted in off hours and the card holder doesn't stop to card out. The next morning the computer thinks the user is still "in."

The firm mode proponents say the delay that occurs at the lane when a card is rejected is enough to ensure that the lazy and/or fraudulent user tries it only once. However, with today's emphasis on service to the user, the soft system has its advantages. We believe soft and firm antipassback should be provided with any system and the owner/operator should be able to select which to use based on the circumstances at hand. The need for firm antipassback increases as the incentive to cheat the system—which is usually the price of parking—increases. If an owner isn't yet sure how tight the controls should be, buying a system with selectable soft and firm antipassback provides flexibility to determine what is the "best" system through experience.

There are, of course, times when many vehicles legitimately depart without carding out, such as if the computer is down or if a special situation occurs. The *resynchronization* feature was invented to correct this problem. When resync is activated, all cards are given one authorization in or out before firm antipassback is restored. This feature can be misused; if done too frequently, the antipassback feature is essentially voided. Both soft antipassback and resync features can also be used for theft or kickbacks by the on-site personnel, and thus passback violation reports need to be monitored.

A good online card system has the capability to allow any individual card access at certain points and at specific times while denying access at others. Take, for example, a hospital with a number of different parking facilities. An employee card would not work at a certain lot until after 2:00 P.M., reserving those spaces for the evening shift. Doctors' cards might work anywhere or at only one location. When the status of a particular card is to be changed (for example, Jane Smith has been promoted to a position that allows her to park in a different area), the information is entered at the central console. Ms. Smith never has to turn in her card to be reassigned to the new lot.

Some of the systems on the market do far more. For example, in a commercial facility, the ledger for monthly payments is part of the system. If someone has not paid on time, the computer can automatically lock out that person at either the entrance or exit point. The cashier has no control, but can certainly accept the individual's payment! If the individual does not pay the monthly bill, he or she can be charged for parking at the *transient* rate.

Another possible feature is the so-called *per diem* option. One major tenant in a building leases a block of spaces for its employees but argues that many of its employees are outside salesman who will not be present most of the time. Therefore, 500 cards are to be issued at the fee for 400. The computer keeps track of occupancy by these users and when the 401st patron enters, it begins charging hourly rates for that and all subsequent patrons from this group until the number drops below 400. At the end of the month a statement is issued to the tenant for the overcharges. This option can also be used for those who regularly come to a facility but stay for shorter periods, such as doctors and part-time employees. The CPU keeps track of the usage, and bills are issued for parking charges accumulated over the previous month.

There is also a *nesting* feature available. If a user pays to park in a certain area on a monthly basis, he or she must pass a second card reader to the area within a set period of time after entering. If the user fails to park in the assigned area, he or she can be refused exit that day, or refused entrance to the facility the next day.

3.2.5 Other Upgrades/Options

One of the most desirable upgrades to the cash control system is the use of *machine-readable* tickets. Machine-read systems substantially reduce keying error and the potential for theft by employees. Audit requirements are reduced as tickets do not need to be checked on a daily basis unless damaged or mutilated. Auditing and tracking of exception transactions become random rather than regular. The speed of the transaction is also somewhat faster, sometimes allowing a reduction in personnel and/or equipment needs.

Declinating systems involve the prepurchase of a ticket or card for certain sum—say, $100 worth of parking. With each use, the fee is deducted from the balance until the prepaid amount is used up. It is usually desirable to have a reader process tickets at both entry and exit, bypassing the cashier. A light on the reader warns when the fee remaining is low. Cashiering needs can thus be reduced, and customer service to regular users is greatly enhanced. This option is quite similar to the technology employed for commuter rail systems like the Washington DC Metro. Some in the industry call these *debit cards*, but that is technically incorrect. In the financial services industry, a debit card is one which results in an immediate draw on a user's checking account. Parking systems may accept debit cards as well as credit cards and thus a potential source of confusion is eliminated when the term declinating is used for prepayment of parking fees.

Declinating cards are highly desirable in situations where a large number of commuters now pay daily fees to park. These cards can also be highly desirable when an institution wants to encourage use of *mass transit*. On most days, the commuter will use mass transit and thus won't want/need to pay for monthly access. However, on days when the employee needs the personal vehicle, he or she can receive a special parking fee through the declinating cards. The system is thus a "win-win" for all parties.

A *decrementing card* or ticket allows a predetermined number of visits to a parking facility, regardless of length of stay or the charge that would otherwise accrue. Declinating or decrementing systems are valuable also for visitors who will arrive and depart over several days or even months such as at a hospital, hotel, or seminar. Prepaid parking tickets can be issued months in advance for use on a specific day and time such as a special event. Advance ticketing substantially reduces the number of lanes and cashiers required for major events.

Valet parking has traditionally been controlled with level 0 or 1 technology: the two-or-three-part ticket. With the computerization of revenue controls and machine-readable tickets, valet parking controls can now be computerized; multipart tickets can be issued at entry to stay with the patron, the car, and the keys. ID cards for the valets can be used to monitor and record who had possession of the vehicle at any point in the stay.

Another desirable option is the *remote lane monitor* (RLM.) This unit, located in a central location such as the parking management office, monitors activity in each lane, such as the fact that the gate remains up too long or the ticket dispenser is running out of tickets. The RLM is especially beneficial for remote lanes where the cashier cannot see problems. The oldest systems were electromechanical, but now electronic and online computerized systems (called *computerized count controllers,* CCC) are available.

Intercoms to remote lanes can be installed directly into, or attached to, ticket dispensers or card readers. The ability to communicate with management greatly reduces frustration by the patron and eliminates some breakage of gate arms.

CCTV monitoring of entry/exit lanes is also valuable in systems with high revenues. Such a system would not have to be continuously monitored. Rather, alarms triggered by exception transactions would summon management, turn on the appropriate camera, and start up a videotape recorder.

License plate inventory (LPI) systems were developed for airports to thwart the parker who has "lost" the ticket and claims to have come in "just an hour ago." In facilities where parkers don't stay for more than one day, the patron with a lost ticket is charged the maximum daily rate. At an airport, however, cars can be parked for days or even weeks. If the parking rate is $10 per day or more, there obviously is substantial incentive to pull the lost-ticket trick. Cashiers also may try to charge the patron the correct fee for the full stay, but enter the transaction into the fee computer as a lost ticket.

With this system, an inventory of the license plates on all vehicles present is taken in the early morning hours each day. Usually, the data are collected with a hand-held device similar to a calculator. A computer tabulates the data downloaded from the hand-held device.

Some systems use the LPI only for exception transactions such as a lost ticket; others require that the license plate be entered for every transaction. In the former case, the database is usually queried by the manager upon request from a cashier via intercom. Paper printouts of vehicles sorted by day of arrival can also be given to the cashier. The most efficient way, however, is to have the LPI database online for automatic query from the cashier for exception transaction processing. In the every-transaction case, the LPI system must be online from the cashier system. The license plate is entered into the fee computer or a pad adjacent thereto which checks to see if the vehicle has been present for the number of days and the elapsed time calculated from a machine read of the ticket or, in the case of a mutilated ticket, from the "in" time and date as entered by the cashier. The entry of the license plate number obviously slows the transaction, especially in states without a front license plate. In that case, the cashier must wait until the vehicle is pulled up to a gate for the plate to be read via CCTV. Compared to a transaction without LPI, the processing time for an LPI transaction may be only 75% as fast with a front plate and 50% with a rear plate. There is then a corresponding increase in the number of lanes, in terms of both equipment and staffing on a day-to-day basis. The number of lanes/cashiers may increase 33% with LPI/front plates and 100% with LPI/rear plates if the LPI is mandatory on every transaction. The cost of the equipment with mandatory license plate check is also substantially more per lane, even before additional lanes are factored into the equation. However, much of that cost is related to the use of more sophisticated, multitasking computer systems, which provide other benefits to the PARC system. It is extremely difficult to isolate the incremental cost and net revenue gain associated solely with mandatory LPI checks. In some cases, the revenue loss owing to fraud and/or theft on "normal" transactions (that is, with a ticket given to the cashier) may not merit the additional capital and operating costs of the mandatory LPI system.

The proponents of mandatory LPI argue that there are a number of ways patrons and cashiers can "pull" tickets, substituting a ticket of much shorter duration. Most airports with LPI on every transaction are those with very high parking fees and very high incentive for theft/fraud.

3.2.6 What Reading Technology Is Right for You?

As systems for automatic card and ticket reading have been developed, different manufacturers have used different technologies. As with other control considerations, the choice of technology for a specific project depends largely on how "tight" a system is desired.

3.2.6.1 Card Technologies

First-generation offline card systems usually have metallic slugs buried in the card in a certain pattern for reading by a magnetic device. All cards are permanently coded with a single code for each facility.

The dominant technology for individually coding cards is the magnetic stripe developed by IBM and often used on credit cards. The major problem with "mag stripes" is that the information can be changed, copied, or recoded. While it takes a pretty sophisticated user to purposely recode a card, a card can be copied by an electronic skimmer. Firm antipassback, of course, minimizes the benefit of a copied card, since two users with the same ID number can't be in the facility at the same time. More critically, the information on a mag stripe can be scrambled by rubbing against a number of magnetic devices, including, on occasion, a card with magnetic spots. The latter cards are formed by a center core of a magnetic material such as barium ferrite, sandwiched between layers of plastic. The increasing use of barium ferrite cards can cause substantial problems for all mag stripe card systems.

Infrared cards were developed by Citibank to minimize fraud and theft with their credit and ATM cards. Infrared systems tend to be more reliable and more difficult to copy or tamper with (but more expensive) because cards and reading devices can only be purchased through licensees of Citibank.

Bar-coded cards have become common because of the lower cost of the technology. Bar-coded cards are the easiest to copy. Again, however, antipassback controls limit the ability to use copied cards. In a multifacility system, such as at a university, copied cards could be used to gain access to different facilities at the same time unless there is some system for cross-checking card utilization between facilities. This is avoided with a *facility management system*, as discussed later in this chapter.

Wiegand effect cards employ a magnetic reaction to read a unique code created by the placement of individual wires in each card. No power is needed at the card reader to read the code, but power is required to check the validity of the number. Even when Wiegand cards are not used, the *protocol* developed for communications in this system has become fairly standard to the security industry. Using Wiegand protocol, some manufacturers of card controllers have the flexibility to use many different types of cards, even within the same system. This is quite beneficial, for example, when an institution already has an ID badge/security system. Designing the card system to read the same badge will eliminate the need to carry multiple cards. In some cases the badge can be dual technology, with one type of read system for parking (mag stripe, for example) and another for ID (bar code, for example.)

All of the preceding systems require the insertion of the card into the reader. Other systems read a card from a distance, in some cases without the driver removing the card from a wallet or other carrier. The distance at which the card can be read varies between systems. *Proximity* systems require the card to be held up within a few inches of the reader; the technology of this type usually involves scanning by very low power radio frequency signals. *Automatic vehicle identification* (AVI) systems can be read at a distance of 10, 20, or even 30 feet. Most of the longer-distance systems can read while a vehicle is in motion, at speeds of 10 mph or more, and were developed for regular users of toll highways and bridges. At least one system uses a decal with a bar code, placed on the lower left front windshield, that is read by laser. The speed of transaction for proximity/AVI readers is faster, especially with the longer-distance systems where the vehicle does not need to come to a full stop, which can reduce the number of lanes required. Proximity readers also eliminate many weather problems that can occur with insertion readers. They are considered substantially more user friendly. However, proximity card systems are more expensive, with AVI yet more expensive, as compared to insertion card readers.

When a local agency has already developed an AVI system for toll collection, it is possible for the parking system to "tag along." An airport parking system, for example, could read the declinating AVI card of a toll authority. It could collect parking fees directly or receive payment for parking charges from the toll authority. Cashiering would be eliminated from the transaction. At present this requires coordination among agencies and is more feasible with public entities. While the toll authority may charge fees to join their system, it would probably be no more than what credit card companies charge to collect fees for merchants.

With more and more users going to computerized access control, new opportunities for control open up. For example, the parking control system at a hotel can read the guest's room access card and report parking charges to the hotel's computer system for inclusion in the guest's bill.

3.2.6.2 Machine-Readable Ticket Technologies

Most machine-read systems for tickets currently use one of three technologies: hole punch, mag stripe, or bar code. Hole punch systems are substantially less expensive, but the coding, once placed, is permanent. Data for such features as declinating tickets cannot be added with each use. Also, hole punch systems can usually be compromised very quickly, simply by comparing the pattern of holes. Finally, hole punch systems have high maintenance costs owing to the litter. Mag stripes, of course, can accommodate additional information; in many pay-on-foot systems, the original ticket issued at entry is recoded with the grace period for use as the exit ticket. In a bar code system, either a serial number or a series of random numbers is preprinted on each ticket. The ticket dispenser "reads" the bar code and tells a central computer when that ticket was issued. When the bar code is read again at the exit, the computer searches its memory for the data on that ticket. The relevant information is all kept in the computer, not on the ticket. The chief drawback is that if the central computer goes down, the entry time and date must be entered manually from the ticket.

The choice between these reading systems again comes down to what kind of problems and what level of cheating are expected. If the only information necessary to calculate a parking fee is the "in" time on a single trip, the less expensive hole punch system may be acceptable. Mag stripe technology works well for tickets which require some rewriting and in most cases can be combined with other control techniques to provide an effective system. The significant advantage of mag stripe is that all data related to that ticket can be recorded on the ticket. Bar code technology, however, is significantly less expensive, in terms of both first cost and ongoing maintenance.

3.2.7 Facility Management Systems

The "ultimate" in gated systems now available is a system fully online to a central computer. The primary reason for going totally online is to allow management of the parking system, be it one facility or a dozen, from a central station. As more complex logic and sophistication are added to any system, it is capable of greater control and management with less human input. The information available increases greatly while personnel time decreases. One of the generic names for these systems is thus a facility management system (FMS). Using *data management* software, the FMS can generate just about any type of report imaginable. While this information has always been available to parking managers, the amount of time required to track trends in utilization and revenues was cost-prohibitive. Now, computers can do the searching and compiling, allowing management to improve performance. Some specific management functions that can be performed by FMS are[4]:

Revenue Maximization. This term refers to a step-by-step refinement of management procedures with the goal of maximizing revenues through improvements in facility performance and elimination of fraud and theft. An integral component of revenue control is the feedback provided to local facility supervisors and employees from a series of timely reports. Information in such reports is derived from the transaction data received from "intelligent" *peripherals*, which include the card reader controller, the ticket dispensers, the fee computers, and the gates.

Facility Utilization. Analysis of peripheral transaction data can also reveal patterns of usage that are vital in the preparation of *overbooking* plans for the facility. Such information is also valuable for setting empirically based rate structures and in formulating expansion plans.

Equipment Maintenance Control. By tracking malfunction data returned from peripherals, objective judgments can be made regarding which devices are failing, the nature of the failure, and environmental factors related to the failure. This information is useful for scheduling preventive maintenance and for deciding which pieces of equipment are due for replacement.

Revenue Forecasting. Information obtained from statistical analysis of peripheral transaction data can be extrapolated for revenue forecasting and management planning. By monitoring specific data, "trends" may be identified early to optimize management response. In addition, hypothetical situations can be analyzed and should provide management insight for business planning.

Alarm Reporting. Communication lines can provide status information, exception transactions, or failure conditions for the various peripherals (e.g., gate arm stuck).

Perhaps the most fundamental technological improvement resulting from online, real-time computers in PARC is *ticket tracking*. As previously discussed, auditing primarily involves correlating tickets issued with other activity. With machine-readable ticket dispensers online to a computer, the system can trace the path of the ticket through the system, eliminating this cumbersome task. This feature allows the system to report how many tickets are outstanding at any given time and how much revenue is represented by those tickets. It can be used to process mutilated tickets, since the cashier can enter the ticket number and the computer will retrieve the entry time. This is among the most beneficial features available today for detecting revenue and fraud.

One significant feature of these online systems is that they are designed to control a number of different lanes and/or different facilities from one central computer. Several parking structures can operate independently, even with different commercial operators, but all transaction data are "off-loaded" to a central computer for analysis and management action by the owner. The owner can program the system to poll each parking facility overnight, tabulate and summarize the activity, and print out reports before management arrives in the morning. Substantial clerical time can thus be saved in tabulating activity at several facilities, while management can spot a new trend in minutes. Fee schedules and other programming changes can be *downloaded* to any individual facility or to all facilities in the system. The online system is thus most effective for an owner with multiple parking structures (such as a parking authority or an operator) or one with many lanes and high revenues (such as an airport).

3.2.7.1 Configuration of an FMS

The number of facilities connected to an FMS has a bearing on the design of the system. When multiple facilities are connected to a single FMS, each individual facility may have a *local facility computer* (LFC), which collects and tabulates the data for that facility before sending it on to the master parking computer (MPC) (see Figure 3-6). The LFC provides the facility's on-site manager with the data necessary for day-to-day operations while allowing central management to track data and monitor the full system.

In other cases one MPC is connected to peripherals at several facilities. While saving on hardware costs, there are far more ramifications if—or should we say when—the central computer goes down.

In a third case, peripherals at each facility are connected to a local controller which makes decisions and/or stores data, but which has no workstation. Data are uploaded and programming is downloaded from the MPC.

The size of the system and the features desired definitely have a bearing on the computer hardware required. When each peripheral is "smart," the FMS may only need to handle one task at a time such as

Figure 3-6. Facility management systems allow managers to maximize revenues, monitor and project performance, and plan equipment maintenance and replacement. Photo courtesy Federal APD.

preparing a certain report or downloading new programming to peripherals. However, other situations require *multitasking*. For example, an LPI and the vehicle counting system may need to be working at the same time. Most *personal computers* (such as the those employing the Intel 386 chip) are simply not big enough and fast enough to perform these tasks "simultaneously." A larger multitasking computer may then be required; Intel's Pentium processor is fast enough that it can perform one task without disrupting or delaying others. Some more sophisticated systems, such as those that have "dumb" peripherals that must be *online* or have large memory requirements, require a minicomputer.

Yet another possibility is to *network* computers, each performing individual functions. One handles the LPI; another, the occupancy and lane monitoring. The MPC provides system management, reporting, administration, and programming. However, the MPC also can be configured to provide redundancy for either of the task computers. Computers do go down; a network usually is the most cost-effective option to minimize system disruption. With the relatively low cost of fast, powerful personal computers, we find the network option to be highly cost-effective as compared to using a minicomputer to run the whole system.

3.2.7.2 Coordinating Peripherals With an FMS

Owners often want to have the flexibility to choose from many vendors for their PARC peripherals. When an FMS system is designed to run on a standard computers, one is not, in theory, married to a particular brand of peripherals. If the peripherals are microprocessor controlled and have the capability to communicate to a central computer, one needs only the *protocol* of the peripherals to integrate the system. The use of Wiegand protocol, for example, has made it possible to use many different card reading technologies within one card system.

In practice, however, most FMS systems now on the market are tied to certain PARC devices, because of the intricacy of communication between devices. Customizing the FMS package for a different set of peripherals might not be cost-competitive with the peripherals that already work with the FMS. The larger parking vendors make all the necessary peripherals **and** FMS systems and may not be particularly interested in sharing protocol.

This issue is most critical if one chooses peripherals now from a vendor in anticipation of a future purchase of that firm's FMS. When you finally get around to adding the FMS, you might not be happy with the local service, or another FMS may have become available that is more attractive.

Some in the parking industry have proposed that a recognized group endorse "standards" for computerized parking devices. Standards, when in place, cover such things as the CPU, *interfaces,* and protocol. If there were standards, *integration* would be much simpler and less expensive. The Parking Consultants Council of the National Parking Association explored the standards issue and declined to adopt any standards. There are too many different needs for any one type of hardware, such as an IBM PC 486 compatible computer, to be designated "standard." Further, technology is changing so fast that features that are today constrained by hardware capabilities—for example, communication by modem—can be revolutionized literally overnight. The PCC also felt that the marketplace will determine if standards are appropriate and which approaches will become standard. This is essentially what happened with the Wiegand protocol in the security industry.

In the absence of standards, one must either purchase a package that has already been developed or pay for integration of components that individually have the features desired. The more detailed the specifications, the smaller the pool of qualified bidders becomes. All of these factors make it difficult to specify and competitively bid PARC/FMS systems. It is forcing designers to use performance specifications rather than specify how that performance is to be achieved. It also makes it more difficult to compare bids on an "apples-to-apples" basis. Whereas in the past, an owner could call a distributor and outline requirements in a telephone call, today that owner must do extensive research or retain a consultant to negotiate the high tech maze of PARC systems.

3.2.8 Pay-on-Foot PARC

Before discussing pay-on-foot PARC, there is one issue of terminology to clarified. As with any "new" technology, there is a lag between the development of the systems and the adoption of terminology industry-wide. Oftentimes, the terms used by the first or leading manufacturer become the standard of the industry. In the case of pay-on-foot, there is yet much confusion over terminology. Some in the industry use the term "pay-on-foot" broadly; others use the term only for cashierless, *automated pay stations* (see Figure 3-7).

It can be confusing when a term is defined more narrowly than what the sum of its parts indicates. Logically, *pay-on-foot* should be defined as any revenue control system in which payment for parking is rendered "on-foot" rather than from a car. Under this definition, pay-on-foot systems range from the traditional parking meter serving one stall to sophisticated automatic pay stations. Pay and Display and Electronic Multi-Space Meters are the higher-technology versions of ungated pay-on-foot.

For gated systems, the microchip allows the cash transaction to be performed at a location other than the exit lane, while maintaining the integrity of the gated system. Any cash transaction is faster when performed on foot rather than from a vehicle; the cashier and/or equipment is not idled while the vehicle pulls into and out of the lane.

The entry to the parking facility with a gated pay-on-foot system is controlled with ticket dispensers and barrier gates. Monthly parkers are processed by card readers at both entry and exit lanes. The cash patron pays the parking fee at a central pay location after visiting the destination but before retrieving the car. The central payment station can be cashiered or equipped with an automated pay station or both. Following payment the patron receives the receipt (if requested) and an "exit ticket." In some systems, the exit ticket is actually the original parking ticket reissued for reading at the exit. This allows each ticket to be printed with the appropriate data at every step along the way,

Figure 3-7. Automated pay-on-foot machines eliminate human cashiers. Photo courtesy Amano Cincinnati, Inc.

which eases auditing. The parking patron then has a preset time period, usually 10 to 15 minutes, to retrieve the car and reach the exit lane. The exit lane is equipped with an exit reader instead of a cashier booth. The patron inserts the ticket into the exit reader, which determines if the ticket is still valid. If so, the gate rises and the patron is free to leave. If the elapsed time is greater than allowed or the ticket has not been validated, the exit reader rejects the ticket and the gate will not open. The patron holding the invalid ticket must then return to a cashier or pay station to pay the additional fee. Some exit readers, however, accept payment for small overtime charges at the exit lane.

Several variations of pay-on-foot solutions are available for gated settings. With *central cashiers*, the traditional cashiers and fee computers are merely relocated to a central location to perform the cash transactions. *Automated pay stations* are machines similar to ATMs that process the transaction, replacing the cashier and fee computer. "Hybrid" systems also exist, in which two different types of equipment are combined to form a system. *Hybrid pay station/exit cashiers* have centrally located automated pay stations and exit lane cashiers. The intent of this combination is to reduce the number of exit lane transactions while providing a means of processing the patron who forgot or chose not to pay at the machine. With *hybrid pay station/central cashiers*, both cashiers and automated pay stations are located at the central location. The cashiers are on duty during the busy times, whereas the automated machines can be operational 24 hours per day. Customers can choose between the human cashiers or the machines. Only one cashier may be required in facilities that would otherwise require multiple cashier lanes.

3.2.8.1 Why Pay-on-Foot?

Pay-on-foot revenue control has been touted for a number of years as the future of PARC. Cashierless parking facilities with automated payment machines were expected to become as common as ATMs. Fully automated, cashierless pay-on-foot systems are widely used and accepted in Europe. However, in the U.S. there have been a number of "disasters" but very few success stories. One of the biggest concerns regarding the acceptance of pay-on-foot in the U.S. has been the perception that the American customer, in general, tends to expect a higher level of customer service than the European parker. In Europe—as well as in much of Asia—parking is at such a premium that the parker is happy just to get a parking spot. A tour of parking facilities in Europe reveals that significantly less attention is paid to user comfort in all aspects of parking design and operation than in the U.S. Lighting, parking geometry, and other functional issues are all designed to a lower standard of user friendliness than in the U.S.

Another issue impeding the acceptance of pay-on-foot has been the dollar bill. In Europe, there are widely circulated coins for dollar-equivalent denominations. In the U.S., however, the lack of acceptance of the Susan B. Anthony dollar has made it imperative to include dollar bill acceptor/changers in most installations. Only recently has the reliability of those units been improved to a level minimally acceptable to the U.S. parking operator.

In 1993, we conducted a survey of all American users of pay-on-foot systems that we could identify, primarily from lists of installations of pay-on-foot provided by manufacturers.[2] We included electronic multi-space meter units in the survey, as well as gated systems.

The general advantages of pay-on-foot applicable to all such systems cited by the respondents are as follows:

- Lower operating costs—primarily owing to savings in labor costs.
- Reduced exit lane queuing—because of the improved speed of the exit lane transaction.
- Increased revenue control/security—because the revenue is collected at a single central location. In the case of central cashiers, the cash is collected in an office setting with other personnel nearby and where management can more easily monitor the performance of the cashier. In cashierless systems, the number of people who handle cash is sharply reduced.
- Reduced staffing problems. Again, the reduced labor in a cashierless system will reduce the headaches of hiring, supervising, and scheduling staff. When the system is cashiered, the work setting is improved and turnover is reduced; also other office staff can more easily "pinch-hit" when a *queue* develops for a few minutes without scheduling additional cashiers.
- Improved customer service—primarily due to the elimination of delay at the exit lane; also in the case of central cashiers, because the transaction is performed in an officelike setting rather than a vehicular exit lane.
- Improved speed of transaction—which not only reduces congestion at the exits, but may result in a reduced number of cashiers and lower labor costs.
- Reduced auto emissions by queuing autos. While some may scoff at the notion that cashier lane queuing is a major cause of pollution, improving air quality will require a lot of individual little steps to reduce auto emissions. Further, removing the cashier from the exit lane is a significant improvement in quality of the workstation as well as eliminating any exposure to vehicle fumes.

Certainly, there are also disadvantages, the most predominant being the need to change American "habits" to accept the pay-on-foot systems. The most common reasons cited in the industry for **not** doing pay-on-foot are accommodating the parker who leaves the ticket in the parked vehicle and the individual with "machine phobia." ATMs are widely accepted and used, but there does remain a small segment of the population that refuses to use them. Like the banking industry, the parking facility owners in the survey who have tried pay-on-foot have found that those two problems can be minimized to a very acceptable level, while garnering the benefits listed above.

The survey also found differences in the application of various pay-on-foot systems.

3.2.8.2 Multispace Meters

The most significant advantages of the electronic multispace meter are the elimination of queuing at the entry and exit, and generally lower capital and operating costs. In many of the successful installations, overpayment of fees apparently compensates for underpayment/scofflaws. However, there are several negatives, chief among which is that writing tickets is a negative approach to providing service to the customer. Customers in systems converted from pay-at-exit (gated) systems complained about overpayment of fees and the lack of customer service. There may also be a net loss of revenue due to non- or underpayment of fees, especially if the enforcement is lax or the owner has no means of collecting ticket fines.

3.2.8.3 Central Cashiers

Gated installations with central cashiers have been very well received. The cashier puts a human face on the parking operation that is important to many American parking operations. Remember that maxim of the parking industry—parking is the first and last experience that the customer has at the ultimate destination, be it business district, shopping center, airport, hospital, or other use. Where competition for patronage exists, customer service will be a key aspect of marketing. Indeed, one manufacturer of pay-on-foot systems noted that some European facilities are starting to add central cashiers to formerly cashierless systems to improve customer service and increase market share.

Customers of central cashier systems are enthusiastic. Several parking facility owners noted that customers comment on how much nicer it is to pay at the central location than from the vehicle. Comments like "Why didn't someone think of this before?" are common.

Overall, operators of systems with central cashiers felt they provided the best overall service to their customers; the number of patrons forgetting to pay before exiting was far lower than expected, and nearly all patrons were provided a better *level of service* than would have been afforded by exit-lane cashiering.

3.2.8.4 Automated Pay Stations

A PARC system relying totally on automated pay stations can be cost-effective in certain situations. However, the owner must accept that a certain percentage of the patrons will have problems with the equipment and require assistance. While the bank customer who is turned away

Figure 3-8. Pay-on-foot machines can accept dollar bills and credit cards. Photo courtesy of Federal APD.

from an ATM owing to problems with the bill receiver/changer simply won't get any money out of the account, the parking patron who can't pay for parking can't get out of the parking facility without either breaking the gate or calling for assistance. Adding the problems with machine phobia to bill rejections and change problems, as many as 10% of the customers will have problems with the system and will leave the facility frustrated and/or dissatisfied. As a result, more and more people are installing credit card acceptance units to minimize the use of cash at automated payment stations (see Figure 3-8).

Therefore, the technology—and the ability of the American public to use that technology—is not yet ready for a parking facility that is totally automated and operated without any staff.

Several owners surveyed who had systems relying totally on central pay stations were satisfied, feeling the benefits outweighed the problems in their particular circumstances. One satisfied user is a university with a high number of regular, cash parkers. The parking office was located in the structure, within sight of the automated machines. When a user has a problem with the machines, assistance is close at hand. At the same time, the staffing problems associated with cashiers have been eliminated.

Another example of an appropriate installation is a commuter train or transit station. There may be an hour or more between trains in the off-hours; stationing a cashier in the lot to collect parking fees from off-hour commuters is not very cost-effective. In situations where commuters are already familiar with automated pay stations for train fares, and an attendant is already present inside the station, going to automated pay stations for parking is an ideal solution. Using the same declinating ticket as the rail system is a further, viable option. Another successful installation of fully automated pay stations was one in which almost all the patrons receive free, validated parking. The gated system was really imposed to keep unauthorized users out and to keep the spaces available for the intended users. The pay station processes the validation issued at the destination and no money is inserted or returned unless the patron overstayed the validation period or did not qualify for free parking. Therefore the potential for dollar bill rejections and other problems is sharply reduced.

3.2.8.5 Hybrid Central Pay Station/Exit Cashiers

As previously noted, hybrid systems with central pay stations and exit cashiers are designed to process those who forgot to take the ticket and/or pay on foot at the exit lane. Another benefit is derived from using machines for off-hours when it is not cost-effective to staff a cashier station, while maintaining exit-lane cashiering in normal hours.

The survey found extremely limited and disappointing use of the machines. People just pass by the pay-on-foot machines, knowing they can pay at the exit. However, they cannot see that there is a backup until they get to the exit area. In one installation where actual data were provided, only 1.5% of the customers used pay-on-foot. While not providing figures, all other respondents who had tried this type of system reported extremely low use.

Because so few people used the automated units, there was no reduction in the requirements for exit lane equipment and cashiers. During design, it was assumed that a certain percentage of the patrons would use the pay-on-foot option, and the number of cashiered exit lanes was reduced accordingly. However, since the actual usage of the pay-on-foot option was far lower, there were not enough exit lanes and, in one case, there was no way of adding any once the facility was constructed. Therefore, there are large backups at peak hours. At the same time the automated pay stations are very expensive, at $70,000 or more per unit.

In all cases where a hybrid system with both pay-at-exit and pay-on-foot was surveyed, the owner considered the system to be a failure, and was forced to abandon the pay-on-foot part of the system. One owner who does not have enough exit lanes has moved the pay-on-foot stations to a shelter near the exit cashier lanes, with parking spaces nearby. When there is a backup, a person stands at the end of the queue and suggests that patrons pull over to the machines, park, pay at the automated station, and then exit through the "express" lane dedicated to pay-on-foot users. The stations are also used for the negligible number of transactions from midnight to 6 A.M.

3.2.8.6 Designing Pay-on-Foot Revenue Controls

Several problems were noted in the survey that require close attention during the planning and design of pay-on-foot systems. One of the biggest problems is the propensity of the American parker to leave parking tickets in the car. It should first be noted that changing this habit is a desirable goal for the parking industry for other reasons. Leaving the parking ticket in the car makes it much easier for someone to steal the car, since the thief can use the ticket to exit the facility without attracting undue attention.

The first action is to place signage in prominent locations in both the parking and pedestrian areas. The messages on the signs can be reinforced with audio messages. Some equipment manufacturers offer ticket dispensers that deliver an audio message when a ticket is issued. A customized message could be developed to remind the parking patron to "take the ticket with you." Care, however, must be taken; patrons may not hear the entire message.

It should be noted that even facilities that are highly transient, such as shopping centers, have a high degree of repeat customers. After a first period of familiarization, the problem is likely to diminish, as patrons will remember to take the ticket after once having a problem at the exit lane.

The design of the pedestrian traffic flow through a parking facility also influences the success of a pay-on-foot system. Pay-on-foot systems work best when patrons must pass through one pedestrian access point to return to a parking area. Too many expensive machines and/or cashier locations may be required with a large number of pedestrian portals. Similarly, pay-on-foot systems work best when the payment stations are prominently located. The parking patrons should not have to search for the pay station.

For the first few months after opening a pay-on-foot operation, the operator should station personnel in a prominent location such as the main elevator lobby to greet patrons, inform them in a positive way of the new system, and remind them to take their tickets with them and to pay for parking before retrieving the vehicle. Operators of well-designed pay-on-foot systems have found that, with this extra assistance, the number of patrons who get to the exit lane without having paid is extremely low. One operator with 1800 spaces said that no more than four or five patrons a day forget to pay, even after just a few months of operation.

It is not recommended that the owner place fee computers and cashiers in booths at the exit lanes for an introductory period in an attempt to mitigate the inconvenience to the patron who forgets to pay. It merely encourages a bad habit that must be broken to achieve a successful installation of pay-on-foot revenue control. That money is much better spent on "greeters" who inform patrons of the need to take the ticket on the way to the destination and to pay before returning to their car. In this case that old saying, "Begin as you mean to go on" is quite applicable.

When the exit lanes are near the parking office, the supervisor can go to the lane and process an exception transaction for the patron who hasn't paid. If the exit lane is distant from the office, it is important that the physical design of the parking facility allow sufficient room for the patron who arrives at the lane without having paid to pull off to the side. A second option is to provide at least two exit lanes and/or excess capacity in the peak hour at each exit location so that other patrons can get to an open lane.

3.2.8.7 Conclusions

For most users, a hybrid system of central cashiers with pay machines for off- and peak hours will:

- lower operating costs and staffing headaches
- increase net operating income
- reduce queuing and pollution
- improve the work environment for employees
- provide the overall best service to customers

A system that is 100% automated pay station may be cost-effective in certain situations, but 5% to 10% of the customers will resist and/or have problems using the stations.

Hybrid systems with automated pay stations and exit-lane cashiering have not worked well and have not been cost-effective because patrons won't use the machines, thereby negating the expected benefits.

To make pay-on-foot work, the facility must have with a limited number of pedestrian portals, so that all patrons pass by a central payment location on the path of travel to/from the ultimate destination. Signage must be placed both in the parking areas and along the path of travel to remind patrons to take their ticket with them after parking the car, and to pay on foot before returning to the vehicle. A method for processing the patron who has not paid or whose grace period has expired before arriving at the exit lane must be provided.

3.2.9 The Future Is Already Here. . . .

Technological advances continue to happen at such a rapid pace that by the time this book is published, there will undoubtedly have been a major technological advance in PARC.

One advance in LPI systems that is now in prototype stages is to read the license plate at the entry. At least one airport now does this manually, which is very labor-intensive. However, using video technology, and today's revenue control, it is possible to capture and store a video image on entry and tie it to the ticket number. When the ticket is presented at exit, the rear end of the vehicle with the license plate that took the ticket on entry is displayed. The cashier can check visually to see if it is the same vehicle, thus detecting ticket swapping and car thefts. If the LPI is recognized and digitized on entry and again at exit, the computer could automatically check it. At the time of this writing, the only thing slowing development of automatic LPI reading is the diverse array and format of license plates in the U.S.

Paper tickets could be eliminated entirely if the license plate of every vehicle is read at the entry gate and then read at the exit. The computer would check its memory for the entry time and for authorization as a monthly parker or calculate the fee as previously discussed.

In the longer term, the U.S. government is investing significant sums in Intelligent Vehicle Highway Systems (IVHS). Eventually all new cars may be equipped with a unique AVI transponder at the factory. The system will then operate similar to the license plate control system described above. Further, there will probably be a national fee collection system, with the vehicle owner receiving a bill for all charges, including tolls, parking, etc. Cashiering could then be almost entirely eliminated.

3.3 COST-EFFECTIVENESS: CHOOSING THE RIGHT SYSTEM

As PARC systems become more sophisticated, choosing the level of sophistication becomes an ever more difficult challenge. Certainly, the hi-tech systems on the market have a lot of bells and whistles that start many parking managers dreaming. At the same time, parking managers are a cynical lot, always questioning whether or not manufacturers' promises can be delivered.

Why do parking managers dream of the perfect PARC system yet remain skeptical of ever seeing that day? As each advancement in PARC closes one avenue for theft, patrons and/or employees have found new and more imaginative ways of defeating the system.

As a result, no PARC system on the market today is 100% theftproof. Today's highly sophisticated systems merely increase the likelihood that thefts and fraud will be detected, but sooner than before or with less auditing effort by management. A hi-tech system may also allow the parking manager to redirect available resources from auditing and management to customer service and amenities, increasing the market share and the gross revenue.

However, the fundamental question remains: Does the increased income justify the incremental investment in a sophisticated system? It is not uncommon today for a "basic" PARC system in a medium-size facility (500 to 1000 spaces) to exceed $100,000 in cost; a "state-of-the-art" system can easily double in cost. More importantly, PARC systems wear out or become technologically obsolete in 7 to 10 years.

While advantages and disadvantages of alternative levels of control and optional features may be qualitatively listed, the quantitative question—Will it pay for itself?—is rarely if ever explored before new equipment is purchased.

Answering that question requires projections of the revenues and operating expenses for each alternative under consideration. This section addresses the variables that affect the cost-effectiveness of alternative PARC system, and discusses the *revenue collection efficiency* of various levels of revenue control to assist in consideration of cost-effectiveness.

In order to explore the cost-effectiveness of PARC, several terms have been "borrowed" or adapted from financial terminology. The *potential revenue* is that which would be collected if every parker paid his or her fair fee. The *gross revenue* is the total revenue collected (after fraud, if any occurs) and retained (after theft, if any occurs.) The *revenue collection efficiency* (RCE) is the gross revenue divided by the potential revenue. It represents the percentage of potential revenue that makes it to the facility owner's bank account. *Net operating income* (NOI) is the gross revenue less the operating expenses associated with collecting it.

The variables that affect the cost-effectiveness of a particular revenue control system may be divided into three areas: revenue issues, equipment issues, and labor issues.

3.3.1 Revenue Issues

The potential revenue generated by the parking facility is perhaps the single most important factor in determining whether a feature or system will be cost-effective. If we assume a particular feature can increase the RCE 1%, the increase in gross revenue in a facility with $100,000 potential revenue will be $1000. In a facility with potential revenues of $10,000,000, however, the gross revenue would increase $100,000. Investing $100,000 in this PARC feature is likely to be cost-effective over the life cycle of the latter but not the former.

Gross revenue is, of course, affected by such factors as the size of the facility, the type of users, the parking rates, and the turnover of the spaces.

The split between monthly and daily parkers is also a critical factor in cost-efficiency of PARC. Adding machine-readable ticketing to a PARC system may not be cost-effective in a facility that mainly serves monthly parkers.

The incentive for theft and fraud is also much higher in a facility that has high ticket value. Patrons are much more likely to try to beat the system when the parking fees are high. Both the temptation and the theft amount (in terms of total dollars) will be much higher when the facility employees handle a lot of cash every day.

The error rate (which occurs naturally when humans process transactions) may also be a factor in systems with high revenues, simply because a 1% to 2% error rate can become a significant dollar amount in a high-revenue facility.

A machine-readable system that reduces the error rate for data otherwise "keyed in" by the cashier is not the only option; reducing the number of transactions handled by cashiers is perhaps a more fundamental solution that is being pursued in state-of-the-art systems today.

It is also important to note that auditing monthly parking or machine-only transactions is far less time-consuming than that for cash transactions. A feature that reduces audit time by management is likely to be more cost-effective in a facility with high revenues than in one with low revenues.

Overall, therefore, features that reduce the amount of cash collected and handled by employees are thus more beneficial in high-fee facilities. Such features not only include automated pay stations but also monthly, declinating, and decrementing card payment systems. Accepting credit cards also reduces the employee incentive to steal.

The above discussion primarily addresses factors that affect the amount of gross revenue (the cash retained once collected). However, the choice of PARC may also affect the potential revenue.

A more sophisticated PARC system will generally result in more accurate calculation of the parking fee and can allow more increments in the fee structure. Some PARC systems provide for a more complicated rate structure than other systems. Electronics allow the machine to calculate the exact fee, without resulting in the error and rounding that used to occur when cashiers manually calculated parking fees.

While one might argue that more frequent increments in the fee structure reduce revenue (the average parker pays more in a fee structure of $1 per hour or fraction thereof than in one at $.50 per half hour), the use of increments can make a higher overall fee structure more palatable to the marketplace, resulting in more parkers and/or higher turnover.

The ability to offer lower rates at less busy periods such as evenings and weekends can provide management with tools to increase utilization and revenues.

Some systems provide a higher level of customer service, which can increase patronage in a competitive market.

3.3.2 Equipment Issues

The most obvious factor in equipment cost is the number of lanes and devices required to operate the system. The cost-effectiveness of pay-on-foot parking systems most often hinges on a limited number of pedestrian portals; with multiple pedestrian entrances, too many payment stations (either automated or cashiered) may be required for pay-on-foot to be cost-effective.

"Capital" cost (to purchase and install) and maintenance costs tend to run in parallel—i.e., the more sophisticated systems cost more both to purchase and to maintain. However, technological differences make it difficult to use a simple rule of thumb for the relationship.

Hi-tech devices tend to require a more skilled—and better-paid—repair person; however, the same technology advance may reduce the frequency of repair or provide diagnostics to more quickly identify the problem.

There may even be differences at the same level of sophistication; mag stripe ticket dispensers cost more to maintain than their bar code technology cousins. Other costs are less obvious. The cost of tickets using mag stripe technology for machine readability is significantly higher than that of tickets for other systems.

In an equipment replacement project, "brick-and-mortar costs" may be a significant factor in cost-effectiveness. Some sophisticated systems have slower processing rates, which can require additional lanes and/or expensive remodeling. It may be expensive to go to a central cashiering system if a new lobby must be constructed at the pedestrian portals. If parking spaces are lost or gained from changes to entry/exit areas, revenue can be affected.

3.3.3 Labor

Cashiering is generally the single largest expense associated with revenue collection. Systems or features that reduce cashiering requirements will generally have short payback periods. These include pay-on-foot systems as well as monthly and declinating payment systems. Conversely, when cashiers must operate sophisticated equipment, there can be substantially increased training costs, especially considering the turnover and level of education of cashiering personnel. Likewise, performing routine maintenance and minor repairs by in-house staff can require substantially more training and/or education with a sophisticated system.

Auditing costs are generally only a small proportion of the cashiering costs, so features that reduce auditing costs are often more difficult to justify on a strict cost-effectiveness basis.

When a PARC system reduces (or eliminates) the need for cashiers or the proportion of management time spent on revenue control, the "freed-up" manpower is often diverted to other purposes such as security, maintenance, or customer service. As previously noted, this could improve the marketability—and gross revenue—of the facility.

3.3.4 Revenue Collection Efficiency Factors

A parking manager can obtain reasonably reliable estimates of the cost to install and maintain a proposed PARC system and can usually project the impact on cashiering staff costs. While a bit more of a stretch, the potential revenue and the management/auditing time may also be projected. There remains one essential assumption: *How much more revenue will be collected and retained in the system by virtue of the particular features of a PARC system?*

The revenue collection efficiency factor is straightforward in concept—gross revenue divided by potential revenue. Clearly, the level of revenue control will result in differences in this ratio. However, there is virtually no documentation of actual case studies in the industry literature; the particular problem is determining the potential revenue.

Gross revenue is easily determined for existing systems, and "before and after" cases may be studied. However, other factors may have changed as well. For example, auditing procedures or fee structures may be changed. In such cases it may be difficult to separate improvements in RCE resulting solely from the change in parking equipment.

More importantly, it is extremely difficult to determine the revenue lost to theft and fraud without a comprehensive, independent audit. Where full audits have been performed, losses of 10% or more have been documented despite state-of-the-art equipment and managements' perception of "tight controls and auditing."

Determining the "missed" revenue in honor systems such as parking meters is even more difficult. An audit would require virtually continuous monitoring of both the time the meters were occupied and the payment status of the meter. In a British study[5] of the effects of changes in enforcement of meters, the percentage of "occupied time paid for" was only 60% to 80% in high-turnover, heavily enforced areas of on-street meters.

Revenue control efficiency factors developed by the author[4] are presented in Table 3-2. The various systems are described by the most common industry terminology, the level of control, and whether or not the system is gated.

Two factors are provided for each type of PARC equipment, depending on the level of management control and auditing. The revenue control efficiency will vary greatly according to the operating and auditing procedures.

In many cases there is virtually no auditing. The owners of many parking facilities view parking as a secondary function—a "service"—and not a revenue-generating asset. Where fees are low, the amount of theft in absolute dollars is generally low, and management may therefore not concern itself with auditing. Because this level of attention to detecting theft and fraud is so widespread, the RCE for this level of auditing/management is denoted as typical.

The commercial parking operator and owners/operators of many high-fee facilities recognize the benefits of a higher level of auditing and management. These operators may not use a maximum level of auditing but, rather, an optimum one. The latter is that degree of effort that is cost effective—i.e., the cost of auditing/management is more than offset by the increased revenue.

As the level of control increases, the RCE naturally increases. There

TABLE 3-2. Revenue Collection Efficiency Factors

Type of System	Gated	Typical Auditing	Optimum Auditing
Level 0			
"Cigar box" with numbered tickets	No	67%	80%
Permits/decals/hang tags	No	67%	75%
Slot boxes	No	50%	67%
Level 1			
Electromechanical meters (without fine income)	No	60%	75%
Coin/token	Yes	75%	85%
Cash register/out clock	Yes	75%	85%
Magnetized cards/readers	Yes	85%	90%
Level 2			
Electronic meters	No	75%	80%
Multispace meters w/monthly cards	No	75%	85%
Fee computer	Yes	80%	85%
Programmable cards/readers	Yes	90%	95%
Level 3			
Fee computers/machine read tickets	Yes	82%	87%
Central cashiers w/fee computer & machine read	Yes	85%	90%
Central pay stations (pay-on-foot)	Yes	90%	95%
Exit lane pay stations	Yes	87%	92%
License plate inventory (multiday parking), exceptions only w/machine-read tickets	Yes	83%	88%
License plate inventory, all vehicles, w/machine-read tickets	Yes	85%	90%
Online card controller	Yes	90%	95%
Level 4			
Online real-time facility management	Yes	90%	97%

Source: Smith, 1993.[4]

may, however, be fundamental differences between different control systems at various levels. Card systems tend to be more efficient than cashiered systems, and both are usually more efficient than honor systems like meters.

As seen in Table 3-2, the increment in RCE is much greater as one moves from Level 0 to 1, or from Level 1 to 2. However, as one adds the "bells and whistles" at Levels 3 and 4, the increment is relatively small.

This phenomenon has a direct relationship with the cost-effectiveness of hi-tech systems, as discussed previously.

Going from a Level 2 fee configuration to a Level 3 machine-readable system alone adds only 2% to the RCE. If potential revenues from transient patrons are $100,000, the annual increment in gross revenue is only $2000. The additional cost in equipment can run about $10,000 per pair of entry/exit lanes. However, in a facility with $1,000,000 in potential revenue, the increment is $20,000 per year, which can quickly pay back the increased cost of equipment.

More importantly, an optimum level of auditing/control on a Level 2 system can achieve nearly the same results (in terms of RCE) as in a Level 3 system. The cost of the auditing to achieve these results in the Level 2 system may be more than in Level 3, but it can be done.

3.3.5 Summary of Considerations in PARC System Selection

In general, a good fee computer system, and/or a programmable or on-line card system is appropriate for many smaller parking facilities. Owners who are motivated to monitor activity closely and who will use the voluminous reports that can be generated will probably benefit having an FMS in an individual facility. The FMS, however, will be most cost-effective to those who own or operate a number of parking facilities or one with relatively high revenue. The purchaser of PARC system equipment must also address how tight a system must be to meet the facility's needs, and select manufacturers and technology appropriate to those needs.

How much to spend on a PARC system is another consideration. In facilities with relatively low revenues, the PARC system is usually designed to keep unauthorized users out more than to keep revenues in, and thus the expenditure is justified on other things than revenue. When a facility or group of facilities has annual revenues exceeding $1,000,000, an investment in the PARC system equal to 10% of the annual gross revenues has been found to be appropriate. When it is appropriate to investigate the cost-effectiveness of alternative PARC systems or features, the potential revenue and revenue collection efficiency factors must be studied.

3.4 DETERMINING LANE REQUIREMENTS

The traditional method for determining the required number of lanes of PARC equipment involves estimating the number of vehicles expected in a certain peak period and dividing that by the "capacity" of the equipment in the same period. In recent years, however, the average size of parking facilities has dramatically increased. Consultants with extensive experience with larger facilities have found that this methodology can be very inaccurate, resulting in a very overdesigned system in one case and a very underdesigned system in another. While overdesigned systems merely result in wasted capital resources, underdesigned systems can result in user frustration sufficient to cause patrons to choose another facility. Crommelin[7] first adapted standard traffic engineering theory for queuing at traffic signals for use in PARC lane design. The author has further developed this approach,[6] updating and expanding the procedures for conditions common today.

3.4.1 How Many Lanes?

The number of lanes needed is estimated by dividing the *volume, V,* of vehicles expected in the *peak hour* by a *peak-hour factor*, PHF, times the *service rate,* μ, of one lane as follows:

$$n = V/(\text{PHF} * \mu)$$

When the peak-hour volumes and peak-hour factors (as discussed in Chapter 2) are estimated conservatively, fewer lanes can be equipped initially to accommodate a more realistic estimated volume. Then, if worse comes to worse, equipment can be added later for additional lanes. It is usually difficult and expensive to add lanes later when no consideration of additional lanes has been made in the initial design.

The queuing model discussed later will provide a better picture of the peak and average activity in the hour, but the PHF allows for the number of lanes to be quickly estimated. In general, the higher the volume and the greater the number of lanes required, the higher the PHF that can be used. This pattern obtains both because the peaks and valleys in activity tend to be moderated as overall activity increases, and because the bursts in traffic can be distributed over several lanes.

If one lane (either in or out) is provided at a certain location, the PHF should be no higher than 75%. As additional lanes in the same direction are added, the PHF can be increased, to about 85% for two lanes, 90% for three lanes, and 92% for four or more. When these PHFs are used, any fraction should be increased to the next highest number—e.g., if 1.2 lanes are calculated, two should be provided.

The service rate is determined by using the inverse of the average time per transaction $\bar{s}$ and converting to hours. Thus, the service rate,

TABLE 3-3. Parking Control Service Rates

	Service Rate μ (vph)	
	Easy Approach	Sharp Turn
Entrance and/or exit		
Clear aisle, no control	800	379
Coded-card reader	400	257
Proximity card reader (2–6 in. distant)	511	300
Coin/token	140	116
Fixed fee to cashier	270	164
Fixed fee—no gate	424	270
Entrance		
Ticket spitter—automatic	522	303
Ticket spitter—push-button	480	257
Ticket spitter—machine-read	400	232
Exit		
Variable fee to cashier	144	120
Validated ticket	300	212
Machine-read ticket	180	144
Machine-read with license plate check		
Front plate—manual	110	NA
Rear plate—camera	80	NA
Pay-on-foot		
Central cashier	200	NA
Automated pay station	212	NA
Exit ticket	400	257

NA = Not applicable.
Source: Klatt, Smith, and Hamouda, 1987.[8]

$\mu = 1/\bar{s}$. If a cashier can process two vehicles per minute, $\bar{s} = 30$ seconds and $\mu = 120$ vph.

Sharp turns in the approach to equipment lanes have a significant impact on μ[8] (see Table 3-3). It should be noted that the service rates of equipment also vary from one manufacturer to another depending on the mechanical and/or electrical technology employed. Certainly if the manufacturer is known at the time of the design, the actual service rates should be obtained and used. However, when several manufacturers are possible bidders, it is neither practical nor advisable to calculate the required number of lanes for each manufacturer. If service rate is that critical, it would be more desirable to specify that the equipment must achieve the desired service rate. In any event, the determination of an accurate design hour volume will be far more critical and valuable to the analysis than fine-tuning the service rates according to likely manufacturer.

3.4.2 Queuing Analysis

The proper design of access points requires additional information. For example, vehicles may back into the street if there is not enough space between an entrance gate and the street, even though there are enough lanes to process the peak flows comfortably in an hour. Problems may also occur if the queue of vehicles waiting for one lane blocks vehicles trying to get to another lane; in such a case the second lane is not effective. Designing sufficient lanes only to meet peak-hour factors may result in an unacceptable level of service in the field, especially in larger facilities. Therefore, additional traffic engineering theory must be employed to ensure good design. Traffic engineers have developed queuing theory using standard statistical procedures to model flow patterns over the course of an hour.

Queuing equations are available for two types of conditions: single-channel and multichannel. Single-channel equations are intended for use where one lane is provided at the access point. The multichannel equations are used when the driver has a choice of two or more similarly equipped lanes at an exit or entry area.

A simple graphical approach avoids the need to use the actual equations. Note that the vehicle at the equipment is in the *service position* and is not counted in the queue.

In traffic engineering, it is generally accepted to design for an 80% to 90% probability. There is relatively small variation in *reservoir* size within this zone. Substantially larger reservoir space and/or more lanes would be required to be adequate for essentially all conditions, as depicted by a 99% curve. Therefore, most systems should be designed for q_{90}. Even if the queue does exceed that indicated by the 90% probability curve, it will probably be quite rare and short-lived.

Ninety percent probability does not imply that this queue will be exceeded 10% of the minutes in the peak hour. A better translation is as follows: If one went out and observed many different lanes, each with this flow intensity for a full hour but with random patterns within the hour, and recorded the queue once each minute, 90% of the recordings would be less than q_{90}.

The average queue, $\overline{q}$ is used to determine the average wait, $\overline{w} = \overline{q} * \overline{s}$. Because the average time per transaction, $\overline{s} = 1/\mu$, $\overline{w} = \overline{q}/\mu$, can also be used. If the service rate, μ, is in vph, $\overline{w}$ will be of the order of magnitude of 10^{-3} or smaller; conversion to minutes or seconds will make $\overline{w}$ more readily understood. Use of $\overline{q}$ for determining the levels of service will be discussed later.

The traffic intensity, λ, is V/μ. Thus, when a V = 300 vehicles is expected to arrive at a card reader with a μ = 400 vph, λ = 0.75. When a mixture of users, such as one volume of monthly parkers (V_m) and another of transient parkers (V_t) is expected at a lane, the service rate must be a weighted average of μ_m and μ_t as follows:

$$\mu_{wa} = \frac{V_m + V_t}{V_m/\overline{\mu}_m + V_t/\overline{\mu}_t}$$

The designer thus calculates λ, goes to the queuing curves, moves vertically up to the line, and then traces horizontally across to determine the queue, q. Because the queuing equation models the approach of vehicles to the lane, a peak-hour factor is not used in the queuing analysis.

The queues for various combinations of service rates and number of channels have been calculated and plotted with the design queue, q_{90}, in Figure 3-9, and the average queue, q, in Figure 3-10. Both q and λ in the graphs are per lane. For example if a V = 600 cars is expected at two lanes, each with a μ = 400 vph, λ = 600/(400 * 2) = 0.75. q_{90} at each lane is just under four vehicles and q is one vehicle per lane.

It can be seen that using the single-channel equation instead of the multichannel equation becomes more conservative (that is, overestimating the queue) as the number of lanes n increases and also as intensity increases. For example, at λ = 0.6 and n = 2, q_{90} with the multichannel equation is two vehicles less (3 versus 1) than with the single-channel equation. At λ = 0.9 and n = 2, the multichannel design queue is more than 10 vehicles less than the single-channel design queue.

The multichannel equation is, of course, only applicable when multiple lanes are located side by side. If two exit lanes are provided with one at each end of a facility, each lane should be designed using the single-channel equations.

3.4.3 Level-of-Service Classification

A question often raised is what queue is acceptable to patrons. The level-of-service (LOS) approach is a useful concept in this case. At a traffic signal, the LOS is related to the average delay encountered in the design or peak hour. This concept is easily applied to delay at a parking gate. The acceptable average delay of each LOS at exit/entry lanes is slightly longer than that at traffic signals.[6] This modification is based on the fact that delay at entry/exit lanes is a single occurrence

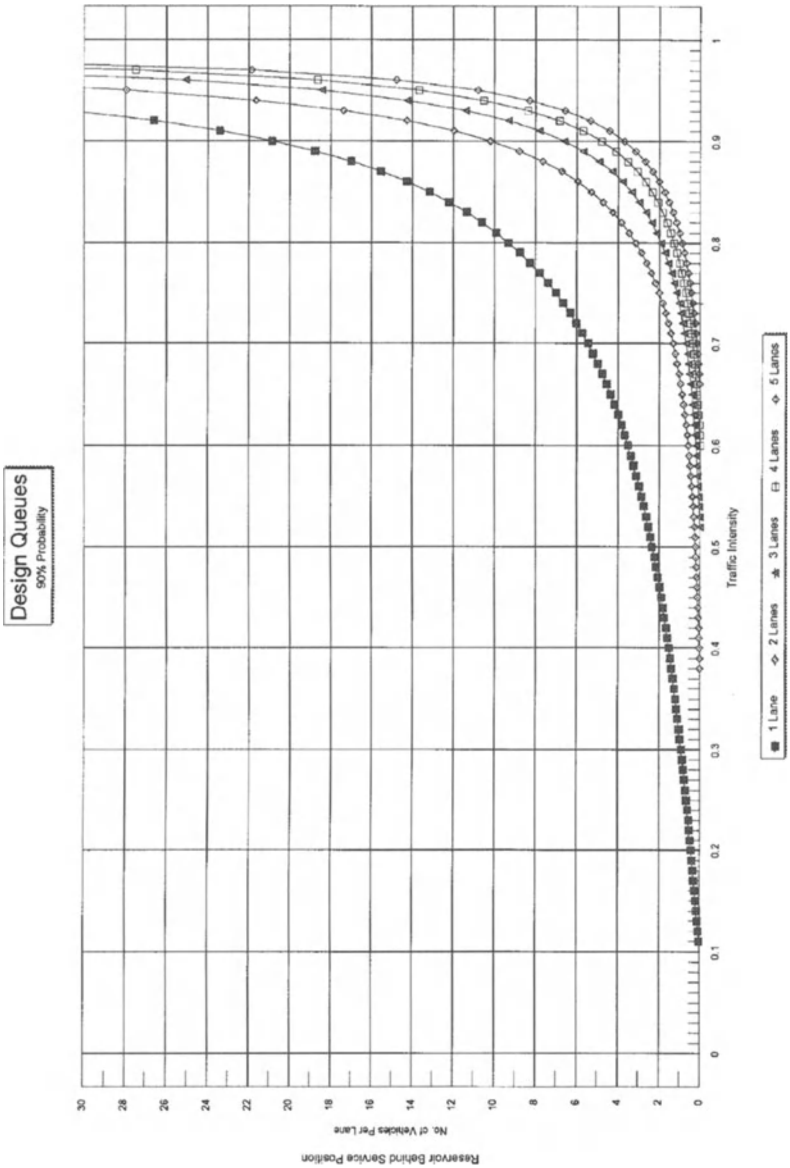

Figure 3-9. Design queue curves.

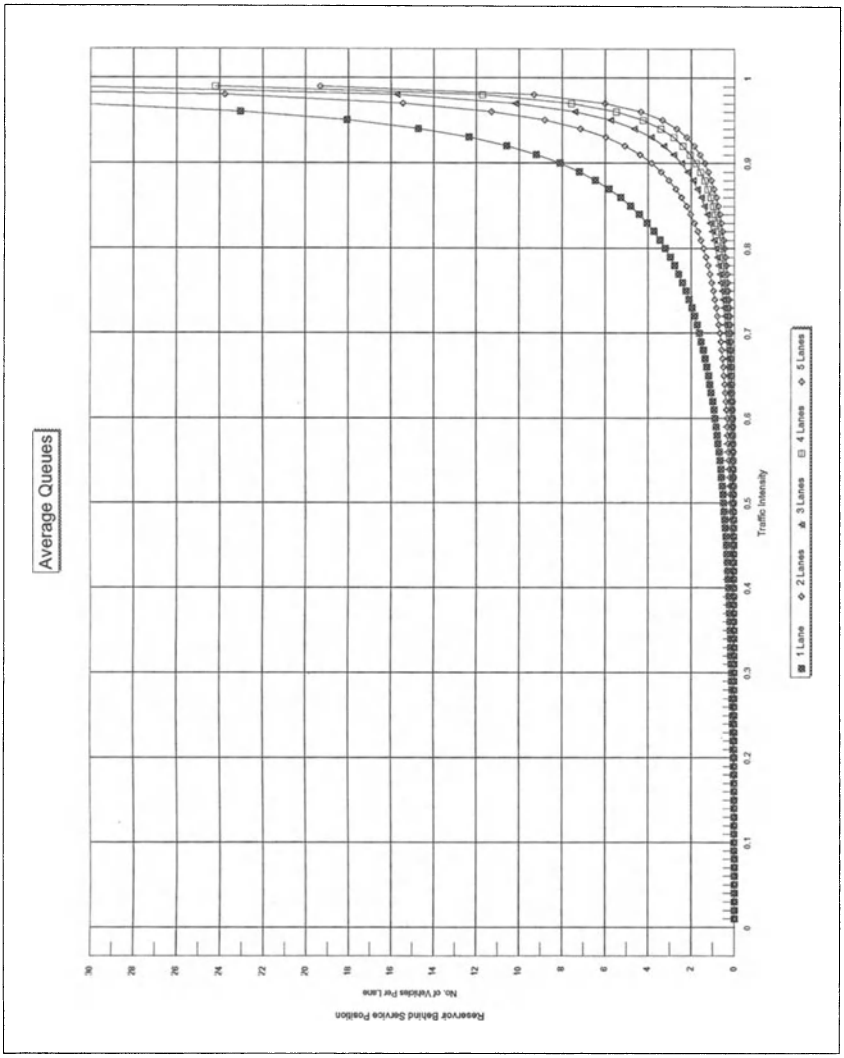
Average Queues
Traffic Intensity
1 Lane
2 Lanes
3 Lanes
4 Lanes
5 Lanes
Reservoir Behind Service Position
No. of Vehicles Per Lane

TABLE 3-4. Entrance/Exit Level of Service

	Average Queue Length, $\bar{q}$ (vehicles)			
Level of Service	D	D	B	A
Average Delay, $\bar{w}$ (min)	1	0.5	0.25	0.08
Coded card				
easy approach	6.66	3.33	1.66	0.55
sharp turn	4.28	2.14	1.07	0.35
Coin/token				
easy approach	2.33	1.16	0.58	0.19
sharp turn	1.93	0.96	0.48	0.16
Ticket dispenser—auto-spit				
easy approach	8.7	4.35	2.17	0.72
sharp turn	5.0	2.5	1.25	0.41
Ticket dispense—push-button				
easy approach	8.0	4.0	2.0	0.66
sharp turn	3.53	1.76	0.88	0.29
Variable fee with license plate				
easy approach	1.83	0.91	0.45	0.15
sharp turn	1.33	0.66	0.33	0.11
Pay-on-foot				
exit	6.66	3.33	1.66	0.55

in each trip to or from the facility. The same delay at each of a series of traffic signals would be more frustrating and less acceptable.

Table 3-4 displays the definition of acceptable delay for each LOS, and the associated average queue. The design queue (maximum expected with 90% probability) would be substantially longer. For example, an exit area with two card-controlled gates each having average queues of 6.66 vehicles (LOS D) would have design queues of 16 vehicles each. Two cashiered controlled exit gates with LOS D would each have average queues of 2.4 vehicles and design queues of approximately six vehicles.

This approach therefore takes into account the fact that some transactions are considerably slower than others, such as a variable fee paid to a cashier versus a card reader. While the length of the line does have some psychological impact, the critical factor to user acceptability is the delay time.

As with other traffic and parking conditions, the acceptable LOS at a facility's entrance/exit depends on the type of user. However, it should be noted that one user type does not require the same LOS at every point in the facility. As discussed in Chapter 2, short-term visitor parking design should have a higher LOS (typically B) than employee area (typically C), because of the frequency of turnover and the lack of patron familiarity with the design. At entry/exits, regular monthly parkers demand a higher LOS than less frequent users. Users who encounter the same delay day after day are more likely to complain or choose a facility with a better LOS. Employees or monthly card holders generally want LOS A, but will accept B. More irregular users such as shoppers will accept LOS C or B. There are relatively few cases where LOS D is acceptable, unless it occurs on a very infrequent basis such as at a parking facility under special-event conditions. Even then, the season ticket holder will find and regularly use a facility with a faster exit time, while the single-game attendee will accept a longer delay. The urban environment also plays a role. If the facility is located in a congested, downtown area, longer queues will be tolerated than in a rural setting where the driver waiting in line can see an almost empty street just outside the facility.

3.4.4 Entry/Exit Layout

When the type of PARC equipment and the number of lanes are known, entry/exit layouts are fairly routine. Typical entry lanes are shown in Figure 3-11. The configuration of "card only" lanes is the same at both entry and exit. At entry lanes, ticket dispensers may be placed just before or after card readers. In this configuration, the patron must press a button on the machine to dispense a ticket. When space is available to separate the dispenser and the card reader, a detector loop in the floor can sense a vehicle approaching the dispenser and "spit" the ticket before the vehicle even comes to a full stop. "Auto-spit" ticket dispensers therefore are faster, as well as less confusing to unfamiliar patrons. The card reader must be placed at least 10′ in front of the ticket dispenser so that the vehicle stopping at the card reader does not activate the auto-spit function of the ticket dispenser. If the vehicle has used the card reader before reaching the ticket dispenser, the auto-spit function is bypassed. A similar bypass control is used when cash and card customers use the same exit lane, but separation of equipment is not required.

"Reversible" lanes, which serve as entry lanes in the morning and exit lanes in the evening, can be very space efficient when peak hour volumes are predominantly one-way. Reversible lanes are less confusing if they are monthly only, but with proper signage they can be cashier equipped as well.

Cashier lane layout has been significantly impacted by the Americans with Disabilities Act (ADA). Although the requirements are discussed in more detail in Chapter 7, it is helpful to repeat one critical and most often misunderstood requirement here. Under ADA, *every* cashier booth must be accessible *to and through the door.* This means that the booth

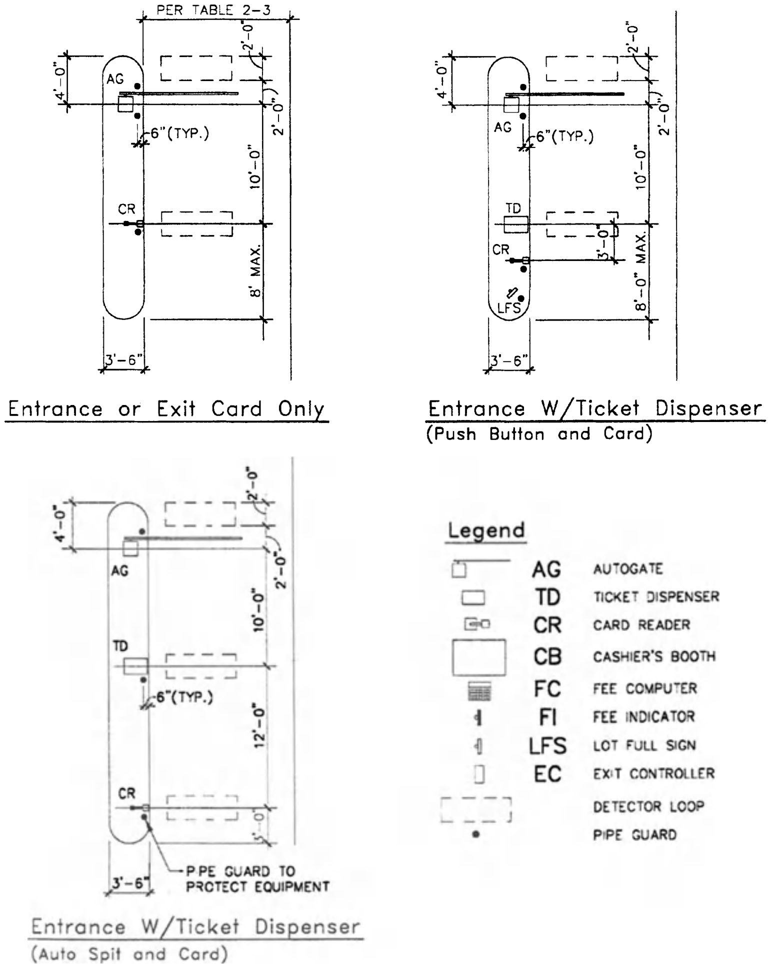

Figure 3-11. Typical entry layout.

must be recessed in the island. It is recommended but *not required* by ADA that at least one of the cashier booths be designed to be fully wheelchair accessible—i.e., have the controls at proper height and the required clear floor space for maneuverability of a wheelchair.

A common error in entry/exit layout is providing inadequate space for the driver to turn into the lane and get aligned with the ticket dispenser or card reader. (See the discussion of turning radius in Chapter 2.) Overhang beyond the wheel track must also be considered. The sharper the turn, the slower the processing of vehicles, as documented

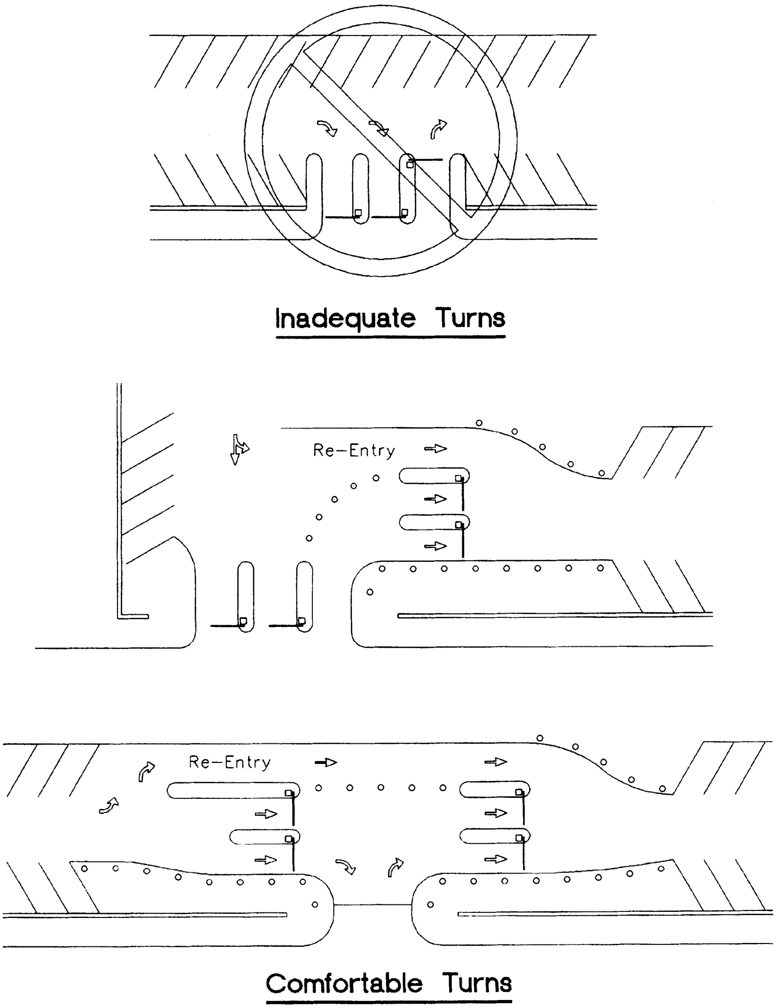

Figure 3-12. Providing inadequate space for turns is a common error in designing access points. Pulling the control equipment inside the facility will provide a much more comfortable arrangement.

previously. Figure 3-12 shows designs of an entry/exit point: one that is too tight, and recommended layouts.

3.4.5 Auxiliary Spaces

In many parking facilities it is desirable to provide an office for management purposes. In smaller facilities, an enlarged prefabricated booth

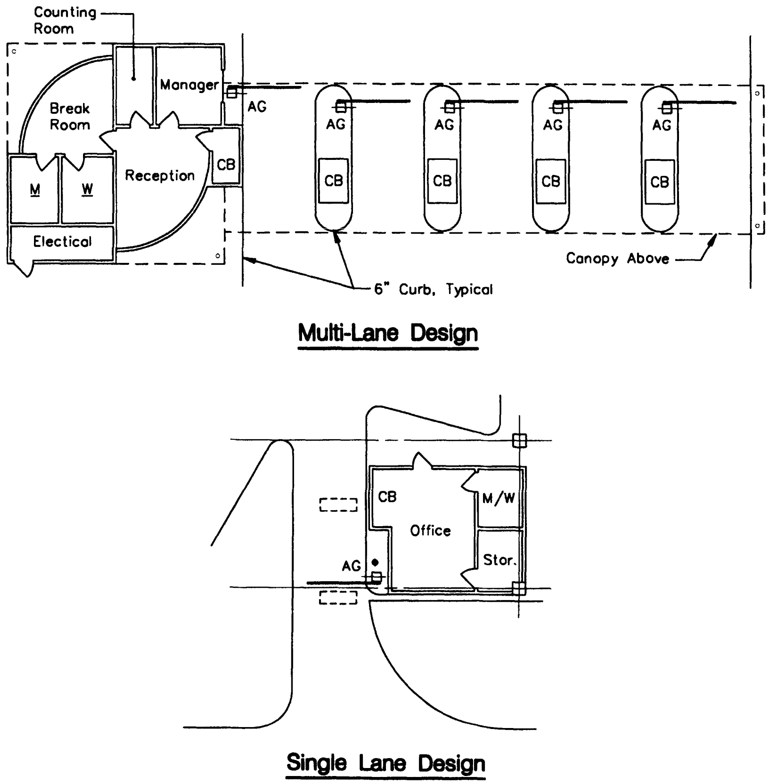

Figure 3-13. Management office layout.

that combines a cashier station and a counter and/or wall space for various panels (such as the facility intercom, the vehicle counting system, etc.) can meet project requirements. However, the design requirements may also include restrooms, security stations, storage, coat/locker facilities, and management workspace. A custom-built office may then be desirable. Figure 3-13 shows custom designs at two ends of the spectrum: a relatively simple combined cashier/management office, and a complex with multiple offices, employee lunchroom, lockers, etc., such as might be required at an airport. Note that all areas in such facilities must be designed to be accessible under ADA.

3.5 REFERENCES

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CASE STUDY

Consider the hospital parking structure example from Chapter 2. Employees will have cards; transients will pay based on length of stay. There will be one entrance/exit area which is located very close to the street, requiring a sharp turn of vehicles from the street to the entrance lanes. All entry lanes will be fitted for both monthlies and transients. Card controls will be proximity. There will not be room to separate the ticket spitter from the card reader, necessitating a push-button mechanism on the spitter. The approach to the exit lanes will be straight and easy. How many lanes of equipment are required for this facility?

The capacity (N) is:

$$N = 650 \text{ spaces}$$
$$N_m = 436 \text{ spaces for monthly parkers}$$
$$N_t = 214 \text{ spaces for transients}$$

Peak morning arrivals are from 6:15 A.M. to 7:15 A.M. The volumes (V) previously established are:

$$V_m = 245 \text{ vehicles}$$
$$V_t = 11 \text{ vehicles}$$
$$V_{in} = 256 \text{ vehicles}$$

From Table 3-1, the service rates for the proposed equipment are:

$$\mu_m = 300 \text{ vph}$$
$$\mu_t = 257 \text{ vph}$$
$$\mu_{wa} = \frac{(245 + 11)}{(11/257) + (245/300)} = 300 \text{ vph}$$

The approximation of the number of entry lanes, assuming a peak-hour factor of .85, is:

$$n = V_{in}/(\text{PHF} * \mu) = 300/(.85 * 300) = 1.0 \text{ lanes}$$

Although one lane is minimally adequate, two lanes will be provided. The traffic intensity is then:

$$\lambda = V_{in}/(n * \mu_{wa}) = 256/(2 * 300) = 0.43$$

Referring to Figure 3-10 for the 90% probability queue, and to figure 3-11 for the average queue, under multichannel conditions:

$$q_{90} < 0.5 \text{ vehicle per lane}$$
$$\overline{q} < 0.1 \text{ vehicle per lane}$$

The average wait $\overline{w}$, can then be calculated

$$\overline{w} < \overline{q}/\mu_{wa} = 0.1/300 = 0.00033 \text{ hr} = 0.02 \text{ min} = 1.2 \text{ sec}$$

From Table 3-2, $\overline{w}$ = .02 min indicates that the level of service,

$$\text{LOS} = \text{A+}$$

Peak afternoon departures are from 3:00 P.M. to 4:00 P.M.

$$V_m = 245 \text{ vehicles}$$
$$V_t = 165 \text{ vehicles}$$
$$V_{out} = 410 \text{ vehicles}$$
$$\mu_m = 400 \text{ vph}$$
$$\mu_t = 144 \text{ vph}$$
$$\mu_{wa} = \frac{245 + 165}{(245/511) + (165/144)} = 252 \text{ vph}$$

Approximation of number of exit lanes, if dedicated to one group:

$$n_m = V_m /(\text{PHF} * \mu_m) = 245/(.85 * 511) = 0.6 \text{ lanes}$$
$$n_t = V_t /(\text{PHF} * \mu_t) = 165/(.85 * 144) = 1.4 \text{ lanes}$$

Approximation of number of exit lanes, if shared:

$$n = V_{out}/(\text{PHF} * \mu_{wa}) = 410/(.85 * 252) = 1.9 \text{ lanes}$$

Therefore use 2 lanes fitted for both:

$$\lambda = V_{out}/(n * \mu_{wa}) = 410/(2 * 252) = 0.81$$

The 90% probability and average queues for multichannel conditions are:

$$q_{90} = 4.5 \text{ vehicles per lane}$$
$$\overline{q} = 1.6 \text{ vehicle per lane}$$
$$\overline{w} < \overline{q}/\mu_{wa} = 1.6/252 = 0.0063 \text{ hr} = 0.38 \text{ min} = 22.9 \text{ sec}$$
$$\text{LOS} = \text{C}$$

Level-of-service C is not acceptable. Use two cash-only lanes and one monthly lane.

$$\lambda_t = V_t/(n * \mu_t) = 165 / (144 * 2) = .57$$
$$q_{90} = 1.5 \text{ vehicles per lane}$$
$$\bar{q}_t = .4 \text{ vehicle per lane}$$
$$\bar{w}_t = \bar{q}/\mu_t = .4/144 = .0028 \text{ hr} = .167 \text{ min} = 10 \text{ sec}$$
$$\text{LOS} = \text{B}$$
$$\lambda_m = V_m/(n * \mu_m) = 245/511 = .48$$
$$q_{90} = 3 \text{ vehicles per lane}$$
$$\bar{q}_m = .5 \text{ vehicles per lane}$$
$$\bar{w}_m = \bar{q}/\mu_m = .5/511 = .0098 \text{ hr} = .059 \text{ min} = 3.5 \text{ sec}$$
$$\text{LOS} = \text{A}$$

Therefore, even though q_{90} for card lane is higher than that for the cash lane, the LOS is better for the card lane owing to faster processing.

Check to see if one lane can be reversed (inbound A.M., outbound P.M.). Morning exiting, 6:15 A.M. to 7:15 A.M.:

$$V'_m = \text{say } 50 \text{ vehicles}$$
$$V'_t = \text{say } 10 \text{ vehicles}$$
$$V'_{out} = 50 + 10 = 60 \text{ vehicles}$$
$$\mu_m = 400 \text{ vph}$$
$$\mu_t = 144 \text{ vph}$$
$$\mu_{wa} = \frac{(50 + 10)}{50/511 + 10/144} = 359 \text{ vph}$$
$$\lambda = V'_{out}/(n * \mu_{wa}) = 54/359 = 0.15$$

Queues are negligible. One lane okay in A.M.. Evening entering, 2:15 P.M. to 3:15 P.M. (does not have to be the same hour):

$$V'_m = 65 \text{ vehicles}$$
$$V'_t = 165 \text{ vehicles}$$
$$V'_{in} = 230 \text{ vehicles}$$
$$\mu_m = 300 \text{ vph}$$
$$\mu_t = 257 \text{ vph}$$
$$\mu_{wa} = \frac{(65 + 165)}{65/257 + 165/300} = 286 \text{ vph}$$
$$\lambda = V'_{out}/(n * \mu_{wa}) = 230/286 = 0.80$$

90% probability, single channel:

$$q_{90} = 9 \text{ vehicles}$$
$$\bar{q} = 3.0 \text{ vehicles}$$
$$\bar{w} < \bar{q}/\mu_{wa} = 3/286 = 0.010 \text{ hr} = 0.63 \text{ min} = 38 \text{ sec}$$
$$\text{LOS} = \text{D}$$

LOS D is not acceptable; provide two lanes in and three lanes out.

CHAPTER
4

SECURITY AND SAFETY

Mary S. Smith

4.1 INTRODUCTION

Security design in parking facilities deals with minimizing the risk of incidents that threaten the safety of parking patrons and parking attendants. Additional concerns include the protection of cars, personal property, cash receipts, and the facility itself. Psychology plays a big role in security design; a good design uses perception to influence people. Obviously, the more secure a facility appears, the more likely parkers will be to accept and use the facility. A potential wrongdoer will normally analyze the situation before committing a crime to determine the odds of being seen, and if seen, of being recognized and apprehended. He or she is less likely to commit the crime in a facility where security features are apparent.

Furthermore, courts often hold owners and operators liable for injuries suffered in criminal attacks when the defendant did not take adequate steps to reduce foreseeable risks.[1] Of course no security system guarantees safety or protection of property. There are also no hard and fast rules about what systems should be provided in specific situations. Negligence rather than omission is a key to liability. Courts will generally not find an owner or operator liable when security risks have been thoughtfully assessed and appropriate measures have been taken even if the expert witnesses disagree about what the "best" system would include.

An additional but parallel issue is that of design hazards that directly threaten the safety of the patrons of a facility without the involvement of a third party (the criminal). In some cases, an element can be a hazard to all users while in others it may be a hazard to those with underdeveloped reasoning faculties such as young children. Building and life safety codes are the general minimum standard, and if the design of an element conforms to the code in force at the time of construction, the owner is usually relieved of liability. However, the codes do not cover all the potential hazards in a facility, and they do not cover reasonably foreseeable special circumstances. For example, if a parking facility is to serve a hospital with psychiatric services, suicide prevention may need to be addressed.

The following sections discuss a variety of security and safety measures for parking facilities addressing security issues first, followed by safety concerns.

4.2 SECURITY DESIGN ISSUES

4.2.1 Crime in Parking Facilities

Parking facilities are at somewhat higher risk of crime—both violent and property—than many other *land uses*. In 1992, parking facilities were the third most frequent place of occurrence for violent crime (rape, robbery, assault), with approximately 1400 per day, accounting for 8.5% of those crimes.[2] However, it is important to note that the most frequent location for a violent crime is at, in, or near one's own residence or a friend's residence. Indeed, the number of violent crimes occurring at or near residences was three times the number in parking facilities. Car thefts were also more likely to occur at residences, with 50% of all car thefts and 46% of larcenies occurring near one's own or a friend's home. Parking facilities accounted for little more than one third of all car thefts, and less than 20% of all larcenies (not involving victim-offender contact.)

The statistics regarding crime must also be put into proper perspective. While there are no statistics available on either the total number of parking facilities or the total number of parking spaces in the United States, it is clear that the number is very large. According to 1990 census data,[3] there are 115 million working adults in the U.S.; 88% of the population uses a personal vehicle to travel to work, and the additional 5% who use *transit* drive and park in a commuter or *intermodal* parking facility. Based on those numbers, it is estimated that 75 million parking spaces are provided for workplace or commuter parking. Add to this all the customer and visitor parking spaces, and it is clear that there must be in excess of 100 million nonresidential parking spaces in the U.S. When you compare 1400 violent crimes per day with 100 million parking spaces, and the fact that a disproportionate number of such crimes occur at night, it is obvious that the risk of being attacked, in general, is relatively low. Statistically, therefore, one is not very likely to become a victim of a violent crime in a parking facility.

Still, it is clear that violent crimes are more likely to occur in a parking facility than in the land use that generates the need for the parking facility. Why are parking facilities at higher risk than other facilities (except residential)? Parking facilities comprise a relatively large volume of space with relatively low activity levels. It is interesting to note that most land uses have more square footage devoted to parking than to the use itself. For example, a 1,000,000 sq ft shopping center will probably have 1,500,000 sq ft of parking. More than 10,000 people may be at the mall at the *peak hour* on a busy Christmas shopping day; however, only a very small fraction will be in the parking lot—which is 1.5 times as large as the mall itself—at any one time.

Other features that are simply inherent to parking facilities make security—perceived or real—difficult, including:

- parked cars provide hiding places and impede distribution of lighting
- sloping ramps, which are necessary to provide *floor-to-floor* circulation, impede *visibility* across the facility
- most parking facilities are necessarily open to the public
- there is an "ideal" mode of escape—the private vehicle

The perception of a high risk of crime in parking facilities is not helped by the media. TV shows and films often feature chase/bombing/attack scenes set in parking facilities. Although attacks at the victim's home are even more frequently shown, we all rationalize that it wouldn't have happened in our neighborhood. Thus we are all left with the impression that parking facilities are high crime areas.

Even press coverage of actual incidents adds to the problem. In several cities, a frightening murder in a parking facility was given front-page coverage, as was the local official's response (blue-ribbon commissions, hearings, and even legislation to mandate security in parking facilities). However, when the suspect turned out to be known to the victim—spouse/friend/family—it was no longer front-page news. Interestingly, according to USDOJ,[2] about 20% of violent crimes in parking facilities were committed by persons known to the victim.

Thus, the general public is left with the impression that parking facilities are high crime areas, even though the statistics prove that both violent and property crimes are much more likely to occur at home.

4.2.2 The Security Audit

The selection of the appropriate security features depends on the history of incidents in the area of the facility, and the likelihood of different incident types occurring in various locations within the facility. The neighborhood in which the facility is located will usually have the greatest impact on the degree of potential risk.

The higher the general level of crime in a neighborhood, the higher the risk for incidents in a facility. The process of assessing the risk is called the *security audit.* The first step in a security audit is an analysis of the risk of different incident types. If there is an on-site security staff, obtain the annual incident reports for the previous five years and data on any personal injury incidents prior to that. Develop an incident history and profile for the neighborhood by contacting the local police and the operators of nearby facilities. Using this information, classify the facility as one of the following:

- **Low-risk** facilities are those with only minor vandalism and juvenile theft problems but no personal injury incidents and no professional theft activity.
- **Moderate-risk** facilities are those where there may be an occasional suspicious person or vehicle theft in off-hours but there is no reason to anticipate personal injury attacks.
- **High-risk** facilities are those with previous incidents of personal injury or a pattern of thefts that might escalate to personal injury.

The second step of the security audit is an evaluation of the design features and constraints of the facility that impact security, either positively or negatively. In an existing facility one can walk the facility to identify problem areas in the security program. In a new facility, however, visualizing a "walk through" of the facility is necessary to assess the strengths and weaknesses in the design.

Two types of security measures, *passive security* and *active security,* are employed to maximize security in a parking facility. Passive security measures are a physical part of the facility, such as lighting and glass-walled elevators and stair towers. The common thread among all passive features is visibility—the ability to see and be seen while in a parking facility.

Active security measures invoke an active response by the management and/or employees of the facility. Examples of these measures include active security patrols and monitored *closed circuit television*

TABLE 4-1. Guidelines for Relating Design Features to Risk Levels

Risk Level	Passive Features	Active Features
Low	As many as possible	For patron perception, not prevention
Moderate	High priority in overall design	To correct defects in passive systems
High	Highest priority in overall design	Comprehensive program including CCTV, patrols, etc.

(CCTV) systems. Active systems are often needed to solve problems created by constraints on the passive security features. For example, some building codes require enclosing exit stairs with little or no glass. This requirement creates a closed space with little or no pedestrian activity. In short, there is no visibility. Active systems such as intercoms and/or CCTV may then be needed. Eliminating the enclosure is really the better solution, because the threat to life safety by attack is far greater than by fire in a parking facility. For this reason, some codes have been changed to reduce the enclosure requirements for open parking facilities. Local officials may also be receptive to modifications and/or variances when security risks are obviously greater than fire risks.

General guidelines for correlating risk levels with the need for passive and active systems are enumerated in Table 4-1. As the risk level increases, the priority of passive features in the overall design should increase. Passive features are still "good" design features in low-risk facilities, if only to add to patron comfort. Furthermore, retrofitting passive features is often expensive and sometimes impossible. Labor-intensive active systems may then be necessary. Therefore, many passive security features can and should be provided in parking facilities of all risk levels.

Active systems are generally not necessary in low-risk facilities but may be provided for patron perception and comfort rather than prevention of incidents. If not provided initially, plan for later installation of additional security systems in case circumstances change, and the facility moves to a higher risk level. Providing conduit in initial construction for future CCTV, for example, can be relatively economical.

The security audit will highlight the most likely locations for problems in moderate- and high-risk situations and will guide the selection of active systems. In a moderate-risk facility, there may be higher-risk locations, such as an enclosed stair. Active systems are generally provided only in these specific locations. In high-risk facilities a comprehensive security program is necessary to achieve a reasonable level of security.

Figure 4-1. Visibility and lighting are two keys to passive security. Photo courtesy Walker Parking Consultants.

The owner and/or operator of the parking facility must be integrally involved in the design of security systems. Owners and operators are in the best position to determine how many dollars can reasonably be spent on security systems. They should be very concerned with the cost-effectiveness of the expenditures, both from capital and life cycle perspectives. In a life cycle analysis, don't forget to include the impact of good security design on liability insurance premiums. In the end, the owner/operator will carry the lion's share of the liability for an attack. Therefore the owner/operator, rather than the architect, engineer, or parking consultant, must make the final decisions on security features and resolve conflicts between security planning and architectural, structural, or other design considerations.

4.2.3 Structural Design

During the design process the structural system of the facility must be evaluated from the security aspect as well as the engineering aspect. *Long-span* construction and high ceilings create an effect of openness and aid in lighting the facility (see Figure 4-1). *Shear walls* should be avoided, especially near *turning bays* and pedestrian travel paths. Large openings in shear walls can help to improve visibility. When vision obstructions are unavoidable, strategically placed mirrors will allow patrons to see around corners where potential attackers may be hiding. Mirrors are a last resort, however, because they can be broken or stolen and not be in place when needed.

4.2.4 Lighting

Lighting is universally considered to be the most important security feature in a parking facility. Good lighting deters crime and presents a more secure atmosphere to parkers. Because lighting is so critical to good parking structure design, a separate chapter has been devoted to its design. (See Chapter 5.)

4.2.5 Stair Towers and Elevators

Rule number 1 in security is to design stair towers and elevator lobbies as open as code permits. The "ideal" solution is a stair and/or elevator waiting area totally open to the exterior and/or the parking areas. If a stair must be enclosed for code or weather protection purposes, glass walls will deter the incidence of both personal injury attacks and various types of vandalism. Elevator cabs should have "glass backs" whenever possible (see Figure 4-2). Elevator lobbies should be well lighted and visible to the public using the facility and/or street. Try to get the local code personnel to approve an automatic fire door or, for a larger opening, a rolling fire shutter with an access door, so that the area is wide open during normal use. The door or the shutter will be closed by a smoke detector instead of a fire-rated door that remains closed all the time.

Also, eliminate nooks and crannies, and close off potential hiding places below stairs.

4.2.6 Restrooms

Parking owners, operators, and consultants all agree that public restrooms in a parking facility are nothing but nuisances. A restroom may also be a security trouble spot because use is infrequent and places of concealment abound. Public restrooms should therefore be provided at the destination itself (office building, shopping center, etc.), where there will be more use and activity. If provided in a parking facility, design restrooms with "maze" entrances instead of outer/inner door arrangements that could trap a victim.[4]

4.2.7 Perimeter Security

Locate any attended booth or office in such a way that activity at pedestrian and vehicular entry points to the facility can be monitored. Likewise, locate a security station, if provided, where it is visible to the public. Provide security screening or fencing at points of low activity

Figure 4-2. Glassback elevators and glass walls in stair towers provide visibility when these spaces must be enclosed. Photo courtesy Walker Parking Consultants.

to discourage anyone from entering the facility on foot (see Figure 4-3). Motion or infrared beam sensors can be used to maintain openness yet alert management to unauthorized pedestrian intrusion. In high-risk cases, design a system of fencing, grilles, doors, etc., to completely close down the entire facility in unattended hours. Any ground-level pedestrian exits that open into nonsecure areas should be emergency exits only and fitted with panic bar hardware for exiting movement only. Consider installing local alarms that activate if a ground-level door is opened. It is very desirable to consider the future implementation of perimeter security controls in the initial design stage, in case the facility's risk level should change.

Figure 4-3. Security screening can be unobtrusive but provide control of the facility perimeter. Photo courtesy Walker Parking Consultants.

4.2.8 Landscaping/Maintenance

Landscaping should be done judiciously so as not to provide hiding places. It is desirable to hold plantings away from the facility to permit observation of intruders. Pruning and trimming shrubbery are equally important. General maintenance and upkeep are of utmost importance in the overall security program. Trash, beer cans, graffiti, etc., may leave the impression that the facility is not policed or managed well.

4.2.9 Signs and Graphics

Careful design and placement of the general *signs* and *graphics* can eliminate confusion and delays for the patron. Help the patron get to his or her destination quickly and efficiently, thereby minimizing the time for an incident. Color coding and/or unique memory aids can help patrons locate the parked vehicle quickly upon returning to the facility. Signs and graphics can also assure the user that his or her safety is being monitored. Likewise, a likely perpetrator may be deterred by a notice that he is under surveillance. A disclaimer of liability for valuables and property left in vehicles should be located at or near the entrance.

It is critical for an owner/operator to back up any claims of security on signage with the services promised. If a sign says that conversations may be monitored for security, a person must be able to monitor the system, at least during higher-risk hours. The latter usually occur at night, when activity is lower but the facility is still open.

4.2.10 Cash Security

A number of important security features help to protect the cash receipts of the facility and relieve the attendant of the accompanying responsibility and holdup hazards.[5] A *drop safe* is most important since it makes the cash unavailable to the potential robber. Second, in moderate- to high-risk facilities, post a sign at the cashier booth(s) stating that all cash is deposited in a safe and the cashier has minimal change on hand.

In high-risk situations, install *duress alarms* that sound at the police station and/or the security office. Duress alarms can be an unmarked key on the *fee computer*, or a foot-operated device. Dollar bill alarm activators that are triggered by removal of all bills in a compartment of the cash drawer can also be useful in this application. Cash receipts should be removed on a regular basis, preventing the accumulation of large amounts of cash.

For liability control purposes, cash security should not be emphasized more than patron security.

4.2.11 Security Personnel

The visible presence of uniformed security officers is one of the best preventions of crime and should be considered in high-risk facilities. Keep patrols unscheduled and vary the routes taken throughout the shift. In very high risk situations, check-in stations should be provided at key locations to monitor and record the frequency of patrols. Medical certification training for security personnel is also highly recommended, particularly CPR and Advanced First Aid Training. Conversely, security patrols can only be in one place at a time, and can pass by a vehicle in which an assault is taking place and not be aware of it.[6]

All personnel charged with any security responsibility must be trained to monitor, operate, and respond to all security equipment provided in the facility, no matter what the risk level.

4.2.12 Emergency Communication

Alarm systems of this type come in many forms: *panic buttons, emergency telephones, two-way intercoms*, and *two-way radio.* Panic buttons are often located in elevators, lobbies, and stairs, and occasionally in parking areas. However, their use is dependent on the victim of the attack reaching the button and sounding the alarm. Panic buttons also seem to be irresistible to pranksters. A "cry wolf" syndrome can develop among those monitoring the system. Intercoms are often added to allow the attendant and the individual to communicate. *Emergency telephones* make it even more difficult to sound an alarm and are more expensive to install and maintain in working order. Emergency communications are therefore not a complete solution in high-risk facilities.

On the other hand, intercoms used together with panic buttons, motion and/or sound surveillance, or CCTV can be very practical security features. CCTV coverage of the area around a panic button discourages false alarms. Two-way intercoms make it possible to zero in on an incident and communicate to the victim that help is on the way, possibly deterring the criminal. *Voice-activated* intercoms with panic buttons should be installed in all elevator cabs and partially or fully enclosed stairwells. In high-risk facilities, intercoms with panic buttons and lighted "emergency aid" signs may be installed as frequently as every 100 to 150 ft in parking areas. Blue lights with strobe effects have become common accessory to such units (see Figure 4-4). Standard voice-activated systems are generally not practical in parking areas because of background noise (vehicles driving by, honking horns, etc.). Intercoms should also be installed in all cashier booths, and at remote entrance/exit lanes. Connect all intercom stations to a master at the nearest point of observation with provision to switch to a manned security office or police station during unstaffed hours.

4.2.13 Closed Circuit Television Systems

CCTV can provide any level of surveillance an owner wishes to provide. However, for CCTV to be an effective component of the overall security plan, it is important to recognize the inherent strengths and weaknesses of CCTV systems. While CCTV will not be able to replace all security personnel, it will frequently permit a reduction in, and provide invaluable support to, the security force.

CCTV monitoring can be very effective both to deter and to detect incidents in progress in the enclosed areas (such as stair towers), which are historically at highest risk for incidents. Parking areas may also be

Figure 4-4. Emergency communication stations now come equipped with blue strobe lights. Photo courtesy Code Blue Corporation.

monitored by CCTV in high-risk facilities. However, the difficulty of positioning cameras to cover all areas fully, lighting shades and shadows, external light sources, vehicles, and sloping floors all restrict the ability to monitor activity in parking areas by a CCTV system. Even with a state-of-the-art system, only a certain proportion of the incidents in a high-risk facility may be first detected on the CCTV system. A recent advancement is a CCTV camera mounted in a protective enclosure that travels a track through parking areas (see Figures 4-5 and 4-6). This allows the camera to view between cars and provide much greater coverage. Initial reports indicate that coverage is greatly improved at lower cost than with typical systems with stationary or pan/tilt cameras in parking areas. The cameras can perform random patrols and respond to activation of motion detectors or emergency aid stations.

Figure 4-5. CCTV cameras ride along track to improve coverage of parking area. Photo courtesy Video Sentry, Inc.

Relying on CCTV to eliminate all patrols when inadequately covered areas remain will invite greater liability problems than not providing CCTV at all. In fact, CCTV is best used in combination with other systems to support security personnel. When a report of a suspicious person or incident or a door alarm is received, the person monitoring the CCTV screen searches for the current location of the individual and directs the responding officer to the scene. If the CCTV operator sees an incident involving a personal-injury attack in progress, the intercom system is used to ward off the offender and let the victim know that help is on the way. The officer continues to monitor the moves of the suspect to assist security or police in apprehension. CCTV can also be useful in apprehension and conviction following an incident by providing an accurate description of a vehicle or suspect. Using a videotape of an incident for apprehension and conviction will in turn convince habitual criminals to choose another facility for their nefarious activities.

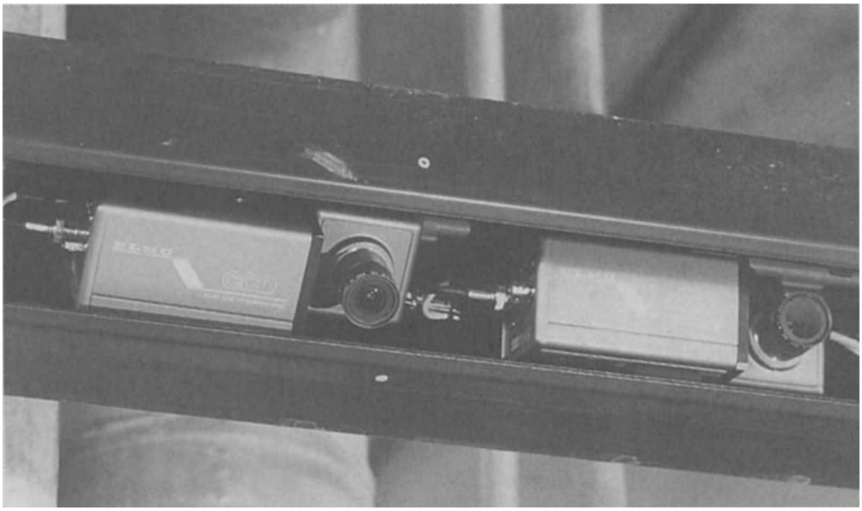

Figure 4-6. Two cameras are mounted in each unit to allow multiple angles of coverage. Photo courtesy Video Sentry, Inc.

Often, several well-equipped cameras strategically located will enhance security system efficiency. Therefore emphasis should be placed on location of cameras and acquiring good capabilities—i.e., adequate light levels, *pan and tilt*, *zoom*, etc.

The environment in which the CCTV system is placed must be considered.[7] Two basic types of housings are available. The traditional rectangular housing covers only the camera and lens. Domed, circular units cover and protect the entire assembly. Both are available in models for indoor and outdoor use and can be used with a pan-and-tilt mechanism. One advantage of the domed unit is that all camera parts including the pan-and-tilt mechanism are enclosed and protected from the elements and vandalism. The domed units are discreet and the patron may not realize that a camera is present. Conversely, the rectangular housings covering only the camera and lens "hold no secrets."

Remote positioning devices or controls allow the attendant to adjust a pan-and-tilt or zoom lens on a camera from the monitoring station.

A multicamera system may require a video *switcher,* which allows the operator to select the scene from any one camera and display it on the monitor. The switcher may also change from camera to camera at predetermined intervals, saving money since it allows one monitor to service multiple cameras. The switcher also makes the system more manageable for the observer.

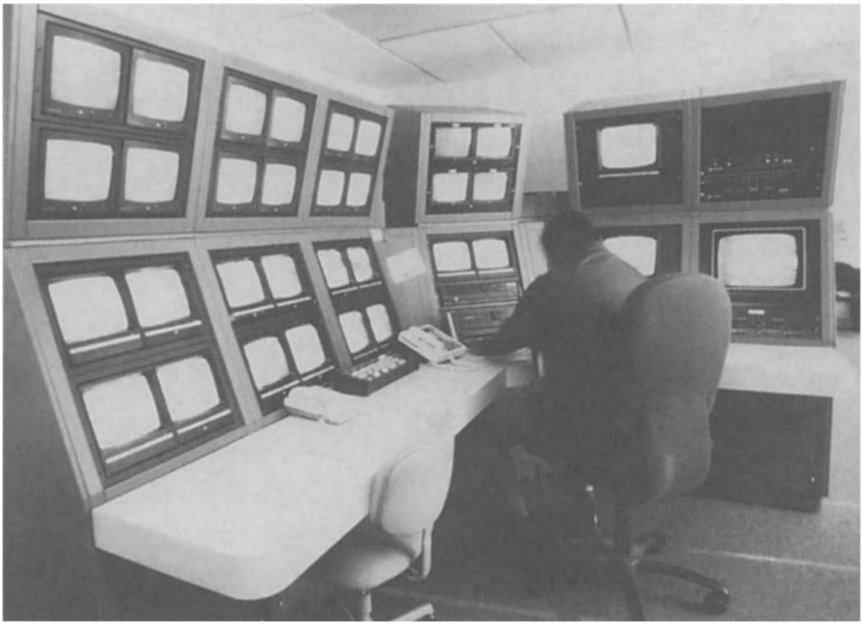

Figure 4-7. A console for monitoring CCTV coverage. Photo courtesy Duke University Medical Center.

Motion detectors and alarm-activated devices may likewise be cost-effective, as areas without activity are neither displayed nor recorded on tape. A panel design might provide several smaller monitors that switch automatically from camera to camera, and one large monitor that the operator can switch to a particular camera. A developing situation can then be observed in greater detail.

The video recorder (VCR) is an important part of the system as it allows the attendant to pinpoint when an incident occurred. The VCR generally records whatever is displayed on the monitors. For example, following a car theft the tapes may show that the car was stolen from the parking space between 11:30 and 11:32 P.M. By reviewing the activity at that camera or other cameras at that time, a description of a suspect can be provided to the police. Following an arrest, the tapes can help get a conviction.

The central CCTV monitoring station, including the operator watching the monitors, should be visible to the parking patrons (see Figure 4-7). It may not be necessary to station an operator at the monitors during hours of relatively low risk, such as the typical daytime activity hours. However, dummy or completely unmonitored systems should never be used. Also, CCTV systems require constant maintenance and upkeep to maintain picture quality. A decision to install CCTV should include an ongoing budgetary commitment to maintain the system and replace parts as they wear.

4.2.14 Security Management

Planning for security in the design and operation of the facility is not enough. If active systems are provided, they *must* be monitored by trained personnel. Policy standards to handle all situations must be established in writing and must be adhered to.

Although booth attendants are not usually security personnel, proper training of these individuals can significantly enhance the security program. Emphasis should be placed on being another set of eyes for security and reporting suspicious activity immediately. Booth attendants should concentrate on developing a good physical description of suspicious persons or an attacker if a crime is observed. Also, all booth attendants should be instructed what to do should a holdup or other crime occur.

A checklist for all security equipment and practices should be developed and regularly completed and filed. Records of incidents should be cataloged by type (vandalism, juvenile theft, rape, etc.), and an annual report should be prepared. While these issues are beyond the scope of the design of a new parking facility, owners/operators must be aware that good professional security management and documentation are one of the best defenses against liability clams. With a high-risk facility, if the owner/operator does not have professional security staff, a security management consultant should be retained to develop policy and training manuals.

4.3 SAFETY CONSIDERATIONS

As noted in the introduction to this chapter, design hazards can create as great (if not greater) liability problems as attacks by a third party. The increasing tendency to sue for damages over what used to be accepted as an accident has begun to change some design philosophies. In many cases, the patron's own actions, such as drinking alcohol, substantially contribute to an accident in a design that meets all codes and standard practices in the industry. Even so, a jury may hold a facility owner liable because of the perception of the insurance company's "deep pockets." Insurance companies, however, pass these costs on to policyholders in the form of increased premiums.

At the same time, it is important to weigh the possibility of an accident occurring with other important life-safety considerations, such as durability, structural integrity, and fire safety. Some features that enhance security also enhance safety, such as lighting, visibility, and openness. Also, good maintenance is critical—it will return sustained yields on the investment in good design. The following pages discuss some of the most common safety design errors in parking facilities.

4.3.1 Tripping and Slipping

Ice (in snow belt areas) is one of the most frequent causes of falls in a parking facility. Good drainage design is the first line of defense. Some areas of icing may not be preventable. The most common one occurs at covered/uncovered ramp junctures. First the sun melts the ice on the uncovered sections. The water then runs down onto the covered section and refreezes. Floor drains can help, but the water tends to run in a sheet across the floor, so that it freezes before it gets to the drain. The owner must be vigilant and monitor and sand all icing spots as they occur.

A slick floor is another potential hazard, especially in a sloping ramp facility. The skilled concrete finisher may take pride in creating a perfectly smooth floor, but it belongs in an industrial plant, not a parking facility. A broom or swirl finish provides both good traction and a durable floor surface.

A roughened surface should be carried into the stair/elevator tower, because snow and rain are often tracked in and may cause slippery spots, especially in unheated towers. *Rubber stud flooring* can be applied to lobbies to correct this problem. *Abrasive nosings* are also desirable on stair treads. Wherever possible the cast-in-type strips should be used rather than pressure-applied strips, which are less durable.

Expansion joints must be carefully designed, and installation coordinated with temperature conditions, if possible, to minimize bubbling, buckling, and other tripping hazards. Good maintenance of expansion joints, and replacement of broken or missing drain grates are equally important.

Liability concerns have made it important to eliminate curbs and wheel stops in areas where pedestrians are likely to be present. When adjacent bays are "level" (sloped for drainage, of course), pedestrians are likely to cut across the structure between cars. The cars necessarily create shadows, and a curb or wheel stop then becomes a potential tripping hazard.

Curbs may still be appropriate in certain situations. Pedestrians very rarely walk to the perimeter of a facility merely to look at the surrounding area. Conversely, the durability and structural integrity of the structure can be greatly enhanced by employing a curb to cover connections between exterior panels and floor slabs. Curbs are also desirable at parking equipment islands. Tripping hazards in these areas are generally reduced to a minimum level by the high level of lighting otherwise necessary. Painting the faces and edges of curbs can further reduce the hazard.

4.3.2 Head Knockers and Other Projectiles

Most codes prescribe minimum *overhead clearances* for pedestrians and vehicles. These standards should be adhered to, even in isolated areas. Whenever substandard (with respect to the code) clearance exists, the international "hazard" symbol (alternating diagonal bars of yellow and black) and a notice of clearance should be affixed to the obstruction, even if it is not intended that pedestrians or vehicles pass underneath. Watch especially for reduced clearance at curbs.

Another "head knocker" problem occurs all too frequently when patrons walk down parking control equipment lanes and are struck by descending gate arms. Sidewalks should always be provided with groups of entry/exit lanes, and should be well marked as available. "No Pedestrians" messages, perhaps using international symbols, may also be added to entry/exit lane signage.

Clearance bars at all entrances stating the minimum *vehicular clearance* have become a standard in the industry. It is not recommended, however, that a fixed, heavy obstruction be employed. In one reported case, a cashier was knocked unconscious by a falling clearance bar while making a tour of the facility at closing time. He was found, still unconscious, more than 30 minutes later. Luckily the person who found him was honest and summoned help rather than leaving him there and absconding with the day's receipts. In other cases, a main beam has been deliberately designed at the posted clearance height to keep oversize vehicles out. This tactic not only raises patron tempers, but also does not eliminate liability if inadequate advance warning is shown to exist. Most parking consultants now use a long, large-diameter (10″) PVC tube hung from chains for a clearance bar at each and every entrance lane. This tube provides a certain stiffness and creates sufficient noise when hit minimizing damage to vehicles or pedestrians. See Chapter 6 for a suggested detail.

Other devices may become projectiles. Sand-filled oil barrels are commonly used as inexpensive traffic control devices. However, if knocked over, these drums will roll down a sloped parking ramp with substantial speed and momentum. Some manufacturers make flat-sided, plastic barrels striped with reflective sheeting for high visibility. Ballast in the form of sand bags can be added as required to keep the barrel in the desired location.

An error commonly made in parking facilities is designing stair towers with doors that swing into drive aisles. One solution, of course, is to eliminate the door, which also enhances security. When doors are required, a careful design can achieve both vision to the aisle and a protected area to open the tower door. A similar problem occasionally occurs when elevator waiting areas are located too near driving aisles. When available dimensions are simply too restricted, pedestrian traffic diverters, perhaps in an "S" pattern, can be used to force the pedestrian to pay attention.

4.3.3 Vehicular and Pedestrian Barriers

In recent years, many building codes have begun to address the issue of preventing out-of-control vehicles from breaking through exterior and interior railings at areas of grade separation. There is, however, no uniformity among standards. The Parking Consultants Council, National Parking Association (PPC, NPA)[8] recommends the following:

> Vehicle restraints should be placed at the perimeter of the structure and where there is a difference in floor elevation of greater than 1 ft.
>
> Vehicle restraint systems should be not be less than 2 ft in height and should be designed for a single horizontal ultimate load of 10,000 lb applied at a height of 18″ above the floor at any point along the structure.
>
> Openings in railings or spacing of components should conform to other sections of the local governing code. If vehicle restraints and handrails are used, no other barriers such as wheel stops or curbs should be necessary.

We recommend that the NPA standard be followed except when the locally adopted code has a higher standard. Unfortunately some codes have well-intended but misguided standards. One state requires an 8″ wheel stop at every parking stall. This not only creates maintenance and tripping problems, but also causes damage to vehicles since many cars have clearance less than 8″ under the front bumper. Some codes specify that the barrier must stop a vehicle moving at a specific speed.

To calculate the force applied to the barrier, which is necessary for design, one must use an energy equation which requires assumptions that 99% of all designers are not qualified to make. Some discussion with local code officials regarding the standard may be required.

Another need for vehicle restraint occurs at entry/exit locations. Inadequate design for turning movements threatens not only the parking control equipment but also a cashier in a booth. The most frequent problem is not providing enough space for turning into the lane and getting aligned properly before reaching the ticket dispenser or card reader.

It is considered good practice to provide a concrete-filled steel post, solidly anchored in the curb, at each piece of parking equipment. Casting a pipe sleeve in the curb facilitates replacing the post, should it be damaged. One word of warning: check for all possible angles of approach. For example, vehicles backing out of nearby stalls can hit the gate from the back side of an island.

In recent years, life safety and/or building codes have been substantially tightened to require handrails at a spacing no greater than 4″. This standard is designed to prevent a toddler from not only going through between the rails, but also from getting his or her head stuck. A facility designed under prior standard (generally, 9″ or 6″ spacing) will usually not have any liability to upgrade to the current code. However, an unsafe condition that is clearly apparent should be corrected.

Codes are often unclear regarding what degree of grade separation requires a handrail. The gray area tends to be that between normal curb height and a differential in grade of 18″. Good professional judgment should be exercised in this area. A handrail should always be provided if there is any possibility of a severe, life-threatening injury.

Codes also prescribe a minimum height of railing. Courts have tended to hold owners to literal compliance with the code; that is, if the handrail is even half an inch low, the owner is liable for an accident. Therefore handrail heights should be very carefully designed for some of the conditions common only to parking facilities such as sloping, *cambered*, and warped floor areas, etc. Attention to minor details such as these will minimize liability for the owner.

4.3.4 Vehicular/Pedestrian Conflicts

Vehicular/pedestrian conflicts are inherent in parking facilities. Thoughtful design, however, can minimize owner/operator/designer exposure to liability. Pedestrians have a tendency to take the shortest possible route rather than a designated pedestrian walkway, especially when a nondesignated route is encountered first. For example, some people will always walk down the middle of a gated entrance/exit lane instead of crossing to the far side of the lane grouping and using the sidewalk provided as recommended. If a sidewalk is provided and clearly visible and/or marked for the user, a court will consider the patron to have used the driving lane at his or her own risk. Beware, however, of designs that expect a pedestrian to take an unnecessarily long route.

4.4 SUMMARY

The key to good security is visibility. Passive security features should be a high priority in virtually all parking facility designs because:

- good passive design maximizes visibility at the lowest possible cost
- circumstances and risk levels change
- retrofitting is very expensive if not impossible
- labor- and equipment-intensive active systems are generally needed because of shortcomings in passive security features.

Progressive reaction to incidents or changes in the risk level, such as adding access control, CCTV, or active patrols, will greatly reduce the potential for crime and the liability should a criminal act occur.

As evidenced by the interest and attendance in security sessions at the conventions of various parking groups, security is one of the biggest problems in the industry today. Security is an ongoing process that good design alone will not achieve. Training and management of security forces by a security professional are equally important. A comprehensive security program will provide the owner and parking patron with a secure and safe parking facility in all but the most high risk situations.

Governing codes do not provide a complete guide for avoiding safety hazards, because of the unique characteristics of a parking facility. Personal injuries due to tripping, "head knockers," and lack of consideration of other hazards in the pedestrian's path of travel generate surprisingly large awards in suits against parking facility owners and operators. Experience in parking facility design and attention to details will minimize the risk of safety hazards, reducing liability exposure to a minimum level.

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CHAPTER
5

LIGHTING

Mary S. Smith

Lighting is one of the most critical elements of parking structure design. Lighting is required for the perception of fixed objects, vehicles, and pedestrians. In many ways, good lighting is more critical in parking facilities than in other building types. Vehicles and pedestrians frequently occupy the same space; pedestrians may step out into driving aisles from between parked cars. Drivers must be more alert to potential hazards, with less time to see, recognize, and react to objects entering the *field of vision* than is necessary for pedestrians. As discussed in the previous chapter, parking facilities are at somewhat higher risk of violent crime than all other *land uses* except residential. Lighting is not only the most critical element in preventing crime, it is also a major contributor to the user's perception of security and safety.

The Illuminating Engineers Society of North America (IESNA) publications are generally recognized as the standard for lighting design. The Subcommittee on Off-Roadway Facilities of the IESNA Roadway Lighting Committee is charged with setting standards for lighting of parking facilities, both surface and structured. The current standard *Recommended Practice RP-20, Lighting for Parking Facilities*[1] was published in 1984 and its guidelines were included in the eighth edition of the IESNA *Lighting Handbook.*[2]

As in other chapters, the actual and complete design methodology is not presented; rather the focus of this text is on the adaptation and application of standard engineering approaches for the specific needs of a parking structure. Concepts and critical issues are discussed so that all team members can be satisfied that the lighting design is state of the art and meets owner and user requirements.

5.1 BASIC LIGHTING CHARACTERISTICS

To comprehend the issues involved in the selection of lamps and fixtures for a parking facility, one must first have an understanding of three fundamental characteristics of lighting systems: illuminance, color, and glare.

5.1.1 Illuminance

Light is radiant energy propagated in the form of electromagnetic waves. The human eye is sensitive to electromagnetic waves in the *visible spectrum* which ranges from violet and blue light at the shortest wavelengths to orange and red at the longest. Ultraviolet light is just outside the spectrum at one end; infrared outside at the other.

Luminance is the emission or reflection of light from an object, such as a lamp. The *lumen* measures the total light-producing output from a source, such as a lamp. *Illuminance* is the intensity of light falling on a surface or plane, measured in footcandles (English units) or lux (metric units.) One footcandle is equal to 1 lumen per square foot; 1 lux is equal to 1 lumen per square meter. One footcandle is equal to 10.76 lux. On a clear June day, there may be as many as 10,000 fc, while only 400 fc may exist on a cloudy December day.[3] On a clear moonlit night, the earth's surface is illuminated with less than 0.02 fc. Although that is not sufficient to read by, it is certainly adequate for walking and enjoying the stars.

Illuminance levels will be different not only on planes that are at differing distances from the light source, but also at differing angles. If you hold a light meter in your hand horizontally, it may give a different reading than if you hold it vertically at the same location. While lighting of parking facilities has generally been predicated on the illuminance of the pavement, which is primarily a horizontal plane, an equally important consideration is the illuminance of vertical planes, such as signs, structural elements, cars, and people.

Reflectance is the bouncing of light off a surface. If you hold a light meter horizontally and face up just above the pavement, it will measure illuminance at that level. However, if you hold the meter face down a few inches off the floor, it will measure reflected light. The ratio of these two measurements is the reflectance of the pavement. The total amount of illuminance at a point is a function of both direct light and reflected light from virtually all the surfaces present in a space. Reflectance can add to both the horizontal and vertical illuminance, depending on the angles of incidence and reflectance off the surface.

5.1.2 Color

The perception of color is a dynamic process, relying on both physical and psychological properties.[3] Colors are differentiated by the wavelengths of the light from the source or as absorbed/reflected off a surface.

Visible light is recognized by the human eye as white light, but is actually the combination of all colors of the visible spectrum. Yellow light is more narrowly composed. As you probably learned in kindergarten, any color can be duplicated by mixing varying quantities of the three primary colors: red, blue, and yellow. The same phenomenon occurs with light. White light can be simulated by combining two complementary colors.

The color of an object is determined by what wavelengths are absorbed by the object and what wavelengths are reflected. White surfaces reflect all wavelengths; black surfaces absorb all light. The "real" color or hue is affected by both the color of the object and the color of the light source. Each individual further has his or her own unique color perception or memory. Factors such as the surrounding colors, what the eye expects to see, and what the eye wants to see all affect the perception of color.[3] A red apple held under a blue-green light will be a different color from one held under an orange-yellow one, but it will still be perceived as red.

Color also affects the perception of the intensity of light. Given the same power or output at each wavelength of color, the eye senses the middle of the visible spectrum, or the yellow-green region, as the brightest and the ends of the spectrum, the red-orange and indigo-violet as the darkest. A white light is perceived to be brighter than a yellow-orange one of the same lumen output.[3]

5.1.3 Glare

Glare is an excessive amount of light reaching the eye in contrast to the amount of light to which the eye was previously adapted. Glare is categorized in two ways: discomfort and disability.[4] In the former case, there is discomfort but the ability to see is retained. An example of discomfort glare is squinting your eyes on a bright sunny day, when ambient illuminance may be 10,000 footcandles. Disability glare occurs when the ability to see and function is affected, such as the temporary blindness that occurs after passing an oncoming car with its high beams on.

There are actually two types of glare. The first is direct glare, which is excessive light from the source directly entering the eye; the second is reflected glare.[3] In some cases, both types of glare are present. Direct glare is controllable by either blocking or deflecting the ray that would otherwise travel a direct line from the lamp to the eye. Reflected glare is more difficult to control because it has more factors affecting it and it is impossible to control all angles of reflection. Reflected glare can be minimized by avoiding glossy surfaces on walls, signs, or objects. Flat paints are recommended versus glossy paints.

Various factors affect the point at which glare passes from a discomfort into a disability. Glare is more of a problem for senior citizens and others whose vision may be impaired. Part of the reason that glare from headlights becomes a disability is the inability of the eye to adjust immediately to different light levels. Glare can also be a problem when it reduces the contrast between an object and its surroundings.[5] For example, glare from lamps or headlights on reflective signs can blank out the message. Other factors are the size of the object and the brightness of its surroundings. The perception of brightness is a function of both intensity and size. A larger object of the same intensity will appear to be brighter than a smaller object. However, a smaller object is more likely to produce glare.

Because it is impossible to control all angles of light refraction and reflection, it is impossible to totally eliminate glare. However, it can be minimized by careful selection and positioning of fixtures.

5.2 LIGHTING DESIGN ISSUES

Issues that must be addressed in lighting design include selection of the lamp or light source, selection of the fixture and placement of the fixture. Before those issues can be resolved, however, one must set the design requirements for level of illumination.

5.2.1 Minimum Illumination Levels

The two primary issues in illumination levels are the intensity, or footcandles, and the uniformity. According to colleague Don Monahan,[6]

> A minimum of 1 footcandle is necessary for the average driver or pedestrian to perceive objects and physical deviations in the driving or walking surface. A higher illuminance (minimum of 2 fc) is required for recognition of details such as overhead signage. Higher illuminance is also required for drivers versus pedestrians because of the faster rate of travel. . . .

Because parking structure lighting requires relatively high intensity fixtures, there is often a problem with "hot spots" and dark areas. Passing from light to dark to light areas creates problems because of the eye's

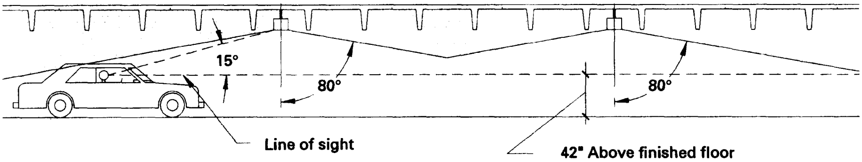

Figure 5-1. Defining the visual field.

inability to adjust, as previously mentioned (see Figure 5-1). The inherent shades and shadows created by parked vehicles also make it imperative to get light into the parking stall areas rather than just driving aisles. The *uniformity ratio* of average to minimum footcandles is thus a prime consideration (see Figure 5-2).

Illuminance on a horizontal plane is typically calculated at many closely spaced points in a representative area of at least six light fixtures. Because the output of a lamp declines over its lifetime and is also

Figure 5-2. Uniformity of illuminance is critical to parking structure lighting. Photo courtesy Quality Lighting, Inc.

affected by the accumulation of dirt and other factors, IESNA[1] recommends that the "average maintained illuminance" levels be calculated at the end of the expected life based on the relamping program to be used. Although manufacturers recommend group relamping at 70% of the rated life, in practice this rarely happens. Lamps are replaced when they burn out, which means that light depreciation factors for the end of the rated life should be used. Further, it must be remembered that the table values are minimum recommendations; the IESNA text suggests that customer convenience, security, and levels of activity should all be considered in selecting the average maintained lighting level for design.

The acceptable minimum illumination values are then prescribed by the uniformity ratio; i.e., if the desired average maintained illuminance is 5 fc and the uniformity ratio is 4:1, the minimum reading must be 1.25 fc or better.

Reflectance from surfaces adds to the illumination which will actually exist in the parking facility. Reflectance of new concrete surfaces is usually 30% to 40%, but it declines over time with the accumulation of dirt. Concrete painted white will have a reflectance of 70% to 80%. Painting the walls and ceilings increases the illumination levels present in the facility, but the surface must be washed down periodically to maintain the benefit. IESNA has not allowed the inclusion of reflectance in calculations of lighting. However, it is our opinion that including reflectance from walls and ceilings is appropriate. We suggest that values of 15% for concrete floors, 30% for unpainted concrete ceilings and 60% for white painted ceilings be used. However horizontal illuminance should always meet or exceed IESNA recommendations, not including reflectance.

Lighting levels have also been recommended by the Parking Consultants Council (PCC) of the National Parking Association (NPA),[7] as seen in Table 5-1. IESNA requirements for horizontal illuminance are at the pavement; NPA's are at 30″ above the floor. The NPA requirements generally exceed IESNA requirements. NPA recommends a 3:1 uniformity ratio while IESNA requires a 4:1. This is significantly different because NPA's ratio must be applied at 30″ above the floor, which is substantially more difficult to achieve. NPA does not address vertical illuminance. IESNA also has more gradations or conditions addressed, such as differences between day and night and high/medium/low activity levels.

The 1984 vertical illuminance requirements of IESNA are a subject of some controversy in the parking industry. IESNA states that the vertical illuminance at 6′ above the pavement should be equivalent to

TABLE 5-1. Industry Standards for Lighting Levels

	Horizontal Illumination (Footcandles)	
	NPA[a]	IESNA[b]
Vehicle entrance	40	50[c]
Vehicle exit	20	—
Stairwells, exit lobbies	20	10/15/20[d]
Parking areas		
general parking areas	6	5
minimum at bumper walls	2	—
ramps and corners	—	10[c]
Roof and surface	2	.2/.6/.9[e]

[a]Minimum 30″ above floor. Uniformity ratio (average to minimum) 3:1.
[b]Average on pavement; uniformity ratio 4:1. IESNA 1984.[1]
[c]Daytime only; 5 fc at night.
[d]See IESNA 1993.[4]
[e]Minimum footcandles for low/medium/high activity areas.

the horizontal illuminance criterion, which is measured at the pavement.

However, measurement of lighting in many existing parking facilities reveals that most structures do not meet this vertical illuminance standard. It is very difficult to achieve at the low mounting heights and with any of the fixtures available for parking facilities, particularly when bay widths exceed 60′. Some experienced designers consider it impossible to achieve in a precast deck with minimum floor-to-floor heights. Some have argued that the only way to achieve it in design is to include reflectance in the calculation (which has not been permitted by IESNA) and/or to use more fixtures than would otherwise be required to meet the horizontal illuminance requirements. The latter is uneconomical and wasteful of energy.

Part of the problem is that the IESNA recommendation involves a relatively high-footcandle reading at a relatively high elevation. A 5 fc requirement at 6′ virtually assures that there will be direct glare to pedestrians (if not drivers) and that more illumination will be provided at the pavement than is required by IESNA with certain fixture types. We believe that the vertical illuminance within 42″ of the floor is more important and readily achievable. This level approximates driver's eye level. We suggest a minimum vertical illuminance of 1 fc is required at that elevation.

The final issue to be discussed in reference to illumination levels is that of energy usage. In 1989 the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) in association with IESNA published a standard[8] that specifies maximum power usage per unit of floor area. The maximum unit power density in parking facilities is specified as 0.3 watts per square foot in drive aisles and pedestrian areas and 0.2 in parking areas. Compliance with this standard is required on all projects that receive federal funding and in all jurisdictions that have adopted this publication in building codes. Designing to both the IESNA lighting standards and the ASHRAE/IESNA energy standards effectively limits the average maintained illuminance at the pavement to about 10 fc with the current efficacy of light sources.

5.2.2 Level of Service in Lighting Design

As has been seen in other areas of parking design, there is more interest in customizing the lighting design for the circumstances at hand than in the past. While minimum light levels used to be employed in every facility without much question, today many owners are asking for higher lighting levels than "minimum." These owners include not only those with a higher emphasis on user-friendliness (such as retail or airport) but also those who are at higher risk for security problems. The level-of-service (LOS) approach is thus a useful concept for selection of lighting levels.

Recommended gradation of the basic lighting levels—average maintained horizontal illumination at the pavement—and uniformity ratio are presented in Table 5-2. We consider the IESNA recommendation as the minimum, or LOS D. The LOS A illumination level for covered parking areas was set based on Walker experience with lighting at airport and shopping center parking facilities, whose owners demanded a higher level of lighting, as well as the ASHRAE/IESNA energy standard.

The roof/surface parking gradations were derived from IESNA[1] recommendations for areas of high, medium, and low activity. It is the author's opinion that "low" activity is not necessarily the place to use low lighting levels. Such areas may in fact require more lighting because of security concerns.

Whether or not reflectance is employed in calculations, analysis of the impact of reflectance on illumination levels indicates that painting the beams and ceilings white effectively increases the level of service by as much 1 notch, with no additional energy utilization, depending on the fixture and lamp selected.

It must be noted that illuminance levels are affected by the lamp, the fixture, the mounting height, and the structural system. It is impossible

TABLE 5-2. Level of Service of Lighting

	Maintained Illumination Levels (footcandles)			
	D	C	B	A
Horizontal illuminance at pavement, average[a]				
Covered parking areas[b,c,d]	5	6 to 7	8 to 9	10
Roof and surface parking areas	1	2	2.5	3
Stairwells, elevator lobbies	10	12 to 14	16 to 18	20
Uniformity ratio (average:minimum)	4:1	4:1	3:1	3:1
Uniformity ratio (maximum:minimum)	10:1	10:1	8:1	8:1
Vertical illuminance 42″ above pavement, minimum				
Covered parking areas	1	1.2	1.4	1.6
Roof and surface parking areas	0.13	0.25	0.31	0.38
Stairwells, elevator lobbies	1.3	1.6	2.1	2.5
Uniformity ratio: none				

[a]Horizontal illuminance should always meet or exceed IESNA recommendations, not including reflectance.
[b]Increase average minimum daytime lighting at vehicular entrances to 50 fc, minimum.
[c]Increase average minimum daytime lighting at vehicular exits to 20 fc, minimum.
[d]Increase average minimum daytime lighting on express ramps to 10 fc, minimum.

to hit a target figure, such as 5 fc, "on the head." Because structural constraints and mounting heights will be predetermined, a design may jump directly to LOS B from LOS D with 1 increment in wattage (such as from 100 to 150 watts).

Selection of the appropriate LOS may be based on owner criteria for user-friendliness and/or other considerations such as security. Indeed, an urban parking structure otherwise being designed to LOS C or D may have lighting designed to LOS B or even A for that reason. Conversely, the minimum or LOS D lighting levels are clearly adequate for the visual tasks required in a parking facility. The additional increments of higher levels of light are primarily for user perception and comfort. Analysis of cost of alternative levels of lighting indicates that the life cycle cost of a design with LOS A illumination is 67% to 75% more than the cost of a LOS D design.

Remember that the LOS approach is not intended to be blindly applied to each and every criterion in a design ("make everything LOS A"), but rather to be used as a guide to customizing each design component to the specific needs of the owner and users.

5.2.3 Lamp Selection

There are several different lamp types that are commonly used in parking facilities. These may be grouped into two broad categories: *fluores-*

cent and *high-intensity discharge* (HID). All of these lamps consist of a sealed arc tube with two electrodes. The tube is sealed with a gas that is ionized by the passage of an arc through the gas. The fluorescent lamp is familiar to most people as the long white tube fixtures used in office lighting and in kitchens. HID lamps commonly used in parking facilities include mercury vapor (MV), metal halide (MH), and high-pressure sodium (HPS). The low-pressure sodium (LPS) fixture used in roadway lighting is not appropriate to the parking environment because of its extremely poor color rendition. One exception to that rule is that where observatories with telescopes are located in the vicinity, top tiers and surface lots may need to be illuminated with LPS because the monochromatic light source can be easily filtered. The MV lamp has largely been replaced by MH lamps and/or improved versions of the fluorescent lamp. Therefore, MV lamps are not further considered here.

The key issues in lamp selection are energy efficiency, lamp performance over its lifetime, efficacy (lumens produced per watt of energy), glare potential, life cycle cost, and color rendering. Table 5-3 summarizes and compares lamp requirements. Note that the selected lamps all provide roughly the illumination levels for LOS C for an assumed mounting height, spacing, and fixture type.

The fluorescent lamp is actually a low-pressure mercury vapor lamp, with a phosphor coating on the tube. Much of the radiation from the arc is actually invisible ultraviolet light; the phosphor converts it to visible light that approximates the color of daylight. Fluorescent lamps have very good color rendition. Fluorescent lamps also start up within seconds, rather than minutes, from both cold and hot starts.

In the past, the efficacy of fluorescent lamps was relatively low and the lamp life was relatively short, at 9000 to 12,000 hr. However, with careful selection of lamp and the addition of electronic ballasts, efficacy in similar ranges to that of HID sources and lamp life of 20,000 to 30,000 hr of continuous operation can be achieved. Lamp life, however, is related to the number of hours per start. Also, the life cycle cost now maybe nearly the same as the most efficient HID source—HPS in certain cases.

The light pattern from fluorescent tubes is along the length of the tube, with very little light emitted at the ends, making this light source difficult to control. While average light levels similar to those with MH and HPS lamps can be achieved, the uniformity is substantially less, as seen in Table 5-3.

Low-temperature lamps should be used in climates where temperatures can be expected to drop below 32°F in winter; cold weather ballasts are required for temperatures below 60°F. However, these lamps have reduced light output at higher temperatures, with as much as 25% loss

TABLE 5-3. Lamp Comparison

	Fluorescent HO F48T12/D35/HO	Metal Halide MXR175/U	High-Pressure Sodium LU150
Watts/lamp[a]	60	175	150
Lamps/fixture	3	1	1
Fixtures/bay[b]	2	2	2
Lamp + ballast watts	195	210	188
Unit power density (watts/sq ft)	0.21	0.23	0.2
Initial lumens/lamp	4300	17100	16000
Lamp lumen depreciation (LLD)	0.78	0.61	0.73
Dirt depreciation	0.9	0.9	0.9
Ballast factor	0.95	1	1
Temperature factor[c]	0.9	1	1
Total light loss factor[d]	0.6	0.55	0.66
Design lumens[e]	15500	18800	21000
Horizontal illumination[f,g]			
Average on pavement (fc)	6.0	6.0	6.3
Uniformity (average:minimum)	4.0	2.1	1.9
Coefficient of variation	0.7	0.3	0.3
Vertical illumination			
Minimum at 42″	0.5	0.7	1.0
Uniformity (average:minimum)	6.9	8.0	6.6
Coefficient of variation	1.4	1.2	1.0
Life cycle cost[h]			
Rated life (hours)	20000	15000	28500
Total cost indexed to HPS cost	1.04	1.19	1.00
Initial cost/life cycle cost	14%	14%	15%
Energy cost/life cycle cost	79%	75%	80%
Maintenance cost/life cycle cost	6%	11%	5%
Other considerations			
Color temperature (Kelvins)[i]	3500	3200	2100
Color rendition index (CRI)	42	65	22
Cold start time (minutes)	0.01–0.02	2–4	3–4
Hot start time (minutes)	0.01–0.02	10–15	1–2

[a]Level of service C design with unpainted concrete is illustrated; painting the underside of slab and beams white increases illumination to LOS B.
[b]18′ by 51′ bays; posttensioned structure; two rows of fixtures at 36′ longitudinally with 18′ stagger.
[c]A temperature loss factor of 0.9 is included for fluorescent lamp to account for lumen loss at 40°F.
[d]Depreciation factors taken at end of rated life.
[e]Total design lumens per bay.
[f]Non-cutoff fixtures assumed.
[g]For fluorescent fixture, nominal lumens and watts are peak values and may be lower depending on ambient temperature.
[h]Analysis assumes 24 hour per day operation, 365 days per year.
[i]Energy cost starting at $0.07 per KWH. Energy and maintenance costs inflated at 3% per year.
[j]CRI is an international number system which indicates the relative color rendering of the lamp: the higher the number the better.

at temperatures above 70°F. Also, the lamp life is sharply reduced. Therefore, fluorescent lamps are not nearly as cost-effective in cold climates. As uniformity and consistency are very high priorities in design, the fluorescent fixture is usually not the first choice of most lighting designers.

Metal halide lamps were introduced into the market to provide more efficacy with better color rendition than mercury vapor lamps, specifically to meet the needs of arenas and stadiums. Metal halides are combinations of halogens and rare earth salts. The lamps produce higher illuminance levels more efficiently and with the better color rendition required by television broadcasting.

One of the major drawbacks to this lamp is that the various combinations of halide, halogens, and rare earth salts are not consistent, even among lamps from the same manufacturer. This inconsistency affects not only color rendition, but also lumen output, which can vary as much as 20% from lamp to lamp.[4] The other drawbacks to metal halide are that it has the shortest lamp life and the greatest depreciation of output over that life, although that effect can be mitigated by careful selection and specification. The newer Super Metalarc lamps have lamp life of 15,000 hr for 100- to 175-watt lamps; the lower-wattage lamps (100 and 150 watts) depreciate more than the 175-watt lamp. When the depreciation factors for the full rated life are used in the calculation of lighting levels, an MH installation will cost up to 30% more over its lifetime than an HPS design. The MH lamp is also sensitive to the orientation of the bulb in the fixture; a lamp oriented horizontally is rated for only 7500 hr of life compared to 10,000 to 15,000 hr for lamps mounted vertically (depending on the lamp specified.)

Another problem with metal halide is that while such lamps start up similarly to other HID fixtures from a cold start, they take 10 to 15 min in restart situations; i.e., if power is out for a few seconds, it will take at least 10 min for the lights to come back on. Note that metal halide lamps must be turned off for 15 min once a week in order to prevent violent, premature termination. This can be a major operational concern in facilities that are operated 24 hours a day.

In sum, the metal halide lamp provides good color rendition and lumen levels when used in groups or banks such as at stadiums, and when it is not used in continuous operation. However, this lamp can produce uneven, inconsistent lighting in a parking structure.

High-pressure sodium lamps are popular in parking structure design because of their high efficacy and long life, generally in excess of 24,000 hr. Because of the efficacy, lower-wattage bulbs can be employed for the same lighting levels, which reduces glare. A disadvantage to HPS lamps is color rendition. Although sodium emits light across the full color spectrum, it leans toward the yellow-orange range and is weak in the blue-green range. For this reason, some mercury vapor is added to the tube.

Approximately 5% of males and 0.8% of females are color blind and up to 30% have some type of color deficiency.[4] The HPS lamp has a golden yellow light and causes a color shift toward the yellow-orange end of the spectrum. For the visual tasks required in a parking facility, the HPS color rendition is quite acceptable.[7] However, it does have an effect on signage and color coding. Color selection should always be checked under HPS light; manufacturers have paint charts that make adjustments for the color shifts that occur in an HPS environment. The other task requiring color recognition is identifying your vehicle upon returning to the facility. HPS effects are most pronounced on colors in the blue-green range. This may be a more significant problem in facilities with a significant number of users driving rental cars such as hotels and tourist destinations. Further, as previously noted, the parking may not be perceived to be as well lighted as it actually is because of the yellow light.

Experienced lighting designers consider that the color rendition of HPS lamps has gotten a bum rap. According to Dr. Richard Corth,[9]

> The human visual system is extremely adaptable to changes in illumination and spectral composition. Further, chromatic adaptation can be extremely rapid depending on familiarity with the luminant. Thus, one is adapted, for example, to incandescent illumination immediately upon entering such an environment from daylight. . . . It might be expected that as the public becomes more familiar with HPS, similar adaptation will occur. There is considerable anecdotal data indicating that this is already the case.

Even when color adaptation is not immediate, as described above, the typical parking structure patron has adequate time to adapt to the light source before color recognition is a critical task.

Knowing that the color rendition is the single biggest problem with HPS, manufacturers are constantly working to improve the lamp. The color-corrected HPS lamp on the market at the time of this writing has lower efficacy (similar to that of metal halide) and reduced lamp life (about 15,000 hr). The life cycle cost is no better than with MH lamps, and therefore MH would be the current choice vis-à-vis color-corrected HPS. Various manufacturers report that they are "close" to producing a color-corrected HPS lamp without those problems. HPS may then be the clear choice for parking applications.

In sum, in most situations, a higher and more uniform lighting level

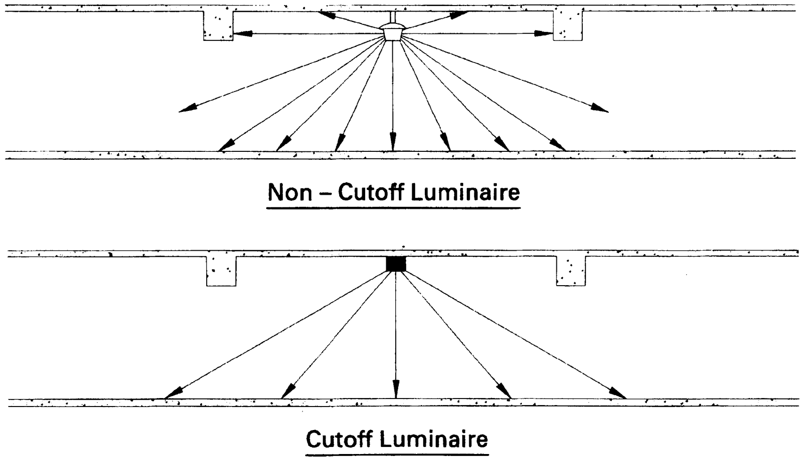

Figure 5-3. Cutoff reflection luminaires control and direct light downward. Noncutoff refraction luminaires have an uplight component for better uniformity and vertical illuminance but more potential for glare.

can be provided at lower operating and life cycle costs with HPS. In situations where there is a higher priority on user perception, however, metal halide or fluorescent may be preferred because of the color rendition. A third alternative is to use HPS in parking areas and fluorescent or metal halide in pedestrian areas, such as stair/elevator towers, where the improved color rendition and the perceptions related to white light are most beneficial.

5.2.4 Fixture Selection

IESNA[1] has specific requirements for the classification of fixtures, based on the amount of light emitted at certain angles, which are known as the cutoff luminaire, the noncutoff luminaire, and the semicutoff fixture. They differ by the amount of high angle light produced by the fixture.

With a cutoff luminaire, the light distribution consists of a cone of light below the fixture at a cutoff angle of approximately 80 degrees from vertical (see Figure 5-3). Technically, no more than 2.5% of the light can be emitted above an angle of 90 degrees from horizontal with no more than 10% above an angle of 80 degrees. The spacing of these fixtures must be relatively close to achieve the recommended uniformity of lighting on the floor, as well as an acceptable uniformity at the plane of the driver's eye. This is critical because, as previously mentioned, the driver going from light to dark to light conditions (all at eye level) has great difficulty adjusting to the changes. Further, it is very difficult to achieve the currently recommended vertical illuminance of an average of 5 fc at 6 ft above the floor. Cutoff fixtures generally do not spread light out enough to meet IESNA standards for vertical illuminance.

Most cutoff fixtures are box-type units which enclose the lamp in a metal housing with a flat lens on the bottom. The lamp is generally in a horizontal position. The fixture box with the reflector effectively hides the source of the light from the eye, thereby eliminating most direct glare for drivers.

The semicutoff fixture has up to 5% of the light emitted above 90 degrees and 20% above 80 degrees, double that allowed for cutoff fixtures. There is no limitation on high angle light with noncutoff fixtures. Some box-type fixtures actually qualify as semi- or even noncutoff. These generally have the lamp mounted vertically. While most of the bulb is shielded from the direct line of sight, openings may be provided in the upper portion of the housing to direct light upward. The uplight illuminates the ceiling, which eliminates the cavernous effect that results from cutoff fixtures and increases vertical illuminance by reflecting light off the ceiling. This fixture minimizes the amount of luminous surface area that is perpendicular to the line of sight and thus minimizes the potential for glare. One cannot simply assume that all box-type fixtures are noncutoff or that all semicutoff fixtures are capable of producing adequate vertical illuminance. Therefore, fixtures must be carefully selected and specified, based on the photometrics of each fixture.

Most noncutoff luminaires are of the refractor type. These fixtures generally have the bulb mounted vertically below the housing and enclose the lamp with a wraparound clear plastic or glass prismatic lens (see Figure 5-4). An internal reflector is sometimes used to redirect the light distribution away from the driver or limit the amount of light distributed between 45 and 90 degrees from vertical. These fixtures create good uniformity of light and can usually meet the vertical illuminance standard with proper fixture placement, at least the lower standard recommended herein. However, there is much greater potential for glare, particularly direct glare. Another disadvantage is that with the bulb exposed to vision from the side, lamps can be individually seen at certain angles and perspectives from the outside of the structure, despite the shielding of spandrel panels. This point source of brightness will increase the overall impression of light spillout from the facility, which may be objectionable to the neighboring uses. A structure with box-type fixtures will emit a gentle glow of light, but a large number of individual lamps will not be simultaneously visible from most angles of view.

Figure 5-4. Hanging the fixture below the tee stem improves uniformity and vertical illumination but increases potential for glare. Photo courtesy Walker Parking Consultants.

Manufacturers of fixtures have introduced several additional innovations to reduce glare. One manufacturer has designed the fixtures to accommodate louvers on the side of the fixture toward the driver. This will, however, affect uniformity of light at various planes. Another manufacturer has added a horizontal band or shield to block light at the angles that create the most objectionable glare for drivers.

Fluorescent tubes, where used for parking facilities, are generally mounted with bare tubes or with a wraparound lens; the length of the tube is mounted parallel to the aisle to reduce glare for drivers and pedestrians traversing the aisle. The glare of fluorescent fixtures is also somewhat less than comparable HID fixtures as the luminous intensity is distributed over a larger area than the point source typical of HID fixtures. Also, the glare of bare fluorescent tubes is reduced by using a wraparound lens.

Glare can be controlled by using low wattage fixtures, at closer spacings. The potential for discomfort glare is reduced 33% to 40% by using a 100-watt HPS lamp as compared to a 150-watt lamp. Lower-wattage fixtures a little closer together also is beneficial to meeting the uniformity standard. However, this does impact both construction and operational costs.

Research shows that a lateral offset of 10 degrees or more from the direct line of sight greatly reduces glare. For this reason the standard of the industry has evolved to placing the light fixtures offset 10 to 15 ft on either side of the driving aisle. This also contributes to good illumination at the edges of the bay.

In general, the differences between posttensioned and precast structures play a major role in the selection of light fixtures. Posttensioned structures are much easier to light because of the large area between beams. The fixture is generally mounted to the underside of the relatively thin floor slab, resulting in higher mounting heights than in precast structures. In general, the higher the fixture mounting, the better the uniformity, and the easier it is to get enough spread of light to meet the vertical illuminance criterion. By increasing the brightness of the background behind the fixture and the ambient lighting level, the potential for glare is minimized in posttensioned decks. The "up light" component of noncutoff and some semicutoff fixtures helps in this area. The background brightness can also be increased by a factor of 2 to 2.5 times by painting the interior of the parking structure surfaces white. The potential for discomfort glare is therefore reduced 50% to 60% with painting of the ceilings and beams. Further, as previously noted, when reflectance of painted beams and ceilings is taken into account, the LOS of a lighting design can increase by as much as 1 LOS.

With the close spacing of tee stems (4 to 5 ft on center), coffers are created that trap uplight and create a nonuniformly illuminated ceiling. In fact, an uplight component may actually detract from the design because it overilluminates one coffer without lighting the next, creating the perception of uneven lighting. Light fixtures in precast structures must be trunnion mounted in order to get adequate uniformity and vertical illumination. Lower wattage and more frequent fixtures located near the bottom of the tee stem are usually recommended. Even so, the tee stems block light, making it more difficult to achieve adequate uniformity. Some in the industry advocate hanging a noncutoff fixture below the tee stem as the only way to achieve the vertical illuminance standard. However, this sharply increases the problem of direct glare and broken refractors. The recommended floor-to-floor height for precast structures in Table 2-3 reflects the need for additional floor-to-floor height to achieve the same perceived ceiling height, uniformity of light, and *readability* of signs. The effect of light trapped in the coffers can be further minimized by staggering the light fixtures (see Figure 5-4). Painting the underside of a precast structure is far less cost-effective in improving lighting levels than in a posttensioned deck. This is because the surface area of the underside of the tees to be painted in a precast deck can be as much as 1.7 times the floor area.

Cutoff fixtures are generally used on the roof and in surface lots no matter what is selected for covered areas, in order to control light spillage. The mounting height should be approximately half the horizontal

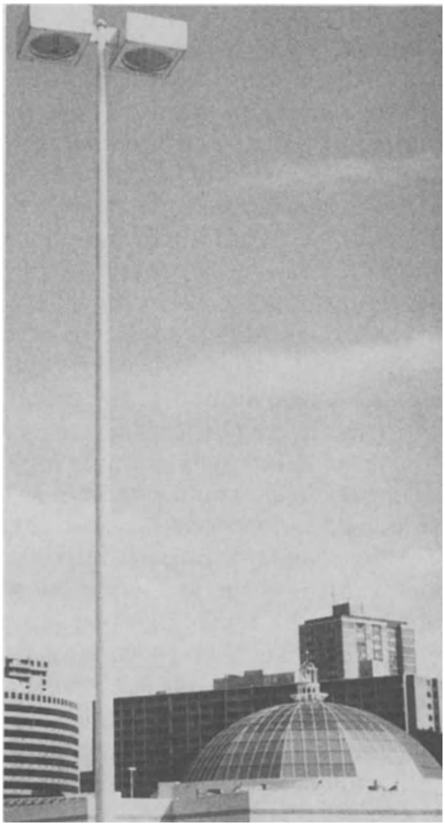

Figure 5-5. Noncutoff fixtures are usually employed for roof lighting. Photo Courtesy Quality Lighting, Inc.

distance of the area to be illuminated.[7] The design illumination and the uniformity standard will affect the spacing of the poles.

5.2.5 Other Design and Maintenance Issues

It is important that the light fixture be UL listed for damp locations at a minimum, and preferably for wet locations. This specification assures that the fixture will be adequately gasketed to prevent dust and bug infiltration as well as to prevent moisture infiltration. Tamperproof hardware should be used to prevent unauthorized dismantling of the fixtures.

Lenses should be impact-resistant. Polycarbonate lenses are not recommended as they become more brittle with age until they ultimately are no stronger than high-impact acrylic. Further, polycarbonate lenses are more prone to yellowing and degradation, particularly when exposed to ultraviolet radiation. Polycarbonate lenses also have lower light transmission characteristics than acrylic or glass. Since metal halide lamps produce ultraviolet radiation, acrylic or a tempered-glass lens must be used with this type of lamp.

As discussed herein, light output is reduced over time owing to accumulation of dirt and bugs in or on the lenses as well as some discoloration of the lens. Annual cleaning is recommended to assure that the reduction in light output does not exceed 10%.

The use of fluorescent lamps in parking structures is often discouraged as the light output is significantly affected by wind and low temperatures. A wraparound lens can help to protect the lamps from wind and from temperatures that may fall below 40°F. The ballast should consist of a full light output, high power factor, and energy-saving, electronic or electromagnetic ballast rated for operation down to 0°F, or as required by local climatic conditions.

Attention to relamping is important to maintain the minimum illuminance in any discrete area for safety and security. Relamping costs are minimized by replacing older lamps all at once before they actually burn out, rather than replacing a few burned-out lamps at a time. The lamps should be replaced when the horizontal illuminance directly under the fixture is below a predetermined value based on the lighting calculations. Annual surveys with a light meter should be performed to maintain the fixtures with adequate functioning lamps.

Energy use will be minimized by controlling perimeter light fixtures during the daytime, when adequate natural sunlight infiltration occurs. Sensors should be placed at strategic locations to detect the amount of daylight infiltration and turn off appropriate fixtures automatically. Roof fixtures should also be controlled by photocell to turn on only when appropriate. Timers and segregated circuits may also be used to reduce the light levels during periods of low activity (i.e., 1:00 A.M. to 6:00 A.M.). Even when the parking facility will be closed down at certain hours, it is recommended that a certain minimum number of fixtures remain on overnight for security.

As discussed in this chapter, painting of ceilings, beams, and walls in posttensioned structures will greatly enhance brightness perception, minimize potential discomfort glare, and increase the illuminance through increased reflectance by as much as 1 level of service. In precast structures, the benefit of painting the coffers is more limited and may not substantially improve the LOS of the lighting design. Maintenance of the painted surfaces is, however, a concern. It is important to use a breathable, acrylic-based paint or stain. Moisture trapped or migrating through the concrete can cause the paint to peel. A breathable material will allow water vapor to escape. The acrylic component provides for good bonding characteristics. It is also important to prepare the surface properly before application, to remove form oils, concrete laitance, etc. that may compromise bonding of the material to the concrete. The right product, applied properly, will last 10 to 15 years before repainting is required. Periodic (1–2 years) pressure-washing of the surfaces is recommended.

5.3 SUMMARY

The objective of any lighting design is to meet or exceed the minimum *visibility* requirements for security and safety, while creating an environment that will make patrons feel at ease. The psychological perception of the user as to whether the space is brightly lighted is often more important to user comfort than the light levels alone.

How much lighting is enough? Industry standards recommend minimum illuminance criteria for the safe movement of vehicle traffic and pedestrians while recognizing the need to deter criminal activity and meet energy constraints. There is not adequate information available to determine the potential decrease in crime, property damage, or personal injuries at enhanced light levels. Certainly, there are psychological and perceptual advantages to increased light levels. Therefore, the determination of the illumination criteria for any project is largely subjective, based on the experience of the owner and the designer. Conversely, excessive illumination is uneconomical and wasteful of energy. To aid in that process, levels of service for lighting design have been developed.

Lamp and fixture selection are governed by many parameters, not the least of which is the structural system in the facility. Lighting design must also consider glare and color rendition, as well as life cycle costs. In general, the high-pressure sodium lamp in a hybrid box-type fixture with an uplight component and qualifying as a semicutoff fixture is the preferred combination, except where color rendition is a higher priority. Metal halide and fluorescent lamps are the usual alternatives, each having advantages and disadvantages.

One of the chief interrelationships in parking design is between lighting and signage and graphics. Now that we have laid a groundwork on the issues of *visual acuity* in parking facilities, the next chapter will discuss signage design.

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CHAPTER

6

SIGNAGE AND GRAPHICS

Mary S. Smith

In Chapter 2, *wayfinding* concerns and considerations were addressed. The ideal wayfinding design is one that requires no signage. Since that ideal is simply impossible to achieve, signage design is an integral part in the development of a parking facility. It is important to remember, however, that signage should reinforce natural means of wayfinding. The first exposure could very well be the last if the parker does not feel comfortable using the structure. Owners, if a designer ever says to you, "We'll take care of that with signage," a red warning flag has just been raised. Signage should never be required to correct design failures or mistakes, especially at the design stage. It can compensate for compromises that are necessary to balance competing objectives in the design process. In retrofit situations, signage can also reduce, but rarely eliminate, problems resulting from poor natural wayfinding.

For definition purposes, *signage* is the system of signs providing directions, identification warnings, and information to the user of a parking facility. *Graphics* are the means by which the message is presented on the sign. *Architectural graphics* are the integration of wayfinding messages into the physical design, including wall treatments, flags, banners, etc.

Signage is a means of communication with the driver and/or pedestrian, especially one using the facility for the first time. To be effective, the signage in parking facilities must be plain, concise, and simple. The driver has no time to read the Preamble to the Constitution or even Lincoln's Gettysburg Address as he or she moves through the facility. While the creative designer may itch to make an architectural statement, "plain" is far better than "fancy," particularly for traffic direction.

It is obvious there are many questions that go through the driver's mind as he or she travels the facility looking for a "good" parking space. The driver must remain alert for pedestrians, other vehicles, structural elements, parking control equipment, and directional information that may be present in the facility. Often much of this information may be obstructed by structure (i.e., beams and columns) or other vehicles.

There are equally as many concerns for the pedestrian finding his or her way through a facility. In addition to being alert to vehicles, structural elements, and visual obstructions while wayfinding, pedestrians are often concerned about security and may thus be hurrying.

6.1 WHAT MUST BE COMMUNICATED?

The essential information required to guide the user through the facility falls into four basic categories:

1. Traffic information, which assists drivers by providing directions at points of decisions (One Way, Right Turn Only, Park, Exit, etc.).
2. Pedestrian information, which helps the user find such destinations as elevators and stairs, and helps in recollecting parking location.
3. Regulatory information, which identifies areas such as reserved, compact, or accessible parking spaces, or which prohibits or restricts entry/exit or vertical clearance limitations.
4. General information, such as parking rates, hours of operation, etc.

Each parking facility has its own characteristic set of requirements. These requirements present specific questions concerning the needs and concerns of the users to be answered during the design of the signage, including:

- What are the points at which information is needed?
- What information is needed?
- How should this information be presented?
- Will there be a high percentage of first-time users in the facility, or is it used by the same people every day?
- Is the patron under stress or hurrying to get to his or her destination, such as at a hospital or airport facility?
- Are there special sign requirements for accessible parking or bilingual patrons?

- Is the layout of the facility complex (multiple decision points, large number of bays)?
- Are there choices in traffic patterns that must be presented to drivers such as directions to parking near the entrance of an anchor tenant or exits to different streets?
- Is there a relationship between structures, such as pedestrian connections at several levels, that may lead to different destinations?
- How many levels of delineation of parking spaces are required for recollection of the parking location: parking space, aisle, zone, floor, structure, destination, entry portal?
- Are there restricted areas or special needs for security?

The airport, transportation terminal, arena, and stadium are types of facilities that have a high percentage of first-time visitors. These patrons are in a hurry to board a plane, or locate their seats before the event starts. Hospitals and retail businesses are very sensitive to customers' choice of patronage; making the parking system "user friendly" is of critical importance. In facilities serving these uses, the driver needs specific directional information in the proper sequence at each point of decision. Pedestrian information must also be well placed, easily read, and conveniently seen. Signs for these types of facilities should stand out clearly.

The facility serving a large office building usually requires less signage. The user is usually under less stress. A structure serving primarily monthly or contract parkers requires fewer signs because the user becomes familiar with the structure quickly and thereafter drives through the facility by habit. Conversely, it is more likely that a complicated design such as a double-threaded helix has been employed, affecting signage needs. The signage in such cases may serve more of a regulatory role. The monthly parker does need to remember where the vehicle is parked each day.

Some general rules for sign design and location are as follows:

- All signage should have a general organizing principle that is consistently evident in the system.
- Directional signage for both pedestrians and vehicles must be continuous (i.e., repeated at each point of choice) until the destination is reached.
- Signs should be placed in consistent and therefore predictable locations.

- A sign should be placed at every point where a driver or pedestrian must make a decision.
- Signs may be located at a point where all users/traffic turns in the same direction even though there is no decision needed. In general, such signs serve as reassurance to first-time or irregular users who are unfamiliar with the path of travel.
- In general, overhead traffic signage should be placed just prior to the turn.
- Traffic signage should always be placed centered over the driving aisle, except that a standard "STOP" sign may be most effective in the standard traffic engineering mounting—i.e., on a post 5 ft above the pavement.
- When there is no end-bay parking, a sign placed on the end bumper wall of the facility, even if slightly below eye level, is often more effective than one placed overhead before the turn., especially when located on down-bound routes (see section 6.2.1).
- Regulatory and pedestrian information signage is usually placed at or over the parking stalls. Avoid placing pedestrian signage in the expected location for traffic signage.
- Location signage in parking areas is most effective overhead (in the parking zone) if the facility is posttensioned and if there are not too many other signs present. Otherwise, column faces can be used. It is generally easier and more economical to paint and stencil location information on the column or beam face. Reflective messages are not required for location signage.
- Identification and location signage at stairs and elevators is often most effective on the door itself, and can be painted and stenciled directly on the door.

6.2 GRAPHICS

An important aspect of signage is the graphics. Effective signage programs combine aesthetics with information. Choice of color; typeface; character size, weight, and spacing; and the use of uppercase and lowercase text all influence *readability*.[1] The arrangement of text and symbols must be visually distinct. They must not contradict their basic meaning or intent, so as not to confuse the user. The background is equally important: backgrounds that are too small or too large for the type size can greatly detract from the effectiveness of the sign. Equally important is to coordinate the design of each sign with its environment.

6.2.1 Environmental Issues

Environmental factors affect signage perception and readability, such as the quality, intensity, and color of light falling on the sign; the possibility of glare from a fixture directly in front of sign; light from behind the sign; sight lines (or conversely, obstructions) between the user and the signs; and the visual clutter in the sign's surroundings.[2] Many of these factors may not be within the designer's control, yet the designer must recognize these factors and design the signage to work effectively in the environment.

Coordinating lighting with signage is one of the most critical and most often neglected elements. *Visual acuity* and speed of recognition improve as illumination levels increase. Conversely, excessive lighting reduces *legibility* by creating glare. *Halation* may also occur with light-colored letters on a dark background. These letters appear "heavy" and blurred (see section 6.2.2).

The ambient or general lighting has a twofold impact. First, of course, is the illumination of the sign itself. Second is the fact that the eye adjusts to ambient light levels. The minimum ambient light level required for nonilluminated signs in interior, lighted spaces is about 25 footcandles.[2] However, outdoors at night, signs can be viewed in as little as 2 fc. As discussed in Chapter 5, the parking industry has traditionally only considered lighting at pavement level in design. While 5 to 10 fc (average) may be maintained at the pavement, there generally has been far less at eye level and above.

Posttensioned structure lighting designed to the Illuminating Engineers Society of North America (IESNA) standard (see Chapter 5) will generally have an adequate number of light fixtures in each bay to ensure that signage placed on beam faces will be properly illuminated. The placement of fixtures over the parking spaces and signs over the aisle avoids overillumination and glare from light sources in front of signs. A sign that has been placed directly in front of a light source, either natural or artificial, is often unreadable. Circumstances in which this can occur include signs placed on an overhead beam on the perimeter, and signs that must be suspended in *turning bays*. If the location of the sign can't be changed, additional lighting can be placed in front of the sign to compensate for the excessive illumination behind it.

In precast structures, the frequency of the tee stems directly impacts the lighting/signage relationship. The tee stem limits the dispersion of the uplight component, if any; placing the sign in the same coffer and immediately behind the light fixture will often result in overillumination; placing the sign several coffers away from the fixture can place it in the shadows. There is substantially more visual clutter in precast structures as well. Generally, it is advisable to suspend the sign below the bottom of the tee stem to assure *visibility*. The additional clearance required below tee stems to accommodate signage is a major factor in the recommendation of different floor-to-floor heights in the level-of-service (LOS) design parameters (Table 2-2). The same posted clearance height should be maintained in a precast deck as in a posttensioned one. For example, the LOS C floor-to-floor height in a posttensioned structure would have a 7′8″ straight vertical clearance to the bottom of the beam and a 7′6″ posted *vehicular clearance*. The LOS C precast deck would have a clearance of 8′10″ to the bottom of tees and but also have 7′8″ posted clearance. Therefore, the signs can be hung so that the full letter is below the bottom of the tee stem, while still keeping the sign several inches above the posted clearance. (See further discussion of sign mounting in 6.3.)

Structural elements are generally among the most limiting factors on sign visibility in parking facilities. In the parking environment signs must be read from a distance of 75 ft to be minimally effective. This is based on a perception-reaction time of 5 sec and 10 mph; 100 ft is a much more desirable standard. Care must be taken that signs not become visible only after it is too late for the driver to make and implement a decision.

Motorists view signs from an approximate height of 45″ (per IESNA[3]), pedestrians from 5 to 6 ft. Signs mounted on structural elements can be at an acute angle to the normal line of vision. As seen in Figure 6-1, beams limit the distance from which a traffic sign may be read in a posttensioned structure. Using the floor-to-floor heights and floor slope gradations for level of service (per Table 2-2), the distance from which a sign mounted on the beam face can be read on a level floor is calculated for beam spacings from 15 ft to 30 ft. This column would also apply to signs placed on a beam face over a sloped parking area or ramp, and viewed from that slope. The impact of increased floor-to-floor height and beam spacing are both clearly demonstrated in Table 6-1. Except for the unusual combination of a 15-ft beam span and LOS D floor-to-floor heights, signs attached to beam faces will be visible from at least 75 ft, with visibility extending nearly 200 ft for the combination of 30-ft beam spacing and LOS A floor-to-floor heights. However, when a sign is placed on a beam face over the level end bay after a down slope, the

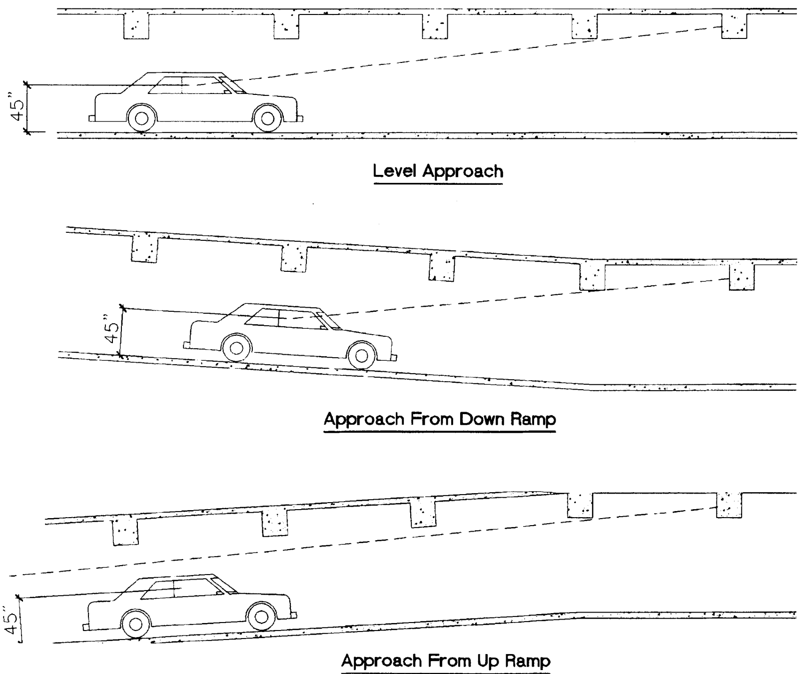


Figure 6-1. Distance from which signs can be read is impacted by structural members and floor slope.

visible distance is sharply reduced. This is most critical at the exit of the parking facility, at the bottom of the main down ramp, where traffic is given a choice of exiting straight ahead or turning in the end bay for reentry. The sign is rendered ineffective by reason of the fact that the driver probably sees it too late to have the sign play any role in decision making. The remedy is to place the sign further in from the end, at the *hinge point* in the floor slope. Conversely, a sign placed in the level end bays at the top of an up slope is visible from more than 250 ft away.

Signs held above the bottom of the tee are generally not visible at 75 ft. If the signs are suspended below the bottom of the tee stem in a precast structure, as previously recommended, the visibility will be more than adequate. The concern in that case remains that the sign is adequately lighted.

Sight obstructions must be avoided when considering sign placement. Architectural features and parked vehicles should not obscure sight lines. Other visual obstructions might include columns, *shear walls*,

TABLE 6-1. Sign Visibility Distances

		Approach to Sign		
Beam Span	LOS	Level	Down	Up
Posttensioned structure				>250′
15	D	54′	28′	
	C	67′	37′	
	B	81′	46′	
	A	95′	56′	
20	D	73′	33′	
	C	92′	43′	
	B	110′	54′	
	A	129′	67′	
25	D	93′	37′	
	C	116′	48′	
	B	140′	61′	
	A	164′	75′	
30	D	112′	39′	
	C	141′	52′	
	B	170′	66′	
	A	198′	81′	
Precast structure, signs above bottom of tee stems				
4	D	37′	25′	71′
	C	44′	31′	79′
	B	51′	37′	87′
	A	59′	43′	93′
5	D	47′	29′	120′
	C	56′	36′	129′
	B	66′	43′	135′
	A	75′	51′	141′

[a]Assumes 6″ letter on 12″ sign. After Bolden, 1981.[1]

and piping. The latter can be a severe problem in flat slab structures, where many elements are competing for the same space.

Visual clutter around and behind the sign can distract from the *readability* of a sign. Increasing the amount of background around sign messages (negative space) will help to compensate for visual clutter. It is important to balance the contrast between the letters, sign background, and surrounding elements. Copy and background should have a minimum difference in reflectivity of 75%[2]; this exceeds the recommendation in ADAAG (see Chapter 7), which is a minimum difference of 70%. A black background with white text provides a brightness differential of 96%. An orange background and white text provides only 68%. White copy on a dark background—preferably black— has been found to be one of the most universally effective combinations,

Figure 6-2. White copy on black background is very effective in parking structures. Photo courtesy Standard Parking Corporation, US Patent No. 4,874,937.

as shown in Figure 6-2. The dark background draws the eye to the sign because of its contrast with *concrete* surfaces and the relatively monochromatic setting inside parking facilities. If unforeseen shadowing occurs, the message will still stand out. Also, when glare occurs, there is less loss of message with white reflective letters on a dark background. There is no need to have the background be reflective. In fact, the contrast is heightened when white reflective colors are used against a flat black background. Also, there is less likelihood of glare with a flat background. In the outdoors, the reverse is true; a white sign is the most conspicuous against the visual landscape. A black panel must be more than twice as large to be equally conspicuous at 250 yd.[2]

Colored light such as that from high-pressure sodium fixtures can affect legibility if it reduces the color contrast between the copy and the background. There will often be a difference in reflectivity values under high-pressure sodium light that may affect selection of colors. Again, white copy on black background avoids this problem. In situations where visual clutter or other visibility constraints exist, illuminated signs may be the best solution. In addition to the traditional

Figure 6-3. Fiber optic signs can compensate for overillumination behind the sign. Photo courtesy C. J. Hood Company.

backlit illuminated sign, fiber optic and LED signs are now a viable alternative (Figure 6-3).

6.2.2 Letter Forms

Typeface must be selected based on legibility. This is primarily affected by the choice of typeface, the thickness and contrast of strokes, and the height. Letter height and typeface style are of equal importance in making a sign legible. The most pleasing, architecturally aesthetic, and "ageless" type style is Helvetica Medium. The relationship of stroke width versus height avoids many problems resulting from *halation* with the light letter on a dark background. The differential can appear up to 10% greater than it actually is. The balance found in the Helvetica Medium takes advantage of this effect without sacrificing legibility.

Where theming or architectural tone makes Helvetica Medium less desirable, a san serif alphabet, such as Univers, Futura, Grotesque Optima, Melior, or Craw Clarendon, is an acceptable choice[2] (see Figure 6-4).

Lowercase letters are 10% to 12% more readable,[2] and lowercase with initial caps occupies 30% to 35% less space; therefore lowercase with initial uppercase is preferred. All-uppercase may then be used for special emphasis, such as STOP. The nominal letter height with upper- and lowercase is the cap height. The height of the cap or uppercase letter is one third larger than the height of the lowercase letter.

Letters are visible at a distance of about 50 ft per inch of cap height. Given the additional constraints of parking structures, a minimum of

HELVETICA MEDIUM
ABCDEFG
abcdefghijk
123456789

FUTURA
ABCDEFG
abcdefghijk
12345678

OPTIMA
ABCDEFG
abcdefghijk
123456789

OPTIMA SEMIBOLD
ABCDEFG
abcdefghijk
123456789

CRAW CLARENDON
ABCDEFG
abcdefghij
123456789

MELIOR
ABCDEFG
abcdefghijk
123456789

UNIVERS
ABCDEFG
abcdefghij
123456789

Figure 6-4. San serif alphabets are the preferred choices for parking structure signage.

1″ height for every 30 ft of distance is recommended for pedestrian signs.[2] For drivers traveling at 10 mph, such as in parking bays, a ratio of 1″ for 20 ft is more appropriate. Letter height on signage for express ramps and roadways should be calculated in accordance with the following formula[4]:

$$H = \frac{(N + 6)V}{100} + \frac{S}{10}$$

where H = cap height in inches, N = number of messages, V = vehicle speed in mph, and S = lateral sign distance.

This is not intended to imply that the letter size on each sign should be customized to the distance from which it can be read. As the recommended range of visibility is 75 to 250 ft in parking facilities, a 6″ cap on a 12″ high sign is strongly recommended for traffic signs in parking bays. It provides a balance of legibility at an acceptable distance with an effective amount of background. Sizing letters under 6″ on the premise that the sign need not be read more than 75 ft away is wasting the opportunity to give the driver more than a minimum amount of time

Figure 6-5. Larger signs and letters for location indicators can be painted directly onto columns. Photo courtesy Simon Design, Inc. and Prudential Center, Boston.

to recognize and read the sign. Oversizing either letter or background is merely distracting in a traffic situation.

Pedestrian signs can use smaller letters because both recognition and reaction time are much longer. Pedestrian destination signage can often be visible for the full length of the structure. Eight-inch letters are then appropriate. Where more immediate directional information is provided, 4″ is a good choice, especially when longer place names must be communicated. Conversely, oversize signs and letters for location indicators emphasize the importance of remembering (see Figure 6-5).

Borders and circles around copy make the sign more difficult to read and should be avoided, especially with the visual clutter inherent in parking facilities. However, a different background color creating a "target" for arrows, in particular, may improve legibility.

Spacing of letters and length of message are the last considerations in the area of copy design. The distance from the left edge of the sign to the first letter or symbol should be equal to the cap height. Standard letter spacing should always be used, unless sign length is very restricted. This most often occurs when a sign must be located between tee stems in precast structures. With the recommended Helvetica Medium typeface, the message will be approximately 0.75 times the cap height times the number of letters and spaces.[2] Additional space should be provided between two separate messages on the same line; a minimum space of two times the cap height is recommended.

No more than 30 characters per line is recommended.[2] Messages should be kept as short and concise as possible. "Park" and "Exit" are most frequently used to guide the driver through the facility. Some consultants prefer to use the word "Out," reserving "Exit" for pedestrians.[5] Avoid excessively wordy messages such as "To Additional Parking." Once the driver is conditioned to seeing Park and Exit at every decision point along the path of travel, don't throw in a new message

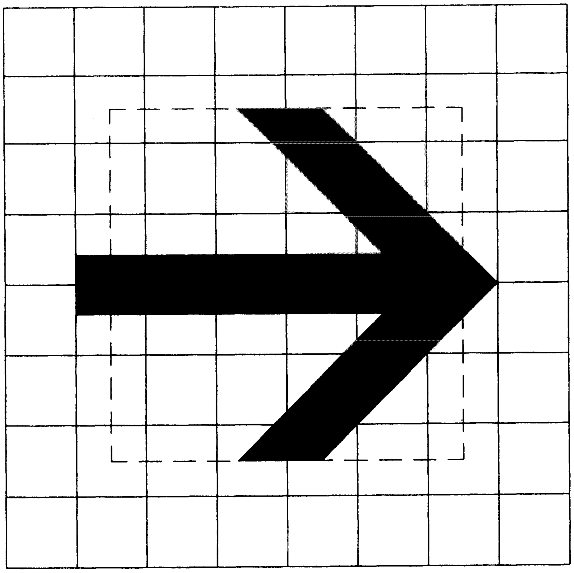


Figure 6-6. A simple block arrow is recommended for parking structure signage.

such as "All Traffic." Two lines of copy on a pedestrian sign is acceptable but should be avoided for traffic signs unless there is extra reaction time. "Do Not Enter" is used to warn a driver not to enter; "Wrong Way" is employed where the driver is looking into the area. Both signs can be used in sequence to reinforce the message.

6.2.3 Arrows and Symbols

Research on visibility of arrows has not pointed to a "best" design.[2] Certainly, an overly stylized or "fussy" arrow should be avoided. The simple block arrow in Figure 6-6 is a good complement to the recommended Helvetica Medium typeface.

Theoretically, arrows may point in virtually any direction; however, in practice they should be limited to the eight visually distinct directions represented by 45-degree increments. The conventions of the Federal Highway Administration's Manual on Uniform Control Traffic Devices (MUTCD)[7] should be used. In general, left and right turns employ horizontal arrows. Some in the industry customize the arrow for up and down slopes. For example, if the driver is to take a right turn and go up a ramp, an arrow pointing right and up at 45 degrees is used. This may take a little longer to recognize and understand, especially if

Figure 6-7. Commonly used pictograms are effective communication tools.

there are multiple messages and arrow directions in the *field of vision*. The 45-degree arrow is probably most beneficial when there is a lack of vision around the corner to see that there is a ramp.

When the intended message is "straight ahead" or "this way," the arrow should point up. A downward-pointing arrow says "this lane" and is most appropriately used when there are multiple lanes from which to choose, such as separate monthly and cash lanes at the exit.

The combination of symbols and words is the most effective means of communication.[6] Only when the symbol alone is universally understood should pictograms replace words (see Figure 6-7). However, as society at large increasingly communicates through pictograms, the universality of symbols will increase and become usable in parking facilities.

The arrangement of copy and particularly of arrows should reinforce the message. Left arrows should generally begin with the arrow flush left on the sign; messages with right arrows should generally be placed to the right with the arrow flush right. When messages with both left and right arrows are placed on a sign, there should be a good visual separation and distance between the two. Up arrows are generally placed to the left of the messages. Since down arrows are used for special emphasis, down arrows are often repeated on both sides of the message.

6.2.4 Colors and Theming

Color can be an important component to a signing program. In the words of colleague Don Monahan,[2] "It can enliven parking structures and public spaces that would otherwise be very dull." Colors for pedestrian signs might be distinctively different from traffic signs for better recognition by the user. Conversely, many years ago we decided it might be a good idea to use the background colors in MUTCD, with the bright green seen on highway signs for all "park" signs and fire engine red for all "exit" signs. We abandoned the idea after the first installation, because it was simply too visually distracting. There is a simple elegance to the white letter on a black sign.

The owner or architect may have a preference for a certain background color—to match window framing or special accents in the architecture. At the same time color must be carefully used. As previously discussed, there must be adequate difference in reflectivity between copy and sign background as well as contrast between the background and the adjacent construction. For example, burgundy letters on a strong gray background may be quite attractive for interior signage in an office tower, but would be a major mistake in the adjacent parking facility.

It has been a favorite tactic of the industry for many years to color-code parking levels. Used forcefully and liberally in conjunction with floor numbers and, if needed, letters for sections, colors can help patrons identify the parking location. However, there are very real limitations to the use of color as a major contributor to wayfinding. The use of "trendy" colors such as teal and aqua certainly adds to the atmosphere or sense of being in a new, different space from the traditional parking garage. However, color-coding one floor with teal and the next with aqua will add little but cost to wayfinding. According to Monahan,[2] "Most people can only distinguish and remember six different colors, not including black and white—red, yellow, blue, green, orange, and brown." If more or other than those six colors are needed, a significant loss of effectiveness occurs. Further, while there may be certain logic in using "warm" colors (red, yellow, orange) in one structure and cool colors (blues and greens) in another, 99% of users will never notice or appreciate such subtle logic.

Another constraint on color-coding is that 5% of males and 0.8% of females are color-blind. In one case, a parking structure with at least

10 floors was color-coded with bands of color on each column and the elevator lobby on each floor boldly painted in the color. Nowhere was there a sign "Remember—purple." The elevator floor buttons were matched to the colors, but with no numbering or words on the adjacent panel. Picking out the difference between blue and purple among the buttons was hard enough, even if you did remember purple correctly. The color-blind person, however, had no hope of getting back to the right floor.

Too many symbols/colors/patterns can actually detract from wayfinding. Don't expect the patron to figure out that the 4 × 8 ft graphic of a lobster with a pair of cherries 6″ high in one corner is supposed to communicate that this is the red floor. The same set of memory aids must be repeated at every location. It does little good to theme a floor with lobsters if the panel in the elevator cab doesn't have the same graphic next to the elevator button.

Conversely, theming that ties together elements and reinforces them with unusual visual elements can be very powerful in wayfinding. A parking operator in Chicago, Standard Parking Corporation, has successfully themed a number of structures, with music playing in the lobby to further reinforce the theme. An award-winning parking structure for Northwestern University has each floor named after a rival university with the school's colors and mascot on each floor and the fight song playing in the lobby while you wait for the elevator. Directories of each floor are provided in the lobby for reference upon return. This touch is far more helpful than just putting a floor number or color next to the elevator button. If you aren't quite sure where you have parked, you can scan the directory to jog the memory. "All you have to do is remember one of the four things: the number, the music concept, the visual concept, and possibly color," according to designer Craig Simon.[8] The concept is so successful that Standard has patented the idea (see Figure 6-8).

When there are multiple parking structures serving a single use, it may be helpful to keep the floors in each structure within an overall theme. However, be careful that the connection is universally obvious. Subtlety is usually wasted, and ambiguities should be avoided. If one of the two structures serving a building had floors named for fruits and the other had vegetables, would you know which structure the tomato floor is in?

6.3 CONSTRUCTION DETAILS

The preferred sign material is 0.080″ aluminum sheet. Recycled post-consumer plastic composites are also becoming more common. Plastic

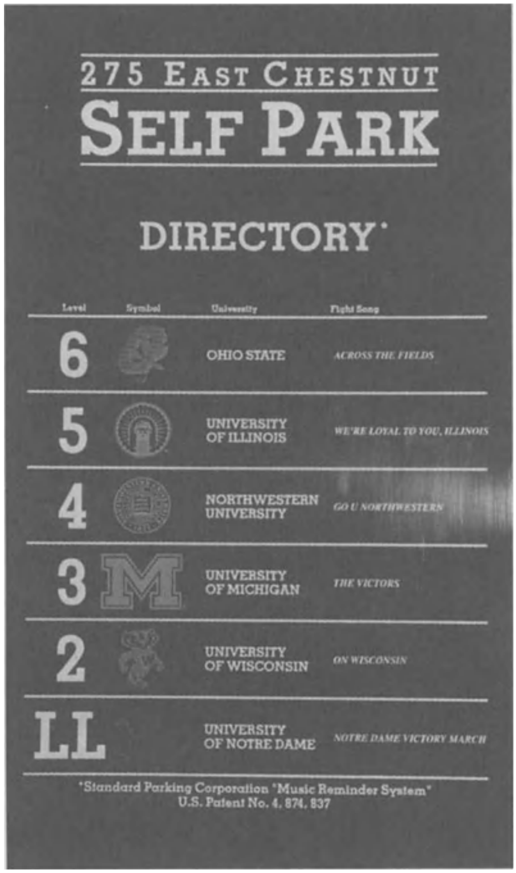


Figure 6-8. The lobby directory for a parking facility with the musical floor reminder system. Photo courtesy Standard Parking, US Patent No. 4,874,937.

composites eliminate any metal reaction between aluminum and concrete, and are not as likely to be stolen as aluminum signs (which get stolen to be sold for recycling). However, the use of plastic composites requires more attention to adhesion of reflective sheets and/or cut vinyl letters. Plywood, Duraply, and tempered hardboard should be avoided because of warping, *checking*, *delamination* of plies and the like, and the lack of a consistent working surface for application of copy.

There are two common methods for applying the copy. One process is a reverse technique where the entire sign is covered with white reflective sheeting and then the background is silkscreened over the top allowing the letters and symbols to show through. There are four basic grades of reflectivity sheeting, in ascending order of cost; Engineer, High Intensity, Visual Impact Performance, and Diamond grade. Coeffi-

TABLE 6-2. Comparison of 3M Reflective Sheeting Grades

Grade	Coefficient of Retroflection	
	New	After 7 Years
Engineer grade	70	35
High intensity	250	212
Visual impact performance	450	250
Diamond grade	800	400

Source: Traffic & Parking Control Co., Inc.

cients of reflectivity are shown in Table 6-2. Engineer grade is the usual choice for parking since most of the signs are weather protected. However, where extra reflectivity is desired, High Intensity would be the choice. It holds its reflectivity very well and is three times brighter than Engineer grade; however, the sheets cost about four times as much as Engineer grade. The inks may be either transparent, which results in a reflective background, or opaque, which results in a flat background. Our experience has found that the flat background reduces the possibility of glare blanking out the message. Opaque inks are also a little more durable.

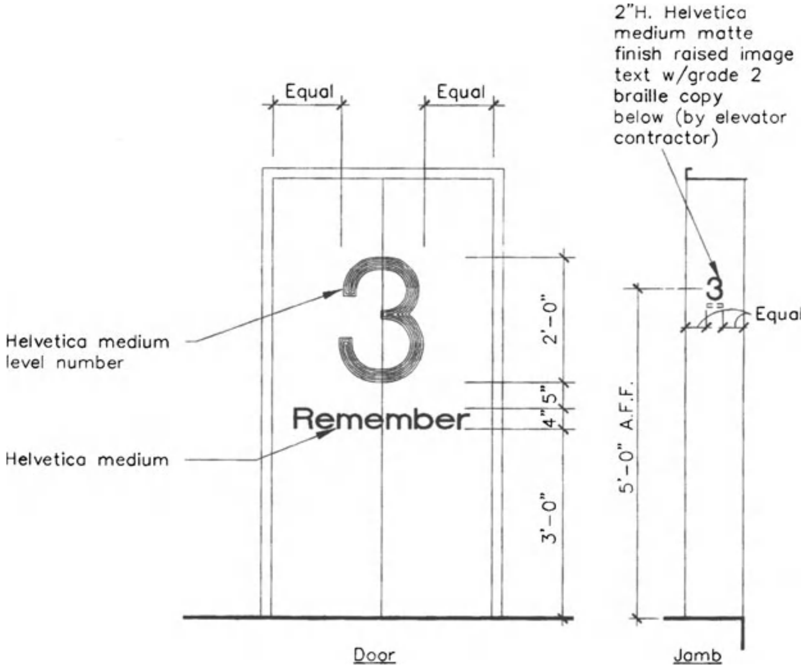
The alternative is to apply reflective, die-cut letters to a painted aluminum blank. Die-cut letters have slightly lower reflectivity and are prone to curling and cracking if not properly applied. Proper specification of die-cut letters is thus critical. Pranksters occasionally pick letters off and/or rearrange messages. A clear overlay is available that prevents curling and *peeling* of die-cut letters and makes the sign more durable and graffiti resistant.

Internally illuminated signs have generally been too expensive to use for parking facility traffic signage. The traditional internally illuminated sign has letters cut into the sign face with a translucent second sheet, behind which is mounted a *fluorescent* light tube.

Neon has occasionally been used effectively, particularly as part of the parking location/theming system.

Advances in fiber optic and low energy display (LED) technology make those desirable options where changeable messages or special emphasis is required. These devices have very low *maintenance* and operating costs.

One of the most cost-effective means of designating floor locations is to paint the elevator door with the floor color and then apply a super graphic (see Figure 6-9). When not painted directly on the construction, signs on stair/elevator walls can be back- or reverse-painted on Lexan to prevent vandalism. Any damage can be readily cleaned and restored.



Notes:
1. Raised image text w/braille copy to conform to requirements of Americans with Disabilities act.
2. Provide sign at each elevator door & each elevator jamb at each tier.

Figure 6-9. Supergraphics on elevator doors are effective location reminders.

Framework for signs is usually painted or galvanized steel tubing. Make sure to specify the painting of saw-cut ends and drilled holes in prepainted tubing prior to final installation to prevent rusting. Inserts, fasteners, etc. should be rust-resistant and tamperproof. Avoid aluminum tubing because special consideration must be given to the electrolytic action between concrete and aluminum. The "softness" of aluminum also leads to crushing and distortion of the tube sections (see Figure 6-10).

Exterior signage must be designed in concert with the owner and architect. Some of the choices include the following:

- Individual cast letters 9″ to 12″ in height over the entrance and exit lanes are an attractive and economical alternative. Be sure that there is adequate contrast between the building façade and the letter. A smooth surface may be needed in a heavily textured panel. This

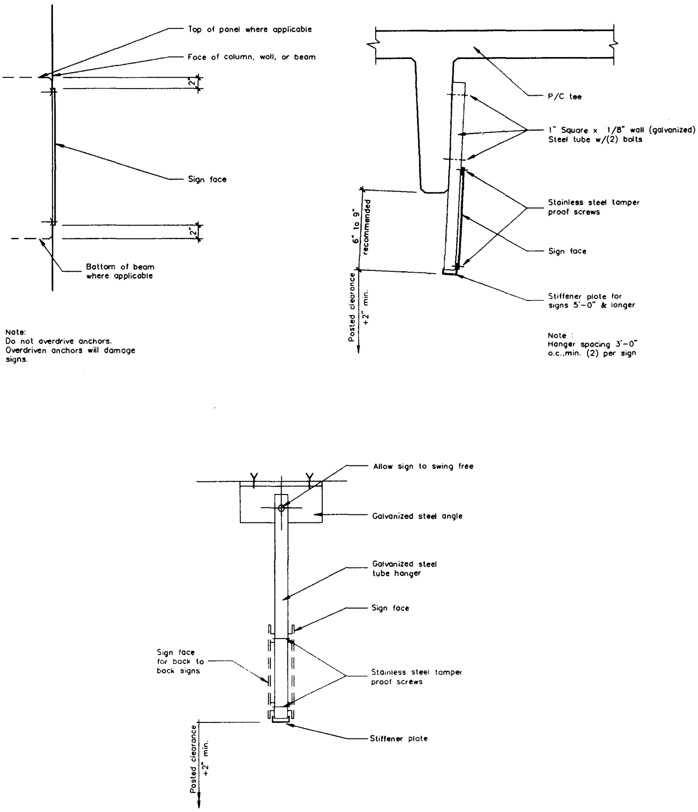


Figure 6-10. Typical sign mounting details.

change in texture can be developed architecturally to emphasize the entrance/exit. Lighting from behind, over, or under the letters must be coordinated with the electrical engineer.

- Illuminated signs may be placed over the entrances/exits. These are especially effective when built into a canopy or larger architectural feature which emphasizes the entry point (see Figure 6-11). Prefabricated illuminated boxes can also be placed either flat or perpendicular to the façade. Unless carefully designed, the boxes tend to look a little "artificial" or "attached" rather than integrated into the façade design.

One concern with any relatively flat sign attached to the face of the building is that it may not be readable by drivers in the street if the facility is pulled tight to a narrow sidewalk. Illuminated kiosks at the

Figure 6-11. Marquee style signs are especially effective in urban settings. Photo courtesy Standard Parking Corporation.

sidewalks are among the most effective signage tools, but they can be relatively expensive. It is also critical to be sure that a kiosk sign does not block the driver's vision while entering or exiting.

It is very important to have a *clearance bar* at the posted vehicular clearance height. Most experienced designers use a *PVC* tube suspended from the façade beam with reflective, die-cut letters (see Figure 6-12).

6.4 FLOOR ARROWS AND STALL STRIPING

Although floor arrows and stall striping will usually be provided by a different contractor, they are part of the system communicating directions to the user and therefore merit discussion here. In general it is desirable to design pavement markings in conformance with MUTCD or state/local requirements. One of the first questions is what color should be used for floor arrows and striping. MUTCD specifies that white paint be used for markings delineating traffic flowing in the same direction and that yellow paint be used between lanes traveling in opposite directions, which implies a warning. Crisp, white paint shows well against the concrete in a new facility. However, over time dirt

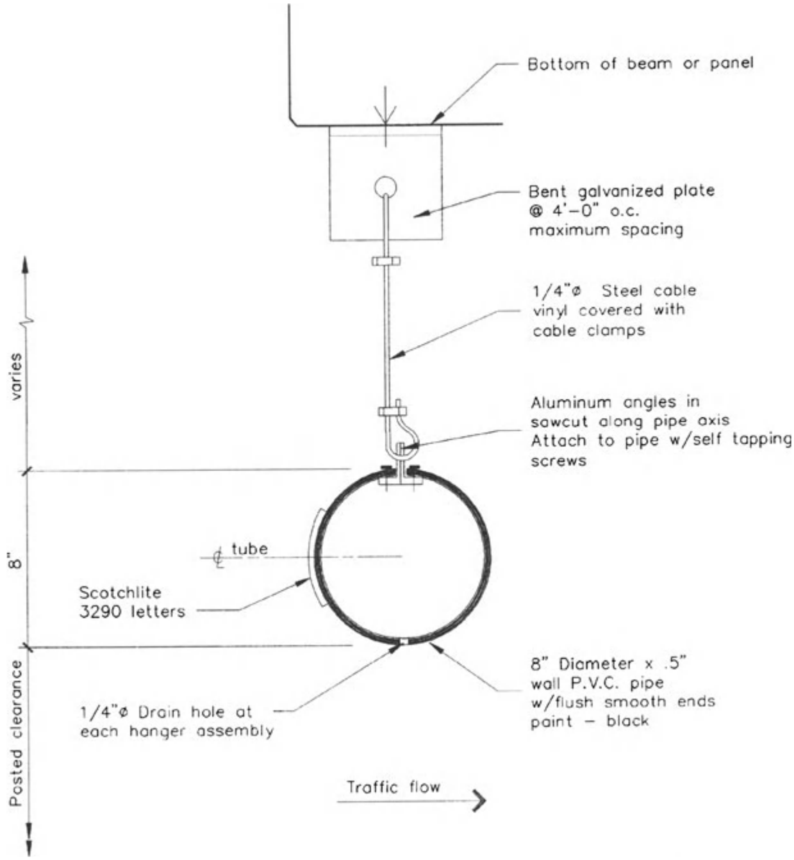


Figure 6-12. Clearance bars are placed at every vehicular entrance and point of change in vehicular clearance.

tends to obscure the paint and yellow seems to be more visible under "average conditions." Either white or yellow is quite acceptable from a visibility standpoint; the choice generally comes down to a personal preference of the designer.

A number of paint choices are available for pavement markings. A major change in the formulation of pavement markings occurred when the Environmental Protection Agency (EPA) regulations limited the use of solvents in paints. All of the paints listed have been formulated to pass EPA's current standard. However, several states have more stringent standards, which effectively limit the choice to water-based paints.

Acrylic thermoplastic and polyester are generally accepted substitutes in those states. Chlorinated rubber paints provide a good balance of durability for the money, and are the traditional choice for parking facilities. Chlorinated rubber, although it meets the current EPA standard, raises environmental concerns when flakes, which are considered carcinogens, are carried off by storm water. It is expected that chlorinated rubber paints will be outlawed in the near future. Water-based paints have the poorest durability and performance. The best performance/durability comes with acrylic thermoplastic paints. However, they are difficult to apply; the paint must be heated to 400°F before application. A study by the EPA found that polyester paints have the lowest life cycle cost, when such parameters as paint cost, labor and application costs, and expected marking durability are considered. Polyester paints are also the most environmentally safe.

The reflectivity of highway paints is often enhanced with the application of glass beads to the paint. Glass beads act as retroreflective lenses that reflect the rays of auto headlights back to the driver. They increase safety and night visibility. Beads are most effective when mixed with the paint and sprayed in a single application; in such cases they increase the paint life. Most parking stripers object to this type of application because it reduces the life of the striping equipment. They prefer to spray the beads from a second nozzle or hand-broadcast beads as a top coat. However, beads applied as a top coat wear off, often in less than a year, and are probably not cost-effective. Therefore glass beads should only be specified if required to be mixed with the paint before application. In parking applications, use of either the most expensive paint and/or glass beads may increase the cost of striping, but in the context of the total construction cost, the increment is negligible.

It should be noted that pavement marking paints may bond poorly to green concrete, owing to hydration as concrete cures and/or curing/sealer applications. The first application of striping will probably have a shorter life than subsequent applications.

Double-line or hairpin striping continues to be preferred by most consultants as encouraging better alignment of vehicles in parking stalls. The cost differential is small compared to the benefits in helping parkers get aligned properly in a stall (see Figure 6-13). Studies[9] have shown that it is better to keep stripe length shorter than the intended stall length, encouraging drivers to pull further into the stall.

Floor arrows should be located centered in the drive aisle just in advance of every turn whether or not a sign is provided. The location of floor arrows is shown on the same drawings as the striping. Be careful not to include arrows that are helpful to a layman looking at a drawing but that are not intended for painting (see Figure 6-14).

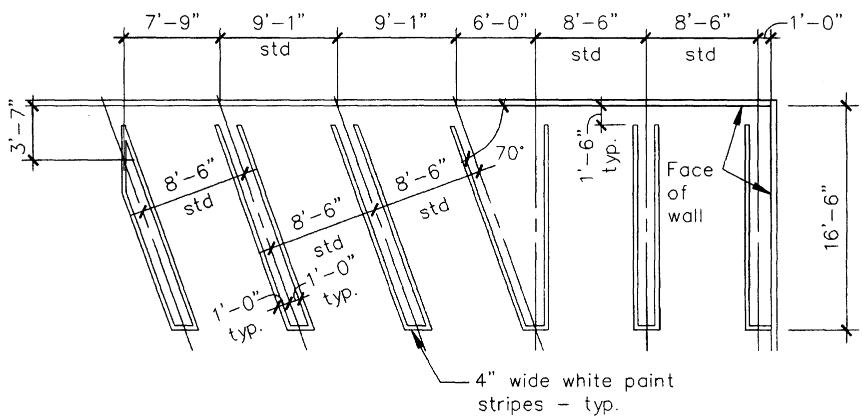


Figure 6-13. Double-line striping detail.

Special sign requirements under ADA are addressed in Chapter 7. It is instructive to note, however, that some states require the use of blue paint in pavement markings for accessible stalls. The preferred method is to paint a large blue square in the middle of the stall or to paint the entire stall between the lines blue and then to paint a handicap logo in white. Less effective is merely painting the stripes and/or cross-hatching blue.

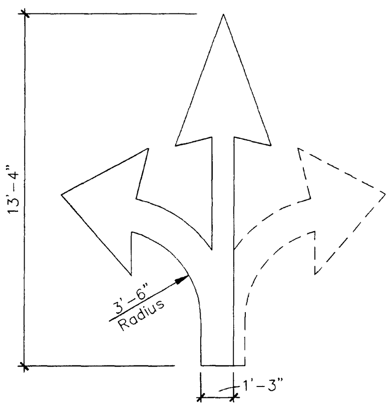


Figure 6-14. Standard floor arrow.

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CHAPTER

7

Accessible Parking Design

Mary S. Smith

7.1 INTRODUCTION TO ADA

In July of 1990, President George Bush signed into law The Americans with Disabilities Act (ADA), one of the most sweeping and far-reaching pieces of civil rights legislation ever passed by the United States Congress. ADA has five titles:

Title I—Employment covers elements related to employment of persons of disabilities, including requirements to make reasonable accommodations such as modifying work stations and equipment.

Title II—Public Services

Part A—State and Local Government Services requires that local governmental entities, which includes schools, state universities, county hospitals, etc., must operate each service, program or activity so that, when viewed in entirety, it is readily accessible to and usable by persons with disabilities. This title also requires that newly constructed buildings owned by (or on behalf of) entities covered by Title II must be accessible. Alterations to existing buildings must be done in an accessible manner.

Part B—Transportation covers requirements for accessibility of transportation facilities.

Title III—Public Accommodations covers requirements for accessibility of those areas of existing privately owned buildings where the public may go to receive goods and services. It also has distinct requirements for accessibility of new buildings and alterations of existing buildings which are places of *public accommodations* or *commercial facilities.*

Title IV—Telecommunications covers telephone companies and phone systems.

Title V—Miscellaneous explains enforcement procedures, fines, etc.

You may note that the Federal Government is absent from the above listing, and indeed it was intentional. Most buildings constructed or altered with federal funds are required to comply with the Architectural Barriers Act of 1968. Recipients of federal financial assistance have similar obligations to ADA under Section 504 of the Rehabilitation Act of 1973. ADA essentially extended similar obligations to state and local governments not in some way covered under the two older acts, as well as private entities. Residential uses are covered by the Fair Housing Act. Private clubs are exempted when they qualify for exemption under Title II of the Civil Rights Act of 1964. There is really only one other type of nonresidential building owner that is exempted from ADA, and that is religious entities. Note that the exemption is restricted to buildings directly associated with the practice of religion including churches, synagogues, and convents but not hospitals, for example, even if directly owned and controlled by religious orders. Further, a nonreligious entity, such as a day care center, must ensure that the facilities it rents from a church are accessible or rent space elsewhere.

Perhaps the most important thing to remember about ADA is that it is a **civil rights law**. The Department of Justice is charged with enforcing the act, and individuals who feel they have been discriminated against can sue the property owner. The guidelines for building and facility design are **not** a building code, subject to state or local approval and variances. (Of course, if a state or local government has a conflicting standard, the higher of the two standards applies.) Even when local officials approve a design as compliant, a federal judge can later decide that it was not compliant and award damages to a plaintiff.

Parking is considered to be a critical element to accessibility. To paraphrase the words of an official of the Access Board at one industry conference, if the individual with disabilities can't drive to and park at a building, there is no sense in requiring the owner to make the building accessible. Actions do often speak louder than words: the first case brought into Federal Court that resulted in a civil penalty under Title III of ADA was for failure to make parking accessible.

7.1.1 Terms and Acronyms

One of the first things that must be addressed in discussion of ADA is all the terms and acronyms that are required to communicate the requirements of ADA in a reasonably succinct fashion. Note that the term "handicapped" is no longer operative. In all of the 300 pages of the *Federal Register* devoted to Title II and Title III rules and regulations, the term "handicapped" is not used once. The correct term is *persons with disabilities.*

When an element is designed to be readily usable by persons with disabilities, it is *accessible.* An *access aisle* is not the driving aisle in a parking facility, but rather an accessible pedestrian space between elements, such as parking spaces, seats, or desks. An *accessible route* is a continuous unobstructed route connecting accessible elements. A *ramp* is not a sloped driving path providing vertical circulation in a parking facility, but rather a walking surface that has a running slope greater than 1:20 (5.0%).

Whenever Congress passes a law, an agency is specifically designated to issue "rules" which establish standards and procedures for implementation of the act; for ADA, several different agencies were charged with rule making. The three primary documents that affect building design under ADA were issued on July 26, 1991. The first is the *Americans with Disabilities Act Accessibilities Guidelines*[1] (ADAAG). It was issued by the Architectural and Transportation Barriers Compliance Board (Access Board) to ensure that buildings and facilities covered by the law are accessible. The Department of Justice (DOJ) also issued its Title II Rule[2] and Title III Rule[3] on that date.

ADAAG is modeled on an older federal standard, the *Uniform Federal Accessibility Standards* (UFAS). ADAAG is essentially a revisiting, updating, and extension of UFAS. The Access Board will, from time to time, issue clarifications of ADAAG. In February 1994 the Access Board issued Bulletin No. 6, addressing parking.

Initially, state and local governments were given the option of complying with ADAAG or UFAS. At the time ADAAG was issued, the Access Board stated that it intended to adopt modifications to ADAAG applicable to governmental buildings and that DOJ would then adopt a rule mandating that Title II entities comply with ADAAG rather than UFAS. On June 20, 1994, the Access Board issued those modifications.[4] In that rule, the board stated that it will use ADAAG as the accessibility guidelines for federal and federally funded buildings, under the 1968 and 1973 acts. However, at the time of this writing, the DOJ has not yet even issued proposed rules (which must be published for comment before final rules can be issued) spelling out how and when state and local governments must switch to ADAAG, nor have most of the individual federal agencies adopted ADAAG. Therefore, the new Title II amendments to ADAAG are denoted an "Interim Final Rule." Technically, no one is yet required to follow the new rule; however, the board strongly recommends that all entities do so. In general, the new rule addresses issues never covered under either UFAS or ADAAG (i.e., courthouses) and as such represents the best available information on how to design those facilities so that they are accessible. Willfully choosing to follow UFAS because it is less restrictive than ADAAG is risky. Making a "good faith" effort to comply with ADA means that you should comply with the best available references, which is ADAAG.

From a parking perspective, the most critical section of the Title II modifications to ADAAG is 14.0 Public Rights of Way, which greatly clarifies design standards for those areas. In particular, there is a section governing on-street parking that sheds light on the board's thinking about parking in general. Also, when parking structure construction requires reconstruction of sidewalks, curbs, and other construction in the public right-of-way, what "comes out" has to be "put back" in accordance with these standards.

A word of warning: every attempt has been made to quote directly from and adequately support and reference all of the design guidelines herein. The material from this chapter is organized to present all of the information relevant to an issue together, rather than in the sequence it is presented in each succeeding federal document. The author, as cochair of a committee on Accessibility for the Parking Consultants Council (PCC) of the National Parking Association (NPA), met with staff members of the Access Board and DOJ on several occasions to discuss issues relating to the design of parking, and to develop a model code for accessible parking requirements as permitted under the law. While the staff members of the Access Board and the DOJ gave us their best advice and opinions, the interpretations and clarifications of ADAAG given in the draft Model Code, which are also presented in this chapter, must be formally approved by the Access Board and the DOJ. Until that approval is received and any comments or reservations transmitted therewith are addressed, this chapter must be viewed as the opinions of the author based on the best available information.

An individual cannot begin to understand ADAAG without reading the Supplementary Information which was published with each rule in the *Federal Register*. The complete documents are available free of charge from the Access Board and the Department of Justice.

7.1.2 Existing Buildings

It is extremely important to note that Titles I, II, and III have distinct and different requirements, especially in regard to existing buildings. Title I says that **existing** areas of buildings that are used only by employees must only be modified when an employee with a disability needs such modifications. Figure 7-1 compares the major differences between

Existing

	Title II	Title III
Who	All public entities/all programs & services	Public accommodations
What	Programs & services must be readily accessible. Physical barriers must be removed only if necessary for accessibility to a program	Remove physical barriers where readily achievable or provide alternative means for providing goods & services
Where	All Facilities where programs and services are delivered. (Work Areas covered under Title I)	The areas of a building where the public receives goods or services (Work Areas covered under Title I)
Exceptions/ considerations	• Undue burden • Fundamental change in program	• Cost • Financial resources • Impact on operation
When	Three years from Jan. 26, 1992 > 50 employees July 26, 1992 < 50 employees	Ongoing
Standard	UFAS or ADAAG until DOJ rule adopting modified ADAAG is final	ADAAG

Figure 7-1. Comparison of rules for existing buildings.

Titles II and III regarding existing facilities. Title II states that programs and services must be accessible to the public unless it would be an **undue burden**. If that requires physical changes or removal of barriers in buildings, so be it. However, if governmental units can make a program or service accessible by relocating it to a part of the facility that is accessible, that's fine too. Title III requires that the existing physical barriers to accessibility in areas of a building where the public may go to receive goods and services be removed if **readily achievable** (Title III Rule 36.304(a)). According to DOJ, "Congress intended the undue burden standard of Title II to be significantly higher than the readily achievable standard of Title III" (Title II Rule, Supplementary Information Section 35.150). Thus while the state/local government has more flexibility to make a program or service accessible, it has a greater obligation to make existing programs and services accessible.

Bulletin #6 addressed one frequently asked question regarding existing parking:

> **Are accessible spaces required in existing parking lots and facilities?** ADAAG establishes minimum requirements for new construction or alterations. However, existing facilities not being altered may be subject to requirements for access. Title III of the ADA, which covers the private sector, requires the removal of barriers in places of public accommodation where it is "readily achievable" to do so. This requirement is addressed by regulations issued by the Department of Justice. Under these regulations, barrier removal must comply with ADAAG requirements to the extent that is readily achievable to do so. For example, if, when restriping a parking lot to provide accessible spaces it is not readily achievable to provide the full number of accessible spaces required by ADAAG, a lesser number may be provided. The requirement to remove barriers, however, remains a continuing obligation; what is not readily achievable at one point may become readily achievable in the future.

That last sentence is extremely important. Public accommodations are expected to remove barriers in small, affordable steps, but to continue to make improvements until all possible improvements have been made. This literally could mean years. Title II entities were given a specific date by which all programs and services must be made accessible (see Figure 7-1).

7.1.3 Alterations

An alteration is defined in ADAAG 3.4 as:

> An alteration is a change to a building or facility made by, on behalf of, or for the use of a public accommodation or commercial facility, that affects or could affect the usability of a building. Alterations include, but are not limited to, remodeling, renovation, rehabilitation, reconstruction, historic restoration. . . . Normal maintenance, re-roofing, painting or wall-papering, or changes to the mechanical and electrical systems are not alterations unless they affect the usability of the building or facility.

"Restoration," as generally defined in the parking industry, is a very broad term that includes anything from limited areas of crack and spall repair to extensive removal and replacement of concrete in floor surfaces. Application of traffic topping and sealers and minor spall repairs are all normal maintenance, equivalent to reroofing, and as such would not be considered alterations. However, a project involving extensive slab removal and replacement would be considered reconstruction or rehabilitation. Likewise, resurfacing and/or changes to the functional layout of a surface lot are alterations.

All sections relating to accessibility in alterations are not repeated here. A two-line summary might be as follows: Whatever is taken out, must be put back accessible unless it is technically infeasible (ADAAG, 4.1.6(1)). In addition, improvements to the path of travel to the area being altered must be made, up to a cost equal to 20% of the project budget (Title III, Rule 36.403(f)).

An example of putting something back accessible would be if a non-conforming curb at an elevator tower is removed during an alteration, a curb ramp fully meeting ADAAG should be put back in.

The path of travel requirement in ADAAG is qualified by a provision that it need only be improved if the area being altered is a primary function. As parking is the primary function in a parking structure, then major rehabilitation of a parking area will usually trigger a need to make improvements to the path of travel.

Figure 7-2 summarizes the requirements for alterations under Titles II and III. This is one area where there is a substantial difference between the requirements of UFAS and ADAAG. UFAS requires that what is taken out must be put back accessible; however, funds only need to be expended on the path of travel to that area if the cost of the alterations is equal to more than 50% of the market value of the building. For example, under ADAAG, a $1 million restoration project requiring extensive slab removal and replacement of the roof floor slab on a parking facility that has a market value of $5 million would be required to spend

Alterations

	Title II	Title III
Who	All public entities	Public accommodations & commercial facilities
What	• Altered elements/ spaces must be readily accessible to maximum extent feasible • Path of travel (silent)	• Same • Path of travel to areas of primary functions must be made accessible
Limitations for altered areas	• ADAAG (same as Title III) • USAF (silent)	• Unless technically infeasible
Limitations for path of travel	Only if cost of alteration > 50% of full fair market value of building (UFAS)	Must spend up to 20% of cost of all alterations on path of travel

Figure 7-2. Comparison of rules for alterations.

up to $200,000 more in improvements to the path of travel to the roof. This facility has only three levels and now has no elevator; it would be required to add the elevator in the restoration project even if there are no accessible parking spaces on the roof (see section 7.2.11), presuming it could be accomplished for $200,000. Under UFAS, no additional expenditure for an elevator would be required because the restoration project is less than 50% of the full market value of the structure.

Parking access and revenue control devices, including prefabricated cashier booths, are considered part of the electrical/mechanical equipment of the building, and replacement of such equipment is not an alteration unless changes in number, location, or layout of lanes are contemplated. Conversely, if the islands are being removed and rebuilt, then the cashier booth must be made accessible (see 7.2.12) unless it is technically infeasible to do so.

In parking facilities, routine maintenance and repair are also necessary to prevent extensive deterioration of floor surfaces and to maintain the structural integrity of the facility, which is analogous to maintaining and repairing roofing or paint that provides protection to the underlying surface or occupied space below. These maintenance items can include, but are not limited to: crack and joint repairs; patching; resealing; application of traffic toppings or membranes; and restriping parking areas. Such *preventive* maintenance is not considered an alteration under ADAAG. Resealing and restriping a parking lot is likewise maintenance, so long as the striping layout is unchanged.

Bulletin #6 confirmed the interpretation that resealing/restriping is normal maintenance but resurfacing/reconstruction is an alteration:

> **Is the restriping or resurfacing of a lot considered an alteration?** According to the definition of alteration, normal maintenance is not considered an alteration unless the usability of the lot is affected. For example, if a lot is to be resurfaced or its plan reconfigured, accessible spaces must be provided as part of the alteration. However, work that is primarily maintenance, such as repainting existing striping, may not trigger a requirement for accessible spaces. Although the work undertaken may not be technically considered an alteration, accessible spaces should be provided where the work, by its nature, makes the addition of such spaces possible.

It should be noted that restriping to add and/or relocate accessible spaces will be required in existing parking facilities that are associated with public accommodations, under the requirement to remove barriers. If restriping to add, locate, stripe, and sign accessible spaces in conformance with these guidelines has not been previously accomplished, making such improvements while resealing and restriping would in many cases be considered "readily achievable" and thus would be required as part of such projects.

Bulletin #6 continues:

> **Are accessible spaces required in alterations?** In alterations, the minimum number is based on the total number of spaces altered in each lot, although it is recommended that the full number of spaces required for new construction be provided where the opportunity to do so exists within the planned scope of work. Accessible spaces are required in each altered lot. However, accessible spaces can—and should—be located closest to accessible entrances even where such locations lie outside the altered area or lot.

A DOJ representative pointed out in a meeting with the PCC that the logic here is related to the fact that an alteration project presents increased opportunity to make accessibility improvements and therefore carries increased responsibility to do so. Therefore, if the three-level deck in the previous examples has 750 spaces, (250 on each level) the minimum number of space that have to be available in the facility after the alteration is seven (based on 250 spaces on the roof). However, if it is at all possible, the total number of accessible spaces in the facility should be increased to 15, of which two need to be van-accessible (see 7.2.1).

Bulletin #6 addresses the issue of what improvements are required in an alteration. Note that Bulletin #6 was written at the time that ADAAG was primarily oriented to Title III.

> **Is full compliance with ADAAG required in alterations?** In alterations, applicable ADAAG requirements must be met except where it is "technically infeasible" to do so. For example, if the resurfacing of a lot does not include regrading, it may be technically infeasible to meet the maximum 1:50 surface slope requirement for accessible parking spaces and access aisles due to existing site constraints. Similarly, if providing the number of accessible parking spaces specified by ADAAG would reduce the number of parking spaces in an altered lot below the minimum number required by a local zoning or land use code it may be technically infeasible to fully meet the ADAAG scoping requirement for accessible parking. For instance, if five accessible parking spaces are required, but the parking lot can only accommodate four accessible spaces and still meet the local code requirement for the total number of parking spaces, then four accessible parking spaces must be provided. However, many zoning adjustment boards are willing to grant limited waivers on the total number of required spaces if accessible spaces are provided.

Similarly, it is probably "technically infeasible" to provide the additional clearance for van-accessible stalls in existing parking structures with lesser clearance. However, the two van-accessible stalls must still be provided. Only the very specific portion of the requirements that is technically infeasible can be waived.

7.1.4 New Construction

Figure 7-3 compares the requirements for new construction under Titles II and III. Basically, they are very much the same at the level of the DOJ rules. However, there are a number of differences based on the evolution of UFAS to ADAAG. There was very little changed between UFAS and ADAAG, but a number of new requirements were added to the latter. The most difficult one for parking relates to the vertical clearance requirements for van-accessible spaces, which has a significant impact on parking structure design.

7.2 PARKING DESIGN UNDER ADAAG

The Access Board defined accessible parking in Bulletin #6 as follows:

> Accessible parking requires that sufficient space be provided alongside the vehicle so that persons using mobility aids, including wheelchairs, can transfer and maneuver to and from the vehicle. Accessible parking also involves the appropriate designation and location of spaces and their connection to an accessible route.

The following sections present the more critical issues relating to designing accessible parking under ADAAG. No attempt has been made to present the requirements of state and local codes which exceed the requirements of ADAAG and therefore supersede it in a design. The difference in requirements of UFAS is also not further discussed because

New Construction

	Title II	Title III
Who	All public entities	Public accommodations & commercial facilities
What	• All elements/ space must be readily accessible	Same
Limitations	• ADAAG (same as Title III) • USAF (silent)	• Unless structurally impracticable (*very* narrowly defined)

Figure 7-3. Comparison of rules for new construction.

TABLE 7-1. Required Number of Accessible Stalls

Total Parking in Lot	Required Minimum Number of Accessible Spaces
1–25	1
26–50	2
51–75	3
76–100	4
101–150	5
151–200	6
201–300	7
301–400	8
401–500	9
501–1000	2% of total
1001 and over	20 plus 1 for each 100 over 1000
Accessible Spaces	**Required Minimum Number of Van-Accessible Spaces**
1–8	1
9–16	2
17–24	3
25–32	4
33 and over	1 additional van-accessible space for every 8 accessible spaces

that issue will become moot when DOJ mandates the transition to ADAAG.

7.2.1 Required Number of Accessible Spaces

ADAAG 4.1.3(5)(a) states the basic requirement for number of accessible spaces as follows:

> If parking spaces are provided for self-parking by employees or visitors, or both, then accessible spaces complying with 4.6 shall be provided in conformance with the table below. Spaces required by the table need not be provided in the particular facility. They may be provided in a different location if equivalent or greater accessibility, in terms of distance from an accessible entrance, cost and convenience is ensured.

See Table 7-1 for the required number of accessible spaces. Bulletin #6 further clarifies this with:

> In new construction, the minimum number of accessible spaces is determined by the total number of spaces provided in a parking lot. If there is more than one lot, the minimum is determined lot-by-lot, not by the total number of spaces provided.

The operative phrase here is "new construction." The PCC attempted to get an interpretation that would allow the required number of spaces to be based on the entire supply of parking serving a building or complex of related buildings (such as a hospital, university, or shopping center) rather than the sum of the required number of spaces calculated lot by lot. Bulletin #6 definitively rejected the proposed PCC interpretation requiring that accessible spaces be added based on the parking capacity of each new facility, without regard to capacities or accessible spaces elsewhere on a site/campus. Thus, a university with thousands of spaces scattered in numerous facilities would still have to add 20 accessible spaces with the construction of a new 1000-space facility, rather than considering the facility as an incremental 1000 spaces to the system and thus only requiring 10 accessible spaces.

However, the Access Board and DOJ representatives stated that it might be reasonable for a private institution to bring the number of accessible spaces in existing facilities up to the number required if the system is taken in aggregate, and to concentrate its "readily achievable" improvements on making those spaces as compliant with ADAAG as possible. Note further that this applies only to existing visitor or general-purpose parking. A Title III entity will be required to add accessible parking to facilities that are restricted to employees only if and when an employee with a disability needs a stall, under the provisions of Title I of ADA. Certainly, it makes sense to have a reasonable number of accessible stalls based on the current needs of disabled employees, but there is no requirement for either public or private entities to add accessible stalls to existing employee parking facilities under ADA unless the lot is otherwise being altered or an employee specifically needs the improvements.

However, when the entity serves and/or employs an unusually high number of persons with disabilities and the table values clearly result in insufficient accessible spaces, the "reasonable accommodation" of Title I, the accessible programs and services requirements of Title II, and the readily achievable requirements of Title III will likely require the institution to add accessible spaces over and above the otherwise required number.

It should also be noted that the Access Board uses the term "lot" rather than "facility." The PCC had requested the term "facility" be used to encompass parking structures as well as surface lots and/or to clarify the interpretation of "lot," but the Access Board apparently declined to do so. The definition of "lot" can become an issue in situations where large lots are divided by nonparking access aisles/roadways or fire lanes, planting strips, etc. The classic example would be the large parking lot surrounding a shopping center. When questioned about such situations, the representatives of the Access Board stated that "lot" should be interpreted "in accordance with typical design industry practice." We posed several examples to them in order to query their thoughts on reasonableness of certain interpretations. *Remember that these conversations with Access Board and DOJ staff are to be considered "best available" interpretations, not official clarifications of the Access Board.* In general, if one can freely circulate from one section to another without going back out onto a public street, the entire facility can be considered one lot. However, where parking areas are separated and access is controlled so that one cannot circulate freely from one area to the other, it is probable they will be considered separate lots.

Conversely there is a possibility that parking structures that are broken into several parking areas with separate entrances, exits, and internal circulation systems could be considered multiple lots, with the number of spaces required in each area determined on a "lot-by-lot" basis.

As will be discussed in more detail later in this chapter, it is sometimes appropriate to provide the accessible spaces required in one facility in another location with better accessibility. This gets especially complicated if new facilities are constructed on existing lots. If a parking system already had accessible spaces to account for the existing parking capacity on the site, the net increase would have to be provided. For example, a 1000-space structure is to be built on a lot that previously had 400 spaces. In previous accessibility planning, eight accessible spaces were provided elsewhere. Twenty accessible spaces are required for the new structure; therefore 12 accessible spaces should be added to the parking system.

Note that those converted spaces must fully comply with new construction standards in terms of width, layout, floor slopes, the accessible route to the building entrance, etc. There will be no "readily achievable" limit on the reasonableness of the cost to convert closer spaces to accessible ones.

It should also be noted that the reference to cost in 4.1.2(5)(a) concerns the cost of parking to the user, not the cost of constructing the accessible spaces. Accessible parking cannot be relocated from a free or low-cost facility to one with a higher fee, thereby forcing a person with a disability to pay the higher fee. A person with a disability can either be given the same choices (distance/convenience versus price) or can be allowed to park in the closer facility at the same rate as charged in the more distant facility.

Nothing in the guidelines or the ADA requires that the disabled shall be afforded free parking when other parkers must pay.

7.2.2 Employee and Contract Parking

As previously noted, neither public nor private entities must add accessible spaces to employee parking lots until or unless the area is being altered or an employee needs an accessible space.

In response to requests for clarification from members of the National Parking Association who had major concerns about the loss of revenue in parking lots that are entirely leased to *monthly parkers* (none of whom require a disabled space), Bulletin #6 contained the following clarification:

> **Must accessible spaces be provided in lots where parking is assigned to individual employees or to paying customers?** ADAAG does not distinguish between lots or garages with assigned spaces and those without. Thus, in lots or garages comprised only of spaces that are leased or assigned to employees, accessible spaces are required. However, in such situations, policies regarding the use of accessible spaces may be feasible so long as they do not discriminate against persons with disabilities. For example, in lots reserved for employees only, accessible spaces may be used by persons without disabilities when they are not needed by employees with disabilities.

This is one of the most significant "new" interpretations in Bulletin #6. Note that it is written for new construction but would be equally applicable to existing and altered lots. In new lots or facilities reserved for employees, the required number of spaces must be designed to be fully accessible. However, they need not be marked or signed as accessible, and any employee can use them, until or unless a disabled employee needs the accessible stall. This interpretation applies to both new and existing parking facilities. Therefore, unnecessary disabled stalls need not sit vacant in employee-only facilities. Bulletin #6 further indicated and a DOJ representative confirmed that this would apply to a parking facility entirely leased to monthly parkers by a commercial parking operator. The operator need not provide preference to the disabled on a waiting list; however, it cannot skip over the disabled person at the top of the waiting list because it can't or won't convert a space to accessible. It must be noted that the entity that chooses not to identify

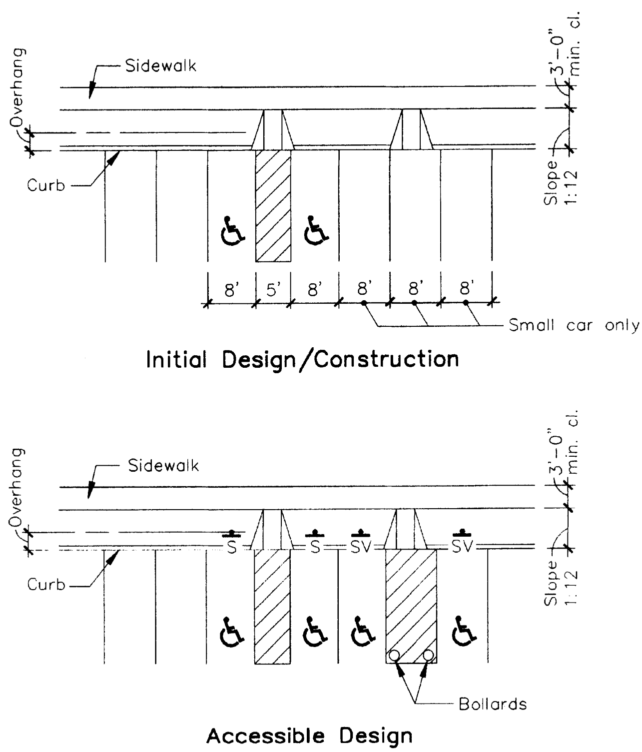


Figure 7-4. Design of employee spaces for future conversion to accessible.

and reserve the spaces as accessible must commit to bear whatever expense is necessary to convert the spaces to fully accessible under ADAAG when needed by a disabled parker. Figure 7-4 provides an example of how an area designed to provide accessible parking spaces might be constructed and used as nonaccessible spaces until needed as accessible. Note that curb ramps and the separate accessible route are already in place; the only cost of converting the spaces to accessible is adding signage. The pavement markings (including cross-hatching of the access aisles) and the bollards (to discourage use of the van access aisle) are optional but are strongly recommended, particularly when parkers have been able to park in those spaces in the past.

It should also be noted that students cannot be treated as employees under ADA and therefore student parking at colleges and universities would have to be treated as public parking. However, where student parking is provided entirely in lots reserved for permit holders, the institution would only have to reserve accessible spaces as required for the needs of a student with disabilities.

7.2.3 Medical Facilities

ADAAG 4.1.2(5)(d) provides special requirements for the number of accessible spaces at certain medical facilities:

> At facilities providing medical care and other services for persons with mobility impairments, parking spaces complying with 4.6 shall be provided in accordance with 4.1.2(5)(a) except as follows:
>
> (i) Outpatient units and facilities: 10 percent of total number of parking spaces provided serving each such outpatient unit or facility.
>
> (ii) Units and facilities that specialize in treatment or services for persons with mobility impairments: 20 percent of the total number of parking spaces provided serving each such unit or facility.

Bulletin #6 further clarified the application of these requirements:

> **Medical Care and Other Services for Persons with Mobility Impairments.** A greater number of accessible parking spaces is [*sic*] required at facilities providing medical care and other services for persons with mobility impairments. The term "mobility impairments" is intended to include:
>
> - conditions requiring the use or assistance of a brace, cane, crutch, prosthetic device, wheelchair or other mobility aid;
> - arthritic, neurological, or orthopedic conditions that severely limit one's ability to walk;
> - respiratory diseases and other conditions which may require the use of portable oxygen; or
> - cardiac conditions that impose significant functional limitations.
>
> At outpatient facilities, 10% of the parking spaces must be accessible. Facilities that specialize in medical treatment and other services for persons with mobility impairment are required to have 20% of parking spaces accessible. Other facilities (including medical care facilities) that do not provide outpatient services or specialized service for persons with mobility impairments are subject only to the general scoping requirement in the table in ADAAG 4.1.2(5)(a).

The question that immediately arose upon the issuance of ADAAG was whether or not doctor's offices, independent clinics, and immediate-care facilities would be considered outpatient facilities. Bulletin #6 continues with a clarification of the term "outpatient facility":

> **What is an outpatient facility?** An outpatient facility is part of a medical care facility, such as a hospital's clinic or ambulatory care center that

provides regular and continuing medical treatment to patients without overnight stay. As defined in the guidelines, medical care facilities are facilities in which the period of stay may exceed 24 hours and physical or medical treatment or care is provided where persons may need assistance in responding to an emergency. Under these guidelines, the term "outpatient facility" does not include doctors' offices, independent clinics, or other facilities not located in medical care facilities.

While the PCC had previously obtained the clarification that doctors' offices are not covered by "outpatient," the exclusion of independent clinics is a significant interpretation. The Bulletin #6 definition of outpatient tends to limit it to services provided at hospitals. Freestanding "immediate-care" and "surgicenters" that have no facilities for overnight stays (even if owned by a hospital) thus are not considered outpatient services unless located on a hospital campus. We have further clarified with the Access Board that facilities provided by teaching medical centers for doctors on the faculty to examine and prescribe treatment (as they would in a private practice) may be considered to be doctor's offices rather than outpatient services.

Bulletin #6 then clarifies the definition of specialized rehabilitation facilities:

Facilities and Units Specializing in Treatment or Services for Persons with Mobility Impairments. Facilities or units that specialize in treatment or other services for persons with mobility impairments, including vocational rehabilitation and physical therapy, must have 20% of parking spaces accessible. These are facilities in which the treatment or service specifically serves persons with mobility impairments, such as spinal cord injury treatment centers, prosthetic and orthotic retail establishments, and vocational rehabilitation centers for persons with mobility impairments. This requirement does not apply to facilities providing, but not specializing in, services or treatment for persons with mobility impairments, such as general rehabilitative counseling or therapy centers. In determining whether a facility is subject to this requirement, both the nature of the services or treatment provided and the population they serve should be carefully considered.

In one of the most important clarifications of Bulletin #6, the following was stated:

Do the 10% and 20% requirements apply to employee parking spaces as well? The higher percentages required for outpatient facilities or those facilities specializing in treatment and services for persons with mobility impairments are intended primarily for visitor and patient parking. If there are separate lots for visitors or patients and employees, the 10% or 20% requirement may be applied only to the visitor/patient lot while accessible parking could be provided in the employee lot according to

TABLE 7-2. Calculation of Required Accessible Spaces for a Hospital

Facility Name	Capacity	Minimum Accessible Spaces	
		New Hospital	Existing Hospital
Outpatient lot	182	18	18
Emergency lot	30	3	3
Visitor lot	430	9	9
Employee lot	973	19	6
Physician lot	308	8	3
Professional office bldg lot	929	19	19
Total	2852	76	58

> the general scoping requirement in the chart. If a lot serves both visitors or patients and employees, 10% or 20% of the spaces intended for use by visitors or patients must be accessible.

This makes compliance with the 10%/20% requirement much easier. Bulletin #6 continues:

> **If a hospital with an outpatient unit is served generally by one lot, must 10% of all spaces be accessible?** At medical care facilities where parking does not specifically serve an outpatient unit, only a portion of the lot would need to comply with the 10% scoping requirement. A local zoning code that requires a minimum number of parking spaces according to occupancy type and square footage may be an appropriate guide in assessing the number of spaces in the lot that "belong" to the outpatient unit. These spaces would be held to the 10% requirement while the rest of the lot would be subject to the general scoping requirement in the chart. Those accessible spaces required for the outpatient unit should be located at the accessible entrance serving the unit. This method may also be used in applying the 20% requirement to hospitals or other facilities where only a portion or unit provides specialized treatment or services for persons with mobility impairments.

The Access Board representatives stated that in the absence of a local zoning standard for required number of spaces for outpatient use, a parking study conducted in accordance with generally accepted practices (such as those outlined in the PCC publication *Parking Studies*[5]) could also be used to determine the proportion of the facility that is subject to the 10%/20% requirement.

Table 7-2 presents sample calculations for the required number of spaces for a hospital with multiple parking facilities. Two calculations are provided: The first assumes that all parking facilities are existing and that parking spaces are already in short supply. The institution is seeking to make "readily achievable" improvements in accessibility. The second assumes that the hospital is an entirely new campus, and that accessible parking requirements must be calculated lot by lot.

The number of accessible spaces should be calculated first for the parking provided to patients and visitors of outpatient units and units specializing in the treatment of mobility impairments, and then Table 7-1 shall be used to determine the required number of accessible spaces for the remainder of the parking provided.

Outpatient parking was calculated as follows:

emergency lot	30*10%=3
outpatient lot	182*10%=18

In the calculation, the total requirement using sitewide parking capacity for the existing hospital is calculated by the following, with the spaces then distributed to the lots closest to the accessible entrances:

outpatient and emergency lots (as above)		21
other parking	20+((2852+182-30-1000)/100=16.4=17)=	37
total accessible spaces		58

Note that we have provided the minimum number of spaces for the visitor/patient lots on the lot-by-lot basis and used the "credit" for the sitewide calculation to reduce the number of spaces in the employee lots. If/when the hospital had employees requiring more accessible parking, they would have to add accessible spaces under Title I.

Also, note that the requirement for "1 per 100" spaces does not allow rounding. 16.4 spaces needed means 17 spaces must be provided.

Note further that the "new" hospital would have to design the employee lot with 19 accessible spaces but would not have to designate/reserve those spaces as accessible until/unless it had employees requiring accessible parking.

Overall the required number of accessible spaces for the "new" hospital is 33% higher than if the required number of accessible spaces is based on the total capacity of parking on site.

This example demonstrates how crucial the interpretations of Bulletin #6 are for understanding the application of ADAAG and also how beneficial and reasonable these interpretations are.

7.2.4 Van-Accessible Spaces

ADAAG 4.1.2(5)(b) requires that some of the accessible spaces be specially designed for the use of persons employing vans for personal transportation:

> One in every eight accessible spaces, but not less than one, shall be served by an access aisle 96 in (2440 mm) wide minimum and shall be designated "van accessible" as required by 4.6.4. The vertical clearance at such spaces shall comply with 4.6.5. All such spaces may be grouped on one level of a parking structure.
>
> EXCEPTION: Provision of all required parking spaces in conformance with "Universal Parking Design" (see appendix A4.6.3) is permitted.

The 96-in-requirement translates to an 8-ft access aisle rather than the 5-ft access aisle as required for the remainder of the accessible spaces. (See Section 7.2.8 for layout of accessible spaces.) In addition, ADAAG 4.6.6 specifies a special clearance requirement of 8′2″ at van-accessible spaces:

> At parking spaces complying with 4.1.2(5)(b), provide minimum vertical clearance of 98 in (2490 mm) at the parking space and along at least one vehicle access route to such spaces from site entrance(s) and exit(s).

Special consideration must be made to provide this clearance at all elements in the vehicular path of travel, including structure at *hinge points*, lighting fixtures, and conduit, drain lines and other projections and appurtenances that protrude into the path of travel.

ADAAG Appendix A4.6.3 further illuminates the requirements:

> The increasing use of vans with side-mounted lifts or ramps by persons with disabilities has necessitated some revisions in specifications for parking spaces and adjacent access aisles. The typical accessible parking space is 96 in (2440 mm) wide with an adjacent 60 in (1525 mm) access aisle. However, this aisle does not permit lifts or ramps to be deployed and still leave room for a person using a wheelchair or other mobility aid to exit the lift platform or ramp. In tests conducted with actual lift/van/wheelchair combinations, (under a Board-sponsored Accessible Parking and Loading Zones Project) researchers found that a space and aisle width totaling almost 204 in (518 mm) was needed to deploy a lift and exit conveniently. The "van accessible" parking space required by these guidelines provides a 96 in (2440 mm) wide space with a 96 in (2440 mm) adjacent access aisle which is just wide enough to maneuver and exit from a side mounted lift. If a 96 in (2440 mm) access aisle is placed between two spaces, two "van accessible" spaces are created. Alternatively, if the wide access aisle is provided at the end of a row (an area often unused), it may be possible to provide the wide access aisle without an additional space. A sign is needed to alert van users to the presence of the wider aisle, but the space is not intended to be restricted only to vans.

The "revision" mentioned above is in reference to the fact that UFAS does not require van access spaces. During the preliminary rule making, some had argued that all spaces should be van-accessible; the PCC, among others, supported language similar to that which is now in ADAAG.

As an alternative to providing van-accessible spaces as detailed above, ADAAG allows the Universal Parking Space Design:

> An alternative to the provision of a percentage of spaces with a wide aisle and the associated need to include additional signage, is the use of what has been called the "universal" parking space design. Under this design, all accessible spaces are 132 in (3350 mm) wide with a 60 in (1525 mm) access aisle. One advantage to this design is that no additional signage is needed because all spaces can accommodate a van with a side mounted lift or ramp. Also, there is no competition between cars and vans for spaces since all spaces can accommodate either. Furthermore, the wider space permits vehicles to park to one side or the other within the 132 in (3350 mm) space to allow persons to exit and enter the vehicle on either the driver or passenger side, although, in some cases, this would require exiting or entering without a marked access aisle.

Bulletin #6 reinforced the concept of Universal Parking Spaces as follows:

> **Universal Parking Spaces.** As an alternative to providing both accessible and van-accessible spaces, "universal" parking spaces may be provided. Universal parking does not require the specific designation of van spaces since each accessible space can accommodate either a car or van. This design features wider parking spaces that are at least 11 feet wide with standard access aisles at least 5 feet wide. The wider space allows users to park to one side or the other of the space, which may ease transfer and travel from the vehicle, especially when an access aisle is provided on only one side of the space.

Clearly, you are not supposed to use Universal Parking Design only for van-accessible spaces; the intent is to use it for all accessible spaces. However, because it is essentially an upgrading of all accessible spaces to van-accessible requirements, it requires significantly more area and thus is little used except where local requirements mandate Universal Parking Design. Further using Universal Parking Design requires that all accessible spaces have the 8′2″ vertical clearance for van-accessible parking (see Figure 7-5).

Bulletin #6 provided the following commentary, which, while not particularly distinct or clarified from ADAAG, does reinforce the requirements as follows:

> **Accessible Van Parking Spaces.** The growing use of vans by persons with mobility impairments has led to a requirement for some accessible spaces that accommodate van users. Most often, vans are equipped with a lift or ramp at a side door. According to research sponsored by the Access

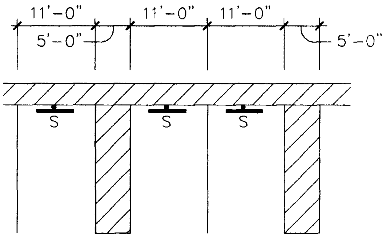


Figure 7-5. Universal parking design.

> Board, almost 17 feet in width is needed for the convenient deployment and use of a van-mounted lift. ADAAG requires the access aisle serving a van space to be at least 8 feet wide, as is the parking space itself, for a combined minimum width of 16 feet. Since accessible spaces may share an access aisle, a single eight-foot aisle can serve two van spaces without additional space impact.

This presumes that 90-degree parking is always provided. With *angled* parking, only the stalls with the access stall on the passenger side should be considered van accessible.

Some folks persist in trying to manipulate ADAAG requirements, such as the term "1 in 8." The requirement is not a percentage requirement which can be rounded. If nine accessible spaces are required, two must be van accessible, and so forth. To eliminate all possibility of misinterpretation, the Access Board provided a table for van-accessible spaces in Bulletin #6. The Bulletin #6 table is summarized in Table 7-1 previously presented.

> **Minimum Number of Van-Accessible Spaces.** One of every eight spaces is required to have an eight foot aisle to accommodate van users. Where spaces share access aisles, it is recommended that both spaces served by the 8 foot aisle be designated as "van-accessible."

Note that Bulletin #6 was issued before the Title II amendments to ADAAG which clarified the ability to share access aisles. (See section 7.2.8.)

Bulletin #6 goes on to address a frequently asked question:

> **Must van-accessible spaces be restricted to van use?** The required "van-accessible" designation, which should be located beneath the international symbol of accessibility, is intended to be informative, not restrictive, in identifying those spaces that are better suited for van use. It should not be interpreted as restricting the use of spaces to vans only. Additional signage may be provided recommending that cars not be parked in van-accessible spaces unless no other accessible parking space is available.

> This distinction could be particularly helpful in those lots where only one accessible space is required, since ADAAG requires that space to be van-accessible.

We recently encountered a design of a new structure that had severe restrictions on the development of the site. The project architect was able to design accessible parking meeting all requirements, except he was having extreme difficulty achieving the additional height requirements for van-accessible parking. The parking facility would serve a large outpatient clinic at an urban hospital, triggering the 10% accessible spaces rule. In fact, the hospital is part of a state university and technically can choose to follow UFAS, which doesn't require any van-accessible stalls. However, because the facility serves an ambulatory care center, the hospital administration wanted it to be designed to ADAAG. The overall required capacity of 500 spaces could not be achieved within the zoning height limitations while providing 50 accessible spaces of which seven are van accessible with 8′2″ clearance. Under the provision that allows van-accessible parking to be provided in another location where equal or greater accessibility is provided, the architect was proposing that all van-accessible parking be valet parked at no charge in an adjacent existing reserved parking area that had the required clear height. The van parking pick-up/drop-off would be closer and more easily accessible to the outpatient clinic. However, this denies the van driver the right to self-park when all other users can self-park. Many individuals don't like to turn their vehicle over to an attendant for valet parking. We suggested the design provide two self-park van-accessible spaces in the area proposed for valet pick-up and drop-off (which was easily accomplished) and valet park any additional vans at no additional cost to the parker.

7.2.5 Valet Parking

ADAAG addresses the unique differences between self-parking and valet parking in 4.1.2(5)(e):

> **Valet parking:** Valet parking facilities shall provide a passenger loading zone complying with 4.6.6 located on an accessible route to the entrance of the facility. Paragraphs 5(a), 5(b) and 5(d) of this section do not apply to valet parking facilities.

The requirements are further clarified in the Appendix A4.1.2(5)(e) Valet Parking.

> Valet parking is not always usable by individuals with disabilities. For instance, an individual may use a type of vehicle controls that render the

> regular controls inoperable or the driver's seat in a van may be removed. In these situations, another person cannot park the vehicle. It is recommended that some self-parking spaces be provided at valet parking facilities for individuals whose vehicles cannot be parked by another person and that such spaces be located on an accessible route to the entrance of the facility.

It should be noted that the term valet parking covers any facility wherein the parker surrenders the car to be parked by an attendant. Bulletin #6 provides further clarification:

> **Are accessible spaces required where valet parking is provided?** Parking facilities that provide valet parking only are not required to provide accessible spaces but must have an accessible passenger loading zone that is connected to a facility entrance by an accessible route. However, it is strongly recommended that some accessible parking be provided even if valet parking is available. Some vehicles may be specially adapted with hand controls only or lack a driver's seat and may not be operable by an attendant. In addition, accessible spaces must be provided if valet service is not available during all hours of operation for users who must sometimes retrieve or park their own vehicles.

While the above addresses most of the valet parking issues, one frequent problem was not covered—lots that are operated partially valet and partially self-park. Based on the other Bulletin #6 clarifications and interpretations (such as that for the calculation of spaces for medical facilities) as well as conversations with Access Board and DOJ staff, a reasonable determination of the maximum number of spaces which are self-parked at any one time can be used to calculate the number of accessible parking spaces required.

Another potential issue is whether or not an operator can valet-park the vehicles of persons with disabilities in lieu of providing accessible spaces. This might be considered a reasonable accommodation of accessible parking in certain circumstances where the provision of accessible parking is severely constrained by existing site conditions. For example, an existing garage has no parking at the grade level, and no elevator is provided to the two supported levels. It would not be "readily achievable" to provide accessible parking, and valet parking would be the most viable solution. However, the person with disabilities cannot be charged an additional fee for valet parking when no self-park accessible parking is provided. For new construction, if all other spaces are self-park, than self-park accessible spaces must be provided. One example of an extreme case for new construction where a small supplement of valet parking of vans is a reasonable design solution was covered under the discussion of van-accessible parking.

7.2.6 Passenger Loading Zones

ADAAG has distinct requirements for passenger loading zones, starting with 4.1.2(5)(c)

> If passenger loading zones are provided, then at least one passenger loading zone shall comply with 4.6.6.

In turn, ADAAG 4.6.6 requires:

> Passenger loading zones shall provide an access aisle at least 60 in (1525 mm) wide and 20 ft (240 in) (6100 mm) long adjacent and parallel to the vehicle pull-up space. If there are curbs between the access aisle and the vehicle pull-up space, then a curb ramp complying with 4.7 shall be provided. Vehicle standing spaces and access aisles shall be level with surface slopes not exceeding 1:50 (2%) in all directions.

Newly constructed passenger loading zones under ADAAG may discharge to a curb as indicated above; however, it is strongly preferred that the curb and sidewalk be gently sloped down to blend with the pavement elevation (see Figure 7-6). Note that improvements to an existing passenger loading zone can be made to bring it into reasonable compliance without meeting the full requirements for new construction. Bulletin #6 adds:

> **Passenger Loading Zones.** An accessible passenger loading zone is required only where passenger loading zones are specifically designed for passenger loading and unloading. Areas not so designed are not subject to this requirement even if, as a practical matter, some drivers may use them for this purpose. Both the pull-up space and adjacent access aisle are required to be level with surface slopes no greater than 2% in any direction. Since the 2% slope requirement applies to the entire aisle surface, curb ramps should be located next to—not within—the aisle, preferably at both ends. Further, there can be no obstructions, such as planters or street furniture, in the access aisle area.

ADAAG 4.6.5 covers the required vertical clearance at passenger loading zones:

> Provide minimum vertical clearance of 114 in (2895 mm) at accessible passenger loading zones and along at least one vehicle access route to such areas from site entrance(s) and exit(s).

One problem that has occurred is misunderstanding about the differences between accessible parking and passenger loading zones. In more than one case, a local building official has argued that all accessible parking spaces are passenger loading zones and thus must have the 9′6″

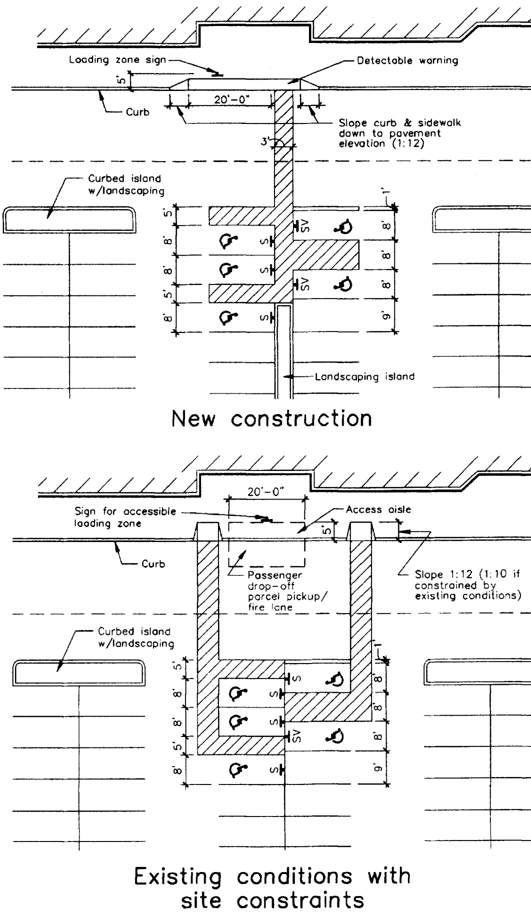


Figure 7-6. Comparison of solutions for new construction and existing facilities.

clearance. Clearly, this was not the intent of Access Board, since it specified a clearance of 8′2″ for van-accessible stalls. Bulletin #6 further addresses this issue:

> **Why does the vertical clearance for parking differ from that required for passenger loading zones?** Because vans used for accessible transit and *paratransit* may have higher roofs than those owned and used by most individuals, the minimum vertical clearance required for passenger loading zones (114 inches) is higher than the one specified for van-accessible spaces (98 inches).

7.2.7 Location of Spaces

ADAAG 4.6.2 addresses the location of accessible spaces:

> Accessible parking spaces serving a particular building shall be located on the shortest accessible route of travel from adjacent parking to an accessible entrance. In parking facilities that do not serve a particular building, accessible parking shall be located on the shortest accessible route of travel to an accessible pedestrian entrance of the parking facility. In buildings with multiple accessible entrances with adjacent parking, accessible parking shall be dispersed and located closest to the accessible entrances.

Bulletin #6 further clarifies one of the frequent issues of contention:

> **Must accessible spaces be provided in each lot or on each level of parking garages?** Accessible spaces can be provided in other lots or locations, or, in the case of parking garages, on one level only when equal or greater access is provided in terms of proximity to an accessible entrance, cost, and convenience. For example, accessible spaces required for outlying parking lots may be located in a parking lot closer to an accessible entrance. The minimum number of spaces must still be determined separately for each lot even if the spaces are to be provided in other lots or locations. Accessible spaces may be grouped on one level of a parking garage in order to achieve greater access. However, where parking levels serve different building entrances, accessible spaces should be dispersed so that convenient access is provided to each entrance.

In sum, accessible spaces can be grouped on one level of a parking garage or in one parking lot in order to achieve greater access. Further, accessible parking spaces need not be distributed to every floor of a parking structure or every lot on a campus, simply because that gives a person with disabilities equal access to all portions of the facility.

Parking is one of the areas in ADAAG where persons with mobility impairments are given preferential, not equal, treatment. Distance, convenience, and safety are the "standards of care" in locating the accessible spaces. Ideally, accessible parking spaces should be placed at the level(s) with direct accessible entrances and closest to those entrances if the facility serves building(s) on the same site, or if a freestanding facility serving multiple uses, the level with direct accessible exits to the public sidewalk. Among other things, this provides an accessible means of egress in the event of emergency. However, other requirements of ADAAG may dictate that accessible spaces be distributed to every floor. These requirements include providing the accessible spaces on level floor surfaces, providing an accessible route that does not pass behind a string of parked vehicles and providing the shortest possible travel distance.

Normally, accessible parking should be moved from remote parking. For example, a university building a new perimeter lot of say 500 spaces (nine accessible spaces required) can convert nonaccessible stalls (as required to provide nine accessible ones) in existing parking facilities closer to the accessible entrances of the building(s). However, if a shuttle service from remote parking provides more convenient access to buildings than the proposed accessible lot location, the accessible parking should be provided at the remote lot and the shuttle service should be accessible.

Bulletin # 6 also addresses specific locational issues related to van accessible spaces.

> Since this clearance may affect the design of multi-level parking structures, van-accessible spaces may be grouped on one level of the structure; providing van-accessible spaces outside parking structures should not be considered as an alternative if equivalent convenience is not provided. Moreover, placement of accessible spaces outside a parking structure may be considered discriminatory if it is not part of an integrated setting and if the same amenities of interior parking, such as weather protection, security, and convenience, are not provided.

This discussion specifically addresses the often-proposed avoidance of the required van clearance in structures by placing the van-accessible spaces in an adjacent surface lot. The Access Board essentially says that this usually does not provide equivalent or better accessibility and thus is not permissible. In weighing the balance between distance, safety, and convenience, climate may be a major factor. Because of the time it takes for a person using a wheelchair to exit a van or transfer to a wheelchair from a car, there is a particular concern with relocating accessible spaces from a structure to a surface lot. Climate protection during this unloading process may be more beneficial than a short path of travel. Because lifts are associated with vans, it is thus more critical to have the van-accessible spaces under cover in the structure if possible. Of course, this then triggers the requirement for 8′2″ clearance. If the surface lot is otherwise more accessible, i.e., much closer, it might be acceptable if a canopy or covering is provided at the accessible spaces. However, relocating all accessible spaces, including the van-accessible spaces, from a remote surface lot to one adjacent to the building would be permissible, because weather is a problem in either location.

The language of various sections of ADAAG puts a high priority on locating accessible spaces as close as possible to the accessible entrances of the associated buildings. Note that the portion of the route traversed via elevator is considered to be "zero" travel distance. The Access

Board considered adopting a specific maximum distance within which accessible spaces must be located. However, it did not mandate a specific maximum distance. (See also A4.3.1 of ADAAG for a discussion of path of travel distance.) For reference, the Canadian accessibility guideline mandates a maximum distance of 83 ft; some other guidelines have maximum distances of 100 to 200 ft. A maximum distance of 100 ft is recommended by the PCC where feasible. However, the recommendation of a certain distance is not a license to provide the spaces anywhere within 100 ft. The spaces must still be the closest to the accessible entrance.

Convenience may also be a factor in determining an appropriate travel distance. Examples of how the distance/convenience/safety balance must be weighed are as follows:

Example 1: An employee-only parking facility is to be built at a walking distance of more than 500 ft from the pedestrian entrance of the parking structure to a hospital. Adjacent to the hospital entrance is a surface parking lot, in which the accessible parking spaces can be placed within a walking distance of less than 50 ft. In this case, the accessible parking spaces otherwise required in the parking structure should be placed in the surface lot, so as to minimize the distance of the accessible route.

Example 2: In the same circumstances as example 1, except that the travel distance is 100 ft, and there is a steep site slope along the path of travel. To achieve an accessible route, extensive ramping with several rest areas will be necessary. Again, placing the spaces in the surface lot is preferable.

Example 3: In the same circumstances as example 1, the owner elects to construct a pedestrian bridge from the parking structure to the hospital. In this case, the convenience of the protected bridge provides a better level of accessibility than the shorter path from the surface lot. Thus, the accessible spaces should be in the structure.

However, nothing in the guidelines should be construed as requiring a pedestrian bridge in such circumstances. There are alternative means of providing a reasonable degree of weather protection, such as locating the accessible spaces under a canopy.

The spaces are to be located so that the greatest degree of accessibility is achieved and the shortest possible path of travel in the pedestrian mode results. For example, a parking facility may have a small area created by the ramping system that provides an ideal location for accessible spaces. This area is highly convenient but out of the path of high vehicular traffic volumes, as seen in Figure 7-7. Locating the accessible spaces in sight of the cashier or security station may also discourage violation of the spaces by persons without disabled parking permits.

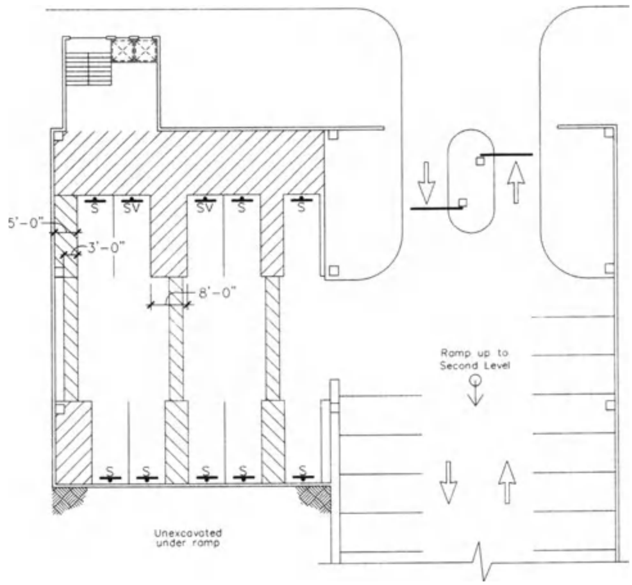


Figure 7-7. Accessible parking in dedicated bay.

Thus locating all accessible spaces at grade level and without passing directly behind parked vehicles is often the most desirable solution.

7.2.8 Layout of Accessible Spaces

ADAAG section 4.6.3 is one of the most frequently misinterpreted, and most often violated, sections relating to parking:

> Accessible parking spaces shall be at least 96 in (2440 mm) wide. Parking access aisles shall be part of an accessible route to the building or facility entrance and shall comply with 4.3. Two accessible parking spaces may share a common access aisle. Parked vehicle overhangs shall not reduce the clear width of an accessible route. Parking spaces and access aisles shall be level with surface slopes not exceeding 1:50 (2%) in all directions.

The required width of the access aisle was specified with the required number of accessible spaces in 4.1.2(5)(a):

> Except as provided in (b), access aisles adjacent to accessible spaces shall be 60 in (1525 mm) wide minimum.

The reference to paragraph (b) is to the required 8 ft width of access aisles for van-accessible spaces.

An essential consideration of any design is having the access aisle level with the parking space. Since a person with a disability using a lift or ramp must maneuver within the access aisle, the aisle cannot include a ramp or sloped area. The access aisle must be connected to an accessible route to the appropriate accessible entrance of a building or facility. The parking access aisle must either blend with the accessible route or have a curb ramp complying with 4.7. Such a curb ramp opening must be located within the access aisle boundaries, not within the parking space boundaries. Figure 7-8 presents "dos and don'ts" for detailing access aisles and curb ramps. Curb ramps in access aisles seem to be a particular pet peeve of the Access Board, as indicated in conversations with staff and hinted in Bulletin #6.

> **Can curb ramps be provided within the access aisle?** The maneuvering necessary to enter or exit vehicles and to transfer to and from wheelchairs requires that all accessible spaces, access aisles, and passenger loading zones be level, with slopes no greater than 2% in any direction. This does not apply to an entire parking lot or level of a parking structure but does include connecting accessible routes which cannot have cross slopes greater than 2%. For safe transfer, access aisles must be level for their full length. Thus, curb ramps, including built-up ramps, are not permitted within the area—the full length and width—of access aisles serving either parking spaces or passenger loading zones. Curb ramp openings must be located at the boundary of the access aisle, not the parking space, so that the ramp is not blocked by a parked vehicle. In addition, the required size of access aisles and width of the accessible route cannot be reduced by planters, curbs, or wheel stops.

The PCC has previously received a clarification which allows the curb ramp to begin at the curb face when vehicles overhang a curb, as shown in Figure 7-8.

Accessible stalls may not be designed as parallel parking stalls discharging to a curbed sidewalk. It is extremely difficult for a person with a disability that requires the use of crutches or a wheelchair to get out of a vehicle parked close to a curb. If parallel parking is to be used, the stall must be pulled away at least 5 ft from the curb face, to provide an overall width of 13 ft. The interim guidelines for on-street parking specifically require a similar access aisle at the street elevation, rather than discharging to a sidewalk.

Vehicle overhang must not intrude into either the access aisle or accessible routes. While the typical vehicle overhang is 2′6″ or less, a few vehicles have front overhangs of as much as 3 ft, and if a vehicle is backed into the stall, the overhang may be much greater. Since the

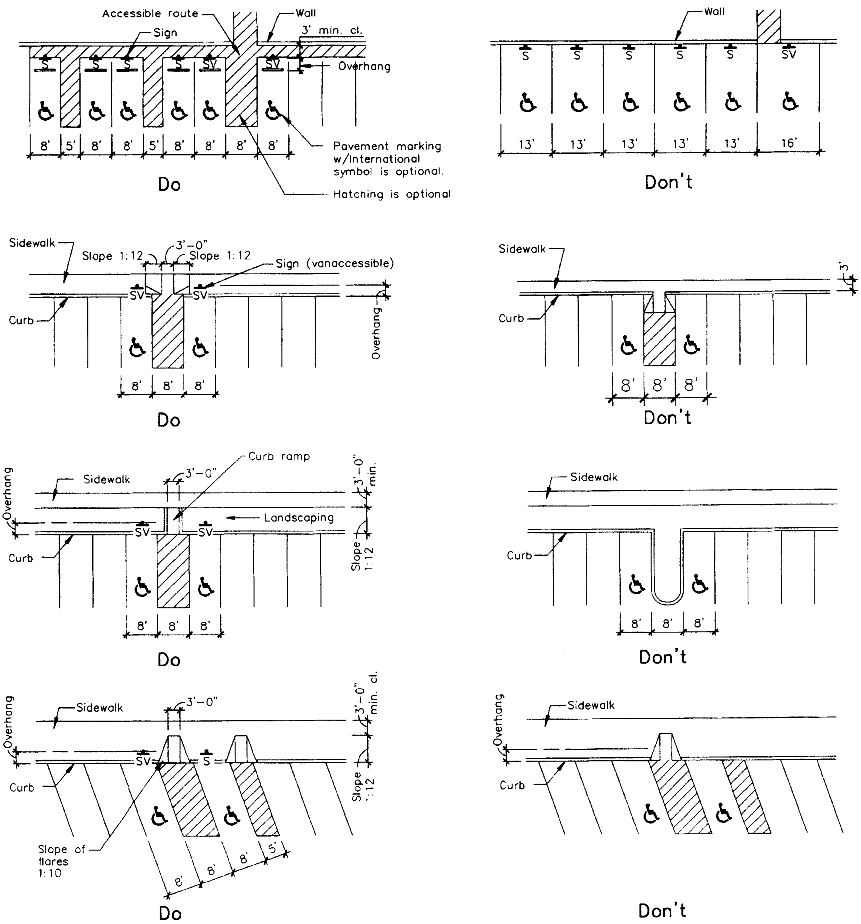


Figure 7-8. Dos and don'ts for accessible parking layout.

guidelines essentially require a sign at each stall, the sign post can be reinforced to serve as a vehicle stop. Setting the post 3 ft from a curb or wheel stop may save wear and tear on the post while still preventing intrusion into the accessible route (see Figure 7-8).

According to the ADAAG Supplementary Information in the *Federal Register* of July 26, 1991, access aisles shall be demarcated; a single wide space is not acceptable (see Figure 7-8). Although not required by ADAAG or other guidelines for pavement markings such as the *Manual on Uniform Traffic Control Devices* it is generally advisable to cross-hatch the access aisle, the accessible route (if it uses a vehicular route), and any marked crosswalks, to improve *visibility* to all drivers and pedestrians in the facility.

Another contentious issue for the parking industry has been the sharing of access aisles. There is no specific requirement in ADAAG that the access aisle be on one side or the other of the parking space; indeed, it states that access aisles may be shared and provides a detail with a shared access aisle. However, the detail shows 90 degree parking into which vehicles can pull either forward or back to keep the access aisle on the side needed by the person with disability.

Bulletin #6 addressed this issue:

> **Is "front-in" only parking prohibited by ADAAG?** Accessible spaces are required to be served by an access aisle which can be placed on either side of the parking space. Drivers may pull in or back in to perpendicular parking spaces depending on which side of the space is served by an access aisle and whether a person with a disability wishes to exit the vehicle from the driver's or the passenger's side. Accessible spaces that drivers can only pull into do not afford the same level of flexibility. ADAAG does not specifically address or prohibit "front-in" only parking. Thus, it is recommended that where such parking is provided, accessible spaces be designed so as to allow "back-in" parking also or that access aisles be provided to serve each side of a space. With respect to van-accessible spaces, it is recommended that the access aisle be provided on the passenger side of spaces since van side doors and side-mounted lifts are typically located on the passenger side.

During the early meetings with the Access Board staff, the PCC presented drawings of angled stalls sharing the access aisle, and were told that it was acceptable, because disabled drivers can use the stall with the aisle to the left, while those who need passenger-side access will use that to the right. It was agreed that van-accessible stalls must always have the access aisle on the passenger side when "front in" only parking is provided. The Access Board used the word "recommended" in Bulletin #6, which seems to indicate that they would continue to accept shared access aisles with *angled* parking. However, in the Title II modifications to ADAAG, they addressed the issue head-on. Section 14.2.6(1)(b)(ii) allows shared access aisles with perpendicular parking, but paragraph (iii) does not allow the same for angled parking. The discussion in Appendix A14.2.6(1) clearly states the Access Board position:

> Parallel and perpendicular accessible spaces allow a driver to locate the access aisle on either the passenger side or driver side as necessary for transfer and therefore may share access aisle. Because angled spaces are approached only from one direction, a driver cannnot always select a

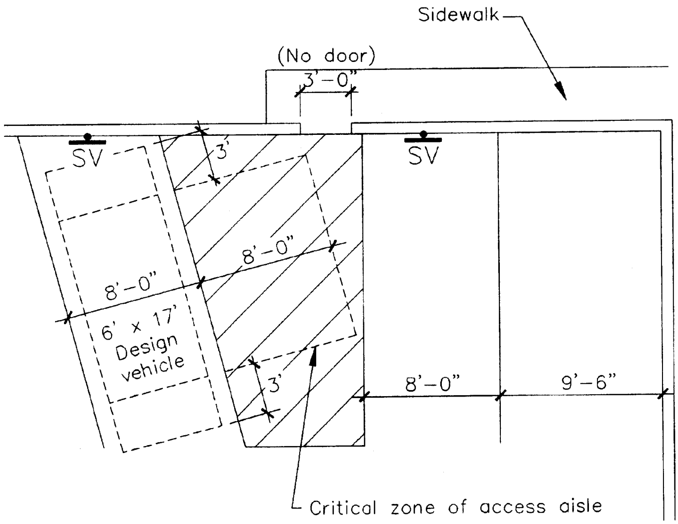


Figure 7-9. Critical zone of the access aisle.

space with an access aisle that will accommodate the desired transfer. Therefore, angled parking spaces may not share an access aisle.

Technically, this paragraph only applies to on-street parking, and further, is not yet law, pending the completion of DOJ rule making. The Access Board does plan (and has reserved the right) to issue supplemental rules modifying ADAAG at certain intervals, and it seems highly likely that the prohibition of shared access aisles with angled parking will be specifically applied to off-street parking at that time.

In parking structures, it is frequently difficult to lay out accessible parking without some intrusion of columns or other appurtenances into parts of the access aisle. At the same time, there are inherently "dead zones" wherein intrusions can be accommodated. Also while the access aisle must be 5 ft wide (8 ft for van spaces) in the area of door opening, the width of the junction with the accessible route need only be 3 ft. There is no requirement for length of the accessible parking stall in ADAAG. Angled parking further complicates the situation. To ensure that the access aisle is functional in situations in question, the designer should draw a *design vehicle* parked in the stall (see Figure 7-9). As discussed in Chapter 2 on parking *geometrics*, a design vehicle of 6 ft × 17 ft would be appropriate. Also as noted in that section, a full-size vehicle will leave an average gap of 8 in to the wall. Next, draw a box with a 3-ft clearance from each end of the vehicle for the length and with the width of the required access aisle. According to data from the Motor Vehicle Manufacturer's Association, the vehicle doors will be located no closer to either end of a vehicle than 3′0″. (In most cases the dimension is about 4 ft for front clearance to doors and up to 6 ft for clearance from the rear of the car.) No *encroachment* into the box shall be tolerated, and a 3-ft minimum width shall be provided if the accessible route passes through the area beyond the "zone of critical access." If, however, the area outside the zone is not part of an accessible route, encroachment can be tolerated.

7.2.9 Accessible Route to Destination

The accessible route is the path of travel from the accessible stall (and specifically from the access aisle) to an accessible entrance of the building(s) served by the parking. ADAAG 4.1.2 requires:

> Accessible sites and exterior facilities shall meet the following minimum requirements:
>
> (1) At least one accessible route complying with 4.3 shall be provided within the boundary of the site from public transportation stops, accessible parking spaces, passenger loading zones if provided, and public streets or sidewalks, to an accessible building entrance.
>
> (2) At least one accessible route complying with 4.3 shall connect accessible buildings, accessible facilities, accessible elements, and accessible spaces that are on the same site.
>
> (3) All objects that protrude from surfaces or posts into circulation paths shall comply with 4.4.
>
> (4) Ground surfaces along accessible routes and in accessible spaces shall comply with 4.5.

We have not reprinted all of the applicable references. However, several issues need to be addressed in any discussion of accessible routes related to parking. First an accessible route may have a running slope of 5% and a cross slope of 2%. These requirements are stated in more definitive units of 1:20 and 1:50 slope, respectively. This is another area where the mathematical result cannot be rounded. A slope of 1:19 is no longer an accessible route but an accessible ramp, with requirements for level landings, handrails, etc.

As long as the parking floor does not exceed 5.0% slope in the main direction of travel and 2.0% cross-slope, the parking floor can meet the requirements for an accessible route. A contentious and frequently ignored issue relating to parking layout is whether or not the accessible route from an accessible stall can pass behind parked vehicles. Bulletin #6 provides this clarification:

> **Is the accessible route leading from accessible spaces prohibited from being located behind other spaces?** Access aisles must connect to an accessible route leading to an accessible entrance of a facility. ADAAG Fig. 9, which illustrates an access aisle shared by two accessible spaces, does not require a specific configuration for the connecting accessible route. However, it is strongly recommended that the accessible route not require travel behind other parking spaces since persons who use wheelchairs are not easily visible to drivers. Where this is not possible, the accessible route should run behind accessible parking spaces only.

The critical phrase is "strongly recommended." The Access Board has stated that each design should take into consideration and balance "distance, safety, and convenience." It does not mandate certain things like maximum walking distances or separated accessible routes because it does not want to eliminate what might otherwise be the preferable design. The representatives of the Access Board and Department of Justice stated that in new construction, the accessible route should not pass behind other spaces, even in parking structures, except in the most extreme circumstances. The PCC developed a number of examples of how to achieve an accessible route without passing directly behind parked vehicles and without excessive cost.

In alterations, it will have to be "technically infeasible" to provide a separated accessible route to avoid providing one. For an existing facility, the Access Board staff agreed that it may not be "readily achievable" to get a separated route in many cases; however, options that minimize the number of vehicles passed will be strongly preferred.

One objection to the requirement for a separate accessible route is that it is very difficult and occasionally very expensive to achieve in facilities with a large number of accessible spaces. In one recent Walker project with 10,800 parking spaces in a single structure, 118 accessible spaces are required. For both accessibility and operational reasons, it is appropriate to group all of these spaces on the level connecting with a pedestrian bridge to the destination, the only such access. Providing 118 accessible spaces was achieved with separated accessible routes, in an area that is approximately 300 ft × 200 ft. The efficiency of this area is thus about 508 sq ft per car, adding less than 20,000 sq ft to a facility with more than 3.5 million sq ft of parking area.

The clarifications in Bulletin #6 relating to the 10%/20% standards for outpatient/mobility impairment facilities (applying them only to visitor/patient parking facilities) do reduce the number of spaces required in those circumstances, making it more feasible to provide separated routes.

Conversely, the ADAAG definition of "accessible route" clearly indicates that crosswalks across vehicular routes may be part of the accessible route. ANSI requires that crosswalks in the accessible route be marked; the definition of "marked crossing" in ADAAG likewise implies that crosswalks should be striped. A number of individuals have argued that the accessible route in parking facilities should never use or cross vehicular routes. The 1991 edition of the Uniform Building Code states, "When practical, the accessible route of travel shall not cross lanes of vehicular travel. When crossing vehicle travel lanes is necessary, the route of travel shall be designated and marked as a crosswalk."

While it is preferable that the access aisle connect to the accessible route at the front of the stall and that vehicular routes not be crossed, this is simply not possible in many circumstances. In many cases such as shopping centers and day care centers, the local code or design considerations require that a fire lane and/or drop-off be provided adjacent to the building. The perimeter of the lot, where accessible spaces might be placed with a dedicated accessible route, may be at a far greater distance from the building entrances (see Figure 7-6). A dedicated accessible route may often be coordinated with landscaping islands and parking geometrics in new construction, but it may not be "readily achievable" in an existing center or "technically feasible" in an alteration. As another example, a rehabilitation hospital with 200 visitor/ patient parking spaces would be required to provide 40 accessible parking spaces. It would in such a case be virtually impossible to provide a dedicated accessible route at the front of all of the accessible stalls. Crossing the vehicular route is clearly preferable.

Structural constraints in parking facilities also make it difficult to provide a dedicated access route in a configuration similar to those in Figure 7-8. The need to provide a relatively level floor surface at the accessible spaces also complicates the design.

There are a number of solutions to maximize the convenience and safety of the accessible spaces. For example, if the access aisle also serves as the circulation path into the elevator tower, accessible spaces can be provided at each level. If a few additional spaces are required on some or all of the levels, reducing the angle of parking by 15 to 20 degrees will permit development of a separated accessible route (per Figure 7-10). This results in a safe path of travel as well as one that is much shorter than an alternative design with parallel parking such as the "don't" example shown. The latter design also requires a parking

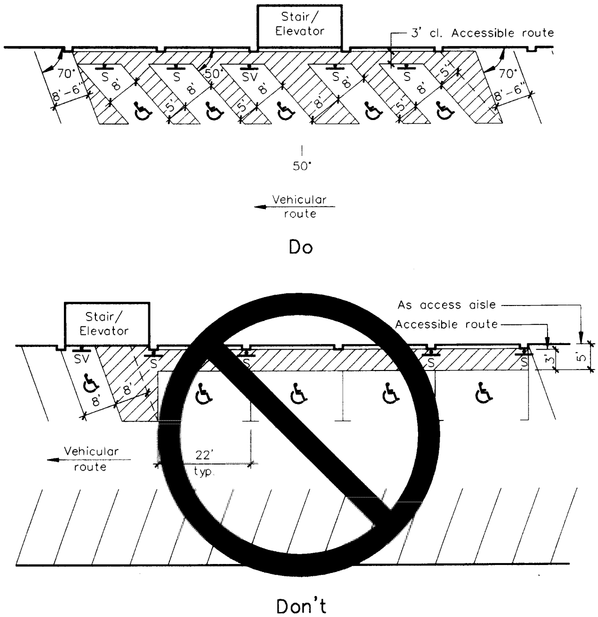


Figure 7-10. Layout of accessible parking with a separated accessible route in a parking structure.

maneuver that is much more difficult—particularly for the disabled—than that required in the preferred layout and would provide access aisles only on the passenger side of the vehicle, forcing a disabled driver to exit the vehicle into a lane of vehicular travel. Further, a person with a rear-discharging lift could only use the van-accessible stall, which, being the most desirable, is the most likely to be occupied. Another solution that is acceptable is the corner layout in Figure 7-11, where one stall can be pulled out from the wall to provide the route, without impeding vehicular traffic flow.

However, with the increasing size of parking structures, and the number of accessible spaces in such large facilities, it may be impossible to locate accessible spaces in a cluster around the elevator towers, and a string of spaces at one or more levels may simply be required to meet the required number of spaces.

One of the most controversial requirements of ADAAG, detectable warnings, has been suspended. As noted in Bulletin #6:

> The Access Board has voted to temporarily suspend the requirement for detectable warnings on curb ramps and at hazardous vehicular areas

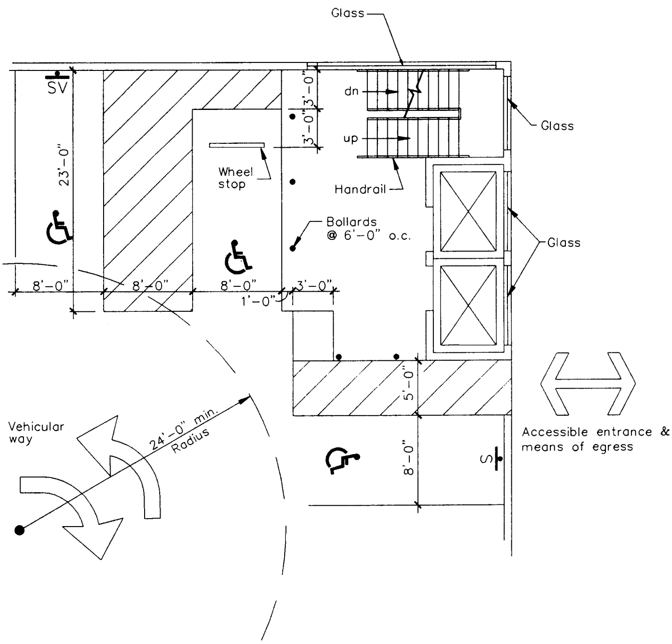


Figure 7-11. Separated accessible route provided at a corner stair tower.

> and reflecting pools until July 1996 pending the completion of further research. . . .

The detectable warning requirement was officially suspended at the November 10, 1993, meeting of the Access Board. A bulletin that clarifies the requirements and specifications for detectable warnings is available from the Access Board.

7.2.10 Signage

The signage requirements of ADAAG are designed to allow visually impaired persons to achieve at least a minimum degree of freedom to move about independently. Some have argued that it is ridiculous to require a Braille sign in a parking facility when at least one member of the party must have good enough sight to pass a driving test. However, there are circumstances where a visually impaired person might separate from the rest of the party in the parking area and have to return to the vehicle alone later. Therefore, ADAAG does require that signs in parking facilities meet the same requirements as those for buildings.

Signage of parking facilities is subject to the general requirements of ADAAG 4.1.2(7):

> Signs which designate permanent rooms and spaces shall comply with 4.30.1, 4.30.4, 4.30.5, and 4.30.6. Other signs which provide direction to or information about, functional spaces of the building shall comply with 4.30.1, 4.30.2, 4.30.3, and 4.30.5. Elements and spaces of accessible facilities which shall be identified by the International Symbol of Accessibility and which shall comply with 4.3.0.7 are:
>
> (a) Parking spaces designated as reserved for individuals with disabilities;
>
> (b) Accessible passenger loading zones;
>
> (c) Accessible entrances when not all are accessible (inaccessible entrances shall have directional signage to indicate the route to the nearest accessible entrance);
>
> (d) Accessible toilet and bathing facilities when not all are accessible.

ADAAG section 4.6.4 further clarifies signage requirements for parking spaces:

> Accessible parking spaces shall be designated as reserved by a sign showing the symbol of accessibility (see 4.30.7). Spaces complying with 4.1.2(5)(b) shall have an additional sign "Van-Accessible" mounted below the symbol of accessibility. Such signs shall be located so they cannot be obscured by a vehicle parked in the space.

As discussed in Chapter 6, signs designed to provide direction to drivers and pedestrians within parking areas will routinely exceed the requirements of 4.30.1, 4.30.2, 4.30.3, and 4.30.5, which apply to signs providing direction, and those requirements are therefore not reprinted herein. It is advisable that these signs comply, to a reasonable extent, with the requirements of the *Manual on Uniform Traffic Control Devices* (see Chapter 6), particularly in the use of international symbols and shapes. This will aid visibility to the moderately visually impaired.

Another type of signage commonly found in parking areas is location indicators, which help the parker remember where the vehicle is parked. Because there is no standardized location and mounting of location indicator signs, it is not appropriate or necessary to put raised and brailled letters on those signs when mounted in parking areas.

The guidelines will require careful attention to the design (particularly to section 4.30.4, requiring raised and Braille letters) and location of signs "designating permanent rooms and spaces." Typically the only such signs in parking facilities are those identifying the entrances to stair/elevator towers, and code-required exit signs both of which "designate permanent rooms and spaces." The need for the visually impaired to stop, find, and "feel" the sign designating the stair/elevator tower entrance may require provision of a larger area protected from vehicle intrusion than has traditionally been provided at the entrances to these towers. It should also be remembered that ADAAG requires that a sign with raised and Braille letters for the visually impaired be mounted below all code-required exit signs.

Regarding the signage of accessible parking spaces, ADAAG requires that each parking stall be marked with a sign that will not be obscured by a vehicle parked in the stall. Bulletin #6 states:

> **Must a sign be provided at each accessible parking space?** While ADAAG requires parking spaces to be designated by the access symbol, it does not specifically require the designation of each space. Alternatives to signs at each space are allowed so long as spaces reserved for use by persons with disabilities are clearly designated and distinguished from other parking spaces.

Neither one or two signs with arrows indicating a long string of accessible stalls nor pavement markings alone are acceptable. Although not required by ADAAG, it is desirable to add a sign indicating the fine for violation under the symbol for accessibility, as this increases voluntary compliance.

As discussed above, ADAAG does not provide a specific guideline for mounting height of signs at accessible parking spaces. As stated in Bulletin #6:

> **At what location and height is signage to be mounted?** ADAAG does not include a specific location or minimum height for signs but requires them to be placed so as not to be "obscured" by a car or van parked in the space. Access symbols provided on the surface of the space do not meet this requirement. Posted signage is typically placed in front of the space but signs can also be mounted on walls or other elements that are in close proximity to the space. Since many local codes address the height of exterior signage, a minimum mounting height is not specified in ADAAG.

ADAAG does require that signage designating permanent rooms and spaces be centered 5 ft above the finished floor. Some have argued that the bottom of the sign must be 80 in. above the ground if mounted on a signpost to meet the protruding objects requirements. However, section 4.4.1 specifically allows that objects mounted on posts may overhang 12 in. maximum in any direction between 27 in. and 80 in. above the ground, so long as the accessible route is not reduced below 36 in. width. Thus a 24-in.-wide sign designating accessible parking spaces may be mounted centered on a post at a height of 5 ft or so. UBC-91 requires that the sign be centered 3 ft to 5 ft above the pavement; the State of California requires that the bottom of the sign be 6′8″ above the pavement if it protrudes into a circulation path, but allows signs on walls or posts not protruding to be mounted with the bottom 3 ft above the pavement. It should be noted that none of these requirements will ensure that the sign is visible when a van is parked in the stall. This can only be accomplished by placing the sign to the side with an arrow toward the stall or in the access aisle. Since the access aisle is required to be at least 5 ft wide, while the curb ramp or other connection to the accessible route need only be 3 ft wide, the sign may reasonably be put to one side of the access aisle—i.e., toward the center of the combination of stall and access aisle.

Bulletin #6 also states:

> **What are requirements for the size and color of signs?** ADAAG requires accessible spaces to be designated by the international symbol of accessibility but does not address the color or size of parking signs, which may be regulated by local code. The "van-accessible" designation is subject to requirements for informational signage found in ADAAG 4.30 and must comply with the specifications for character proportion (4.30.2), height (4.30.3), and sign finish and contrast (4.30.5).

Finally, Bulletin #6 addresses specifications for striping:

> **Does ADAAG contain specifications for the striping of parking spaces or the designation of accessible spaces on the surface of the parking space?** ADAAG does not specify the method or color in which accessible spaces are striped nor does it require placement of the access symbol on the surface of parking spaces. Local codes, not ADAAG, may contain requirements for the striping of spaces, including color, and any surface decals or designations.

7.2.11 Accessibility of Remainder of Facility

An important concept to understand is that even when all accessible spaces are located on the grade level, the rest of the building must meet applicable sections of ADAAG. For example, all doors and hardware must meet ADAAG. Elevators must meet ADAAG. This is based on the premise that a person needing some of those features may not qualify for a disabled parking permit or may not have it with them.

Some have argued that parking structures are "exterior facilities," not "buildings," as defined in ADAAG, and thus none of the items scoped in section 4.1.3 (Accessible Buildings: New Construction) are applicable to parking structures. This seemed to be reinforced by the following language in the ADAAG Supplementary Information (4.1.3(9)), page 35240 of the *Federal Register* July 26, 1991:

> The scoping provisions of 4.1.3(9) do not apply to exterior facilities covered by 4.1.2. For example, parking lots and open parking structures are only covered by 4.1.2 and are not required to comply with the scoping provisions of 4.1.3(9) for areas of rescue assistance.

However when we asked the ATBCB staff to clarify the classification of open parking garages as exterior facilities not subject to all of the scoping in 4.1.3, the staff stated that they never intended to exempt parking structures from all requirements in 4.1.3 and that parking structures are clearly buildings subject to 4.1.3.

ADAAG A4.1.3(5) requires that:

> One passenger elevator complying with 4.10 shall serve each level, including mezzanines, in all multi-story buildings and facilities unless exempted below. If more than one elevator is provided, each full passenger elevator shall comply with 4.10. EXCEPTION 1: Elevators are not required in facilities that are less than three stories or that have less than 3000 square feet per story unless the building is a shopping center, a shopping mall, or the professional office of a health care provider, or another type of facility as determined by the Attorney General. The elevator exemption set forth in this paragraph does not obviate or limit in any way the obligation to comply with the other accessibility requirements established in section 4.1.3. For example, floors above or below the accessible ground floor must meet the requirements of this section except for elevator service. If toilet or bathing facilities are provided on a level not served by an elevator, then toilet or bathing facilities must be provided on the accessible ground floor. In new construction if a building or facility is eligible for this exemption but a full passenger elevator is nonetheless planned, that elevator shall meet the requirements of 4.10 and shall serve each level in the building. A full passenger elevator that provides service from a garage to only one level of a building or facility is not required to serve other levels.

As a multistory self-park structure would never have less than 3000 sq ft per floor, that clause is considered moot. Two level parking structures owned by private entities may thus be constructed without an elevator. However, Title II specifically states that all buildings owned by public entities with more than one story shall be served by an elevator (Title II Rule: 35.151(c)). Again, the elevator must be provided even if all accessible spaces are on the grade level.

If all of the floor(s) of the parking facility have a direct accessible means of egress (either at grade or via an accessible bridge or tunnel to an adjacent accessible building floor served by an elevator), no elevator is required. (This exception is based on 4.1.3(5), EXCEPTION 3, which states that accessible ramps may be used in lieu of elevators.)

A4.1.3(8) provides scoping for accessible entrances to buildings. It is important to remember that the public entrance(s) to a parking structure as defined in ADAAG would be the access point(s) to the facility used for normal pedestrian entering. For the purposes of this guideline, points of vehicular entry and exit to parking facilities are not considered entrances.

The requirements are somewhat complex and must be carefully reviewed. The two principal requirements are that at least 50% of the public entrances must be accessible and the number of accessible entrances may not be less than the number of exits required by building code, except if that would cause more public entrances than otherwise planned. The latter will frequently occur in parking facility design because it is common to have only one public entrance and several code-required emergency exits. This may simply be because there is only one logical route to the building(s) served or because of security concerns. In higher security risk situations, the public access may be restricted to one public entrance, with the exit stair towers enclosed and panic alarmed at all points of entry to the tower, for use only in emergencies. Thus, the grade level access to each code-required stair is often not a "public entrance" to a parking facility.

In general public entrances must be accessible if they are associated with accessible routes (from accessible parking spaces). In parking facilities, elevator towers are almost always associated with a public entrance (at grade, a pedestrian bridge or a tunnel or combinations thereof); therefore, the requirement of 4.1.3(8)(a) is to have 50% of the public entrances accessible and the accessible parking spaces should be grouped at those public entrances that are accessible. However, it is generally preferable to make all public entrances to elevator lobbies accessible.

4.1.3(9) Means of Egress requires that "Areas of Rescue Assistance" should be provided at all code-required exits in enclosed parking structures, even when there are no accessible parking spaces in the vicinity, because it is possible that on occasion a vehicle transporting a person with disabilities may not have a permit to park in the reserved accessible spaces. This could be for a variety of reasons, but most often because the person is being transported by a friend or relative who does not qualify for a permit. The frequency of this happening is low, the amount of time spent in a parking area is short, and the risk of fires is demonstrably quite low, making it reasonable to conclude that the probability of a disabled person being present in an area without accessible parking spaces when a fire occurs is quite small. However, the cost of providing an area of rescue assistance in a stair tower required to be enclosed by building code is small. Therefore providing an accessible means of egress is recommended. It should be noted, however, that if a supervised automatic sprinkler system is provided in an enclosed parking facility, the requirement for areas of emergency assistance is also waived.

In open parking structures, however, the case is entirely different. With the openness, any smoke will dissipate rapidly as an individual moves away from the immediate vicinity of the fire. Thus, there is essentially no threat to life safety unless the individual is injured in an explosion, in which case there is no benefit to the area of rescue assistance. ADAAG recognizes that sprinklers render areas of rescue assistance unnecessary. The Access Board in its preamble indicated that it does not believe that areas of rescue assistance are required in open parking structures as previously discussed. Furthermore, there is one very good—indeed life safety—reason for providing open stairs in open parking structures: security. It would be counterproductive to require an enclosed area of rescue assistance adjacent to an open stair.

In order to clarify design guidelines for parking facilities, Bulletin #6 categorically stated: "Another important design consideration is that accessible parking spaces should always be located in close proximity to an accessible means of egress."

As previously discussed, the preferred method to achieve this is to locate accessible spaces at the grade level. Where this is not possible the stair must be designed as an accessible means of egress. While the area of rescue assistance is not required to be enclosed, the other elements specified in 4.3.10 must be followed. These are primarily designed to facilitate evacuation of disabled persons by rescue personnel.

7.2.12 Cashier Booths and Office Space

4.1.1(3) Areas Used Only by Employees as Work Areas states:

> Areas that are used only as work areas shall be designed and constructed so that individuals with disabilities may approach, enter, and exit the areas. These guidelines do not require that any areas used only as work areas be constructed to permit maneuvering within the work area or be constructed or equipped (i.e., with racks or shelves) to be accessible.

Appendix A4.1.1(3) goes on to state:

> Where there are a series of individual work stations of the same type (e.g., laboratories, service counters, ticket booths), 5%, but not less than one, of each type of work station should be constructed so that an individual

> with disabilities can maneuver within the work stations. Rooms housing individual offices in a typical office building must meet the requirements of the guidelines concerning doors, accessible routes, etc. but do not need to allow for maneuvering space around individual desks. Modifications required to permit maneuvering within the work area may be accomplished as a reasonable accommodation to individual employees with disabilities under Title I of the ADA. Considerations should also be given to placing shelves in employee work areas at a convenient height for accessibility or installing commercially available shelving that is adjustable so that reasonable accommodations can be made in the future.
>
> If work stations are made accessible they should comply with the applicable provisions of 4.2 through 4.35.

There are essentially two distinct issues of accessibility to workstations—getting to the workstation, and maneuvering within the workstation. Regarding the first issue, the requirement of section 4.1.1(3) may be translated as: an accessible route must be provided to and through the door to every workstation. All common areas such as locker rooms, lunch rooms, conference rooms, restrooms, etc., must also be fully accessible. The reasoning for this requirement is as follows: Title I of ADA states that an employer must make reasonable accommodations to allow a person with disabilities to perform the essential functions of the job. While in most cases, an employer can retrofit one workstation to meet the needs of an employee with disabilities at reasonable cost, completely renovating an office to provide wider aisles, accessibility to conference rooms, lunch areas, etc., would be far more expensive and could be an undue burden. ADAAG thus requires that common areas, hallways, and doors all be accessible in new construction or alterations, so as to minimize the probable cost of "making reasonable accommodations" for an employee in the future. There are no exemptions for workstations and common areas that will serve positions for which it would be inappropriate to hire a person with a significant mobility impairment (e.g., security, valets, etc.) because a supervisor or colleague might also be disabled.

Both NPA and IMPC attempted to get cashier booths exempted from the "to and thru the door" requirement. The ATBCB declined to do so. Further in the course of the rule making for Title II adoption of ADAAG, the Access Board issued this clarification in the Supplementary Information (page 31682 of the *Federal Register*, June 20, 1994):

> **Response.** An exception has been provided in ADAAG 4.1.1(5)(b)(iii) for single occupant structures accessed only by passageways above or below grade, such as toll booths that are required to be accessed from tunnels below grade. This exception does not apply to toll booths accessed at grade level.

> **Comment.** Other facilities recommended by commenters for exception include: cashier booths, border station inspection booths, guard booths, and portable classroom structures.
>
> **Response.** These recommendations did not point to specific structural conditions that would make access infeasible. Consequently, such facilities would not be exempt unless the conditions listed in ADAAG 4.1.1(5) (General Exceptions) are met.

Thus, in the rare case where the only access to a cashier booth is from a tunnel or overhead structure, cashier booths can be exempted from the "to and thru the door" provision. However, cashier booths accessed from grade shall be accessible.

Regarding accessibility within the workstation, 4.1.1(3) specifically states that ADAAG does not require any workstation to have interior maneuvering space, adjustable shelves, accessible controls and operating devices, etc. The sentence in A4.1.1(3) above recommending that 5% of all work stations, with a minimum of one, be accessible, is only considered a guideline or suggested design standard. The intent of this guideline is also to minimize future costs of "reasonable accommodations," because it will likely be far less expensive to modify a workstation to meet the specific needs of a person with disabilities if it is already large enough for interior maneuvering.

Thus, in parking facilities, an accessible route must be provided to every new cashier booth and the door must be accessible, but the booth interior need not be designed to meet the clear floor space, reach ranges etc., unless the owner/operator so chooses. It should be noted that the owner who chooses not to purchase a booth that can be modified easily to accommodate a person with a disability runs the risk of encountering significant expense to remove/replace the equipment, booth, and island to provide the required interior maneuvering clearance. Since the requirements for door opening and latch side clearance essentially require a booth size within a few inches of that required for interior maneuvering space, it is advisable to specify/purchase the slightly larger booth initially.

Even disregarding the requirements for interior maneuvering, the "to and thru the door" requirement presents a considerable change in the design of entry/exit lanes, because booths have traditionally been designed to sit on 6″-high islands that are relatively narrow. Providing an accessible route into the booth requires either setting the booth floor at the level of the driving lane or providing a curb ramp at the end of the island.

In the first case, the booth must be recessed into the island, as seen in Figure 7-12. The sliding door on the side of the booth would use the

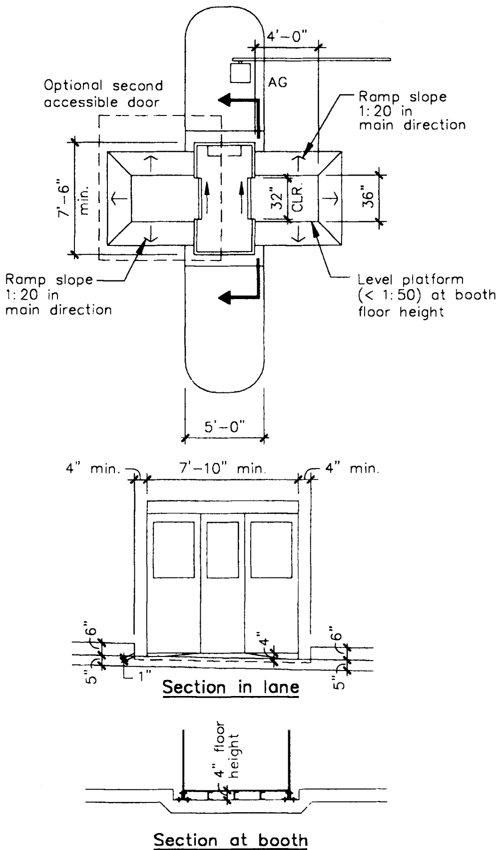


Figure 7-12. Accessible access to cashier booth through side doors.

driving lane as the accessible route; note however, that a 3 ft × 4 ft level area (slope less than 2% in any direction) immediately outside the door is required to allow a person in a wheelchair to maneuver the door open. (This is called the latch side clearance area.) It is desirable to slope the driving lane up to this elevation on either side of the latch side clearance area for drainage away from the door, but without creating an excessive "bump" at the booth for vehicles to pass over. The standard booth doors and thresholds must be modified to meet ADAAG. Ceiling heights within the booth (indeed within all new booths) must be increased to 6′8″. The clear door opening must be 32″, which requires a nominal 34″ door. To slide the door fully open, the booth must be 7′10″ or longer. It should be noted that adding an accessible door on the opposite side provides a T-shaped wheelchair turning space that meets the requirements of interior maneuvering even with a 4-ft (nominal) width booth. Other modifications required for interior accessibility could be made later to bring the booth into compliance as a fully accessible workstation. There are, however, a number of other technical problems with this approach in many climates, particularly assuring proper drainage.

In the second case, the door is provided at the end of the booth. The island must be widened, and the latch side clearance area provided outside the door at the booth floor level. With a sliding door, the area must be 3 ft × 4 ft as before; with a swinging door the area must be 5 ft × 5 ft. If the booth is placed on top of the island and the floor slopes down along the length of the slab in the direction of the curb ramp, it becomes possible that the curb ramp will have a rise exceeding 6 in. This, in turn, makes it a ramp, and triggers a requirement for handrails on both sides. Putting the booth on top of the island also combines with the 6′8″ ceiling height to compound the height clearance problems that already exist in parking facility applications. If the booth is recessed into the island so that the floor is at the top of curb elevation, an accessible means of bridging the gap required for placement tolerances and anchoring is required at the door and the platform outside the booth. The requirements for latch side clearance at the platform and door will bring the island to the width required to accommodate a booth with interior maneuvering space. In Figure 7-13, a layout has been shown for a rear swinging door to the cashier booth. The booth width must be 5′4″ to provide the required latch side clearance between the curb and the door edge, while at the same time keeping the cashier window close to the exit lane. In this case the length of the booth is not affected by the requirement to get to and through the door; however, with a 7′4″ or longer booth, the 5-ft diameter interior maneuvering clearance for interior accessibility is provided. An alternative detail would have a rear sliding door; the booth must then be wider at 6′0″. Thus, purchasing a 5′4″ × 7′4″ booth with a rear swinging door, or a 6′0″ by 7′4″ booth with a rear sliding door, will allow for easy future adaptation to the needs of an employee in a wheelchair.

To achieve full interior accessibility, it is necessary to place all controls and operating devices within the ADAAG-specified reach clearances. This will greatly limit the placement of controls, panels, switches, etc., under the counter. Also, it may be necessary to provide an adjustable counter so that the cashier can perform all essential functions including changing journal tapes. An adjustable counter in turn may affect the security of conduits and other control devices now provided

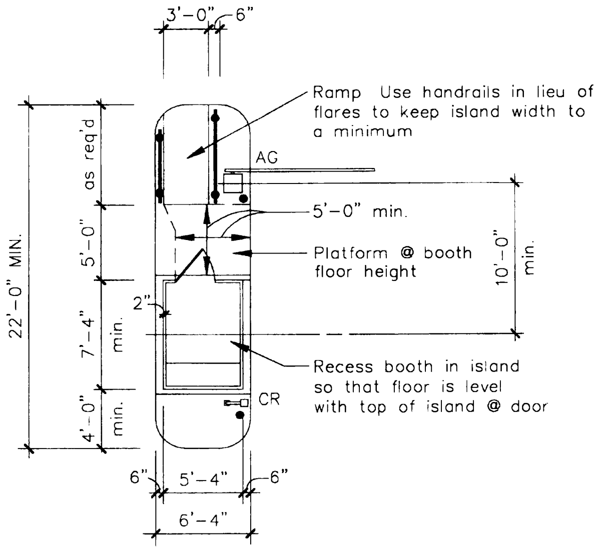


Figure 7-13. Accessible access to cashier booth through end doors.

in more secure rigid conduit. As previously noted, Title I of ADA says that reasonable accommodations must be made to meet the specific needs of the employee with a disability; it is very difficult to anticipate those needs in advance. Therefore, even though most booths will automatically have the required interior maneuvering space, it may be preferable to delay making all controls and operating devices fully accessible until the workstation must be modified to meet the specific needs of a person with disabilities.

There will be no exceptions based on the argument that there often is only one booth at a facility and a person in a wheelchair would not be placed as a cashier in such a facility. There will also be no exceptions allowed for valet/attendant facilities. This rule is based on the premise that a supervisor or manager visiting the site may be in a wheelchair.

As this is such a critical issue, and one that is often ignored, let us restate the overriding issues: **every** design for new construction must provide a means to get a person in a wheelchair **to and through the door** of **every** workstation, which includes **every cashier booth**. There are **no** exceptions! The interior of the booth does not **have** to be designed for full accessibility. The Appendix to ADAAG **recommends**, but does not require, that 5% of all work stations, with a minimum of one, be fully accessible.

7.2.13 Parking Access and Revenue Controls (PARC)

ADAAG requires that controls and operating mechanisms, as well as ATM machines must be accessible to pedestrians. Drive-up ATM machines, and by inference, PARC equipment in entry/exit lanes are excepted. *Pay-on-foot* devices that may need to be accessible include but are not limited to *meters*, slot boxes, multispace meters, pay-and-display stations, and automated pay-on-foot stations. Some parking facilities may have both types of equipment; for example, a parking facility designed for pay-on-foot may issue a ticket from a dispenser at the vehicular entry lane and require that an "exit ticket" indicating payment be inserted by the driver into a lane controller that opens the gate at the exit. Payment, however, is made at a central location while in the pedestrian mode. Only the pay-on-foot devices must be accessible.

Although technically applicable to meters in the public right-of-way, ADAGG 14.2(2) address the accessibility of parking meters:

(a) Parking meter controls shall be 42 in (1065 mm) maximum above the finished public sidewalk. Controls and operating mechanisms shall be operable with one hand and shall not require tight grasping, pinching, or twisting of the wrist. The force required to activate controls shall be no greater than 5 lbf (22.2 N).

(b) Where parking meters serve accessible parking spaces, a stable, firm, and slip-resistant clear ground space a minimum of 30 in by 48 in (760 mm by 1220 mm), shall be provided at the controls and shall comply with 4.2.4.1 and 4.2.4.2. Where only a parallel approach is provided, controls shall be within 10 in (255 mm) horizontally of and centered on the clear ground space. Where only a forward approach is provided, controls shall abut and be centered on the clear ground space. Parking meters shall be located at or near the head or foot of the parking space so as not to interfere with the operation of a side lift or a passenger side transfer.

Note that paragraph (a) requires all meters (not just those at accessible spaces) to meet this standard. This will apply to new meters at existing spaces and thus represents a new standard for the industry.

When pay-on-foot devices are centrally located to serve multiple parking spaces, each device should comply with 4.34, Automated Teller Machines, except where two or more similar devices are provided at a location, when only one must comply. When central cashier stations are provided in pay-on-foot systems, at least one such payment station should comply with 7.2, Sales and Service Counters. Note that pay-on-foot PARC devices are required to comply with 4.34.4, Equipment for Persons with Vision Impairments.

7.2.14 Communication Systems

All fire and other alarm systems must now be designed to communicate both visually and aurally. If two-way communication systems are provided in exterior facilities for use in emergencies, they shall include both audible and visual means of communication. A panic button and light that illuminates to indicate that the alarm has been noted and help is on the way will generally be sufficient to communicate with the hearing impaired.

7.3 SUMMARY

Accessible parking design has been and continues to be a major concern for the industry. A number of official clarifications have been issued via Bulletin #6; other, unoffical clarifications and interpretations have been obtained through meetings with the Access Board and DOJ staff. While this text presents the "best available" interpretation, it is almost a surety that at least one thing in this chapter will be outdated by the time you need the information. The requirements are complex, and still subject to future changes and clarifications. It behooves each owner and design professional to obtain the latest information before embarking on a parking structure design project.

7.4 REFERENCES

1. Architectural and Transportation Barriers Compliance Board, 1991. *Americans With Accessibilities Act (ADA) Accessibility Guidelines for Buildings and Facilities; Final Guidelines*, 36 CFR Part 1191, July 26, 1991.
2. Office of the Attorney General, Department of Justice, 1991. *Nondiscrimination on the Basis of Disability in State and Local Government Services; Final Rule*, 28 CFR Part 35, July 26, 1991.
3. Office of the Attorney General, Department of Justice, 1991. *Nondiscrimination on the Basis of Disability by Public Accommodations and in Commercial Facilities; Final Rule*, 28 CFR Part 36, July 26, 1991.
4. Architectural and Transportation Barriers Compliance Board, 1994. *Americans With Disabilities Act (ADA) Accessibility Guidelines for Buildings and Facilities; State and Local Governments; Interim Final Rule*, 36 CFR Part 1191, June 20, 1994.
5. Parking Consultants Council, 1992. *Parking Studies*, Washington: National Parking Association (June 1992).

CHAPTER
8

STRUCTURE

Anthony P. Chrest

8.1 INTRODUCTION

Section 8.2 will discuss the various factors influencing the structural design of a parking facility. Among the items covered will be cost, schedule, and building codes.

Section 8.3 is a guide to help narrow down the selection of structural systems. Some systems are better than others for parking structures, and some should be avoided.

Section 8.4 helps identify and design for volume change effects in parking structures. Their large plan areas and exposed structure makes parking structures more susceptible to these effects than other building types.

Certain design items are unique to parking structures. Discussed in section 8.5 are beam-column joints, variable height columns, torsion, and the relationship of stair and elevator structures to the main structure. Section 8.6 comprises a chapter summary. Please note that this chapter addresses only structural design as it pertains to parking structures. Seismic design is addressed separately in Chapter 9.

8.2 DESIGN

8.2.1 General

Structural design should satisfy requirements for strength, flexibility, durability, ease of maintenance, and repair. Equally important are function, cost, appearance, and user comfort.

8.2.2 Factors Affecting Design

8.2.2.1 Effect of Local Construction Technology on Cost

Let's say your design calls for a column concrete strength of 14,000 psi, and no cast-in-place building in the project city has ever been built with concrete strength exceeding 10,000 psi. Bids for your cast-in-place structure will be higher than you expect; you may not get any bids. However, assume for this example that precasters in the city have had experience with concrete strengths as high as 14,000 psi. Unless you are willing to increase the cross-sectional dimensions of your columns to permit use of 10,000-psi concrete, you should select a structural system that uses precast concrete columns, not cast-in-place ones. Another alternative would be for you to embark on an education program with the local ready-mix supplier, which has already been done as seen below.

A similar example relates to silica fume concrete, also called microsilica concrete. The material is stronger and less permeable than conventional concrete, but if it has never been used in the project city, the bids will probably again exceed expectations or not even materialize.

A final example concerns pretopped double tees. If no precaster in the project city has ever built a structure with pretopped tees, it is likely that none will be interested in bidding on your pretopped structure. Or, bids will be high to cover the precaster's and erector's learning curves.

All of the above should not lead you to believe that there is no innovation in the construction industry. It is true that the engineer may have to spend more time educating builders and/or precasters in a given area, but, once understanding is reached, these people are almost always ready to adopt new technology or practices. As one example, with a high-strength concrete consultant, we helped a ready-mix supplier and builder team consistently produce 14,000-psi concrete for columns in a 15-story multiuse parking structure. As another example, we have helped a number of precasters fabricate and erect their first pretopped double-tee parking structures. Having done their first, all of the precasters wanted to do more.

8.2.2.2 Effect of Bidding Climate on Cost

If there is a general contractor around who likes to place concrete and is short on work, it is likely to give you a very good bid on a cast-in-place structure. Conversely, if no precast projects have been built recently and there are hungry precasters around, a precast job will attract low bids.

On the other hand, if there are no precasters in an area or all available precasters have a full backlog, it would be unwise to put a precast structure out for bid.

In some areas, there may be a shortage of construction tradesmen. A structural system that is less site-labor intensive, such as pretopped precast concrete or structural steel with a precast concrete floor, might be a good choice in such circumstances.

To achieve an economical structure, poor soil conditions will require the lightest structural system possible, making steel your choice.

8.2.2.3 Cost of Quality Construction

A concern similar to that above is that even in some cities of North America, there are few builders capable of producing quality cast-in-place concrete construction. A related problem is that trade union rules in at least one region require all rebar bending to be done on site. These two circumstances, singly or combined, have nearly eliminated cast-in-place concrete parking structure construction in those areas.

8.2.2.4 Effect of Owner's Budget on Cost

The project budget may eliminate some systems from consideration. As an example, though long-span construction is best for parking structures because it permits easier parking and flexibility in striping and in resizing parking spaces, short-span construction in which cars park between columns is less expensive. If the building code requires parking as part of the total project and the project will not be built unless the parking structure cost is rock bottom, then long-span structural systems will probably have to be discarded from further investigation.

8.2.2.5 Costs Associated With Building Codes

Local building codes and ordinances, especially those that have not recognized downsizing trends in automobile manufacture, may mandate parking module wall-to-wall dimensions of 65 ft. If the owner's and engineer's desires are to use clear span construction, then some systems will not work. For instance, if 24″ precast concrete double tees are the deepest available within economical shipping range, a double-tee system will be eliminated because the available members do not have the capacity to carry typical parking structure loads for the required 65-ft-clear span.

8.2.2.6 Durability Costs

Durability requirements will raise the cost of certain structural systems more than others, because some systems are inherently more durable than others. (For additional discussion, see section 8.3 and Chapter 10.)

8.2.2.7 Schedule Costs

Speed always costs more, no matter what the structure. If a compressed schedule is necessary and the project budget cannot be increased, the increased costs may dictate a compensatingly less expensive structure, which leads back to the discussion on budget.

The second aspect of schedule is that in cold climates, winter construction is significantly more expensive than construction in moderate temperatures. Summer construction is more expensive in hot climates. There is not always the freedom to choose when to start construction. If there is a choice, scheduling with the seasons in mind can lead to significant savings or permit extra features to be added to the facility while keeping the project cost within the original budget.

8.2.2.8 Appearance Costs

Façade choices are almost limitless, and corresponding costs can range from zero dollars over the cost of the "bare bones" structure to tens of percent of the total project cost. As with schedule, there may be freedom in selecting the façade treatment, or there may not. As an example of the latter situation, it is not unusual to find a hospital campus surrounded by an urban or suburban residential neighborhood. In planning a parking structure to serve such a hospital, the planners often encounter objections to the structure from neighborhood groups. The objections must be overcome, either because the hospital wants to be a good neighbor or in order to get a building permit, or both. Overcoming the objections usually requires that the parking structure façade screen the cars inside from view from the surrounding streets, that its architectural appearance blend in with the hospital campus and/or the neighborhood, that the structure not be so high as to tower over surrounding residences or block sunlight, and that structure lighting does not spill outside. Answering each of these objections will add to the cost of the project.

If the structure must park sufficient cars and the ground space is limited, several stories of parking will be required. Yet if the structure height must be limited, the only solution to both requirements will be to go underground. On a per-car basis, all else being equal, underground parking construction costs are roughly double those for an aboveground parking structure.

8.2.2.9 Schedule

The project schedule should encompass the entire project, with durations assigned for all design phases; whatever reviews are required by parties such as the client, local citizens groups, the building department, zoning, other public agencies, the financing body, and others; bidding or negotiating, and construction. Take long lead-time items, such as elevators, into account. Remember that winter weather in cold climates will affect the schedule for an open parking structure more than it would for a conventional building. A conventional building will be closed in at some point, permitting completion of finish items that require moderate temperatures. Examples of these items are sealers, membranes, sealants, paints, curing compounds, and defect patching.

8.2.2.10 Building Code Loading Criteria

Magnitudes of live loads on floors and of live load reductions to floor members and columns will vary. (Car bumper-impact load magnitudes and height above the floor to load point vary more.) These loads in turn will influence the structural design.

8.2.2.11 Live Loads, General

Building codes commonly require a uniformly distributed load of 50 psf and a 2000-lb concentrated wheel load distributed over a 20-sq-in. area anywhere on a floor, with additional load for snow (see next section) on the top (roof) level. Most building codes allow for the reduction of live loads for members supporting tributary slab areas. In some parts of North America, roof-level parking requires combining parking live loads with roof snow loads.

8.2.2.12 Snow/Live Load Combination

Some building codes require adding roof loads (usually snow) to the normal parking load. Some designers believe that for the design of principal members, this requirement is too restrictive. Combinations of snow and live loads that might be encountered are:

- Full snow load over entire bay with live load reduced as permitted by building code
- Full snow load over entire bay with live load in stalls only
- Full snow load over entire bay with live load (reduced by code) in stalls only
- Full snow load over entire bay with auto load in stalls only (no impact load or live load reduction)

An appeal may be made in advance of construction to local building departments to reduce the requirements. The following is an example of the last option above for combining snow and parking live loads to produce a realistic prediction of required capacity of a top level, which we recommend.

The last option approach to combining live loads assumes autos in the parking stalls only. The autos, however, are considered immobile and therefore no impact is considered (that is, L=25 psf live load nonreducible). For this example, we will assume a building code snow load of S=40 psf over the entire 60-ft simple span and a 1-ft tributary width, as shown in Figure 8-1.

Service load moment $= w_1 l^2/8 + w_2 l_2/2$
$= (40\times60\times60)/8 + (25\times20\times20)/2$
$= 23{,}000$ ft-lb

Equivalent load $= (23{,}000\times8)/l^2$
$= (23{,}000\times8)/60^2 = 51.1$ psf

In comparison, ANSI requires a combined loading of 1.4 D + 1.7L +0.5S or 1.4D + 0.5L + 1.7S, whichever is worse. Applying these load factors to the L=25 psf and S=40 psf above, and omitting, for this example, the D load, produces a worst-case combined service load 27% higher than that obtained using the last option above.

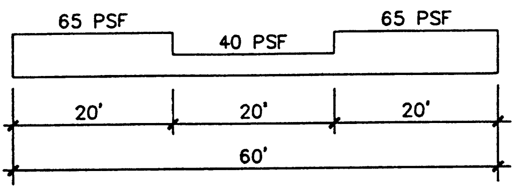


Figure 8-1. Snow and live load diagram.

8.2.2.13 Wind Loads

Design and construct every parking structure and its component elements to resist the equivalent wind pressures given in governing building codes. Model building codes have methods with which to calculate wind pressures, using basic wind speed, importance factor, exposure factor, and projected areas. In most cases it is unrealistic to use anything less than the full building face area for the projected area. Don't subtract the open areas of the face; consider the face solid unless you make a more rigorous analysis.

8.2.2.14 Seismic Loads

Please see Chapter 9.

8.2.2.15 Barrier Requirements

Handrail heights, live load, and railing spacing requirements may vary, and all affect design. Openings in barriers that resist car bumper impact are limited in size by codes, but these limits vary also.

Not all building codes deal with lateral load requirements for car bumper barriers at floor edges. Requirements vary from none, to the National Parking Association's (NPA) recommendation given below, to Houston's 12,000 lb. Designing for these loads will restrain a slowly moving vehicle. These requirements are in addition to other building code requirements for handrails or similar barriers. The Parking Consultants Council of the NPA recommends a factored concentrated lateral load (strength design load) of 10,000 lb at 18″ above the driving surface. At least one code requires the load be applied 27″ above the floor—50% more than the NPA requirement. Barrier-load-resisting reinforcement is additive to that required by other loads.

A typical curb, 6″ high, or a precast wheel stop will not stop anything more than a slowly moving car, and should never be considered as a barrier. A faster-moving car will jump the curb or wheel stop and will hit the bumper barrier beyond with barely diminished force. Curbs do add to driver comfort with the facility, though. A curb of proper width will ensure that the car's rubber tires hit the curb before its bumpers hit the wall beyond.

Some building codes require a barrier with greater impact resistance at locations like the perimeter wall at the bottom of a ramp, especially if there are no parking places directly in front of that wall.

8.2.2.16 Fire Ratings

Fire ratings vary considerably from one jurisdiction to the next. Protection requirements have the effect of dictating structural element thickness, and therefore weight, which in turn affects the structural design of all superstructure members as well as the foundations.

8.2.2.17 Standpipes and Sprinklers

Almost any parking structure of more than two or three stories will be required to have dry standpipes. Some building codes will require all standpipes, dry or wet, to be interconnected so that they can be filled or drained from any hose bibb. Hose-bibb threads must meet local fire department requirements. Underground garages and some multiuse parking structures, whether open or not, will be required to have an automatic sprinkler system. An example of the latter might be a multilevel parking structure taller than a mandated height, meeting the requirements to be considered *open* but having office space on its top floor or floors, even though the "roof" of the parking structure (bottom floor of the office space) meets the separation requirements for mixed-use occupancy.

8.2.2.18 Ventilation

As stated in Chapter 1, requirements for open space around the exterior walls of a parking structure vary. If the structure meets or exceeds the particular openness requirements, no mechanical ventilation of the parking and drive areas will be needed. There may be separate building code requirements for ventilation of ancillary facilities, such as restrooms, maintenance areas, stairs and elevators, attendants' booths, offices, isolated or dead-end areas, or low points where carbon monoxide could collect and endanger patrons or staff.

If the structure does need mechanical ventilation in large areas or throughout because it does not meet building code openness requirements, the project cost will increase.

8.2.2.19 Storage Room

A parking structure will often contain a storage room for maintenance equipment and supplies, parking and revenue control equipment parts and supplies, and odds and ends. As a corollary to the sections on fire protection and ventilation requirements above, if the storage room is truly for storage only, and is not used for maintenance or anything other than storage, it is important to label that room as *Dead Storage* on the contract documents. Otherwise, heat, mechanical ventilation, and sprinklers may be required.

8.2.2.20 Height and Area Limits

These, too, will vary across the continent, and are often tied to fire rating requirements. As in the example of the hospital campus located in a residential neighborhood, the height limitation may not be a previously set limit, but may be subject entirely to the opinions of a special interest group.

8.2.2.21 Appearance

Appearance is not within our scope; however, the nature of parking structures often requires a structural element to also serve an architectural function. An example is the typical exterior beam: it carries live, dead, and bumper loads, and may be part of a rigid frame that carries wind or earthquake forces, yet it must also contribute to the appearance of the structure. A second example is the often-required resolution of the conflict between the functional design, which may require sloping floors, and the desire for horizontal elements on the building façade. As a third example, on a recent project, the architect wanted to reflect the 20-ft module of an adjacent existing building in the structure of the new parking project. A 20-ft column spacing is economical for a cast-in-place posttensioned one-way slab and beam system, but not for an 8- or 10-ft-wide precast prestressed double-tee system. The architectural façade in this case decided the structural system. It is also important to resolve the possible conflict between the requirement for a stiff structure to support a rigid façade, such as masonry, and the flexibility of the main structure.

8.2.3 Associated Design Elements

8.2.3.1 Snow Removal

In cold climates, a snow removal system may be required. This provision may involve design for special vehicle loading in addition to the snow loads. Consider provisions for snow-melting equipment and chutes or containment structures.

8.2.3.2 Drainage

Proper drainage is *essential* to structure durability. If water is allowed to stand (pond) on the parking structure floors for long periods, deterioration will accelerate in the concrete beneath the ponds. If the water that collects is salt-laden, chances for accelerated deterioration are greater. If the structure is to be durable, it is important that the drainage system carry away all water rapidly, whatever its source, and not allow ponding anywhere. Drainage design requires attention to three criteria: proper slopes, proper catchment area sizes, and proper drains.

First, no parking structure floor should ever be flat, even if no rain can fall directly on it. Windblown rain will come into floors below the roof. Cars will carry water in to lower floors also. Heavy rains may overload top floor drains. The overflow will run down ramped floors until the lower-floor drains can carry it away.

For drainage, the absolute minimum slope should be ⅛ in./ft, or about 1%. Preferred slope is ¼ in./ft, or about 2%. Note that cement finishers will have a difficult time consistently achieving a slope of less than ⅛ in./ft, if they can achieve it at all.

When setting slopes on design drawings, be sure to take expected prestressed member camber and deflections of all members into account; either could reduce or eliminate design slopes if not recognized and allowed for. Pay particular attention to cantilever spans so that water drains off them instead of collecting at the free ends.

Prevent ponding anywhere by controlling deflection of slabs and beams. In addition to sloping top surfaces, deflection control may be achieved by prestressing and by setting slopes or cambers into forms.

At the same time, do not forget that pedestrians will be walking across the slopes and swales; do not make walking uncomfortable.

Drain catchment areas should not exceed around 4500 sq ft on floors that are nominally flat—that is, sloped 1% or 2% for drainage only. On floors that have more than minimum slopes, drains may be spaced to drain more than the 4500 sq ft maximum. However, drains should be located so that runoff does not have to cross an isolation (expansion) joint seal or turn a corner to reach the drain.

Drains must be adequately sized or slightly oversize for the design storm. Locate them in gutter lines or other low points. Recess the drain 1″ below the adjacent floor surface.

The drain basin should be shaped to generate a vortex in the water which will speed the runoff flow out of the drain and into the downspout.

The top grate should have sufficient openings to admit the design runoff, but individual opening size cannot be so large as to present a hazard like catching a shoe heel. The grate should be permanently attached to the drain body with a hinge on one side and a tamperproof screw on the other. With a hinged grate, lifting off the grate to clean out the drain will not run the risk of losing the grate. With a tamperproof screw to hold it shut, vandals will not be able to open the grate.

The drain should also have a sediment bucket that can be removed and emptied during regular drain maintenance. Drains at lower floors should include backwater valves to prevent flow from the downspouts backing up and overflowing into the lower levels.

Circular and square drains are usually sized small enough not to interfere with structure. For example, in a posttensioned floor, the slab tendons can be curved around the drains easily. Sometimes, though, smaller drains are inadequate, particularly at a top floor (roof) or at the bottom of a ramp or ramped floor leading to a roof. Segmented or continuous trench drains may be necessary to accommodate runoff volume in such cases.

Segmented trench drains are simply short sections of trench drain, 12–24″ long, separated by a foot or 2 of floor slab structure. Slope the floors between the drain segments into them. Below the floor slab, the trench drain segments are continuously connected to a downspout. The segmented trench drain permits less disruption of the floor structure. A continuous trench drain running completely across a bay creates a structural isolation joint. The resulting separation must be treated like any other isolation joint.

8.2.3.3 Electrical Conduit

If there is a choice, do not cast electrical conduit into the structure. While exposed conduit is initially more expensive than embedded, maintenance will be far easier. Rewiring, if ever needed, will be less expensive if the conduit is initially installed exposed.

Concrete durability will be improved. With cast-in conduit, if moisture enters the conduit through leaks or condensation, deterioration of the concrete around the conduit may be accelerated. If the moisture freezes and the ice is not free to expand within the conduit, the conduit may split and the surrounding concrete may spall. Moisture inside or around the conduit may cause the conduit to rust. The rust in turn will exert pressure on the surrounding concrete, spalling it. If conduit is cast-in, provide for three-dimensional movement capacity in the conduit whenever it crosses an expansion joint. Some designers may object to exposed conduit on esthetic grounds, but, if it is properly installed, the average patron will never notice it. If conduit is to be exposed, provide formed holes in floor beams and/or tee stems to permit economical conduit runs.

8.2.3.4 Expansion Joint Seals

Even the best expansion (isolation) joint seals for parking structure floors will present problems sooner or later. If floor expansion joints can prudently be avoided, do so, and you will save yourself and the owner trouble later.

Expansion joint spacing is discussed in a later section. Seal types, uses, pros, and cons are discussed in the remainder of this section.

The trouble with expansion joint seals is that the requirements for the perfect seal are contradictory. The perfect seal should:

- be leak-free
- not be under tension or compression most of the time
- not be a tripping hazard
- meet ADA requirements
- not collect water, ice, dirt, or debris
- stand up to normal abrasion from car tires, even studded snow tires
- be protected from snow plow damage
- not deteriorate under normal use

Expansion joint seal types are outlined in Table 8-1 and discussed below. The premolded seal satisfies most of the list of requirements above, except that it is almost always in tension or compression, not bending. It also is not particularly resistant to damage from snow plows. It is better, when possible, to install the premolded seal in summer, when the expansion joint gap is at its narrowest. Otherwise it will bulge upward in hot weather and become a tripping hazard. If necessary, the seal may be temporarily installed during cold weather, and permanently installed when summer comes.

A variation of the premolded seal is shown in Figure 8-3. It is used to seal the gap between a floor slab and a vertical surface, such as a stair tower wall. Where the detail of Figure 8-2 meets that of Figure 8-3, ignoring strain compatibility will lead to seal failure. Figure 8-4 is a

TABLE 8-1. Common Types of Isolation (Expansion) Joint Seals

Type	Figure	Description	Pro or Con
Premolded	8-2, 8-3, 8-4	Economical; good track record when used in the right applications	Economical, but exposed to tire or snow plow damage, joint movement puts seal in tension, maintenance more expensive
Metal edged	8-5, 8-6	Seal protected from tire or snow plow damage. Joint movement puts seal in bending, not tension. Easy seal replacement for repair	Most expensive
Elastomeric concrete edged	8-7	Same as for metal edged, except repair more difficult	Expense between metal edged and premolded
Adhered extruded	8-8	Same as for elastomeric concrete edged	Expense between premolded and elastomeric concrete edged
Extruded compression	8-9	Protected	Economical, but a poor track record. Not recommended
Foam compression	8-10a	Protected	Same as for extruded compression

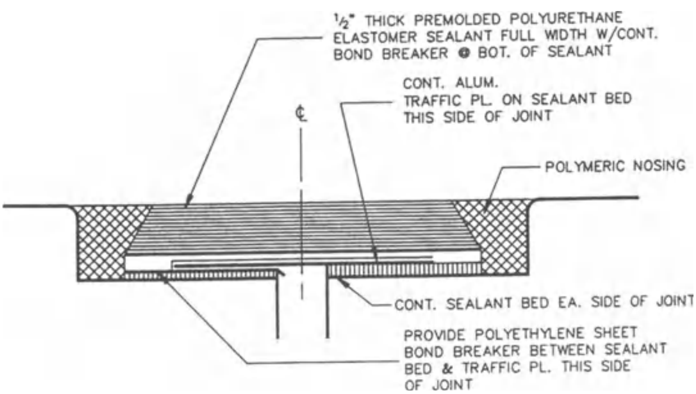


Figure 8-2. Premolded expansion joint seal—floor to floor.

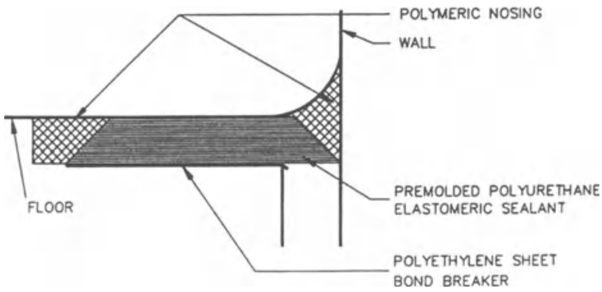


Figure 8-3. Premolded expansion joint seal—floor to wall or column.

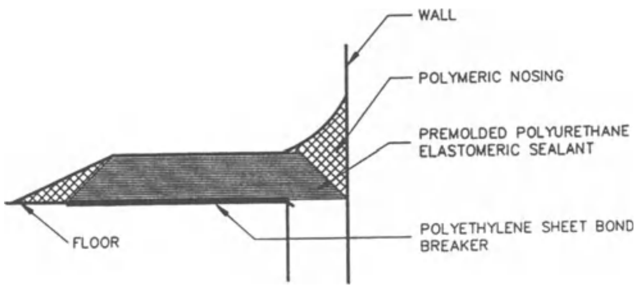


Figure 8-4. Premolded expansion joint seal—floor to wall or column. Mounted on surface of slab.

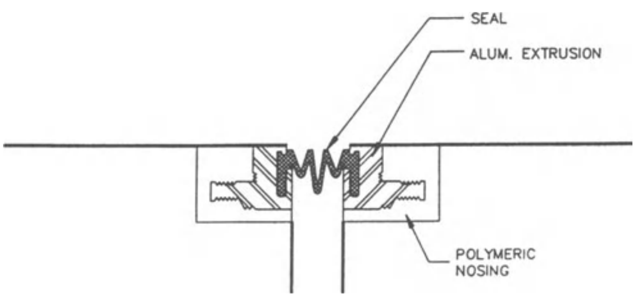


Figure 8-5. Metal-edged expansion joint seal—floor to floor.

second variation of Figure 8-2. It may be used where there are no possibilities of tripping hazards, traffic, or snow plow damage. Its advantage is that it does not need a formed recess in the concrete. The detail of Figure 8-4 may be combined with that of Figure 8-2 to seal the condition shown in Figure 8-10b where the expansion joint has to go around a column.

Figure 8-5 shows an armored strip seal. There are many variations

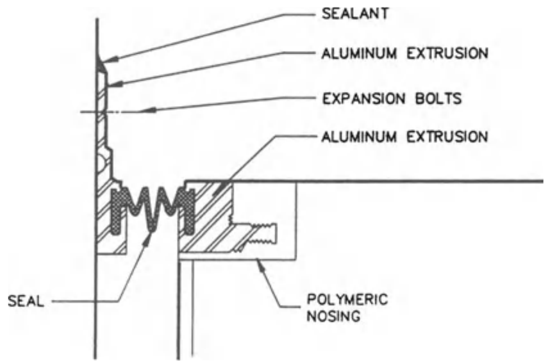


Figure 8-6. Metal-edged expansion joint seal—floor to wall.

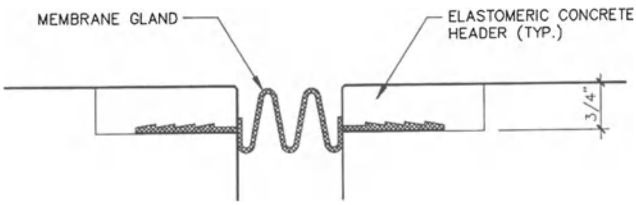


Figure 8-7. Elastomeric concrete edged expansion joint seal—floor to floor.

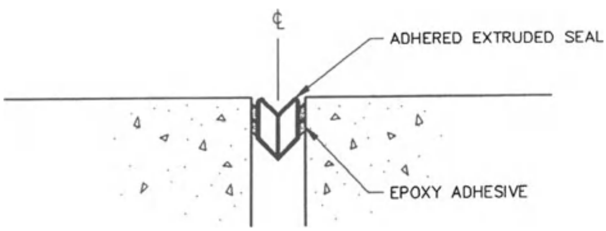


Figure 8-8. Adhered extruded expansion joint seal—floor to floor.

on the metal-edged seal, but the basic concept is the same. It satisfies most of the requirements in our list. During cold weather, when the expansion joint opens to is widest, the seal may be a tripping hazard, however. Figure 8-6 shows the variation of Figure 8-5 similar to that of Figure 8-3, the slab to wall seal.

There are also many variations of the elastomeric concrete-edged seal. One example is shown in Figure 8-7. The comments above for the metal-edged seals also apply to the elastomeric concrete-edged seals.

The adhered extruded seal does not need an edging for installation,

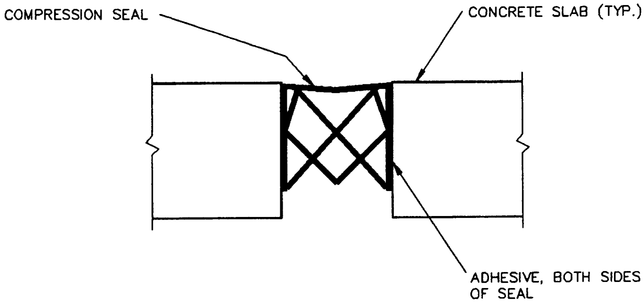


Figure 8-9. Extruded compression expansion joint seal—floor to floor.

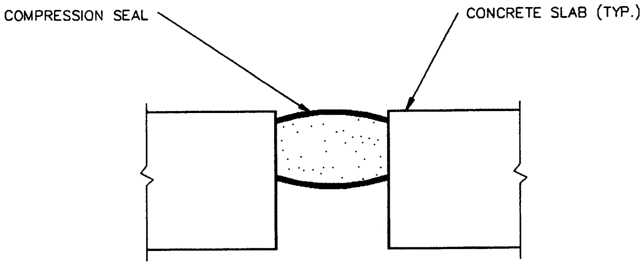


Figure 8-10a. Foam compression expansion joint seal—floor to floor.

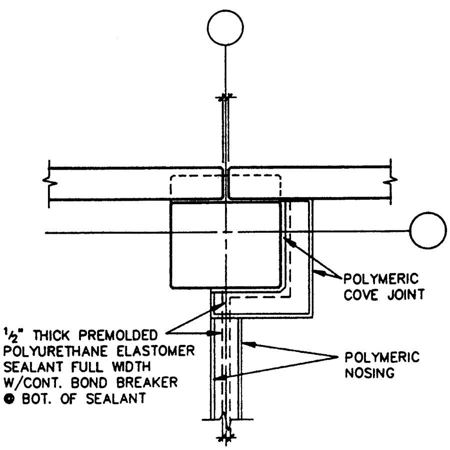


Figure 8-10b. Plan of expansion joint seal around column.

which is helpful for restoration work particularly, and any work in general. It performs well for a limited range of movement.

We do not recommend the extruded compression seal for floor joints. It does not stay in place. We also do not recommend the foam compression seal for floor joints. Its best use is to seal between nonmoving joints. An example would be between elements of a precast concrete wall on a building façade.

Whichever seal you select, you can improve its chances of performing well following the advice below, if at all possible.

Locate expansion joints at high points in the floor drainage pattern; keep expansion joints out of the path of runoff; locate expansion joints so as to avoid columns and other elements that will complicate installation and impede performance. If there are conditions that require that the seal go around a column or up a curb or wall, provide the details and views necessary to show what is to be done. Locate expansion joints away from breakovers where the floor changes from sloped to flat, off express ramps, away from turns, and away from areas where cars will accelerate, as when they leave entry areas. Isolation joints in seismic zones must often be quite wide. Seal design for these joints is challenging and still evolving.

Again, if possible, eliminate the need for the expansion joint so that you can prudently eliminate the joint. Also see the following section.

8.2.3.5 Structure Vibrations

Structures with an efficient parking layout often have column spacing producing inherently limber long-span beams in one direction and a multiple of the parking spacing in the other. Alternatively, if the floor is precast, the dimension should be a multiple of the precast module, usually 24 or 30 ft or, if cast in place, an economical span in the 18- to 24-ft range. These long-span floors must have the necessary stiffness and mass to reduce vibration and noise to acceptable levels. Perceptible vibrations are a normal consequence of the span-depth ratios found in modern parking structures. As a rule, such vibrations are not detrimental to the use of the structure; what is acceptable is somewhat subjective, as no building code requirements exist. The best resolution might be to visit several existing parking structures with the client, reaching agreement as to what is an acceptable level of vibration. Remember that pedestrians using the facility will feel vibration more than motorists.

A specific consideration is the effects of vibrations on an isolation (expansion) joint seal. Concern is normally necessary only when the seal bridges between two cantilevered elements or between a cantilevered element and a rigid element. For instance, an expansion joint may be located between two cantilevered slab ends, which are in turn located midway between two beams or double-tee stems. If differential vibration/deflection of the cantilever ends will expose the seal to premature wear from car tires or snow plows, then eliminate the differential. Provide a shear connection, which will permit free expansion and contraction of the joint in the horizontal plane while preventing relative movement in the vertical plane.

8.2.3.6 Tensile Stress Control

Areas of tensile stress-induced cracking are among the first to yield to weathering deterioration. The rate at which concrete deteriorates and steel corrosion begins will be proportional to the amount of concrete cracking.

Minimize bending stresses in exposed reinforced concrete in design by attention to structural depth and reinforcement clear cover, quantity of reinforcement, and provision of closely spaced small-diameter bars at the tension face. Limit factor z (ACI 318, section 10.6) to 55 or less under dead load.

Reduce or eliminate tensile bending stresses and, in turn, tensile cracks, by judicious use of prestressing. Use only as much prestressing as required to reduce stresses to noncracking levels under service load conditions. Stiff walls and columns, and wide beams can reduce prestressing forces applied at a building perimeter. Account for this reduction by increasing the applied forces or by using temporary hinges to reduce member stiffness. Higher levels of prestressing will only increase problems due to elastic shortening and creep. Also see section 8.4.6.2.

8.2.3.7 Future Additions

Scope-of-work discussions with the owner should always include whether or not the design will allow for future horizontal or vertical additions. If future additions are planned, provide adequate structural capacity. Define the nature and extent of the future addition in the contract documents.

If the original structure is to be precast concrete, consider whether or not a precast addition will be feasible. There must be room for erection cranes. Will a crane be able to reach far enough to place the precast pieces? Cast-in-place additions have been built atop precast existing structures because a precast addition was not feasible.

Include details to permit easy future addition in the original contract

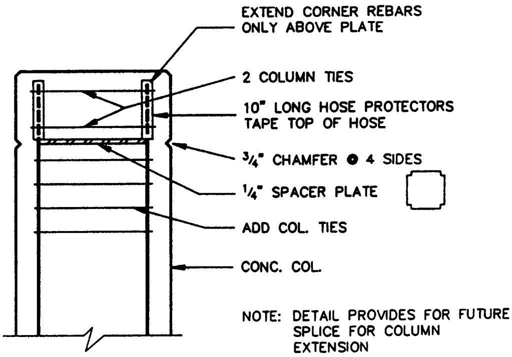


Figure 8-11. Detail at top of column to provide for future extension.

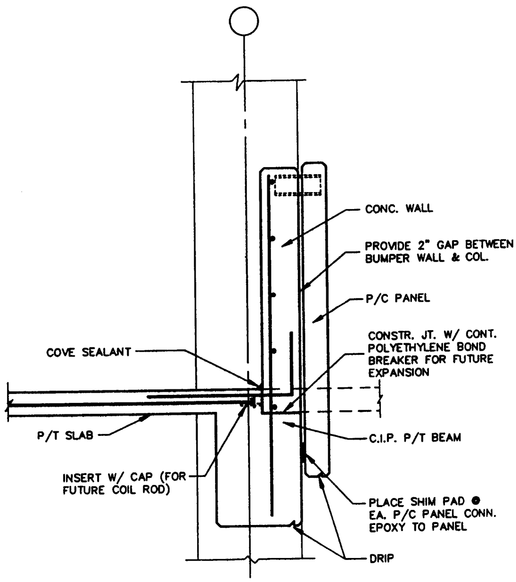


Figure 8-12. Detail at edge of floor to provide for future extension.

documents. Figure 8-11 shows a detail that will accept a future column extension. Figure 8-12 shows a detail that permits future extension of a supported post-tensioned slab.

8.2.3.8 Lighting

See Chapter 6 for a discussion of the interrelation between lighting and structure.

8.3 STRUCTURAL SYSTEM SELECTION

8.3.1 General

Selection of the structural system for a parking structure will be influenced by the factors cited in section 8.2. The designer provides the client with design options which the designer then develops into a final concept to satisfy the client. Though the engineer must recommend a structural system alternative, together with associated costs, the client ultimately decides which system will satisfy its requirements.

Important considerations in selecting a structural system are availability, cost, expected quality of construction, expected life, function, and appearance. The first five factors are equally important; the sixth may be less so. However, if the owner is a developer who intends to sell the project soon after it is completed, the owner may only be concerned about first cost. The owner may not appreciate the values of expected life and function in establishing an asking price. Educating this owner type may be difficult. In the extreme case, the designer probably should not take the project.

Concern about quality has been much discussed in the construction industry. If a structure meets the requirements set for it in the scope-of-work statement, which must be part of the design services agreement, then it is a quality structure. Stating the project requirements clearly in the design agreement and the scope-of-work statement is of prime importance. Failure to reach agreement on project requirements should lead the designer to withdraw.

8.3.2 Restraint

Parking structures tend to move more than other building types. Here is one common error as an example.

A designer considers the unbraced length of the first-floor columns as the dimension from top of column footing to bottom of beam at first-supported level. The designer uses that dimension in the frame analysis and column design. The foundation details, however, show a foundation wall between footings and rising 3′6″ above grade. These details further show the walls cast tightly to the columns with wall reinforcement continuous from the walls into the columns. The resulting unbraced column length is actually only 50% to 60% of what the designer assumed. The column as shown in Figure 8-13 will probably crack. The point is to design properly and to be sure that construction mirrors design. This lesson was again learned the hard way in the 1994 Northridge, California, earthquake.

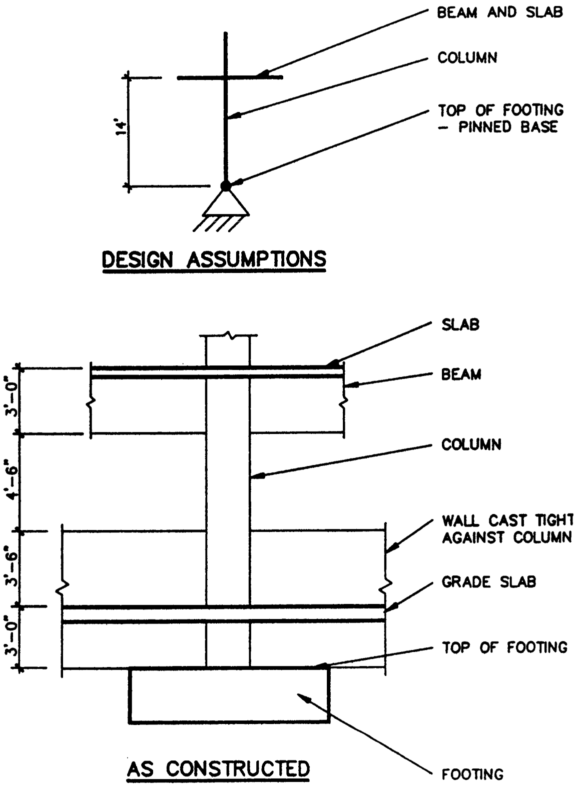


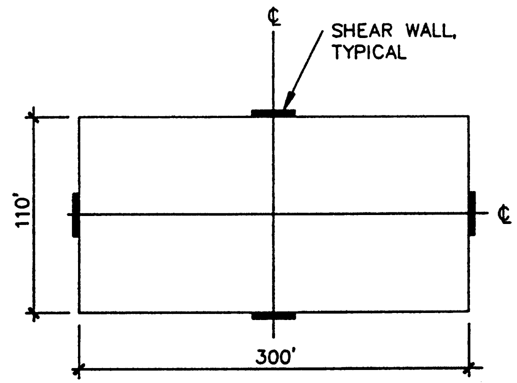
Figure 8-13. Assumed vs. actual column conditions.

8.3.3 Lateral Load Resistance

Lateral loads arise from wind or earthquakes. At least one model building code now states that all regions of the United States have to be designed with at least some capacity for resistance of earthquakes; all require capacity to resist wind loads. Below are discussed the three systems by which lateral loads are commonly resisted in parking structures.

8.3.3.1 Frame Action

This method uses the frames formed by the beam-and-column assembly typically occurring at each grid line to resist lateral forces. Using frame action to resist lateral loads has much to recommend it, all else being equal. Frame action implies that there will be no shear walls to interfere



NOTE: PLAN REPRESENTS A 2–BAY STRUCTURE

Figure 8-14. Example of shear wall arrangement. Keeping shear walls at the exterior simplifies traffic planning but may adversely affect performance of structure.

with parking or circulation. Shear walls also provide concealment to lawbreakers, so should be avoided if feasible.

Since the typical structure contains 10 or more such frames, the load distributed through the properly designed floor system to each will be reasonable, and required reinforcement quantities should be moderate. All structural systems described in this chapter may be modified so that frame action can be used effectively to resist lateral loads. However, frame action uses the bending resistance of the beams and columns to stiffen the structure laterally; it is not as efficient with taller buildings or greater loads. Therefore, if, because of building height or magnitude of loads, the resistance furnished by frame action is insufficient, other methods must be used, alone or in combination with frame action.

8.3.3.2 Shear Walls

In order to minimize slab cracking in large plan area structures, and if temporary isolation joints in shear walls are not practical, arrange the walls so they do not restrain the normal volumetric changes accompanying posttensioning, temperature, shrinkage, and creep. Remember that these effects are more significant in parking structures than in other structures. Ideally, locate the walls at or near the center of rigidity of the structure, whether in the interior or on the perimeter. Interior shear walls may form hiding places—large formed holes will improve passive security. Coordinate wall location with isolation joints. Figures 8-14 through 8-16 show example arrangements.

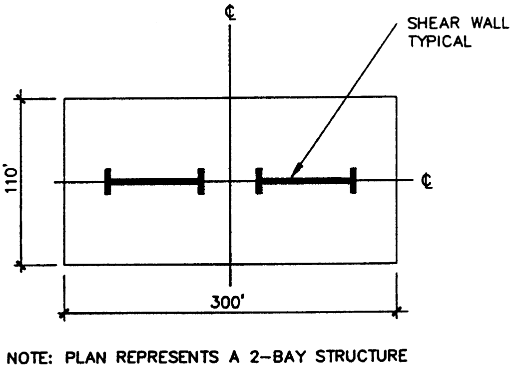


Figure 8-15. Example of shear wall arrangement. Placing shear walls near the center of mass will simplify structural design but may adversely affect traffic and parking planning.

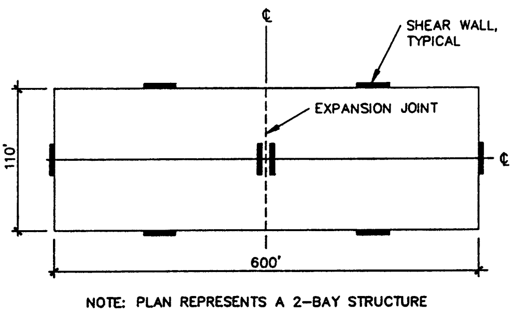


Figure 8-16. Example of shear wall arrangement. For a larger structure, some combination of Figures 8-11 and 8-12 arrangements may be the best solution.

8.3.3.3 Truss Action

Frame action necessary to resist lateral forces may be lessened by the presence of structurally integral ramps connecting consecutive floors. This same approach may be used with continuously sloping floors. In some configurations you may achieve truss action by taking the ramps into account, perhaps in one direction only, but carefully analyze the effect of lateral displacements on interconnecting elements. (Figure 8-17.)

8.3.4 Superstructure Systems

Superstructure systems commonly used for parking structures may be classified into the following groups:

Cast-in-Place (CIP) concrete	Structural steel
Precast concrete	Combinations

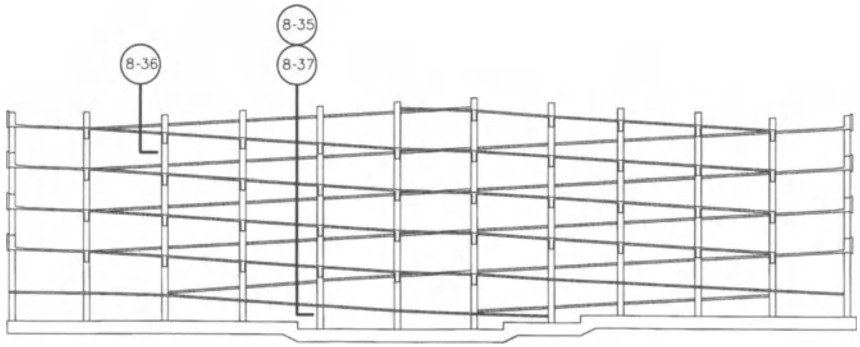


Figure 8-17. Simplified section showing truss-like construction of structure.

When considering any superstructure system, remember that parking structure design and construction demand more attention to durability design than for design of structures protected from the weather.

8.3.4.1 Cast-in-Place Concrete, General

CIP concrete structures are typically rigidly framed with monolithically cast slab-to-beam-to-column connections.

8.3.4.2 Posttensioned CIP Concrete

Figures 8-18 and 8-19 show plan and section views of a typical posttensioned one-way slab, posttensioned beam, and conventionally reinforced column-framing system. Posttensioning a member reduces its size for a given span. The more economical member size produces a

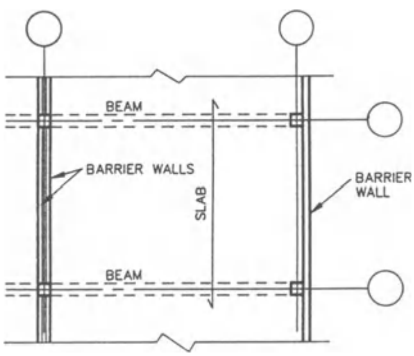


Figure 8-18. Example of posttensioned system—plan view.

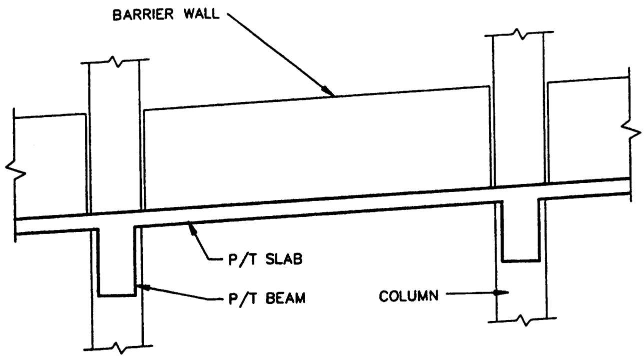


Figure 8-19. Example of posttensioned system—section view.

smaller total structural weight, reducing moments. Negative moments and associated cracking are further reduced by posttensioning-induced compressive stresses. This reduction lowers the exposure of steel reinforcement. Despite this advantage, maintain proper concrete cover.

Though posttensioning will generally reduce cracking, it is not necessary, or even desirable, to design posttensioning to carry all gravity loads. Instead, use it only to reduce the tensile stresses at strategic locations. One concept uses posttensioning to offset a percentage of the dead load stresses. Too much posttensioning will increase both elastic shortening and creep-associated problems. Even at the lowest effective level of posttensioning, these factors are important in design.

Posttensioned structures contain areas where care must be taken to preserve system durability, especially where reinforcement is near the top surface of the concrete.

Through design, control volume change, creep deflections, and initial camber. Check the initial member camber, elastic deflection, and creep deflection so the final floor profile is consistent with the deck drainage system. Provide adequate concrete cover for reinforcement protection and fireproofing.

8.3.4.3 Conventionally Reinforced CIP Concrete

Flexural members are typically deeper when designed in conventionally reinforced concrete than they are for posttensioned concrete members of equal span and load. Because of larger member size and monolithic construction, performance under vehicle-induced vibrations is generally good. Increased member weight leads to increased reinforcement, form work, and foundation costs. Increased structural depth may lead to taller structures. This system's greater deflections may affect drainage design. This system would be used typically with short-span construction as part of a multiuse structure, such as basement parking in an office building.

Analyze for allowable crack width control at negative moment locations such as beam column joints. Water penetration at these points can lead to corrosion. Provide proper rebar cover everywhere. Provide sealant details at construction joints.

8.3.4.4 Precast Concrete, General

Figures 8-20 through 8-23 show a typical precast double-tee framing system plan and sections. For parking structures, precast concrete has two primary advantages: concrete quality is good, and the speed of assembly reduces on-site construction time and cost. Disadvantages are the installation and maintenance of the large number of connections and sealed joints.

Plant-fabricated members are manufactured with close dimensional tolerances. Embedded item location control is usually critical for achieving quick erection. Coordinate drains and openings to ensure a properly detailed structure. When locating drains, account for member

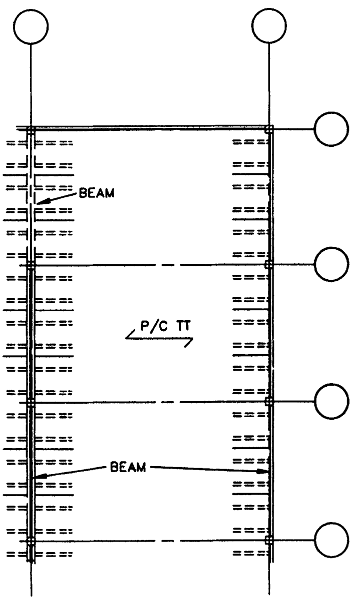


Figure 8-20. Example of precast double-tee system—plan view.

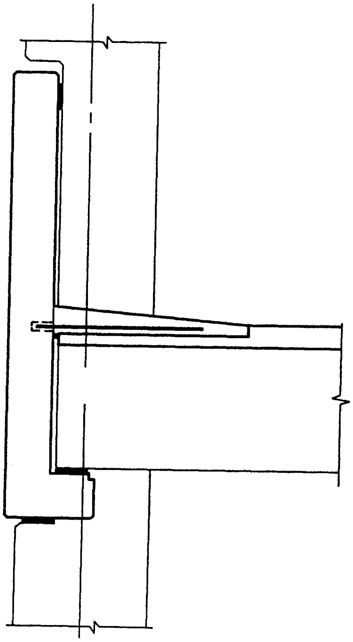


Figure 8-21. Example of precast double-tee system—section at exterior L beam.

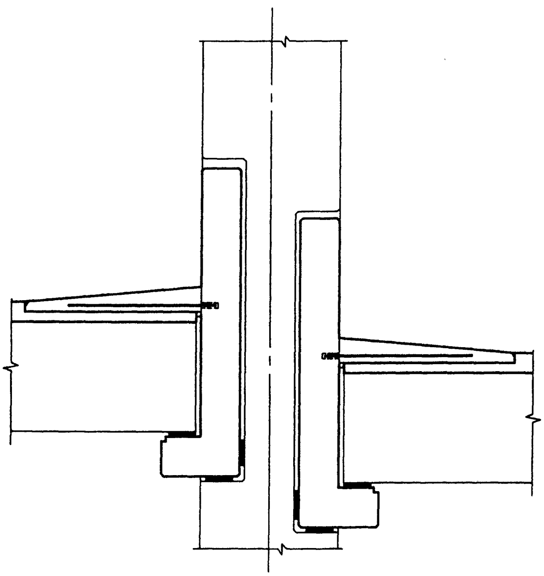


Figure 8-22. Example of precast double-tee system—section at interior L beams.

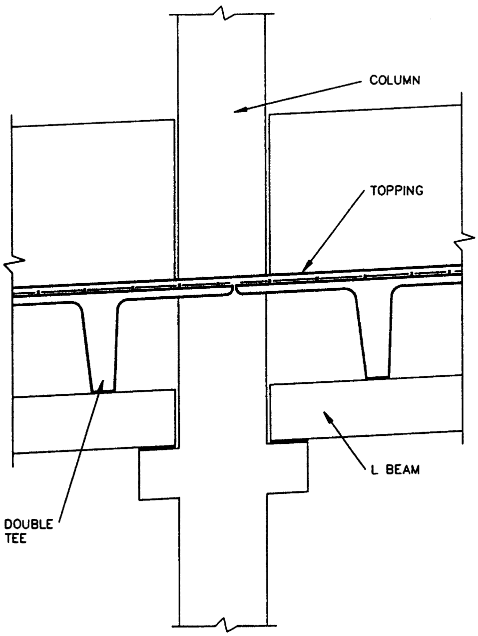


Figure 8-23. Example of precast double-tee system—section through tees at interior L beams.

deflections and cambers. Provide for adequate member clearances in design. Pay particular attention to casting and assembly tolerances. Prohibit forcing units into position during erection; such erection stresses can cause local failures.

Detailing member connections is critical. Review special connections with a local fabricator for ease of construction. Connections are often exposed to water penetrations through cracked topping and leaking joints. To prevent cracking and leaking, use proper materials. If connections are to be concealed in pockets that are concreted after the connections are made, and if building codes permit, use a sealant, not a grout, to fill the pockets. Consider stainless steel connections and anchors to reduce metal corrosion and corrosion-caused concrete spalling. Where field welding is required, detail to allow heat-caused expansion of the metal embedments without cracking the adjacent concrete. Use field-applied coatings to protect welds and ferrous metals after welding. Connections need not be concealed if detailed to be clean and simple. Exposed connections, suitably protected against corrosion, are not objectionable; in fact, it may be better to have visible connections, which are more easily monitored and maintained.

Connections may become complicated in areas of seismic risk where continuity is essential. Even in areas of low seismic risk, volumetric and temperature changes in large structures may induce large forces and moments in connections. (See Chapter 9.)

8.3.4.5 Conventionally Reinforced Precast Concrete

Precast concrete with conventional reinforcement is sometimes used for architectural spandrel beams and for short-span structural members.

Structural columns, stair units, walls, short-span slabs, and short ramps may be designed in conventionally reinforced precast concrete. Some precasters prefer pretensioning these members for ease of handling, so check local precaster preferences to save time checking shop drawings later. See the discussion for conventionally reinforced CIP concrete.

8.3.4.6 Pretensioned Precast Concrete

Properly used, pretensioning provides strength, deflection, and crack control, and shallower slabs, joists, and beams. Pretensioning may be used simply to protect against damage during transportation and erection.

Proper pretensioning effectively closes service load cracks, reducing water penetration. If cracks are likely to be an owner perception problem in façade members, pretension those members. Pretensioned concrete units have already undergone full elastic shortening before erection, so further elastic shortening may be neglected. However, do not neglect the effects of long-term creep of pretensioned members after erection. Much of the discussion for posttensioned CIP concrete, as it relates to crack control and stressing levels, applies here also.

8.3.4.7 Posttensioned Precast Concrete

Coupling together an assembly of precast units with posttensioning may be desirable. Take care to ensure that such stressing does not cause unacceptable geometry changes in the structure, either at the time of stressing or in the long term. Individual members also may be posttensioned. A common scheme is to pretension a large member for self, dead, and construction loads, and then posttension it for live loads.

8.3.4.8 Structural Steel

Figure 8-24 shows one structural steel framing system for parking garages. This system features a cast-in-place posttensioned concrete floor. As supplied by one firm, after shop fabrication the steel members are cleaned to white metal, then three coats of epoxy paint are applied, providing long-lasting protection against corrosion. All erection connections are bolted; no welding means no field touchup of damaged coating will be required. A plan view of this scheme would resemble the all-concrete scheme shown in Figure 8-18, with steel substituted for the concrete beams.

Figure 8-25 shows a steel frame with a floor of short-span precast prestressed double tees. This system has much to recommend it. It can be built quickly, capitalizes on the strengths of concrete and steel, and performs well. Another scheme rotates the double tees 90 degrees to span the long dimension of the bay to take better advantage of their structural efficiency.

Corrugated metal deck forms, open web steel joists, and certain weath-

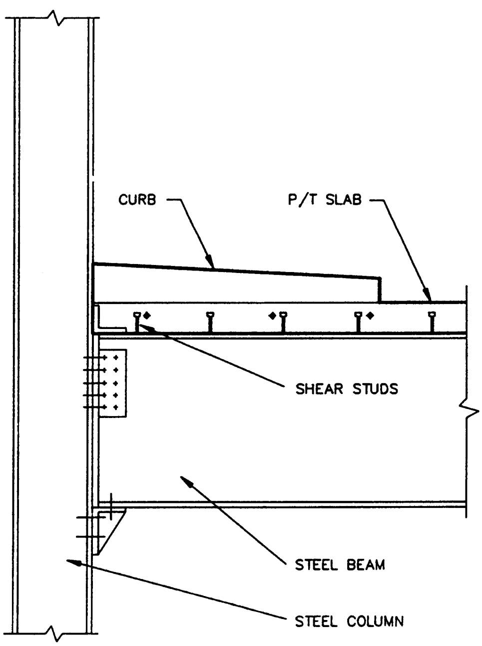


Figure 8-24. Example of a structural steel frame/posttensioned concrete slab system.

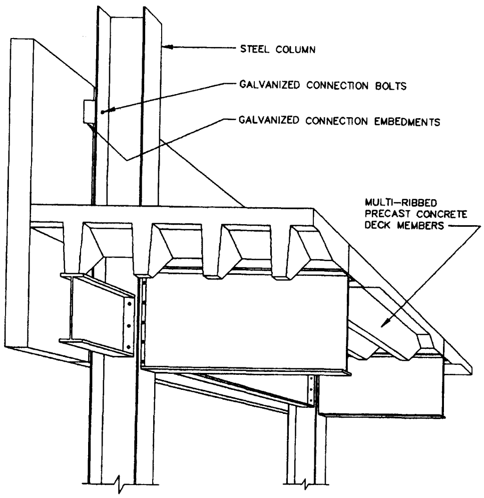


Figure 8-25. Example of a structural steel frame/precast double-tee system.

ering steel connections may not perform well in regions where road salt use is common, rainfall is high, or in coastal environments. Protective coatings are necessary for these systems in such areas. Local building codes may require fireproofing.

In many areas, a life cycle analysis will show that first cost and maintenance cost of a structural steel frame are greater than those of a corresponding concrete frame; however, recent developments in coating technology and in building code requirements have made steel parking structures more competitive. Reasons for using structural steel might be (1) the need for as lightweight a structure as possible to permit economical foundations despite poor soil; (2) a shortage of skilled concrete tradesmen in the project locale; or (3) local preference.

8.3.4.9 Combinations

A number of combinations of cast-in-place and precast concrete combinations are discussed in both the section above and in the sections following. All utilize composite action between the precast and cast-in-place elements, or between concrete and structural steel members. The combination of precast beams and columns, or of precast beams, girders, and columns, is noted here for two reasons. First, it is not mentioned elsewhere. Second, it is widely used on the west coast of

North America, and its use is spreading. This system was used not uncommonly in many locales 15–20 years ago, then fell into disuse. Now there is a resurgence.

8.3.5 Structural Components

8.3.5.1 Thin-Slab CIP Floor Systems

Thin-slab systems, such as waffle slabs and pan joists, usually require less concrete than one-way-slab designs and so may appear economically attractive initially.

These systems use thin slabs, usually 3–4 in. thick, stiffened by a stem-web pattern underneath. The main advantage of these systems is that long spans are achieved with a relatively light structure. However, there are more drawbacks than advantages.

Waffle slabs and pan joists present specific problems with cracking and reinforcement protection. Small-scale cracking can be expected at the slab periphery owing to variations in curing rates and shrinkage between slabs and joists because of the differences in volume/area ratios. These characteristics lead to stress cracking, which might not otherwise occur. In any case, the cracks will accelerate the weathering process when water is present. In a thin slab, it is more likely that cracks will fully penetrate the slab, permitting water to reach both top and bottom reinforcing and causing objectionable leaching on the slab underside. These problems may be lessened by careful control of the construction process, particularly curing, and by attention to the arrangement and placement of the reinforcement. A traffic-bearing protective membrane should be required protection. Crack control by tooled and sealed control joints may reduce the section to an unacceptable degree and is not generally practical for thin slabs. However, provide tooled and sealed joints at every construction joint. Waffle slab and pan joist systems are not recommended for parking structures.

A system with similar characteristics incorporates cast-in voids to form a floor structure resembling a thick hollow-core unit. A composite system incorporating precast pretensioned joists spaced at around 7′6″ on centers and spanning 40–68 ft shares the same behavior. This system can perform well if designed with sufficient control joints and slab reinforcement to prevent cracks, but it seldom is. This system is not recommended for parking structures.

Hollow-core units with topping share thin-slab characteristics. They are also vulnerable to slab deflections and shear stress failure. In design, reduce excessive elastic and creep deflections to prevent ponding and poor drainage. Specify weep holes in the downslope ends to permit drainage. This system is not recommended for parking structures.

We have seldom used any of the above-described systems, but have seen problems with them in our restoration practice. We do not recommend their use. Beware of any structural system with thin elements and vulnerable top reinforcement.

One- and two-way slab systems will generally have high tensile stresses at slab-top fibers at supports. Cracking is likely to be more visible at these locations and may penetrate the slab full depth. The top reinforcing in these systems is vulnerable, and will require protection against corrosion. Deflections are a concern in the design of longer spans. Careful control of camber and attention to live load deflection are essential. Two-way slab systems are not recommended for parking structures.

In general, most structural systems can be made to perform adequately in parking structures if sufficient effort is made in both design and construction. As discussed above, however, some systems are more suited for parking structures, while others are better avoided.

8.3.5.2 Precast Concrete Floor Systems

Parking-structure floors may be made of solid or hollow-core plank. Tees of all kinds, single, double, triple, and quad, and in widths from 8 to 12 ft, depending on which forms local precasters use, have been used. Plank and tees may be made composite with cast-in-place topping or may not require topping. The latter, referred to as "pretopped," have become more common in recent years. (See Figures 8-26 and 8-27 for illustrations of field-topped and pretopped double tees.)

In both field-topped and pretopped floors, welded connections between members are required to provide deflection compatibility between adjacent members and to help transfer shear across slab diaphragms.

If floor members are topped, there is a change in structural cross section at the joints between adjacent members. Though the composite thickness of the 2-in.-thick tee flange and the 3-in. topping is 5 in., at the joint between flanges, only the 3-in.-thick topping exists. This thinner section comprises a weakened plane which will crack as the topping concrete cures and shrinks. To make a more durable floor structure, it is important to control cracking and minimize leaks by specifying tooled and sealed control joints in the topping at every joint between precast

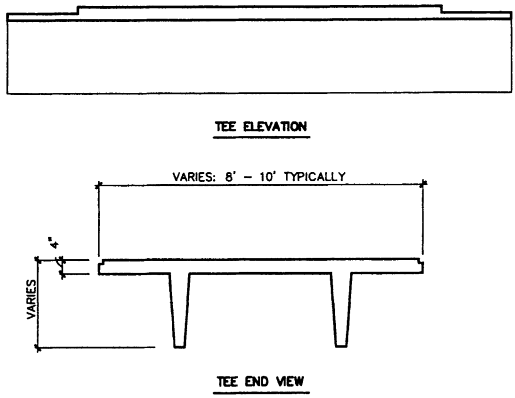


Figure 8-26. Pretopped double tee.

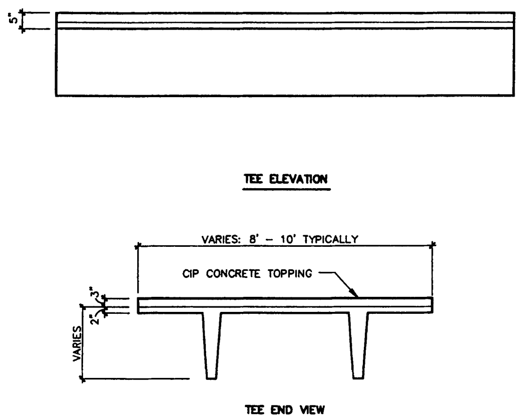


Figure 8-27. Field-topped or site-topped double tee.

members. Joint depth should be 20% to 25% of the concrete thickness to be effective (see Figure 8-28).

Avoid saw-cutting control joints. If sawing is done too early, the edges of the cut will ravel, leaving an uneven joint which will be difficult to seal and which will be objectionable in appearance. If the sawing is done too late, the concrete will have already cracked. Even if done right, the saw cut leaves a right-angle edge which is weaker than the rounded edge left by tooling the joint. Even if the saw-cut joint is initially sealed successfully, which because of its narrow width is not easy to do, the edge is likely to crack, rendering the joint sealant useless.

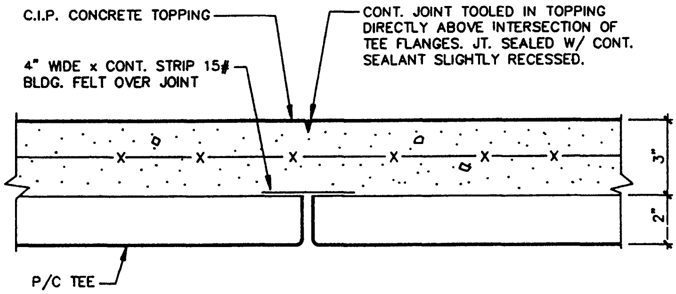


Figure 8-28. Tooled and sealed joint in site-cast concrete topping over precast double tee.

Concrete topping for precast floors is often the last concrete placed. Quality of placing, finishing, and curing may suffer because of the hurry to finish the job. Also, because the topping usually varies in depth from 3 in. typically to 5 in. at a thickened edge at the floor perimeter, one truckload of poor concrete means poor topping over a large area. A 9-cu-yd truck will cover 972 sq ft with 3-in.-thick concrete.

8.3.5.3 Floor Systems With Structural Steel Framing

Floors in steel-framed parking structures may be cast-in-place conventionally reinforced or posttensioned concrete on composite steel decking or on corrugated metal form, or precast members. For CIP slabs, the Steel Deck Institute recommends that steel deck be used only as the form for the concrete slab, not as composite reinforcement. The institute also recommends that in corrosive environments, a traffic-bearing membrane be applied over the concrete.

Concrete topping placed on corrugated steel forms often cracks owing to shrinkage. Control this cracking with properly spaced, tooled, and sealed construction and control joints. Also, use welded-wire fabric or fiber reinforcement or both. Short- or long-span precast concrete double tees work well with steel framing.

8.3.5.4 Beams and Joists

Cast-in-place beams are usually formed in a T or L shape, the latter occurring at spandrel beams which may have the vertical leg of the L either upturned or downturned.

Precast members may have many shapes, such as rectangular, trape-

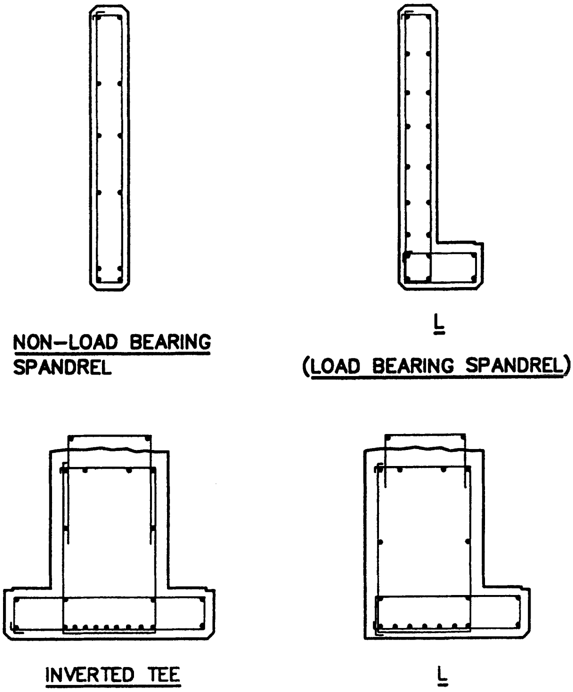


Figure 8-29. Commonly available precast concrete beam types.

zoidal, tees, inverted tees, L beams, I beams, etc. (see Figure 8-29) and may be conventionally reinforced, pretensioned, posttensioned, or some combination of two or all three. Precast members are often made composite with a cast-in-place topping. (For a discussion of torsion in beams, see section 8.5.4.)

If a perimeter curb is cast perpendicular to and atop a cast-in-place T beam, it is likely that the curb will crack parallel to the sides of the beam below. We have never seen problems with reflective cracking over the beam with the slab alone, or with a thickened edge, but a 6-in.-high curb will crack. Prevent these cracks by tooling and sealing a control joint in the curb directly above and parallel to each beam face below.

Steel studs are often used with structural steel members to develop composite action between the member and a cast-in-place slab. Beams and girders may be castellated or cover-plated. Joists may be the open-web type, but are not recommended.

8.3.6 Summary of Structural System Selection

As seen from the discussion above, some structural systems are more suitable for parking structures than are others. Some systems will work just as well as others, but only if additional protection is provided. That additional protection, though, will likely make the selected system uneconomical.

In summary, of all the structural systems that have been used for parking structures, there are perhaps half a dozen which can be recommended, without added protection such as traffic-bearing membranes (Chapter 10). A durable system should include a pretensioned or posttensioned concrete floor to reduce the likelihood of cracks and render a traffic-bearing membrane unnecessary. The floor should be thick enough to provide sufficient cover for reinforcement and sufficient mass to prevent undesirable vibration. The system must permit good drainage. Its nature must permit unsophisticated construction practices. Finally, the cost of the system must be competitive.

The systems currently meeting these requirements, in no particular order:

- Cast-in-place posttensioned concrete framing and floors
- Precast pretensioned concrete framing with pretopped double-tee floors
- Precast pretensioned concrete framing with field-topped double-tee floors
- Precast pretensioned concrete framing with cast-in-place posttensioned concrete floors
- Structural steel framing with cast-in-place posttensioned concrete floors
- Structural steel framing with double-tee floors

It should be noted that in some regions, building codes effectively prohibit posttensioned concrete floors. Some parking structures are now being built in those regions with nonprestressed reinforcement in the floors (protected by traffic-bearing membrane) and posttensioned beams.

8.4 VOLUME-CHANGE EFFECTS

Volumetric changes affect frame action in structures, especially those large in plan area. The results can include development of high shears and bending moments in the first-story frames at or near the building periphery.

8.4.1 General

Volume change is the change in dimensions in the structural elements due to drying shrinkage, temperature change, elastic shortening, and horizontal creep. The strains and forces resulting from structural restraints have important effects on connections, service load behavior, and ultimate load capacity. Consider these strains and forces in design. The restraint of volume changes in moment-resisting frames causes tension in the beams and slabs, and moments and deflections in the beams and columns.

8.4.2 Drying Shrinkage

Drying shrinkage is the decrease in concrete volume with time. This decrease is due to changes in concrete's moisture content and chemistry. These changes are unrelated to externally applied loads. If concrete shrinkage is restrained sufficiently, cracking will provide relief at weak points. For proper durability and serviceability, predict and compensate for drying shrinkage, which is likely to be significant in open parking structures. (ACI 209R, *Prediction of Creep, Shrinkage, and Temperature Effects in Concrete Structures* gives recommended shrinkage values.)

8.4.3 Elastic Shortening

In prestressed concrete, axial compressive forces applied to the concrete by prestressing tendons cause elastic shortening. This shortening causes some loss of prestressing force, which must be accounted for in determining the final effective prestressing force. Elastic shortening is additive to drying shrinkage. The Precast/Prestressed Concrete Institute and Post-Tensioned Concrete Institute Design Handbooks provide recommendations for predicting elastic shortening and all the types of volume change described in this section.

8.4.4 Creep

Creep is the time-dependent change in dimension in hardened concrete subjected to sustained loads. Concrete continues to deform inelastically over time under sustained loads. Its total magnitude may be several times larger than short-term elastic shortening. Frequently, creep is associated with shrinkage, since both occur simultaneously and provide the same net effect—increased deformation over time.

8.4.5 Temperature

A change in temperature will cause a volume change which will typically affect the entire structure. In addition, sunlight will affect local areas such as the roof and edges of lower levels more than the rest of the structure. The change can be expansion or contraction, so may be additive or subtractive to the above-discussed volume changes. Unlike drying shrinkage, elastic shortening, and creep, temperature changes are cyclic. The resulting expansion and contraction occur in both daily and seasonal cycles. The structural movements resulting from temperature changes must be a major consideration in every design.

8.4.6 Control Measures

8.4.6.1 Overall Structure

The degree of fixity of a column base has a significant effect on the size of the forces and moments caused by volume-change restraint. The assumption of a fully fixed column base in the analysis of the structure may result in significant overestimation of the restraint forces. Assuming a pinned-column base may have the opposite effect. The degree of fixity used in the volume-change analysis should be consistent with that used in the analysis of the column loads, determination of column slenderness, and construction document details.

A change in center of rigidity or column stiffnesses will change the restraint forces, moments, and deflections. The areas of a structure to be treated with extra care for volume change are:

1. Any level with direct exposure to the sun and the columns directly below that level
2. The first supported level and the columns directly below it
3. The southern (in the northern hemisphere) and western faces

Creep- and drying-shrinkage effects occur gradually. The effect of the shortening on shears and moments at a support is lessened because of creep and microcracking of the member and its support. These volume-change shortenings can be designed for by using the concept of equivalent shortening in the *Precast/Prestressed Concrete Institute Design Handbook.*

TABLE 8-2. Example Guidelines for Isolation Joint Spacing

Number of Isolation Joints	Cast-in-Place, Posttensioned Concrete	Precast Concrete Prestressed in Direction of Consideration	Precast Concrete, No Prestress in Direction of Consideration
None	200 ft maximum w/ no additional pour strips, or 275 ft maximum w/1 pour strip at center	225 ft maximum	300 ft maximum
One, about at the center	550 ft maximum, with two additional pour strips at quarter points.	450 ft maximum	600 ft maximum
Two, at about the third points	600 ft maximum w/ no additional pour strips, or 825 ft maximum w/3 additional pour strips at sixth points	675 ft maximum	900 ft maximum

8.4.6.2 Design Measures

In dealing with the volume-change forces, consider:

1. Parking structures have large plan areas. This characteristic will result in significant secondary stresses due to temperature change, shrinkage, and creep. Place isolation joints to permit separate segments of the structural frame to expand and contract without adversely affecting the structure's integrity or serviceability. Table 8-2 gives *general* guidance in spacing permanent and temporary isolation joints in a structure. Dividing the structure into smaller areas with isolation joints may be complicated by the presence of interfloor connecting ramps. Full-structure isolation joints must be aligned in both the vertical and horizontal planes in order to keep the full height of each column on one side or the other of the joint; otherwise columns may shear or other distress result.
2. Isolate the structural frame from stiff elements—walls, elevator cores, stair cores. Do not allow the superstructure to move freely with respect to the substructure; this is a trap for the unwary. Figures 8-30 and 8-31 show two details that will be helpful.
3. Reduce the rigidity of certain members or connections, using pinned (or partially pinned) connections at column foundations, or using

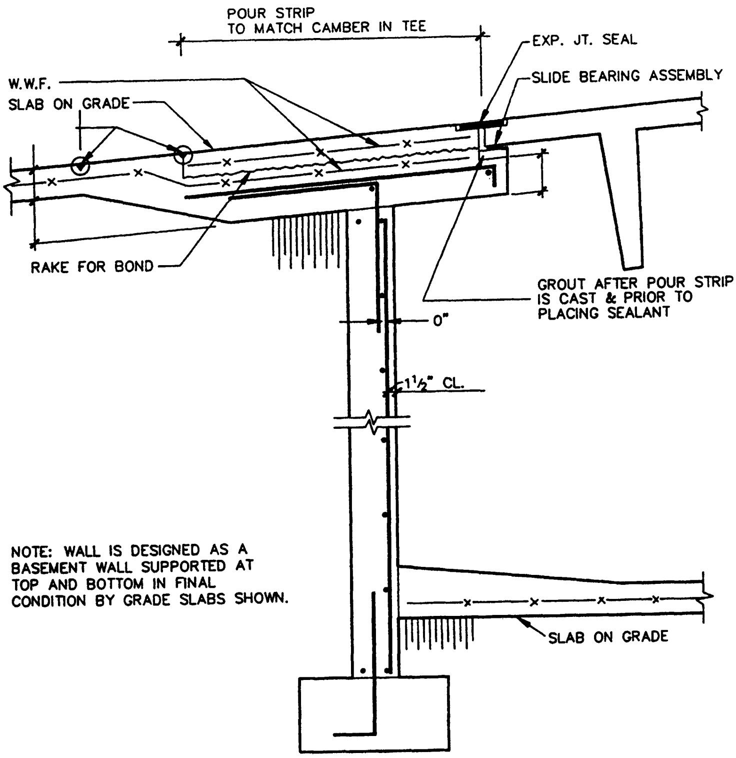


Figure 8-30. Example of a detail that permits relative movement between foundation and superstructure elements.

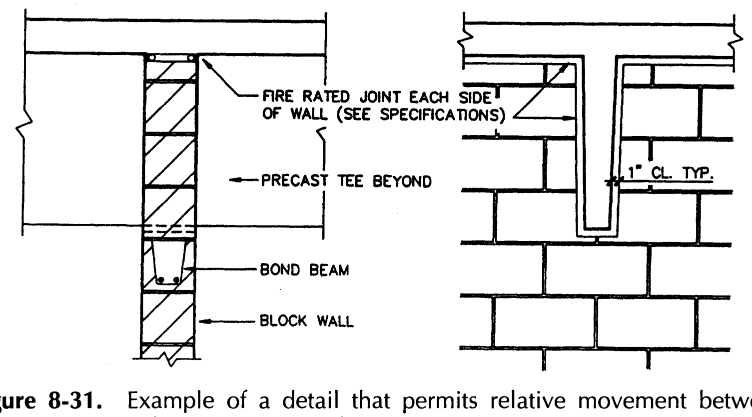


Figure 8-31. Example of a detail that permits relative movement between a foundation wall and a superstructure beam.

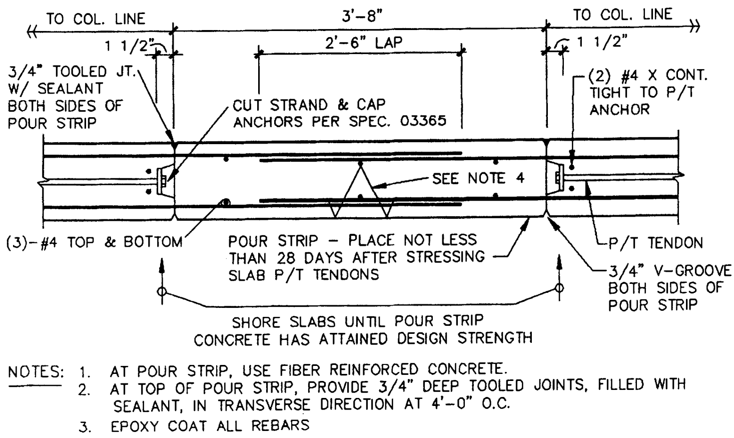


Figure 8-32. Pour-strip detail. Also called temporary isolation joint.

longer unbraced column lengths. Unbraced column lengths may be increased without increasing structure height, particularly between grade and first supported levels.

Leave a sealed gap between slab on grade and the column to produce an unbraced length beginning at top of foundation rather than top of grade slab. This measure may also be combined with lowering the top of foundation to further increase the unbraced length. Use only soft connections at the first supported level to increase the unbraced length when needed.

To temporarily reduce column rigidity at any location, consider a temporary hinge. Block out the column form, leaving a length of concrete supported only by the vertical reinforcement; later fill the gap. If you use this method, be sure to check the capacity of the vertical reinforcement alone versus the column loads expected before the gap is filled and full column capacity is restored.

4. Install temporary open "pour-strip" joints which are closed before construction is complete (see Figure 8-32). These temporary contraction joints allow the dissipation of early-age volume-change effects, such as elastic shortening, temperature movement, and shrinkage, which occur before placing the pour strip. Give close attention to pour-strip concrete quality. Use tooled and sealed construction joints and protected reinforcement. Control joints transverse to the pour-strip length at spacing equal to the strip width, and fibrous reinforcement may be necessary. In particularly hostile environments, consider a traffic-bearing coating overlapping the pour-strip edge construction joints.

5. Frames with unequal column heights and stiffnesses, differential thermal response of members, and inelastic behavior cause further difficulties in predicting isolation joint movement. Computer modeling of parking structure frames can be effective in predicting volume-change-induced moments, forces, and movements, provided the model is not oversimplified.

8.5 PROBLEM AREAS

8.5.1 Structure Flexibility

Parking structures are large and exposed to the weather. They are comprised of concrete to a large degree. That concrete may be pretensioned or posttensioned. All of these factors combine to produce a structure that tends to expand and contract with daily and seasonal temperature cycles, to shrink and shorten as the concrete ages, and to shorten both elastically and inelastically under compressive load. This movement is real and cannot be ignored. As one well-respected engineer puts it, "Let the structure breathe." The solution is to allow the structure, particularly the columns, to be flexible enough to permit movement without structural distress. The trick is to do this while providing for adequate strength to carry the imposed loads. Further discussion occurs elsewhere in this chapter.

8.5.2 Beam Column Joints

Columns in parking structures are often subjected to unusual forces compared to those in other buildings. Effects of the prestressing system, relatively high joint moments and shears associated with long spans, and effects of volume change all contribute to highly stressed joints.

Exterior columns and beams will typically have high joint moments, requiring special consideration of the anchorage of the beam top reinforcement. In columns, the shear within the joint caused by the beam negative moment can exceed the shear capacity of the concrete alone. Ties are required within the joint. (Factors affecting the behavior of these joints are discussed in ACI 426, *Shear Strength of Reinforced Concrete Members,* and ACI 352, *Recommendations for Design of Beam-Column Joints in Monolithic Reinforced Concrete Structures.*) Shear in the columns may require increased tie reinforcement throughout the column height, particularly in seismic zones. Where column vertical bars lap, development of those bars and the corresponding column-

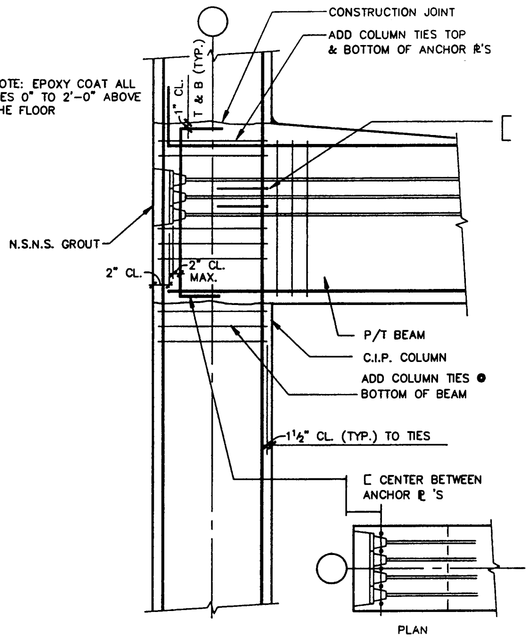


Figure 8-33. Cast-in-place posttensioned concrete beam/column joint at exterior of structure.

tie requirements both need evaluation. Typical posttensioned beam column details are shown in Figures 8-33 through 8-36.

In cast-in-place posttensioned structures, shortening of the first supported level beams due to elastic shortening, creep, and shrinkage will induce tension in the beam bottoms. Similar but lesser effects will occur at the upper levels.

Precast concrete beam column joints require special attention. Joints in precast concrete structures are subjected to repeated movement owing to cyclic volume change and vehicular traffic.

On the roof levels of parking structures of all types, the sun heats the top surface of the structure while the underside remains cooler. The result is a daily cycle of camber and deflection. Resulting rotations and forces at member ends can distress both simple-span and rigid-frame construction. Special detailing may be necessary.

8.5.3 Variable-Height Columns

The typical method for accessing the successive levels of a multilevel structure is via continuous sloping ramps. These ramps may comprise

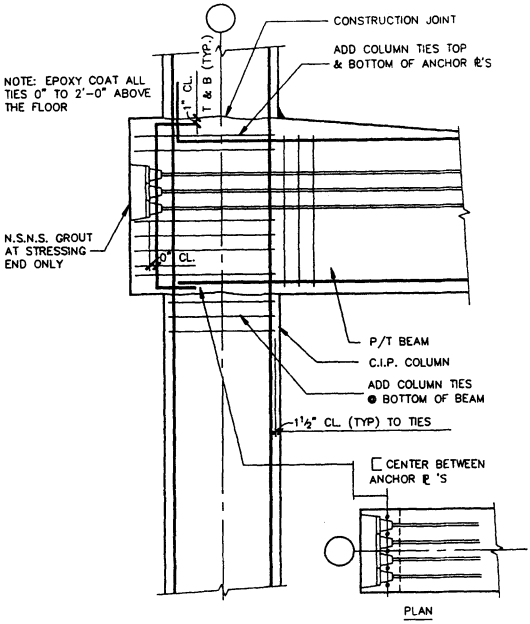


Figure 8-34. Cast-in-place posttensioned concrete beam/column joint at exterior of structure. This detail alleviates reinforcement congestion at the posttensioning anchorages by moving them outside the column reinforcement. It is also suited for use when the column cross section is not rectangular.

entire floors and be used for both parking and through traffic (refer to Figure 8-17 and see Figure 8-37).

The presence of integrated interior or exterior ramps will have a significant effect on the action of the structure. Internal ramps interrupt the floor diaphragms and complicate their analysis. High moments and shears are induced in columns adjacent to ramps where monolithic beams enter opposite sides of the columns at varying elevations (Figure 8-37). Split columns—that is, columns divided in two, each with beams framing in from one side only—will help.

8.5.4 Torsion

Avoid torsion if you can. Spandrel beams at slab edges, built integrally with the floor slab, are subjected not only to transverse loads, but to a torsional moment per unit length, equal to the restraining moment at the slab's edge. The 1995 edition of ACI 318, Section 11-6, addresses design requirements with respect to torsion requirements in combina-

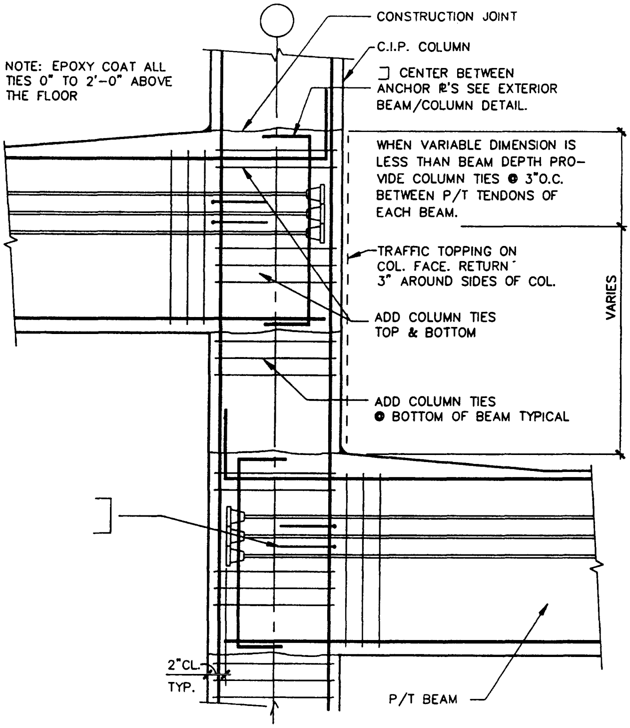


Figure 8-35. Cast-in-place posttensioned concrete beam/column joint at interior of structure. Ramped floors result in beam/column relationships like this and that shown in Figure 8-37.

tion with shear and bending. Typically, monolithically cast spandrel beams, whether prestressed or not, are easily reinforced to meet minimum code requirements, but design them to minimize cracking.

Precast spandrel beam design is one of the most complex elements in parking structures. Figure 8-38 shows the major loads on one such typical beam. The *PCI Design Handbook*, Section 4.4.2, and the PCI Research and Development Project No. 5 also address the behavior and design of precast spandrel beams. Pocketed beams, such as that shown in Figure 8-39, are one way to reduce torsion in spandrel beams. PCI R&D Project No. 5 considers both L and pocketed beams.

8.5.5 Stair and Elevator Shafts

Shafts interrupt the regular pattern of framing (see Figures 8-40 and 8-41) and may cause differential deflections in the adjacent structure,

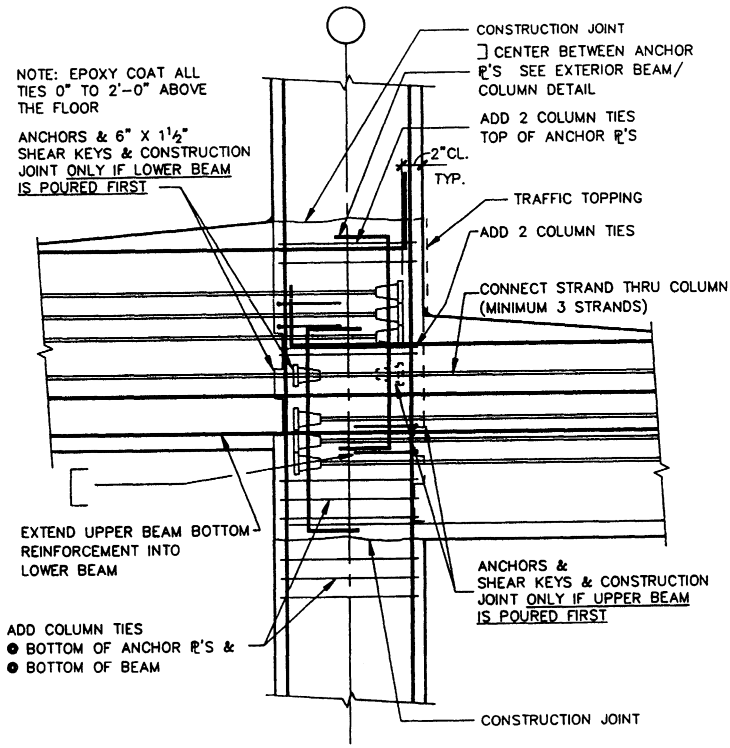


Figure 8-36. Cast-in-place posttensioned concrete beam/column joint at interior of structure. This detail would apply near the point where two ramped floors meet.

causing localized cracking. For instance, one beam or tee may end at the wall of a shaft while the adjacent one continues. The effects of dead load deflection may be minimized by prestressing; however, differential deflections due to live load will occur both in beams and in the connecting floor structure. Local differential cambers and movements parallel to the members may also be a problem. These concerns may be addressed with a reinforced, cast-in-place topping or by accepting the movements and installing an isolation joint between the two members.

8.5.6 Expansion Joints

The best expansion (isolation) joint is one formed by a complete separation of one side of the joint from the other. Avoid sliding joints. (See section 8.3 for more discussion.)

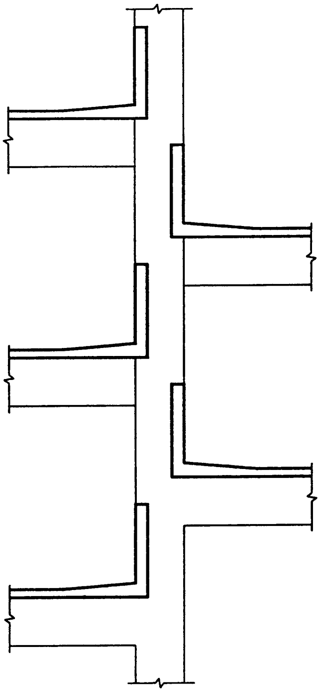


Figure 8-37. Section view of ramped floors at the column line between them.

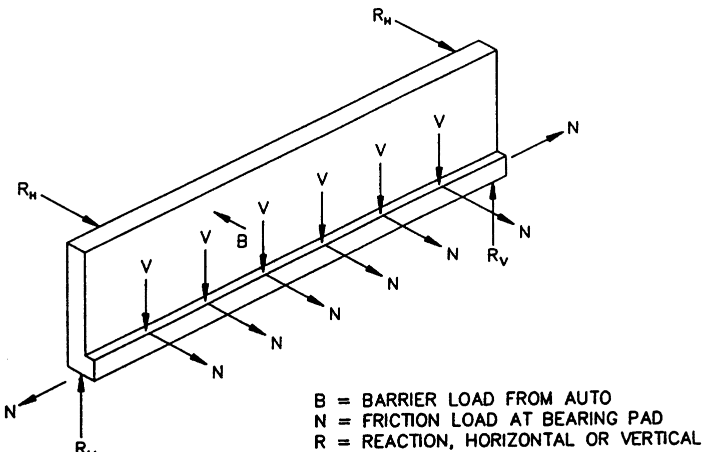


Figure 8-38. Example of the loads and reactions on a precast concrete L beam.

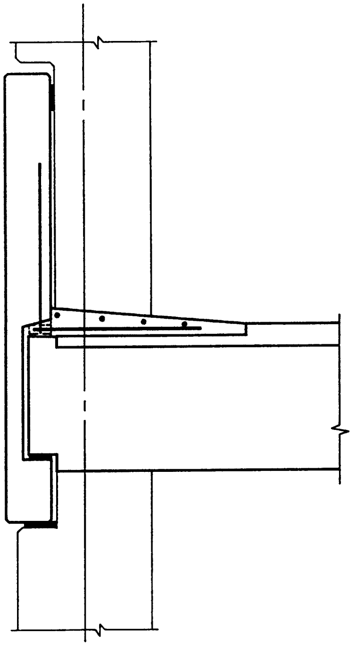


Figure 8-39. Example of a precast concrete pocketed beam—an alternative to the L-beam type.

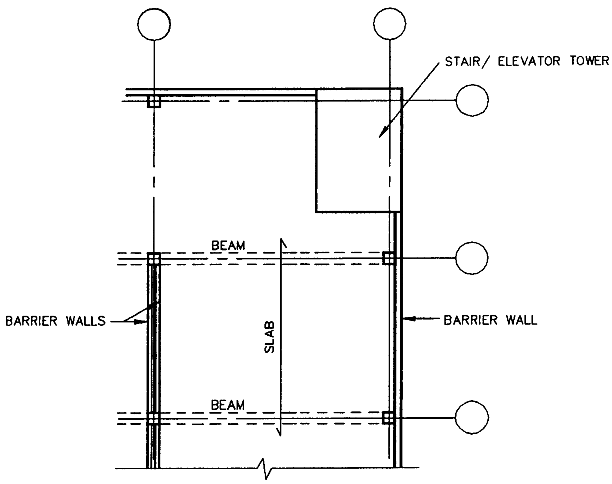


Figure 8-40. Structural framing around a stair or elevator tower—cast-in-place concrete construction.

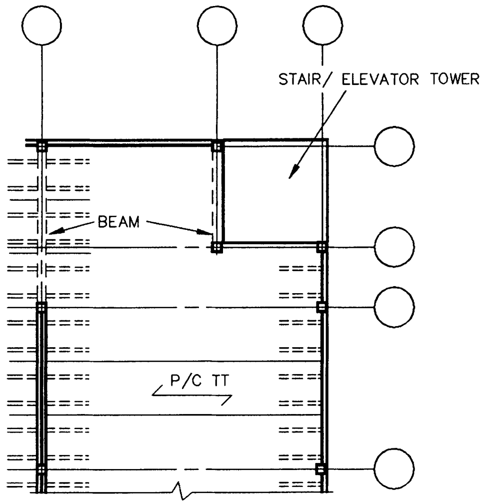


Figure 8-41. Structural framing around a stair or elevator tower—precast concrete double-tee construction.

8.6 SUMMARY

In Chapter 8 we have reviewed a number of factors that might influence the structural design of a parking structure, such as cost, schedule, and local building codes.

We have also looked at items such as drainage of rainwater runoff and expansion joint sealants that, while not an integral part of structural design, must certainly be taken into account if the structure is to work.

We have considered many possible structural systems regarding the relative suitability of each for parking structures. We have also noted which systems will need additional protection in corrosive environments and which are not recommended for parking structures.

Since parking structures are usually large enough and exposed enough to the elements for volume-change-induced forces to become significant in structural design and performance, we have examined the effects of shrinkage, elastic shortening, creep, and temperature.

There are some areas of design that are unique to parking structures, such as variable height columns, which we have also discussed.

CHAPTER
9

SEISMIC DESIGN

Anthony P. Chrest

9.1 INTRODUCTION

The earthquake that occurred in Northridge, California, on January 17, 1994, greatly affected structural engineers in California and elsewhere. Vertical forces and ground motions induced by the earthquake were greater than had been experienced before. Newly built structures, designed according to then-current building codes, suffered damage severe enough to render them unusable. In one instance, apparently similar structures a block apart came through the quake with far different results. One structure suffered only superficial damage while the other had to be demolished, so poor was its condition. Though not initially evident, not only precast concrete structures, but cast-in-place concrete and structural steel buildings numbered equally among the casualties. Parking structures of all types, with their long spans and large plan areas, were among some of the spectacular failures. Until more evidence was discovered, the seismic performance of concrete parking structures, both precast and cast-in-place, in the Northridge earthquake came under heavy criticism in newspapers and technical journals.

Since then, the response of the engineering community has been well documented, with the dedication of countless engineer volunteers a matter of record. With equal alacrity, advisory groups to building-code-making bodies studied the evidence gathered from many sites of damaged buildings and made their recommendations. Well within a year of the earthquake, most building codes in effect in earthquake-prone regions of the U.S. had adopted the revisions developed by their advisory groups. Research continues, and more building code revisions will doubtless result as clearer understanding of causes and effects are reached.

The code changes recommended by various groups for the design of new buildings may be summarized as follows.

1. Tie spacing in columns not part of a seismic frame should not exceed 6 in. over the full height of the column.
2. Ensure that all columns can withstand the lateral distortions induced in them by the movement of the lateral force resisting systems.
3. Improve the performance of the diaphragms that collect and transmit the earthquake-induced lateral forces to the lateral force-resisting systems.
4. Design for reinforcement used in the diaphragm chords and collectors mentioned above should use a strength reduction (phi) factor of 0.6 instead of 0.9.

A parallel project already under way before the Northridge earthquake, and due to be published in 1997, is a set of guidelines for seismic rehabilitation and upgrading of existing buildings. In contrast to building codes, the rehabilitation guidelines, funded by the U.S. Federal Emergency Management Agency, will focus on deformation states, rather than member strengths. However, about a year after the Northridge earthquake, the earthquake that struck Kobe, Japan, showed that the engineering and construction community still has much to learn.

9.2 DESIGN

Here are a few guidelines for design. Some reflect the code changes discussed in section 9.1. Others are reiteration of ideas that sometimes get lost or forgotten.

9.2.1 Column Modeling

Use the effective moment of inertia, not the gross moment of inertia, of columns in computer modeling and analysis. Use of the column gross moment of inertia will portray the column considered stiffer in design than it will behave under load. This suggestion is a good example of a simple but profound idea: all structural elements must be designed so that their actual behavior will reflect their designed behavior. Design and behavior must be congruent.

9.2.2 Confinement Reinforcement

Increase confinement reinforcement. So doing increases the effectiveness of the member primary reinforcement, particularly in compression members and at reinforcement splices. For one specific recommendation, see section 9.1.

9.2.3 Lateral and Vertical Load Design

Integrate lateral and vertical load design. This is another example of the idea stated in section 9.2.1. Buildings behave in three dimensions. Two-dimensional design may not be a satisfactory approximation. Three-dimensional computer modeling may be necessary. Computer software that can analyze in three dimensions exists, though its use can be cumbersome. Perhaps the Northridge earthquake and other recent seismic events will provide the impetus for easier-to-use software for three-dimensional analysis.

9.2.4 Load Path

Ensure that there is a simple, adequate, and complete load path for all loads to reach the load-resisting elements of the building. This statement applies to both vertical and lateral loads, but particularly to lateral loads. Two of the four code recommendations given in section 9.1 address this issue. Several seismic failures in the Northridge quake occurred because the diaphragm failed, not the shear wall or moment-resistant frame. This recommendation is yet another example of the idea expressed in section 9.2.1.

9.2.5 Simple Structure

Make every effort to design a simple and symmetrical structure. Too often the structural designer is called in at the end of the schematic design or design development phase, presented with a building, and instructed to "make it work." Trying to oblige, the designer usually does make it work, possibly by stretching a few points and cutting a few corners. Of course, in the U.S., the designer also has to reduce construction costs while trying to make a building work. The result is invariably a building with a suboptimum design. It costs less than it should, and it just barely meets building code requirements. This is the sorry state of structural engineering in the U.S. today, and so it will remain until the owner-designer-builder coalition changes its mindset. It can be done. It has been done in other countries, why not the U.S.?

Simple structures with short, direct load paths are best. Symmetrical structures are simple. Distribute lateral load-resisting elements uniformly throughout the structure plan. Avoid concentrations of lateral loads. Do not vary member sizes and reinforcement too much. So doing will produce a more expensive structure anyway.

9.2.6 Construction

Make sure that your design is built as you designed it. A corollary is that you should ensure that your design is buildable. (See section 9.2.5.) Avoid restraint in construction that you did not design for. A cautionary example is in section 8.3.2 and the associated Figure 8-13. In the Northridge quake, columns were stiffened by walls cast tightly against them. The columns were not designed to be that stiff, but they attracted load and they cracked. This suggestion is another simple point often forgotten.

9.3 STRUCTURAL SYSTEM SELECTION

There are two bodies of opinion on how best to resist earthquake-induced lateral forces. One body advocates extremely stiff buildings braced by shear walls or X-braced frames. The other advocates a more flexible building braced by moment-resistant frames. Either approach has advantages and disadvantages. Our experience has been that simple, straightforward "brute force" solutions are better than too-sophisticated ones. Often, sophisticated systems cannot be built properly. Any of the three structural systems cited at the beginning of this chapter—precast concrete, cast-in-place concrete, and structural steel—will do well if designed with sound engineering and attention to structure behavior. Fortunately, there is really not that much structure in parking garages, so there are not that many load paths, and behavior can commonly be seen intuitively, before computer modeling and analysis are begun.

9.4 PROBLEM AREAS

Problem areas are both economic and technical. In the economic area, parking structures may be designed and constructed using the *design/build* method of procurement, instead of the traditional *design/bid* method. Though fine buildings have been designed and built using the design/build process, there is a built-in conflict of interest in that the structural designer works for the constructor, and is pressured to reduce structure cost whenever possible. There are still local jurisdiction review and permitting, but not all jurisdictions have the ability to do a thorough check of construction documents and calculations.

Second, in parking structures there are seldom elements like partitions or ceilings to absorb earthquake-induced energy. The basic structure is left to resist the full force that in a more typical structure would have been reduced by nonstructural elements.

Third, parking structures are typically large in plan. They cover a lot of area. Since they are subject to significant movements, as discussed in Chapter 8, the structural designer may try to reduce the lateral load-resisting systems and place them at the centroid of the plan of the structure. While the intention is understandable, these actions may overload the lateral load distribution system by overconcentrating the lateral load resistance. Also, redundancy of the lateral load-resisting system may be insufficient.

Fourth, parking structures are often built with sloping floors or ramps that complicate the structural geometry. These ramps can interfere with the lateral force-resisting system by resulting in many short columns in the building interior. Being shorter, these columns will also be stiffer than typical exterior columns and will attract more load than they were designed for. Interior column failure was one of the hallmarks of the Northridge earthquake.

Fifth, parking structures are often built of precast concrete. The nature of this type of construction is that large elements like beams and columns are connected discretely, commonly causing stress concentrations. It should be noted that the same observation is true of steel construction, as post-Northridge investigations have confirmed. Cast-in-place concrete construction lends itself much more easily to monolithic construction with adequate connections. However, today's construction technology readily allows monolithic construction with precast concrete. It just costs more, which brings us back to economics and the all-too-true cliché that you get what you pay for. If cost is paramount, there will be problems with structural design.

In closing, let us point out that problem areas occur when and where structure behavior is not understood. Or, if behavior is understood, it is not accounted for in design. Attention to the suggestions made in the previous sections of this chapter, *if the design and construction budgets are adequate*, will prevent design and performance problems.

CHAPTER

10

DESIGNING FOR DURABILITY

Anthony P. Chrest

10.1 INTRODUCTION

You will have seen from Chapter 8 that with parking structures, structural design and durability design go hand-in-hand. One depends on and directly affects the other. For organizational purposes, this chapter will address construction material use that will improve the useful life of your structure. Tables are inserted at intervals to summarize the discussion of a material or to close a major section.

Parking structures deteriorate more rapidly than other building types, simply because they are more exposed to attack. Exposure conditions, even in climates like those found in southern North America, can be severe, and require proper protection.

The cost of protection systems varies widely. Some measures are almost free. Others are uneconomical except as a last resort, or because the project involves more than just the parking structure. For example, consider an office building with parking below. The structure of the parking area supports that of the office area above. If the parking structure deteriorates to the point where it is unsafe, the entire building would have to be condemned; this has already happened.

The discussion of why some concrete deteriorates and some does not appears in Chapter 14. There you will also find an explanation of why it is a good idea to keep road salt and water out of your concrete.

This chapter classes protection systems as (1) internal or built-in, and (2) external or applied. With a few exceptions, internal measures are relatively inexpensive, while external systems are usually more expensive. In sections 10.2 and 10.3, the alternatives presented range from least expensive to most expensive. Use any system with proper care, or it will be a waste of money. Another caution: Do not expect the impossible from a product; each one has limitations, and none will work miracles.

For example, we were once consulted on a project in New England because the protective sealer was not working. A review of the construction records showed that the concrete quality was poor and that floor deflections exceeded acceptable limits. The result was floor cracking. No sealer can bridge cracks in concrete. The cheap fix obviously desired was not successful, not because the sealer was poor quality, but because of ignorance of its capabilities.

As a final introductory note, when considering one element of durable design, do not forget to look at its impact on the total design. For example, increasing reinforcement cover may increase cracking, unless crack widths and tensile stress levels are checked and adjusted if required.

10.2 BUILT-IN PROTECTION SYSTEMS

10.2.1 Drainage

While proper drainage is not an ingredient of concrete, build it in. If we do not allow chloride-carrying water to collect anywhere in a structure, we reduce considerably the opportunities for chloride attack. Minimum pitch for drainage should be 1%, with 2% preferred. Size the drains to handle anticipated runoff volume. Include a sediment bucket (to reduce chances of clogging the piping) and corrosion protection.

Don't be misled by the brevity of treatment of drainage here. It is your first line of defense against corrosion. For more discussion of drainage in new structures, see Chapter 8. For remedial measures to drainage in an existing structure, see Chapter 15.

10.2.2 Concrete

Look at the basic ingredients of a good-quality concrete first—cement, water, and aggregate. As basic as they are, these materials are not always selected properly, so take nothing for granted.

10.2.2.1 Cement

Any type I cement conforming to ASTM C150 should be acceptable, provided local experience records show that it will perform well. Depending on the project area requirements, special-use cements such as sulfate-resistant cement, high-early-strength cement, or quick-setting cement may be needed. Different brands of cement will produce different results, so it is wise to specify that only one brand be used throughout the project. Be more careful about cement selection when you are designing for 28-day yield strengths exceeding 7000 psi, or when concrete color is important.

10.2.2.2 Water

Water must conform to ASTM C94, which requires drinkable-quality water. Chloride content must be such that total chloride content of the mix does not exceed the limits given in the next section.

10.2.2.3 Aggregate

Both coarse and fine aggregate must conform to ASTM C33. For coarse aggregate, use crushed and graded limestone, or an acceptable local equivalent. For fine aggregate, use natural sand having the preferred grading shown for normal-weight aggregate in Table 4.2.1 of ACI 302.1R, *Guide for Concrete Floor and Slab Construction.*

Aggregate gradation is important. Too many small particles will increase the water requirement, leading to a high water-cement ratio and consequent shrinkage cracking. There will be more information on water-cement ratio later in this chapter. Gradation may have to be different for pumped concrete. See ACI 304, *Guide for Measuring, Mixing, Transporting, and Placing Concrete.*

Another important but easily overlooked characteristic of an aggregate is its chloride ion content. Check this quantity through the laboratory making the trial concrete mixes. According to ACI 318, the total mix water-soluble chloride ion content, including all ingredients, should not exceed 0.06% chloride ions by weight of cement for prestressed concrete. The corresponding figure for reinforced concrete is 0.15%. Use ASTM C1152, "Sampling and Testing for Total Chloride Ion in Concrete and Concrete Raw Materials."

10.2.3 Additives

10.2.3.1 General

In this context, the term "additives" will include compounds added in relatively small amounts to the ingredients already mentioned. In section 10.2.4 we will address ingredients such as fly ash, silica fume, and ground granular blast furnace slag, which may be used to replace some of the cement in the concrete mix.

Prohibited additives are calcium chloride or additives containing more than 1% chloride ions by weight of additive. Additionally, each additive must not contribute more than 5 ppm, by weight, of chloride ions to total concrete ingredients. We arrived at these limits after discussion with additive manufacturers. Interestingly, we found that chloride percentages of additives, even from the same manufacturer, varied greatly.

The engineer must approve all additives in writing before use. Use all additives according to the manufacturer's instructions. Prudent practice requires all additives to be furnished by the same manufacturer. Require a statement of additive compatibility from the manufacturer (see section 10.2.4.5).

10.2.3.2 Air Entraining Agents (AEA)

These materials must conform to ASTM C260. AEAs give the concrete resistance to freezing and thawing. Without an AEA, concrete in a cold climate will deteriorate quickly, as highway engineers discovered early in this century. Concrete mixed and placed using conventional practice will have 1% to 3% entrapped air. Entrapped air is air trapped in relatively large pockets distributed randomly in the mixture. Entrapped air does not help freeze-thaw resistance. Entrained air is distributed uniformly throughout the mixture in millions of tiny bubbles. The bubbles relieve the pressure generated by water becoming ice, thus preserving the concrete integrity. To be effective in climates where freeze-thaw damage may occur, air entrainment should be in the 5% to 7% range in the placed mix for 3/4″ nominal size aggregate. (See ACI 301 for entrained air requirements for other aggregate sizes.) Transportation, handling such as pumping, overconsolidation, and overfinishing will all reduce the air content. How do you know how much entrained air is in the hardened concrete? (See Chapter 11.) A fringe benefit of air entrainment is that it improves the workability of concrete. Air-entrained concrete segregates less easily and handles better than non-air-entrained concrete.

10.2.3.3 Water-Reducing Additives (WRDAs)

In most regions, use these additives to reduce the water content of a mix while retaining workability and slump. The result is a lower water-

TABLE 10-1. Calcium Nitrite Summary

Characteristic	Favorable Aspect	Unfavorable Aspect
Effectiveness	Internal—not susceptible to traffic wear and abrasion. Barrier extends completely through member.	Must be designed and built into structure. No barrier to concrete contamination. May not protect rebar for structure design life.
Life	25–40 years, depending on dosage rate.	Field performance data limited to 20± years.
Effect on plastic concrete properties		May accelerate concrete setting time.
Initial cost	Relatively expensive	
Maintenance cost		May require additional protection against corrosion.
Surface texture		Finishing may be adversely affected by accelerated setting time.

cement ratio, which leads to stronger and more durable concrete without adding cement.

Normal-range WRDAs should pass ASTM C494, type A. High-range WRDAs, usually called superplasticizers, sharply reduce the water needed for a mix. Or, they dramatically increase slump, or both, depending on dosage amount and water volume. Dosage must be kept within the manufacturer's limits. High-range WRDAs should meet ASTM C494, type F or G. Use must not change the specified requirements for:

- Maximum allowable water-cement ratios
- Minimum allowable concrete strength
- Minimum allowable air content
- Minimum allowable cement content.

10.2.3.4 Corrosion Inhibitors

Certain proprietary products containing calcium nitrite as their main ingredient slow corrosion of unprotected mild steel reinforcement (see Table 10-1). Calcium nitrite reacts with ferrous ions to protect steel reinforcement. With continued addition of chloride ions from outside sources, the calcium nitrite supply ends and chloride ion corrosion starts. Organic corrosion inhibitors that function by a different mechanism are also commercially available. As with most other forms of protection described here, corrosion is delayed, not stopped. These products, while effective, are relatively more expensive than the measures listed above. Whether or not they will be cost-effective for your project is something only value engineering and life cycle cost analysis will indicate.

10.2.4 Admixtures

10.2.4.1 General

The admixtures described here are used in superstructure concrete to replace some of the cement in the original mix. Except for fly ash and ground granular blast furnace slag, cost considerations tend to limit their use to certain elements within a parking structure. Silica fume may be used in beam, column, and slab concrete and in slab toppings. Because of its relatively high cost, latex is commonly used only in slab toppings.

10.2.4.2 Fly Ash

Fly ash is the finely divided residue resulting from the combustion of ground or powdered coal. It is a material with cementitious properties used as a partial replacement for cement. When properly used, it will improve workability and final strength. It may improve impermeability; however, fly ash-rich concrete will gain strength more slowly than a comparable mix without it, even though final strength may be greater. We do not permit fly ash to replace more than 25% of the cement by weight in a mix on a pound-for pound basis in other concrete.

Fly ash should meet ASTM C618, class C or F; test according to ASTM C311. Use trial mixes to be sure that the proposed fly ash does not cause variation in specified strength or entrained air content by more than the specified tolerances. Finally, by our practice, fly ash carbon content should be 4% or less.

10.2.4.3 Ground Granular Blast Furnace Slag (GGBS)

This material is a processed byproduct of steel manufacturing. It is used as an additive or as an ingredient in two types of blended cement, types IS and ISM. ACI 301 limits GGBS to no more than 50% of the total weight of cementitious material and requires that it conform to ASTM

C989. GGBS will lighten the color of cured concrete, which is often desirable. This characteristic is useful in lightening the color of concrete containing silica fume, as silica fume darkens the color of cured concrete. The other effects of GGBS on concrete are similar to that of other pozzolans. If you have no experience with it, rely heavily, via your project specifications, on the manufacturer's representative, and specify a large-scale sample panel (Chapter 11) to practice on. It is far less costly to lose a 20-ft square piece of slab on grade concrete than the same area of supported slab.

10.2.4.4 High-Reactivity Metakaolin (HRM)

HRM is a manufactured white powder conforming to ASTM C618, class N pozzolan specifications. HRM particle size is much smaller than cement, but larger than silica fume. While new in the construction marketplace, HRM's properties should bring it into increasing use in the future. Concrete made with HRM has properties similar to concrete made with silica fume (see section 10.2.4.5), at less cost. Properties include high strength, low permeability, good air void system, and excellent freeze-thaw resistance. In addition, cured HRM concrete is lighter in color than silica fume concrete, and less superplasticizer is needed to produce adequate workability. The latter property should ease the curing and finishing difficulties often associated with silica fume concrete.

10.2.4.5 Silica Fume

Silica fume, also called microsilica, is another finely divided byproduct of industry that has properties helpful to concrete (see Table 10-2). When added to a concrete mix in the right proportions, the silica fume particles fill some of the spaces between cement particles and react chemically with the one of the hydrogen prducts of cement. The result is a concrete with much improved strength, impermeability, and electrical resistivity. These properties make the concrete considerably more durable than a comparable mix without silica fume. Finishing and curing procedures require careful attention.

By the time the silica fume concrete is one year old, the impermeability of the concrete reaches a value comparable to that of concrete coated with a protective sealer. (See section 10.3 on Exterior Protection Systems for more on sealers.) You need not seal silica fume concrete of a proper mix design after it is over a year old. Because it does take a year for the full impermeability to develop, initial protection will be needed

TABLE 10-2. Silica Fume Summary

Characteristic	Favorable Aspect	Unfavorable Aspect
Effectiveness	In concrete; not susceptible to traffic wear and abrasion. Can by itself provide barrier to chloride and moisture. Barrier extends completely through member. Increased electrical resistivity of concrete reduces corrosion rate.	Must be designed and built into structure. Does not bridge cracks. Does not prevent leakage through cracks. Performance data limited to last 10–15 years.
Life	25–40 years estimated	
Effect on plastic concrete properties	Concrete bleeding during finishing reduced-conducive to not overfinishing	Finishers must be trained properly to work with silica fume concrete. Difficult to finish if addition rate >8% by weight of cement. Susceptible to cracking during hot and/or windy weather.
Effect on hardened concrete properties	Significant reduction in concrete permeability.	Concrete requires water curing during first 7 days to reduce potential for cracking
Cleaning	Normal washdown in spring and fall.	
Structural maintenance	Sealer need not be reapplied after initial application. Sealer can be of lower quality.	Chloride ion monitoring program necessary to evaluate performance and need for additional protection against corrosion.
Initial cost	Moderate	
Maintenance cost	None	
Appearance	Usually darker than Portland cement concrete	
Surface texture		Finishers must be trained properly to work with silica fume concrete.

for silica fume concrete. There then will be no first-cost savings for not sealing silica fume concrete, but maintenance costs will be lower. To reduce first cost, consider using a sealer with a shorter expected life, instead of a more expensive, longer-lasting one that will be more than is needed. The first coat of sealer will be the last. Comparable concrete without silica fume will require sealer application every one to three years, depending upon traffic loads.

Proprietary silica fume products may contain a retarder. Require a statement from the manufacturer that the product is compatible, that is, will not react deleteriously) with the other additives. Silica fume will usually darken the color of the cured concrete. The darker color, if objectionable, may be lightened by adding white cement or GGBS to the concrete mix (see section 10.2.4.3).

10.2.4.6 Latex

Latex is a water emulsion of synthetic rubber obtained by polymerization. It is used in place of water to produce latex-modified concrete (LMC). LMC shares many of the properties of silica fume concrete, though for different reasons, since strength does not improve. LMC is relatively more expensive than either ordinary portland cement concrete or silica fume concrete. For that reason, it is commonly used only as a topping for new or rehabilitation work.

Finishing can be troublesome because the fresh surface tears easily. Curing must be done with care to prevent excessive surface cracking. Choose your contractor with care. You need an experienced speciality contractor; make sure your project is not the contractor's first LMC project.

10.2.4.7 Other Admixtures

There are a number of polymer admixtures, such as methyl methacrylate, which will produce improved concrete. Characteristics usually include improved impermeability, high early strength, and thin layer installation—as thin as ¾ in. in some products. These products are all relatively expensive and are used to repair structures.

10.2.4.8 Summary

Table 10-3 summarizes concrete ingredients.

TABLE 10-3. Concrete Ingredients

Ingredient	Reference	Requirement	Reason for Use
Cement	ASTM C150	≥564 lb/cubic yard	Strength, durability, freeze-thaw resistance
Water	ASTM C94	w/c ≤0.40	Durability
Aggregate	ASTM C33	Varies	Strength, durability, pumpability, alkali-aggregate reactivity avoidance
Chlorides	AASHTO T260	≤0.06% for P/S, otherwise ≤0.15%	Durability
Entrained air	ASTM C260	Varies w/ climate	Freeze-thaw resistance, workability
Water reducers	ASTM C494, type A	Varies	Durability, workability
Superplasticizers	ASTM C494, type F or G	Slump ≤6 in.	Durability, workability
Accelerators	ASTM C494, type C	Varies, but chloride free	Cold-weather concreting
Retarders	ASTM C494, type B	Varies	Hot-weather concreting
Corrosion inhibitors		Varies	Durability
Fly ash	ASTM C618	≤25%	Economy, handling, low heat, impermeability
Ground granulated blast furnace slag	ASTM C989	≤50%	Economy, lighten concrete color, impermeability
High-reactivity metakaolin	ASTM C618	≤25%	Strength, lighten concrete color, impermeability
Silica fume	ACI 226	≤5 to 7%	Strength, durability, impermeability
Latex	ACI 548R	Varies	Impermeability

10.2.5 Reinforcement

10.2.5.1 Cover

ACI 318 recommends increased cover over reinforcement in corrosive environments such as those in parking structures. ACI is referring to reinforcement that is not epoxy coated. Increase cover over code requirements to allow for cover loss through traffic abrasion. Our practice in floor structures is to specify a minimum of 2 in. cover over all reinforcement exposed to the weather that is not epoxy coated. We prefer, however, to epoxy-coat all reinforcement within 3 in. of the floor surface, and provide 1½ in. cover, minimum, or 3 bar diameters, whichever is greater. (See Figures 10-1 and 10-2 for examples involving sloping floors. This discussion applies to floors in regions where pavements are salted for snow and ice removal.)

10.2.5.2 Epoxy-Coated Reinforcement

This heading refers to welded wire fabric, conventional reinforcing bars, and high-strength prestressing strand. Welded wire fabric and reinforcing bars may be epoxy coated to reduce the opportunities for corrosion. Epoxy-coated pretensioning strand is available. Present practice in most regions is to epoxy-coat only the strand reinforcement used in pretensioned precast concrete, when additional protection is needed, if fire protection of the epoxy coating is not a problem. Protect the strand reinforcement used in posttensioned concrete with a coating of grease and a plastic sheath. Epoxy-coated strand for posttensioning use is also available. (See Chapter 11 for more information on posttensioning strand protection.) Protected reinforcement is worth the investment in

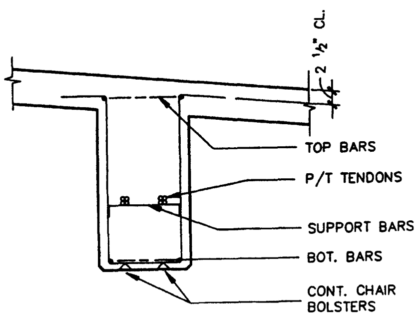


Figure 10-1. Cast-in-place posttensioned concrete beam cross section—open stirrups.

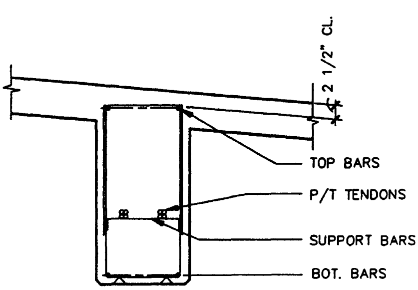


Figure 10-2. Cast-in-place posttensioned concrete beam cross section—closed stirrups.

TABLE 10-4. Epoxy-Coated Reinforcement Summary

Characteristic	Favorable Aspect	Unfavorable Aspect
Effectiveness	Provides barrier at reinforcement. Internal to concrete; not susceptible to traffic wear and abrasion.	Not a barrier to concrete contamination. Must be designed and built into the structure. Defective coating will reduce protection. May not protect rebar for structure design life. May contribute to increased cracking and wider cracks.
Life	Should add 10–15 years	Field performance data available only over last 20± years.
Initial cost	Moderate in most regions, but expensive in some.	
Structural performance		Requires increased development length.

climates where pavements are salted for snow and ice control. Note that ACI 318 requires longer anchorage and development lengths for epoxy-coated reinforcement than for uncoated reinforcement. Epoxy-coated bonded strand needs a grit embedded in the epoxy coating to develop bond. (See Table 10-4.)

Most designers will be aware of the controversy surrounding epoxy-coated rebar that arose in the early 1990s. As of this writing, several state Departments of Transportation in the U.S. prohibit epoxy-coated rebar in some or all types of structures. These prohibitions occurred because severely corroded epoxy-coated rebars were found in structures that were but a few years old. Research at the same time showed that there was no way to predict the durability of a specific piece of epoxy-coated rebar. Contributing to the problem were perceptions, fed by marketing hype, that epoxy-coated rebar would last almost forever. The controversy has abated somewhat. Now we know that epoxy-coating rebar will extend its life in a corrosive environment by 10–15 years, not 50. Also, standard specifications for coating application have been made more stringent, and coating manufacturers have developed higher-performance coatings. Like many other situations, this one proves that the way to quality in construction is not always through technology but through careful, informed workmanship and quality control.

10.2.5.3 Galvanized Reinforcement

Field studies do not support laboratory studies indicating that galvanized reinforcement does not work long term in the corrosive environments commonly found in parking structures. Galvanizing is sacrificial protection; therefore, in a corrosive environment it, too, corrodes. The corrosion products occupy more space than do the uncorroded galvanizing. The resultant pressure exerted on the surrounding concrete will spall or crack it. Laboratory and field test results conflict, but we do not specify galvanized reinforcement.

10.2.5.4 Other Types of Nonprestressed Reinforcement

Bars of stainless steel and glass fiber are available and expensive. Their use in parking structures is overkill.

10.2.5.5 Prestressed Reinforcement

Prestressing high-strength steel reinforcement puts a concrete structural element into compression before it is loaded by its own weight and service loads. Prestressing a floor slab or beam will result in that member's remaining in compression or at a low level of tension under self and service loads. No or little tensile stress in the concrete means little cracking of the kind usually found in conventionally reinforced concrete.

In most precast concrete parking structures, the pretensioned precast elements are of simple-span construction, which means that the top fibers of those elements are always in compression. Further, the pretensioned reinforcement is below the centroid of the concrete section. In the case of a typical 24-in.-deep double tee, that reinforcement is likely to be protected by a foot or more of concrete cover above it. So long as there are no cracks in the precast concrete through which moisture can penetrate, the pretensioned reinforcement will be adequately protected from corrosion by the concrete alone. Also, since the entire length of the top fibers of the member are in compression, any cracks that do form will be kept closed by that compression.

In most cast-in-place posttensioned concrete parking structures, the posttensioned concrete elements are of continuous span construction, which means that the member top fibers will be in tension at supports and in compression at midspans. The posttensioned reinforcement must therefore be close to the member top surface at the supports. Not only is the protective concrete cover for the reinforcement less at the supports, but if there is sufficiently high tensile stress in the negative moment area at a support, flexural cracks may open, providing a path for surface moisture from the floor to reach the posttensioned reinforcement. It is necessary, then, to provide additional protection for the posttensioned reinforcement.

The first layer of protection around the posttensioned reinforcement strand is a coating of corrosion-inhibiting grease, which also lubricates the strand to reduce friction when the strand is tensioned. The second layer of protection is a continuous, seamless plastic sheathing extruded around the greased strand. The grease must completely fill the annular space between the strand and the sheathing. This sheathing keeps moisture away from the strand. At the ends of the strand, the anchor assemblies are completely encapsulated and the joint between strand sheathing and anchor encapsulation is made watertight.

Stressing pockets are very susceptible to water penetration. The joint between the pocket and the pocket fill may form a path for water penetration. Provide sealants or bonding agents at pockets. Also provide a sealed, tooled joint and epoxy-coated conventional reinforcement at each construction joint to minimize water penetration through slabs and to provide structural redundancy should tendon integrity be breached. For more information, see Chapter 11.

10.2.5.6 Fiber Reinforcement

Fiber reinforcement may be steel or plastic; we specify a polypropylene product because we have found that steel fibers ball up during mixing. When mixed uniformly throughout the concrete in the manufacturer's recommended proportions (usually 1 lb of fibers per cubic yard of concrete), the fibers improve the concrete's crack resistance during finishing and curing. Claims have been made that fiber can be used instead of bars for shear reinforcement. Though research indicates that these claims may be true for much higher dosages of fiber than given here, fiber reinforcement should not be substituted for bars unless and until recognized by building codes. We use them for concrete where, because of location or place in the construction sequence, cracks can be frequent. Examples are the cast-in-place pourstrips at the ends of pretopped double tees and at temporary isolation joints. These are long, narrow placements which tend to crack owing to plastic shrinkage and drying shrinkage-induced stress, due to neglect of proper curing. Further, concrete at these locations is commonly placed late in the project, when schedules are pressing. With the best of intentions, workmanship quality may drop. If the standard-quality control procedures are not working, reduce cracking at these locations by using fiber-reinforced concrete. An evaporation retarder may also be effective, but neither measure will replace simply following correct placing and curing practices.

10.2.6 Construction Practices

10.2.6.1 Mixing, Transporting, and Placing Concrete

It is hard to know where to stop explaining when concrete is the subject; there are so many pitfalls for the unprepared. ACI has a number of publications to help guard against the many mistakes that will lower concrete quality. For a start, read ACI 304 through 306.1. Next, set up a concrete preinstallation meeting with the owner, general contractor, ready-mixed concrete supplier, concrete pumping contractor, finishing contractor, forming contractor, testing agency, design professionals, and anyone else whose work will affect concrete quality. Define procedures and agree on them. The outcome of this meeting (it may take more than one) should be a written procedure outlining every major step in the process. It must cover producing, delivering, placing, finishing, testing, and curing each type of concrete on your project. Everyone involved must sign off on the written procedure. There is more on these topics in later sections of this chapter and in Chapter 12.

10.2.6.2 Formwork for Concrete

Aside from suggesting that formwork be built tightly enough to prevent paste loss from the hardened concrete, which will result in honeycombing repairs, and that formwork be kept clean (cigarette butts, paper, and sawdust are not acceptable admixtures in concrete), we recommend ACI SP-4 on formwork; the subject matter is well covered there.

10.2.6.3 Consolidation

Properly done, consolidation reduces the quantity and size of trapped air voids, improving the end-product concrete. Most of the time, consolidation is done with vibrating screeds for thin slabs and overlays. Internal vibrators are used for thicker slabs and other members. Too little vibration will produce voids. The visible voids cost money to repair. The hidden voids will reduce strength and durability. Too much vibration will drive entrained air out of the plastic concrete and will bring too much paste to the surface. Both these effects will make the concrete less durable, though the loss of entrained air in the final product will be important only in colder climates where freeze-thaw damage is a concern. Premature surface deterioration because of too much cement paste at the floor surface is a concern in any climate. Good inspection will help prevent overvibration. Using ACI 309, *Guide for Consolidation of Concrete,* educate the people operating the vibrators will be better prevention.

10.2.6.4 Finishing

Finishing is another operation that can help or hurt the final product. As with many procedures, it is easier to do wrong than right. In the mistaken belief that more is better, finishers will overwork the concrete surface, bringing paste and fines to the top and driving out entrained air. The result is a weakened surface susceptible to scaling.

The best finish for floors with auto and pedestrian traffic consists of these operations; screed to the specified elevations and profiles. A vibrating screed will reduce the internal vibration needed. Wait until bleed water has evaporated or remove it. Bullfloat, then final finish with a light broom perpendicular to the direction of traffic. The term, "light broom finish" in this context means a textured finish achieved with a soft broom where the amplitude between adjacent grooves and ridges is between $1/32$ in. and $1/16$ in. The surface must not be too smooth. A typical sidewalk finish is too smooth. If the finish is too rough, it will be a tripping hazard. Be careful not to drag aggregate from the surface.

If a traffic-bearing membrane is to be installed on the slab, be sure to check with the membrane manufacturer to obtain the finishing requirements; then specify them. Include specification wording to the effect that the finish shall conform to the membrane manufacturer's requirements wherever the membrane is to be installed.

Some finishers like to add water to the surface as they work. This practice produces a thin surface layer which is weak and permeable. Again, inspection will help prevent this practice. Education via the concrete preinstallation meeting mentioned earlier is better and will work even when the inspector isn't around. We also recommend that the same finishing foreman be kept throughout the project to maintain a consistent quality of finish.

10.2.6.5 Curing

Curing is the important last step in the concreting process, but is sometimes ignored or done carelessly. Using a curing compound is often the preferred method. Curing compounds do not perform well on rough

TABLE 10-5. Construction Practices

Activity	References
Mixing	ACI 304
Transporting	ACI 304
Placing	ACI 304, ACI 304.2
Formwork	ACI 347, ACI SP-4
Consolidation	ACI 309, ACI 309.1R, ACI 309.2R
Finishing	ACI 302.1R
Curing and protection	ACI 305R, ACI 306.1, ACI 308

surfaces such as the light broom finish discussed above. We prefer to specify a wet cure; it is proven to produce the best results. The cost is higher than other methods, but the results are worth it.

Pay special attention to ACI 305, *Hot Weather Concreting*; ACI 306, *Cold Weather Concreting*; and ACI 306.1, *Standard Specification for Cold Weather Concreting*. Some practices to avoid should be well known, but every so often they reappear, so we will mention them. In cold weather, heaters may be needed to maintain proper curing temperature in the concrete. Be sure to vent the combustion products of the heaters to the outside air, not onto the concrete surface. If the combustion products come in contact with curing concrete, carbonation occurs. Carbonation produces dusting of the surface, which is impossible to stop. As cold weather approaches in northern climates, do not seal concrete; it will not continue to loose moisture as it should, and damage will result when the water in the concrete freezes. Also, sealers are not effective on high-moisture concrete.

In hot weather, especially on windy days, plastic shrinkage cracking is a real danger. Windbreaks, fogging, and application of an evaporation retarder will reduce the chances of it occurring.

10.2.6.6 Summary

Table 10-5 summarizes construction practices.

10.3 EXTERIOR PROTECTION SYSTEMS

10.3.1 General

Systems under this heading will range from least to most expensive. Remember, though, that no external protection can make a silk purse out of a sow's ear. In other words, if the underlying concrete is not of good quality, no external protection system, no matter how expensive, will work for long. To emphasize the point yet one more time, spend your money on good concrete: then you will not have to waste it away later on applied protection that should not have been necessary.

10.3.2 Sealants

There is sometimes confusion between the terms *sealant* and *sealer.* A *sealant* is a viscous material applied in fluid form, hardening somewhat to provide a long-term flexible seal which adheres to the surrounding concrete. In the next section, we will cover *sealers.*

In parking structures use sealants to keep water out of joints. These joints may be gaps inches wide between members. They may be grooves tooled into the plastic concrete to provide weakened planes for crack control. Whatever the joint width, a good sealant will keep water and waterborne salts out of the joint, extending its serviceability. Water and waterborne salts attack both the concrete and any unprotected ferrous metals in the joint.

Always specify that the edges of joints to be sealed be tooled, not sawn, then ground to remove concrete laitance. Next, the joint should be primed. Both practices will greatly improve the bond between sealant and concrete.

Though some engineers and architects prefer a two-part sealant over a one-part sealant, there are pluses and minuses for each. We have never had a problem with the one-part sealants we specify. We have occasionally had problems with installer mistakes in proportioning or mixing two-part sealants. See Chapters 8 and 14 for more on proper joint design and sealants.

Sealant joints between precast double-tee flanges can be troublesome. The usual connection detail involves field welding together steel embedments spaced at 4 to 8 ft on centers along the flange edges. Often too much heat is generated by the welder, cracking the flange concrete adjacent to the weld. The cracks are hairline, invisible until after the joint is sealed. With time and volume changes, the cracks widen and leak. The result appears to be a failed sealant joint, but the real cause is an improperly welded connection.

10.3.3 Sealers

Sealers are protective coatings applied over a concrete surface to prevent water and waterborne salts from penetrating that surface. A good sealer penetrates into the concrete surface, but allows vapor to escape. A good

TABLE 10-6. Sealer Summary

Characteristic	Favorable Aspect	Unfavorable Aspect
Effectiveness	Provides a barrier at top surface. Makes concrete less permeable.	Susceptible to wear and abrasion. Eventually allows salt and moisture to enter the concrete. Continued protection requires reapplication. Unable to bridge active or wide cracks to prevent leaks.
Life	Easy reapplication	Reapplication every 3–5 years necessary.
Ease of reapplication	Easy to apply with few disruptions.	Reapplication every 3–5 years necessary.
Cleaning	Normal washdown in spring and fall.	No protection of concrete from difficult-to-remove grease and oil stains.
Structural maintenance		Chloride ion monitoring program necessary to evaluate effectiveness, reapplication frequency, and need for additional protection against corrosion.
Initial cost	Relatively inexpensive	Many reapplications necessary during structure service life.
Maintenance cost	Relatively inexpensive	Will require additional protection against corrosion during structure service life.
Appearance	No change to concrete surface.	Concrete surface can be stained by grease and oil.
Surface texture	No change for sealers that penetrate.	Some sealer types remain on the surface and may reduce skid resistance and/or become slippery.

sealer may extend the service life of a sound concrete surface, but will not bridge cracks.

There are both good and worthless sealers available. To tell them apart, see Chapter 11 for an extensive discussion. A summary of sealer characteristics appears in Table 10-6.

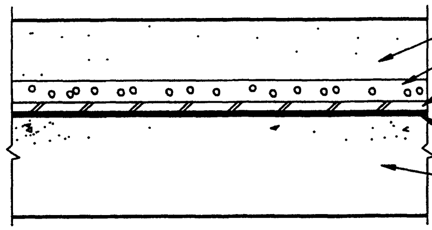


Figure 10-3. Example section view of a non-traffic-bearing membrane system.

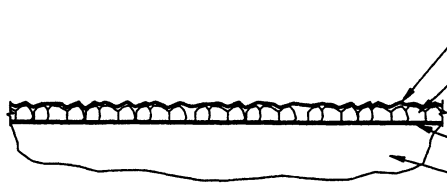


Figure 10-4. Example section view of a traffic-bearing membrane system.

10.3.4 Membranes

We classify waterproof membrane systems (sometimes called traffic toppings) for parking structure pavements into two kinds—those applied over the pavement as a traffic-bearing surface, and those that must be protected by a wearing course. See Figures 10-3 and 10-4 for illustrations of each. Note that the protected membrane installation has more components than the traffic-bearing type. The protection and drainage systems for the protected type are often difficult to install correctly. Protected systems are more expensive than traffic-bearing systems. Finding a leak in a protected membrane can be difficult. Repairing that leak means removing some part of the protection layer, fixing the leak, and replacing the protection layer. If the protection layer is made of brick or concrete pavers, the removal and repair operations are not particularly difficult, but if the protection layer is cast-in-place concrete, removal and repair operations are more difficult. On the other hand, protected membranes are not subjected to traffic wear or to deterioration from the ultraviolet rays in sunlight.

Traffic-bearing membranes typically come in four wear grades. The first is for zones in which wear is low, such as in parking spaces or pedestrian areas. The second is for flat, straight driving aisles. The third is for places where high wear is likely. Examples are turns, steeper slopes, ramps, and spots where stopping and starting will occur, as at gates or ticket dispensers. The fourth grade is not really a grade at all.

It can be any of the other three grades, except that it has a light-colored top coating. It should contain an aliphatic compound, to increase its resistance to ultraviolet light. This grade is for areas exposed to sunlight.

Traffic-bearing membranes are relatively easy to repair. Service life varies with abrasion wear received. Turns or areas where frequent starts and stops occur may need repairs every two or three years. Parking spaces may need repairs only after 10 years or so. At this writing, there are no data available relating membrane wear to traffic volume.

Like good sealers, good membranes keep water and waterborne salts out of the underlying concrete while letting vapor out. Unlike good sealers, good membranes will bridge the narrow cracks that may develop in the underlying concrete after the membrane is in place. (For specification information, see Chapter 11.)

If a traffic-bearing membrane is to be used over a precast double-tee floor, use field-topped tees, not pretopped. The differential camber between pretopped tees will produce a number of ridges in the floor. When these ridges are coated with the membrane, the ridges will remain, presenting and edge off of which traffic will quickly wear away the membrane. For a summary of traffic-bearing membranes, see Table 10-7.

10.3.5 Overlays

10.3.5.1 General

Except for cast-in-place overlays on precast concrete, overlays are not often used in construction of new parking structures. Their use, particularly of the more exotic materials, is more common in restoration work. (For further discussion, see Chapter 14.) For the sake of completeness, here is a brief discussion.

Topping on precast concrete is commonly used to provide a level, even-wearing surface which compensates for the unevenness in the tops of the precast members caused by differential camber. It may also be used to provide drainage difficult to achieve with pretopped tees alone. At the same time, the topping reinforcement may also serve to transfer lateral loads to the structural framing. Further, the topping can be used to conceal connections between precast members. Keep in mind that the joints between the precast pieces beneath a topping will reflect up through that topping. Tool and seal the topping above all joints between precast pieces.

On a few recent projects, owners have requested that we specify a noncomposite sacrificial topping over already pretopped precast double tees.

TABLE 10-7. Traffic Bearing Membrane Summary

Characteristic	Favorable Aspect	Unfavorable Aspect
Effectiveness	Provides impermeable surface barrier to moisture and chloride. Protects occupied space below from moisture above. Bridges active cracks.	Susceptible to traffic abrasion and wear. Proper application by experienced contractor essential. Application will not stop corrosion in already contaminated concrete. Maintenance required.
Life	Quality initial application may last 10–15 years. Top coat reapplication extends life another 10± years.	Buys only 5–10 more years if applied over already-contaminated concrete. UV from sunlight reduces life.
Ease of reapplication	Few disruptions in most areas. Easy to repair damaged areas.	More frequent disruptions in heavy traffic areas like turns, entries, exits, ramps, and any areas with frequent stops and starts. Requires rubber-edged snow plow blade to reduce damage to membrane. Studded snow tires will damage membrane.
Cleaning	Oil stains easily removed. Clean annually.	Requires special sweeper and scrubber.
Initial cost		Relatively high initial cost.
Maintenance cost		Cost can vary considerably depending on actual traffic patterns and intensity. Heavily used areas may need recoating every 3–5 years. Complete replacement required after 25± years. Life cycle cost is 2–3 times cost of any other combination of comparable systems designed to protect against corrosion for service life of structure.
Appearance	Provides neat, uniform appearance.	UV from sunlight will discolor. Black or dark-colored membrane reduces light levels and tends to conceal areas made slippery with grease or oil.
Texture	Can improve surface skid resistance.	Heavily used ares require more frequent repairs to maintain skid resistance.

Several different types of concrete overlays will be presented here. Though they will all fulfill the functions listed in the above two paragraphs, they do differ in durability and in expense, and are listed in order of increasing degree of expense. These overlays also vary in minimum recommended thickness. The densities of the overlays listed below are all around 145 lb/cu ft. So, the thinner it can be applied, the lighter the overlay will be. Extra structure weight drives up the cost of construction in both new and restoration work.

10.3.5.2 Portland Cement Concrete Overlay

This economical alternative has been used successfully as an overlay many times. Where high impermeability, low dead weight, and a thin overlay are requirements, this material would not be a solution. A 3-in.-thick overlay is a practical minimum. If of normal-weight (145 lb/cu ft) concrete, it will weigh 35–40 lb/sq ft. If thickness and self-weight are acceptable, you could use a sealer or membrane on the new overlay to improve impermeability. The cost of such a combination will probably exceed the cost of one of the other overlays listed below.

10.3.5.3 Low Slump, Dense Concrete Overlay (Iowa Method)

This alternative has the same attributes as that above. However, its lower water-cement ratio makes it more durable and less permeable. It has been used extensively on new and repaired highway bridge decks.

10.3.5.4 Silica Fume Concrete Overlay

Density is a little higher than that of the two alternatives above. Its much higher strength makes a 1½ to 2 in. thickness practical. Impermeability is quite high. See Section 10.2.4.5 for more information on this material.

10.3.5.5 Latex-Modified Concrete (LMC) Overlay

Similar in performance to silica fume concrete, but significantly higher in cost and of lower strength. Thickness may be less. See Section 10.2.4.6 for more information.

TABLE 10-8. Exterior Protection Systems

System	Usual Application	Relative Cost[a]
Sealants	Waterproof control, construction, and isolation joints.	Lower
Sealers	Keep out chlorides	Lower
Membranes	Keep out water and chlorides; bridge cracks	
traffic-bearing	Parking structures	Lower
non-traffic-bearing	Pedestrian plazas	Higher
Overlays	Durability, protection	
Portland cement concrete		Lowest
low slump, dense concrete		Lower
silica fume concrete		Higher
latex-modified concrete		Highest

[a]Costs are relative only within a system category.

TABLE 10-9. Durability Measures

Element	Basic Protection	Added Protection
Surface	Finishing, curing, sealer	Traffic topping
Concrete	Mix design, low w/c ratio, entrained-air, superplasticizer, etc.	Silica fume, GGBS, HRM
Reinforcement	Cover, epoxy coating	Corrosion inhibitor, stainless steel
Design	Drainage, prestressing, detailing for volume change	

10.3.5.6 Other Overlays

Combinations of materials and protection are not uncommon. Fiber-reinforced overlays and overlays with covered or exposed membranes are not unusual. See Section 10.2.5.6 for more information on fiber reinforcement.

10.4 SUMMARY

See Table 10-8 for a summary of exterior protection systems, and Table 10-9 for a summary of recommended combinations of protection measures.

CHAPTER

11

SPECIFICATIONS

Anthony P. Chrest

11.1 INTRODUCTION

This chapter is primarily directed at project managers, designers, and specification writers, though it may interest others. The chapter scope will be limited to discussing sections of specification divisions 3 and 7 as they relate to parking structures. These sections cover technical areas of concrete, reinforcement, and waterproofing systems and are the heart of parking structure specifications. They represent areas of continually changing technology and are often the basis of disputes, so should be written with care. Be sure to define all terms. Enforce the specification at all stages of construction. Unfortunately, enforcement is often lacking. Determined long-term education of project field staff is the only practical way to improve enforcement.

11.2 COMMUNICATION

Make it your business to talk to suppliers of all types. Ask them to review your specifications and discuss their views with you. You will soon know who is trying to be genuinely helpful and who is just promoting a product or service. These reviews will improve your specifications. More importantly, they will build good communications, respect, and trust between the supplier and you. If suppliers know that you are approachable, they may be able to help you prevent some of the inevitable problems that arise during construction. Supplier familiarity with your specifications will produce lower bid prices.

Some people will be reluctant to invite these review discussions. They will feel uncomfortable because they think such action will suggest lack of knowledge. Such a view is short-sighted and self-defeating in today's competitive market. Think about how you react when a stranger asks you for directions. Your first reaction is likely one of pleasure at being asked to share your knowledge. Everyone likes to be thought helpful, so don't waste time worrying about how a supplier will take your request; just do it.

11.3 PERFORMANCE SPECIFICATIONS

A performance specification states *what is wanted,* not *how to get it.* As an example, a performance specification for concrete might list required strength, water-cement ratio, air-entrainment range, maximum slump, and minimum cement content. It will not list required ingredient proportions or give directions as to how to achieve the results.

A prescription specification states both the what *and* the how. In the example above, the prescription specification would require the same results, but would continue with details as to how to proportion, mix, transport, place, consolidate, finish, and cure the concrete. Most specifications today are a combination of the prescription and performance approaches.

As much as possible, we use a performance specification approach. Prescription specifications can lead to headaches for the designer, especially in areas where new product developments are rapid. Within reason, we really do not care what a product is made of so long as it meets all our requirements. A good performance specification must contain requirements that are measurable quantitatively by standard testing methods such as those of ASTM. Pass/fail limits must be set for each test required. If a product is not listed in a specification section, the product vendor should be able to find all the performance requirements for the product category in that section. Make sure that your specifications contain the flexibility to deal with local or regional conditions—more reason to communicate as suggested above.

If there is an industry-accepted requirement for a product, such as ASTM C 260 for air-entraining agents for concrete, it is sufficient to list only that requirement. If there are no industry-accepted requirements for a product type, then listing acceptable products by name, followed by the corresponding performance specification, reduces questions during bidding and construction and limits time spent with prospective vendors.

We make changes to our master specifications as needed, but only rarely make exceptions to them. The exceptions are only for trials of a new product. Exceptions may help one vendor, but they are unfair to everyone else. When we explain to a vendor that an exception on the project at hand might lead to an exception for a competitor on the next, the vendor will not persist in a request for an exception.

11.4 SPECIFICATION PRODUCTION

Computer-assisted specifying (CAS) has been available for several years. The National Institute of Building Standards, the American Institute of Architects, the Construction Specifications Institute, the military, and firms such as Sweet's provide CAS systems. Reexamine your present specification production system in light of these developments. There may be little reason to maintain your current methods. Our firm's experience is a good example.

For nearly 30 years we have maintained our own specification, tailored to our specialized market. We updated some part of our in-house specification every month. This specification has worked well for us. Within the past two or three years, however, several factors have combined to cause us to reevaluate our specification. First, several clients required us by contract to use the AIA MasterSpec master specification for their projects. Second, our market has changed. Parking structures are becoming more complex. They now often contain features requiring architectural specification sections our in-house document never had or needed. Third, we had no full-time specification specialist to develop and maintain new sections.

We examined two "industry standard" master specifications at some length, deciding to adapt and adopt the AIA document as our new standard. The AIA document is weak in division 3, concrete, where our in-house specification is strong. Conversely, our document was weak in the architectural divisions, 6–10. We concluded that we could easily strengthen AIA's division 3, while acquiring strengths we did not have in other sections. The other master specification document we reviewed seemed weaker in both architectural and engineering sections, so we considered it no further. Acquiring the AIA MasterSpec permits us to transfer some of our specification development effort and much of the maintenance outside the firm. All in all, adopting the AIA document has been a positive step for us.

With advances in word processing software and printers, producing an easier-to-edit and read project specification has become easier. Various print fonts are available, as are graphics features such as shading and boxes. See the appendices to this chapter for examples.

11.5 DIVISION 3

11.5.1 Section 03300, Cast-in-Place Concrete

In many bidding situations, bidders may neglect to read your concrete requirements in full. For example, concrete specified with a 28-day strength of 4000 psi *and* a water-cement ratio of 0.40 will cost appreciably more than that specified with the strength requirement alone. If the bidder sees the first requirement but not the second, the profit margin may be reduced enough to cause the bidder, and you, problems as the project progresses.

Example:

Required: 4000 psi compressive strength at 28 days
0.40 water/cement ratio
3-in. slump

Water demand: Concrete requires approximately 275 lb (33 gal) of water per cubic yard to achieve a 3-in. slump.

Cement factor: water/cement = 0.40
cement = 275 lb/0.40 = 687.5 lb/cu yd

Problem: If the strength requirement is shown as 4000 psi at 28 days, the ready-mix concrete producer often bids on this information but misses the maximum water/cement ratio that governs. A cement factor of 550 lb/cu yd is usual for 4000-psi compression strength. The 137.5 lb of cement per cubic yard increase (687.5–550) necessitated by the water-cement ratio is a significant extra cost to the ready-mix producer if not included in the bid.

Result: The mix design may be "adjusted" to meet the specification. The cement factor included in the bid may be used with a fictitious water content in order to conform to the maximum water-cement ratio of 0.40.

Listed water content = Cement factor × 0.40
= 550 lb × 0.40
= 220 lb/cu yd (26.4 gal)

Concrete cannot be mixed at this water content. If you include a short caution under the "Scope of Work" heading in section 03300, Cast-in-Place Concrete, it might prevent this problem.

Example:

Work included: In accordance with contract documents, provide all materials, labor, equipment, and services necessary to furnish and install cast-in-place concrete.

Concrete Supplier: *This section contains requirements for high-strength air-entrained concrete with low water-cement ratio and superplasticizer.*

Note that ACI 318 Chapter 4 commentary opens by emphasizing the need that strength and water-cement ratio be consistent.

11.5.2 Entrained Air

Correct entrained-air content in concrete improves workability and protects the hardened concrete from freeze/thaw damage. Other common additives will improve workability, but few others will provide freeze/thaw protection—and none as inexpensively.

Entrained-air content requirements to provide adequate protection vary widely depending on climate. Requirements in North America typically vary from a range of 5–7% in northern latitudes to 4% or less farther south. State or provincial department of transportation requirements for entrained air for bridge construction are reliable guidelines if you have no experience in a locality.

If requirements are set, the next question is, where should the air content be measured? If the concrete leaves the ready-mix plant with x% entrained air, chances are that the in-place concrete will have ½ x% entrained air or less. Transportation, pumping, consolidation, and finishing all tend to remove entrained air from plastic concrete, particularly the latter two.

Check air content at the truck. Also check it after screeding. A sample specification for section 03300 is included in Appendix 11-1 at the end of this chapter.

11.5.3 Finishing

Improper finishing is usually overfinishing. The best finishing is that accomplished with the least effort.

For a parking structure, the finish itself should be rough enough to provide traction for car tires and to prevent slipperiness when wet. It must not be so rough as to become a tripping hazard for pedestrians. Suggested finish is light broom. See Appendix 11-1.

11.5.4 Section 03365, Posttensioned Concrete

Unbonded tendons, with hardware and protection, should be treated as an integral system and viewed as a whole. Some available computer-aided specifications do not include posttensioned concrete. For those reasons, we've reproduced the entire section in Appendix 11-2 at the end of this chapter.

11.5.5 Section 03410, Structural Precast Concrete-Plant Cast

Whether you use a performance specification with some or all of the piece design assigned to the precaster, or you provide full structural design services, the success of any project with sizable quantities of precast elements is in the precaster's hands. While even the best precaster cannot produce a good project from a poor design, a poor precaster can certainly spoil a good design. Your best defense is to work with precasters whom you have come to trust. If you are working in a locale new to you, use well-written prequalification requirements to exclude questionable performers. Require PCI plant certification. Keep in mind, though, that no industry standards will protect you from dishonesty by any vendor. Sometimes your only defense may be to refuse to work with a vendor who has cheated on a previous project, even if it means losing the current project.

11.6 DIVISION 7

11.6.1 Section 07100, Waterproofing Systems

This section contains example requirements for protective concrete sealers, traffic toppings, expansion (isolation) joint sealants, and concrete control joint sealants, and is included in its entirety in Appendix 11-3 at the end of this chapter. As you read this appendix and included commentary, you may wonder if the constant safeguards and checking are necessary. There are honest people and firms in the construction business, but it has been our experience that safeguards and checking are necessary, particularly in the Protective Concrete Sealer market. Competition is fierce, the market is crowded, corners do get cut, and outright dishonesty does exist. Be on your guard; give no one a chance to cheat you or your client.

11.7 KEEPING CURRENT

Treat your master specification as a living document (we update some part of ours every month). What you see in this chapter was current when it was written. By the time this book is published, several months will have elapsed. We guarantee that some part of the quoted sections will have been superseded during the intervening months because of new experiences, changing technology, and new product research.

11.8 SUMMARY

Specifications are one of the two principal means to communicate project requirements from the designer to the builder. As such, specifications must be clear, complete, and fair. We have discussed some of the likely trouble spots in a typical parking structure specification and have included excerpts and sections from our master specification. Finally, no matter how watertight the specification, without enforcement at the job site, the specification will be worthless.

APPENDIX 11-1: SECTION 03300

CAST-IN-PLACE CONCRETE

PART 1 GENERAL

1.1 RELATED DOCUMENTS

A.—Drawings and general provisions of Contract, including General and Supplementary Conditions and Division 1 Specification Sections apply to this Section.

1.2 SUMMARY

A.—This Section specifies cast-in-place concrete, including formwork, reinforcing, mix design, placement procedures, and finishes.

B.—CONCRETE SUPPLIER, CONCRETE SPECIFIED HERE REQUIRES:

- **1.**—Cementitious materials content: See Article "Proportioning and Design of Mixes," paragraph "Strength."
- **2.**—Water/cementitious materials ratio: See Article "Proportioning and Design of Mixes," paragraph "/Special Exposure Requirements," or "Water/Cementitous Materials Ratio."
- **3.**—Entrained air.
- **4.**—Superplasticizer.
- **5.**—High strength.

C.—Work in other Sections related to Cast-in-Place Concrete:
  1.—Division 2 Section "Auger Cast Piles."
  2.—Division 2 Section "Drilled Piers."
  3.—Division 2 Section "Unit Pavers."
  4.—Division 2 Section "Portland Cement Concrete Paving."
  5.—Division 3 Section "Architectural Cast-in-Place Concrete Formwork."
  6.—Division 3 Section "Concrete Toppings."
  7.—Division 3 Section "Special Concrete Finishes."
  8.—Division 3 Section "Post-Tensioned Concrete."
  9.—Division 3 Section "Structural Precast Concrete—Plant Cast."
  10.—Division 3 Section "Architectural Precast Concrete—Plant Cast."
  11.—Division 3 Section "Latex Modified Concrete and Mortar."
  12.—Division 3 Section "Pressure Applied Concrete."
  13.—Division 3 Section "Trowel Applied Concrete."
  14.—Division 3 Section "Silica Modified Concrete."
  15.—Division 7 Section "Waterproofing System."
  16.—Division 7 Section "Joint Sealants."
  17.—Division 9 Section "Painting."
  18.—Division 9 Section "Pavement Marking."

1.3 SUBMITTALS

A.—General: Submit the following in accordance with Conditions of Contract and Division 1 Specification Sections.

B.—Product data for proprietary materials and items, including reinforcement and forming accessories, admixtures, patching compounds, waterstops, joint systems, curing compounds, and others as requested by Engineer including, but not limited to:
  1.—Manufacturer's product data and installation instructions for proprietary form coatings, manufactured form systems, ties, and accessories.
  2.—Steel producer's certificates of mill analysis, tensile tests, and bend tests.
  3.—Manufacturer's product data, specifications, and installation instructions for proprietary materials, welded and mechanical splices, and reinforcement accessories.
  4.—Epoxy Coating for Reinforcement:
    a.—Written certification from coating manufacturer that coating resin for reinforcement has been approved by National Bureau of Standards.
    b.—Written information from coating manufacturer on proper use and application of coating resin.
    c.—Coating applicator's written certification of results of quality control program.

5.—Submit all materials and methods for concrete curing to Engineer for approval before beginning concreting Work. Include certification of curing compound allowable moisture loss.

6.—Submit certification for substitution of curing compound, if appropriate.

7.—Submit certification that curing compound or evaporation retarder, if used, is compatible with sealer specified in Division 7 Section "Waterproofing System."

8.—Submit certification that curing compound or evaporation retarder is compatible with stain specified in Division 9 Section "Painting."

9.—Contractor: Submit concrete mix design to Engineer two weeks before placing concrete. Use mix design submission form at end of this Section. Any other mix design submission form will be rejected. Proportion mix designs as defined in ACI 301 Article 3.9. Mix designs shall be proportioned by party other than Testing Agency responsible for testing concrete for Project. Mix shall be proportioned to minimize effects of thermal and drying shrinkage. Construction means and methods shall not adversely affect low volume change characteristics of mix design. Include following information for each concrete mix design:

- **a.**—Method used to determine proposed mix design, (ACI 301 Article 3.9).
- **b.**—Gradation of fine and coarse aggregates.
- **c.**—Proportions of all ingredients including all admixtures added either at time of batching or at job site.
- **d.**—Water/cementitious materials ratio.
- **e.**—Slump, ASTM C143.
- **f.**—Certification of the chloride content of admixtures.
- **g.**—Air Content:
  - **1)**—Of freshly mixed concrete by pressure method, ASTM C231, or volumetric method, ASTM C173.
  - **2)**—Of hardened concrete by microscopical determination, including parameters of air-void system, ASTM C457.
  - **3)**—Freeze-thaw resistance, ASTM C457 and C666. If superplasticized concrete cannot meet hardened air content requirements of Part 2 Article "Proportioning and Design of Mixes," paragraph "Air Entrainment," subparagraph "Hardened concrete. . . ." ASTM C666 laboratory test result of specimens with concrete mix proportions similar to proposed mix for project shall be submitted for review by Engineer. Report air void parameters (spacing and specific surface area in accordance with ASTM C457) of specimens tested. Test specimens shall contain specified entrained air content (within ± 1%) and superplasticizer that will be used in concrete for

project. Report relative durability factor of concrete for specimens tested in accordance with Procedure A of ASTM C666.

h.—Unit weight of concrete, ASTM C138.

i.—Strength at 4, 7, and 28 days, ASTM C39.

j.—Water-soluble chloride ion content of concrete: AASHTO T260.

k.—Shrinkage (length change), ASTM C157 (modified).

10.—Contractor: At preconcrete meeting, submit procedures to protect fresh concrete from rain.

11.—Testing Agency: Promptly report all field concrete test results to Engineer, Contractor, and Concrete Supplier. Include following information:

a.—See Article "Quality Assurance."

b.—Weight of concrete, ASTM C 138.

c.—Slump, ASTM C 143.

d.—Air content of freshly mixed concrete by pressure method, ASTM C 231 or volumetric method, ASTM C 173.

e.—Concrete temperature (at placement time).

f.—Air temperature (at placement time).

g.—Strength determined in accordance with ASTM C 39.

h.—Shrinkage (length change) of superstructure concrete, ASTM C 157.

12.—Contractor: Submit grout temperature limitations with grout submittal.

13.—Current certification of welders.

C.—Shop drawings for reinforcement:

1.—Prepared for fabrication, bending, and placement of concrete reinforcement. Comply with ACI SP-66 (88), "ACI Detailing Manual," showing bar schedules, stirrup spacing, diagrams of bent bars, and arrangement of concrete reinforcement. Include special reinforcement required for openings through concrete structures.

2.—Because Work of this Section and Section "Post-Tensioned Concrete" are interdependent, Contractor shall have both suppliers review the other's Shop Drawings and note any potential interferences. Contractor shall then review this Section and Section "Post-Tensioned Concrete" Shop Drawings against each other and inform Engineer of any potential interferences.

D.—Shop drawings for formwork for fabrication and erection of forms for specific exposed finish concrete surfaces. Show form construction including jointing, special form joint or reveals, location and pattern of form tie placement, and other items that affect exposed concrete visually.

1.—Engineer's review is for general architectural applications and features only. Design of formwork for structural stability and efficiency is Contractor's responsibility.

E.—Samples of materials as requested by Engineer, including names, sources, and descriptions, as follows:
- **1.**—Normal-weight aggregates.
- **2.**—Fibrous reinforcement.
- **3.**—Reglets.
- **4.**—Waterstops.
- **5.**—Vapor retarder.

F.—Laboratory test reports for concrete materials and mix design test.

G.—Materials certificates in lieu of materials laboratory test reports when permitted by Engineer. Materials certificates shall be signed by manufacturer and Contractor, certifying that each material item complies with or exceeds specified requirements. Provide certification from admixture manufacturers that chloride content complies with specification requirements.

H.—Minutes of concrete pre-installation conference.

1.4 QUALITY ASSURANCE

A.—Codes and Standards: Comply with provisions of following codes, specifications, and standards, except where more stringent requirements are shown or specified:
- **1.**—ACI 301, "Specifications for Structural Concrete for Buildings."
- **2.**—ACI 318, "Building Code Requirements for Reinforced Concrete."
- **3.**—Concrete Reinforcing Steel Institute (CRSI), "Manual of Standard Practice."

B.—Materials and installed work may require retesting at any time during progress of work. Tests, including retesting of rejected materials for installed work, shall be done at Contractor's expense.Concrete Pre-Installation Conference: Conduct conference at Project site to comply with requirements of Division 1 Section "Project Meetings" and the following.

C.—At least 35 days prior to submittal of design mixes, conduct a meeting to review detailed requirements for preparing concrete design mixes and to determine procedures for satisfactory concrete operations. Review requirements for submittals, status of coordinating work, and availability of materials. Establish preliminary work progress schedule and procedures for materials inspection, testing, and certifications. Request that representatives of each entity directly concerned with cast-in-place concrete attend conference, including, but not limited to, the following:
- **1.**—Contractor's superintendent.
- **2.**—Laboratory responsible for concrete design mixes.
- **3.**—Laboratory responsible for field quality control.
- **4.**—Ready-mix concrete producer.

5.—Concrete subcontractor.
6.—Primary admixture manufacturers.
7.—Engineer or Owner's representative.

D.—Structural properties of permanent steel formwork shall be determined in accordance with AISI "Specification for the Design of Cold-Formed Steel Structural Members."

E.—Welders and welding procedures for permanent steel formwork shall conform to requirements of AWS D1.1.

F.—Welders and welding procedures shall conform to requirements of AWS D1.4. Except where shown on Drawings, welding of reinforcing steel is prohibited unless accepted in writing by Engineer.

G.—Submit steel producer's certificates of mill analysis, tensile tests, and bend tests for reinforcing steel. Coordinate with welders and welding procedures.

H.—Epoxy coated reinforcement, ASTM A775 and A884:
- **1.**—Coating applicator shall have quality control program to assure that coated reinforcement comply with requirements of Specification.
- **2.**—Submit proof of current certification for rebar coating plant from Concrete Reinforcing Steel Institute.

I.—Submit following information on Inspection of Reinforcement unless modified in writing by Engineer:
- **1.**—Project name and location.
- **2.**—Contractor's name.
- **3.**—Inspection Agency's name, address, and phone number.
- **4.**—Date and time of inspection.
- **5.**—Inspection Agency technician's name.
- **6.**—Fabricator's name.
- **7.**—Weather data:
  - **a.**—Air temperatures.
  - **b.**—Weather.
  - **c.**—Wind speed.
- **8.**—Inspection location within structure.
- **9.**—Reinforcement inspection data (including but not limited to):
  - **a.**—Bar size, spacing, cover, and grade.
  - **b.**—Splices, bends, anchorages, welding.
  - **c.**—Epoxy coating or galvanizing as required.
  - **d.**—Support methods and construction sequencing.
- **10.**—Diary of general progress of Work.

J.—Testing Agency:
- **1.**—Independent testing laboratory employed by Owner and acceptable to Engineer.
- **2.**—Accredited by AASHTO under ASTM C1077. Testing laboratory shall submit documented proof of ability to perform required tests.

K.—Sampling and testing of concrete shall be performed by ACI certified

Concrete Field Technicians Grade I. Certification shall be no more than three years old.

L.—Testing Agency is responsible for conducting, monitoring, and reporting results of all tests required under this Section. Testing Agency has authority to reject concrete not meeting Specifications.

M.—Submit following Field Test information for Concrete unless modified in writing by Engineer:

1.—Project name and location.

2.—Contractor's name.

3.—Testing Agency's name, address, and phone number.

4.—Concrete supplier.

5.—Date of report.

6.—Testing Agency technician's name (sampling and testing).

7.—Placement location within structure.

8.—Elapsed time from batching at plant to discharge from truck at site.

9.—Concrete mix data (quantity and type):

a.—Cement.

b.—Fine aggregates.

c.—Coarse aggregates.

d.—Water.

e.—Water/cementitious materials ratio.

f.—Air entraining admixtures.

g.—Water-reducing admixture and high-range water-reducing admixture.

h.—Other admixtures.

10.—Weather data:

a.—Air temperatures.

b.—Weather.

c.—Wind speed.

11.—Field test data:.

a.—Date, time, and place of test.

b.—Slump.

c.—Air content

d.—Unit weight.

e.—Concrete temperature.

12.—Compressive test data:

a.—Cylinder number.

b.—Age of concrete when tested.

c.—Date and time of cylinder test.

d.—Curing time (field and lab).

e.—Compressive strength.

f.—Type of break.

N.—Provide certification that curing compound has passed requirements of ASTM C 309.

O.—Provide certification that curing compound and evaporation retarder are compatible with sealer specified in Division 7 Section "Waterproofing System."

P.—At all times during warm and hot weather, maintain adequate supply of evaporation retarder at site.

Q.—Testing Agency: Identify those of concrete supplier's trucks which meet requirements of NRMCA Quality Control Manual. Permit only those trucks to deliver concrete to Project.

1.5 REFERENCES

A.—American Association of State Highway and Transportation Officials (AASHTO):

1.—AASHTO, "Standard Specifications for Highway Bridges."

B.—American Concrete Institute (ACI):

1.—ACI 214, "Recommended Practice for Evaluation of Strength Test Results of Concrete."

2.—ACI 301, "Specifications for Structural Concrete for Buildings."

3.—ACI 302.1R, "Guide for Concrete Floor and Slab Construction."

4.—ACI 305R, "Hot Weather Concreting."

5.—ACI 306.1, "Standard Specification for Cold Weather Concreting."

6.—ACI 306R, "Cold Weather Concreting."

7.—ACI 308, "Standard Practice for Curing Concrete."

8.—ACI 318, "Building Code Requirements for Reinforced Concrete."

9.—ACI 347, "Recommended Practice for Concrete Formwork."

10.—ACI 362.1, "Guide for the Design of Durable Parking Structures."

C.—American Iron and Steel Institute (AISI):

1.—AISI, "Specification for the Design of Cold-Formed Steel Structural Members."

D.—American Society for Testing and Materials (ASTM):

1.—ASTM A 36, "Specification for Structural Steel."

2.—ASTM A 185, "Specification for Welded Wire Steel Fabric for Concrete Reinforcement."

3.—ASTM A 497, "Specification for Welded Deformed Steel Wire Fabric for Concrete Reinforcement."

4.—ASTM A 615, "Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement."

5.—ASTM A 706, "Specification for Low-Alloy Steel Deformed Bars for Concrete Reinforcement."

6.—ASTM A 775, "Specification for Epoxy-Coated Reinforcing Steel Bars."

7.—ASTM A 884, "Specification for Epoxy-Coated Steel Wire and Welded Wire Fabric for Reinforcement."

8.—ASTM B 633, "Specification for Electrodeposited Coatings of Zinc on Iron and Steel."
9.—ASTM C 31, "Method of Making and Curing Concrete Test Specimens in the Field."
10.—ASTM C 33, "Specification for Concrete Aggregates."
11.—ASTM C 39, "Test Method for Compressive Strength of Cylindrical Concrete Specimens."
12.—ASTM C 94, "Specification for Ready-Mixed Concrete."
13.—ASTM C 109, "Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or 50-mm Cube Specimens)."
14.—ASTM C 138, "Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete."
15.—ASTM C 143, "Test Method for Slump of Portland Cement Concrete."
16.—ASTM C 150, "Specification for Portland Cement."
17.—ASTM C 172, "Method of Sampling Freshly Mixed Concrete."
18.—ASTM C 173, "Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method."
19.—ASTM C 231, "Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method."
20.—ASTM C 260, "Specification for Air-Entraining Admixtures for Concrete."
21.—ASTM C 309, "Specification for Liquid Membrane-Forming Compounds for Curing Concrete."
22.—ASTM C 311, "Methods of Sampling and Testing Fly Ash or Natural Pozzolans for Use as a Mineral Admixture in Portland Cement Concrete."
23.—ASTM C 330, "Standard Specification for Lightweight Aggregates for Structural Concrete."
24.—ASTM C 457, "Practice for Microscopical Determination of Air-Void Content and Parameters of the Air-Void System in Hardened Concrete."
25.—ASTM C 494, "Specification for Chemical Admixtures for Concrete."
26.—ASTM C 567, "Test Method for Unit Weight of Structural Lightweight Concrete."
27.—ASTM C 618, "Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete."
28.—ASTM C 666, "Test Method for Resistance of Concrete to Rapid Freezing and Thawing."
29.—ASTM C 672, "Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals."
30.—ASTM C989, "Specification for Ground Granulated Blast-Furnace Slag for use in Concrete and Mortars."

31.—ASTM C 1077, "Standard Practice for Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation."

32.—ASTM C 1116, "Standard Specification for Fiber-Reinforced Concrete and Shotcrete."

33.—ASTM C 1152, "Sampling and Testing for Total Chloride Ion in Concrete and Concrete Raw Materials."

E.—American Welding Society (AWS):

1.—AWS D1.1, "Structural Welding Code-Steel."

2.—AWS D1.4, "Structural Welding Code—Reinforcing Steel."

F.—Concrete Reinforcing Steel Institute (CRSI):

1.—CRSI MSP, "Manual of Standard Practice."

G.—Prestressed Concrete Institute (PCI):

1.—PCI MNL 116, "Manual for Quality Control for Plants and Production of Precast Prestressed Concrete Products."

2.—PCI MNL 117, "Manual for Quality Control for Plants and Production of Architectural Precast Concrete Products."

3.—PCI MNL 120, "Design Handbook Precast Prestressed Concrete."

4.—PCI MNL 122, "Architectural Precast Design Handbook."

5.—PCI MNL 129, "Parking Structures—Recommended Practice for Design and Construction."

H.—Contractor shall have following ACI publications at Project construction site:

1.—ACI SP-15, "Specifications for Structural Concrete for Buildings ACI 301-84 (Revised 1989) with selected ACI and ASTM References."

2.—ACI 302.1R, "Guide for Concrete Floor and Slab Construction."

3.—ACI 305R, "Hot Weather Concreting."

4.—ACI 306R, "Cold Weather Concreting."

5.—ACI 306.1, "Standard Specification for Cold Weather Concreting."

1.6 DELIVERY, STORAGE, AND HANDLING

A.—Store all formwork and formwork materials clear of ground, protected, so as to preclude damage.

B.—Deliver reinforcement to Project site bundled, tagged and marked. Use metal tags indicating bar size, lengths, and other information corresponding to markings shown on placement diagrams.

C.—Store concrete reinforcement materials at site to prevent damage and accumulation of dirt or excessive rust.

D.—Epoxy Coated Reinforcement:

1.—Contact areas of handling and hoisting systems shall be padded or be made of nylon or other acceptable material.

2.—Use spreader bars to lift bundles of coated steel to prevent bar-to-bar abrasion.
3.—Pad bundling bands or fabricate of nylon or other acceptable material.
4.—Store coated steel on padded or wooden cribbing.
5.—Do not drag coated steel members.
6.—After placement, restrict traffic on coated steel to prevent damage.

E.—Concrete transported by truck mixer or agitator shall be completely discharged within one and one half hours (one hour for hot weather concreting) after water has been added to cement or cement has been added to aggregates.

F.—Additional Water: Prohibited unless requirements of both paragraph "Special Exposure Requirements" under Part 2 Article "Proportioning and Design of Mixes" and ACI 301, paragraph 7.5.2, are met. Add **NO WATER** after superplasticiser added.

PART 2 PRODUCTS

2.1 FORM MATERIALS

A.—Forms for Exposed Finish Concrete: Plywood, metal, metal-framed plywood faced, or other acceptable panel-type materials, to provide continuous, straight, smooth, exposed surfaces. Furnish in largest practicable sizes to minimize number of joints and to conform to joint system shown on Drawings.

1.—Use plywood complying with U.S. Product Standard PS-1 "B-B (Concrete Form) Plywood," Class I, Exterior Grade or better, mill-oiled and edge-sealed, with each piece bearing legible inspection trademark.

B.—Forms for Unexposed Finish Concrete: Plywood, lumber, metal, or other acceptable material. Provide lumber dressed on at least 2 edges and one side for tight fit.

C.—Forms for Textured Finish Concrete: Units of face design, size, arrangement, and configuration to match Engineer's control sample. Provide solid backing and form supports to ensure stability of textured form liners.

D.—Forms for Cylindrical Columns and Supports: Metal, fiberglass-reinforced plastic, or paper or fiber tubes. Provide paper or fiber tubes of laminated plies with water-resistant adhesive and wax-impregnated exterior for weather and moisture protection. Provide units with sufficient wall thickness to resist wet concrete loads without deformation.

E.—Form Coatings: Provide commercial formulation form-coating compounds with a maximum VOC of 350 mg/l that will not bond with, stain, or adversely affect concrete surfaces and will not impair subsequent treatments of concrete surfaces, including but not limited to water-curing, curing compound, stains, or paints.

F.—Form Ties: Factory-fabricated, adjustable-length, removable, or snap-off metal form ties, designed to prevent form deflection and to prevent spalling concrete upon removal. Provide units that will leave no metal closer than 1½ in. to exposed surface.

1.—Provide ties that, when removed, will leave holes not larger than 1-in. diameter in concrete surface.

G.—Shores:

1.—Nail Ellis clamps, if used with wood shores, to shores with minimum of two nails to prevent slipping.

2.—Wedges: Hardwood or steel. Softwood wedges prohibited.

H.—Nails for P/T Anchors: Stainless steel ring nails, Clendenin Brothers, Baltimore, MD.

2.2 REINFORCEMENT MATERIALS

A.—Reinforcement Bars: ASTM A 615 or ASTM A 706; yield strength: as noted on Drawings.

1.—Provide in Bid ___ additional tons of placed reinforcement bars or welded wire fabric for inclusion in Project as Engineer directs. Return cost of unused portion to Owner at unit price stated on Bid Form. Submit to Engineer breakdown of use each month.

B.—Welded wire fabric: ASTM A185 or ASTM A497: as noted on Drawings:

1.—Welded wire fabric: provide in mats only. Roll stock prohibited.

C.—Supports for Reinforcement: Bolsters, chairs, spacers, and other devices for spacing, supporting, and fastening reinforcing bars and welded wire fabric in place. Use wire-bar-type supports complying with CRSI specifications.

1.—For slabs-on-grade, use supports with sand plates or horizontal runners where base material will not support chair legs.

2.—For exposed-to-view concrete surfaces, both horizontal and vertical, where legs of supports are in contact with forms, provide supports with legs that are plastic protected (CRSI, Class 1) or stainless steel protected (CRSI, Class 2).

3.—Chairs shall be sized and spaced to prevent cover loss during construction operations.

4.—Bar supports shall be manufactured from dielectric material, or wire bar supports shall be coated with dielectric material, such as epoxy or vinyl, compatible with concrete, for minimum distance of 2 in. either side of point of contact with epoxy-coated reinforcement.

D.—Epoxy Coating Materials for Reinforcement: ASTM A775 and A884:
- **1.**—Supplier shall be certified currently under CRSI Fusion Bonded Epoxy Coating Applicator Plant Certification Program.
- **2.**—Provide one of following epoxy coatings for reinforcement and steel accessories as noted on Drawings:
  - **a.**—"Scotchkote 213," 3M Company.
  - **b.**—"Flintflex 531-6086," E. I. DuPont DeNemours Company, Inc.
  - **c.**—"Epoxiplate R346 or R349," Armstrong Products Company.
  - **d.**—"Epoxy Powder 720-A-009," Cook Paint and Varnish Company.
- **3.**—Use patching material recommended by epoxy powder manufacturer, compatible with epoxy coating and inert in concrete. Acceptable:
  - **a.**—"Scotchkote 213 PC," 3M Company.
  - **b.**—"Sikatop 108 Armatec," Sika Corporation.

E.—Posttensioned Reinforcement: See Section "Posttensioned Concrete."

2.3 CONCRETE MATERIALS

A.—Portland Cement (ACI 301, ARTICLE 2.1):
- **1.**—Portland cement, Type I, ASTM C150. Use one cement clinker source throughout project. No change in brand without prior written acceptance from Engineer.
- **2.**—Blended cement, ASTM C595, Type IP only with prior written acceptance from Engineer.

B.—Fly Ash:
- **1.**—Permitted in all parts of structure.
- **2.**—ASTM C618, Class C or F, except maximum loss on ignition: 3%. Maximum percent retained on #325 sieve: 28%. Maximum water requirement, stated as percentage of control: 100%
- **3.**—Testing: ASTM C311.
- **4.**—Percentage of fly ash in mix design shall be by weight, not by volume. Water/cement ratio will be calculated as water/cementitious (total cement and fly ash) ratio.
- **5.**—If project contains post-tensioned members, see Section "Posttensioned Concrete," Part 3 heading "Installation," paragraph "Tensioning" for high early strength requirements for concrete to be post-tensioned.
- **6.**—When minimum cement or cementitious contents are specified:
  - **a.**—Class C fly ash may be substituted for up to 25% of cement or cementitious at one pound of fly ash for one pound of cement substitution rate, providing required strength at all specified ages is attained.Class F fly ash may be substituted

for up to 20% of cement or cementitious at substitution rate (not more than one pound of fly ash to one pound of cement) sufficient to provide required strength at all specified ages.

7.—Prohibited: fly ash in same mix with Type IP blended cement.

8.—If strength or air content varies from that specified more than specified tolerances, concrete shall be rejected by Engineer or designated representative.

9.—Submit all fly ash concrete mix designs per ACI 301.

10.—For posttensioned concrete, high strength within 96 hours of casting is requirement. See Section "Posttensioned Concrete."

C.—Ground Granulated Blast Furnace (GGBF) Slag:

1.—ASTM C 989, Grade 100 or higher.

2.—Percentage of GGBF slag in mix design shall be by weight, not by volume. Water-cement ratio shall be calculated as water-cementitious (total portland cement + GGBF slag) ratio.

3.—Use GGBF slag at susbstitution rate of 1 lb for every lb of cement or cementitious.

4.—Permitted only in listed lelements at associated substitution amounts:

a.—Slabs on grade: Less than or equal to 35%.

b.—Columns, walls, grade beams, footings, drilled piers, pier caps: Less than or equal to 50%.

c.—Underground mass concrete (minimum dimension 3 ft): Less than or equal to 65%.

5.—If strength or air content varies from value specifed by more than specified tolerances, Engineer or designated representative shall reject that concrete.

6.—Prohibited: GGBF slag in same mix with cementitious materials other than portland cement.

7.—Submit all GGBF slag concrete mix designs per ACI 301.

D.—Normal Weight Aggregates (ACI 301, ARTICLE 2.4):

1.—Normal weight concrete aggregates:

a.—Coarse aggregate: Crushed and graded limestone or approved equivalent conforming to ASTM C33 except as noted here, minimum class designations as listed below:

1)—Below grade construction: Class 1S.

2)—Walls not exposed to public view: Class 3S.

3)—Walls exposed to public view: Class 5S.

4)—Slabs on grade: Class 4S.

5)—All other concrete: Class 5S.

6)—No deleterious materials such as, but not limited to, chert or opaline.

b.—Fine aggregate: Natural sand conforming to ASTM C33 and having preferred grading shown for normal weight aggregate in ACI 302.1R, Table 4.2.1.

2.—Coarse aggregate: Nominal maximum sizes indicated below, conforming to ASTM C33, Table 2:

a.—Footings: Size number 57.

b.—All other members: Size number 67.

3.—Chloride Ion Level: Chloride ion content of aggregates shall be tested by laboratory making trial mixes.

E.—Lightweight Aggregates: ASTM C 330.

F.—Water (ACI 301, Article 2.3):

1.—ASTM C 94.

G.—Chloride Ion Content of Mix:

1.—Water soluble chloride ion content of concrete mix (including all constitutents) shall not exceed 0.06% chloride ions by weight of cement for prestressed concrete and 0.15% for reinforced concrete. Test to determine chloride ion content shall conform to ASTM C 1152.

2.—Concrete chloride ion content shall be determined by Testing Agency prior to placement. Cast samples from current production of concrete mix proposed for superstructure.

H.—Fibrous Reinforcement:

1.—Polypropylene fibers for plastic shrinkage control in concrete members.

2.—Products: Subject to compliance with requirements, provide one of the following:

a.—"Forta," Forta Corp.

b.—"Fibermesh," Fibermesh, Inc.

c.—"Grace Fibers"or "Grace Microfibers," W. R. Grace & Co., Inc.

d.—"Fiberstrand 100," Euclid Chemical Co.

3.—Additional requirements:

a.—Collated fibrillated materials: Dosage rate 1½ lb/cu yd of concrete minimum, containing at least 3 million individual fibers.

b.—Multifilament fibers: Dosage rate 1 lb/cu yd of concrete minimum, containing at least 50 million individual fibers. Minimum length ¾ in.

c.—Meet requirements of ASTM C 1116, "Standard Specification for Fiber-Reinforced Concrete and Shotcrete," designation Type III, 4.1.3.

d.—Meet minimum plastic shrinkage crack reduction of 70% When tested in accordance with ICBO ES, Appendix B (7-92).

4.—Use shall not change water requirement of mix.

5.—Conform to manufacturer's recommendations for quantity of fiber. See paragraph "Additional Requirements" above for minimums.

6.—See Drawings for amount and use locations.

7.—Fiber manufacturer or approved distributor: Provide services of qualified person at preconstruction meeting, concrete preinstallation meeting and first concrete placement containing fibers.

I.—Storage of Materials (ACI 301, Article 2.5).

2.4 RELATED MATERIALS

A.—Reglets: Where resilient or elastomeric sheet flashing or bituminous membranes are terminated in reglets, provide reglets of not less than 0.0217 in. thick (26-gage) galvanized sheet steel. Fill reglet or cover face opening to prevent intrusion of concrete or debris.

B.—Waterstops: Provide flat, dumbbell-type or centerbulb-type waterstops at construction joints and other joints as indicated. Size to suit joints.

C.—Rubber Waterstops: Corps of Engineers CRD-C 513.

1.—Manufacturers: Subject to compliance with requirements, provide products of one of the following:

a.—The Burke Co.

b.—Progress Unlimited.

c.—Williams Products, Inc.

D.—Polyvinyl Chloride Waterstops: Corps of Engineers CRD-C 572.

1.—Manufacturers: Subject to compliance with requirements, provide products of one of the following:

a.—The Burke Co.

b.—Greenstreak Plastic Products Co.

c.—W. R. Meadows, Inc.

E.—Granular Base: Evenly graded mixture of fine and coarse aggregates to provide, when compacted, a smooth and even surface below slabs on grade.

F.—Sand Cushion: Clean, manufactured or natural sand.

G.—Vapor Retarder: Provide vapor retarder cover over prepared base material where indicated below slabs on grade. Use only materials that are resistant to deterioration when tested in accordance with ASTM E 154, as follows:

1.—Polyethylene sheet not less than 8 mils thick.

H.—Vapor Barrier: Premoulded membrane, seven-ply construction consisting of reinforced core and carrier sheet with fortified bitumen layers, protective weathercoating, and plastic antistick sheet. Water vapor transmission rate of 0.00 grains/sq ft/hr when tested in accordance with ASTM E 96, Method B. Provide manufacturer's recommended mastics and gusset tape.

1.—Product: "Sealtight Premoulded Membrane With Plasmatic Core," W. R. Meadows, Inc.

I.—Mechanical and chemical anchors shall be manufactured by Hilti Fastening Systems, Tulsa, Oklahoma, or accepted equivalent. Anchor bolt composition shall be from one or more of carbon steel and stainless steel, lead, Zamac alloy, nylon, plastic, polypropylene, and jute fibre. For chemical anchors, adhesive composition shall be as shown on Drawings.

1.—Carbon steel anchors shall be either zinc plated in accordance with ASTM B633, or hot-dipped galvanized in accordance with ASTM A-153-78. Refer to Drawings for carbon steel nut and washer specifications. Provide mill test reports and manufacturer's quality control certification upon Engineer's request.

2.—Stainless steel anchors shall be manufactured from 303, 304, or 306 stainless steel. Refer to Drawings for stainless steel nut and washer specifications. Provide mill test reports and manufacturer's quality control certification upon Engineer's request.

3.—Plastic, lead, or Zamac alloy anchors shall not be used for overhead applications. Chemical anchors shall not be used to resist pullout forces in overhead and wall installations unless proper consideration is given to fire conditions. For chemical anchors, consult with manufacturer's engineer.

4.—Safety Factors: Static loads 4:1 minimum. Static load safety factors shall be per manufacturer's published data. Critical load (vibratory, overhead, etc. or more) safety factors shall be 10:1 minimum. Provide test reports for manufacturer's published load data upon Engineer's request.

a.—If necessary, for purposes of determining tensile and/or shear capacity in questionable base material, testing shall be done prior to actual anchor installation. A maximum of five tension and/or shear tests shall be performed by manufacturer's engineer. Anchors shall be proof loaded in tension and/or shear to assure that working load capacity is within specified allowable load limit as published by manufacturer.

5.—Anchor spacing and edge distance shall be as indicated on Drawings. Loading and cluster spacing shall be as established by minimum industry standards for anchors except as follows: Anchor loading, cluster spacing and edge distances shall be as published in manufacturer's literature. Consult with manufacturer's engineer for specific requirements.

6.—Anchor installations shall be as required by manufacturer's written instructions.

7.—See Drawings for more information.

J.—Inserts and Coil Rods:

1.—Provide sizes shown on Drawings.

2.—Yield strength: 65,000 psi minimum.

3.—Galvanizing: Where indicated, electrodeposited zinc coating, ASTM B633, Service Condition 1, Type III.

4.—Epoxy coating: Where indicated.

5.—Acceptable manufacturers:
  a.—Richmond Screw Anchor Company, Inc., Fort Worth, TX.
  b.—Dayton Superior Corporation, Miamisburg, OH.
6.—Details shown in Contract Drawings are based on Richmond Screw Anchor Co., Inc. products and their respective capacities. Dayton Superior products may be used only if precaster submits calculations, sealed by professional engineer or structural engineer registered in state in which project will be built, substantiating strength of connection with Dayton Superior product. Calculations are subject to Engineer's acceptance before fabrication is to proceed.

K.—Joint Filler:
1.—Joint filler in slabs and curbs: Asphalt impregnated fiber board; as shown on Drawings. Acceptable products:
  a.—"Flexcell," Celotex Corp.
  b.—"Fibre Expansion Joint," W. R. Meadows, Inc.
2.—Joint filler used vertically to isolate walls from columns or other walls: White molded polystyrene beadboard type, as shown on Drawings.
3.—Joint cover used to bridge gap between columns and grade walls, retaining walls, or basement walls: Minimum width: Gap width plus 4 in. For gaps over ¼ in. wide, protect cover with protection board sized to span gap satisfactorily. Acceptable products:
  a.—"Sealtight Premoulded Membrane Vapor Seal," W. R. Meadows, Inc., Elgin, Illinois.
  b.—"Sealtight Melnar," W.R. Meadows, Inc., Elgin, Illinois and shall be applied according to manufacturer's instructions.

L.—Slide Bearing Systems at Expansion Joints:
1.—Provide slide bearing systems as shown and detailed on Drawings:
  a.—Beam and double tee bearings shall be reinforced PTFE: 100 percent virgin tetrafluoroethylene polymer and ground glass fiber reinforcing aggregate, prebonded to stainless steel and/ or preformed fabric (Section "Structural Precast Concrete," Part 2 Article "Materials," paragraph "Bearing Pads") bearing pads. Acceptable slide bearing systems:
    1)—"Fluorogold," Fluorocarbon, Pine Brook, New Jersey.
    2)—"Balco," Balco, Inc., Wichita, Kansas.
    3)—"Alert 15175 Shock Pads with TFE," Alert Manufacturing and Supply Co., Chicago, Illinois.
    4)—"Dura-Slide," Tobi Engineering, Inc., Elk Grove Village, Illinois.
    5)—"Dynalon Slide Bearings with Masticord," JVI, Inc., Skokie, Illinois.
  b.—Slab and plank bearings shall be ultrahigh molecular weight, high-density polyethylene resin: Acceptable material:

1)—"Korolath PE," Korolath Corporation, Hudson, Mass.
2)—"Tivar-100," Poly-Hi/Menasha Corporation, Fort Wayne, Indiana.
3)—"UHMW Econ-o-Shim," Deslausiers, Inc., Bellwood, IL.

2.—Backing material for reinforced PTFE slide bearing systems as shown on Drawings:

a.—Galvanized steel.

b.—Stainless steel.Reinforced elastomer, having durometer hardness of 90 +/− 5 and meeting requirements of Article 2.10.3(L) of AASHTO Standard Specifications for Highway Bridges (1983).

M.—Absorptive Cover: Burlap cloth made from jute or kenaf, weighing approximately 9 oz per sq yd, complying with AASHTO M 182, Class 2.

N.—Moisture-Retaining Cover:

1.—Polyethylene-coated burlap, complying with ASTM C 171.

O.—Curing Compound:

1.—Products: Subject to compliance with requirements, provide one of the following:

a.—"Kurez DR," Euclid Chemical Co., East Brunswick, NJ.

b.—"RxCure-30%," Conspec Marketing & Manufacturing Co., Kansas City, KS.

2.—Substitutions: Accepted by Engineer and:

a.—Dissipating, Type I, ASTM C 309, except as noted herein.

b.—Allowable moisture loss shall not exceed 0.030 g/sq cm.

c.—Supplier shall submit certification by independent testing laboratory that proposed curing compound has passed requirements of this Section. Certification shall be submitted to Engineer 30 days before first use of material. Material shall not be used without written acceptance from Engineer.

P.—Evaporation Control: Monomolecular film-forming compound applied to exposed concrete slab surfaces for temporary protection from rapid moisture loss.

1.—Products: Subject to compliance with requirements, provide one of the following:

a.—"Aquafilm," Conspec Marketing and Mfg. Co.

b.—"Eucobar," Euclid Chemical Co.

c.—"E-Con," L&M Construction Chemicals, Inc.

d.—"Confilm," Master Builders, Inc.

Q.—Acceptable repair materials:

1.—Bonding Admixture: "SBR Latex" or "Flexcon," Euclid Chemical Co., or "Acryl 60," Standard Drywall Co.

2.—Epoxy Adhesive: 2 component, 100% solids, 100% reactive compound suitable for use on dry or damp surfaces, "Euco Epoxy #463 or #620," Euclid Chemical Co., or "Sikadur Hi-Mod," Sika Chemical Corp.

3.—Patching Mortar: Free-flowing, polymer-modified cementitious coating, "Euco Thin Coat," Euclid Chemical Co. or "Sikatop 122," Sika Chemical Corp.

4.—Repair Topping: Self-leveling, polymer-modified high strength topping, "Thin Top," Euclid Chemical Co.

2.5 PROPORTIONING AND DESIGN OF MIXES (ACI 318-89, Chapter 5)

A.—Prepare design mixes for each type and strength of concrete by either laboratory trial batch or field experience methods as specified in ACI 301. If trial batch method used, use an independent testing facility acceptable to Engineer for preparing and reporting proposed mix designs. The testing facility shall not be the same as used for field quality control testing.

B.—Submit written reports to Engineer of each proposed mix for each class of concrete at least 15 days prior to start of work. Do not begin concrete production until proposed mix designs have been reviewed by Engineer.

C.—Special Exposure Requirements:

1.—Proportion all concrete to resist freezing and thawing and provide corrosion protection:

a.—Water/cementitious materials ratio shall not exceed ___ by weight, including water added to meet specified slump in accordance with requirements of ASTM C 94, unless noted otherwise on Drawings.

b.—Admixture Usage: Concrete for parking structure supported slabs shall contain specified high-range water-reducing admixture (superplasticizer). Supported concrete slabs placed at air temperatures below 50 degrees F. shall contain specified non-corrosive, non-chloride accelerator.

D.—Chloride Ion Content:

1.—See Part 2 Article "Concrete Materials," paragraph "Chloride Ion Content of Mix" for requirements.

2.—Concrete not meeting requirements of Part 2 Article "Concrete Materials," paragraph "Chloride Ion Content of Mix" shall contain appropriate amount of D.C.I. Corrosion Inhibitor (see Part 2 Article "Concrete Materials," paragraph "Corrosion Inhibiting Admixture"). Concrete supplier shall provide laboratory test results from Part 2 Article "Concrete Materials," paragraph "Chloride Ion Content of Mix" showing excess chloride in concrete mix is derived from aggregate. For each pound of chloride ion in excess of amount allowed, mix shall contain D.C.I. Corrosion Inhibitor on one-to-one basis (lb of chloride ion per cu yd to gal of D.C.I. per cu yd). Maximum of 1.5 lb of chloride ion per cu yd may be offset in this manner. Minimum dosage shall be 0.5

gal per cu yd. Concrete not meeting requirements of Part 2 Article "Concrete Materials," paragraph "Chloride Ion Content of Mix" due to surface contamination of mix aggregate or mixes which contain more than 1.5 lb per cu yd of excess chloride ion shall be rejected.

E.—Strength (ACI 301, Article 3.2):

1.—Specified compressive strength (f'c) of concrete at 28 days: as noted on Drawings.

2.—When field data in accordance with ACI 301, Article 3.9.1 is not available, required average compressive strength shall be in accordance with Article 3.9.2.2.

3.—Concrete shall be proportioned in accordance with Article 3.9, ACI 301: 564 lb cementitious minimum per cu yd of concrete for 4,000 psi (or less) concrete and 650 lb cementitious per cu yd for concrete more than 4,000 psi.

F.—Air Entrainment:

1.—See General Notes on Drawings for total air content (percent by volume).

2.—Permissible variation from specified total air content: Plus or minus 1½%.

3.—Hardened concrete shall have an air void spacing factor of 0.0080 in. maximum. Specific surface (surface area of air voids) shall be 600 in^2 per cu in. of air-void volume, or greater. Concrete mixes not meeting these values as determined by ASTM C 457 may require adjustments unless accepted in writing by Engineer. Refer to Part 1 Article "Submittals," paragraph "Product data for proprietary materials. . .," subparagraph "Contractor: submit. . .," sub-subparagraph "Air Content"

G.—Lightweight Concrete: Proportion mix as specified. Design mix to produce strength and modulus of elasticity as noted on drawings, with a splitting tensile strength factor (Fct) of not less than 5.5 for 3000-psi concrete and a dry weight of not less than 95 lb or more than 110 lb after 28 days. Limit shrinkage to 0.03 % at 28 days.

H.—Slump (ACI 301, Article 3.5):

1.—Maximum slump for concrete is indicated on Drawings. Where field conditions require slump to exceed that shown, increased slump shall be obtained by use of superplasticizers only, and Contractor shall obtain written acceptance from Engineer who may require an adjustment to mix.

2.—All concrete containing high-range water-reducing admixture (superplasticizers) shall have 9+/– 1½ in. slump. Before permission for plant addition of superplasticizers to be granted by Engineer, fulfill following requirements:

a.—Submit letter from testing laboratory which developed original mix design(s), for each superplasticized mix design, certifying volume of mix water which will produce specified slump and water/cement ratio, taking into account aggregate moisture content.

b.—Submit plant computer printout of mix contents for each truckload of superplasticized concrete with delivery of that truckload. Mix water volume greater than that certified shall be cause for concrete rejection.

c.—Over retarding or crusting of flatwork surface shall be cause for concrete rejection.

d.—Segregation or too short superplasticizer life due to superplasticizer type or underdosing shall be cause for concrete rejection.

I.—Shrinkage (Length Change):

1.—Determine length change of hardened concrete test specimens in accordance with ASTM C157, except as noted in paragraph below. Existing test data from previous project may be acceptable.

2.—Test specimens shall be moist cured, including period in molds for 7 days. Then store specimens **in air** for period of 28 days.

3.—Utilize concrete materials and mix proportions submitted, for use in floor slab and beam, in accordance with Part 1 Article "Submittals."

4.—Report length change of specimens after periods of air drying after curing of 4, 7, 14, 21 and 28 days.

5.—Average length change at 28 days shall be limited to 0.04%, unless otherwise accepted by Engineer.

J.—Engineer's acceptance of mix design shall not relieve Contractor from responsibility for any variation from requirements of Contract Documents unless Contractor has in writing called Engineer's attention to each such variation at time of submission and Engineer has given written approval of each such variation.

K.—Adjustment to Concrete Mixes: Mix design adjustments may be requested by Contractor when characteristics of materials, job conditions, weather, test results, or other circumstances warrant, as accepted by Engineer. Laboratory test data for revised mix design and strength results must be submitted to and accepted by Engineer before using in work.

2.6 ADMIXTURES

A.—Use water-reducing admixture or high-range water-reducing admixture (superplasticizer) in concrete as required for placement and workability.

B.—Use nonchloride accelerating admixture in concrete slabs placed at ambient temperatures below 50 deg. F.

C.—Use high-range water-reducing admixture (HRWR) in pumped concrete, concrete for concrete with water/cement ratios below 0.50.

D.—Use air-entraining admixture in exterior exposed concrete unless otherwise indicated. Add air-entraining admixture at manufacturer's prescribed rate to result in concrete at point of placement having total air content with a tolerance of +/− 1½% within limits shown on Drawings.

E.—Only admixture manufacturers listed shall be acceptable. Do not submit alternate manufacturers.

F.—Concrete supplier and manufacturer shall certify compatibility of all ingredients in each mix design. Use admixtures in strict accordance with manufacturer's recommendations.

G.—Prohibited Admixtures: Calcium chloride or admixtures containing more than 0.05% chloride ions, by weight of admixture, are *not* permitted. Additionally, each admixture shall not contribute more than 5 ppm, by weight, of chloride ions to total concrete constituents.

H.—Air-Entraining Admixture: ASTM C 260, certified by manufacturer to be compatible with other required admixtures.

1.—Products: Subject to compliance with requirements, provide one of the following:

a.—"Air-Mix," or "AEA-92," Euclid Chemical Co.

b.—"Micro-Air" or MB-VR," Master Builders, Inc.

c.—"Daravair 1000," "Darex," or "Darex II AEA" (in Florida), W. R. Grace & Co.

I.—Water-Reducing Admixture: ASTM C 494, Type A.

1.—Products: Subject to compliance with requirements, provide one of the following:

a.—"Eucon WR-75," Euclid Chemical Co.

b.—"Pozzolith 322N," Master Builders.

c.—"Daracem 55," "WRDA with Hycol," or "WRDA-79" (in Florida), W. R. Grace & Co.

J.—High-Range Water-Reducing Admixture (Superplasticizer): ASTM C 494, Type F.

1.—Products: Subject to compliance with requirements, provide one of the following:

a.—"Eucon 37," Euclid Chemical Co.

b.—"Rheobuild 1000," Master Builders, Inc.

c.—"WRDA 19," W. R. Grace & Co.

K.—High-Range Water-Reducing, Retarding (superplasticizer), ASTM C 494, Type G:

1.—Products: Subject to compliance with requirements, provide one of the following:

a.—"Eucon 537," Euclid Chemical Co.

b.—"Rheobuild 716," Master Builders.

c.—"Daracem 100," W. R. Grace & Co.

L.—Water-Reducing, Accelerating Admixture: ASTM C 494, Type E.

1.—Products: Subject to compliance with requirements, provide one of the following:
a.—"Accelguard 80," Euclid Chemical Co.
b.—"Pozzutec 20," Master Builders.
c.—"Polaraset," W. R. Grace & Co.

M.—Water-Reducing, Retarding Admixture: ASTM C 494, Type D.
1.—Products: Subject to compliance with requirements, provide one of the following:
a.—"Eucon Retarder-75," Euclid Chemical Co.
b.—"Pozzolith 100XR," Master Builders.
c.—"Daratard-17," W. R. Grace & Co.

N.—Corrosion Inhibiting Admixture:
1.—Products: Subject to compliance with requirements, provide one of the following:
a.—Acceptable material: "DCI," W. R. Grace.
b.—Add at rate of 3 gal/cu yd of concrete.
c.—Show DCI as an Add Alternate on Bid Form.

2.7 CONCRETE MIXING

A.—Provide batch ticket for each batch discharged and used in work, indicating project identification name and number, date, mix type, mix time, quantity, and amount of water introduced.

B.—Ready-Mix Concrete: Comply with requirements of ASTM C 94, and as specified.
1.—When air temperature is between 85 deg. F and 90 deg. F, reduce mixing and delivery time from 1½ hours to 75 minutes, and when air temperature is above 90 deg. F, reduce mixing and delivery time to 60 minutes.

2.8 TOOLS

A.—For tooled joints in concrete, use:
1.—"Goldblatt Groover #06-314-M7," Goldblatt Tool Co., 511 Osage, Kansas City, KS 66105.

PART 3 EXECUTION

3.1 GENERAL

A.—Coordinate installation of joint materials and vapor retarders with placement of forms and reinforcing steel.

3.2 FORMS

A.—General: Design, erect, support, brace, and maintain formwork to support vertical and lateral, static and dynamic loads that might be applied until concrete structure can support such loads. Construct formwork so that concrete members and structures are of correct size, shape, alignment, elevation, and position. Maintain formwork construction tolerances complying with paragraph "Formwork Tolerances" and ACI 347.

B.—Construct forms to sizes, shapes, lines, and dimensions shown and to obtain accurate alignment, location, grades, level, and plumb work in finished structures. Provide for openings, offsets, sinkages, keyways, recesses, moldings, rustications, reglets, chamfers, blocking, screeds, bulkheads, anchorages, inserts, and other features required in work. Use selected materials to obtain required finishes. Solidly butt joints and provide backup at joints to prevent leakage of cement paste.

C.—Fabricate forms for easy removal without hammering or prying against concrete surfaces. Provide crush plates or wrecking plates where stripping may damage cast concrete surfaces. Provide top forms for inclined surfaces where slope is too steep to place concrete with bottom forms only. Kerf wood inserts for forming keyways, reglets, recesses, and the like, for easy removal.

D.—Provide temporary openings where interior area of formwork is inaccessible for cleanout, for inspection before concrete placement, and for placement of concrete. Securely brace temporary openings and set tightly to forms to prevent loss of concrete mortar. Locate temporary openings in forms at inconspicuous locations.

E.—Chamfer exposed corners and edges as indicated, using wood, metal, PVC, or rubber chamfer strips fabricated to produce uniform smooth lines and tight edge joints.

F.—Provisions for Other Trades: Provide openings in concrete formwork to accommodate work of other trades. Determine size and location of openings, recesses, and chases from trades providing such items. Accurately place and securely support items built into forms.

G.—Cleaning and Tightening: Thoroughly clean forms and adjacent surfaces to receive concrete. Remove chips, wood, sawdust, dirt, or other debris just before concrete is placed. Retighten forms and bracing before concrete placement as required to prevent mortar leaks and maintain proper alignment.

H.—Set edge forms or bulkheads and intermediate screed strips for slabs to obtain required elevations and contours in finished slab surface. Provide and secure units sufficiently strong to support types of screed strips by use of strike-off templates or accepted compacting type screeds.

3.3 PREPARATION OF FORM SURFACES

A.—Coat contact surfaces of forms with accepted, nonresidual, low-VOC form-coating compound before reinforcement is placed.

B.—Thin form-coating compounds only with thinning agent of type, and in amount, and under conditions of form-coating compound manufacturer's directions. Do not allow excess form-coating material to accumulate in forms or to come into contact with concrete surfaces against which fresh concrete will be placed. Apply in compliance with manufacturer's instructions.

C.—Coat steel forms with nonstaining, rust-preventive form oil or otherwise protect against rusting. Rust-stained steel formwork not acceptable.

3.4 SHORES, RESHORING, AND SUPPORTS

A.—Comply with ACI 301 and ACI 347 for shoring and reshoring in multistory construction, except as modified in this Section.

B.—Extend shoring and reshoring from ground to roof for structures 4 stories (3 supported levels) or less, unless otherwise permitted.

C.—Extend shoring and reshoring at least 3 floors under floor or roof being placed for structures over 4 stories (3 supported levels). Shore floor directly under floor or roof being placed, so that loads from construction above will transfer directly to these shores. Space shoring in stories below this level in such manner that no floor or member will be excessively loaded or will induce tensile stress in concrete members where no reinforcing steel is provided. Extend shores beyond minimums to ensure proper distribution of loads throughout structure.

D.—Remove shores and reshore in planned sequence to avoid damage to partially cured concrete. Locate and provide adequate reshoring to safely support Work without excessive stress or deflection.

E.—Keep reshores in place as required until heavy loads due to construction operations have been removed.

3.5 REMOVAL OF FORMS

A.—Formwork not supporting weight of concrete, such as sides of beams, walls, columns, and similar parts of Work, may be removed after cumulatively curing at not less than 50 degrees F. for 24 hours after placing concrete, provided concrete is sufficiently hard to not be damaged by form removal operations, and provided curing and protection operations are maintained.

B.—Beam soffits, slabs, and other members that support weight of concrete:

1.—For posttensioned concrete, formwork shall remain in place until posttensioning has been completed. Do not place additional loads on structure until concrete has been properly reshored.

2.—For non-post-tensioned concrete, formwork shall remain in place until concrete has reached minimum ⅔ of 28-day strength. Do not place additional loads on structure until concrete has been properly reshored.

C.—Determine potential compressive strength of in-place concrete by testing field-cured specimens representative of concrete location or members.

D.—Form facing material may be removed 4 days after placement, only if shores and other vertical supports have been arranged to permit removal of form facing material without loosening or disturbing shores and supports.

3.6 RE-USE OF FORMS

A.—Clean and repair surfaces of forms to be re-used in Work. Split, frayed, delaminated or otherwise damaged form facing material will not be acceptable for exposed surfaces. Apply new form coating compound as specified for new formwork.

B.—When forms are extended for successive concrete placement, thoroughly clean surfaces, remove fins and laitance, and tighten forms to close joints. Align and secure joint to avoid offsets. Do not use "patched" forms for exposed concrete surfaces, except as acceptable to Engineer.

3.7 FORMWORK TOLERANCES

A.—General: Comply with tolerances for formed surfaces as defined in ACI 301, Chapter 4, except as modified in this Section.

B.—Drilled Pier Caps and Pile Caps:

- **1.**—Variation of center from specified plan location: ½ in.
- **2.**—Variation of bearing surface from specified location: Plus or minus ½ in.
- **3.**—Variation from specified dimensions in plan: Plus 2 in. minus 0 in.
- **4.**—Variation decrease from specified thickness: ½ in.

C.—Footings:

- **1.**—Footings other than those to receive masonry construction: Variation of bearing surface from specified elevation: Plus or minus ½ in.
- **2.**—Footings to Receive Masonry Construction:
  - **a.**—Variation of center from specified location in plan: Plus or minus ¼ in. in any 10 ft but not to exceed plus or minus ½ in.
  - **b.**—Variation of bearing surface from specified elevation: Plus

or minus ¼ in. in any 10 ft but not to exceed plus or minus ½ in.

D.—Piers, Columns, Walls, Beams, and Slabs:

1.—Variation in cross-sectional dimensions of piers, beams, and columns and in thickness of walls and slabs: 12 in. or less: Plus ⅜ in., minus ¼ in. Greater than 12 in.: Plus ½ in., minus ⅜ in.

2.—Variation in elevation from specified elevation for piers, columns, and walls: Plus or minus ½ in.

E.—Permissible variations from plumb and designated building lines for portions of buildings more than 100 feet above ground: ______.

3.8 VAPOR RETARDER/BARRIER INSTALLATION

A.—General: Following leveling and tamping of granular base for slabs on grade, place vapor retarder/barrier sheeting with longest dimension parallel with direction of pour.

B.—Lap joints 6 in. and seal vapor barrier joints with manufacturers' recommended mastic and pressure-sensitive tape.

C.—After placement of vapor retarder/barrier, cover with sand cushion and compact to depth as shown on Drawings.

3.9 PLACING REINFORCEMENT

A.—General: Comply with Concrete Reinforcing Steel Institute's recommended practice for "Placing Reinforcing Bars" for details and methods of reinforcement placement and supports and as herein specified.

1.—Avoid cutting or puncturing vapor retarder during reinforcement placement and concreting operations.

B.—Examine conditions under which concrete reinforcement is to be placed, and immediately notify Engineer in writing of unsatisfactory conditions. Do not proceed with Work until unsatisfactory conditions have been corrected in acceptable manner.

C.—Clean reinforcement of loose rust and mill scale, earth, ice, and other materials that reduce or destroy bond with concrete.

D.—Fabricate reinforcement to conform to required shapes and dimensions, with fabrication tolerances complying with CRSI MSP. In case of fabricating errors, do not re-bend or straighten reinforcement in manner that will injure or weaken material.

E.—Bends in reinforcement are standard 90 degree bends unless noted otherwise.

F.—Reinforcement with any of following defects will be rejected:

1.—Lengths, depths, and bends exceeding CRSI fabrication tolerances.

2.—Bends or kinks not indicated on Drawings or final Shop Drawings.

3.—Reduced cross-section due to excessive rusting or other cause.

G.—Perform all welding of mild steel reinforcement, metal inserts, and connections with low hydrogen welding electrodes in accordance with AWS D1.4.

H.—Epoxy coated reinforcement: Fabricator and applicator to provide installer with written instructions to handle, store, and place epoxy coated reinforcement to prevent damage to coating.

I.—Comply with ACI 301, Chapter 5 for placing reinforcement.

J.—Use rebar chairs and accessories to hold all reinforcing positively in place. Provide rebar chairs at all formed surfaces, both vertical and horizontal, to maintain minimum specified cover. Set wire ties so ends are directed into concrete, not toward exposed concrete surfaces. Maximum spacing of chairs and accessories shall be per CRSI Manual of Standard Practice. In situations not covered by CRSI, provide support at 4 ft on center maximum each way.

K.—Install welded wire fabric in as long lengths as practicable. Lap adjoining pieces at least one full mesh and lace splices with wire. Offset laps of adjoining widths to prevent continuous laps in either direction.

L.—Splices:

- **1.**—Provide standard reinforcement splices by lapping ends, placing bars in contact, and tying tightly with wire. Comply with requirements of ACI 318 for minimum lap of spliced bars.
- **2.**—For mechanical tension splices of reinforcement:
  - **a.**—Column bar lengths shall not exceed 30 ft between splices. In any bar, no splices shall occur at any floor level.
  - **b.**—Exercise care to assure that no reduction of cross-sectional area of reinforcement occurs.
  - **c.**—Use Barsplice Products, Inc., Bar-Grip or Grip-Twist, NMB Splice Sleeve, or Erico LENTON splices.
  - **d.**—For all mechanical splices, perform splicing in strict accordance with manufacturer's requirements and instructions.
  - **e.**—All splices to develop 125% of specified yield strength of bars, or of smaller bar in transition splices.
  - **f.**—Stagger splices in adjacent bars.
  - **g.**—Except where shown on Drawings, welding of reinforcement prohibited without prior written authorization by Engineer.
- **3.**—Compression splices: Mechanically coupled splices in accordance with ACI 318, Chapter 12.

M.—Epoxy Coated Reinforcement:

- **1.**—Rest epoxy coated steel members supported from formwork on coated wire bar supports, or on bar supports made of dielectric material or other suitable material.
- **2.**—Coat wire bar supports with dielectric material for minimum distance of 2 in. from point of contact with coated steel member.
- **3.**—Fasten epoxy-coated steel members with nylon-, epoxy-, or plastic-coated tie wire, or other suitable material acceptable to Engineer.
- **4.**—Mechanical connections, when required, shall be installed in

accordance with splice device manufacturer's recommendations. Repair any damage to coating.

5.—All parts of mechanical connections on epoxy-coated steel, including steel splice sleeves, bolts, and nuts shall be coated with same material used for repair of coating damage.

6.—Do not cut epoxy-coated steel unless permitted by Engineer. When cut, coat ends with material used for repair of coating damage.

7.—All welding of epoxy-coated steel shall conform to AWS D1.4.

8.—Adequate ventilation shall be provided when welding epoxy-coated steel.

9.—After welding, repair coating damage as specified in Part 3 heading "Quality Control Testing During Construction," paragraph "Epoxy Coated Material."

3.10 JOINTS

A.—Joints in Concrete (ACI 301, Chapter 6):

1.—Construction, control and isolation joints are located and detailed on Drawings:

a.—Tool joints at time of finishing. Tool: Part 2 Article "Tools." Sawcut joints prohibited.

b.—Isolation joints: interrupt structural continuity resulting from bond, reinforcement or keyway.

c.—Construction and control joints in walls: Space joints at 20 ft on center unless smaller spacing is shown on Drawings.

d.—Construction or control joints in floor slabs on grade: Maximum slab area controlled by jointing 600 sq ft. Space joints at twenty ft on center maximum unless different spacing is shown on Drawings.

e.—Coordinate configuration of tooled joints with control joint sealants.

B.—Provide keyways at least 1½ in. deep in construction joints in walls and slabs and between walls and footings. Accepted bulkheads designed for this purpose may be used for slabs.

C.—Place construction joints perpendicular to main reinforcement. Continue reinforcement across construction joints except as otherwise indicated. Do not continue reinforcement through sides of strip placements.

D.—Use bonding agent on existing concrete surfaces that will be joined with fresh concrete.

E.—Waterstops: Provide waterstops in construction joints as indicated. Install waterstops to form continuous diaphragm in each joint. Make provisions to support and protect exposed waterstops during progress of work. Field-fabricate joints in waterstops in accordance with manufacturer's printed instructions.

F.—Isolation Joints in Slabs-on-Ground: Construct isolation joints in slabs-on-ground at points of contact between slabs-on-ground and vertical surfaces, such as column pedestals, foundation walls, grade beams, and elsewhere as indicated.

1.—Joint filler and sealant materials are specified in Division 7 Sections of these Specifications.

G.—Contraction (Control) Joints in Slabs-on-Ground: Construct contraction joints in slabs-on-ground to form panels of patterns as shown.

1.—Tool contraction joints.

2.—If joint pattern not shown, provide joints not exceeding 15 ft in either direction and located to conform to bay spacing wherever possible (at column centerlines, half bays, third bays).

H.—Joint sealant material is specified in Division 7 Sections.

3.11 INSTALLATION OF EMBEDDED ITEMS

A.—General: Set and build into work anchorage devices and other embedded items required for other work that is attached to or supported by cast-in-place concrete. Use setting drawings, diagrams, instructions, and directions provided by suppliers of items to be attached thereto. Anchor bolts, unless specifically furnished by others, shall be furnished under this Section.

B.—Install reglets to receive top edge of foundation sheet waterproofing and to receive thru-wall flashings in outer face of concrete frame at exterior walls, where flashing is shown at lintels, relieving angles, and other conditions.

C.—Forms for Slabs: Set edge forms, bulkheads, and intermediate screed strips for slabs to obtain required elevations and contours in finished surfaces. Provide and secure units to support screed strips using strike-off templates or compacting-type screeds.

D.—Contractor shall be responsible for controlling proper placing of all embedded pipe, conduit, and other fixtures. ACI 318, Article 6.3, shall apply to all cases of embedded fixtures.

E.—Use suitable templates to accurately set and support against displacement andetilt all bolts, inserts, sleeves, or other embedded items.

F.—Cast anchor bolts in top of cast-in-place concrete columns for light standards. Templates and anchor bolts shall be supplied by light standard manufacturer.

G.—Anchor Bolt Tolerances:

1.—Make template for anchor bolt group.

2.—Template tolerance for bolt group for specified location in plan: plus or minus ¼ in.

3.—Tolerance for individual bolt within group: plus or minus 1⁄16 in.

4.—Variation from specified elevation: plus or minus ¼ in.

H.—Sleeve Tolerances:

1.—Variation from specified location in plan: Plus or minus ¼ in.

2.—Variation from specified elevation: Plus or minus ¼ in.

3.12 CONCRETE PLACEMENT

A.—Inspection: Before placing concrete, inspect and complete formwork installation, reinforcing steel, and items to be embedded or cast in. Notify other crafts to permit installation of their work; cooperate with other trades in setting such work.

B.—General: Comply with ACI 304, "Recommended Practice for Measuring, Mixing, Transporting, and Placing Concrete," and as herein specified.

C.—Install, secure and clean all forms, concrete reinforcement, embedded items and related items before placing concrete.

D.—Do not place concrete against frozen ground.

E.—Receive Engineer's written acceptance of finish used on flatwork in parking and drive areas before beginning slab construction.

F.—Contractor shall have sufficient protective covering available at all times during placement operations to protect fresh concrete surface from rain damage.

G.—Temperature of concrete as placed shall not exceed 90° F. Costs for precautionary measures required by Engineer shall be borne by Contractor.

H.—Deposit concrete continuously or in layers of such thickness that no concrete will be placed on concrete that has hardened sufficiently to cause the formation of seams or planes of weakness. If a section cannot be placed continuously, provide construction joints as herein specified. Deposit concrete to avoid segregation at its final location.

I.—Placing Concrete in Forms: Deposit concrete in forms in horizontal layers not deeper than 24 in. and in a manner to avoid inclined construction joints. Where placement consists of several layers, place each layer while preceding layer is still plastic to avoid cold joints.

1.—Consolidate placed concrete by mechanical vibrating equipment supplemented by hand-spading, rodding, or tamping. Use equipment and procedures for consolidation of concrete in accordance with ACI 309.

2.—Do not use vibrators to transport concrete inside forms. Insert and withdraw vibrators vertically at uniformly spaced locations not farther than visible effectiveness of machine. Place vibrators to rapidly penetrate placed layer and at least 6 in. into preceding layer. Do not insert vibrators into lower layers of concrete that have begun to set. At each insertion limit duration of vibration to time necessary to consolidate concrete and complete embedment of reinforcement and other embedded items without causing segregation of mix.

J.—Placing Concrete Slabs: Deposit and consolidate concrete slabs in a continuous operation within limits of construction joints, until the placing of a panel or section is completed.

1.—Consolidate concrete during placing operations so that concrete is thoroughly worked around reinforcement and other embedded items and into corners.

2.—Bring slab surfaces to correct level with straightedge and strike off. Use bull floats or darbies to smooth surface, free of humps or hollows. Do not disturb slab surfaces prior to beginning finishing operations.

3.—Maintain reinforcing in proper position during concrete placement.

K.—Cold-Weather Placing: Comply with provisions of ACI 306 and as follows. Protect concrete work from physical damage or reduced strength that could be caused by frost, freezing actions, or low temperatures. Also see Part 3 Article "Concrete Curing and Protection," paragraph "Cold Weather Concreting."

L.—When air temperature has fallen to or is expected to fall below 40° F, uniformly heat water and aggregates before mixing to obtain a concrete mixture temperature of not less than 50° F and not more than 80° F at point of placement.

1.—Do not use frozen materials or materials containing ice or snow. Do not place concrete on frozen subgrade or on subgrade containing frozen materials.

2.—Do not use calcium chloride, salt, and other materials containing antifreeze agents or chemical accelerators unless otherwise accepted in mix designs.

M.—Hot-Weather Placing: When hot weather conditions exist that would seriously impair quality and strength of concrete, place concrete in compliance with ACI 305 and as herein specified.

1.—Cool ingredients before mixing to maintain concrete temperature at time of placement below 90° F. Mixing water may be chilled, or chopped ice may be used to control temperature provided water equivalent of ice is calculated to total amount of mixing water. Use of liquid nitrogen to cool concrete is Contractor's option.

2.—Cover reinforcing steel with water-soaked burlap if it becomes too hot, so that steel temperature will not exceed the ambient air temperature immediately before embedment in concrete.

3.—Fog spray forms, reinforcing steel, and subgrade just before concrete is placed.

4.—Use water-reducing retarding admixture when required by high temperatures, low humidity, or other adverse placing conditions acceptable to Engineer.

5.—Also see Part 3 Article "Concrete Curing and Protection," paragraph "Hot Weather Concreting."

3.13 FINISH OF FORMED SURFACES

A.—Rough Form Finish: For formed concrete surfaces not exposed to view in the finish work or concealed by other construction. This is the concrete surface having texture imparted by form-facing material used, with tie holes and defective areas repaired and patched and fins and other projections exceeding ¼ in. in height rubbed down or chipped off.

B.—Smooth Form Finish: For formed concrete surfaces exposed to view or to be covered with a coating material applied directly to concrete, or a covering material applied directly to concrete, such as waterproofing, dampproofing, veneer plaster, painting, or other similar system. This is an as-cast concrete surface obtained with selected form-facing material, arranged in an orderly and symmetrical manner with a minimum of seams. Repair and patch defective areas with fins and other projections completely removed and smoothed.

C.—Smooth Rubbed Finish: Provide smooth rubbed finish to scheduled concrete surfaces, which have received smooth form finish treatment, not later than one day after form removal.

  1.—Moisten concrete surfaces and rub with carborundum brick or other abrasive until a uniform color and texture is produced. Do not apply cement grout other than that created by the rubbing process.

D.—Grout-Cleaned Finish: Provide grout-cleaned finish to scheduled concrete surfaces that have received smooth form finish treatment.

  1.—Combine one part portland cement to 1½ parts fine sand by volume, and a 50:50 mixture of acrylic or styrene butadiene-based bonding admixture and water to consistency of thick paint. Blend standard portland cement and white portland cement, amounts determined by trial patches, so that final color of dry grout will match adjacent surfaces.

  2.—Thoroughly wet concrete surfaces, apply grout to coat surfaces, and fill small holes. Remove excess grout by scraping and rubbing with clean burlap. Keep damp by fog spray for at least 36 hours after rubbing.

E.—Other finishes: See Section "Special Concrete Finishes."

F.—Related Unformed Surfaces: At tops of walls, horizontal offsets, and similar unformed surfaces occurring adjacent to formed surfaces, strike-off smooth and finish with a texture matching adjacent formed surfaces. Continue final surface treatment of formed surfaces uniformly across adjacent unformed surfaces unless otherwise indicated.

3.14 MONOLITHIC SLAB FINISHES

A.—Flatwork in Parking and Drive Areas (BROOM Finish, ACI 301, 11.7.4):

  1.—Bullfloat immediately after screeding. Complete before any excess moisture or bleed water is present on surface (ACI 302.1R, Article 7.2.3).

  2.—After excess moisture or bleed water has disappeared and concrete has stiffened sufficiently to allow operation, give slab surfaces coarse transverse scored texture by drawing broom across surface. Texture shall be as accepted by Engineer from sample panels.

3.—Finishing tolerance: ACI 301, Paragraph 11.9: Class B tolerance. In addition, floor surface shall not vary more than +/–¾ in. from elevation noted on Drawings anywhere on floor surface.

4.—Before installation of flatwork and after submittal, review, and approval of concrete mix design, Contractor shall fabricate two acceptable test panels simulating finishing techniques and final appearance to be expected and used on Project. Test panels shall be minimum of 20 ft. by 30 ft. in area and shall be reinforced and cast to thickness of typical parking and drive area wearing surface in Project. (Maximum thickness of test panels need not exceed 6 in.) Test panels shall be cast from concrete supplied by similar concrete batch, both immediately after addition of superplasticizer or water-reducing admixture, and at maximum allowed time for use of admixture supplemented concrete in accordance with Specifications. Intent of test panels is to simulate both high and low workability mixes, with approximate slump at time of casting of test panels to be 6 in. and 3 in., respectively. Contractor shall finish panels following requirements of paragraphs above, and shall adjust finishing techniques to duplicate appearance of concrete surface of each panel. Finished panels (one or both) may be rejected by Engineer, in which case Contractor shall repeat procedure on rejected panel(s) until Engineer acceptance is obtained. Accepted test panels shall be cured in accordance with Specifications and may be incorporated into Project. Accepted test panels shall serve as basis for acceptance/rejection of final finished surfaces of all flatwork.

5.—Finish all concrete slabs to proper elevations to insure that all surface moisture will drain freely to floor drains, and that no puddle areas exist. Contractor shall bear cost of any corrections to provide for positive drainage.

B.—Flatwork in Stairtowers and Enclosed, Finished Areas (Floated Finish, ACI 301, 11.7.2):

1.—Give slab floated finish. Texture shall be as accepted by Engineer from sample panels.

2.—Finishing tolerance: ACI 301, Paragraph 11.9: Class A tolerance. In addition, floor surface shall not vary more than +/– ⅜ in. from elevation noted on Drawings anywhere on floor surface.

3.15 CONCRETE CURING AND PROTECTION

A.—General: Protect freshly placed concrete from premature drying, mechanical injury, and excessive cold or hot temperatures. In hot, dry, and windy weather, protect concrete from rapid moisture loss before and during finishing operations with an evaporation-control material. Apply in accordance with manufacturer's instructions after screeding and bull floating, but before power floating and troweling.

B.—Start initial curing as soon as free water has disappeared from concrete surface after placing and finishing. Weather permitting, keep continuously moist for not less than 7 days.

C.—Curing Methods: Perform curing of concrete by moist curing, by moisture-retaining cover curing, by curing compound, and by combinations thereof, as herein specified.

D.—Provide moisture curing by following methods for all slabs-on-grade, supported slabs, and concrete toppings. Curing compounds PROHIBITED.

- **1.**—Keep concrete surface continuously wet by covering with water.
- **2.**—Use continuous water-fog spray.
- **3.**—Cover concrete surface with specified absorptive cover, thoroughly saturate cover with water, and keep continuously wet. Place absorptive cover to provide coverage of concrete surfaces and edges, with 4-inch lap over adjacent absorptive covers.
- **4.**—Cover concrete surfaces with moisture-retaining cover for curing concrete, placed in widest practicable width with sides and ends lapped at least 3 in. and sealed by waterproof tape or adhesive. Immediately repair any holes or tears during curing period using cover material and waterproof tape.

E.—Provide curing compound for concrete not included in paragraph "Provide moisture curing. . ." as follows:

- **1.**—Apply specified curing compound to concrete slabs as soon as final finishing operations are complete (within 2 hours and after surface water sheen has disappeared). Apply uniformly in continuous operation by power spray or roller in accordance with manufacturer's directions. Recoat areas subjected to heavy rainfall within 3 hours after initial application. Maintain continuity of coating and repair damage during curing period.
- **2.**—Use membrane curing compounds that will not affect surfaces to be covered with finish materials applied directly to concrete.
- **3.**—Apply curing compound at rate equivalent to rate of application at which curing compound was originally tested for conformance to requirements of ASTM C 309.
- **4.**—Use curing compound compatible with and applied under direction of system manufacturer of protective sealer and traffic topping.
- **5.**—All concrete must achieve 4000 psi compressive strength before being subjected to freezing and thawing cycles.
- **6.**—Apply two separate coats with first allowed to become tacky before applying second. Direction of second application shall be at right angles to direction of first.

F.—Curing Formed Surfaces: Cure formed concrete surfaces, including underside of beams, supported slabs, and other similar surfaces, by moist curing with forms in place for full curing period or until forms are removed. If forms are removed, continue curing by methods specified above, as applicable.

G.—Cold Weather Concreting (ACI 306R):

1.—hen concrete is placed under conditions of cold weather concreting (defined as period when average daily temperature drops below 40 degrees F. for more than three successive days or the air temperature is not greater than 50 degrees F. for more than one-half of any 24-hour period), take additional precautions as specified in this Section and in ACI 306R, when placing, curing, monitoring, and protecting fresh concrete.

2.—Warm mix water, sand and aggregate so that no frozen lumps of ice, snow or aggregate will survive mixing but do not overheat ingredients to cause flash setting of concrete or loss of entrained air.

3.—Place and maintain internal concrete temperature as near to minimums given in following table:

Least Dimension of the Member	Minimum internal concrete temperature as placed and maintained:
Less than 12 in.	55°F.
12 to 36 in.	50°F.
36 to 72 in.	45°F.
Greater than 72 in.	40°F.

Do not exceed given minimum placement temperature by more than 20 degrees F.

4.—Begin protection and curing of concrete immediately after placement to maintain internal temperature of concrete at 50 degrees F. or above (but not to exceed 75 degrees F.) throughout curing process operation:

a.—Cure slabs on grade, foundations, and substructures other than grade beams not subject to early loading, at placement temperature for 2 days minimum.

b.—Temporary heaters used to maintain temperature of air surrounding exposed, uncured concrete during curing operations shall be vented type, vented to outside of protection envelope.

c.—Before placing concrete topping, structure upon which topping is to be placed shall be preheated to placement temperature of topping.

d.—Cure and protect concrete for supported slabs, beams, columns and bumper walls at temperature specified above until attainment of 75 percent design strength, but no less than 4000 psi 28 day strength.

e.—Cure and protect concrete topping on precast concrete until (5000 psi 28 day strength reached). (4000 psi 28 day strength reached.).

f.—Determine strength of curing concrete by either of following methods:

1)—Calculate maturity factor based upon curing time and measured internal concrete temperature as described in ACI 306R, Chapter 7.

2)—Cast and field cure at least six test specimens from last 100 cu yd of concrete but not fewer than three specimens for each two hours of entire placing time or for each 100 cu yd, whichever yields greatest number of specimens. Make specimens in accordance with ASTM C31. Cover specimens properly, immediately after finishing. Protect outside surfaces of cardboard molds, if used, from contact with sources of water for first 24 hours after molding. Field cure test specimens on structure as near to point of sampling as possible and protect from elements in same manner as that given to portion of structure specimen represents. Test cylinders in accordance with ASTM C31 and C39.

5.—Cast expendable thermistors or thermocouples in concrete at rate of at least one per 100 cubic yards of concrete placed for supported structure. Monitor internal temperature of concrete at twelve hour maximum intervals throughout curing process.

6.—During curing operation, maintain temperature of placed concrete as constant as possible, and protect from rapid atmospheric temperature changes.

7.—Maintain concrete in continually moist condition during curing process by leaving forms in place as long as possible and by use of steam or moisture retaining covers on unformed surfaces.

8.—Following curing operation, avoid rapid changes in concrete temperature. Do not allow internal temperature of concrete to change at rate exceeding 50 degrees F. in any 24-hour period or 5 degrees F. in any one hour.

H.—Hot Weather Concreting (ACI 305R):

1.—When concrete is placed under conditions of hot weather concreting, Contractor shall provide extra protection of concrete against excessive placement temperatures and excessive drying throughout placing and curing operations. Hot weather is defined as any combination of high temperature, low humidity and high wind velocity which causes rate of evaporation in excess of 0.2 lb per sq ft per hour as determined by ACI 305R, Figure 2.1.5.

2.—Forms, reinforcement, subgrade and air shall be cooled by water fog spraying immediately before placing concrete. Placement temperature of concrete shall not exceed 90 degrees F.

3.—Protect concrete during finishing operations by continuous fog spray between finishing operations.

4.—Immediately following screeding, apply specified evaporation retarding agent in accordance with recommendations of manufacturer. Plastic cracking conditions may require application of compound several times during concrete finishing sequence.

5.—During curing operation cover concrete with wet burlap or cotton mats. Keep mats constantly wet for 7 days minimum. Leave mats in place for 3 additional days after discontinuing wetting process.

3.16 MISCELLANEOUS CONCRETE ITEMS

A.—Filling In: Fill in holes and openings left in concrete structures for passage of work by other trades, unless otherwise shown or directed, after work of other trades is in place. Mix, place, and cure concrete as herein specified, to blend with in-place construction. Provide other miscellaneous concrete filling shown or required to complete work.

B.—Curbs: Provide monolithic finish to interior curbs by stripping forms while concrete is still green and steel-troweling surfaces to a hard, dense finish with corners, intersections, and terminations slightly rounded.

C.—Steel Pan Stairs: Provide concrete fill for steel pan stair treads and landings and associated items. Cast-in safety inserts and accessories as shown on drawings. Screed, tamp, and finish concrete surfaces as scheduled.

3.17 CONCRETE SURFACE REPAIRS (ACI 301, CHAPTER 9)

A.—Patching Defective Areas: Repair and patch defective areas with cement mortar immediately after removal of forms, when acceptable to Engineer.

1.—Cut out honeycomb, rock pockets, voids over ¼ in. in any dimension, and holes left by tie rods and bolts, down to solid concrete but in no case to a depth of less than 1 in. Make edges of cuts perpendicular to the concrete surface. Thoroughly clean, dampen with water, and brush-coat the area to be patched with specified bonding agent. Place patching mortar before bonding compound has dried.

2.—For exposed-to-view surfaces, blend white portland cement and standard portland cement so that, when dry, patching mortar will match color surrounding. Provide test areas at inconspicuous location to verify mixture and color match before proceeding with patching. Compact mortar in place and strike-off slightly higher than surrounding surface.

B.—Repair of Formed Surfaces: Remove and replace concrete having defective surfaces if defects cannot be repaired to satisfaction of Engineer. Surface defects, as such, include color and texture irregularities, cracks, spalls, air bubbles, honeycomb, rock pockets, fins and other projections on surface, and stains and other discolorations that cannot be removed by cleaning. Flush out form tie holes, fill with dry-pack mortar, or precast cement cone plugs secured in place with bonding agent.

1.—Repair concealed formed surfaces, where possible, that contain defects that affect the durability of concrete. If defects cannot be repaired, remove and replace concrete.

C.—Repair of Unformed Surfaces: Test unformed surfaces, such as monolithic slabs, for smoothness and verify surface plane to tolerances specified for each surface and finish. Correct low and high areas as herein specified. Test unformed surfaces sloped to drain for trueness of slope and smoothness by using a template having required slope.

1.—Repair finished unformed surfaces that contain defects that affect durability of concrete. Surface defects, as such, include crazing and cracks in excess of 0.01 in. wide or that penetrate to reinforcement or completely through nonreinforced sections regardless of width, spalling, popouts, honeycomb, rock pockets, and other objectionable conditions.

2.—Correct high areas in unformed surfaces by grinding after concrete has cured at least 14 days.

3.—Correct low areas in unformed surfaces during or immediately after completion of surface finishing operations by cutting out low areas and replacing with patching compound. Finish repaired areas to blend into adjacent concrete. Proprietary underlayment compounds may be used when acceptable to Engineer.

4.—Repair defective areas, except random cracks and single holes not exceeding 1 inch in diameter, by cutting out and replacing with fresh concrete. Remove defective areas to sound concrete with clean, square cuts and expose reinforcing steel with at least ¾-in. clearance all around. Dampen concrete surfaces in contact with patching concrete and apply bonding compound. Mix patching concrete of same materials to provide concrete of same type or class as original concrete. Place, compact, and finish to blend with adjacent finished concrete. Cure in same manner as adjacent concrete.

D.—Repair isolated random slab cracks and single holes not over 1 in. in diameter in accordance with procedures and materials specified in

Division 7 Section "Waterproofing System." Receive Engineer's written acceptance of methods and materials selected prior to application.

E.—Perform structural repairs with prior approval of Engineer for method and procedure, using specified epoxy adhesive and mortar.

F.—Repair methods not specified above may be used, subject to acceptance of Engineer.

3.18 QUALITY CONTROL TESTING DURING CONSTRUCTION

A.—General: Owner will employ a testing laboratory to perform tests and to submit test reports.

B.—Epoxy Coated Material:

- **1.**—Perform field inspection of installed epoxy coated material under provisions of Division 1 Section "Quality Control."
- **2.**—Repair all epoxy coating damage due to fabrication and handling.
- **3.**—Repair all damaged areas using manufacturer's recommended patching material and method.
- **4.**—No damaged area shall be left uncorrected.
- **5.**—Epoxy coated welded wire fabric with consistent visible holes in epoxy coating (particularly at mesh intersections): unacceptable. Remove from project.

C.—Air Content:

- **1.**—Sample freshly-mixed concrete at point of final placement in accordance with ASTM C 172 and conduct one air content test in accordance with ASTM C 231 or ASTM C 173 for each truck of ready-mix, air-entrained concrete delivered to Project.
- **2.**—Sample fresh concrete immediately following placement and screeding and conduct air content tests in accordance with ASTM C 231 or ASTM C 173 at rate of one for every 10 truck loads of ready-mix, air-entrained concrete delivered to Project.

D.—Concrete Compressive Strength:

- **1.**—Mold test cylinders in accordance with ASTM C 31 as follows:
  - **a.**—Take minimum of six cylinders (eight for post-tensioned cast-in-place concrete) for each 100 cu yd or fraction thereof, of each mix design of concrete placed in any one day.
  - **b.**—Additional cylinders shall be taken under conditions of cold weather concreting per Part 3 heading "Concrete Curing and Protection," paragraph "Cold Weather Concreting."
  - **c.**—At Contractor's option and cost, cylinders may be taken to verify concrete strength prior to form removal.
- **2.**—Sample plastic concrete for testing at point of final placement, in accordance with ASTM C 172. Engineer will select sampling locations which may include points where plastic concrete has already been screeded and floated. Sample concrete for test cylinders to be used for verification of concrete compressive strength

for post-tensioning as near as possible to actual tendon anchorages.

3.—Cover specimens properly, immediately after finishing. Protect outside surfaces of cardboard molds, if used, from contact with sources of water for first 24 hours after molding.

4.—Cure test cylinders per ASTM C 31 as follows:

a.—To verify compressive strength prior to post-tensioning or form removal or for additional test cylinders required due to cold weather concreting conditions:

1)—Store test specimens on structure as near to point of sampling as possible and protect from elements in same manner as that given to portion of structure as specimen represents.

2)—Transport to test laboratory no more than 4 hours before testing. Remove molds from specimens immediately before testing.

b.—To verify 28-day compressive strength:

1)—During first 24 hours after molding, store test specimens under conditions that maintain temperature immediately adjacent to specimens in range of 60 to 80 degrees F. and prevent loss of moisture from specimens.

2)—Remove test specimens from molds at end of 20 +/– 4 hours and store in moist condition at 73.4 +/– 3 degrees F. until moment of test. Laboratory moist rooms shall meet requirements of ASTM C511.

5.—Compression tests for non-prestressed concrete:

a.—Test 2 cylinders at 7 days.

b.—Test 2 cylinders at 28 days.

c.—Test 2 cylinders at 56 days for concrete strength requirement of 7000 psi or greater.

d.—Hold 2 cylinders in reserve for use as Engineer directs.

6.—Compression tests for post-tensioned concrete:

a.—Test 2 cylinders immediately before tensioning slabs and 2 cylinders before tensioning beams. Cylinders must be field cured in accordance with paragraph "Cure test cylinders per ASTM C 31. . .," subparagraph "To verify compressive strength prior to post-tensioning. . ."

b.—Test 2 cylinders at 28 days.

c.—Hold 2 cylinders in reserve for use as Engineer directs.

7.—Unless notified by Engineer, reserve cylinders may be discarded without being tested after 56 days.

E.—Slump Test:

1.—Conduct one slump test per truck load of ready mixed concrete delivered to Project at truck.

2.—When high-range water-reducing admixture (superplasticizer) is used, initial slump must be verified by Testing Agency.

3.19 EVALUATION AND ACCEPTANCE OF CONCRETE (ACI 301, CHAPTER 17 AND ACI 318, ARTICLE 4.7):

A.—Concrete compression tests will be evaluated by Engineer in accordance with ACI 301, Chapter 17. If number of tests conducted is inadequate for evaluation of concrete or test results for any type of concrete fail to meet specified strength requirements, core tests may be required as directed by Engineer. Air content and parameters of air-void system shall meet requirements of this Section.

B.—Core tests, when required, in accordance with ACI 301, Article 17.3.

C.—Should tested hardened concrete meet Specifications, Owner will pay for coring and testing of hardened concrete. Should tested hardened concrete not meet Specifications, Contractor shall pay for coring and testing of hardened concrete and for any corrective action required for unaccepted concrete.

3.20 ACCEPTANCE OF STRUCTURE (ACI 301, CHAPTER 18):

A.—Acceptance of completed concrete Work will be according to provisions of ACI 301, Chapter 18.

B.—Concrete rejected due to entrained air content below specified limit will be accepted if any of following conditions are met:

1.—ASTM C 457: Three concrete specimens tested in accordance with ASTM C457 meet air void parameters of Part 2 Article "Proportioning and Design of Mixes," paragraph "Air Entrainment," subparagraph "Hardened concrete. . ." (spacing factor of 0.008 in. and specific surface area of 600 $in.^2$ per cu in. of air void volume).

2.—ASTM C 457: Three concrete specimens tested shall meet air void parameters of concrete reported and approved by Engineer in Part 1 Article "Submittals," paragraph "Product data for proprietary submittals. . .," subparagraph "Contractor: submit concrete mix designs. . .," sub-subparagraph "Freeze-thaw resistance. . . ."

3.—ASTM C 666, Test Procedure A: Test three concrete specimens removed from structure. Concrete specimens tested shall have durability characteristics similar to that reported in Part 1 Article "Submittals," paragraph "Product data for proprietary submittals. . .," subparagraph "Contractor: submit concrete mix designs. . .," sub-subparagraph "Freeze-thaw resistance. . . ."

CONCRETE MIX DESIGN SUBMITTAL FORM

Submit separate form for each mix design

Project: ______________________ City: ______________________

General Contractor: ____

Mix Design No.: __________________ Concrete Grade: ____________

Use (Describe)[1]: ____

A. DESIGN MIX INFORMATION:

Based on Standard Deviation Analysis: ___ or Trial Mix Test Data: ___

Design Characteristics—Density: __________ pcf; Strength: _________ psi (28 day)

Slump: ___ in. required **BEFORE** adding superplasticizer

Slump: ___ in. required **AFTER** adding superplasticizer

Air: _________% specified

Materials:

Aggregates (size; type; source; gradation; specification):

Coarse: ____

Fine: ____

NOTE: Fill in all blank spaces. Use -0- (Zero) or N/A (Not Applicable) where appropriate. See "Design and Control of Concrete Mixtures," 13th Edition, by Portland Cement Association, for assistance in completing this form.

WALKER ACCEPTANCE STAMP:

[1]Footings, interior flatwork, columns, etc.

Mix # ______________________

Job Name ____________________

Other Materials:

	Type	Product-Manufacturer (Source)
Cement:	______________	____________________________
Flyash:	______________	____________________________
Other:	______________	____________________________

Admixtures:

Water Reducer: ____

Air Entraining Agent: ___________________________________

High Range Water Reducing Admixture (HRWR) (superplasticizer): ____

Non-Corrosive Accelerator: _______________________________

Other: ____

B. FINAL MIX DESIGN DATA:

MIX PROPORTIONS[2]		
	WEIGHT (LBS.)	ABSOLUTE VOL. (CU. FT.)
Cement		
Fine aggregate[3]		
Coarse aggregate[3]		
Water[4]		
Entrained Air		
Other		

[2]Proportions per cubic yard.
[3]Saturated surface dry weights.
[4]Includes free water contained in aggregates.

Mix # ____________________

Job Name ____________________

RATIOS	
Water[4]/Cementitious Materials	lb./lb. = __________
Fine Aggregate/Total Aggregate	lb./lb. = __________%

SPECIFIC GRAVITIES	
Fine Aggregate	
Coarse Aggregate	
Other	

ADMIXTURES	
HRWR ___ oz.	per 100# cement
Non-corrosive Accelerator ___ oz.	per 100# cement
W.R. ___ oz.	per #100 cement
A.E.A. ___ oz.	per #100 cement
___ oz.	per #100 cement

PLASTIC CONCRETE	
Initial Slump	___ in.
Final Slump	___ in.
Air Content	___ %
Unit Wet Wt.	___ pcf
Unit Dry Wt.	___ pcf

STANDARD DEVIATION ANALYSIS (if available from experience records):

Number of Test Cylinders Evaluated: ______

Standard Deviation: ______ Average fcr ______psi

Required average fcr must be greater than:

fcr = f′c + 1.34s = ______ and fcr = f′c + 2.33s − 500 = ______

(Refer to ACI 301 for increased deviation factor when less than 30 tests are available.)

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[4]Includes free water contained in aggregates.

Mix # ______________________

Job Name ___________________

C. LABORATORY TEST DATA (HARDENED CONCRETE):

COMPRESSIVE STRENGTH (use when std. dev. data not available)	
Age (Days)	**Compressive Strength**
7	
7	
7	
28	
28	
28	
28 day average compressive strength, fcr: ____________ psi	

Mix design proportioned to achieve fcr = f′c +1200* psi = _____ psi
*use 1400 psi for f′c > 5000 psi.

CHLORIDE ION CONTENT per AASHTO method T260: _______%

HARDENED AIR CONTENT per ASTM C457:

Air content _________% **Air void spacing factor** _________ **in.**

Specific surface _________ **in2/in3**

Remarks:

____

____

SHRINKAGE (Length Change, Average)

____________ % @ 4 days ____________ % @ 21 days

____________ % @ 7 days ____________ % @ 28 days

____________ % @ 14 days

Mix # ____________________

Job Name ____________________

D. REQUIRED ATTACHMENTS:

__________ Coarse aggregate grading report

__________ Fine aggregate grading report

__________ Concrete compressive strength data used for standard deviation calculations

__________ Chloride ion data and related calculations

__________ Admixture compatibility certification letter

__________ ASTM C 457

Main Plant Location ____________________

Miles from Project Site ____________________

Secondary or Backup Plant Location ____________________

Miles from Project Site ____________________

Submitted by:

Ready Mix Supplier:

My signature below certifies that I have read, understood, and will compy with the requirements of this Section.

Signature ____________________

Typed or Printed Name ____________________

Address ____________________

____

Phone Number ____________________

Date ____________________

APPENDIX 11-2: SECTION 03365

POSTTENSIONED CONCRETE

PART 1 GENERAL

1.1 RELATED DOCUMENTS

A.—Drawings and general provisions of Contract, including General and Supplementary Conditions and Division 1 Specification Sections apply to this Section.

1.2 SUMMARY

A.—In accordance with Contract Documents, provide all materials, labor, equipment, and supervision to fabricate and install all posttensioning Work. Support bars shall conform to Division 3 Section, "Cast-in-Place Concrete."

B.—Related work in other Sections related to Posttensioned Concrete:

1.—Division 3 Section "Cast-in-Place Concrete."

2.—Division 3 Section "Structural Precast Concrete–Plant Cast."

3.—Division 3 Section "Architectural Precast Concrete–Plant Cast."

1.3 SYSTEM DESCRIPTION

A.—Unbonded posttensioning system described here is intended to perform in corrosive environment without long-term corrosion or other distress. Posttensioning strand, couplers, intermediate and end anchorages shall be completely protected with watertight system. Tendon grease shall be as specified, with corrosion inhibitors. End anchors shall be protected against long-term corrosion. Posttensioning system is expected to function satisfactorily for forty years.

1.4 SUBMITTALS

A.—Make submittals in accordance with requirements of Division 1 and as specified in this Section.

B.—Because Work of Sections "Cast-in-Place Concrete" and "Posttensioned Concrete" are interdependent, Contractor shall have both suppliers review other's Shop Drawings and note any potential interferences. Contractor shall then review both Sections' Shop Drawings against each other and inform Engineer of any potential interferences.

C.—Shop Drawings: Include:

1.—Numbers and arrangement of posttensioning tendons.

2.—Methods of maintaining tendon alignment.

3.—Type of post-tensioning sheathing.

4.—Type and chemical analysis of grease.

5.—Type, material, and thickness of posttensioning sheathing repair tape.

6.—Detailing of anchorage devices.

7.—Other incidental features.

8.—Superintendent qualifications.

D.—Submit following information with Shop Drawing submittal:

1.—Sealed calculations, prepared under supervision of qualified, professional, legally registered structural engineer in state where Project is located, of losses due to anchorage seating, elastic shortening, creep, shrinkage, relaxation, friction, and wobble, used to determine tendon sizes and number. Friction and wobble coefficients shall be in accordance with PTI recommended values unless test data submitted to substantiate lower values.

2.—Posttensioning tendon and end anchorage sizes.

3.—Sample of concrete anchorage assembly.

E.—After review, Shop Drawings and data shall not be changed, nor shall construction operations be revised unless resubmitted for acceptance by Engineer. Engineer's review of details and construction operations will not relieve Contractor of responsibility for completing Work successfully in accordance with Specifications and within Contract Time.

F.—Submit following to Engineer for review before beginning construction:

1.—Posttensioning experience record of contractor who is to perform posttensioning Work.

2.—Certified mill test reports for each coil or pack of strand, containing, as a minimum, following test information:

a.—Heat number and identification.

b.—Standard chemical analysis for heat of steel.

c.—Ultimate tensile strength.

d.—Yield strength at 1% extension.

e.—Elongation at failure.

f.—Modulus of elasticity.

g.—Diameter and net area of strand.

h.—Type of material.

3.—Relaxation losses for low relaxation type material shall be based on relaxation tests of representative samples for period of 1000 hours, when tested at 70°F. and stressed initially to not less than 70% of minimum guaranteed breaking strength of strand. Tests shall be in accordance with ASTM E328, and ASTM A416.

4.—Evidence of satisfactory performance on similar projects in United States of America, if strand manufactured outside USA.

5.—Results of tests required by ACI 301, Article 15.2.3.

6.—Current certification of welders.

G.—Keep posttensioning records and submit to Engineer. Record on each report:
- **1.**—Calculated elongation, based upon elastic modulus and cross sectional area of tendons used.
- **2.**—Actual field elongation of each tendon.
- **3.**—Calculated gauge pressure and jacking force applied to each tendon.
- **4.**—Actual gauge pressures and jacking forces applied to each tendon.
- **5.**—Required concrete strength at time of jacking.
- **6.**—Actual concrete strength at time of jacking.
- **7.**—Range of allowable elongations for jacking force.
- **8.**—Jack and gauge identification numbers.

H.—Submit copies of actual field records to Engineer promptly upon completion of each member or slab tensioning run. At time of stressing first member of each type, check individual tendon to establish procedure for insuring uniform results.

I.—Certify that stressing process and records have been reviewed, and that forces specified have been provided.

J.—If it appears that design posttensioning stresses are not being attained, re-check may be ordered by Engineer.

K.—Do not cut or cover tendon ends until Contractor receives Engineer's written review of post-tensioning records.

1.5 REFERENCES

A.—American Concrete Institute (ACI):
- **1.**—ACI 301, "Specifications for Structural Concrete for Buildings."
- **2.**—ACI 318, "Building Code Requirements for Reinforced Concrete."
- **3.**—ACI 347, "Recommended Practice for Concrete Formwork."
- **4.**—ACI 423.3R, "Recommendations for Concrete Members Prestressed with Unbonded Tendons."

B.—American Society for Testing and Materials (ASTM):
- **1.**—ASTM A416, "Specification for Uncoated Seven-Wire Stress-Relieved Strand for Prestressed Concrete." including supplement, "Low Relaxation Strand."
- **2.**—ASTM E328, "Recommended Practice for Stress-Relaxation Tests for Materials and Structures."

C.—American Welding Society (AWS):
- **1.**—AWS D1.1, "Structural Welding Code-Steel."
- **2.**—AWS D1.4, "Structural Welding Code—Reinforcing Steel."

D.—Concrete Reinforcing Steel Institute (CRSI):
- **1.**—CRSI MSP-2, "Manual of Standard Practice."

E.—Post-Tensioning Institute (PTI):
- **1.**—PTI, "Guide Specifications for Posttensioning Materials."
- **2.**—PTI, "Performance Specification for Corrosion Preventive Coating."

3.—PTI, "Specification for Unbonded Single Strand Tendons."
4.—PTI, "Field Procedures Manual for Unbonded Single Strand Tendons."

1.6 QUALITY ASSURANCE

A.—Work shall conform to requirements of ACI 301, ACI 318, and CRSI MSP-2 except where more stringent requirements are shown on Drawings or specified in this Section.
B.—Welders and welding procedures shall conform to requirements of AWS D1.1 and AWS D1.4. Except where shown on Drawings, welding is prohibited unless accepted in writing by Engineer.
C.—Provide posttensioning strand systems supplied by PTI-certified manufacturers and licensees only, conforming to all material and installation requirements of ACI 301, ACI 318, and approved by International Conference of Building Officials (Uniform Building Code).
D.—Compliance with ACI 301 Article 15.2.3 required.
E.—Posttensioning Work: By organization that has successfully performed at least five previous post-tensioning installations similar to one involved in this Contract.
F.—All posttensioning Work shall be under immediate control of person experienced in this Work. Exercise close check and rigid control of all operations as necessary for full compliance with all requirements. Posttensioning Contractor's superintendent assigned to Project shall have supervised five prior projects of similar magnitude and design, and shall be present during all placing and posttensioning operations. Superintendent shall be acceptable to Engineer. Superintendent's failure to ensure full compliance with Specification will result in removal from Project.
G.—Submit following information on inspection of reinforcing steel and post-tensioning reinforcement unless modified in writing by Engineer:
1.—Project name and location.
2.—Contractor's name.
3.—Inspection agency's name, address and phone number.
4.—Date and time of inspection.
5.—Inspection agency technician's name.
6.—Fabricator's name.
7.—Weather data:
a.—Air temperatures.
b.—Weather.
c.—Wind speed.
8.—Inspection location within structure.
9.—Posttensioning steel inspection data (including but not limited to):
a.—Tendon size, spacing, cover, drape, grade, fabrication.

b.—Sheathing type, damage, and repair.
c.—Anchorages, sleeves, accessories, protection system.
d.—Support methods and construction sequencing.
10.—Diary of general progress of Work.

1.7 DELIVERY, STORAGE, AND HANDLING

A.—Assign all posttensioning tendons within every group or in same member heat number and tag accordingly.

B.—Strand shall be packaged at source in manner which prevents physical damage to strand during transportation and storage and which positively protects strand from moisture and corrosion during transit and storage. No part of any strand shall ever be unprotected against moisture. Greased bare strand unacceptable.

C.—Remove and replace at no cost to Owner wires or strands which are broken or show severe fabrication defects.

D.—Do not store material on slabs to be prestressed before final prestress of slabs is accomplished. At no time shall weight of stored material placed on slab area, after prestressing is completed and concrete has reached specified 28 day strength, exceed total design load of that slab area. Between time final posttensioning is accomplished and time concrete has reached specified 28 day strength, weight of stored material placed on slab area shall not exceed half total design load of that slab area.

1.8 SEQUENCING

A.—See Drawings for construction and tensioning sequence. No departure permitted without written agreement from Engineer.

1.9 ALTERNATES

A.—High strength bar and button-headed wire systems may be used instead of wire strand systems only with prior written acceptance from Engineer.

PART 2 PRODUCTS

2.1 POSTTENSIONING MATERIALS

A.—Posttensioning tendons, ASTM A416: Seven-wire, uncoated low relaxation steel strand, Grade 270 with minimum ultimate strength of 270,000 psi, unbonded system. All strand shall be manufactured by single source. If manufactured outside United States of America, strand shall be subject to Engineer's acceptance. Acceptance will be based on Engineer's review of evidence of satisfactory performance of strand in United States of America over past five years.

B.—Sheathing: Make tendon sheathing for unbonded single strand tendons of material with following properties:

1.—Sufficient strength to withstand unrepairable damage during fabrication, transport, installation, concrete placement and tensioning.

2.—Watertightness over entire sheathing length.

3.—Chemical stability, without embrittlement or softening over anticipated exposure temperature range and service life of structure.

4.—Non-reactive with concrete, steel, and tendon corrosion preventive coating.

5.—Color shall contrast with black grease so that sheathing tears will be readily visible. Black/dark colored sheathing is unacceptable.

6.—Sheathing: seamless and extruded.

7.—Sheathing thickness: Not less than 0.040 in., +/– 0.003 in., for high density polypropylene.

8.—Inside diameter: at least 0.010 in. greater than maximum diameter of strand.

9.—Make all connections and components watertight.

C.—Tape: "3M Tape No. 226," 3M, St. Paul, MN.

D.—Tendon grease: Lithium-based, containing corrosion inhibitors, wetting agents, and less than fifty parts per million of chlorides, sulphides or nitrates:

1.—Acceptable greases:

a.—"Shell PT Grease," Shell Oil Company, West Orange, New Jersey.

b.—"Visconorust PT 1000," Viscosity Oil Division of Tenneco, Chicago, Illinois.

c.—"Visconorust PT 1001," Viscosity Oil Division of Tenneco.

d.—"Mobil Greasrex K218," Mobil Oil Company, Houston, Texas.

e.—"Unocal PT1 Cable Grease," Unocal Corporation, Schaumburg, Illinois.

2.—Grease shall completely fill void between tendon and sheathing.

3.—Minimum weight of grease on tendon strand shall be 2.5 pounds per 100 feet of 0.5 inch diameter strand, and 3.0 pounds per 100 feet of 0.6 inch diameter strand.

4.—Grease shall meet all requirements of PTI "Performance Specification for Corrosion Preventive Coating."

E.—Couplings: In accordance with ACI 301 Article 15.2.2 where indicated on Drawings or specified by Engineer.

F.—Anchorages: In accordance with ACI 301 Article 15.2.2: design slab and beam anchors for transfer at 2,500 psi concrete strength; size bearing plates in accordance with ACI 301 unless certified test reports are submitted proving acceptable deviation. Anchorage system shall meet all requirements below and those of PTI Guide Specifications for aggressive environments. All anchorage systems shall be accepted at least 14 days before Bid date. All anchor plates shall be plastic coated or epoxy coated in accordance with coatings specified in Section "Cast-in-Place Concrete."

G.—Tendon anchorages and couplings shall be designed to develop static and dynamic strength requirements of Section 3.1.6(a) and Section 3.1.8 (1) and (2) of PTI "Guide Specifications for Posttensioning Materials." Castings shall be nonporous and free of sand, blow holes, voids, and other defects. Provision shall be made for plastic cap which fits tightly and seals barrel end on stressing side of anchor. Bearing side of anchor casting shall have provision for plastic sleeve which shall prevent moisture leaks into anchor casting or tendon sheathing. For wedge type anchorages, wedge grippers shall be designed to preclude premature failure of prestressing steel due to notch or pinching effects under static and dynamic test load conditions stipulated under paragraph (a), for low relaxation prestressing steel materials.

H.—Tendon anchor plates and wedges shall be same as those which passed static and dynamic test in accordance with ACI 301, Article 15.2.3.

I.—Blockouts: Plastic pocket former shall be used at stressing end to provide minimum recess of 2″ to anchor casting and minimum of 3″ in width to allow access to cut off excess strand. At intermediate stressing ends, grommet shall be used to prevent moisture leaks into anchor casting or tendon sheathing.

J.—Anchor Cap:

- **1.**—Stressing End: Plastic cap shall fit tightly, covering stressing end of barrel and wedges, and shall be fitted with sealing device. Cap shall allow minimum 1¼″ protrusion of strand beyond wedges.
- **2.**—Intermediate Stressing Ends: Plastic cap similar to above shall be used with exception that cap shall be open to allow passage of strand with minimum ¾″ chimney extension of cap.
- **3.**—Coating Material: Wedge area and plastic cap shall be completely filled with same grease used along length of strand.

K.—Sleeve: Plastic sleeve shall be used on bearing side of anchor casting which will prevent moisture leaks into anchor casting or tendon sheathing. Plastic sleeve shall be minimum 10″ long.

L.—Intermediate Anchorage Sheathing: At intermediate stressing anchorages, exposed stressing length shall be protected with corrosion preventive coating (same as above), covered with plastic sheathing, adequately taped along its length, and taped to tendon sheathing and chimney.

M.—Acceptable protection systems, subject to compliance with requirements:

1.—"CP + Monostrand Posttensioning System" with epoxy coated anchors, VSL Corporation, 101 Albright Way, Los Gatos, CA 95030.

2.—"ACP 5," Great Southwest, Dallas, TX.

3.—"Sure-Lock Posttensioning Corrosion Protection System," Varitech Industries, P.O. Box 0770, Stafford, TX 77477.

a.—Leakproof bushing between strand sheathing and anchor chimney required.

b.—Steel ring molded into stressing head required. Anchor cap shall snap into ring to make leakproof seal.

Figure 11-1 shows an generic system.

N.—Nails for attaching anchor assemblies to forms:

1.—Stainless steel ring nails, Clendenin Bros., Baltimore, MD, or equal as acceptable to Engineer.

O.—Design Forces and Stresses:

1.—Effective posttensioning forces, after all losses have occurred, are shown on Drawings.

2.—Maximum tensile stress in posttensioning tendons due to jacking forces shall not exceed 80% of specified tensile strength or 94% of specified yield strength of posttensioning tendon, whichever is smaller, but not greater than maximum value recommended by manufacturer of posttensioning tendons.

3.—Maximum tensile stress in posttensioning tendons immediately after anchorage shall not exceed 70 percent of specified tensile strength.

4.—Allowable slip of strand at anchorage shall not exceed ¼ inch. Measured elongation shall be within +/− 7% of calculated.

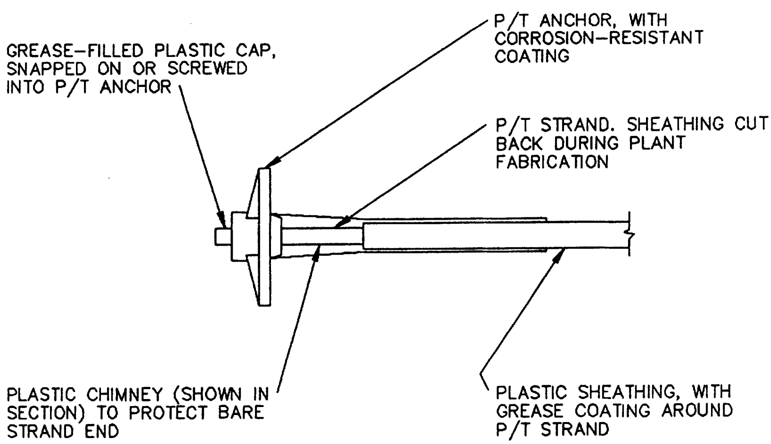


Figure 11-1. Example of a posttensioning encapsulation system.

5.—Design effective prestressed force shown on Drawings and design moment strength of all posttensioned sections are based on effective stress of 173,000 psi in prestressed reinforcement after allowance for all prestress losses.

2.2 GROUT MATERIALS

A.—Nonmetallic Shrinkage-Resistant Grout: Premixed, nonmetallic, noncorrosive, nonstaining product containing selected silica sands, portland cement, shrinkage compensating agents, plasticizing and water reducing agents, complying with ASTM C 1107, Grade B, with fluid consistency and a 30-minute working time.

B.—Products: Subject to compliance with requirements, provide one of THE following:

1.—Nonmetallic Shrinkage-Resistant Grout:

a.—Sure Grip Grout, Dayton Superior.

b.—Euco N.S., Euclid Chemical Co.

c.—Masterflow 928, Master Builders, Inc.

PART 3 EXECUTION

3.1 PREPARATION

A.—Furnish necessary information, materials, accessories and other items for prestressing and attaining effective posttensioning forces, after all losses have occurred, as shown on Drawings and specified in this Section.

B.—Maintain posttensioning equipment in safe, working condition.

C.—Satisfactorily protect posttensioning tendons from rust or other corrosion before placement. Provide sufficient protection for exposed prestressing steel at ends of members to prevent deterioration by rust or corrosion.

3.2 INSTALLATION

A.—Placement:

1.—Place tendons with parabolic profile in vertical plane conforming to control points shown on Drawings unless otherwise specified:

a.—Dimensions locating profile are given to center of gravity of tendons.

b.—Low points are at midspan unless noted otherwise.

c.—Where tendons interfere with one another, contact Engineer before relocating tendons.

d.—Support slab tendons independently of beam reinforcement.

2.—Space tendons evenly within slab to achieve required effective prestress as shown on Drawings:

a.—Slight deviations in spacing are permitted to avoid specifically located openings and inserts.

b.—Maximum main slab tendon spacing is eight times slab thickness but not more than 54 in..

c.—Prohibited: Bundling of more than two slab tendons without prior written permission from Engineer.

3.—Straighten strands to produce equal stress in all tendons that are to be stressed simultaneously and to insure proper positioning of anchors.

4.—Run tendons parallel to grid lines unless otherwise noted.

5.—Run tendons full length within pour without splices or couplers.

6.—Install horizontal and vertical spacers or chairs to hold tendons in required position and to conform to specified profile.

7.—Space tendon support chairs at 48″ maximum.

8.—Tendons and anchorages shall be supported firmly to prevent displacement during subsequent operations.

9.—Place tendons and anchorages to both horizontal and vertical tolerances for corresponding horizontal and vertical member dimensions:

a.—8 in. and less: Plus or minus ⅛ inch.

b.—8 to 24 in.: Plus or minus ⅜ inch.

c.—Greater than 24 in.: Plus or minus ½ inch.

d.—Deviations in horizontal plane which may be necessary to avoid openings or inserts shall have radius of curvature of not less than 21 feet.

10.—Over occupied/finished areas, permanently mark tendon locations on slab soffit.

B.—Sheathing Inspection and Repair:

1.—After installing tendons in forms and before concrete casting, sheathing shall be inspected for possible damage.

2.—Damaged areas shall be repaired by restoring grease coating in damaged area, and repairing sheathing.

3.—Sheathing repair procedure:

a.—Restore tendon grease coating in damaged area.

b.—Coat with grease outside of sheathing length of damaged area, plus 2 in. beyond each end of damage. Example: If sheathing tear is 6 in. long, then greased area will be 10 in. long, centered on tear.

c.—Place piece of longitudinally slit sheathing around greased tendon. Slit shall be on side of tendon opposite tear. Length of slit sheathing shall overlap greased area by 2 in. at each end. Example: If greased area is 10 in. long, then sheathing will be 14 in. long, centered on tear.

d.—Tape entire length of slit sheathing, spirally wrapping tape around sheathing to provide at least two layers of tape. Taping shall overlap slit sheathing by 2 in. at each end. Before taping, sheathing shall be dry and free of grease. Example: If slit sheathing is 14 in. long, then taped area will be 18 in. long, centered on tear.

C.—Tensioning:

1.—Take safety precautions to prevent workers from standing behind or above jacks during tensioning.

2.—It is imperative that concrete slabs to be prestressed reach 2,500 psi compressive strength in 96 hours or less. Tensioning should commence as soon as concrete strength reaches 2,500 psi. If within 96 hours (including Saturdays, Sundays and holidays) after concrete placement commenced, strength has not reached this limit, apply ½ stress to each wire or strand and full stress applied when concrete compressive strength reaches 2,500 psi. No exceptions to this requirement permitted.

3.—It is imperative that P/T beams and slabs reach 2,500 psi compressive strength in 48 hours or less. Tensioning should commence as soon as these strengths are achieved. If within 48 hours (including Saturdays, Sundays and holidays) after concrete placement commenced, strength has not reached these limits, ½ stress shall be applied to each wire or strand in slabs and beams and full stress applied when concrete reaches these limits. Note: Silica fume concrete may reach 2,500 psi compressive strength in less than 16 hours after placement. See Section "Silica Fume Concrete" for strength gain curve submittal requirements and for compression test requirements.

4.—No tensioning will be permitted unless posttensioning tendons are free and unbonded in enclosure. Orient anchorage wedges vertically before jacking.

5.—Stress all post-tensioning tendons by means of hydraulic jacks, equipped with accurate reading, calibrated hydraulic pressure gauges to permit stress in post-tensioning steel to be computed at any time:

a.—Provide certified calibration curve with each jack.

b.—If deviation greater than 7% occurs between measured elongation and computed elongation for given jack gauge pressure, immediately recalibrate gauges.

c.—If, after recalibration, computed and measured elongation for given gauge pressure still deviate by more than 7% cease tensioning operations until cause of deviation is found and corrected.

6.—Anchor prestressing steel at initial force that will result in effective forces, after all losses occur, of not less than those shown on Drawings.

D.—Cutting Tendons After Stressing:

1.—Do not cut tendons or cover pockets until elongation records are reviewed and accepted by Engineer.

2.—Clean tendons, anchorages and pockets of grease with non-corrosive solvent before removal of excess length of posttensioning tendons.

3.—Do not damage tendon, anchorage or concrete during removal of excess length of tendon.

3.3 FIELD QUALITY CONTROL

A.—Encapsulated tendons shall not be exposed to weather more than 7 calendar days prior to concrete placement. Bare strand never permitted.

B.—Tendon sheathing damaged over more than ten percent of length shall be rejected. Damaged length need not be continuous.

C.—Before concrete placement around sheathing, all tendon damage shall be repaired to watertight condition. Repairs shall be acceptable to Engineer.

D.—Inspect sheathing for unrepaired damage, for watertight seal between sheathing and anchor, and for correct installation of anchors, before concrete is placed around tendons.

E.—Relative wedge embedment into anchor shall not exceed ⅛ in.

3.4 PROTECTION

A.—After removing excess length of tendon, exposed end of tendon and chucks shall be made watertight immediately by covering with approved grease-filled tendon cap, or by other acceptable methods.

B.—After sealing exposed end of tendon and chucks, and before grouting tendon pocket, coat pocket surfaces with bonding agent.

C.—Grout tendon pockets solid with non-shrink, non-stain, chloride free grout as specified in this Section.

3.5 EXTRA STOCK

A.—Maintain on site adequate supplies of repair tape and tendon grease to make repairs.

B.—Maintain spare jack on site during post-tensioning operations.

3.6 REPAIRS

A.—General Contractor: Responsible for all repairs.

B.—Posttensioning Contractor: Submit repair procedures to Engineer for evaluation and acceptance.

APPENDIX NO. 11-3: SECTION 07100

WATERPROOFING SYSTEM

PART 1 GENERAL

1.1 RELATED DOCUMENTS

A.—Drawings and general provisions of Contract, including General and Supplementary Conditions and Division 1 Specification Sections apply to this Section.

1.2 SUMMARY

A.—**Single installer** shall be responsible for providing complete sealant and waterproofing system designed to minimize occurrence of common sealant, waterproofing, and concrete deterioration problems. All measures called for in these Specifications will be rigorously enforced.

B.—This Section includes the following:

1.—Concrete sealer on these surfaces:

a.—Supported concrete floor and concrete roof surfaces including curbs, walks, islands and pour strips.

b.—Concrete stair treads and landings.

c.—Slab-on-grade within parking facility, including curbs, walks, and islands.

d.—Approach drives and adjoining sidewalks within construction limits.

2.—Traffic topping: Fluid applied, waterproofing, traffic-bearing elastomeric membrane with integral wearing surface.

3.—Expansion joint sealant system.

4.—Concrete control and construction joint sealant system.

C.—Materials shall be compatible with materials or related Work with which they come into contact, and with materials covered by this Section.

D.—Related Sections: Following Sections contain requirements that relate to this Section.

1.—Division 3 Section, "Cast-in-Place Concrete."

2.—Division 3 Section, "Architectural Precast Concrete—Plant Cast."

3.—Division 3 Section, "Structural Precast Concrete—Plant Cast."

4.—Division 7 Section, "Firestopping."

5.—Division 9 Section, "Pavement Marking."

1.3 SUBMITTALS

A.—Make submittals in accordance with requirements of Division 1 and as specified in this Section.

B.—General:

1.—Section "Waterproofing System" contractor's experience record for past five years.

2.—Superintendent qualifications.

3.—Evidence of applicator's being licensed by manufacturer.

4.—Reviewed Shop Drawings distributed to all others whose Work is related.

5.—Certification that products and installation comply with applicable EPA, OSHA and VOC requirements regarding health and safety hazards. VOC also comply with South Coast Air Quality Management in southern California (SCAQMD) Rule 1113.

6.—Five copies of snow removal guidelines for areas covered by guarantee.

7.—Two copies each of manufacturer's technical representative's log for each visit.

8.—Signed statement from this Section applicator certifying that applicator has read, understood, and shall compy with all requirements of this Section.

C.—Concrete Sealer:

1.—Written computations to Engineer of material quantities to be applied to concrete surfaces at least 60 days before sealer application.

2.—Proposals for alternate application methods to Engineer at least 60 days before sealer application.

3.—Supplier shall furnish application rate at which following tests were passed:

a.—NCHRP 244 tests:

1)—Four Inch Cube Series II (incorporating 5 days of air drying prior to coating test cubes): Upper limits of average weight gain and net chloride content at completion of cube test series shall be limited to 16% of weight gain and 14% of net chloride gain of untreated control cubes.

2)—Southern Climate Exposure (Series IV): Upper limits of average chloride content at end of 24 weeks shall be limited to 4% of net chloride content of untreated control cubes.

b.—ASTM C672 test (non-air entrained concrete): Acceptable scaling rating shall be "zero plus."

c.—All laboratory testing specified shall be performed with manufacturer's product. Test results based on utilization of substitute sealer formulations are not acceptable.

4.—Quality Service Requirements:

a.—Show evidence of nationwide vendor and licensed/approved applicator network. List of names, addresses and phone numbers, with copies of licensing/approval agreement with each, satisfies requirement.

b.—Provide copies of manufacturing statistical process control charts for current month.

D.—Traffic Topping:

1.—Written computations to Engineer of material quantities (by components) to be applied to concrete surface at least sixty days before application of traffic topping.

2.—Proposed method of preparation of concrete surface.

3.—Proposed method and details for treatment of cracks and other defects on concrete surface.

4.—Product samples: One 12 in. by 12 in. stepped sample showing each component for each duty grade to be applied.

5.—Quality Control Procedures: System manufacturer shall submit written quality control plan to Engineer for acceptance 1 month prior to construction for application procedures which specifically address following:

a.—Surface preparation acceptance criteria.

b.—Method of application of coats.

c.—Primer type and application rate.

d.—For all coats, wet mils required to obtain specified dry thickness. System dry mil thickness including aggregate.

e.—Number and type of coats.

f.—Quality control plan for assured specified uniform membrane thickness that utilizes grid system of sufficiently small size to designate coverage area of not more than 5 gallons at specified thickness. In addition, employ wet mil gauge to continuously monitor thickness during application. Average specified wet mil thickness shall be maintained within grid during application with minimum thickness of not less than 80% of average acceptable thickness. Immediately apply more material to any area not maintaining these standards.

g.—Type, gradation and aggregate loading required within each coat.

h.—Maximum and minimum allowable times between coats.

i.—Temperature, humidity and other weather constraints. Specify substrate moisture testing criteria.

j.—Final cure time before resumption of parking and/or paint striping.

k.—Any other special instructions required to ensure proper installation.

l.—Quality Service Requirements:

1)—Show evidence of nationwide vendor and licensed/ approved applicator network. List of names, addresses and phone numbers, with copies of licensing/approval agreement with each, satisfies requirement.

2)—Provide copies of manufacturing statistical process control charts for current month.
3)—Provide copy of field application quality control procedures.

m.—Flash point of each component 200° F. minimum.
n.—Static coefficient of friction shall meet minimum requirements of Americans with Disabilities Act (ADA).
o.—Provide certificate stating materials have been tested and listed for Class "A" rated materials/system by UL for traffic topping application specified on project.

E.—Expansion Joint Sealant System:

1.—Material samples.
2.—Installation plans and large scale details. Show all conditions including, but not limited to, splices, terminations, and change in section or alignment.
3.—Field samples of premolded joint sealant. Width, thickness and durometer hardness of sealant shall be checked by Testing Agency.
4.—Joint movement specified.
5.—Other information required to define joint placement or installation.
6.—ADA Certification: Prior to installation, submit written certification from manufacturer indicating that expansion joints conform to Americans with Disabilities Accessibility Guidelines for Buildings and Facilities, as published by U.S. Architectural & Transportation Barriers Compliance Board, 1111 18th Street, N.W., Suite 501, Washington, DC 20036-3894.

F.—Concrete Control and Construction Joint Sealant System:

1.—Material samples.
2.—Installation plans and large scale details.
3.—Any other information necessary to show placement of control joint system.

1.4 QUALITY ASSURANCE

A.—Testing Agency: Independent testing laboratory employed by Owner and acceptable to Engineer.

B.—Prequalification of Bidders:

1.—With Bid, submit proposed Section "Waterproofing System" subcontractor qualifications. Engineer shall notify General Contractor whether or not subcontractor is acceptable within 10 working days of Bid.
2.—Prequalification Criteria, all in writing:

a.—Evidence of compliance with paragraph "General," below and with Summary paragraph "Single Installer."

b.—Evidence of acceptable previous work on WALKER-designed projects. If none, so state.

c.—Engineer retains absolutely, right to reject any prequalification statement.

d.—Evidence of financial stability acceptable to Engineer.

C.—General:

1.—Provide written certification by each system manufacturer to Engineer that system installer is approved applicator.

2.—All Work under Section "Waterproofing System" shall be performed by organizations which have successfully performed at least five verifiable years of installations similar to those involved in this Contract. System installer shall submit listing of 5 or more prior installations in climate and size similar to that for this Project.

3.—Final selection of Section "Waterproofing System" installer shall be subject to acceptance of Engineer. Engineer retains right to reject any installer.

4.—All Section "Waterproofing System" Work shall be under immediate control of person experienced in this type Work. Exercise close check and rigid control of all operations as necessary for full compliance with all requirements. Contractor's superintendent assigned to Project shall have supervised five prior projects of similar magnitude and design, and shall be present during all operations. Superintendent shall be acceptable to Engineer. Engineer retains right to remove superintendent from project if superintendent fails to ensure full compliance with Specification.

5.—Information Statement: Annually Engineer evaluates manufacturer/applicator performance based on Owner satisfaction. Ratings of Below Expected Performance, At Expected Performance, and Above Expected Performance are assigned. Manufacturers/applicators receiving Below Expected Performance rating will be deleted from Specification for one year, minimum.

D.—Concrete Sealer:

1.—Manufacturer: Sealer shall be compatible with all materials to which it would be applied including, but not limited to, curing compounds, sealants, expansion joint and threshold assemblies, caulking, and concrete.

2.—Sealer shall be applied to Project at same rate used to pass NCHRP 244 test. However, Section "Waterproofing System" Installation/Application paragraph "Install three trial sections. . ." must also be met. If both requirements cannot be met simultaneously with single application rate, sealer will be rejected.

3.—Testing Agency shall take a) one core from each trial section referenced under Section "Waterproofing System" Installation/Application paragraph "Install three trial sections. . .," and b) three additional cores as directed by Engineer after sealer application to test for sealer effectiveness in accordance with ASTM C642 for "absorption by immersion only" and modified as follows: a) Concrete core samples shall be taken 14 days after application of sealer. Report water absorption through top and bottom surfaces of core only. Sealer effectiveness as determined by comparison of water absorption through sealed top surface and core bottom surface shall be at least 85%; b) Core samples shall be tested in "Triaxial Apparatus," which forms rubber impervious membrane around core, leaving only top surface exposed.

E.—Traffic Topping:

1.—Manufacturer: Review concrete finish specification and confirm in writing to Engineer and General Contractor that finishes as specified are acceptable for system to be installed. Send to Engineer and General Contractor one month before placement of any concrete which will receive traffic topping.

2.—Testing Agency employ wet mil gauge to periodically monitor thickness during application. See Submittals paragraph Traffic Topping, Quality Control Procedures, Quality Control Plan.

3.—Manufacturer: **Provide qualified representative on site for duration of Work.**

4.—Use trial sections under Installation/Application paragraph Traffic Topping, "Install one trial section. . ." to determine adequacy of pre-application surface cleaning. Obtain Owner, Engineer and manufacturer acceptance of cleaning before proceeding with topping application.

5.—Determine overall topping system mil thickness:

a.—Contractor shall provide 6 in. by 6 in. bond breaker (topping coupon) on concrete surface for each 25,000 sq ft, or fraction thereof, of topping to be placed as directed by Engineer and manufacturer. Dimensionally locate coupon for easy removal.

b.—Contractor shall assist Testing Agency in removing topping coupons from concrete surface at completion of manufacturer-specified cure period. Contractor shall repair coupon area per topping manufacturer's instructions.

c.—Testing Agency shall determine dry mil thickness of completed readings (minimum) in 3 in. by 3 in. pattern at 2 in. on center. No reading shall be taken closer than one inch from coupon edge. Report individual readings and overall topping system average to Engineer. Readings shall be made with micrometer or optical comparator.

6.—Pre-installation Conference: Meet at project site well in advance of time scheduled for Work to proceed to review requirements for Work and conditions that could interfere with successful topping performance. Require every party concerned with topping Work, or required to coordinate with it or protect it thereafter, to attend. Include manufacturer's technical representative and warranty officer.

F.—Expansion Joint Sealant System:

1.—Manufacturer: Review and approve all details before construction. Confirm in writing to Engineer.

2.—Coordinate services with related Work including layout of joint system and approval of methods for providing joints.

3.—Inspect site to insure proper joint configuration in field.

4.—Testing Agency shall check Shore A hardness in accordance with ASTM D2240.

5.—Manufacturer: **Provide qualified representative on site for duration of Work.**

G.—Concrete Control and Construction Joint Sealant System:

1.—Review and approve joint details before construction.

2.—Coordinate layout of joint system and approve methods for providing joints with precast concrete and concrete contractors.

3.—Inspect site and precast plant before precast production to insure proper joint configuration.

4.—Flood test joints where shown on Drawings.

5.—Testing Agency:

a.—Check shore hardness per ASTM standard specified in sealant manufacturer's printed data.

b.—If flood test of joints required by this Section, report results to Engineer.

1.5 REFERENCES

A.—American Society for Testing and Materials (ASTM):

1.—ASTM C642, "Test for Specific Gravity, Absorption and Voids in Hardened Concrete."

2.—ASTM D2240, "Test for Indentation Hardness of Rubber and Plastics by Means of a Durometer."

3.—ASTM E119, "Fire Tests of Building Construction and Materials."

1.6 DELIVERY, STORAGE, AND HANDLING

A.—Deliver all materials to site in original, unopened containers, bearing following information:

1.—Name of product.

2.—Name of manufacturer.

3.—Date of preparation.

4.—Lot or batch number.

B.—Store materials under cover and protect from weather. Replace packages or materials showing any signs of damage with new material at no additional cost to Owner.

C.—Do not store material on slabs to be post-tensioned before final post-tensioning of slabs is accomplished. At no time shall weight of stored material being placed on slab area, after post-tensioning is completed and concrete has reached specified 28 day strength, exceed total design load of slab area. Between time final post-tensioning is accomplished and time concrete has reached specified 28 day strength, weight of stored material placed on slab area shall not exceed half total design load of slab area.

1.7 PROJECT CONDITIONS

A.—Weather and Substrate Conditions for Sealers: Do not proceed with application (except with written recommendation of manufacturer) under any of the following conditions:

- **1.**—Ambient temperature is less than 40° F.
- **2.**—Substrate surfaces have cured for less than one month.
- **3.**—Rain or temperatures below 40° F predicted for a period of 24 hours.
- **4.**—Earlier than 24 hours after surfaces became wet.
- **5.**—Substrate is frozen or surface temperature is less than 40° F.
- **6.**—Windy condition such that repellent may be blown to vegetation or substrates not intended.

B.—Weather and Substrate Conditions for Other Materials: Proceed with work only when existing and forecast weather will permit work in accordance with manufacturer's recommendations.

1.8 WARRANTY

A.—This article applies to all materials covered in Section "Waterproofing System" EXCEPT Concrete Sealer.

B.—System Manufacturer: Furnish Owner with written total responsibility guarantee that system will be free of defects, water penetration and chemical damage related to system design, workmanship or material deficiency, consisting of:

- **1.**—Any adhesive or cohesive failures.
- **2.**—Spalling surfaces (applies to traffic topping only).
- **3.**—Weathering.
- **4.**—Surface crazing (does not apply to traffic topping protection course).
- **5.**—Abrasion or tear failure resulting from normal traffic use.
- **6.**—Failure to bridge cracks less than 1/16 in. or cracks existing at time of traffic topping installation on double tees only.

C.—If material surface shows any of defects listed above, supply labor and material to repair all defective areas and to repaint all damaged line stripes.

D.—Guarantee period shall be five years commencing with date of acceptance of Work.
E.—Perform any repair under this guarantee at no cost to Owner.
F.—Before construction, provide Engineer with sample of final guarantee. Guarantee shall be provided by manufacturer.
G.—Snowplows, vandalism, abnormally abrasive maintenance equipment, and spinning studded snow tires are not normal traffic use and are exempted from warranty.

PART 2 PRODUCTS

2.1 MATERIALS

A.—Concrete Sealer:
  1.—Acceptable concrete sealers are listed below. Minimum application rate in square feet per gallon (sf/g) is listed for each product name. Sealers shall be compatible with all other materials in this Section and related work.
    a.—Class Siloxane:
      1)—"Saltguard," ProSoCo, Inc., 125 sf/g, Kansas City, KS (apply only to surfaces NOT exposed to direct sunlight).
      2)—"6000H," 125 sf/g, 3M Company, St. Paul, MN.
      3)—"Iso-Flex 620," 125 sf/g, Harry S. Peterson Companies, Inc., Pontiac, MI.
      4)—"Stifel H," 125 sf/g, Noxcrete Chemicals, Omaha, NE.
    b.—Class Silane:
      1)—"Iso-Flex 618 (40% solids)," 125 sf/g, Harry S. Peterson Co., Inc., Pontiac, MI.
      2)—"Chem-Trete BSM 40," 125 sf/g, Huls America, Inc., Piscataway, NJ.
      3)—"Hydrozo Enviroseal 40," 125 sf/g, Hydrozo Coatings Company, Lincoln, NE.
      4.—"Decktite 440 Silane Sealer," (40% solids), 125 sf/g, Tremco, Cleveland, OH.
      5.—"Chemtrete BSM 40 VOC," 200 sf/g, Huls America, Inc. Piscataway, NJ.
  2.—Proposed substitutions: **None** for this project. Contact Engineer for consideration for future projects.
B.—Traffic Topping:
  1.—Acceptable low odor toppings are listed below. One will be selected as an alternate. In bid form, list bid price for each topping listed below. Contract for topping will not necessarily be directed to lowest bid priced topping. Toppings shall be compatible with all other materials in this Section and related work.

a.—Medium Duty:

1)—"Scotch-Clad Deck Coating System—MDV," 3M Company, St. Paul, MN.

2)—"Autogard II," Neogard Corporation, Dallas, TX.

3)—"Iso-Flex 750-U—MVT," Harry S. Peterson Co., Inc., Pontiac, MI.

4)—"Decktite 315/325 Standard Duty" or "TBS 950-35K," Tremco, Cleveland, OH.

5)—"Vulkem 350/345/345/346 (medium) Deck Coating System," Euclid Chemical/Mameco International, Cleveland, OH.

6)—"Kelmar TE Exposure 1," Master Builders, Cleveland, OH.

b.—Heavy Duty:

1)—"Scotch-Clad Deck Coating System—HDV 70," 3M Company, St. Paul, MN.

2)—"Iso-Flex 750-U or Iso-Flex 750-EU—HD," Harry S. Peterson Co., Inc., Pontiac, MI.

3)—"Autogard II, HD-56," Neogard Corporation, Dallas, TX.

4)—"Decktite 315/325 Standard Duty" or "TBS950-80K System" or "TBS950-500K System," Tremco, Cleveland, OH.

5)—"Vulkem 350/345/346/346 Deck Coating System," Euclid Chemical/Mameco International, Cleveland, OH.

6)—"Kelmar TE Exposure 2 or 3," Master Builders, Cleveland, OH.

2.—Provide ultraviolet screening for all traffic topping placed on this project.

3.—Finish top coat shall be colored grey.

4.—Substitutions: **None** for this project. Contact Engineer for consideration for future projects.

C.—Expansion Joint Systems:

1.—General:

a.—Conform to Americans with Disabilities Accessibility Guidelines for Buildings and Facilities, as published by U.S. Architectural & Transportation Barriers Compliance Board, 1111 18th Street, N.W., Suite 501, Washington, DC 20036-3894.

b.—Surfaces accessible to pedestrian traffic: anti-slip construction.

2.—Premolded expansion joint sealant system where shown. Acceptable systems:

a.—"Iso-Flex Factory Molded Expansion Joint Sealing System," Harry S. Peterson Co. Inc., Pontiac, MI.

b.—"Decktite 505 ETS Type A" or "Decktite 505 ETS Textured Type B" "Elastomeric Joint Systems," Tremco, Cleveland, OH.

c.—"Dynaspan Expansion Joint System," Pecora Corporation, Harleysville, PA.

3.—Metal edged expansion joint sealant system where shown. Acceptable systems:

a.—"Metal Flex Aluminum Expansion Joint Systems," Harry S. Peterson Co., Inc., Pontiac, MI.

b.—"Wabo Econo-Tite Aluminum Expansion Joint System," Watson Bowman Acme Corp., Amherst, NY.

c.—"Watson Bowman Expansion Joint System" using Wabo Strip Seal Extrusion Type A or E and Gland Type S(E), L(E), EF(E), or SEC, all as indicated on Drawings, Watson Bowman Acme Corp., Amherst, NY.

4.—Elastomeric concrete edged, extruded rubber expansion joint sealant system where shown. Acceptable systems:

a.—"Wabocrete/Membrane 101 or 201 System," Watson Bowman Acme Corp., Amherst, NY.

b.—"Thermaflex Membrane/Nosing System, Type TM and TCR Series," Emseal Joint Systems Ltd., Westborough, MA.

c.—"Polycrete/Membrane System, Type M or CR Series," Erie Metal Specialties, Inc., Akron, NY; membranes may be heat spliced at directional changes.

d.—"Decktite 525 NTS Neoprene Traffic Joint System," Tremco, Inc., Cleveland, OH.

5.—Adhered extruded rubber expansion joint sealant system where shown. Acceptable systems:

a.—"Hydrozo/Jeene Structural Sealing Joint System," Hydrozo, Lincoln, NE.

6.—Reinforced nosepad, blockout mounted, mechanically anchored expansion joint sealant system where shown. Acceptable systems:

a.—"KONFLEX," with EM, KB, or KCR series glands, EMSEAL Joint Systems, Ltd., Westborough, MA.

b.—"Decktite 550 ATS Armored Traffic Joint System," Tremco, Inc., Cleveland, OH.

c.—"Wabo Elastoflex Expansion Joint System" with E Series gland element, Watson Bowman Acme Corp., Amherst, NY.

7.—FRP angle edged expansion joint sealant system where shown. Acceptable systems:

a.—"Interspan Flexible Expansion Joint System," Larsen Products Corp., Jessup, MD.

b.—Substitutions: **None** for this project. Contact Engineer for consideration for future projects.

D.—Concrete Control and Construction Joint Sealant System:

1.—In addition to locations and extent of sealant shown on Drawings, Provide sealant at following conditions:

a.—At all control joints in slabs on grade, pour strips, cast-in-place slabs, topping, and in joints between pretopped precast double tee flanges.
b.—Around perimeter of all floor drains.
c.—At all exterior horizontal joints between precast and cast-in-place concrete. Color to match precast concrete.
d.—At all vertical and horizontal joints between precast vbeams and columns at tiers exposed directly to weather. Color to match precast concrete.

2.—Provide complete system of compatible materials designed by manufacturer to produce waterproof, traffic-bearing control joints as detailed on Drawings.
3.—Compounds used for sealants shall not stain masonry or concrete. Aluminum pigmented compounds not acceptable.
4.—Color of sealants shall match adjacent surfaces.
5.—Bond breakers and fillers: as recommended by system manufacturer.
6.—Primers: as recommended by sealant manufacturer, used in accordance with manufacturer's printed instructions.
7.—Acceptable control joint sealants:
a.—"Iso-Flex 880GB/881/830," Harry S. Peterson Co., Inc., Pontiac, MI.
b.—"Dynatred," Pecora Corporation, Harleysville, PA.
c.—"Sonolastic SL-2," Sonneborn Building Products, Minneapolis, MN.
d.—"Decktite 230 SL," "Decktite 235 GS," "Decktite 248 NS" (bedding and nosing only), Tremco, Cleveland, OH.
e.—"3M SC-2 or SC-2NS Sealant," 3M, St. Paul, MN.
f.—"Vulkem 227, Vulkem 245, or Vulkem 922 Polyurethane Sealants," Mameco International, Cleveland, OH.

8.—Sealant for Vertical and Cove Joints: Acceptable sealants:
a.—"Iso-Flex 881/830," Harry S. Peterson Co., Inc., Pontiac, MI.
b.—"Tremseal HP or Dymeric 511," Tremco, Cleveland, OH.
c.—"Dynatrol II," Pecora Corporation, Harleysville, PA.
d.—"Sonolastic NP-2," Sonneborn Building Products, Minneapolis, MN.
e.—"Vulkem 922," Mameco International, Cleveland, OH.

9.—Proposed Substitutions: **None** for this project. Contact Engineer for consideration for future projects.

E.—Vertical Structural Expansion Joints and Vertical Continuation of Horizontal Expansion Joint Sealant Systems. Acceptable sealants:
1.—"25V," where black appropriate, EMSEAL, Westborough, MA.
2.—"Colorseal," where colored seal required, EMSEAL, Westborough, MA.
3.—"Seismic Colorseal," where high movement required, EMSEAL, Westborough, MA.

F.—Fire rated joint sealing systems: See Section "Firestopping."

PART 3 EXECUTION

3.1 INSPECTION

A.—General:

1.—Inspect surfaces to receive Work and report immediately in writing to Engineer any deficiencies in surface which render it unsuitable for proper execution of Work.

2.—Coordinate and verify that related Work meets following requirements:

a.—Concrete surfaces are finished as acceptable for system to be installed.

b.—Curing compounds used on concrete surfaces are compatible with Work to be installed.

c.—Concrete surfaces have completed proper curing period for system selected.

3.—Acid etching: Prohibited.

4.—All openings to occupied space shall be sealed to prevent cleaning materials, solvents and fumes from infiltration. All protective measures and/or ventilating systems required to prevent infiltration are incidental to this Work.

3.2 PREPARATION

A.—Concrete Sealer:

1.—All control joint and expansion joint Work shall be complete and accepted by Engineer before beginning concrete sealer surface preparation and application.

2.—Repair or replace all sealant materials damaged by surface preparation operations.

3.—Shot blast clean all surfaces to be sealed as acceptable to sealer manufacturer before sealer application, unless slab water cured per ACI 308, Paragraph 2.2. Cleaning method and materials shall be sufficient to allow absorption criteria stated in Quality Assurance, paragraph Concrete Sealer, "Testing Agency shall take. . ." to be met. See Installation/ Application paragraph Concrete Sealer, "Install three trial sections. . ." also.

4.—Equipment used during floor slab cleaning shall not exceed height limitation of facility and shall not exceed 3,000 lb axle load or vehicle gross weight of 6,000 lb.

5.—Mask off adjoining surfaces not to receive sealer and mask off drains to prevent spillage and migration of liquid materials outside sealer area. Provide neat/straight lines at termination of sealer.

B.—Traffic Topping:

1.—Remove all laitance and surface contaminants, including oil, grease and dirt by shotblasting.

2.—Before applying materials, apply system to small area to assure that it will adhere and dry properly and to evaluate appearance.
3.—All cracks on concrete surface shall be prepared in accordance with manufacturer's recommendations.
4.—Mask off adjoining surfaces not to receive traffic topping and mask off drains to prevent spillage and migration of liquid materials outside membrane area. Provide neat/straight lines at termination of traffic topping.

C.—Expansion Joint Sealant System:
1.—General Contractor: Correct unsatisfactory conditions in manner acceptable to installer before installing sealant system. All bugholes and air voids in blockouts shall be patched as acceptable to Engineer prior to installation of Expansion Joint Sealant system.
2.—Coordinate expansion joint sealing system with other related Work before installation of expansion joint sealant.
3.—Check adhesion to substrates and recommend appropriate preparatory measures.
4.—Proceed with expansion joint sealant only after unsatisfactory conditions have been corrected in manner acceptable to installer.
5.—Clean joints thoroughly in accordance with manufacturer's instructions to remove all laitance, unsound concrete and curing compounds which may interfere with adhesion.
6.—Cease installation of sealants under adverse weather conditions, or when temperatures are outside manufacturer's recommended limitations for installation.
7.—Prepare for installation of extruded expansion joint systems in accordance with manufacturer's recommendations.

D.—Concrete Control and Construction Joint Sealant System:
1.—General Contractor: Correct unsatisfactory conditions in manner acceptable to installer before installing sealant system.
2.—Sealant Installer: Grind joint edges smooth and straight with bevelled grinding wheel before sealing. All surfaces to receive sealant shall be dry and thoroughly cleaned of all loose particles, laitance, dirt, dust, oil, grease or other foreign matter. Obtain written approval of method from system manufacturer before beginning cleaning.
3.—Check preparation of substrate for adhesion of sealant.
4.—Prime and seal joints according to manufacturer's directions and protect as required until sealant is fully cured.

3.3 INSTALLATION/APPLICATION

A.—General:
1.—Do all Work in strict accordance with manufacturer's written instructions and specifications including, but not limited to,

moisture content of substrate, atmospheric conditions (including relative humidity and temperature), coverages, mil thicknesses and texture, and as shown on Drawings.

2.—Manufacturer's technical representative, acceptable to Engineer, shall be on site during surface preparation and installation.

3.—Cease material installation under adverse weather conditions, or when temperatures are outside manufacturer's recommended limitations for installation, or when temperature of work area or substrate are below 40F.

B.—Concrete Sealer:

1.—Submit manufacturer's recommended application rates in writing before start of sealer application. Quality Assurance paragraph Concrete Sealer, "Testing Agency shall take. . ." states minimum rate.

2.—All concrete to be treated shall be cured above 50° F. for at least 14 days before applying sealer.

3.—All concrete to be treated shall be air dried for at least 72 hours (following surface wetting) at temperatures above 50° F. immediately before applying protective sealer system.

4.—Ambient and concrete temperatures shall be 50° F. or higher during application of protective sealer, but temperature, humidity and wind velocity shall be within manufacturer-specified limits to prevent solvent flash-off.

5.—Install three trial sections of sealer to verify treated surface is not glazing as result of sealer application. If application of sealer causes glazing at trial section, Contractor shall contact sealer manufacturer to obtain written recommendations for solving problem. Contractor shall not proceed with sealer application following trial section applications until directed to do so in writing by Engineer.

6.—Clean all surfaces affected by sealer material overspray and repair all damage caused by sealer material overspray to adjacent construction or property at no cost to Owner.

7.—Unsatisfactory test results reported under Quality Assurance paragraph Concrete Sealer, "Testing Agency shall take. . ." shall be grounds for rejection of sealer and sealer application or sealer reapplication at no additional cost to Owner.

C.—Traffic Topping:

1.—Refer to Submittals paragraph Traffic Topping, "Quality Control Procedures. . ." and Quality Assurance paragraph Traffic Topping.

2.—Do not apply traffic topping material until concrete has been air dried at temperatures at or above 40° F. for at least 30 days after curing period specified.

3.—Install one trial section of topping system for each duty grade specified. Do not proceed with further topping application until trial sections accepted in writing by Engineer. Remove and replace rejected trial sections with acceptable application. Trial section shall also be tested for:

a.—Wet mil thickness application per manufacturer's literature and Submittals paragraph Traffic Topping, "Quality Control Procedures. . . ."

b.—Adhesion to concrete substrate per manufacturer's printed test data.

c.—Overall dry mil thickness per Quality Assurance paragraph Traffic Topping.

4.—All adjacent vertical surfaces shall be coated with traffic topping minimum of four inches above coated horizontal surface. Requirement includes, but is not limited to pipes, columns, walls, curbs (full height of vertical faces of all curbs) and islands.

5.—Complete all Work under this Section before painting line stripes.

D.—Expansion Joint Sealant System:

1.—During months when historic mean daily temperature at Project is 20° F. or more colder than annual mean daily temperature, premolded sealant shall be installed on temporary basis to prevent hot weather buckling. Permanent installation shall be done in summer when Engineer directs.

2.—Install extruded expansion joint system in accordance with manufacturer's instructions.

E.—Concrete Control and Construction Joint Sealant System:

1.—Completely fill joint without sagging or smearing onto adjacent surfaces.

2.—Fill horizontal joints slightly recessed to avoid direct contact with wheel traffic.

3.—Contractor and Engineer shall determine one of following two methods of sealant testing to verify sealant profile:

a.—Contractor, at Engineer's direction, shall cut out lesser of one percent of total lineal footage placed or total of 100 lineal ft of joint sealant at isolated/random locations (varying from inches to feet of material) for Engineer and Manufacturer's Representative inspection of sealant profile.

b.—Contractor, at Engineer's direction, shall install three trial joint sections of 20 ft each. Contractor shall cut out joint sections, as selected by Engineer, for Engineer and Manufacturer's Representative inspection. Additional isolated/random removals may be required where sealant appears deficient. Total cut out sealant shall not exceed lesser of one percent of total lineal footage placed or total of 100 lineal ft of joint sealant at isolated/random locations (varying from inches to feet of material) for Engineer and Manufacturer's Representative inspection of sealant profile.

4.—Contractor to repair all random joint sealant "cut out" sections at no cost to Owner.

3.4 CLEANING

A.—Clean off excess material and material smears adjacent to joints as work progresses using methods and materials approved by manufacturers.

CHAPTER
12

CONSTRUCTION

Anthony P. Chrest

12.1 INTRODUCTION

This chapter is for owners, engineers, and builders. The construction process involves all of you, or should. When it does not, problems arise. All too often relations between owner, engineer, and builder become adversarial shortly after construction begins. Then they stay that way for the rest of the project. Instead of working *with* each other, the team members waste most of their energy working *on* each other. This sorry state does not have to be. Imagine how much less time a project would take if even half the disputes and "cover your tail" paperwork could be cut. It can be done; it has been done. Trust is the key; however, trust is not free; it must be earned. Earn trust by fair treatment, clear communications in every step, and clear communications *before* every step. All this will take unaccustomed effort. It also may initially require behavior that makes you uncomfortable, but the resulting savings in time and hassle will be worth it. Give it a chance.

12.2 COMMUNICATION

12.2.1 Plans and Specifications

The lifeblood of the construction process is communication—clear, concise, and constant. It must begin well before construction begins—during plans and specification preparation in the engineer's office. At this point the owner and engineer must communicate. The owner must make clear its intentions for the project. The engineer must achieve that intent while keeping the project within the owner's total budget. Trade-offs during this process are likely.

Repetition through different modes of communication will make the message clearer. It is usually best to follow up spoken messages with written confirmation of one party's understanding of what was said. Invite corrections before a stated deadline. If the deadline passes with no corrections received, the ground rules must say that the written message stands. Memories are short, especially in disputes where what really happened conflicts with what we would like to have happened. During the preparation of plans and specifications, engineer and owner should review the documents together, signing off as they go. This practice, if followed, will bring the project to completion with few detours. Keep in mind, though, that some arguments will happen and may even make for a better project.

Drawings must clearly give the prospective builder enough information both to estimate a construction cost and to build the project.

Quality control during drawing production is important. Drawings for a recent project, for which we were consulted as an expert witness, showed an obvious conflict between column vertical bars and slab dowels, yet the conflict was not noticed until construction, when the dowels pulled out of the columns. When questioned, the response from the Engineer of Record was, "The draftsman showed it that way." The response betrayed both lack of quality control and lack of knowledge of what was on the drawings.

Enough has been said elsewhere on the subject of unclear documents. Unfortunately, there are still engineers who take on document preparation at a fee so low as to prevent doing a complete job. What results is a project with many problems, an unhappy owner, and lawsuits. Any savings resulting from the low design fee will be wiped out by added costs during construction. A higher design fee may produce a lower total cost for a project. Owners should learn to look at the total cost of the project: design cost *and* construction cost. Owners, ask the design firm you are thinking of hiring for its track record of self-caused construction change orders. If no such record is forthcoming, how can you know the total cost of your project? So, if an engineer quotes you—an owner—a fee that seems too good to be true, it probably is, and it will likely cost you more in higher bids and construction change orders and than you saved in design fees.

12.2.2 Understandable Specifications

Too many design professionals believe that a good specification must be full of legalese. A review of proprietary master specifications such as the PSAE "MasterSpec" or the Construction Specifications Institute "Master Specification" shows that the briefer, the better. Specifications must be clear, concise, and no longer than necessary. Look for ways to shorten your specifications while still stating your message clearly.

12.2.3 Bidding or Negotiating

Common bidding procedures often work against good communications during this critical phase of a project's life. Adversarial relationships may begin at this stage because information that one party, usually the bidder, wants is not available.

Use a prebid conference during the middle of the bidding period to emphasize to bidders what you want them to understand, particularly those items unique to parking structures or to your specification. (See the commentary to the Chapter 11 appendices for some examples.) Though a prebid conference is common practice, our experience has been that meaningful questions are seldom asked. Bidders, being competitors for the project, will not say too much for fear of giving away a real or imagined edge. The result, while certainly understandable, is little worthwhile communication.

Another problem with bid jobs is there may be little control over who may bid and thus who gets the work. Unless prequalification procedures are permitted and used, the owner may have no control over to whom it gives its hard-earned money. Even then the successful contractor may not be the owner's first choice. So, bidding may result in a forced marriage. How many of those work?

Step 1 in successful construction price negotiating is owner selection, with engineer advice, of a reputable builder with demonstrated success in parking structure construction. Check the prospective builder's financial stability too, even (and especially) if the builder is a friend or has worked with you before. In negotiating, the parties must talk. Make available the opportunity for give and take on both sides. All three sides must win the negotiation. Fairness is the key. Mutual trust and a spirit of working *with*, not *on*, one another will begin here. The negotiated price may end up higher than a bid price might have been; however, the final negotiated project price will not, because there is better understanding of what is in the project by all parties, which will result in fewer change orders during construction. And, the owner's increased control over who does the construction work stacks the deck for just such an outcome.

12.2.4 Preconstruction

Before the initial euphoria of signing the construction contract wears thin, begin preconstruction planning. The owner, engineer, and builder must meet with all the major players in the construction process, such as:

- Concrete supplier
- Concrete placer
- Concrete finisher
- Concrete curer
- Concrete inspector
- Concrete tester
- Precaster supplier
- Precast erector
- Others

"Others" includes contractors, suppliers, and professionals who are involved in almost any multilevel building construction. Examples are excavators, elevator contractors, roofers, soil engineers, and painters, to name a few. We are concentrating on matters more particular to parking structures. Since concrete is the single most important and expensive component of most parking structures, we emphasize it here. It is advisable to hold more than one preinstallation meeting for different parties and/or during different phases of construction. Example: why discuss painting until the builder schedules that work?

The outcome of a concrete preinstallation meeting, one of the preinstallation meetings to be held, must be a written procedure that spells out who will do exactly what and when. This written procedure must be reviewed, discussed, and signed by every party involved in the work for the items listed:

- Mix design(s)
- Mix design(s) submission
- Mix design(s) approval
- Concrete proportioning and mixing
- Concrete transportation
- Concrete placement method
- Consolidation procedures
- Finishing procedures
- Weather protection procedures
- Curing procedures
- Testing procedures, locations, and frequency
- Testing personnel qualifications
- Inspection requirements
- Inspector qualifications
- Test and inspection reporting
- Repair criteria and procedures
- Conflict resolution
- Acceptance criteria
- Criteria for reduced payment
- Suppliers' quality control
- Subcontractors' quality control
- General contractor's quality control
- Designer's site quality control

Every party must keep a copy of the agreed-upon procedure on hand, particularly when at the job site. The above list may seem too long, but every item there has been disputed among some of the parties involved in construction. Several examples of common disputes are in the following paragraphs. You can avoid them all by reaching agreement on the list above before construction begins, not after the problem occurs.

On several projects a year, we used to receive a frantic call from the Builder, "We're ready to pour footings. The truck is here. Is the mix design okay?" To which we would reply, "What mix design?," because we had not received it. Builder: "Well, can we pour anyway?" We always say no, making sure that the problem will never again arise on that project.

Another dispute may arise just after the first compression test cylinder reports come in, showing that some concrete is under strength. Next, the builder alleges that the testing agency's site person took, stored, handled, and transported the test cylinders wrongly. Besides, the person was just some kid who didn't know which end was up anyway. The testing agency stoutly denies all these ridiculous claims. The important point, whether or not the concrete is really under strength, is left hanging.

The project specification clearly states that provisions must be ready to protect fresh concrete from rain and snow. The first time it rains we suddenly discover that no protection of any kind is ready. Once more, blame is tossed back and forth while the real problem is obscured. The unacceptable concrete surface will still be there, too.

Opportunities for mistakes abound during the finishing process. Since the slab finish is exposed to the weather, it has to be durable. The best finish is therefore one that can be produced with the least working of the surface possible. It also must be roughened somewhat so that it is not too slippery for tires or shoes. The best way to define the finish: take the finishing crew foreman to another project. Show the foreman what you want for appearance. Spell out the finishing requirements in the project specification and review them with the foreman also. For these requirements, see Chapters 10 and 11. Take the time to explain why you want what you do. We've found that few engineers take time to give explanations for what they want. When we do, it really makes an impression. The people doing the work are appreciative of our concerns and become very cooperative.

Sometimes it seems as though everyone is trying to add water to the fresh concrete. You have to be alert. Extra water will find its way into or onto fresh concrete when you least expect it. If you see a concrete finisher with a bucket of water doing anything other than cleaning tools with it, get rid of the bucket. Some finishers do not feel they have done a good job unless they add water to the surface as they work. This practice does make finishing easier, but it results in a weakened surface that will deteriorate quickly. Avoid this potential problem too, with good use of a concrete preinstallation meeting.

If the project includes precast concrete, a similar preinstallation meeting with a similar result is necessary for:

- Precast concrete mix design(s)
- Precast concrete mix design(s) submission
- Precast concrete mix design(s) approval
- Reinforcement and accessories submission
- Reinforcement and accessories approval
- Shop drawing submissions, including schedule
- Shop drawing approvals
- Design requirements (if applicable)
- Design submission (if applicable)
- Design approval (if applicable)
- Manufacturing tolerances
- Testing procedures
- Inspection procedures
- Testing personnel qualifications
- Inspector qualifications
- Test and inspection reporting
- Precaster's quality control
- Fabrication, curing, storage, and handling procedures
- Erection plan
- Shipping plan
- Handling procedures at site
- Erection procedures
- Erection tolerances
- Erector's quality control
- Engineer's site quality control
- Repair criteria and procedures
- Acceptance criteria
- Criteria for reduced payment

The following examples discuss areas of potential dispute. You can avoid them by good communication in a preconstruction meeting.

Most precasters would prefer that the engineer not check their shop drawings. The checking process delays the start of production even if all drawings are correct. More delays occur if the engineer finds mistakes or makes changes. These delays cut into the already tight schedule, completely filling the time between precast concrete contract signatures and erection of the first piece. Yet if no one checks the shop drawings, serious mistakes will carry through to fabrication, erection, and the final structure. We know of two recent structures where members were made with insufficient reinforcement. The result in both cases was partial dismantling of the structures and replacement of the defective pieces.

We now have a policy of requesting from the precaster a list of what we call the basic piece marks. We check the shop drawings for the basic piece marks carefully. The precaster must follow corrections made on the basic piece mark shop drawing for the applicable associated piece marks. An example of a basic piece mark is T1, a typical 10-ft-by-2-ft, 55-ft-long double tee. Another is B4, a typical 8-in.-thick, 6-ft deep, 30-ft-long beam. An associated piece mark for T1 might be a double-tee mark T1a. It is the same in all respects as T1, including reinforcement, but has a blockout for a floor drain at one corner. An associated piece mark for B4 could be an L beam mark B4c, like B4, but 6 in. shorter.

Improper storage practices in the precaster's holding yard can result in damaged pieces. Your experience may suggest that you caution the precaster about support points and stacking heights, even though these matters are really not your responsibility.

Other potential trouble spots are erection tolerances, which affect connections, and the sequence of erection and connections. The Precast/Prestressed Concrete Institute has adopted erection tolerances, but you may have to adopt more to fit your project requirements. If you do, you are also probably aware of who the precast bidders are likely to be for your project. Before you add new tolerances, check with the prospective bidders to get a consensus of what's realistic. Then try to work from that information. Most erectors will want to make permanent connections as late in the erection process as they can. Doing otherwise interrupts and delays erection, costing expensive crane time. However, C-clamps and other temporary connections are not as strong as permanent ones. Frame stability may be less than it should. With the serious construction collapses of the past, the last thing anybody needs is a collapse waiting to happen. You should agree on some middle ground so that permanent connection installation does not lag much behind erection.

Another preinstallation meeting must be held for those involved with concrete reinforcement, especially if posttensioned (P/T) reinforcement will be used:

Materials submissions
Materials approvals
Shop drawing submissions
Shop drawing approvals
Design requirements
Placement tolerances
Stressing procedures
Stressing record keeping
Stressing record submission
Stressing record approval
Tendon cutoff procedures
Stressing pocket fill and seal procedures
Repair criteria and procedures
Acceptance criteria
Contractors' quality control
Inspection procedures
Inspector qualifications
Engineer's site quality control

Note the number of items in the list having to do with stressing the P/T tendons. That's because there are usually problems. Too often the stressing records submitted are too neat and the recorded elongations are exactly the same. We do not trust such reports. Another point: we do not allow the posttensioner to cut off tendons and fill the stressing pockets until all tendon-elongation discrepancies are resolved.

12.2.5 Construction

Whether you are the owner, builder, or engineer, if you laid the groundwork properly during the preconstruction phase, you will have fewer communications problems during the construction phase. Do not relax, though; answer questions from the other two major parties quickly and completely. Concentrate on building and maintaining trust. This business of trust is not easy. It requires setting your own ego second to the success of the project. Whether or not you are covered against any eventuality is not all that important. What is important is the completion of the project according to requirements—including being on schedule and under budget.

Some years ago, to sort out some ongoing construction disputes, the architectural, engineering, and construction management firms met. At the end of an inconclusive meeting, the architect's principal announced that he was leaving before the general contractor was to come in for the next meeting. His comment, "I do not want to talk to any contractors." The project finished with poor quality, behind schedule, and over budget. The lawsuits went on for several years, but the principal's ego was protected.

Many of us approach construction problems by ignoring them in the hope that they will go away or get better. They do not.

12.3 BUILDABLE DETAILS

Designers, do not contribute to construction problems by detailing items that have to be built like a watch. Our firm requires all design engineers to spend at least six months on a construction site so they can see firsthand which details work and which do not.

One situation that may arise is the case when a detail that works well with precast concrete is translated into a cast-in-place detail; it may have little chance of proper execution. Consider the detail shown in Figure 12-1. This detail is not uncommon in precast parking structures. It shows a beam column sliding joint. A few years ago a contractor called us in for help with a construction dispute. The plans showed this detail, but in cast-in-place concrete. Note the construction sequence required.

First, form the column and place it to the top of the haunch. Next, form and place the portion of the column above the haunch, then strip the column form. Install the lower slide-bearing assembly so that it will not be displaced during subsequent steps; form the beam. The end of the beam bottom form must be left open to allow the upper slide-bearing assembly to bear directly on the lower assembly. Install the upper bearing assembly so that it too will not be displaced during later steps. Seal between the upper bearing assembly and the beam form so that the cement paste will not leak out, leaving voids. Install the congested beam end and main reinforcement. Place the beam concrete.

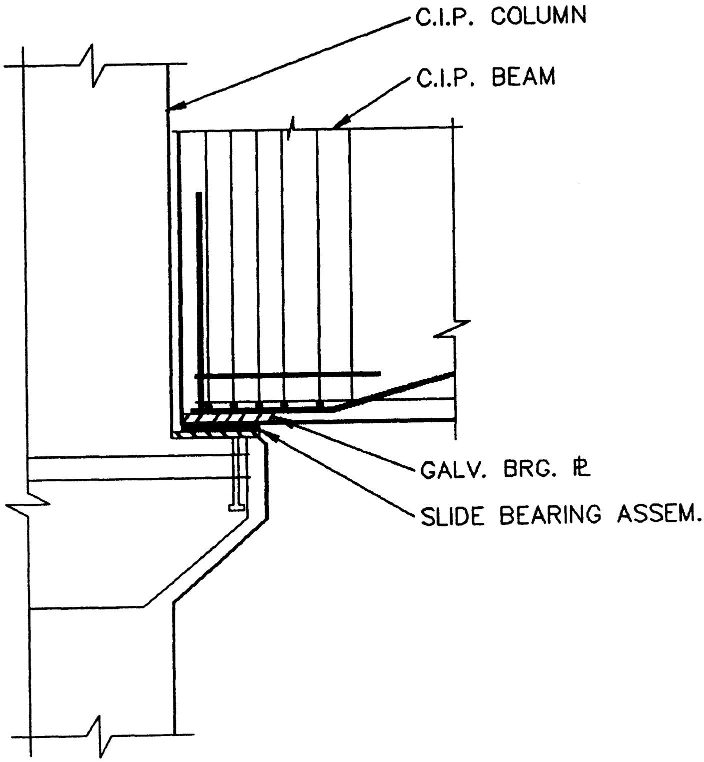


Figure 12-1. Beam slide bearing.

Figure 12-2 illustrates a similar detail for a slab bearing and sliding on a beam. While not as difficult to build as the detail shown in Figure 12-1, it is easier to build it wrong than right.

Rather than use details like those shown in Figures 12-1 and 12-2, we recommend using only details that are easy to build in the particular structural system. Simply put, avoid opportunities for error. With but a few specific exceptions, we recommend avoiding slide bearings unless no other solution works. Avoiding slide bearings may result in having to add a column to replace a group of beam slide bearings, but the extra initial cost will be saved in lower maintenance costs. The only condition where we use slide bearings is illustrated in Figure 8-30. There the vertical load on the bearing is low, producing low friction forces on the bearing surfaces. The anticipated movement is small because of the location of the joint in the structure and the fact that only one side of the joint is free to move.

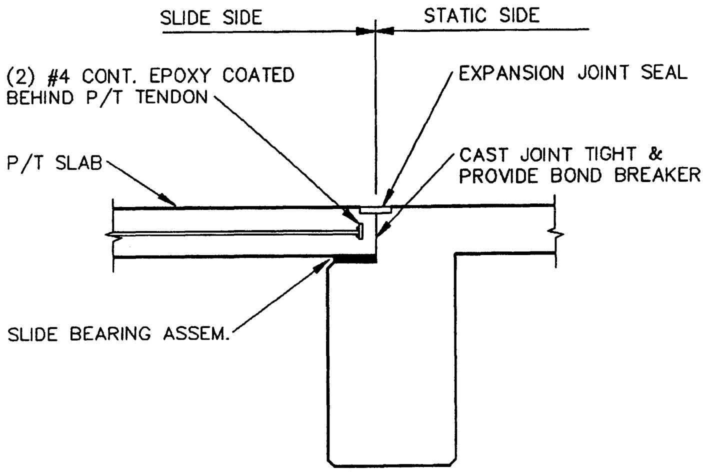


Figure 12-2. Slab slide bearing.

We were engaged as expert witnesses on a project built some years ago. One of the owner's complaints was that a large number of posttensioning tendons had little or no cover and were becoming exposed. The contractor had been instructed by the structural engineer to maintain a top cover of between ½ in. and ¾ in. Conscientious workmen can maintain a vertical tolerance of plus or minus 0.4 in. in placing reinforcement. Within that tolerance, the tendons would be placed with covers ranging from 0.1 in. to 1.15 in. The lower figure is just about what the engineer got. Why is the contractor being criticized?

12.4 CONSTRUCTION SEQUENCE

The task of building a structure with floors that continually slope carries with it a few problems that may not be immediately apparent to one who has never built one before. Obviously, the floors are not discrete segments, but form a continuous ribbon of concrete from bottom to top and back again. While the engineer will suggest a construction sequence and may give certain constraints, the builder must decide for itself what the best arrangement of construction joints and concrete pours will be. Figure 12-3 gives an example of a suggested construction sequence. The circled numbers indicate the order of concrete placement. (See Figures 12-4, 8-30, and 8-32 for sections cut on Figure 12-3. Also see Chapter 11 for further discussion.)

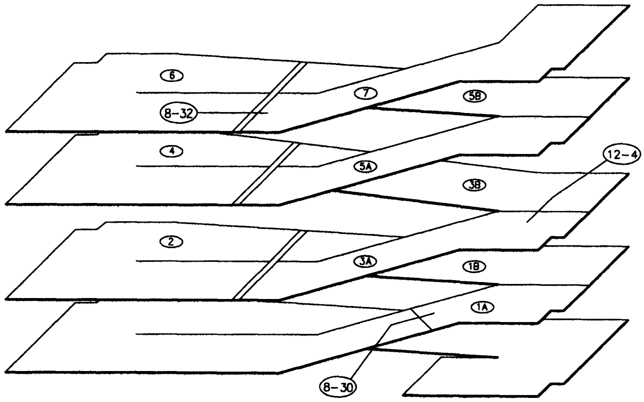


Figure 12-3. Example of a suggested concrete placement sequence.

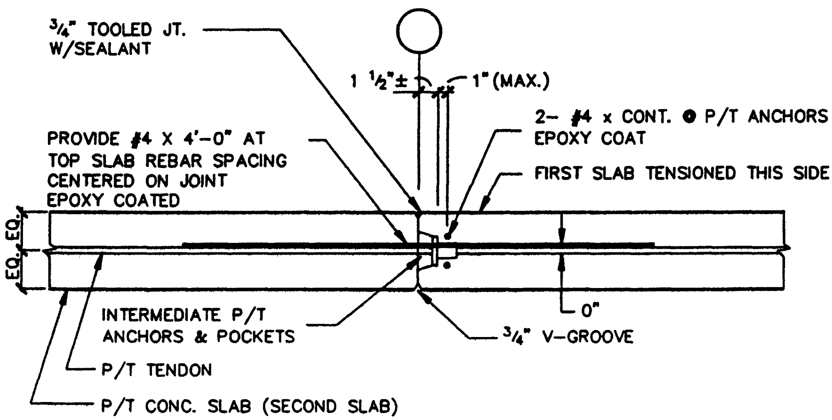


Figure 12-4. Section view at a slab construction joint.

12.5 SITE VISITS

12.5.1 General

Engineer, set the tone for all future visits with your first. Answer all questions promptly and completely. If you do not know an answer, say so instead of trying to come up with a statement you may have to retract later. Get a response back to the questioner quickly if you cannot answer at the site. *Listen* to the project superintendent. You can learn a lot if you're willing; the superintendent may have been working in construction before you were born.

Do your best to maintain good relations with the builder's people, but hold your ground on important requirements. We believe that the best way to approach a construction project is to have clear requirements in the contract documents. If, on a project, a requirement cannot be fully satisfied after the construction contract has been signed, there must be a trade-off to compensate the owner for getting less value than the contract stated. The trade-off could be a credit to the owner, a reduction in the originally-agreed upon construction time, or enrichment in some other aspect of the project. Whatever the eventual agreement on the particular requirement, record it. If the owner does not receive fair value, you, the engineer, have not performed.

If the contract documents give you the right to remove a contractor's or subcontractor's superintendent for nonperformance or incompetence and such turns out to be true, don't hesitate to assert your right. Life is to short to continue to buy trouble.

12.5.2 Before Supported Cast-in-Place Concrete Floor Placement

Rarely will a concrete parking structure floor receive a floor covering later. The only protection for the structural reinforcement is the concrete itself. Proper cover is therefore vital. Check to see that all reinforcement—nonprestressed and posttensioned—is placed correctly. Ensure that posttensioning tendons are free from kinks. Check for cover and alignment of tendon anchors. See that tendon sheathing is continuous and intact from anchor to anchor. Get all sheathing tears repaired according to the procedure specified in Appendix 11-2.

Ironworkers often tie sheathed tendons to support chairs or bars so tightly that the sheathing is crimped. The crimp provides a spot for moisture already inside the sheathing to condense. This condensation is the first step toward tendon corrosion. Get all too-tight ties redone. Better yet, work with the foreman and crew before they start. Explain to them what you want and why. You will likely find them pleased with the time you took and quite cooperative. If the ironworker foreman does not cooperate, get one who will.

Likewise, work with the concrete finisher and crew to be sure that they understand that you want the absolute minimum working of the concrete floor surface necessary to achieve the desired finish—screed, bullfloat, broom, or float. (See Appendix 11-1 for detailed requirements for concrete finish.) Be certain that everyone involved in the concreting operation understands that *no* water may be added to the concrete surface during finishing.

12.5.3 During Supported Cast-in-Place Concrete Floor Placement

Do not permit vibrators to be used to move concrete, even if it is superplasticized. Guard against overvibration, which will drive out entrained air and bring paste to the surface. Both results reduce durability; undervibration results in honeycombing.

The typical placement (pour) in a parking structure is rectangular in plan. Place the concrete beginning at one of the shorter ends of the rectangle and bring the pour face forward toward the opposite shorter end in the direction parallel to the two longer sides. Always keep the pour face parallel to the shorter sides, which will result in the open or forward face of the pour being kept as short as possible. You should not have to advise a builder to reduce risk by maintaining a short pour face. However, for the good of the project, we have had to do so.

Watch for posttensioned tendon sheathing tears, dislodged reinforcement, and crushed support chairs. Get these items repaired or replaced before they are covered by concrete. In long-span construction with relatively shallow members, there is little tolerance for misplaced or damaged reinforcement.

12.5.4 Field Observation Guidelines

12.5.4.1 Cast-in-Place Posttensioned Structure

We prefer to have a project resident on site full time during all cast-in-place posttensioned concrete construction to help guard the owner against deviations from the contract documents. If the project budget renders a full-time resident infeasible, then we would like to have one on site at least the day before each slab and beam pour to review conventional and posttensioned concrete placement. We would also want the resident on site during the pour itself to guard against reinforcement being displaced and posttensioning system protection being damaged. The resident should also review all the concreting, finishing, and curing operations, as well as concrete quality control testing.

One person can usually handle these tasks satisfactorily for each pour. If two or more pours occur simultaneously, more people will be needed.

Appendix 12-1 at the end of this chapter contains a guideline, which could easily be converted into a checklist for the resident, for reviewing the items that must be checked for cast-in-place posttensioned concrete prior to each pour.

12.5.4.2 Precast Structure

Field observations for precast concrete structures are confined to concern with erection and connection of the precast pieces.

There will be some cast-in-place concrete work, for instance, at the ends of the double tees for a pretopped double-tee structure, or over the entire tee for site-topped double tees. Treat that work as you would any other cast-in-place work, but recall the cautions about topping work in Chapter 8.

Watch for conformance to specified erection and connection sequences. Appendix 12-2 at the end of this chapter contains a guideline that could be converted into a checklist for the resident's use each day or each site visit.

12.6 PRECAST CONCRETE PLANT VISITS

Visit the plant supplying your project during fabrication of the first few pieces of each member category. Check for proper placement of reinforcement and cast-in assemblies such as connection hardware. If welding of conventional reinforcement is detailed, spot-check the welds. Review concrete test results. Visit the storage yard to see if members are stacked in a way that will not damage them. Revisit the plant at appropriate intervals.

Appendix 12-3 at the end of this chapter contains a checklist for use for each visit to the precast concrete fabrication plant.

12.7 SUMMARY

We have talked about the overriding need to establish good communication among members of the project team during the construction phase. Concentrate on prevention of common problems before they occur. The president of a large construction company once told us, "You are going to have problems on any job." The implication was that problems cannot be avoided. With good communications, many problems—though admittedly not all—can and will be avoided. Along that line, we discussed using buildable details to help ensure proper execution of contract documents. A well-planned construction sequence, covered here and in Chapter 11, is another preventive measure. Finally, we offered some help with site and precast plant visits during construction. During construction, the engineer's most important task is to guard against unplanned departures from the intent of the contract documents. What was designed must be built.

12.8 TRANSITION

Sometimes, providing a maintenance program for the new parking structure is part of the agreement between owner and engineer for professional services. Sophisticated owners will recognize the prudence of funding a maintenance budget and providing programmed maintenance from the beginning. In other cases, maintenance is not considered until the need becomes obvious. Chapters 13 and 14 review parking structure maintenance needs.

APPENDIX 12-1

GUIDELINES FOR FIELD OBSERVATION FOR A CAST-IN-PLACE POSTTENSIONED CONCRETE PARKING STRUCTURE

A.—P/T Tendons—General
- **1.**—Sheathing thickness
- **2.**—Tears repaired
- **3.**—Proper amount of grease
- **4.**—Encapsulation system

B.—Slabs
- **1.**—Main tendons
  - **a.**—Number
  - **b.**—Drape profile
- **2.**—Temperature tendons
  - **a.**—Number
  - **b.**—Location at center of slab
  - **c.**—Straight placement
  - **d.**—Properly supported so that they do not affect main tendons profile
- **3.**—Plates at ends
  - **a.**—Correct position
  - **b.**—Truly vertical
  - **c.**—#4 Bars behind plates
  - **d.**—1½″ min/2″ max cover for dead end
  - **e.**—Epoxy coating

- **4.**—Nonprestressed reinforcing
  - **a.**—At slab midspan
  - **b.**—At slab supports
  - **c.**—Epoxy-coated?
  - **d.**—Epoxy-coated chairs, tie wires?
- **5.**—Expansion joint
- **6.**—Bumper wall steel placement/Size
- **7.**—Stainless steel, plastic-tipped, or plastic chairs for slabs with bottom exposed.

C.—Beams
- **1.**—Stirrup number and spacing
- **2.**—Conventional rebars
  - **a.**—Top
  - **b.**—Bottom
- **3.**—Hook at ends of top and bottom steel to outside face of column in line with column steel
- **4.**—Tendons
  - **a.**—Number
  - **b.**—Location at midspan
  - **c.**—Location at ends
  - **d.**—Spot-check at ¼ point
at ¾ point
- **5.**—P/T plates
  - **a.**—Correct location
  - **b.**—Extra ties at each side of plate
  - **c.**—Rebars behind plates
- **6.**—Expansion joint
- **7.**—Steel from adjacent beam in place if required
- **8.**—Other

D.—Columns
- **1.**—Vertical rebars
  - **a.**—Number
  - **b.**—Location
  - **c.**—Splices
- **2.**—Ties
  - **a.**—Number
  - **b.**—Location

E.—Miscellaneous
- **1.**—Provisions for future construction
- **2.**—Provisions for precast facia connections
- **3.**—Provisions for expansion joint: structural, electrical, mechanical
- **4.**—Joints at stair towers
- **5.**—Electrical boxes and conduits in proper position
- **6.**—Forms to be clean: free of cut bars, tie wire, debris, etc. before pour
- **7.**—Cylinders for P/T concrete—leave open on site and cure with the members

8.—Undue slab and frame restraint
9.—Check drain number and locations

F.—Possible Problem Areas

1.—Forms shall not be removed before tensioning
2.—Stressing shall be performed according to specifications
3.—Vertical elevations to be checked before and after pouring and prestressing
4.—Ensure that removal of forms at pour strips is according to notes on structural drawings
5.—Contractor should be aware that the structure is going to shorten upon prestressing (May be accomplished by the Project Manager at preinstallation meetings)
6.—Use a reference point on the ground to check plumbness and elevations for all levels; **Do not use the previous floor as a reference**
7.—Check edges of structure to ensure cover for reinforcing and anchor plates
8.—Slab plates shall be vertical and shall not project above pour
9.—Tendons shall be straight in a horizontal position
10.—Be sure bottom of reinforcing cage is such as to have proper concrete cover
11.—If in your judgment, pour should not be allowed, inform project manager immediately

APPENDIX 12-2

GUIDELINES FOR FIELD OBSERVATION FOR A PRECAST CONCRETE STRUCTURE

A.—Connections

1.—Column/column
  a.—Column base grout
  b.—Column/column splice

2.—Beam/column
  a.—Exterior L beam
    1.—Coil rods/rebars
    2.—Pockets grouted
    3.—Bearing pads

- **b.**—Interior L beam
  - **1.**—Coil rods/rebars
  - **2.**—Pockets grouted
  - **3.**—Bearing pads
- **c.**—Interior inverted tee beam
  - **1.**—Coil rods/rebars
  - **2.**—Bearing pads
- **d.**—End spandrel
  - **1.**—Coil rods/rebars
  - **2.**—Pockets grouted
  - **3.**—Bearing pads

3.—Tee/beam
- **a.**—Exterior/interior "L" beam
  - **1.**—Coil rods
  - **2.**—Weld plates
  - **3.**—Bearing pads
- **b.**—End spandrel beam coil rods

4.—Tee/tee
- **a.**—Flange connections
- **b.**—WWF in topping/pour strip
- **c.**—Rebars at crossovers
- **d.**—Rebars at pourstrips/topping

5.—Wall panel/tee
- **a.**—Wall panel/beam
- **b.**—Wall panel/column

B.—P/C Members
- **1.**—Finish
  - **a.**—Columns
  - **b.**—Tees
  - **c.**—Beams
  - **d.**—Walls

C.—Miscellaneous
- **1.**—Provisions for future construction
- **2.**—Provisions for light standards at top tier
- **3.**—Provisions for expansion joint: structural, electrical, mechanical
- **4.**—Joints at stair towers
- **5.**—Electrical boxes and conduits in proper position.
- **6.**—Undue column and frame restraint

APPENDIX 12-3

CHECKLIST FOR PRECAST CONCRETE PLANT VISIT

A.—Previsit Review
- **1.**—Reviewer has obtained permission to observe operations.
- **2.**—One authority in plant has been designated to receive reviewer's report.
- **3.**—Reviewer has not interfered with plant operations.
- **4.**—Report of review has been given to the designated authority.
- **5.**—A copy of this review report has been sent to the plant.

B.—Pretensioning Strand
- **1.**—Strand is clean and free of dirt or form oil.
- **2.**—Strand is new and free of broken or nicked wires.
- **3.**—Strand is located per plans.
- **4.**—Strand mill report verifies size and strength.

C.—Tensioning
- **1.**—Strand vises are clean.
- **2.**—Strand jack has been calibrated within last year. (Report is available.)
- **3.**—An initial stress of approximately 5% of the final is applied.
- **4.**—Final stress is checked by measuring elongation and jack gauge reading.
- **5.**—If strand is depressed during stressing, frictionless hold-down devices are used.
- **6.**—Strand is depressed at the proper locations.

D.—Concrete
- **1.**—Mix design is approved.
- **2.**—All concrete admixtures are approved.
- **3.**—Admixtures containing calcium chloride are prohibited.
- **4.**—All admixtures are properly measured.
- **5.**—Admixtures applied to mix at proper time and per manufacturer's recommendation.
- **6.**—Aggregate used is of correct size.
- **7.**—Various aggregates are properly segregated.
- **8.**—Aggregates are stored and handled in a manner that will keep them clean.
- **9.**—Moisture content of aggregate is determined twice daily.
- **10.**—Gradation of aggregate is checked weekly.
- **11.**—Mill reports are available for cement.
- **12.**—Cement is protected from moisture during storage.
- **13.**—Scales for measuring cement, aggregate, and water have been calibrated in the last four months.

14.—All scales are in proper working order.
15.—Water in aggregate is accounted for in measuring water.
16.—Cement is not allowed to free-fall into mixer.
17.—Mixer is free of hardened concrete.
18.—Mixer blades are not excessively worn or missing.
19.—Concrete is mixed for the length of time equipment manufacturer recommends.

E.—Placing Concrete

1.—Concrete is not allowed to segregate in transporting from mixture to form.
2.—Concrete temperature is checked and maintained between 50°F. and 80°F.
3.—Concrete is properly vibrated by either internal or external vibration.
4.—No cold joints are allowed to form in adjacent layers of concrete.
5.—If placed in layers, lower layer is still plastic when the upper layer is placed and the layers are consolidated.
6.—Workmen do not move embedded items or reinforcing while placing concrete.
7.—If inserts, plates etc., are placed in concrete after it is placed, the concrete is still plastic and concrete around insert, etc., is properly consolidated.
8.—All pockets, blockouts, ledges, etc. allow air to escape during concrete placement.
9.—If ambient air temperature is below 40°F form is preheated to above 40°F prior to placing concrete.

F.—Finishing Concrete

1.—Concrete surfaces are screeded to correct dimensions prior to applying finish.
2.—Surfaces receiving form finish or manual finish are as specified in plans and specs.
3.—If broom finish is specified, striations are made in specified direction.
4.—If rough finish is specified, a minimum of 1/4" amplitude is maintained.
5.—If steel trowel finish is specified, final finishing operation does not start until all surface water has evaporated and surface cannot be easily dented with a finger.

G.—Curing Concrete

1.—Concrete is covered to prevent loss of moisture.
2.—If ambient temperature is below 50°F, form is heated or insulated to prevent concrete temperature from dropping below 50°F.
3.—If heat is used to accelerate cure, continuous recording thermometers are used to monitor temperatures.
4.—At no time is concrete temperature allowed to go below 50°F or above 175°F. If alkali-aggregate reactivity is a factor, keep the curing temperature as low as practical. Current research for PCI suggests 73°F.

H.—Concrete Testing
- **1.**—Cylinders are made in accordance with specifications.
- **2.**—Air content is checked in accordance with specifications.
- **3.**—Slump is checked in accordance with specifications.
- **4.**—Cylinder testing machine was calibrated within the last six months.
- **5.**—Cylinders are properly capped prior to testing.
- **6.**—Operator applies load to cylinder at a uniform rate.
- **7.**—Two cylinders are cured on the form in the same manner as the concrete and break at or above 3500 psi prior to detensioning strand or stripping product.
- **8.**—Twenty-eight-day cylinders are tested and concrete strength is in accordance with the specifications.

I.—Detensioning
- **1.**—Concrete strength has reached 3500 psi strength as required by design prior to detensioning.
- **2.**—Strands are detensioned by slowly heating the strand.
- **3.**—Strands are heated simultaneously from both ends.
- **4.**—Strands are detensioned in a symmetrical pattern.

J.—Quality Control
- **1.**—Plant does have a designated quality control department.
- **2.**—Quality control department supervises the tensioning, detensioning, and all concrete testing.
- **3.**—The quality control department checks dimensions on all products.
- **4.**—The quality control department maintains records of all stressing, testing, mill reports, etc.

K.—Storage
- **1.**—Dunnage is placed only at pick points.
- **2.**—Product is handled only at pick points.
- **3.**—Product is stored on a level plane.
- **4.**—Product is marked so it can be identified by date cast and location in the building.
- **5.**—If product is stacked more than three high, plant engineer has calculations showing he is not exceeding allowable concrete strength.
- **6.**—If product is stored at below 32°F, all inserts, sleeves etc. are sealed to prevent ice forming in them.

L.—Precast Double Tee Inspection
- **1.**—Tee forms
  - **a.**—Forms are clean and free of pits, bends, bowing, and uneven joints.
  - **b.**—Form will provide an approved finish.
  - **c.**—Form oil is applied properly per manufacturer's recommendations, and no puddles are left in form.
  - **d.**—Form is of correct configuration and dimensions.
  - **e.**—All skews and blockouts are correctly positioned.
- **2.**—Tee reinforcing
  - **a.**—Shear reinforcing in stems provided per drawings.

b.—Shear reinforcing held with nonferrous chairs which provide specified concrete cover.
c.—End bearing plate in place and held in proper position.
d.—Bearing plates have received the proper finish and have the correct reinforcing welded to them.
e.—Proper preheat used in welding reinforcing.
f.—Mill reports verifying size and strength of all rebar are available.
g.—Flange WWF located per plans and held with nonferrous chairs which provide specified concrete cover.
h.—Extra layer of flange WWF at 2″ flange.
i.—WWF from 4″ flange extends proper distance into 2″ blockout.
j.—Mill reports available showing proper strength and size for all mesh.
k.—Flange WWF extends through floor drain holes.
l.—Additional reinforcing around all flange holes.
m.—Flange connectors made per plan.
n.—Flange connectors properly spaced and held securely.
o.—Lifting devices in 2″ flange area only.
p.—All reinforcing held securely so that correct cover is maintained.
q.—Flange WWF lapped at least two cross-wires plus 2″ or a minimum of 8″ at all laps.

M.—Precast Beam Inspection

1.—Beam forms

a.—Forms are clean and free of pits, bend, bowing, and uneven joints.
b.—Form will provide an approved finish.
c.—Form oil is applied per manufacturer's recommendations, and no puddles are left in form.
d.—Form is of the correct configuration and dimensions.
e.—All skews and blockouts are correctly positioned.

2.—Beam reinforcing

a.—Mill reports verifying size and strength of all rebar are available.
b.—Proper preheat is used when welding reinforcing.
c.—No unspecified tack welds are used on the reinforcing.
d.—All bearing plates are in proper position and held securely so that they remain level during concrete placement.
e.—Bearing plates have received the specified finish and have the correct reinforcing welded to them.
f.—All reinforcing is correctly positioned.
g.—All reinforcing is bent to specified tolerances.
h.—Proper lap lengths are used for all lap splices.
i.—All reinforcing has the specified concrete cover.
j.—All reinforcing is held with nonferrous chairs.
k.—All reinforcing is held securely to prevent movement during concrete placement.
l.—All reinforcing is free of dirt, form oil, hardened concrete, etc.

m.—All steel that will be exposed in the final condition has received the specified finish.
n.—All inserts, plates, etc. that are to be patched in the final condition are recessed to provide the proper concrete cover.
o.—All sleeves are lined with the specified material—PVC, steel, etc.
p.—All lifting devices are so positioned that they will not be exposed in the final position.

N.—Precast Column Inspection
1.—Column forms
a.—Forms are clean and free of pits, bends, bowing, and uneven joints.
b.—Forms will provide an approved finish.
c.—Form oil is applied per manufacturer's recommendations, and no puddles are left in the form.
d.—Form is of the correct configuration and dimensions.
e.—Column corbels and beam blockouts are of correct configuration and provide for correctly sloped bearing surfaces.
2.—Column reinforcing
a.—Mill reports are available verifying all steel is of proper strength and size.
b.—Proper preheat is used when welding all reinforcing.
c.—No unspecified tack welds are used on the reinforcing.
d.—All main reinforcing bars are continuous without splices.
e.—All lifting devices are so positioned that they will not be exposed in the final erected position.
f.—All inserts, plates, etc. that must be patched in the final erected position are recessed to provide proper concrete cover.
g.—Column ties are properly spaced and all extra ties specified are provided.
h.—All column ties are bent to specified tolerances.
i.—All reinforcing has the specified concrete cover.
j.—All reinforcing is held with nonferrous chairs.
k.—All reinforcing is held securely to prevent movement during concrete placement.
l.—All steel that will be exposed in the final condition has received the specified finish.
m.—All reinforcing is free of dirt, form oil, hardened concrete, etc.
n.—Sleeves for beam connections are lined with specified material—PVC, steel, etc.
o.—Bearing and base plates are properly positioned and held securely so that they remain level during concrete placement.
p.—Provisions for future extension of columns conform to detail.

CHAPTER

13

DESIGNING FOR MAINTENANCE

Anthony P. Chrest and *Sam Bhuyan*

13.1 INTRODUCTION

Chapter 10, "Designing for Durability," addressed designing for reduced maintenance. Nothing is ever maintenance free, so designing for reduced maintenance is the best we can do. It is unwise to use the phrase "minimum maintenance," because it raises unrealistic expectations and leads to a false sense of security in both the designer's and the client's minds. This chapter will address the design of items that require more frequent maintenance. The point here is that if we cannot design an item for reduced maintenance, then we should design it for easy and inexpensive maintenance.

13.2 MAINTAINABILITY

13.2.1 Corrosion Protection System

The externally applied and the internal corrosion protection systems were discussed in Chapter 10. The externally applied systems include the sealers and membrane coatings. The built-in systems include use of silica-fume admixture, low water-cement ratio (0.40), adequate concrete cover (1½ to 2 in.), epoxy-coated reinforcement, and calcium nitrite. Refer also to Figure 15-58 in Chapter 15. The external corrosion protection systems require periodic reapplication and/or maintenance. Also, the external systems are subjected to traffic abrasion and wear, which make them less effective. They all eventually permit chloride ions (road salt) to get into the concrete and contribute to accelerated deterioration of the structure (see Figure 15-2).

Therefore, include the built-in corrosion protection systems to enhance the corrosion protection of the structure. This will reduce the overall maintenance required during the service life of the structure and will also help to extend the useful life of the facility. If you want to reduce maintenance costs, do not let budget constraints eliminate any of the important elements of the corrosion protection system. Guidelines for minimum level of corrosion protection for different climatic regions are included in ACI362.

13.2.2 Posttensioning Anchorages

Posttensioning anchorages, no matter what system is used, are one of two types—*live ends* or *dead ends*. The live end is the one where the jack is applied. The dead end is buried in concrete at the other end of the posttensioning tendon. After tendon jacking is complete and accepted, the tendon is trimmed off and the jacking pocket is filled to cover the tendon end and anchorage. The pocket is often filled with nonshrink, nonmetallic grout. The grout often shrinks, despite manufacturers' claims to the contrary. Then the grout falls out, or water seeps into the pocket around the grout. If water seeps in, the first sign of a problem is a line of rust-stained water leaking from the pocket. To reduce maintenance and to make the remaining maintenance easier, use a good grade of sealant to fill the jacking pockets instead of grout. Check the fire code in the project jurisdiction, though. It may require fire protection for the tendon end that some sealants alone cannot supply. However, sealant can be combined with a layer of ceramic fiber, or a fire-rated sealant can be specified. See Figures 13-1 through 13-3.

13.2.3 Precast Concrete Connection Hardware

Similar to the treatment of posttensioning anchorages, the hardware used to connect precast concrete elements is often covered up with grout. It often falls out or allows water to get at the ferrous metal connection hardware. The first sign of a problem is the same as described above. Rust-colored water runs from beneath the grout.

The connections need not be hidden. When properly designed, connections can look unobtrusive and tidy. The connection hardware is typically galvanized steel, which weathers to a dull gray color. Design the connections without field welds so that galvanizing does not have to be touched up in the field. Use bolted connections with slotted holes so that holes do not have to be flame cut when adjustments are necessary. Bolted connections also provide less opportunity for error than welded

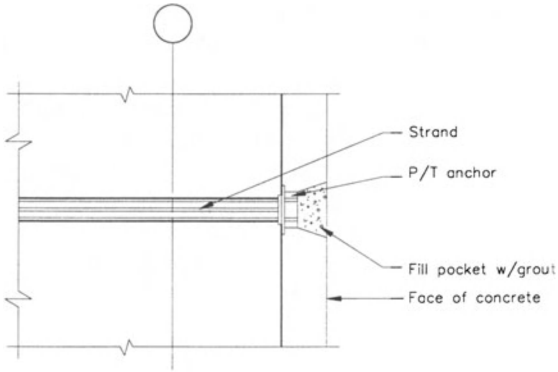


Figure 13-1. Posttensioning end anchor; tensioning pocket sealed with nonshrink, nonstain grout.

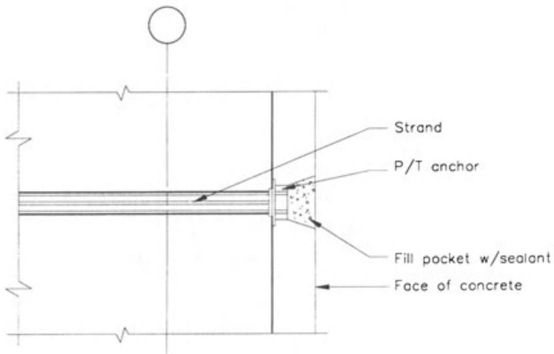


Figure 13-2. Posttensioning end anchor; tensioning pocket sealed with flexible sealant.

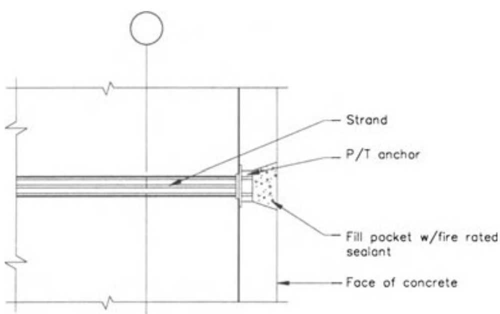


Figure 13-3. Posttensioning end anchor; tensioning pocket sealed with flexible fire-rated sealant.

connections. It is better to have a connection visible so that if there is any deterioration, it will show up immediately, instead of after corrosion is well along.

Erection loops are usually cut off and the ragged hole left is patched with grout. In time, the same old rust staining as described above starts. Lifting loops are put on the top surfaces of the precast elements. Leaving the holes unfilled leaves a place for water to stand and eventually provides a path for corrosion to start inside the element. Therefore, lifting loop holes must be filled. The solution is to use sealant to fill the hole, not grout.

13.2.4 Ferrous Metals

Protect all exposed ferrous metals. Hot-dip galvanizing will require less maintenance than electrodeposited galvanizing. Electrodeposited galvanizing, in turn, is better than zinc-rich paint, which is better than nonmetallic paint. As stated in section 13.2.2, avoid field welding or any other process that will require shop-applied protection to be damaged by field operations. Field repairs are seldom durable.

13.2.5 Stair Tread Nosings

This is a minor topic, but if designing a facility with a long service life, detail nosing embedments that have replaceable wearing surfaces. This case is a simple example of the idea that if you cannot make it durable enough, make it easily maintainable.

13.2.6 Expansion Joint Seals

Some expansion joint assemblies are designed for easy repair. The soft rubber gland, which is the part most likely to be damaged or to deteriorate, is designed for easy replacement. The damaged length of gland can be cut loose and pulled out of the extrusion holding it. A new length of gland is fitted into the extrusion, and the seams between new and existing glands field vulcanized. Figures 13-4 and 13-5 show examples of expansion joint assemblies that are not as easy to repair as that shown in Figure 13-6.

13.2.7 Membrane Waterproofing

See Section 10.3.4 and Figures 10-3 and 10-4. The unprotected membrane is obviously more repairable. Repairs commonly involve removal

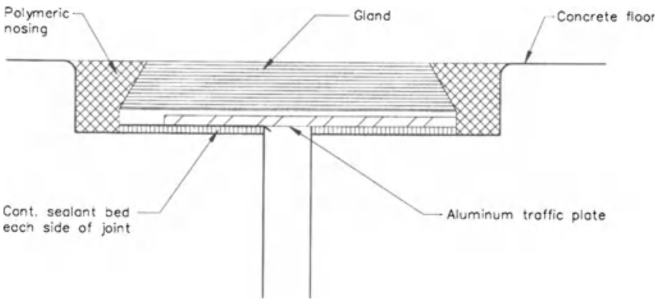


Figure 13-4. Premolded expansion joint sealant; example of a type among the more difficult to repair.

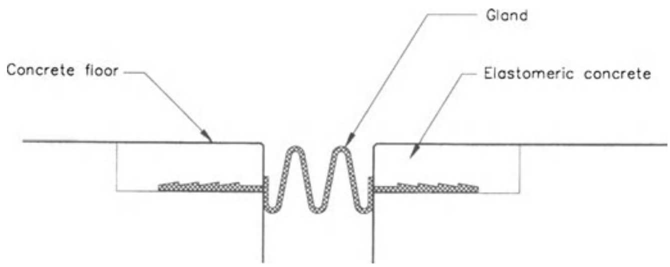


Figure 13-5. Elastomeric concrete edge, extruded rubber expansion joint sealant; example of a type among the more difficult to repair.

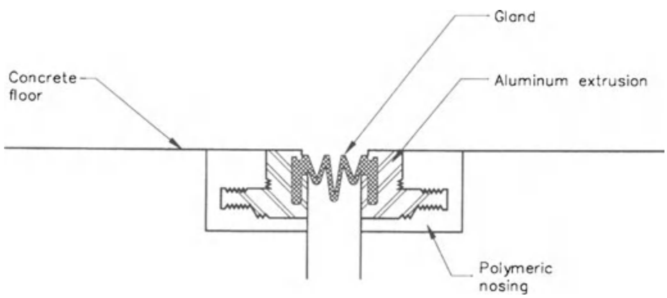


Figure 13-6. Metal-edged expansion joint sealant; example of a type among the easier to repair.

of the damaged membrane and some adjacent undamaged area. Then the cleaned area is primed. Next, new membrane is built up to the required number of coats and thickness. Finally, grit is broadcast into the fresh top coat to provide the proper wearing surface. Repairs can be done quickly. Night repairs to reduce interference with operations are common.

13.2.8 Mechanical Items

Make them easy to check and access when maintenance is needed.

13.2.9 Electrical Conduit

In site-topped double-tee construction and in cast-in-place construction, it will always be cheaper to conceal electrical conduit inside the concrete. In the first case, the conduit is laid atop the double tees and covered by the site-placed concrete topping. In the second case, the conduit is laid atop the formwork and covered when the floors are cast. In either case elements already there support the conduit at no extra cost. Conduit in pretopped double-tee construction has to be exposed because there is nothing to conceal it in. It hangs from the precast elements. Conduit in site-topped double-tee construction and in cast-in-place construction may be installed exposed, but installation cost will be higher.

However, repairs in exposed conduit are much easier than in those embedded in concrete. Also, if rewiring for more efficient fixtures is desired later, that task will be much easier. Maintenance people always favor exposed conduit.

The idea of exposed conduit often strikes people as distasteful. They believe that the conduit will be ugly and will detract from the facility. This view conflicts with the facts. The public simply does not look up. Consider the number of restaurants with exposed conduit and ductwork. No one ever patronized a restaurant because its ductwork was hidden. The same is true of parking structures. The issue is not esthetics. The issue is first cost versus life cycle cost.

13.3 SUMMARY

It costs more to build maintainability into a parking structure. However, initial costs have to be evaluated against maintenance costs for the expected useful life of the facility. Only then can an informed decision be made.

CHAPTER

14

MAINTENANCE

Sam Bhuyan

14.1 INTRODUCTION

The purpose of parking facility maintenance is to assure proper and timely preventive actions to minimize premature deterioration of structural elements and equipment failure. The material in this chapter has been adapted from the maintenance manual published by the National Parking Association. The reader should refer to the "Parking Garage Maintenance Manual, First Edition," for further details related to the maintenance of parking facilities.

This chapter is directed primarily at owners or operators of parking facilities. The material will assist architects and engineers to develop an understanding of the essential elements of parking structure maintenance. An important objective in designing new and restoring existing structures is to minimize operating and maintenance costs.

Parking facilities experience unusually harsh exposure conditions compared to most buildings. Temperature extremes, dynamic loads, and de-icer attacks are potentially destructive to all parking facilities. Premature deterioration, such as scaling, spalling, cracking, and leaking, can reduce the integrity of exposed concrete surfaces, especially the floor slab.

Deferred structural maintenance can lead to serious deficiencies. Premature deterioration of concrete floors is costly and, in extreme cases, can impair the structural system's integrity. To minimize the impact and the cost of structural deterioration, timely corrective and preventive maintenance action is needed. On the other hand, failures associated with certain operational features, such as lighting, parking equipment, or security monitoring devices, are relatively easy to correct. Preventive maintenance defers major repairs, and it is usually more cost effective and less disruptive to operations.

Parking facilities today are structurally more complex than ever. Challenges facing the designer include:

- Building codes and city ordinances impose design requirements not present several years ago.
- Integration of parking facility operational and structural features. Parking structures require special attention for structural maintenance in order to assure long-term structural integrity.
- Multiuse facilities or high-rise structures with integrated parking demand a life expectancy of well beyond 40 years.
- Quality control of materials, labor, and erection is more critical than in most buildings.
- The service environment is more severe and potentially more destructive than conventional structures are capable of effectively withstanding.

Parking facility operational programs also feel the demand of new challenges. These include:

- Equipment failures that occur owing to high utilization rate and sensitivity of components to adverse conditions. Automation instead of manpower is required to minimize operating costs.
- Pay facilities that are quite competitive and have little money for structural maintenance or for establishing a budget to support a maintenance program.
- Extensive salt use contaminating the concrete, allowing chloride to corrode embedded reinforcing steel, causing progressive surface spalling. Other destructive processes are structural-member cracking, leaking, floor-slab spalling, and surface scaling.
- Legal liability for code or regulatory violations and negligence to enforce security.

This chapter will address general and specific maintenance actions required to extend the life of parking structures. General maintenance is associated with operational aspects of the facility. Specific maintenance is associated with the structural system and is required periodically during the life of the structure. It is intended to provide guidelines for maintaining parking facilities at a satisfactory level of service.

TABLE 14-1. Maintenance Category

Structural System	Operational	Aesthetics
1. Floors	1. Cleaning	1. Landscaping
2. Beams, columns, and bumper walls	2. Snow and ice control	2. Painting
3. Stair and elevator towers	3. Mechanical systems	3. General appearance
4. Joint-sealant systems	4. Electrical systems	
5. Architectural sealants	5. Parking control equipment	
6. Exposed steel	6. Security systems	
7. Masonry	7. Signs (graphics) and striping	
8. Bearing	8. Inspection	
	9. Safety checks	

14.2 RECOMMENDED MAINTENANCE PROGRAM AND CHECKLIST

As shown in Table 14-1, maintenance needs for a parking facility can be separated into the following three broad categories:

- Structural
- Operational
- Aesthetic

Each of the above items has characteristics that are significantly different from the others, which will require each item to be treated separately. Also, maintenance must be performed at regular intervals if the full benefit of the effort is to be realized. Irregular or incomplete maintenance will provide a marginal return on the investment. To ensure that a maintenance program is functional, a schedule must be established and appropriate maintenance procedures must be followed.

When should an owner develop and implement a maintenance program for his facility? Ideally, develop and implement the program from the very first day of operation. Also, it is important to realize that the level of maintenance required for a facility is designed into the facility and further impacted by the construction quality. Refer to Chapter 13 if you are planning to build a new facility that will be easier to maintain.

The first step in developing and implementing a maintenance program is a walk-through review, which is a visual inspection of the entire facility. For existing or restored structures, limited nondestructive and laboratory testing may be required to qualify construction materials and as-built conditions. The walk-through review by an experienced restoration engineer assists in developing a tailored maintenance program for a specific facility based on factors such as:

- Age and geographic location of the facility
- Structural system and the design details
- Quality of construction material
- Construction quality or deficiencies
- Existing distress in structural elements, such as spalling, cracking, scaling, or excessive deformations
- Corrosion-protection system specified or implemented
- Operational elements of the facility

Once relevant maintenance needs are identified, procedures and schedules can be set up for maintaining the structure. Regularly scheduled walk-through inspections then form the basis for implementing and monitoring the effectiveness of the maintenance programs.

The walk-through inspections can be performed by the in-house maintenance staff. The in-house maintenance crews should be on the alert to locate distress of structural elements in accordance with fixed schedules. All such areas should be noted on plans for annual examination and evaluation by an engineer who is a restoration specialist. Areas of concern may then be further examined and evaluated under his guidance. If necessary, a condition appraisal of the facility and repairs should be performed, as discussed in Chapter 15. Refer to Section 14.2.2.8 for recommended frequency of walk-through inspections.

14.2.1 Structural System Maintenance

Structural elements may be divided into several distinct categories: floor slabs, beams, columns, bumper walls, stair and elevator towers, joint systems, and exposed steel. Structural maintenance consists of repairing deteriorated members, renewals of protective coatings, and replacement of sealants to extend the service life of the structure. Repairs may be cosmetic in nature or "major." If left undone, cosmetic repairs will not adversely affect the operation or integrity of structural elements. Major repairs correct distress due to spalling, scaling, and cracking, which, if left unattended, can contribute to accelerated deterioration of structural elements. A detailed explanation of deterioration and distress that are common to structural members is provided in Chapter 15. Selection of appropriate repair methods and materials are also discussed in that chapter.

Maintenance of the structure is considered very important since neglect of structural maintenance can lead to major problems and high repair costs. In addition to the actual repair costs, lost parking revenue costs during facility repairs can be substantial. Table 14-2 presents the recommended program for satisfying structure maintenance. Structural system elements are listed and the appropriate action required is specified.

14.2.1.1 Concrete Floor Slab and Surfaces

The most significant maintenance needs are associated with the floor slab and consume the largest share of the maintenance budget. Typical conditions of deterioration that influence the floor slab are delaminations, scaling, spalling, cracking, leaking, and leaching. These conditions can contribute to accelerated deterioration of the structure and adversely affect the serviceability of the floor slab.

Periodic application of surface sealer or elastomeric coatings can minimize floor slab deterioration by reducing water penetration. For structures in northern climates exposed to road salts, an unprotected concrete surface will eventually permit chloride ions to migrate in sufficient quantity to promote corrosion of embedded reinforcement. The "time to corrosion" and need to protect the floor surface depends upon factors such as geographic location of the structure, concrete quality (water-to-cement ratio), the clear concrete cover of embedded steel, the permeability of the concrete, and the corrosion protection system specified. Even for structures in the southern climatic region, sealer and coating will extend the service life of the structures. This is particularly true for structures that can potentially be exposed to airborne chlorides from large bodies of salt water.

The supported entrance and exit lanes, helix, turn lanes, and flat floor areas are subject to more severe exposure conditions. Special attention must also be given to turning areas at end bays, crossovers, gutter lines, and water ponding. The high-wear areas may require more frequent treatment of a sealer application than the general parking surface. All areas should be closely monitored, and if deterioration develops, heavier sealer application rates or an application of elastomeric coating may be necessary.

Elastomeric coatings installed on floors, over offices, or in commercial space should be examined for wear and tear. Damaged coating areas should be repaired as soon as possible to prevent leaking and contamination, since the integrity of the entire coating system and floor slab can be jeopardized if left unrepaired. These coating systems are usually proprietary and should be inspected and repaired by the system manufacturer's authorized representative.

TABLE 14-2. Structure Maintenance Schedule

Item	Description	Frequency: Annual	Frequency: As Required
1.0	Concrete slabs		
	1.1 Visual inspection	Perform	
	A. Floor		
	B. Ceiling		
	C. Floor coatings	Perform	
	1.2 Delamination testing & patching		
	A. Floor		
	B. Ceiling		a
	1.3 Protective sealer application		
2.0	Beams, columns, bumper walls, and connectors	Perform	
	2.1 Visual inspection	Perform	
	A. Columns		
	B. Beams		
	C. Bumper walls		
	D. Connections		
	E. Snow chute		
	2.2 Delamination testing & patching	Perform	
	A. Columns		
	B. Beams		
	C. Bumper walls		
	D. Connections		
	E. Snow chute		
	2.3 Protective sealer application		b
3.0	Stair towers		
	3.1 Visual inspection	Perform	
	A. Stairs & landings		
	B. Walls		
	C. Glass		
	3.2 Apply protective sealer to landings and stairs	Inspect	c
4.0	Joint-sealant systems		d
	4.1 Visual inspection & repairs	Perform	
	A. Expansion joints		
	B. Construction joints		
	C. Control joints		
	4.2 Crack routing and sealing	Inspect	Perform
5.0	Architectural sealants	Inspect	Perform
6.0	Exposed steel	Inspect	
7.0	Masonry	Inspect	Perform
8.0	Bearing pads	Inspect	Perform

[a]Reapply every 3–5 yr. Areas that are subject to more intense and severe exposure may require retreatment on an annual basis. Testing and inspection should be performed to determine degree of exposure. A traffic coating may be more cost-effective in areas of heavy leaking or floor deterioration.
[b]Apply sealer every 3 yr on those structural members subject to frequent leaking and saltwater splash.
[c]Sealer application should be made every 3 yr.
[d]Budget for total replacement every 10 yr.
Adapted from "Parking Garage Maintenance Manual, First Edition," Parking Consultants' Council, National Parking Association, 1982.

The ability of the sealer to reduce water absorption, screen chloride ions, and resist ultraviolet exposure should be verified by laboratory tests. The test procedures for measuring sealer effectiveness are provided in a National Cooperative Highway Research Program (NCHRP) report entitled "Concrete Sealers for Protection of Bridge Structures, NCHRP Report 244." In addition, the method of surface preparation and sealer application should be verified by trial applications in selected areas of the structure. Trial applications also help to identify sealers that can potentially "glaze" and create slip hazards.

The horizontal surfaces of a parking structure are usually subjected to traffic abrasion and wear, which can reduce sealer effectiveness. Sealers that penetrate deeper into the pores and capillaries of the concrete surface perform better than sealers that cannot penetrate as much. The NCHRP test method was developed for vertical bridge deck members that are not subjected to this traffic wear and abrasion.

The Alberta Department of Transportation (Alberta DOT) has developed a sealer test method that simulates this traffic abrasion and wear in laboratory samples. The laboratory samples are sandblasted and surface is abraded prior to testing. Test results published by Alberta DOT indicate that silanes generally perform better than the other generic type of sealers that are currently on the market. The silane sealer has a smaller molecular structure, making it possible for silanes to penetrate more effectively into the concrete than the other sealers.

Surface sealers should be reapplied every 3–5 years. The frequency of reapplication can be verified by annually monitoring the chloride content of the concrete at various depths from the floor surface to at least the level of the top mat of reinforcement. See sample form for an annual chloride monitoring program included in Appendix 14-1 at the end of this chapter.

Liquid applied membrane systems (traffic toppings) provide more effective protection against moisture and chloride contamination than surface sealers. The membrane system waterproofs the surface and allows moisture penetration only at localized imperfections, such as holes and tears. The membranes are capable of bridging some active floor systems with extensive through-slab cracking. Membranes are significantly more costly (by four to six times) than surface sealers and are susceptible to wear, especially in the driving and turning aisles of the parking facility. Recoating of the top layer of the membrane system is often necessary in high-wear locations. However, with proper maintenance, some membranes can last well beyond 10 years.

Preventive maintenance measures, such as applying a protective sealer and elastomeric coating, are most effective when applied to a floor slab that has not been contaminated by road salt. When sealers and elastomeric coatings are applied to older facilities with chloride contaminated floor slab, concrete deterioration cannot be effectively controlled owing to the continuing corrosion of embedded reinforcement. Therefore, the floor-slab maintenance cost for restored facilities is relatively higher than maintenance costs associated with a new parking facility; also, older facilities require more frequent repairs.

A facility should be monitored annually for concrete deterioration. Open spalls and delaminations in floor slab should be patched to reduce the impact of progressive deterioration and to maintain serviceability. Also, open spalls and exposed reinforcement are a tripping hazard for facility users. Owing to time or weather constraints some spalls may have to be repaired temporarily with asphalt or prepackaged repair materials. Asphaltic repair materials generally tend to trap and retain moisture, which in some instances can contribute to accelerated deterioration of the underlying and adjacent concrete. For relatively permanent repair, all unsound concrete must be removed. Corroding reinforcement should be completely excavated, cleaned, and epoxy coated. The repair area should then be patched with properly air-entrained, high-quality Portland cement-based patch materials, which are relatively impervious to moisture. Preventive measures and maintenance procedures for chloride-induced deterioration are fairly comprehensive, and usually help to minimize other forms of concrete deterioration.

Sealing cracks and joints in floor slabs is necessary to limit ceiling deterioration. All loose overhead concrete spalls are potential safety hazards that can damage vehicles or injure facility users. Remove loose overhead spalls as soon as possible.

Ponding is also a potential slipping and skidding hazard, particularly during the winter months, owing to freezing. Also, ponded areas can contribute to more rapid floor-slab deterioration and joint leakage. Eliminate isolated ponded areas by installing supplemental drains. Relatively large areas may require resurfacing to provide adequate drainage.

14.2.1.2 Beams, Columns, and Bumper Walls

Beam and column deterioration can adversely affect the structural integrity and the load-carrying capacity of floor slabs. Extensive deterioration can sometimes result in localized wheel punch-through by vehicles. Deterioration of these underlying members can be attributed primarily to water leakage through failed joints and floor-slab cracks. Vertical surfaces of columns and bumper walls are also susceptible to damage by salt water spray from moving vehicles.

Beam and columns adjacent to and below expansion joints are most susceptible to deterioration. Beam and column deterioration can be minimized by proper maintenance of joint sealant systems of the floor surface and sealer application on the column base and bumper wall. Water leakage can contribute to the corrosion of embedded reinforcement, freeze-thaw deterioration, rust staining, and leaching.

Concrete bumper walls can potentially be subjected to vehicle impact; the bumper walls should be monitored for cracking and spalling. Structural steel connections should be monitored for corrosion and distress due to impact. Ponded areas and gutterlines adjacent to bumper walls can contribute to the corrosion of steel connections, leaching, and rust staining. These adverse conditions generally require installing new curbs, supplemental drains, or concrete wash.

14.2.1.3 Stair and Elevator Towers

Without regular maintenance, leaks between the floor-slab surface and stair and elevator towers can be a problem. Quite often the leakage can be attributed to poor drainage conditions around the towers. Drainage can be improved by providing curbs and washes, which will then tend to minimize deterioration of underlying elements, such as doors, light fixtures, electrical conduits, metal stairs, exposed structural steel members, connections, etc. In addition, rust staining, leaching, and paint peeling can be aesthetically unpleasing. Frequent inspections and repair of the damaged elastomeric expansion-joint seal between the tower and floor surface will also minimize distress caused by leaking.

Stairs and landings are exposed to salt contamination, and concrete surfaces require periodic resealing. Masonry walls should also be maintained by sealing the surface. Stair and elevator wall cracking should be evaluated and repaired. Door and window glazing, if present, should be replaced when damaged or leaking.

14.2.1.4 Joint Sealant Systems

Expansion, construction, and control joints in parking structures accommodate movements due to the volume change of concrete. The volume-change movement can be attributed to concrete shrinkage, the seasonal temperature variations, elastic shortening in prestressed structures, and creep of concrete. The joints in the structure are sealed with flexible elastomeric sealant to minimize water leakage and accelerated deterioration of the structure. In addition to the joints, random floor-slab cracking can also contribute to leakage and to the deterioration of the structural members. When and where appropriate, seal random through-slab cracks with flexible elastomeric sealant material. A discussion of concrete cracking, joint distress, and causes of sealant system failure is included in sections 15.3.3 and 15.3.4 in Chapter 15.

Joint-sealant systems have a limited life expectancy. Depending on the structural configuration, wear and tear, exposure conditions, and the joint-sealant system can be expected to provide 8–10 years of service prior to complete replacement. Spot-patch repair of joints is cost-effective only when less than 30% of the joint-sealant system shows deterioration or leaking. Concrete surfaces adjacent to expansion joints, construction joints, control joints, and sealed random slab cracks should be treated periodically with a surface sealer. Also, the concrete surfaces adjacent to the joints and cracks must be inspected for deterioration to maintain effectiveness of the joint-sealant system.

14.2.1.5 Architectural Sealants

Periodic inspection of the condition of architectural sealants and repair is necessary. Areas include sealants at window and door framing, in block masonry, exterior sealants in or adjacent to concrete walks, drives, curbs, and landings, at structural precast to adjacent surfaces or dissimilar structure, all control joints, and at exterior perimeters of curbs. Replace all damaged sealants.

14.2.1.6 Exposed Steel

Exposed steel within a concrete parking facility is generally limited to the structural steel connections, stairs, pedestrian railings, vehicular guardrails, and metal decking. Premature deterioration of metal components is caused by neglect and the chemical reaction between the metals and the corrosive environment. Check for potentially unsafe conditions due to the corrosion of connections monthly. Treatment of metals with proper surface preparations and a quality paint will minimize corrosion.

14.2.1.7 Masonry

Most concrete masonry walls contain nonprestressed reinforcement. Recommendations for the inspection, cleaning, tuck-pointing, and sealing of these walls are similar to those for concrete walls.

14.2.1.8 Bearing Pads

Beams, columns, spandrels, and floor members are set on bearing pads. Bearing pads may be made from steel, hardened plastics, TFE assemblies, neoprene, or fiber reinforced neoprene singly or in combination. They help ensure the correct placement of loads and provide partially restrained lateral movement between structural members.

Weathering, misplaced, or omitted pads and excessive movement can result in the movement of pads from their original positions. As pads move or fail, the resulting deterioration, cracking, spalling, and excessive deflections can affect the structure. Deterioration should be evaluated by an engineer and repaired. Bearing pads that are missing must be replaced.

14.2.2 Operational Maintenance

Special emphasis is placed on operational maintenance because malfunctions or breakdowns can take part, or all, of the facility out of service and/or reduce user security and safety. Operational maintenance involves regular and scheduled inspection and repair of items such as parking equipment, elevators, electrical systems, heating and ventilation systems, security monitoring, and fire-fighting equipment. Routine cleaning, including sweeping and washdown, is also a part of operational maintenance. Snow and ice control is important in climates where appropriate. Table 14-3 presents a recommended program for satisfying operational maintenance needs. A more detailed checklist of maintenance tasks is included as Appendix 14-2 at the end of this chapter.

14.2.2.1 Cleaning Requirements

One of the most frequently overlooked aspects of parking facility maintenance is proper floor cleaning. Sweeping can be accomplished by using hand brooms or mechanized sweepers designed for use in buildings. The maximum weight for mechanized sweeping equipment in a parking facility is generally limited to 8000 lb gross weight or 4000 lb per axle.

All dirt and debris should be removed from the facility. Dirt and debris should be kept away from drain basins and pipes, as blockage may cause leaking and failure. Dirt and debris in expansion joint systems can potentially damage elastomeric seals.

TABLE 14-3. Operational Maintenance Schedule

		Frequency		
Item	Description	Monthly	Annual	As Required
1.0	Cleaning requirements			
	1.1 General cleaning	Perform		a
	1.2 Sweeping	Perform		a
	1.3 Remove ponded water			Perform
	1.4 Floor-surface flushdown		Perform	a
2.0	Snow removal and ice control		Perform	
3.0	Mechanical/electrical systems			
	3.1 Drainage system (includes sediment trap)		Inspect	
	3.2 Elevators	Inspect		Perform
	3.3 Ventilation equipment	Inspect		
	3.4 Fire protection	Inspect		
	3.5 General lighting	Inspect		
	3.6 Exit and emergency lighting	Inspect		a
	3.7 Emergency generator	Inspect		
	3.8 Parking equipment	Inspect		
	3.9 Security monitoring	Perform		a
	3.10 Safety checks	Perform		a
4.0	Graphics and striping		Inspect	
5.0	Inspection (see structural-maintenance schedule)		Perform	

[a]More frequent performance of this task is suggested.

Grease buildup in parking spaces should be removed with appropriate degreasers. In addition, a poultice made with limestone, sodium hydroxide solution, and trisodium phosphate (TSP) is effective in cleaning oil spills. Refer to the *Concrete Construction* magazine publication "Removing Stains From Concrete" for more detailed information on removing stains. Excessive grease build-up is common at the entrance gate and adjacent to the cashier's booth. Grease should be removed regularly.

Salt accumulates during winter months and should be removed each spring by flushing the surface. A flushdown with low-pressure water hoses is advisable after the facility has been swept. Flushing can be incorporated with a check of the standpipe system, which can be coordinated with the deck washing. Flushing of critical areas such as entrance and exit lanes, turn lanes, flat areas, and main drive aisles should be performed frequently during the winter when moderate temperatures prevail. If moderate temperatures do not prevail, in-house maintenance personnel should use sponge mops or brooms to remove accumulated salt-laden slush or water. Entrance and exit lanes would benefit most from periodic removal of snow and slush deposits.

When flushing the floor surface, avoid washing sand into the drain system. Temporary burlap or straw filters are effective methods to prevent sand from plugging drains.

14.2.2.2 Snow Removal and Ice Control

It is possible to damage the joint-sealant and deck-coating systems with abnormal and/or abusive traffic. The three most common causes of damage to the systems are:

- Dropping heavy or sharp objects onto the surface
- Dragging heavy or sharp objects across the surface
- Unprotected snow removal equipment and studded tires or tire chains

To minimize damage, the following snow removal guidelines need to be implemented:

1. All expansion joint locations must be clearly marked by means visible to the equipment operator while the deck is covered with snow. It is recommended that markings such as red, yellow, or orange stripes be placed on the adjacent walls or columns at each end of the expansion joint. Where walls or columns do not exist, place safety flags, properly anchored 55-gal drums filled with sand, or other means of identification at each end of the joint.
2. Piling snow in corners or other locations within the facility is not recommended. Snow varies greatly in weight, but packed snow can be quite dense, and ice often forms at such piles during freeze/thaw cycles. While the structure can probably safely support most snow piles, the weight may be sufficient to crack the concrete. Such cracking could permit water (and dissolved salt) penetration of the concrete, which could hasten the deterioration of the slab. Therefore, the accumulation of snow piles over long periods of time must be avoided.
3. Establish a snow removal pattern so that the snow removal equipment approaches the expansion joints at an angle not greater than 75 degrees and preferably parallel to the expansion joint. This will reduce the chance of catching the snowplow blade on the expansion-joint system. Snowplow damage is not usually covered by the expansion-joint warranty. Snow and ice packed in an expansion-joint system can contribute to seal failure. Follow manufacturer's guidelines

and where necessary, clean snow in the expansion-joint gland to minimize failure of the seal.

4. Snow is normally plowed utilizing a vehicle with an axle weight of 4000 lb maximum. Snowplow blades and bucket loaders should be modified with a heavy rubber cutting edge attached to the bottom, or with "shoes" or other positive means designed to keep the steel blade from making contact with the concrete floor surface. It is necessary to keep the steel blade a minimum of ⅛ in., but preferably ½ in., above the floor surface to avoid damage to the concrete, deck coating, and expansion-joint sealant systems. Whenever possible, using a power brush for snow removal is suggested.
5. Snow is plowed to specific locations within the facility where a bucket loader or industrial snowblower can be used to throw the snow over the side. In congested areas, snow chutes or off-peak snow removal operation may be required to effectively deal with heavy snowfall. Care must be taken with a bucket loader or snowblower to avoid damage to the concrete walls, connection hardware, deck coating, and expansion joints.
6. Schedule an inspection of the deck coating, control joints, expansion joints, and concrete walls in early spring to assess the winter's wear. If damage has occurred, repairs can be scheduled in the upcoming construction season.

The slope of the floor is designed to drain surface water as quickly as possible. However, certain areas are particularly vulnerable to freezing when water drains from sun-warmed surfaces into shaded areas. This occurs on the top level and at entrance/exit lanes. In-house maintenance crews must be aware of these areas and take steps to control icy conditions as they occur.

Most common chemical de-icers can have major physical effects on concrete. Several de-icers are listed with a general description of common effects on materials typically located in and around the parking facility. The effect on any single material may progressively affect the entire concrete system. It must be noted that no de-icing compounds, including road salt, work in extremely cold temperatures.

Some of the common chemicals associated with ice control are:

1. *Sodium chloride* (halite, table salt, or rock salt) has little chemical effect on concrete, but will damage lawns and shrubs. It does promote metal corrosion. **Do Not Use** Sodium chloride by itself or packaged with corrosion inhibitor.
2. *Calcium chloride,* a major active part of many proprietary de-icers,

has little chemical effect on concrete, lawns, and shrubs, but does cause corrosion of metal. It is particularly hazardous to prestressed steel. **Do Not Use.**

3. *Ammonium nitrate or ammonium sulfate* will not harm most vegetation. It may lead to complete destruction of concrete because of direct chemical attack on concrete reinforcement. **Do Not Use.**
4. *Calcium magnesium acetate* (CMA) helps break the bond between the ice and driving surface. It acts similarly to salt, but is slower-acting, typically takes 10 to 15 minutes longer. CMA has no known adverse affects on concrete or embedded reinforcement. CMA will not damage lawns or shrubs and like road salt, will perform at temperatures as low as 20°-F. It will be available more readily once it can be processed more economically. Other acetates such as sodium and potassium are also available. CMA is generally used in its granular form, but is also available as a liquid.
5. *Prilled urea* does not damage concrete, lawns, shrubs, or metal. Prilled urea does not behave like common road salt. It will attract moisture and stay "mushy" longer than salted areas. It also will take longer than salt to penetrate ice, and work best at breaking up ice with solar action. Prilled urea has little effect after dark or at temperatures below 24°F. For best results, use urea to break up ice and then shovel. Urea should not be used in proximity to streams and lakes.
6. *Ethylene glycol,* or a solution of ethylene glycol and urea, is used by many airports for ice control on runways and planes. While effective to about 0°F and nondamaging, it is more expensive than urea, and local ordinances may prohibit its discharge into sewers. Glycols also tend to be quite slippery.

It is important to minimize the use or the amount of deicing chemicals during the first two years of concrete curing. It is emphasized that properly designed, air-entrained, cured concrete is required in order to have a durable concrete structural system. Also, do not use sodium chloride, calcium chloride, ammonium nitrate, or ammonium sulfate on the concrete surface.

Ice build-up can be controlled by using hot sand. Do not apply deicing chemicals containing chloride directly to the concrete unless extremely icy conditions exist. Small amounts of salt (3–5% of weight) added to sand can be very effective at increasing traction and preventing skid problems. Apply the sand/salt mixture to ice only as needed.

Drain systems should be protected against runoff-related sand accumulating during ice control operations. Temporary burlap or straw filters should be used to prevent drain clogging and possible damage to drain systems.

The following is a series of recommended de-icing measures in order of decreasing preference:

1. Clean, plow, and scrape off ice and snow; do not use de-icing agents.
2. Use sand to increase traction; when washing down the floor, protect the drainage system.
3. De-ice with urea. See if CMA or other acetate products are available economically in your area.
4. Use a mixture of sand and calcium or sodium chloride, but protect the drainage system.

14.2.2.3 Mechanical Systems

All mechanical equipment should be inspected regularly and serviced as required. Mechanical systems include the drainage system, ventilation equipment, elevators and shafts, and fire-fighting equipment.

Drain basins, inlet grates, leaders, downspouts, heat tape, and all support brackets should be inspected for leaks, damage, or distress. Sediment basins should be cleaned as required to prevent clogging and water ponding. Floor sleeves should be examined and sealed against leaking also. Inspect all electrical connections and make repairs to assure a safe heat tape system. All deficiencies noted should be recorded and appropriate action programmed.

Where water is ponding, such as near corners or at other areas of floor surface, consideration should be given to installing supplemental floor drains. A small drain and leader to the floor below can alleviate hazardous ice build-up and minimize chloride ion infiltration into the concrete. The minimum recommendation would be to broom or sponge-mop the water to existing floor drains. Ponding water, as it evaporates, leaves behind a high concentration of salt, which can migrate into the concrete and contribute to corrosion of the reinforcement progressive concrete deterioration.

Heating, ventilation fans, air-conditioning equipment ductwork, and the necessary support systems should be inspected. Service manuals provided for this equipment by the manufacturer should be checked for appropriate maintenance action. All servicing required should be performed promptly and to the specifications provided by the equipment manufacturer. Replacement belts and pulleys for fans should be kept in stock. Replacement of worn or damaged parts should be completed periodically to minimize the chances of breakdown. All questions regarding servicing should be directed to the equipment manufacturer or supplier.

The elevators, shafts, and associated hardware should be inspected and serviced in accordance with the elevator manufacturer's recommendations. A maintenance agreement with a reputable elevator service company or the manufacturer is the most effective method for servicing the elevators to minimize breakdowns. Water leaking into the elevator shaft should be corrected as soon as it is discovered. Use of an auxiliary pump system may be required if water build-up becomes excessive.

Standpipe and sprinkler systems should be periodically charged and activated to check for proper operation. Coordinate the standpipe system check with the fire department and your washdown of the floors. Portable fire extinguishers should be checked for satisfactory charge. Broken extinguishers, damaged fire hoses, and cabinets should be repaired or replaced.

Before the onset of cold weather, the parking facility must be winterized. Water risers, fire protection systems, standpipes, landscaping sprinklers, and hose bib systems must be flushed and completely drained to prevent ice build-up and bursting of pipes. Drain lines and other underground piping should be flushed and checked for blockage.

Heating systems should be started and tested. Often overlooked in winterization procedures are the heating units in the parking equipment, which must be checked for proper operation. In the spring, after danger of freezing has passed, these procedures must be reversed and plumbing systems restored to full operation. Heating systems must be shut down.

14.2.2.4 Electrical System

The effective operation of any parking facility requires adequate lighting to ensure that users can move securely and easily within the facility—motorists as well as pedestrians. If the existing lighting system becomes functionally obsolete, it should be replaced with a new system. New systems, such as high-pressure sodium vapor and metal halide, can be substantially more energy efficient than the older fluorescent system. Replacement of fluorescent light fixtures should be considered since they are inefficient in cool weather. Capital expenditure, maintenance, and energy savings must be evaluated for "cost-effectiveness."

An annual detailed inspection of all fixtures and equipment is required. Inspect pedestrian exit and emergency light fixtures on a more periodic basis. Fixtures not working properly should be repaired or

TABLE 14-4. Relamp Schedule

Lamp Type	Typical Rated Life (Hours)	Typical Mean Output (% of Max.)	End of Life Output (% of Max.)	Recommended Replacement Life (% of Rated Life)
High-pressure sodium	24,000	85%–90%	70%–80%	80%
Metal halide	10,000–20,000	75%–80%	60%–70%	70%
Fluorescent	12,000–20,000	85%–90%	75%–80%	80%

replaced; damaged lenses should be replaced; timers and photo cells should be periodically checked and calibrated.

Studies by manufacturers have shown that the energy consumed by some lamps increases rapidly toward the end of lamp service life. Scheduled relamping before burnout may reduce energy costs. Review service life expectancy versus power consumption with your local lamp supplier. See Table 14-4 for typical relamping information.

Electrical conduit exposed to leaking water or rusting should be cleaned and repaired. Damaged conduit that has pulled loose from its mount or has exposed conductors should be maintained in proper condition. Damaged or rusted electrical panels should be cleaned and repainted or replaced.

If the parking facility is interconnected with an emergency generator, periodic checks of the system should be made per the manufacturer's recommendations to assure reliance of the generator system.

14.2.2.5 Parking Control Equipment

All parking equipment within the facility should be examined, and a preventive maintenance program should be established to minimize breakdowns. It is prudent to maintain an inventory of critical components so that your maintenance crew can quickly repair the equipment. Periodic servicing of the parking equipment is essential for smooth facility operation. A service agreement should be established with the parking equipment supplier so that the supplier is on call to provide assistance in the event of a breakdown.

Equipment added to the facility after the original installation must be compatible with the existing equipment. Copies of operation and service manuals for all parking equipment should be kept nearby for easy reference. A log of maintenance and service calls should be established for each piece of equipment.

14.2.2.6 Security

As evidenced by interest and attendance at conventions of various parking groups, security is one of the biggest problems in the industry today. Security is an ongoing process that good design alone will not achieve. Careful selection of equipment, training, and management by security professionals is equally important.

Two types of security measures, "passive security" and "active security," are employed to maximize security in a parking facility. Passive security does not require human response. These security measures are a physical part of the facility, such as lighting and glass-walled stair towers. The common thread among all passive features is visibility—the ability to see and be seen while in a parking facility. Lighting is universally considered to be the most important security feature in the facility. Staining concrete has also proved to be a cost-effective method of increasing brightness. White stains on ceilings, beam soffits, and walls can improve brightness; however, staining seems to encourage graffiti, which can sometimes tend to hurt the perception of security. The additional general maintenance and upkeep are also important in maintaining security.

Active security measures invoke an active human response. The active systems, such as those listed below, where applicable, should be tested frequently to ensure proper operation:

- Television surveillance camera
- Audio-monitoring devices
- Telephone in elevator cabs and cashier's booth
- Panic hardware on doors
- Security monitoring
- Alarms
- Other special features

Security policing of the facility, such as a scheduled drive-through by trained security personnel, should be maintained to deter undesirable behavior within the facility. The importance of security monitoring cannot be overstressed; it is essential to maintain security systems in proper working order at all times. Periodic inspection of all equipment and observation by in-house personnel is required. When deficiencies in security monitoring are found, corrective actions should be taken immediately.

14.2.2.7 Graphics and Striping

Proper graphics are essential to the smooth operation of the parking facility; they must be kept clean and visible. Graphics combining words or symbols with arrows are most effective for traffic and pedestrian movement control. All entrance, exit, traffic directional, and display signs should be kept clean and legible. Paint or facing material for graphics should be examined annually for deterioration and repainted or repaired as required. Also, replace lights in illuminated signs.

Floor-level and stair-elevator-tower designations directing patrons to their parking locations should be kept legible and visible from all entrances and exits. Stair and elevator-tower level designations should be located on both sides of the door.

Floor striping should be inspected each spring after cleaning and should be repainted as required. In older facilities, consideration should be given to restriping so as to accommodate smaller cars. Be careful to maintain proper illumination levels when relocating designated pedestrian walkways. The restriping plan should not remove the walkway from underneath a lighted source, thus creating a tripping hazard. Restriping should be performed after resealing the concrete floor surface.

14.2.2.8 Inspection

Annual inspections are the best way to assure that minor conditions requiring repair are contained and corrected before they cause major problems. Inspections should be performed each spring to determine if salt and wear exposure has caused concrete deterioration. The inspection and concrete testing are recommended to be accomplished by qualified restoration engineers.

A sample inspection checklist is included in Appendix 14-3 at the end of this chapter. This checklist, appropriately modified, may be used by in-house maintenance staff or the restoration specialist to document existing condition of the structure. A similar checklist can also be prepared for the operational and aesthetic elements discussed in this chapter.

The results of the initial inspection can be summarized as shown by the sample forms included in Appendix 14-4 at end of this chapter. Once documented, the initial inspection results then form the database for the annual review and inspection dates.

14.2.2.9 Safety Checks

It is important to minimize potentially unsafe conditions within a facility. Certain elements of operational and structural maintenance can have an impact on safety. Also, some features that enhance security tend to enhance safety.

Structural system maintenance will tend to minimize tripping hazards and potential injury to facility users due to loose overhead concrete. Concrete spalls can develop on ceilings as well as on bumper walls, precast panels, and concrete facades. Proper maintenance of the pedestrian guard rails and inspection of vehicular barriers will minimize unsafe conditions.

Ice and snow control will tend to reduce slipping and skidding hazards for pedestrians and vehicles. Proper selection and application of surface sealer is important to reduce glazing, which tends to make surfaces slippery. Repainting the face and edge of concrete curbs annually is essential to maintaining high visibility and minimizing tripping hazards. Other safety considerations include maintaining proper illumination levels within the facility, lighting exit signs, emergency lights, fire safety equipment, and active security systems. In addition, in enclosed or underground structures carbon monoxide detectors and other ventilation systems should be checked daily for proper operation.

14.2.3 Aesthetic Maintenance

In addition to operational and structural maintenance needs within the parking facility, aesthetic features also require regular maintenance. The most obvious features of the parking facility associated with aesthetics are landscaping, painting, and the facility appearance in general. The parking facility deserves maintenance similar to other buildings (Table 14-5).

TABLE 14-5. Aesthetic Maintenance Schedule

		Frequency	
Item	Description	Annual	As Required
1.0	Landscaping	Inspect	
	1.1 Mow grass		Perform
	1.2 Prune shrubs		Perform
	1.3 Tend flower beds		Perform
2.0	Painting	Inspect	
	2.1 Clean and paint		Perform
3.0	General appearance	Inspect	
	3.1 Take corrective action		Perform

Adapted from "Parking Garage Maintenance Manual, First Edition," Parking Consultants' Council, National Parking Association, 1982.

14.2.3.1 Landscaping

Landscaping features around the parking facility enhance its appearance. Flower beds, shrubbery, and grass plots should be well attended. Planters should be cleaned and cultivated frequently. Landscaping should be done judiciously so as not to provide hiding places and reduce security.

14.2.3.2 Painting

Painting exposed structural elements, fascia panels, stair and elevator tower interiors, step landings, pedestrian handrails, vehicular guardrails, and miscellaneous metals on a periodic basis is essential. Where painting is required, it should be completed as soon as time and budget constraints allow.

Painted surfaces should be inspected annually to determine their condition. Small rust spots should be cleaned and touched up each year. Repainting should be done as required by the elements, type of paint, and exposure conditions. Most painted surfaces need repainting at 3- to 7-year intervals.

Repainting the face and edge of concrete curbs should be done semiannually to minimize any potential for tripping by maintaining high visibility. Concrete surfaces are typically painted with the following types of paints:

Water-based Portland cement paints
Water-based polymer latex paints
Single- or two-component polymer paints
Oil-based paints

Refer to ACI 515 for general guidelines on the selection of paints for a particular use. Water-based Portland cement paints exhibit properties similar to those of concrete. Primary uses are filling in and leveling minor imperfections of concrete surfaces. The disadvantages of Portland cement-based paints are that they cannot be applied over existing paints, they have a limited color selection, the surfaces tend to show stains and dirt, and they are hard to clean.

Water-based polymer latex paints are available for interior and exterior use. Latex paints form a breathable layer and are able to resist blistering when applied to concrete with a high or varying moisture content. Latex paints must be applied to a moistened surface and may require a primer coat of a low-viscosity-penetrant paint before application to some concrete surfaces.

Polymer paints are available in single- or two-component forms. Both form a smooth, dense, high-gloss finish that is highly resistant to humidity, stains, or dirt. Polymer paints are available in a wide range of colors. Single-component polymer paints offer flexibility and extensibility; when applied, sufficiently thick single-component polymer paints are able to bridge minor cracks that may form in the concrete surface. Two-component polymer paints form a high-gloss surface that is highly resistant to chemical attack and is easy to clean. Since polymer paints form a moisture barrier, they should not be applied to moist surfaces or to a concrete substrate with a high or varying moisture content.

Oil-based paints are those that contain derivatives of fatty acids or drying oils. These paints are not resistant to the natural alkalinity of concrete. Oil-based paints should always be applied with a primer coat. The primer coat will reduce the paint's susceptibility to a reaction with the alkalinity of the concrete, but will not eliminate it.

Water-based polymer latex paint should be used in most parking facility concrete painting applications. It will provide a durable, breathable surface protection for general use on concrete and masonry walls. Contact the manufacturer and follow the recommendations for surface preparation, storage of paint, and its application.

Metal surfaces are typically painted with enamel paints or zinc-rich paints. Enamel paint is a general-purpose interior/exterior paint used for protection against weather. Enamel paint is readily applied to primed, previously painted, or galvanized-metal surfaces. Surface preparation includes the removal of dirt, oil, grease, and other surface contaminants; rust and paint that is not tightly bonded should be removed and the area spot-primed. Primers should be applied as per manufacturers' recommendations. Enamel paints should not be applied to damp or wet surfaces. Enamel paint should be applied when the air, product, and surface temperatures are at least 50°F. Care should be taken not to apply the paint late in the day, when dew and condensation are likely, or when rain is possible.

Zinc-rich paints can be used as a one-coat maintenance coating or as a permanent primer. Zinc-rich paints can be used in areas with varying temperature conditions and high humidity. Zinc-rich paint when applied to a surface forms a coating which self heals and resumes protection when damaged. As with enamel paints, application should be done when the air, paint, and surface temperatures are at least 50°F. Care should also be taken not to apply the paint late in the day, when condensation is likely, or on days when rain is possible.

14.2.3.3 General Appearance

Glass in the stair towers is provided for security as well as aesthetics. Windows and floors of the stair and elevator towers, cashiers' booth, and lobbies should be swept or washed on a regular basis. Damaged window glass or deteriorated glazing should be repaired as the need dictates. Roof systems should be checked periodically for leaks.

Occupied and heated spaces beneath the parking floor, such as the office spaces, public areas, cashiers' booths, restrooms, and mechanical/electrical equipment rooms, may require special consideration. If floor-slab cracking or leaking overhead occurs, then vehicular deck coatings may be required to protect against water-related damage.

Walkways leading to and from stair tower entries should be kept clean and presentable. Trash receptacles placed at convenient locations around the facility help ensure proper trash disposal.

Rust stains are usually indicators of other problems, such as concrete cracking or paint or sealant failure. The cause of rust staining should be determined and corrected. Refer to the *Concrete Construction* magazine publication "Removing Stains From Concrete."

14.2.4 Checklists

Checklists are important to record the completion of required maintenance tasks. To perform maintenance tasks in a timely manner, develop checklists for the daily, weekly, monthly, semiannual, and annual frequencies recommended by the maintenance program. The checklist of parking structure maintenance tasks and recommended frequencies included in Appendix 14-2 can provide a good start to identify group tasks and prepare the checklists for your facility. Also, refer to the sample checklists included as Forms F-1 through F-4. Review and make appropriate changes to the checklists annually. Add or delete checklists as dictated by operational changes or modifications.

14.3 COST OF MAINTENANCE

Many factors influence the cost of maintaining a parking facility. The total cost to maintain the facility is related to the three categories structure, operational, and aesthetic maintenance outlined in the previous section. Maintenance costs should be developed for each category separately to plan and budget effectively for comprehensive maintenance of the facility.

Most owners who want to maintain their facility tend to budget inade-

FORM F-1

MAINTENANCE MANUAL AND PROGRAM **Inspector** ________________
DAILY OPERATIONAL CHECKLIST **Date** ________________
PARKING STRUCTURE NAME
Owner
City, State

CLEANING

☐ Pick up trash
☐ Sweep elevator tower
☐ Sweep stair tower
☐ Sweep office and collection booth
☐ Wash away parking areas required to remove odors
☐ Remove graffiti

SNOW PLOW REMOVAL AND ICE CONTROL

☐ Remove snow
☐ Apply sand or de-icer

DRAINAGE

☐ Clean off floor drain grates—all levels
☐ Squeegee ponded water to nearest drain—all levels

INSPECTION

☐ Check for trip hazards and other safety concerns

NOTES AND CORRECTIVE ACTION NEEDED: ________________________

____

FORM F-2

MAINTENANCE MANUAL AND PROGRAM **Inspector** ________________
MONTHLY OPERATIONAL CHECKLIST **Date** ____________________
PARKING STRUCTURE NAME
Owner
City, State

MECHANICAL EQUIPMENT

ELEVATORS
☐ Normal operation of elevators
☐ Clean door tracks at each level and in cab
☐ Maintenance performed per service contract

HVAC SYSTEM
☐ Normal operation of entire system
☐ Change air filters
☐ Normal operation of fans
☐ Check for broken or work pulleys and belts
☐ Maintenance performed per service contract

FIRE PROTECTION EQUIPMENT
☐ Check standpipes for operation
☐ Check charge on portable fire extinguishers
☐ Normal operation of smoke and heat detectors

NOTES AND CORRECTIVE ACTION NEEDED: ________________________

____

FORM F-3

MAINTENANCE MANUAL AND PROGRAM **Inspector** ______________
SEMI-ANNUAL OPERATIONAL CHECKLIST **Date** ______________
PARKING STRUCTURE NAME

ELECTRICAL SYSTEM

☐ Control and power panels for proper operation
☐ Timers and photo cells for proper operation
☐ Ground fault circuit interrupters for operation

MECHANICAL EQUIPMENT

FIRE PROTECTION EQUIPMENT

☐ Test sprinklers for proper operation

GRAPHICS AND FLOOR STRIPING

☐ Clean signs
    Directional signs
    Entrance/exit signs
    Tier/level designations
☐ Examine paint or facing material for deterioration
☐ Floor striping and graphics

NOTES AND CORRECTIVE ACTION NEEDED: ______________________

____

FORM F-4

MAINTENANCE MANUAL AND PROGRAM **Inspector** ________________
ANNUAL OPERATIONAL CHECKLIST **Date** ____________________
PARKING STRUCTURE NAME
Owner
City, State

ELECTRICAL SYSTEM

☐ Distribution panels
☐ Electrical conduit

CLEANING

☐ Prune trees

WINTERIZATION

☐ Washdown
☐ Flush
Standpipes
Sprinklers
Hose bibs
Drains
Piping
☐ Check for blockages

OVERALL

☐ General review of all operational components

NOTES AND CORRECTIVE ACTION NEEDED: ____________________________

____

quately for the program. The purpose of this section is to assist in identifying maintenance costs that should be included by facility owners to budget effectively for their maintenance needs. The types of items that need to be included are as follows:

- Cost of periodic repairs and/or corrective actions that are necessary to maintain serviceability and facility operations. This includes daily or routine maintenance.
- The replacement cost for structural and operational elements at the end of their estimated service life.
- Cost of preventive maintenance actions that are required to extend the service life of the facility.

Most owners recognize and budget for the periodic repairs and/or corrective measures for operational elements, which are often referred to as routine or daily maintenance. However, many owners do not budget funds to replace structural or operational elements at the end of their service life. Replacement cost is often viewed as a capital expenditure, which may or may not be authorized when needed. It is difficult to assess the cost of preventive actions and is often missed by many owners.

Usually, facility engineers and maintenance supervisors tend to have a strong mechanical/electrical systems background that enables them to more easily understand, plan, and budget adequately for the operational elements of the maintenance program. On the other hand, review by a restorations specialist is required to identify the need and budget appropriately for the structure maintenance cost.

How much does it cost to maintain a parking facility? The results of a survey of parking facility owners is shown in Table 14-6. Maintenance is one of the many expenses incurred in operating a parking facility. The table shows the breakdown of the annual operating cost for each of the expense categories identified.

The maintenance expenses shown in Table 14-6 include the structural, operational, and aesthetic maintenance elements identified in this chapter. The percentage of the total operating cost spent on maintenance of the facilities appears to be very low. The trend to spend so little on maintenance by parking facility owners is yet another confirmation that most owners continue to budget inadequately for structural maintenance. The maintenance expenses reported by the owners probably represent only the routine or daily maintenance costs. In the author's opinion, the maintenance cost for a newer facility is about twice that

TABLE 14-6. Operating Costs of Parking Facilities

Expense Category	Annual Operating Cost Per Space 1990	Annual Operating Cost Per Space 1993[a]	Percent
Cashiering/management	$162	$172	52.6
Utilities	45	47	14.5
Maintenance	42	44	13.5
Miscellaneous	60	63	19.4
TOTAL	$307	$326	100.0

[a]Equal to 1990 survey figures inflated by increase in consumer price index (CPI) from 1990–92.
Source of CPI: Dept. of Labor, Bureau of Labor Statistics. Does not include property, parking, or sales taxes; debt service; and depreciation.
Courtesy: WALKER Parking Consultants/Engineers, Inc., Kalamazoo, Mich.

shown by the survey. For an older or restored facility, the cost is expected to be even higher.

Table 14-7 is included to serve as an example for computing anticipated annual maintenance cost for a facility. In addition to assisting in budgeting for the facility's maintenance program, the exercise is also very useful in comparing the life cycle cost of different types of structures during the design phase, and comparison of repair schemes for restoring an existing facility. All the applicable structural, operational, and aesthetic elements of a maintenance program should be included in estimating the total maintenance cost. Also, the cost for periodic repairs, replacement costs, and preventive actions should be included. The following sections provide further discussion of maintenance costs.

14.3.1 Structural System Maintenance Cost

The structure maintenance cost usually represents the largest portion of the total maintenance budget. Facility owners tend to grossly underestimate the structure maintenance cost and budget inadequately for timely corrective actions that must be performed to cost-effectively extend the service life of the facility. Also, the adverse impact of ineffective structure maintenance is deferred. Therefore, it is difficult for most owners to recognize or realize the long-term benefits of timely corrective and preventive maintenance actions. The cost of structure maintenance is relatively small considering the potential liability associated with the neglect to properly maintain the facility.

The age and the geographic location of a parking facility will impact maintenance costs. Older facilities require more maintenance than a

TABLE 14-7. Anticipated Annual Maintenance Cost

Item Description	Total Cost	Frequency	$/SF/YR
Replacement/preventive costs			
Sealants			
Replace tee/tee and cove joint sealants	$56,000	10	$0.04
Sealant at column/spandrel joints	3,000	10	0.00
Architectural sealants	35,000	12	0.02
Traffic coating strip at perimeter	54,000	12	0.04
Penetrating sealer at supported levels	38,000	5	0.06
Replace drainage system	80,000	25	0.03
Supplemental drains & piping	15,000	25	0.00
Replace lighting/conduits	235,000	20	0.09
Replace light fixtures	60,000	20	0.02
Replace parking & revenue control	40,000	10	0.03
Replace signage	23,000	25	0.01
Replace expansion joints	12,000	10	0.01
Periodic repairs and/or corrective actions			
Maintain miscellaneous joint sealants	1,300	1	0.01
Maintain traffic topping	1,200	1	0.01
Floor slab patching	3,000	1	0.02
Beam & column repairs	1,000	3	0.00
Miscellaneous stairtower maintenance	1,000	1	0.01
Maintain drainage system	1,000	3	0.00
Maintain parking/revenue control equipment	2,000	1	0.02
Annual inspection & testing	5,000	1	0.05
Average annual maintenance cost per square foot per year			0.47

new facility. The cost of maintaining the structure will also increase as the structure gets older. A structure located in a moderate climatic region is likely to require less maintenance than a structure located in the northern climatic region, which is subjected to harsher exposure conditions.

The structural system of the parking facility will influence maintenance costs. However, it is important to realize that the true cost over the life of the structure consists of two components—the initial cost to construct the facility, and the maintenance cost. Structural systems that initially cost less may eventually turn out to be more expensive considering the higher cost of maintaining the structure over the entire service life of the facility. Conventionally reinforced structural systems are more likely to incur higher maintenance costs than a cast-in-place posttensioned parking structure. Precast prestressed structures are likely to require more frequent maintenance and may also incur higher maintenance costs. For a restored structure, the following is a list of some of the important factors that can impact the cost of future maintenance:

- The type of corrosion protection of the existing structure.
- The type of waterproofing system installed.
- The level of chloride contamination and the extent of concrete removals specified during construction.
- Existing structural system, design deficiencies, and adverse conditions related to drainage, water leakage, joint deterioration, and concrete quality.

When comparing repair alternatives to restore an existing parking facility, it is important to recognize and consider the maintenance cost associated with each of the repair schemes selected. Again, a repair that is initially less costly may be burdened with a higher maintenance cost. Life cycle cost comparison of repair alternatives should always include the anticipated maintenance cost with each repair scheme to make the analysis more complete and accurate.

The periodic structural maintenance includes items such as patching concrete spalls and delaminations in floor slabs, beams, columns, walls, etc. In many instances there are maintenance costs associated with the facade elements. Other periodic repairs may include repair of traffic topping membranes, the routing and sealing of joints and cracks, and the expansion/construction joint repairs. The cost of these repairs can vary significantly from one structure to another. The factors that will impact the maintenance cost are the value the owner places on the maintenance of the facility, the local climate, the age of the structure, and other factors discussed previously in this section.

A review by a restoration specialist is usually necessary to identify the preventive maintenance needs of a facility. In addition to the annual or other periodic inspections, material testing and examinations may also be necessary to determine and recommend these maintenance measures. One example of this is the chloride monitoring testing that is necessary to monitor the effectiveness of sealer and coatings. The chloride testing also helps to determine the frequency and extent of sealer reapplication. The results of the periodic inspections may also indicate the need for other materials examinations and laboratory testing. Refer to Chapter 15, Table 15-2, for other commonly used tests and their application. It is important to include these materials testing and inspection expenses in the maintenance budget.

14.3.2 Operational Maintenance Cost

The operational maintenance includes tasks that are sometimes referred to as routine or daily maintenance. The desired degree of cleanliness, as well as the frequency of certain cleaning tasks, will affect daily management cost. Daily maintenance includes sweeping and washing floors, washing walls, removing graffiti, snow removal, replacing light bulbs and ballasts, repairing parking access revenue control equipment, cleaning restrooms, cleaning floor drains, and line restriping. Owners who value and demand more cleanliness in their parking facility will undoubtedly experience higher maintenance costs than those that are less concerned about cleanliness.

In addition to the daily maintenance, operational maintenance costs should include replacement costs for items such as the lighting system, drains and drain pipes, parking revenue control equipment, signage, security systems, etc. Replacement costs should be included in the maintenance budget so that funds will be readily available when needed. Cost of service contracts to service elevators, electrical, mechanical, and revenue control equipment should also be included in the budget. Also, refer to checklist in Appendix 14-2 for additional operational maintenance items that need to be included in the budget for your facility.

APPENDIX 14-1

CHLORIDE MONITORING CHART

Depth of sample	Floor	Year						
CL−1 0"−1" 1"−2" 2"−3"								
CL−2 0"−1" 1"−2" 2"−3"								
CL−3 0"−1" 1"−2" 2"−3"								
CL−4 0"−1" 1"−2" 2"−3"								
CL−5 0"−1" 1"−2" 2"−3"								
CL−6 0"−1" 1"−2" 2"−3"								
CL−7 0"−1" 1"−2" 2"−3"								
CL−8 0"−1" 1"−2" 2"−3"								
CL−9 0"−1" 1"−2" 2"−3"								
CL−10 0"−1" 1"−2" 2"−3"								

APPENDIX 14-2

PARKING MAINTENANCE TASKS AND RECOMMENDED FREQUENCIES

Parking Maintenance Tasks and Recommended Frequencies

Task	DAILY	WEEKLY	SEMIMONTHLY	MONTHLY	QUARTERLY	SEMIMONTHLY	ANNUALLY
CLEANING:							
• Sweep localized areas.	D	M					
• Sweep all areas/curbs.		D	M				
• Empty trash cans.	D	M					
• Clean restroom floors/fixtures.	D	M					
• Clean restroom walls.			D	M			
• Clean cashier booths (floors/windows)	D	M					
• Clean elevator floors.	D	M					
• Clean elevator walls/windows.			D		M		
• Clean stairway windows.		D		M			
• Clean stairway windows.					D		M
• Clean lobby/office floors.	D	M					
• Clean lobby/office windows.		D		M			
• Wash parking-area floors.				D		M	
• Clean parking-control equipment.		D	M				
DOORS AND HARDWARE:							
• Check hinges/latches.	D	M					
• Check mechanized doors.	D	M					
• Check panic hardware on security doors	D	M					
• Lubricate mechanized doors.				D	M		
ELECTRICAL SYSTEM:							
• Check light fixtures.		D		M			
• Relamp fixtures.*							
• Inspect special units.*							
• Check distribution panels.						D	M
ELEVATORS:							
• Inspect for normal operation.	D	M					
• Check indicators and other lights.	D	M					
• Perform preventive maintenance.**							
HVAC SYSTEM:							
• Inspect for proper operation.				D	M		
• Check ventilation in enclosed/ underground areas.	D	M					
• Perform preventive maintenance.*							
LANDSCAPING:							
• Remove trash.	D		M				
• Mow, trim and weed.		D		M			
PAINTING:							
• Look for rust on doors/door frames.						D	M
• Look for rust on handrails/guardrails.						D	M
• Look for rust on exposed pipes/pipe guards/conduit.					D	M	
• Look for rust on other metal surfaces.						D	M
• Inspect striping.						D	M
• Check signs.				D	M		
• Check walls.						D	M
• Inspect curbs.				D		M	
• Touch up paint.						D	M
• Repaint. *							
PARKING CONTROL EQUIPMENT:							
• Inspect for proper operation.	D	M					
• Perform preventive maintenance. ***							
PLUMBING SYSTEM:							
• Inspect sanitary facilities.	D	M					
• Inspect irrigation.			D	M			
• Check floor drains.	D		M				
• Check the sump pump.		D		M			
• Test the fire protection system.				D	M		
• Check drain-water sytems(for winter).							M
ROOFING/WATERPROOFING:							
• Check roof for leaks.				D		M	
• Check joint sealant in floors.				D		M	
• Inspect expansion joints.				D		M	
• Inspect windows/doors/walls.				D		M	
• Inspect the floor membrane.						D	M
• Check for deterioration.							
SAFETY:							
• Check carbon-monoxide monitor(s).	D	M					
• Check handrails/guardrails.				D	M		
• Check exit lights.		D		M			
• Check emergency lights.		D		M			
• Eliminate tripping hazards.		D		M			
SECURITY SYSTEM:							
• Check closed-circuit television.	D	M					
• Check audio surveillance.	D	M					
• Test panic buttons.	D	M					
• Test stair-door alarms.	D	M					
GRAPHICS:							
• Check sign placement.	D	M					
• Check sign cleanliness.				D	M		
• Check sign visibility.	D	M					
• Check sign legibility.				D			M
• Check sign illumination.	D	M					
SNOW/ICE CONTROL:							
• Check for icy spots (in season).	DM						
• Remove snow and ice (as required).	DM						
STRUCTURAL SYSTEM:							
• Check floor-surface deterioration.						D	M
• Check for water leakage.						D	M
• Inspect concrete for cracks.						D	M
• Inspect structural steel for rust.						D	M
• Make repairs. (see a consultant).							
• Replace floor coating. (see a consultant).							

D-Desirable M-Minimum

Adopted from "Parking Garage Maintenance Manual, First Edition," Parking Consultants Council, National Parking Association, 1982

APPENDIX 14-3

ANNUAL STRUCTURAL CHECKLISTS

FORM F-5

ANNUAL STRUCTURAL CHECKLIST
PARKING STRUCTURE NAME
MAINTENANCE MANUAL AND PROGRAM
Owner
City, State

Inspector ______________

Date ______________

FLOORS

________ When was the last floor sealer application? (Typically applied every 3–5 years)

________ Are there rips, tears, debonded areas, or signs of embrittlement in the traffic topping?

________ Are there cracks in the floor slab? If yes, where are they located and how wide are they?

________ Are there signs of leaking?

________ Any spalls or delaminations? If yes, how big are they and where are they located?

________ Has chloride ion content testing been performed this year?

BEAMS AND COLUMNS

________ Are there cracks? If yes, are they vertical or horizontal and how wide?

________ Are there any signs of leaking?

STAIR/ELEVATOR TOWERS

________ Are there any signs of a leaking roof?

________ Are there any cracks in the exterior brick?

________ Are there any cracks in the mortar joints?

NOTES AND CORRECTIVE ACTION NEEDED: ______________________________

____

JOINTS

________ Are there any signs of leaking, loss of elasticity, or separation from adjacent surfaces?

Expansion joints
Control joints
Construction joints
Tee-to-tee joints

ARCHITECTURAL SEALANTS

________ Are there any signs of leaking, loss of elasticity, or separation from adjacent surfaces?

Between windows and doors
In block masonry
Exterior sealants
Concrete walks, drives, and curb landings

EXPOSED STEEL

________ Is there any exposed steel? If yes, where is it located and is it rusted?

MASONRY

________ Are there any cracks in the brick?

________ Are there any cracks in the mortar?

________ Are there any brick spalls? If yes, where are they located and how big are they?

NOTES AND CORRECTIVE ACTION NEEDED: ________________________________

____

BEARING PADS

________ Are bearing pads squashed, bulging, or out of place? If yes, where?

AFTER ANSWERING THE ABOVE QUESTIONS, PLEASE CONSULT A QUALIFIED ENGINEER TO DISCUSS YOUR ANSWERS.

NOTES AND CORRECTIVE ACTION NEEDED: ________________________________

____

____

____

APPENDIX 14-4

SAMPLE ANNUAL CONDITION SURVEY SUMMARY

FORM 1

Structure Name ________	Inspection Date ________
Location ________	Inspector ________
	Next Scheduled Inspection Date ________

1. STRUCTURAL REPAIRS	
Structural Element	Typical Deterioration Observed and Location
Floors/Ceilings	
Beams/Joists	
Columns	
Walls	

REQUIRED REPAIR	REPAIR PRIORITY*
Floor Surface Preparation	
Floor Repair	
Ceiling Repair	
Beam and Joist Repair	
Column Repair	
Wall Repair	
Precast Tee Beam Repair	
Expansion Joint Repair	
Expansion Joint Replacement	
Crack and Joint Repair	
Concrete Surface Repair	
Concrete Overlay	
Overlay Control Joint System	
Protective Sealer	
Traffic Topping	
Floor Drainage System	
P/T System Repair	
Brick/Masonry Repair	
Structural Steel	

*Priority Classification
1 = Immediate action required
2 = Repair within 1–3 years
3 = Repair within 3–5 years
4 = Repair after 5 years

NOTES: ________

____

FORM 2

Structure Name ________	Inspection Date ________
Location ________	Inspector ________
	Next Scheduled Inspection Date ________

2. MAINTENANCE/REPLACEMENT			
Action required	Frequency Required	Date last Performed	Date next Scheduled
A. Structural			
Floor/Beam/Column/Wall Patches			
Joint Repair			
Joint Replacement			
Crack Repair			
Expansion Joint Repair			
Expansion Joint Replacement			
B. Operational			
1. Lighting Replace Light Bulbs Replace/Replace Exposed Conduit Replace Timers and Photocells			
2. Snow Removal			
Cleaning Sweep Floors Wash Down Floors Clean Expansion Joint Glands Part/Stain Landscaping			

NOTES: ________

____

FORM 3

Structure Name ____________	Inspection Date ____________
Location ____________	Inspector ____________
	Next Scheduled Inspection Date ____________

3. PREVENTIVE MAINTENANCE			
Action required	Frequency Required	Date last Performed	Date next Scheduled
Chloride Ion Tests			
Sealer Application			
Traffic Topping Application/Repairs			

TEST LOCATIONS			
Location Number	Location	Level	
			Cl = Chloride C = Compressive P = Petrographic S = Shear Bond

NOTES: ____

____

NEXT INSPECTION DATE: ____________________

CHAPTER
15

Repair

Sam Bhuyan

15.1 INTRODUCTION

Although concrete is a relatively durable construction material, preventive maintenance and necessary corrective actions are required to extend the useful life of parking structures. Parking facilities experience harsh exposure conditions which can contribute to accelerated concrete deterioration and adversely affect the life expectancy of the structure. Quite often, owners and operators have to repair deteriorated structures with only 15–20 years of service (Figure 15-1). It is not uncommon for repair costs to exceed $10.00 per square foot. In addition, the repairs disrupt the facility's operations and cause inconveniences for users, which result in a loss of revenue.

The impact of deterioration on repair costs and service life of parking structures is shown by curves in Figure 15-2. Most structures deteriorate normally over time. This normal rate of deterioration is shown by the line close to the horizontal axis in the figure. Structural elements of buildings that are enclosed, protected, and maintained in a controlled environment tend to experience normal deterioration as represented by this line with a gentle slope. In comparison, the deterioration rate experienced by parking facilities is shown by the curve connecting the points A through D. The curve indicates that initially, during the early stage of their service life, parking structures also deteriorate at a normal rate. However, after they have been in service for a period of time, they tend to deteriorate at a very accelerated rate.

There are several mechanisms that accelerate deterioration and reduce the life expectancy of the parking facilities. In the northern regions, corrosion of embedded reinforcement due to chloride contamination

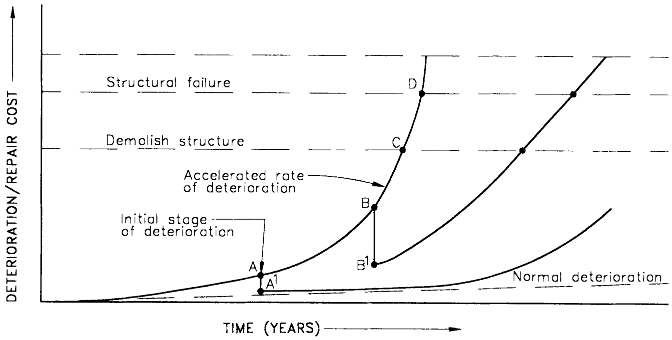
(a)

(b)

Figure 15-1. (a) Facility in need of repairs. (b) Facility after the repairs.

by road salt is generally the primary contributor of accelerated deterioration. Another commonly observed concrete deterioration is due to the lack of, or inadequate, air entrainment in concrete. In this instance, freezing and thawing can contribute to progressive and rapid deterioration. Some structures in the southern regions also are exposed to an equally harsh environment. Concrete structures located in the vicinity of large bodies of salt water and in coastal regions are susceptible to corrosion-induced deterioration. Airborne chlorides and marine water sprays can be just as damaging as road salts.

The durability of structures is also adversely affected by a lack of corrosion-protection systems. Today, an owner can use a combination of state-of-the-art corrosion protection systems such as concrete sealers,



NOTES:

1. Points A – D represent stages of accelerated deterioration in parking structures.
2. Structures repaired at point A cost less overall and last longer than structures repaired at point B. (Compare curve at A1 to curve at B1.)

Figure 15-2. Parking structure deterioration curve.

membrane coatings, epoxy-coated reinforcement, admixtures to reduce concrete permeability, corrosion-inhibiting admixtures, and cathodic protection to extend the life of a structure effectively. See Chapter 10 for a discussion of durability requirements for new parking structures.

Other deterioration mechanisms such as cracking, leaching, carbonation, and abrasion can adversely affect structures in severe as well as moderate climates. In addition, inadequate design details, poor drainage conditions, poor-quality concrete, and joint deterioration can have a significant impact on the service life of structures.

Appropriate repairs must be performed to address existing deterioration due to service exposure and inherent structure deficiencies. The repair methods and materials selected must be durable and capable of extending the service life of the structure cost effectively.

In Figure 15-2, the vertical lines AA^1 and BB^1 represent such corrective actions taken or repairs performed to maintain serviceability and extend the service life of the structure. Also, note the following:

1. Repairs performed at an early stage of distress cost less than repairs that are delayed. Length of vertical line BB^1 is longer than vertical line AA^1. The increased repair cost is due to increased deterioration in the structure.
2. Structures that are in an advanced stage of deterioration (between point C and D on the curve) cannot be repaired cost-effectively. For such structures the best strategy is to perform Band-Aid repairs that will buy some time to fund a new facility or make other arrangements for the lost parking spaces.

3. It costs more to repair and the benefits realized are reduced with increase in deterioration. The service life (benefit realized) of the repaired structure represented by the curve beyond point A^1 is much longer than the service life represented by the curve beyond point B^1. The deterioration rate experienced by the structure beyond point A^1 is slower than the deterioration rate beyond point B^1.
4. Periodic and timely repairs can add significant service life to the structure. Routine repairs performed at an initial stage of deterioration such as at point A are often referred to as maintenance. These less costly maintenance efforts defer major repairs and greatly extend the service life of the structure.

15.2 APPROACH TO RESTORING A PARKING STRUCTURE

15.2.1 General

To correct problems and restore a parking structure, owners must develop a comprehensive program for evaluating existing conditions, making repairs, and setting up maintenance procedures that extend the life of the facility. A comprehensive and cost-effective restoration program is built around an accurate evaluation of the condition of the structure. For a parking structure the program generally focuses on the following issues:

1. Repair deteriorated concrete floor slabs to restore integrity.
2. Provide durable wearing surfaces that will effectively waterproof the structure and minimize further deterioration.
3. Perform repairs to other underlying structural members for continued safe use of the facility.

The primary objective of the repairs is to cost-effectively realize additional service life for the structure. How much longer the structure will last depends on the existing condition of the structure and the repair approach that is selected. The repairs can be short term (3 to 5 years) or long term—i.e., intended to last over 20 years. The long-term repairs usually cost more than the short-term repairs. The more permanent repairs also take longer to implement and have a greater impact on the patrons and lost parking spaces during construction. Therefore, it is common to phase major restoration work over several years to reduce the adverse impact of the repairs on the facility operation.

Implementing the repairs will require that you select a contractor who is specialized in restoration of parking facilities. Also, budget more time for the engineer to perform field observation during construction.

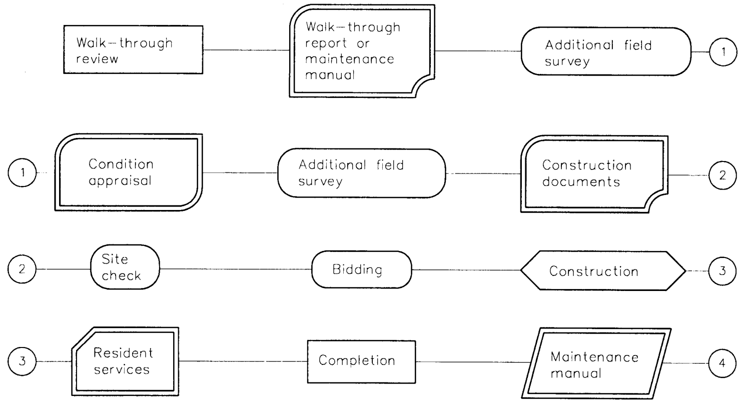


Figure 15-3. Flow diagram of a systematic approach to restoring a parking structure.

Compliance to specification with respect to concrete removals, surface preparation, material placements, and unexpected field conditions demands immediate response to maintain project schedules and budget. A full-time project representative is often required to assist in the administration, management, and observation of the construction.

After a structure is restored, it needs to be maintained. Restoring a structure does not eliminate all the adverse conditions that contributed to the premature deterioration of the facility in the first place. Some of the built-in deficiencies can be corrected and improve many other conditions. However, the structure will require more maintenance in comparison to a newly constructed facility. The repairs will lower the deterioration rate of the restored structure, but it will continue to deteriorate at a faster rate than a new facility and cost more to maintain. Refer to Figure 15-2, which shows the deterioration rates for parking structures. A flow diagram for a systematic approach to restoring a parking structure is shown in Figure 15-3.

15.2.2 Types of Restoration Services

An owner should have a clear understanding of what his needs are in order to obtain appropriate services. Table 15-1 summarizes some of the reasons for an owner to request restoration services.

15.2.2.1 Walk-Throughs

The purpose of a walk-through service of the structure is to provide a general overview of the structure's condition or to report any significant additional change in the condition of the structure. The work should be performed by an experienced restoration engineer or trained in-house personnel. Observations are generally limited to visually obvious items, such as spalling, cracking, rust staining, cold joints, leaking, leaching, poor formwork, debris in the concrete, and honeycombing. Appendix 1 in Chapter 14 contains a sample inspection checklist that may be used for the walk-through reviews.

15.2.2.2 Condition Appraisal

A condition appraisal is required to assess the condition of the facility. The time and effort required to perform the condition appraisal can vary considerably from one structure to another. The nature and the extent of the work required to perform the condition appraisal needs to be evaluated by a restoration specialist. The specialist should perform a preliminary walk-through review of the structure to properly assess the scope of the work required to evaluate the structure. The scope of the condition appraisal should also include upgrading of other operational and aesthetic elements, such as:

- ADA compliance
- Electrical system, including the lighting levels
- Mechanical systems, related to floor drainage, air quality, fire protection, and elevators
- Parking control equipment
- Signs
- Functional review to improve traffic pattern and restriping for increased efficiency
- Appearance related to painting, staining, and landscaping

With respect to the structure, the following factors can affect the level of effort required to conduct an appropriate assessment:

- Age, location, and size of the structure
- The structural system
- Existing condition of the structure
- Extent of materials testing and examination required

Older structures generally show more distress and deterioration than newer facilities (see Figure 15-2). Also, structures that are exposed to more severe weather conditions are likely to be more deteriorated. It takes more time and effort to complete the field survey, document

TABLE 15-1. Restoration Services

Owner's Need	Type of Service	Scope of Work
Do I have a problem?	Walk-through review	State problems, if any; recommend further work, if any.
Just how bad is my problem?	Field survey and condition appraisal	Identify problems, causes, and effects; recommend repairs.
How much should I budget for repair and/or maintenance?	Field survey and condition appraisal or maintenance program	Give repair cost budget estimate. May also provide life cycle cost analysis of various repair alternatives and may provide structural analysis.
I want to repair my deck.	Field survey and construction documents	Develop plans and specifications, final quantities, and cost estimates for bidding.
How will I know the repairs will be done correctly?	Project resident	Record of actual quantities of work done. Daily records of work progress. Implement plans and specifications.
I have a new deck, or I just had the deck restored. Now, how do I maintain it?	Field survey and maintenance program	Provide customized maintenance manual listing annual maintenance items, priorities, schedule, and estimated maintenance costs for structure's service life.
I am concerned about the water leakage through the floor slab. I am concerned about specific structural or member-durability problems.	Field survey and condition appraisal	Identify cause and effect of the specific problem. Recommend repairs and provide repair cost estimates. Also recommend further work, if any, for areas not covered by the present scope of work.

the results, and evaluate the data collected from a more deteriorated structure. The size of the structure will obviously have a similar impact on the time and effort required.

Some structural systems, such as one-way slab and beam, and flat slab systems with relatively large flat exposed soffit areas, take less time to complete the field survey. Precast double-tee systems, pan-joist systems, waffle where the view of the soffit is interrupted by the closely spaced floor slab elements require more time to complete a review of the floor slab underside. The materials testing and examination required vary considerably depending on the nature and extent of deterioration and the type of structural system.

The following three classifications of the condition appraisal are presented to more appropriately match the services provided to meet the owner's specific needs:

Level I—The level I condition appraisal provides a general professional opinion of the condition of the parking structure. The opinion is based on a visual examination of the structure. This process will identify the existence and nature of visible problems with the structure including scaling conditions; cracks in the slab, columns, and beams; rust staining; spalling; etc. All components of the structure are examined including stair towers, elevators, exit/entrances, rooms, and exterior facades. Subsurface problems are not identified in this level other than on the most limited representative basis, based on visual evidence of cracking, etc. Chain dragging of selected areas will provide a representative view of subsurface problems that have yet to manifest themselves on the surface.

The purpose for this level of appraisal is to provide a record of the structure's "health," including evaluation of the existing maintenance program or recommendations for developing such a program. It also provides a baseline from which to gauge the structure's rate of deterioration. This level of appraisal will not provide enough information on which to base or budget a repair program.

Level II—The level II condition appraisal provides an in-depth "health report" on the condition of the parking structure. It identifies the existence and extent of problems in the structure. In addition to the visual examination described in level I, selected areas are tested to obtain representative repair quantities. Selective chain dragging and limited chloride ion testing combined with the visual examination provide enough information to determine a range of restoration alternatives and order-of-magnitude repair costs.

This level of condition appraisal allows monitoring of the structure's rate of deterioration. Recommend preventive measures for potentially serious problems that are obvious. Provide a basis for preparing preliminary estimate of the range of repair costs.

Level III—The level III condition appraisal can provide an in-depth analysis of the structure's condition. Comprehensive testing including chloride ion, petrographic, and chain dragging, combined with the visual examination described in level II, provides a complete cataloging of the problems, their nature, effect on the structure, and accurate quantity estimates. Repair program alternatives are evaluated and prioritized, and a restoration program is recommended to meet available funds and operational constraints.

The information gathered and evaluated in a level III condition appraisal provides the owner with the necessary budget data and justification to begin immediate repair, planning, and budgeting funds for construction. The construction document stage can begin without need for further field evaluation of the structure.

The scope of work for the three levels of the condition appraisal identified is also presented in Table 15-2.

15.2.2.3 Construction Documents

Construction documents implement condition appraisal findings, which requires preparation of plans and specifications. Construction documents should not be based only on a walk-through of the facility.

15.2.2.4 Resident Services

Field observation of repair/restoration work by project resident and contract administration. This service supplements the more traditional periodic observations at appropriate intervals during construction.

15.2.2.5 Maintenance Programs

Maintenance program development is generally based on a brief walk-through inspection that allows the restoration engineer an opportunity to get a feel for the facility and its existing or potential problems. In addition, chloride samples are sometimes taken and original construction documents reviewed. The maintenance inspection is intended only to qualify the conditions requiring maintenance and provide general procedures and guidelines to extend the service life of the structure.

15.3 CONCRETE DETERIORATION

This section will present the most common types of distress observed in parking facilities in need of repair or maintenance. Concrete deterioration generally falls into one of the following major categories—spalling, cracking, scaling, and leaching. Joint deterioration is also included in this discussion because it generally contributes to distress in underlying structural members. Other forms of deterioration, such as abrasion of driving surfaces, carbonation, and distress due to reactive aggregates in the concrete are generally less frequent, observed only in isolated instances. Discussion of concrete deterioration will be limited only to the major categories listed above. This deterioration contributes to the serviceability and structural integrity problems experienced by parking structures. In addition, the following conditions tend to aggravate and contribute to the deterioration process:

TABLE 15-2. Condition Appraisal: Level of Services

Tasks	Level I	Level II	Level III
Field investigation			
1. Visual survey			
a. Identify distress	Yes	Yes	Yes
b. Document locations	No	Some	Yes
c. Document quantities	No	Some	Yes
2. Nondestructive testing			
a. Delamination (chain drag)	Some	Limited	Yes
b. Concrete cover measurements	No	Limited	Yes
c. Half-cell potential testing	No	No	Yes/no
3. Material testing			
a. Chloride ion content	Some	Limited	Yes
b. Compressive strength	No	No	Yes
c. Microscopic examination	No	No	Yes
d. Shear bond	No	No	Yes
e. Air content	No	No	Yes/no
f. Excavations (test wells)	No	Limited/no	Yes/no
g. Others (as required)	No	No	Yes/no
Report			
1. Results of visual survey			
a. Identify conditions (distress)	Yes	Yes	Yes
b. Describe problems			
c. 1) Cause	Some	Some	Yes
2) Effect	Some	Some	Yes
3) Impact on structure	Some	Some	Yes
2. Provide recommendations			
a. Immediate repairs	Yes	Yes	Yes
b. Further investigation required	Yes	Yes	Yes/no
c. Alternative repair schemes	No	No	Yes
d. Repair priorities	No	Some	Yes
e. Specific actions	No	No	Yes
3. Construction cost estimates			
a. Range of estimated cost	No	Yes	
b. For budgeting/planning	No	No	Yes
c. For alternative repair schemes	No	No	Yes
4. Life cycle cost analysis	No	No	Yes
5. Structural capacity analysis	No	No	As required

- Selection of a less durable structural system and inadequate design details
- Poor drainage
- Material Construction deficiencies
- Lack of an appropriate corrosion protection system
- Lack of effective maintenance

A parking structure has to be properly planned, designed, built, and maintained to minimize deterioration and realize a reasonable service life.

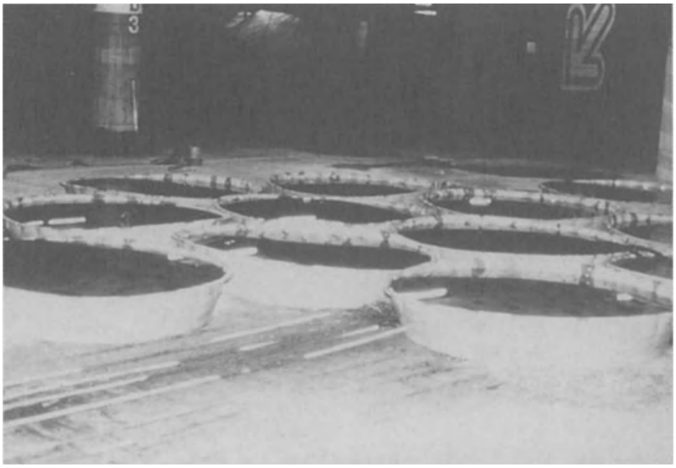
15.3.1 Corrosion-Induced Deterioration

Spalling and delamination of concrete due to corrosion of embedded reinforcement is a common form of distress in structures located in northern climates or in other areas subjected to salt environment. The use of road salt during winter months often results in chloride contamination of the floor slabs and acceleration of reinforcement corrosion in the presence of oxygen and moisture. (Figure 15-4). Many relatively older structures in the mild climatic region are also susceptible to corrosion-induced deterioration to a lesser degree. The spalls in reinforced-concrete surfaces are usually dish-shaped cavities 1″ to several inches deep with varying surface areas. Floor slab spalling can be quite extensive, sometimes covering several hundred square feet (Figure 15-5). Corrosion-induced deterioration can also occur in structures having extremely porous concrete that is susceptible to carbonation (Figure 15-6).

Before open spalls or "potholes" can occur on the floor surface, a horizontal fracture called "delamination" will usually develop below the concrete surface. Fractures begin at the level of the corroding rein-

Figure 15-4. Spalling is progressive and steps must be taken to restore and protect the surface from further deterioration.

(a)



(b)

Figure 15-5. (a) Extensive deterioration can adversely affect load-carrying capacity of structural members. (b) Load testing of slab to determine impact of deterioration on structural integrity.

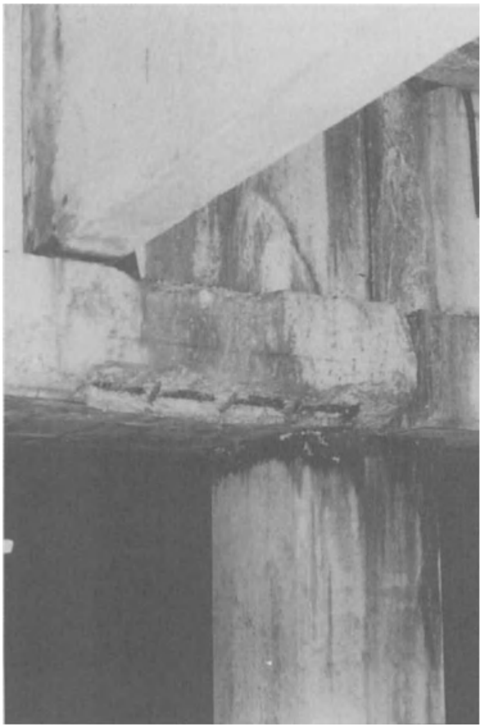


Figure 15-6. Corrosion of reinforcement due to leaching and carbonation of poor quality concrete.

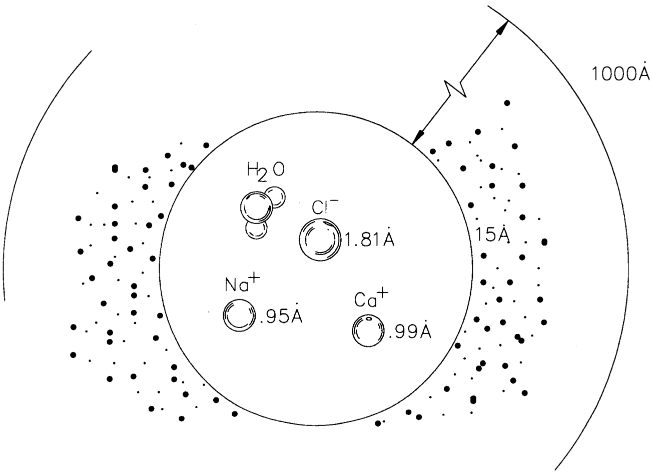
forcement or other embedded metal and migrate to the surface. These floor slab delaminations can be detected by tapping the floor surface with a hammer or by a chain-drag survey. Freeze-thaw cycles, traffic action, and additional corrosion tend to further accelerate the rate of spall development.

15.3.1.1 Chloride Contamination

Concrete is not an impervious material. Excess water, not required for hydration, eventually dries, leaving behind an interconnected network of capillary pores. Concrete capillary pores have a relatively larger diameter, ranging from 15 to 1000 Å (Figure 15-7). The measure for the capillary pores diameter is an angstrom. One angstrom is equal to 10 millionths of a millimeter. In comparison, the chloride ion diameter is less than 2 Å. Therefore, chloride ions can eventually penetrate into the concrete. Once the chloride ion reaches down to the level of the reinforcement, the concrete is contaminated to initiate chloride induced concrete deterioration. The contamination process is accelerated by salt accumulation on surfaces, shallow concrete cover, and wetting and drying.

ELELMENT	ATOMIC NO.	ATOMIC RADIUS	IONIC RADIUS
Cl^-	17	0.99Å	1.18Å
Ca^+	20	1.97Å	0.99Å·
Na^+	11	1.86Å	0.95Å·

Capillary pores in hardened concrete
estimated to measure: 15A – 1.000A

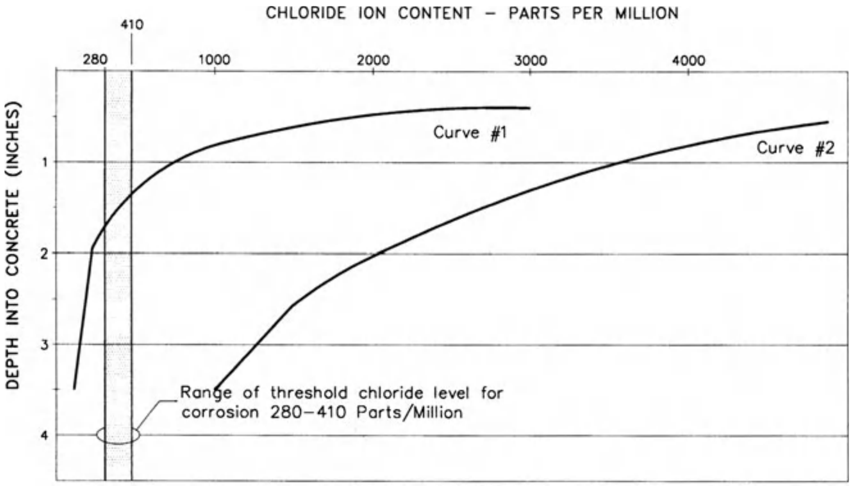


Magnified one million times
Schematic representation only

Figure 15-7. Concrete porosity can eventually permit migration of chloride ions to the level of reinforcement.

The amount of chloride content in concrete that will contribute to corrosion of the embedded steel reinforcement is referred to as the "corrosion threshold." The National Cooperative Research Program Report #57 defines corrosion threshold as the minimum quantity of chloride required to initiate the corrosion of embedded steel in the presence of moisture and oxygen (Figure 15-8). The chloride content is reported in various units such as:

- percentage chloride ion by weight of concrete
- ppm chloride ion by weight of concrete
- percentage chloride ion by weight of cement
- pounds of chloride ion per cubic yard



Curve #1 Moderate chloride contamination profile.
Curve #2 Severe chloride contamination profile.

Figure 15-8. Chloride content vs. depth into concrete.

The chloride ion content is reported as acid-soluble or water-soluble based on the analytical test procedure utilized to obtain the results. The acid-soluble test method measures the chloride that is soluble in nitric acid. The test procedure recommended by the ACI Building Code (ACI 318) for water-soluble chloride is AASHTO T 260.

Chlorides in concrete occur in the water-soluble form or may be chemically combined with other ingredients. The water-soluble chlorides initiate corrosion, while combined chloride is believed to have little effect on corrosion. When considering the probability of corrosion, it is more appropriate to consider only the water-soluble chloride ion content test results of the concrete since the acid-soluble chloride results include chlorides that are chemically combined.

The ACI Building Code (ACI 318) reports chloride ion contents as percentage chloride ion by weight of cement. Research done by the Federal Highway Administration indicates that corrosion threshold is 0.20% acid-soluble chloride ion by weight of cement. ACI 318 limits the maximum permissible water-soluble chloride ion content for mild steel reinforcement to 0.15% by weight of cement which is 75% of acid-soluble chloride ion content. For prestressed-concrete structures, the ACI 318 chloride ion content limit has been established at 0.06% by weight of cement. This is primarily to reflect the severity of corrosion and loss of cross-sectional area of highly stressed steel reinforcement.

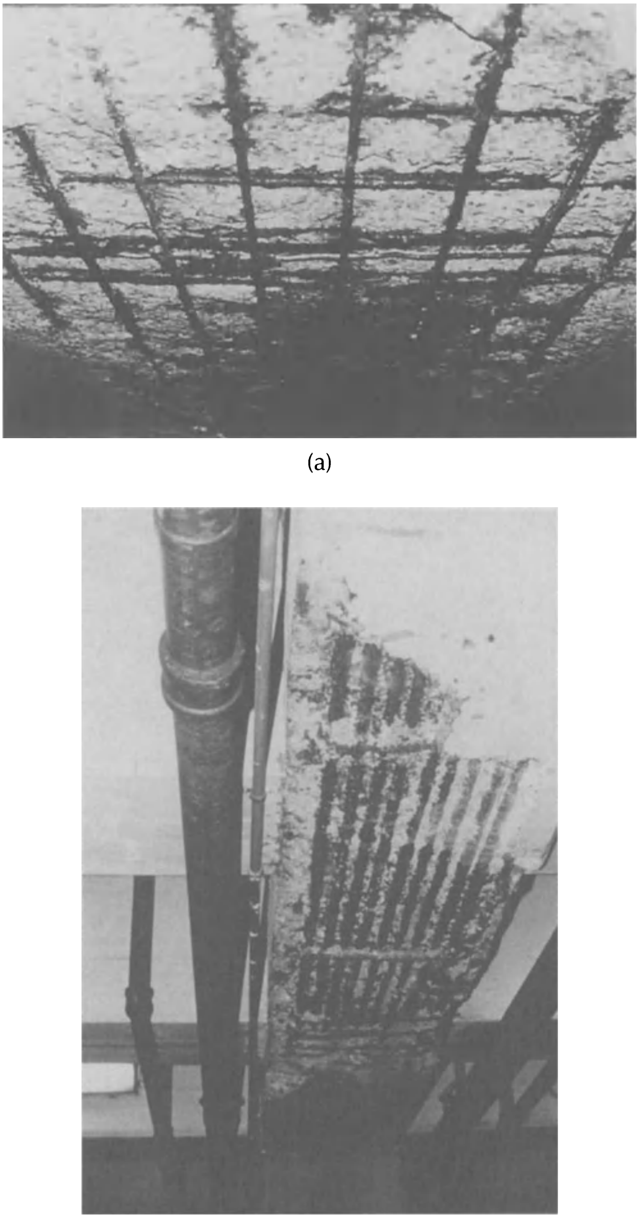
The floor slab and other horizontal members of a parking facility are most susceptible to chloride contamination. Road salt tracked into the facility or directly applied on the surface during the winter accumulates on the surface and accelerates the penetration of the chloride ions into the concrete. Ponding only makes the situation worse and tends to further accelerate the concrete contamination. Vertical members of the parking facility such as beams, columns, and walls are also susceptible to chloride contamination, but to a lesser degree than the floor slabs. The contamination of vertical members tends to be more localized and limited to the areas where salt water can leak through the floor slab system. Therefore, leaking cracks and joints in the floor slab system can cause conditions that will lead to chloride contamination of the concrete in the underlying structural members. The bases of columns and bumper walls also get contaminated by salt spray from moving vehicles (Figure 15-9).

How long will it take to contaminate the concrete in my parking structure? The three most basic factors that control the "time to corrosion" are: Concrete permeability, water-cement ratio, and the concrete cover to the embedded steel reinforcement. Other factors include design practices (deficiencies), effectiveness of corrosion protection system, and maintenance. The reader should refer to the ACI Committee 362 report "Guide for Design of Durable Parking Structures" for a more detailed discussion of the factors that can adversely affect the life expectancy of parking facilities. Facility maintenance is discussed in Chapter 14.

The use of special additives to reduce concrete permeability in construction of new facilities was not customary prior to the mid 1980s. Instead, finishing and curing practices were primarily relied upon to provide less permeable concrete. More recently, latex-modified polymers and pozzolans such as silica fume admixtures have been used in new construction and repair materials to reduce concrete permeability.

The water-cement ratio of the concrete currently specified for use in parking facilities by the ACI Building Code and that recommended in ACI 362 report on design of parking facilities is 0.40 to 0.45. Structures designed prior to the 1977 ACI Building Code utilized a water-cement ratio of 0.53 or greater, in accordance with the specified limits. Therefore, many older facilities are now susceptible to chloride-induced concrete deterioration.

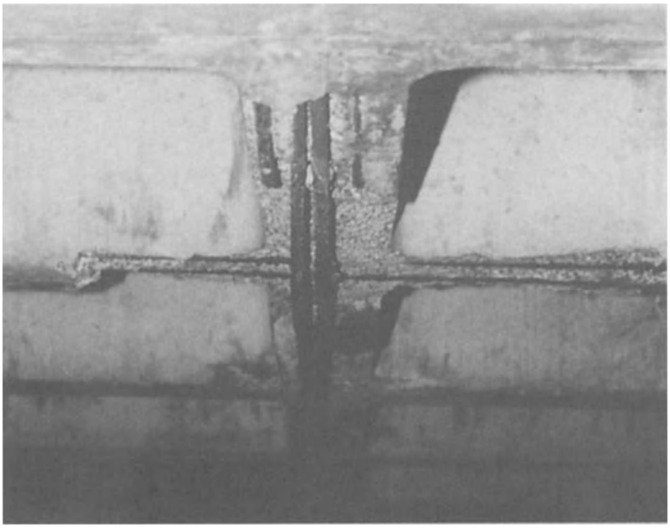
The minimum concrete cover specified by the ACI Building Code is 1½ in. The minimum concrete cover specified by the ACI 362 Committee parking structure design guide is 2 in. The cover may be reduced to 1½ in. for epoxy-coated reinforcement and concrete with a corrosion inhibitor. For most older facilities built in accordance with the Building



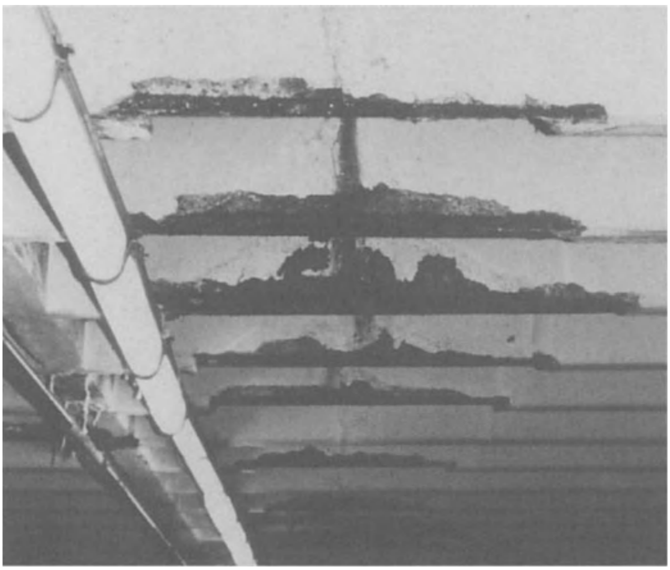
(a)

(b)

Figure 15-9. (a) Deterioration of underside of slab due to water leakage through slab cracks. (b) Beam deterioration.

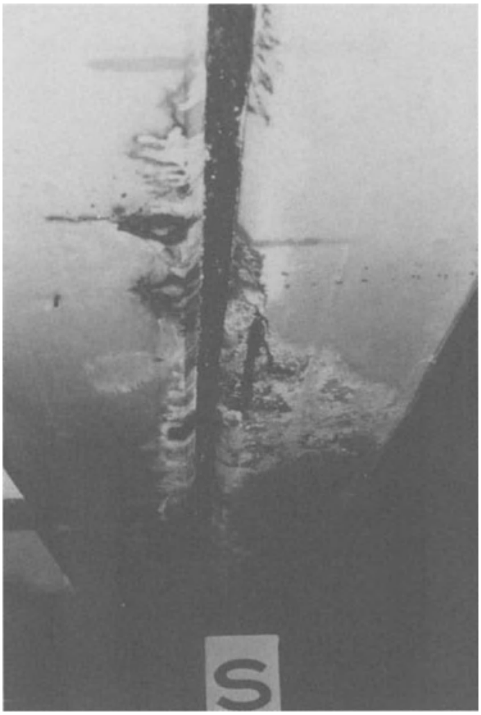


(c)



(d)

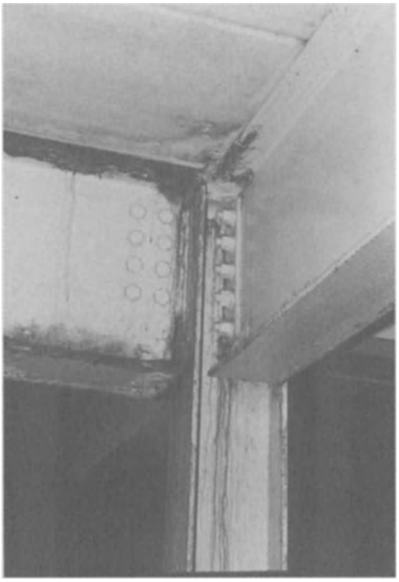
Figure 15-9. (*Continued*) (c) Deterioration of underside of waffle slab. (d) Pan joist deterioration at leaking construction joint.



(e)

(f)

Figure 15-9. (*Continued*) (e) Beam deterioration at leaking expansion joint. (f) Corrosion of metal deck.



(g)

(h)

Figure 15-9. (*Continued*) (g) Corrosion of underlying structural steel beam and column. (h) Deterioration of column base.

Codes prior to 1977, the minimum specified concrete cover is ¾ in. Again, the older facilities are very susceptible to chloride contamination owing to the potential for presence of shallow concrete cover over embedded reinforcement.

The type and extent of cracking will affect the time to corrosion of the embedded reinforcement in structural members. The cracks and joints in concrete member provide avenues for moisture and chloride ion penetration into concrete. Crack control measures such as reducing the bar size and/or limiting the reinforcement stress in negative moment region will reduce flexural crack widths and the potential for corrosion of the embedded reinforcement. Many older structures were designed without these effective crack control results. Surface cracks in slab can be reduced by following proper finishing and curing procedures during construction. As-built conditions and extent of surface cracking can vary considerably from structure to structure.

The answer to the previous question with regard to the rate of chloride contamination is that it can vary considerably. The older structures have inherent deficiencies that make them more susceptible to corrosion-induced deterioration. These less durable structures require more frequent and costly repairs owing to the progressive nature of chloride-induced deterioration.

The complete life cycle of a parking structure can be represented by the four stages of deterioration shown in Figure 15-10. Often, the adverse effects of chloride contamination are not apparent to many owners until the final stage of the deterioration process (stage 4). By then it is too late to implement any preventive measures, and costly repairs are needed to extend the service life of the structure. Also, stage 1 and stage 2 of the process cannot be determined by a mere visual review. Chloride monitoring at periodic intervals is necessary to determine the progressive contamination of the structure. This monitoring assists in implementing appropriate and timely preventive maintenance measures. Maintenance performed when the structure is in stage 1 or 2 provides the best return on the investment of the repair efforts and funds (refer to Figure 15-2).

15.3.1.2 Corrosion Mechanism

Corrosion of metal in concrete is an electrochemical process that contributes to progressive concrete deterioration. The impact of chloride contamination and corrosion can be explained by understanding the protective, as well as the corrosive, mechanism of reinforcement in concrete. The ability of metal to form a protective film greatly reduces the rate

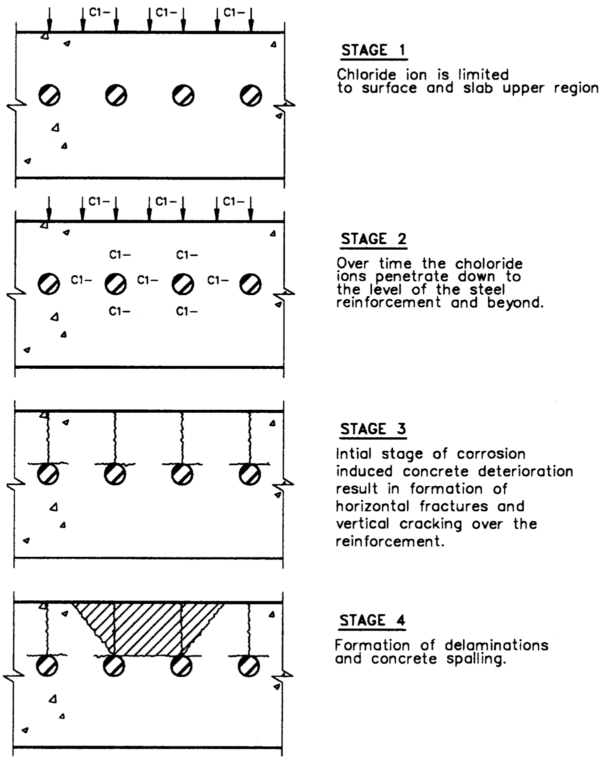


Figure 15-10. Stages of concrete deterioration.

at which it corrodes. This protective film is generally an oxide and plays an important role in the corrosion resistance of metal, such as aluminum, chromium, stainless steel, lead, and other relatively noble metals. The oxide film on the steel reinforcement embedded in the concrete is relatively stable in a caustic (alkaline) environment with a high pH.

Concrete is a product of the cement hydration process. When water is added to cement, it reacts to form a gel that is the binder in the concrete matrix. Another primary reaction product of the cement hydration process is calcium hydroxide [$Ca(OH)_2$]. The presence of this calcium hydroxide in the concrete results in an environment within the concrete that is at a high pH of 12 to 13. This highly alkaline environment provides a passive environment that naturally protects the steel embedded in the concrete. However, if the pH of the concrete falls below 11.5, the protective oxide film on the surface of the steel becomes

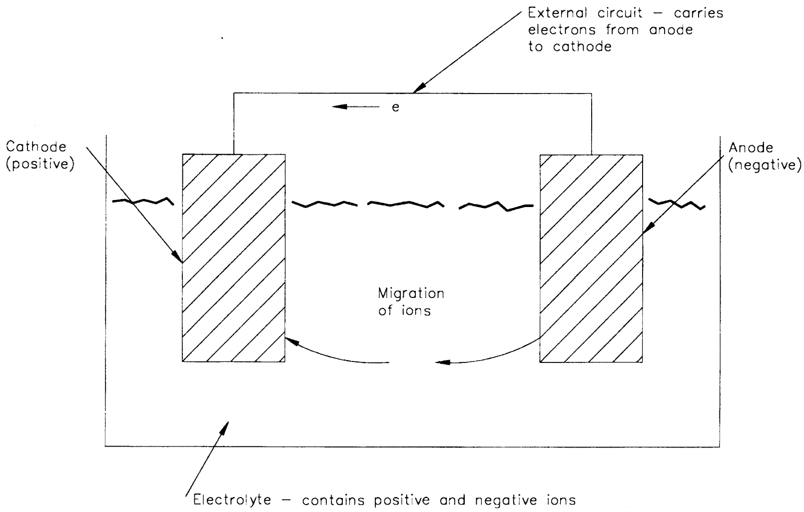


Figure 15-11. Schematic diagram of a basic corrosion cell.

unstable, which can then initiate corrosion of the embedded reinforcement.

The electrochemical reactions of the corrosion process involve the transfer of electrons and migration of ions. The essential elements of a basic corrosion cell are illustrated in Figure 15-11. The anode is the point where corrosion occurs by migration of ions into the electrolyte. The cathode is the point where electrons are consumed and no corrosion occurs. The electrolyte is usually an aqueous solution containing ions, capable of conducting current. The return circuit is a metallic path through which electrons move from the anode to the cathode, which usually consists of the metallic reinforcement itself.

The voltage difference between the anode and the cathode needed to drive the corrosion current can exist owing to the presence of dissimilar metals in the concrete which are electrically connected. It can also exist in a continuous metallic element, such as an embedded reinforcement, owing to the difference of the environment between two areas on the same element. The difference of the environment along a reinforcement in concrete can be attributed to variations in chloride ion concentrations, variations in surface condition, extent of consolidation, availability of oxygen, pH of concrete, or moisture (Figure 15-12). This corrosion cell is also referred to as the "microcell."

In a chloride-contaminated slab, the potential difference that will sustain the corrosion process can be attributed to the difference in

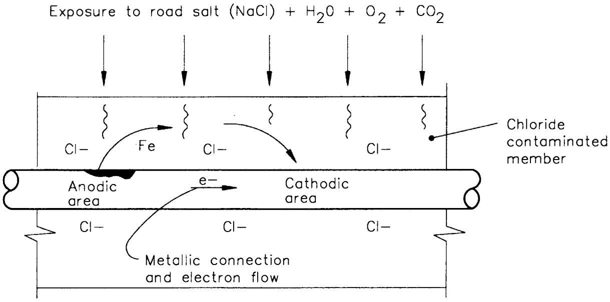


Figure 15-12. Development of corrosion cell along embedded reinforcement (microcell).

the chloride ion concentrations along the reinforcement as well as the amount of chloride ions reaching the top and lower mats of the slab. The upper layer of reinforcement in the more chloride-contaminated concrete will be anodic to the bottom layer and results in development of a strong corrosion cell referred to as a "macrocell." This will result in the corrosion of the upper layer of reinforcement when the mats are electrically connected (Figure 15-13). Generally, a macrocell corrosion will contribute to a more rapid deterioration of the structure than a microcell corrosion. A single reinforcement electrically isolated, but embedded in chloride-contaminated concrete, is likely to corrode at a relatively slower rate than a top reinforcement also connected to the

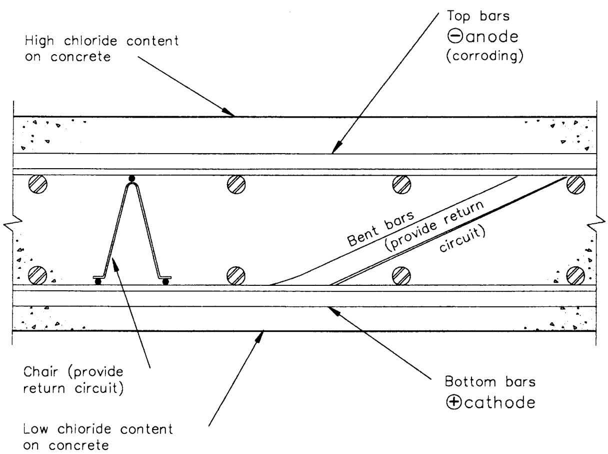


Figure 15-13. Development of corrosion cell between top and bottom layers of slab reinforcement (macrocell).

lower mat of reinforcement in uncontaminated concrete. Most reinforced concrete structures tend to deteriorate owing to micro- as well as macrocell corrosion.

Another example of accelerated corrosion is a reinforcing bar exposed to both concrete and water, as at a spalled area of the floor slab. The reinforcing section in the water is likely to corrode owing to the different electrolytes to which it is exposed. The reinforcement in the water will be anodic to the reinforcement in the concrete. The rate at which corrosion occurs is also affected by the relative areas between the anode and the cathode. If the anodic area is small relative to the area of the cathode, the anode (the upper mat of reinforcement in a slab) will tend to corrode rapidly. This is because the corrosion current is concentrated in a smaller area.

Corrosion byproducts (rust) occupy a volume at least 2.5 times that of the parent metal. This expansion causes high tensile stresses which crack ("delaminate") the surrounding concrete. Concrete cracking can occur when section loss of the corroding metal is 5% or less. Cracks first appear vertically over, and parallel to, the corroding reinforcement. These cracks permit more moisture, oxygen, and chloride ions to the level of the reinforcement, causing accelerated corrosion and concrete delamination (refer to Figure 15-10). The corrosion-induced cracks running along the length of the reinforcement are potentially more damaging than transverse cracks running across the length of the reinforcement. If the concrete has low permeability and/or high resistivity, relatively fine hairline transverse cracks (0.007 in. wide) are unlikely to contribute to accelerated corrosion of embedded reinforcement. However, wide transverse and through-slab cracks can contribute to localized corrosion of embedded reinforcement at the cracked location.

15.3.1.3 Corrosion-Induced Distress

Corrosion of concrete reinforcement can adversely affect structural members. The adverse impact on serviceability and structural integrity is as follows:

- Concentrate deterioration causes serviceability, maintenance, and operational safety problems. The corrosion mechanism is initiated when the chloride ions penetrate the level of the embedded reinforcement.
- Concrete cross section loss due to corrosion of reinforcement can adversely affect the load-carrying capacity of individual elements of the structural system, such as floors, slabs, beams, and columns.

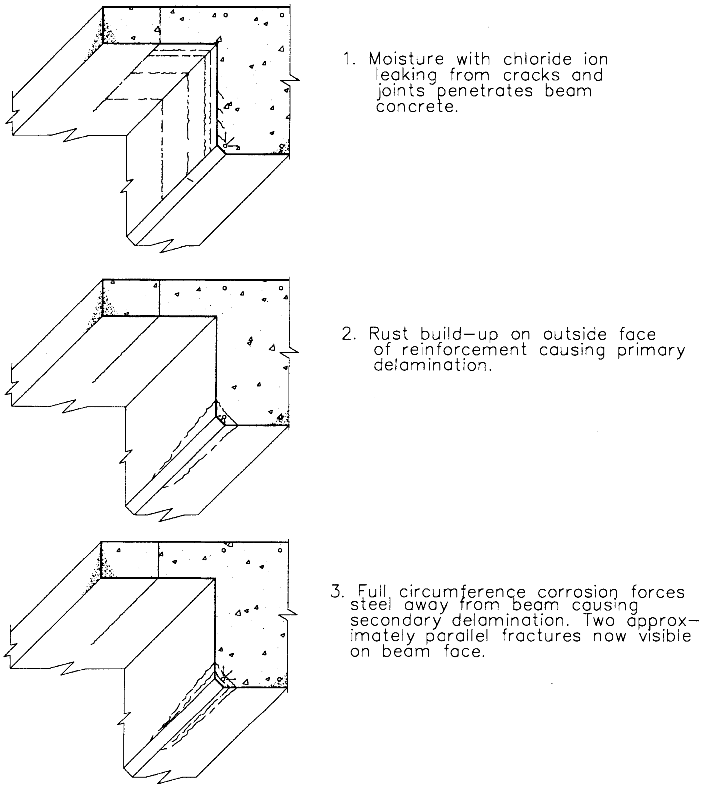


Figure 15-14. Beam deterioration mechanism.

- The reinforcement loses significant cross section owing to corrosion, which can contribute to stress redistribution and possible overstressing of the structure.
- The reinforcement debonds from the concrete in delaminated areas, which can result in reduced load-carrying capacities of members due to loss of anchorage.

Spall development in beams due to water leakage is shown in Figure 15-14.

Surface spalling near midspan reduces the concrete section. Concrete section reduction at midspan can significantly reduce the structural capacity of the concrete member. At the same time, severe corrosion of bottom reinforcement due to leakage can also result in overstressing and possible reinforcement yielding or failures. Loose spalls and delam-

Figure 15-15. Water leakage through control joints in precast double-tee floor.

ination as a result of corrosion-induced deterioration can be hazardous for facility users and can damage vehicles.

Prestressed structures tend to limit the extent of flexural and through-slab cracking and generally perform better than conventionally reinforced structures in an aggressive environment. However, there are some vulnerable locations of the posttensioning system that need to be well protected to assure long-term performance of prestressed concrete structures. Prestressed concrete structures are not immune to corrosion-induced deterioration. The impact of the slab tendon failure is more extensive and affects several bays between construction joints and/or end anchorages.

Precast prestressed structures are susceptible to joint leakage and subsequent corrosion damage of the embedded welded wire fabric in the upper portion of the floor system and the underlying structural steel connections. The water leakage can also contribute to corrosion of the embedded reinforcement in the floor slab members, beams and columns (Figure 15-15). The double-tee precast members are most commonly used in the floor slab system for parking structures. The precast double tees are pretopped or field topped. Corrosion of the welded wire fabric and embedded steel connectors in the concrete topping or the flanges of pretopped precast double tees can contribute to widespread flange deterioration. Corrosion of prestressing systems and the impact on the structure is discussed in more detail in the following section 15.3.1.4.

Most parking facilities built prior to 1977 generally did not utilize an effective corrosion protection system, such as surface sealer, epoxy-coated reinforcement, or corrosion inhibitor, except that some structures were occasionally sealed with boiled linseed oil. Concrete surface treatment with boiled linseed oil is considered to be relatively ineffective in screening chloride ions.

A more detailed discussion of corrosion is provided in the American Concrete Institute's (ACI) committee reports entitled "Guide to Durable Concrete," ACI 201.2R, and "Corrosion of Metals in Concrete," ACI 222R, and other materials referenced within the text. The subject matter discussed in this section is intended to provide an overview of the corrosion process and familiarize the reader with the impact of this distress mechanism on structural members.

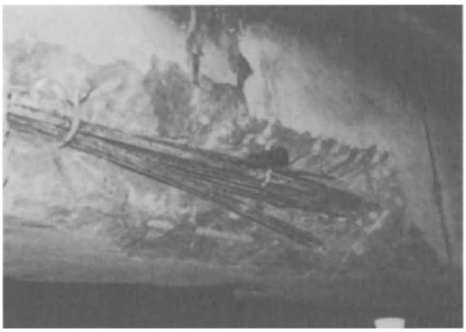
15.3.1.4 Corrosion of Prestressing Tendons

Many older prestressed structures are now starting to show evidence of corrosion related distress. The corrosion of prestressed structures appears to be more evident in the cast-in-place posttensioned structures (Figure 15-16). In the author's opinion, the precast parking structures are just as vulnerable to corrosion-induced deterioration. Some of the adverse conditions that can contribute to the accelerated deterioration of parking facilities are listed in section 15.3. In addition, other specific conditions that can further affect prestressed structures are:

- The type of corrosion protection system of the tendon in the structure
- Water leakage through random cracks, construction joints, control joints, and expansion joints
- Water leakage into the tendons through end anchorage
- Shallow concrete cover to tendons at high points of the tendon profile
- Corrosion of mild steel reinforcement and open spalls that can expose the tendon directly to traffic abrasion and wear
- Chloride contamination of the slab to the level of the tendon

15.3.1.4.1 Corrosion Mechanism. Prestressing tendons are made of high-strength steel, and the corrosion mechanism of prestressing steel is similar to that discussed for the mild steel reinforcement. Chloride ions will cause accelerated corrosion of prestressing steel. In addition, the tendons are susceptible to "stress-corrosion cracking," which results in microcracking and loss of ductility of the high-strength steel. The stress corrosion cracking is accelerated in presence of certain other ions

(a)



(b)

(c)

Figure 15-16. (a) Corrosion of unbonded button-head wire tendon. (b) Corrosion of bonded button-head beam tendon. (c) Corrosion of strand at end-anchorage beam pocket.

such as nitrate and bisulfide ions. Do not confuse nitrate with calcium nitrite, which is a corrosion inhibitor often used for corrosion protection of embedded reinforcement in concrete. Stress corrosion-related failures are uncommon. Failure related to "hydrogen embrittlement" is also very uncommon. Hydrogen embrittlement failure is caused by the tendon coming in contact with the hydrogen ion. Hydrogen ions are formed by applying external electrical currents to the structure. In some instances the application of external currents to the structure is intentional, such as in the cathodic protection of mild steel reinforcement. The most common cause of tendon failure is accelerated corrosion in presence of chloride ions, sometimes referred to as "pitting corrosion." The prestressing steel will corrode when it is exposed to the atmosphere. Therefore, the tendon needs to be always protected by a special coating and/or wrapping.

15.3.1.4.2 Corrosion Protection. Cross-sectional loss of prestressing tendon due to corrosion will have a significant impact on the load-carrying capacity and the integrity of the structure. The prestressing wires or strands require protection from corrosion prior to, during, and after construction of the structure. The best protection for the strand is to provide a concrete with a high pH. In precast concrete members the tendons are encased and the concrete provides the corrosion protection of the tendon.

Since the 1950s, several different types of encasements for the prestressing tendons have been developed for cast-in-place posttensioned construction. The encasement prevents the tendon from bonding to the surrounding concrete. In addition, the encasement also provides corrosion protection of the tendon under service conditions. After prestressing the tendons, the annular space or void in the duct (chase) created by the encasement is filled with grout or grease containing corrosion inhibitors. In an aggressive environment, the corrosion protection provided by the encasement is an important factor that will influence the service life of the structure. Refer to Figure 15-17 for a summary of the evolution of the strand corrosion protection systems.

The tendon corrosion protection systems that have been used in the construction of parking structures are as follows:

1. Greased and paper-wrapped tendons. The greased and paper-wrapped tendons were used in parking structures built in the late 1960s and the early 1970s. Both strands as well as buttonhead wire elements were paper-wrapped. At times, a mastic was substituted for the grease (Figure 15-18). The paper-wrapping provided very minimal protection against moisture and chloride ion intrusion. The

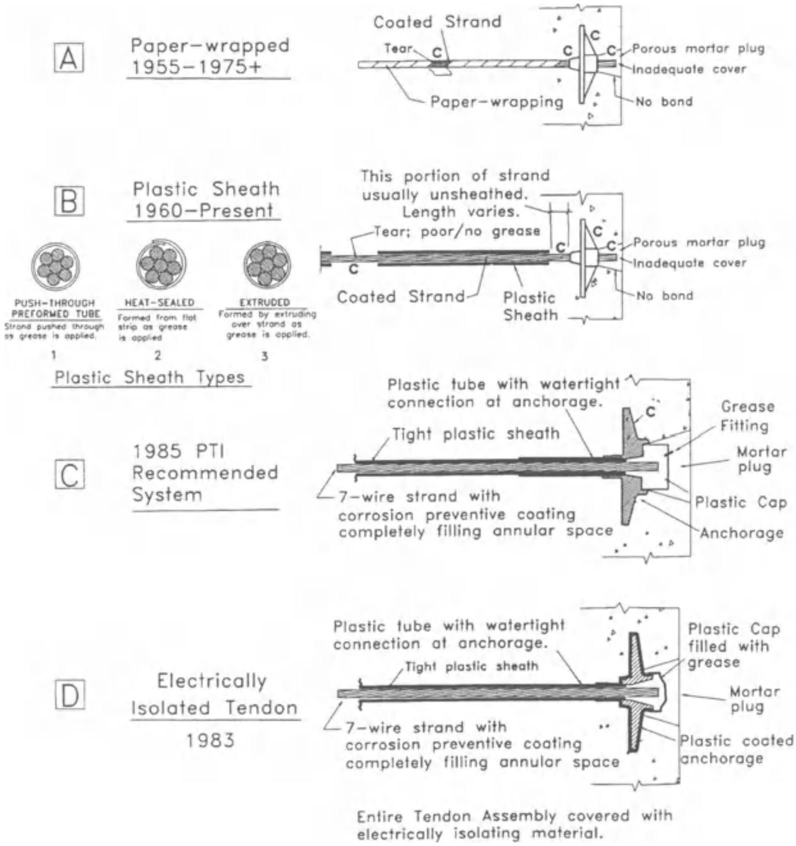
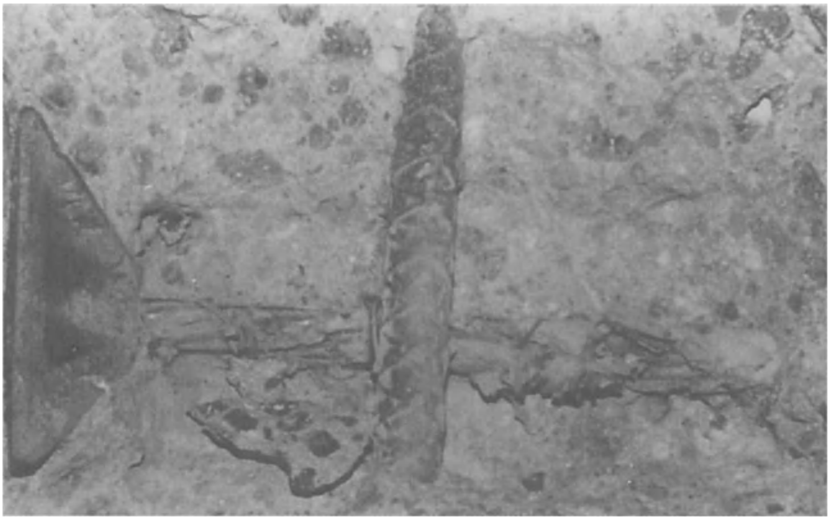


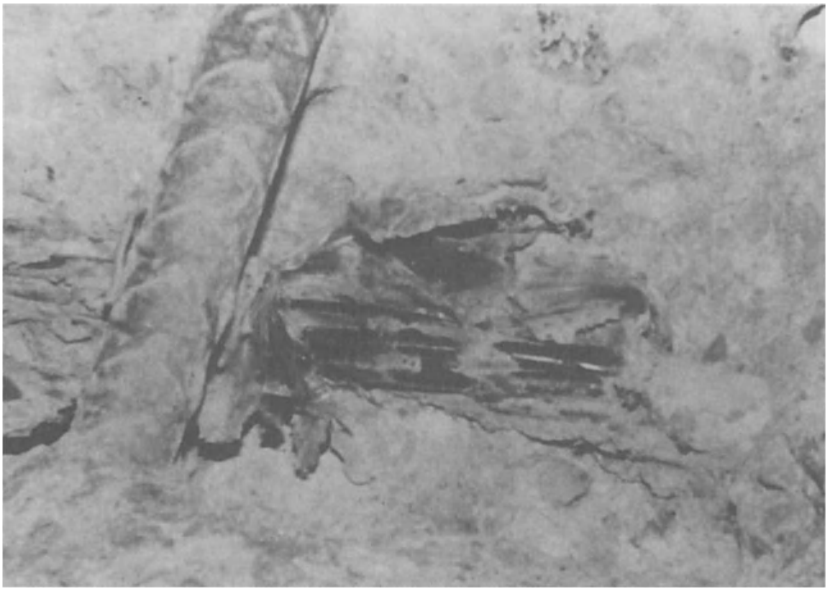
Figure 15-17. Evolution of unbonded tendon corrosion protection systems. From "Unbonded Tendons—Evolution and Performance," by Morris Schupack, Concrete International Journal, American Concrete Institute, December 1994.

paper is easily damaged during concrete placements. Intermediate anchorage hardware is usually left unprotected. The tendon end sections close to anchorages are also left unprotected. Structures built with prestressing tendons protected by this system are getting to be over 20 years old and have the greatest potential for problems.

2. Plastic sheathing with grease. The plastic sheathing with grease was primarily used in structures built since the early 1970s. There are two types: the heat sealed, and the extruded type. The push-through and heat-sealed plastic sheathings were developed first, and the extruded type was introduced later. The push-through and the heat-



(a)



(b)

Figure 15-18. (a) Greased and paper-wrapped strand. (b) Greased and paper-wrapped wire tendon.

Figure 15-19. Strand with grease and push-through sheathing.

sealed plastic sheathing are a loose fit, and the extruded type is a tight fit. The push-through and the heat-sealed sheathing leave a much larger void around the tendon and provide an avenue for moisture to enter into sheathing (Figure 15-19). It is much more difficult for the moisture to get into the tightly wrapped extruded sheathing. Structures built with this tendon protection system are venerable to corrosion in sections that are left unprotected by sheathing. The tendon sections close to anchorages are usually left unprotected. Also, the end and intermediate anchorage hardware are left unprotected.

3. Encapsulated tendons. Based on the recommendations of the 1985 Post Tensioning Institute (PTI) guide specifications, the totally encapsulated systems were developed for corrosion protection of the prestressing tendons. In this system the tendons, as well as the anchorages, are completely sealed for water tightness.
4. Sheet metal duct with grout. The sheet metal duct with the grout is primarily used for bonded tendons (Figure 15-20). The grout provides corrosion protection of the tendons.

Most parking facilities tend to use unbonded tendons for posttensioning of slabs and beams. The use of bonded tendons in the older facilities is primarily limited to posttensioning of beams and girders, although one might occasionally come across a parking structure with a bonded post-tensioning system in the slab. The grouted tendons are

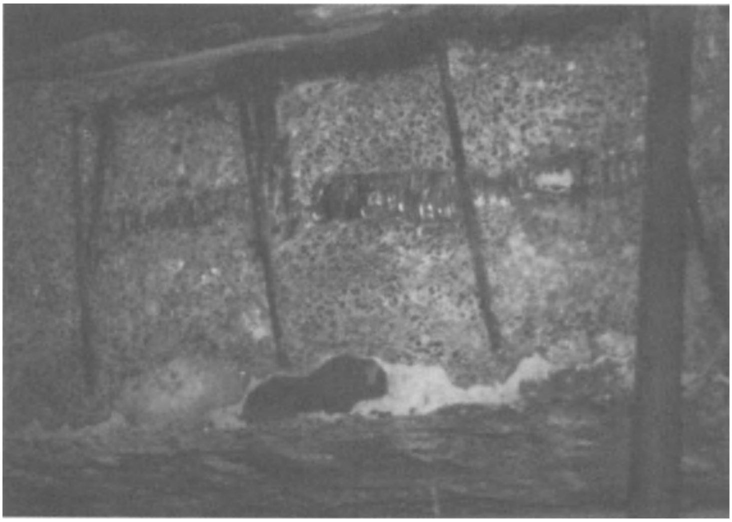
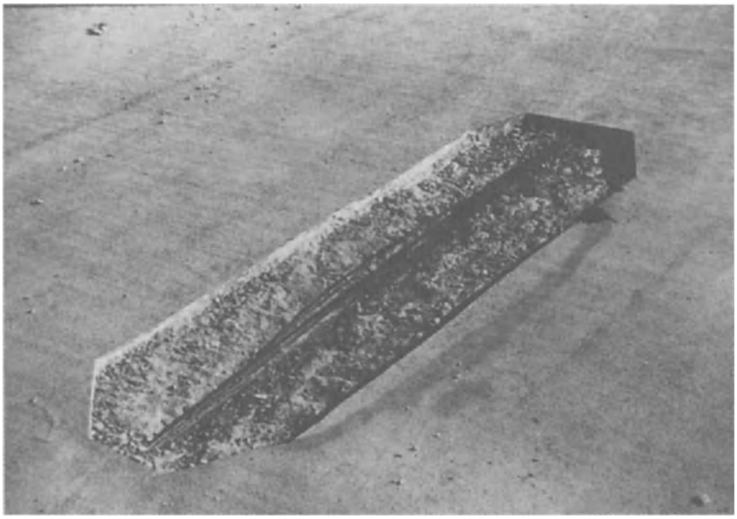


Figure 15-20. Grouted beam tendon encased by sheet metal duct.

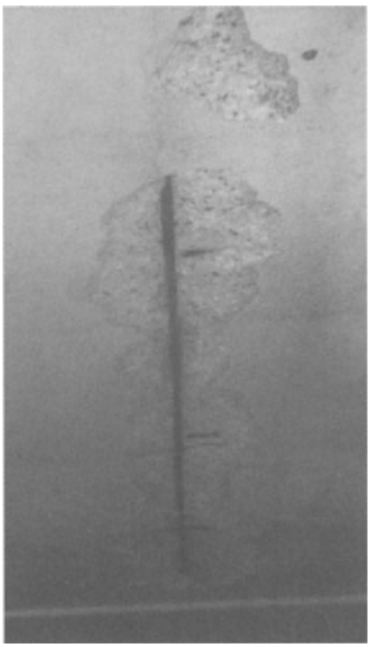
susceptible to moisture infiltration into the system if voids are left in the duct during the grouting of the tendons. Also, the metal duct sheathing is just as susceptible to corrosion in chloride-contaminated concrete as any other metal.

Corrosion of posttensioning tendons results in formation of cracks directly over the tendon, delamination, and/or spalls. Spalling can occur on the slab surface or underside (Figure 15-21). Release of the posttensioning force due to tendon failure sometimes causes the tendon to break through the surface of the slab, as shown in Figure 15-22. The probability of this type of tendon breakthrough increases if there are areas of shallow concrete cover over the tendon. The tendon breakthrough can occur on the top or the bottom surface of the slab. There is generally no correlation between the tendon failure location and the location where the tendons break through the surface. This type of tendon breakthrough generally occurs with the strand posttensioning systems. Other areas where one can look for evidence of tendon breakages are slab and beam tendon end anchorages.

Corrosion of the prestressing tendon can occur at many points along the tendon profile. (Figure 15-23). Water leakage through random slab cracks and construction joints can corrode and damage tendons. If the sheathing is damaged, moisture can enter the sheathing or wrapping and migrate to any locations along the tendon profile and cause tendon damage in other areas. This situation can also occur as a result of



(a)



(b)

Figure 15-21. (a) Tendon corrosion and spall on slab surface. (b) Spalling and cracking on underside of slab due to tendon corrosion.

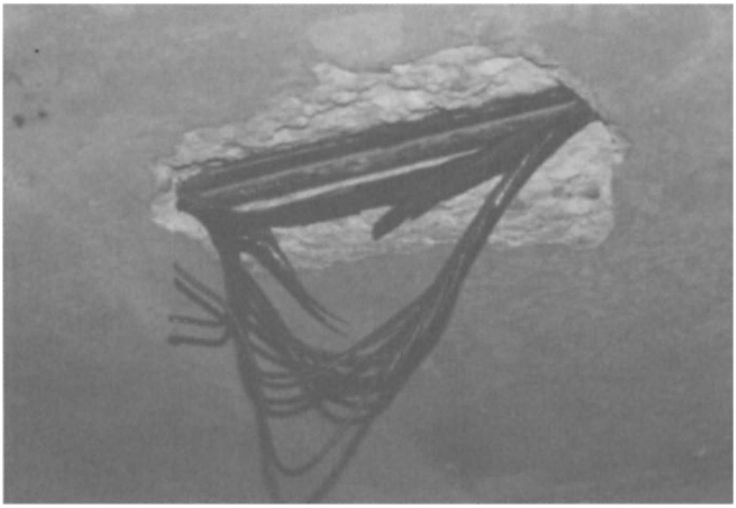
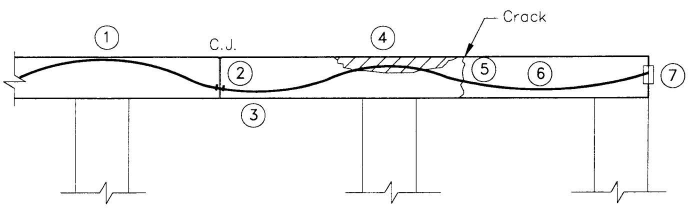


Figure 15-22. Tendon breakthrough on slab underside in area with very shallow concrete cover (>¾″).



1. Shallow cover over tendon at tendon profile high point.
2. Tendon corrosion due to water leakage at construction joints.
3. Moisture can collect at low points of profile due to damaged sheathing at high point.
4. Tendon exposed by concrete spalls due to corrosion of embeded reinforcement.
5. Tendon corrosion at random through-slab cracks.
6. Moisture can enter the tendon from end anchorage.
7. End anchorage corrosion.

Figure 15-23. Tendon corrosion locations.

sheathing damage over high points of the tendon profile. Sometimes tendons over beams, for instance, are exposed to traffic abrasion and wear due to concrete spalling or improper tendon placement. The damaged tendon sheathing provides an avenue for moisture to run down and collect at the tendon low points located at midspans. The tendons with plastic sheathing provide better protection than the paper-wrapped tendons. Leaching and/or rust staining at random cracks may indicate tendon corrosion (Figure 15-24).

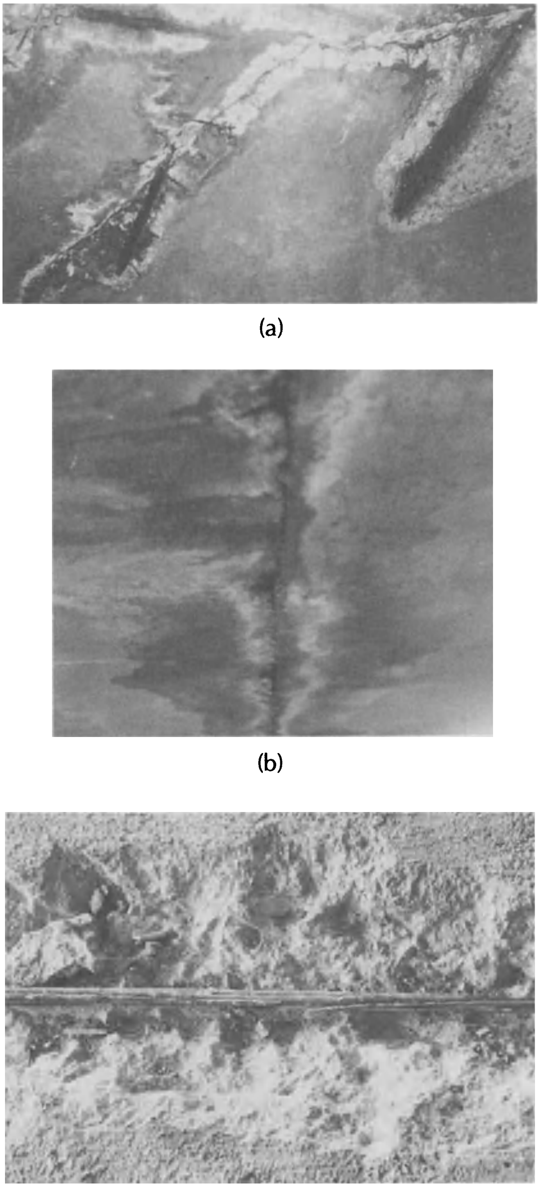
The end and intermediate tendon anchorages are also susceptible to corrosion damage. Structures without the encapsulated tendon protection system are extremely vulnerable to the tendon corrosion at leaking construction joints. A large majority of the tendon corrosion problems currently encountered with older parking facilities can be attributed primarily to tendon corrosion at construction joints. Some couplers tend to be very large, which can result in reduced concrete cover over the embedded anchorage and initiate surface deterioration that can eventually cause tendon corrosion (Figure 15-25).

The end anchorages need to be protected from corrosion. Poorly grouted tendon pockets or poor-quality grout can trap moisture, which will tend to accelerate the corrosion of the tendon and/or anchorage hardware. The grout should be capable of preventing water entering into the tendon through the end anchorage. Moisture will enter and collect at the tendon profile low points. End anchorages at expansion joints and unsealed pour strips are particularly susceptible to water leakage. Leaching and/or rust staining at slab or beam grout pockets is an indication of potential problems (Figure 15-26). Grease stains on ceilings sometimes indicate moisture intrusion into the tendon sheathing.

Tendon failure is accelerated by routine patching of open spalls to maintain serviceability. These temporary patches are generally acceptable for normal mild steel reinforcement, but can be very damaging for prestressing tendons. Open spalls should not be patched without restoring the continuity of the tendon sheathing to isolate the tendon from accelerated electrochemical corrosion (see section 15-7.4)). A detail to minimize potential for accelerated corrosion of the tendon in floor slab patches with prestressing tendons is shown in Figure 15.27.

15.3.2 Freeze-Thaw-Induced Deterioration

Concrete floor surfaces of parking facilities are susceptible to freeze-thaw deterioration, especially if the concrete is not adequately air-entrained and critically saturated owing to ponding or poor drainage. The most common form of surface deterioration is scaling. Scaling is characterized by the progressive deterioration of the concrete surface through paste (sand/cement) failure. It results from the disruptive forces generated in the paste when the concrete is saturated and freezes. Scaling is common in those areas of the continent subject to freeze-thaw cycling.

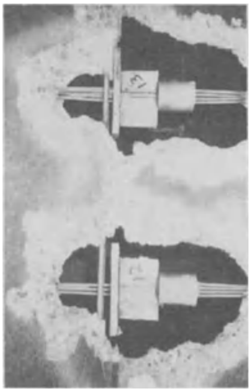


(a)

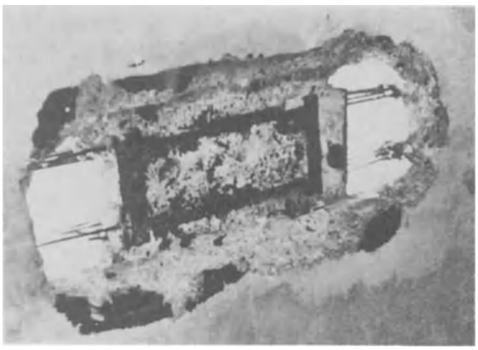
(b)

(c)

Figure 15-24. (a) Leaking, leaching, rust staining, and tendon corrosion at random crack. (b) Leaking construction joints with leaching and rust staining. (c) Tendon corrosion at tendon profile high point over beam.



(a)



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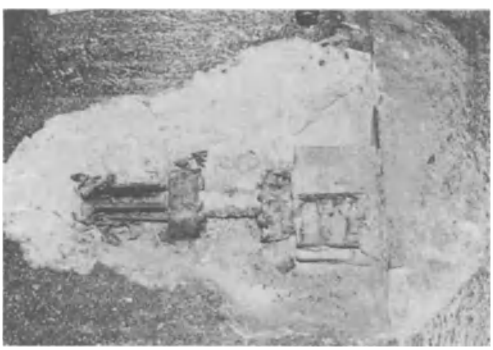


(c)

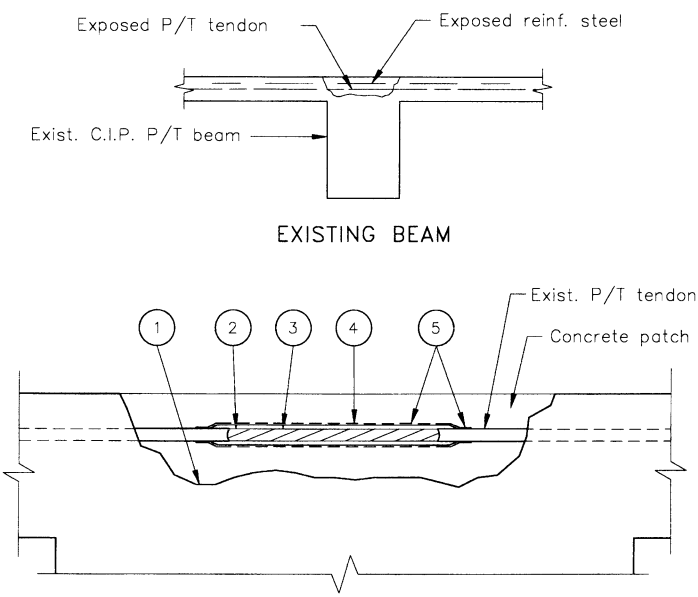
Figure 15-25. (a) Tendon corrosion at construction joint. (b) Tendon corrosion at center-stressing pocket. (c) Intermediate anchorage coupler and wire tendon at construction joint.

(a)

(b)

(c)

Figure 15-26. (a) Grout plug for beam tendon end anchorage. (b) Grout plug for slab tendon end anchorage. (c) Strand corrosion at slab end anchorage.



Notes:

1. Remove concrete back to light grey steel
2. Remove paper wrap & sandblast rusted cable to light grey steel
3. Grease tendon
4. Cover P/T tendon with plastic sheating
5. Cover P/T tendon with waterproof tape & seal ends to paper wrap

Figure 15-27. Tendon protection at spall repairs.

Scaling begins with a slight surface flaking or internal horizontal delamination close to the surface, which becomes deeper with continuing exposure. Initially, only the surface texture and a small amount of paste are eroded. Surface flaking and scaling create depressions that can retain water and contribute to progressively deeper and more extensive deterioration. Eventually, however, coarse aggregate is exposed, and larger surface areas are affected (Figure 15-28).

Scaling can significantly impair the serviceability of concrete intended as driving or walking surfaces. Flat portions of floor slabs, gutter lines, areas near drains, and ponded areas are more susceptible to scaling owing to greater potential for saturation of the surface and the presence of de-icing chemicals (Figures 15-29 and 15-30). Also, exposed

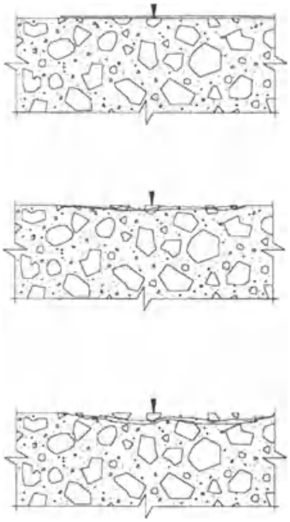


Figure 15-28. Concrete surface scaling mechanism. Source: "Parking Garage Maintenance Manual," Parking Consultants Council, National Parking Association.

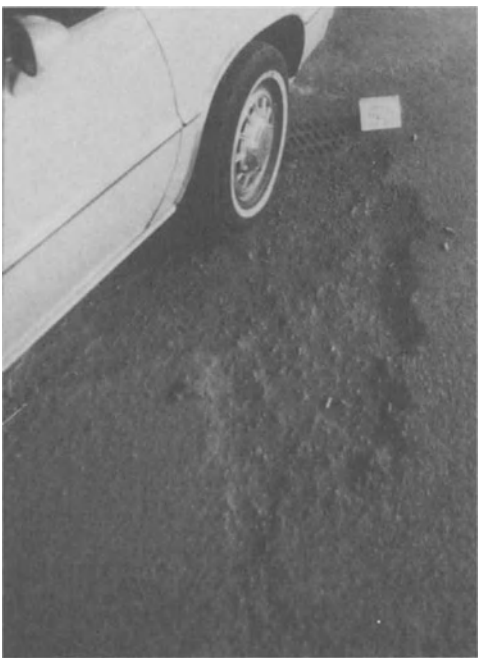


Figure 15-29. Scaling adjacent to drain can contribute to ponding and progressive deterioration of concrete.

surfaces, such as the uppermost floors, are subjected to more freeze-thaw cycling and are therefore more susceptible to scaling.

A concrete mixture with a proper entrained air-void system is required to protect concrete against freeze-thaw deterioration (Figures 15-31, 15-32, and 15-33). Air-entrained concrete is generally produced by using an air-entraining admixture during mixing. Unlike entrapped air, the entrained air voids in air-entrained concrete are microscopic in size and uniformly distributed to accommodate the expansive forces generated by frozen moisture in the saturated concrete.

15.3.2.1 Deterioration Mechanism

Concrete is naturally porous. Excess water not required for hydration (hardening), but needed for workability during mixing, placement, consolidation, and finishing eventually dries, leaving behind a continuous network of pores and capillaries. This network gives concrete its porosity. Porosity, or "permeability," is generally high for concrete mixes with a high water-cement ratio and low for mixes with a low water-cement ratio. High porosity allows the concrete to absorb significant free water during exposure to rain or snow. If concrete cannot dry and becomes saturated during a freeze cycle, ice accumulates in the pore structure.

The destructive mechanism is not ice accumulation itself, but rather water pressure generated during ice development. Water migration through the pore network exerts significant pressures during freezing. It has been substantiated that water pressures cause the paste failure.

15.3.2.2 Influencing Factors

There are a number of factors that influence the nature and extent of scaling on concrete surfaces. The following discussion is not intended to convey any particular order of importance for the factors reviewed, which are divided into two categories.

1. The first category defines and describes those factors related to the service environment. Factors associated with the environment are number and intensity of freeze-thaw cycles, presence of de-icer chemicals, and degree of saturation.
2. The second category of influencing factors is that associated with the particular concrete and its design features. Material properties

Figure 15-30. Scaling at construction joint.

Figure 15-31. Deterioration of non-air-entrained concrete accelerated by poor drainage.

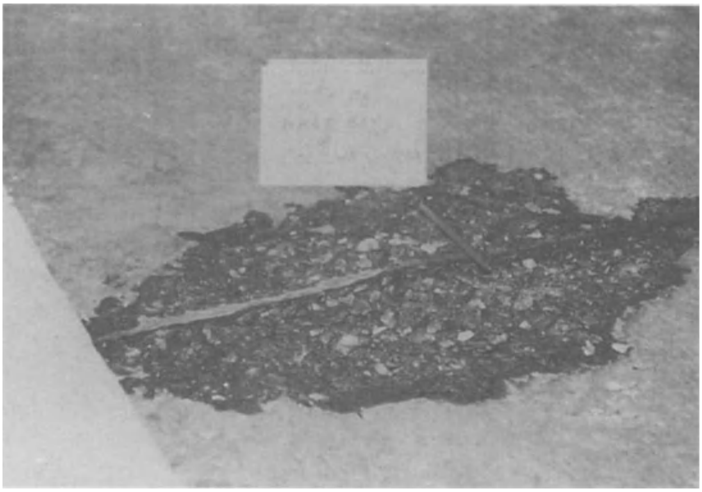


Figure 15-32. Undermining of control joint by deterioration of concrete adjacent to the sealant.

Figure 15-33. Scaling on underside of slab.

that greatly influence the susceptibility of concrete to scaling and freeze-thaw deterioration are air entrainment, strength, water-cement ratio, and mix design.

As previously discussed, freezing is the principal cause of scaling. If there were no freeze-thaw cycles, scaling could not occur. It has been established that the number of freeze-thaw cycles directly influences the deterioration rate. For similar concretes subjected to equivalent degrees of saturation, concrete exposed to the higher number of freeze-thaw cycles will disintegrate earlier and more severely than concrete subjected to fewer freeze-thaw cycles.

In addition to the number of cycles, the rate or cycle intensity is also significant. Rapid freeze-thaw is cycling due to the redistribution of the pressures in the concrete matrix. Concrete surfaces exposed to direct sunlight during winter periods are subject to more frequent and rapid cycling than concrete that is exposed to ambient temperatures but shaded from direct sunlight.

The impact de-icer chemicals (salt) have on scaling is both mechanical and chemical. High concentrations of salt depress the pore water freezing point and increase the osmotic pressures, which causes paste failure. Also, high salt concentrations can set up a countersystem of pressures caused by the alkaline/acid relationships between the concrete and pore water, respectively.

As previously discussed, excess water is required within the pore network during freezing to induce disruptive pressures. Concrete that is relatively dry and subject to freeze-thaw cycling experiences minimal disruption. Continually moist concrete will disintegrate rapidly during freeze-thaw cycling because the water cannot escape without generating disruptive pressures.

Air entrainment has been used successfully over the past several decades to protect concrete against scaling. Air entrainment consists of a uniform dispersion of small bubbles in the paste matrix. These bubbles compete with the pore network for water during freezing and thus relieve the destructive pressures. Research has shown that the bubbles must have a particular size and spacing to be effective at protecting concrete.

In addition to air entrainment, the development of minimum strength prior to the first frost exposure is needed to ensure adequate resistance against freeze-thaw damage. Concrete strength must be at least 3500 psi prior to exposure to the freezing cycle if it is to remain durable in service. Properly air-entrained concrete that has not gained sufficient strength before freezing will be subject to premature freeze-thaw deterioration.

The water-cement ratio directly influences concrete porosity (permeability). Highly permeable concretes are more susceptible to rapid saturation than are those of lower permeability. Concrete has a certain tolerance for moisture. Moisture diffusion within a relatively dry matrix can influence the concentrations of water and can minimize saturation, thus preventing premature deterioration.

Design of the concrete mix, especially the cement factor, water-cement ratio, and use of the maximum-size coarse-aggregate fraction can also enhance long-term durability. The mix design should be tested prior to concrete placement to ensure that the air system specified is achieved during construction. It is common to find differences between the specified and measured air entrainment in the plastic concrete and in the air content of the finished hardened slab.

Concrete design details and concepts also influence susceptibility to scaling. Concrete floor surfaces subject to frequent freezing and de-icer chemical application can be designed to drain rapidly, minimizing critical saturation potential. Parking facility floor slabs with a minimum of 1½–2% grade will drain rapidly and will be inherently less susceptible to scaling owing to the limited potential for saturation.

The above discussion is intended to provide an overview of the scaling process and familiarize the reader with the conditions that impact upon this distress mechanism and its influence on structural members. A more detailed discussion is provided in the American Concrete Institute's (ACI) committee report entitled "Guide to Durable Concrete," ACI 201.2R.

15.3.3 Concrete Cracking

Concrete is strong in compression but relatively weak in tension. Therefore, concrete cracking is caused by development of tensile stress in concrete members. Concrete cracking can occur in plastic as well as in hardened concrete. Plastic concrete cracking can be attributed to improper concrete placement, consolidation, and/or plastic shrinkage of the concrete. Cracking in hardened concrete is usually due to the internal stresses induced by the normal response of structural members due to applied loads, temperature changes, support settlement, or drying shrinkage (Figures 15-34, 15-35(a-c) and 15-36). In some instances, cracking in slabs, beams, columns, walls, and load-bearing areas can be attributed to restraints to volume change of concrete due to design

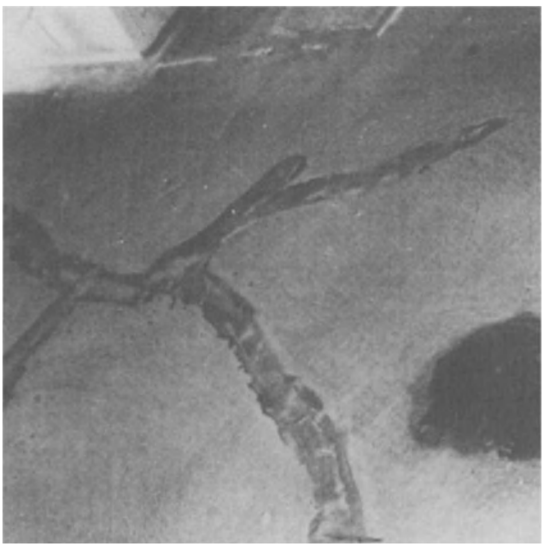
Figure 15-34. Pattern surface cracks on floor slab due to drying shrinkage.

or construction deficiencies. Cracking is also an indication of concealed problems in the concrete floors or supporting members, such as the initial stages of corrosion of embedded reinforcement (See Figure 15-10). Localized loss of prestressing forces due to prestressing strand or tendon deterioration, or embedded anchorage failure, can also result in cracking.

Concrete cracks occur when the concrete member is subjected to tensile stresses and reinforcement is provided to transfer stress across the cracks. Properly designed, sized, and positioned reinforcement helps to distribute and control crack widths. For floor slab exposed to de-icing chemicals, ACI 224R suggests limiting crack widths on the tension face of members to 0.007 in. Cracking can be detrimental when it will permit water leakage or contribute to concrete deterioration. These cracks should be repaired and sealed to minimize the adverse effect of cracking on the long-term durability of the structure.

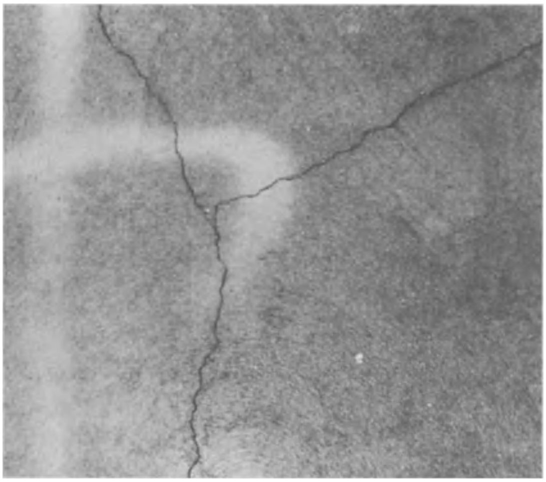
Concrete cracking can be minimized by proper selection of structural systems at the time of design. Other crack control measures are dis-

(a)



(b)

Figure 15-35. (a) Radial cracks over column due to flexural stresses. (b) Floor slab cracks around column.



(c)

(d)

Figure 15-35. (*Continued*) (c) Random through-slab crack. (d) Crack in slab at embedded electrical conduit.

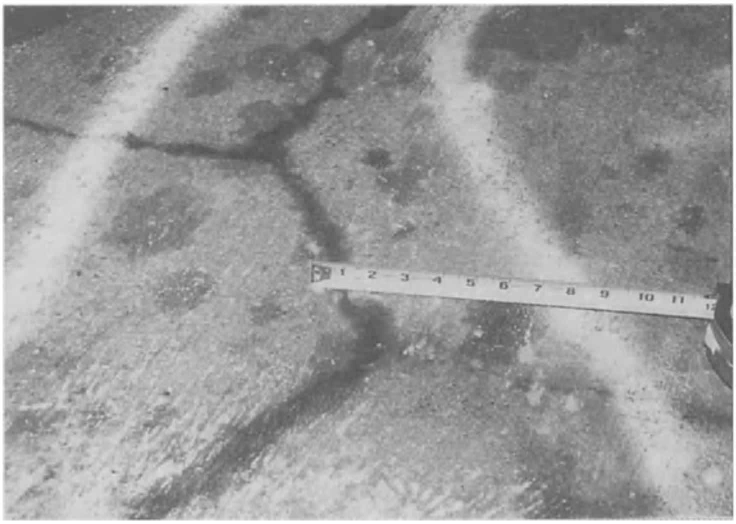


Figure 15-36. Overlay shrinkage crack. The chalk mark indicates that the overlay is debonded.

cussed in ACI 224R. Conventional reinforced concrete floors are highly susceptible to cracking due to shrinkage, thermal, and flexural stresses. Precast pretensioned or cast-in-place posttensioned concrete floor systems are much less susceptible to cracking.

Proper design and installation of control and expansion joint systems will also limit concrete cracking. Floor slab joints allow for shrinkage and temperature-related volume changes, which limit the tensile stresses in concrete. When volume change of concrete is restrained, random concrete cracking can occur. The restraint to volume change is provided by various parts of the structure, such as shear walls, stair towers, and rigid columns. The likelihood of crack formation from volume change is increased by the presence of geometrical discontinuities, construction discontinuities (joints), and tension already existing from applied loads. Concrete spalling and cracking can occur owing to inadequacy of design details, which can result in "binding" of expansion joints and slip-bearing joints. All floor slab joints should be detailed and installed to effectively seal and minimize leakage and potential deterioration of underlying beams, columns, and connections (Figure 15-37). Concrete cracking due to corrosion of embedded reinforcement is discussed in section 15.3.1. Pattern cracking due to chemical reactions such as alkali silica reactivity and carbonation is less commonly noted in parking structures.

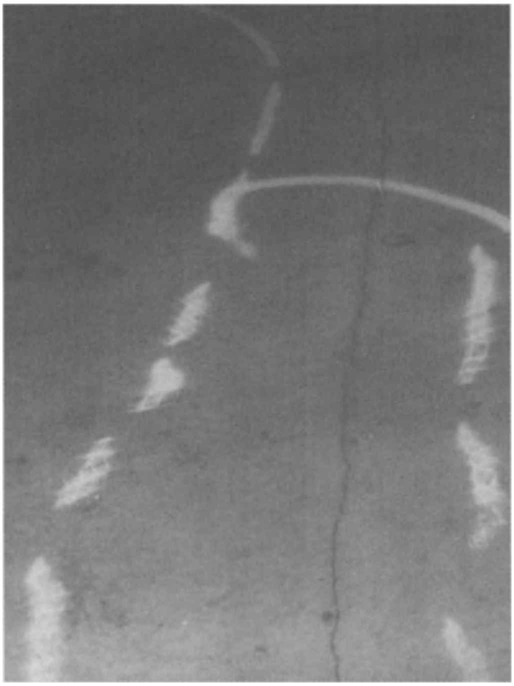


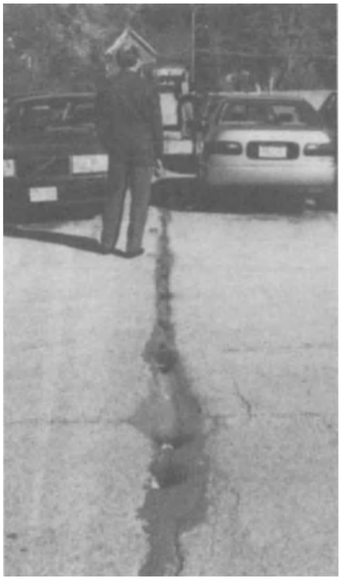
Figure 15-37. Unsealed random crack in concrete topping. Concrete toppings over precast members are susceptible to reflective cracking.

The above discussion is intended to provide an overview of concrete cracking and the conditions that impact upon this distress mechanism and its influence on structural members. A more detailed discussion is provided in the American Concrete Institute's (ACI) committee report entitled "Control of Cracking in Concrete Structures," ACI 224.1R.

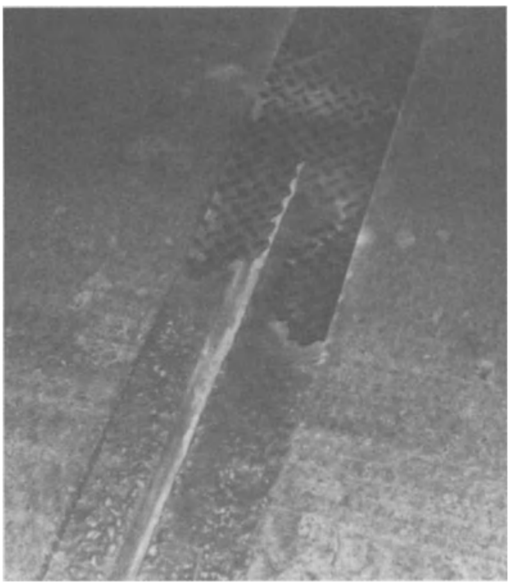
15.3.4 Joint Distress and Leakage

Construction joints are installed at preselected locations to limit the size of concrete placements. These joints are tooled and filled with a flexible sealant to prevent leakage. Control joints provide for concrete volume change movements by creating a series of weakened planes for cracking at predetermined points in the plastic concrete and then filled with a flexible sealant to prevent water leakage. Joints must be properly designed, installed, and maintained to minimize premature deterioration of underlying structural elements (Figure 15-38)

Flexible-joint sealant material installed in joints in the structure will deteriorate owing to exposure to ultraviolet rays, abrasion, and age

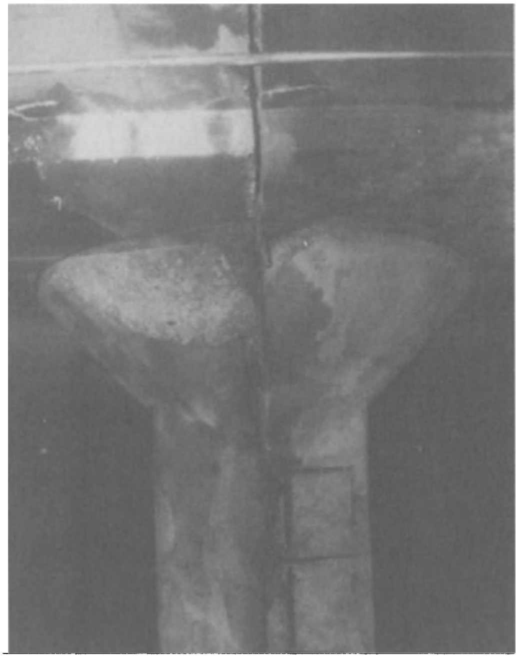


(a)



(b)

Figure 15-38. (a) Unsealed expansion joint. (b) Ineffective and outdated expansion joint.

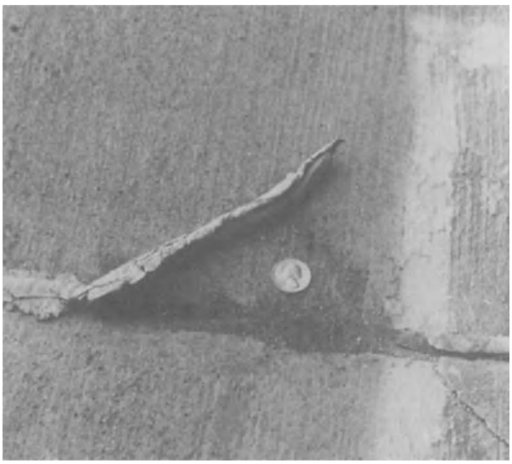


(c)

Figure 15-38. (*Continued*) (c) Underlying structural member deterioration due to leakage at expansion joint.

(Figure 15-39). Joints on supported floor slabs must be maintained by sealing against water leakage and intrusion of debris. To maintain the effectiveness of floor slab joints, most sealant material needs to be removed and replaced at 8- to 10-year intervals. Often, joint sealant deterioration is not the only cause for failed and leaking construction and control joint systems. A joint sealant for a particular application should be selected based on the required degree of flexibility, hardness, bond, strength, or durability. Deterioration of the concrete joint edge also affects joint system performance. Edge deterioration due to wheel or snow plow impact is a typical observation. Freeze-thaw-related distress from entrapped moisture between a failed sealant material and the adjacent concrete can contribute to edge deterioration (see Figure 15-32). Overfilled sealant material is typically ripped from joints or cracks by vehicular traffic. Inappropriate application of the flexible sealant material, in either too deep a groove or too wide and shallow a joint, can result in premature joint failures.

(a)



(b)

Figure 15-39. (a) Damaged wide-seal expansion joint. (b) Control joint sealant failure.

Expansion joints provide a practical limit on structure dimensions to accommodate movements associated with temperature changes, concrete creep, and long-term concrete shrinkage. Expansion joint openings are also sealed with a flexible material. The expansion joint system's effectiveness to seal the opening varies considerable. Some systems that are properly designed, installed, and maintained can be effective;

however, design and installation failures in expansion joint systems are often due to a lack of cleaning of dirt and debris and the potential corrosion of exposed metal components. Also, expansion joints are susceptible to vandalism.

Premolded flexible urethane expansion joints are quite often specified for parking structures. When properly designed and installed, these joints can be effective; however, improper design considerations, such as undersize sealant width, lack of provisions for shear transfer across the joint, positioning of joints in or adjacent to turn aisles, and excessive vehicular and snow plow abuse, usually result in premolded joint failure. Failures can also be attributed to improper preparation of the concrete joint edge and variations in thickness of the installed joint sealant.

Metal-edged expansion joint systems with flexible glands are capable of withstanding greater abuse than premolded joint systems. It is preferable to specify a metal-edged system on exposed levels of a structure. However, these systems are susceptible to dirt and debris accumulation, and require periodic cleaning. The metal-edged joint systems are more costly to install and repair.

Leakage through a failed and unmaintained joint system in a parking facility can create concerns for corrosion-induced and freeze-thaw-related distress on interior levels. Serious concerns for patron safety, damage to vehicles, and general aesthetics are also affected by failed joint systems.

15.3.5 Leaching

Leaching is caused by frequent water leakage through cracks. The water leaking through the crack carries along part of the hydrated lime and other water-soluble products and deposits them as a white film, a stain, or, in extreme cases, stalactites on the ceiling below (Figure 15-40). Continued leakage will weaken the concrete over a period of years, and the deterioration rate is affected by the concrete quality. Leaching is generally more noticeable in cracks along gutterlines and areas that are susceptible to ponding. Water that leaks through cracks can leave deposits that will damage automobile paints.

15.4 CONDITION APPRAISAL

Parking-structure restoration and maintenance programs begin with a thorough facility appraisal. The condition appraisal assists in locating existing distress, qualifying materials, and quantifying the extent of deterioration. Therefore, the condition appraisal provides a foundation

Figure 15-40. Formation of stalactite on slab underside due to continued leaching.

for selecting repair materials, repair methods, and evaluating specific repair alternatives to restore the facility. This section contains details that can assist practicing professionals to develop a restoration program and that enable owners to evaluate proposed programs. Again, proper condition appraisal is necessary to assure success in restoring a structure.

An appraisal requires an in-depth review of existing conditions by observing individual elements and performing selective material and nondestructive testing. Evaluation of laboratory and field survey data collected requires review both by a materials specialist and a structural engineer. The primary objectives of the condition appraisal are to:

1. Define and describe conditions that exist within the facility, focusing mainly on the deterioration of floor slabs and supporting structural elements.
2. Identify cause(s) of the observed deterioration.
3. Describe the extent of the observed deterioration.
4. Evaluate the impact of the observed deterioration on the serviceability, durability, and structural integrity of the facility. (Detailed survey must often be supported by materials and nondestructive testing to identify causes of deterioration.)

5. Develop repair alternatives for the facility. Repair alternatives should include discussion of only feasible repairs which can effectively extend the useful life of the facility.
6. Recommend repairs for the facility based on technical interpretation of data and establish repair priorities to stage construction over several years.
7. Identify items that can adversely affect safety:
   a. Accelerated deterioration of structural members
   b. Code items, such as barrier heights, barrier wall lateral-load-carrying capacity, and mechanical/electrical systems
   c. Structural distress of *as-built* members due to material quality, design deficiencies, or construction practices.

Evaluation of structural distress requires a more extensive testing program to verify results of the analytical work performed to determine the cause(s) of the problem. In some cases, full-scale load testing of the structural element is required to verify results of field, laboratory, and analytical work.

The following ACI Committee reports are recommended as additional reference material: ACI 201.1R, "Guide for Making a Condition Survey of Concrete in Service"; ACI 437R, "Strength Evaluation of Existing Concrete Building"; and ACI 364.1R, "Guide for Evaluation of Concrete Structures Prior to Rehabilitation."

Prior to preparing a comprehensive condition appraisal of a structure, it is essential to perform an accurate and complete field survey. Three key words characterize the field survey: locate, qualify, and quantify. Deterioration found in the survey is recorded on field survey plan sheets that may become part of the condition appraisal report. Materials testing also constitutes an essential part of the survey.

The field survey consists of six phases: preparation, initial walk-through, visual examination documentation, photographic recording, materials testing, and preliminary evaluation. Each of these phases will be discussed in detail. Emphasis placed on any one phase is a function of the condition of the structure being surveyed. Usually structures in a more advanced state of deterioration require more effort than structures showing minimal deterioration. Effective preparation is essential to ensure efficient use of field survey time.

15.4.1 Preparation for Field Survey

Effective preparation is essential to ensure efficient use of field survey time and systematic accumulation of relevant information. Readiness for the survey consists of reviewing the document, preparing field survey sheets, and obtaining appropriate equipment.

15.4.1.1 Document Review

The first step in preparing for the field survey is to attempt to obtain and review plans and specifications used in construction of the structure. It is also helpful to review other available construction records, such a shop drawing submittals, mix-design data, testing and inspection reports, and any maintenance or restoration work that may have been performed. This review is necessary to:

- Become aware of problems characteristic of the type of construction.
- Identify potential problem areas that may require more extensive investigation and preliminary selections of test methods and locations.
- Reduce amount of start-up orientation period (time in the field getting your bearings, etc.).
- Obtain details on materials (i.e., type of steel, prestressing system, concrete, and admixtures) and cover requirements.
- Determine type, size, and orientation of embedded reinforcing. For prestressed structure, review types of tendon corrosions protection and system specified.
- Determine strength of concrete and steel.
- Determine design loads for supported tiers and roof.
- Examine drainage characteristics and locate gutterlines and drains.
- Locate stair towers, elevators, and other features.

Prepare a checklist of items to be covered during the survey, including quantity and types of testing to be performed. Also review ACI 201.1R, "Guide for Making a Condition Survey of Concrete in Service," which contains a checklist for making a condition survey of structures. Contact the appropriate testing agencies to establish requirements and lead time required to perform the evaluation of samples collected during the field survey. Contact testing laboratory or coring company to take cores at the job site and arrange for shipment of the cores back to the office. For prestressed structures contact contractor to assist in exploratory excavation of tendons and anchorages.

When construction or previous repair documents are unavailable, try to retrieve from other sources. Potential sources for obtaining construction records and documents include:

- Municipal building and zoning departments or inspectorial services departments
- Original architects (or later-generation firms)
- Historical society archives
- Contractor's or fabricator's (or later-generation firms') records
- Physical plant or engineering departments of major corporations, educational, or health care institutions

Have as much information as possible on hand when making inquiries. The following will prove useful:

- Building location
- Original name or owner facility (if different)
- Date of construction
- Name of architect, structural engineer, fabricator, and/or contractor

Any of the above information may provide a clue which could lead to tracking down a set of drawings. Especially with older facilities, even as obscure a clue as a rebar identification tag can prove to be essential information that may result in obtaining a source of drawings.

Always try to supplement paper review with verbal discussions with the owner (or other staff member). From your conversations, try to get a feel for the past history of problems and to obtain information regarding specific problems that are most troublesome to the owner.

Reviewing contract documents and construction records can be invaluable in determining the cause(s) of problem(s). Results of any analysis performed should accurately predict measurement of crack widths, deflections, relative movement, etc. made during the field survey. Analysis is based on actual existing loads, geometry, and material properties, rather than design values.

When design and construction documents are not available for review, in addition to use of a pachometer (refer to section 15.4.8), other nondestructive test methods that use X-ray, radar, and infrared thermography are also required to determine reinforcement location and pattern. In most instances, nondestructive test results are visually verified by limited exploratory excavations or test wells. Developing design information by these methods is time-consuming. Therefore, the need for and extent of information required should be established based on results of an initial walk-through review of the structure.

15.4.1.2 Field Survey Sheet

Prior to the field survey determine the scale to be used for the condition survey sheets. Points to consider are (1) minimize number of sheets required for report; (2) keep scale large enough to accurately record data, typically $\frac{1}{16}$ or $\frac{3}{32}$ in. scale; (3) choose a sheet size that can be easily handled during the field survey; and (4) where possible, use the same scale that will be used for the contract documents. Typically, photocopies of original design drawings can be utilized for the condition survey. (Architectural plan sheets are typically the "cleanest" drawings available and usually indicate all "landmarks" within the facility.) Otherwise, draft a grid and produce sufficient blank sheets for the survey. Two sample field survey blank sheets are illustrated in Figures A-1 and A-2 included in Appendix 15-4.

15.4.1.3 Equipment

Get the appropriate equipment ready. Decide which members of the field survey team are to bring which equipment. Avoid field delays by making sure that all equipment is clean, charged, complete, and ready to use.

15.4.2 Initial Walk-Through

Conduct an initial walk-through of the structure during the initial stages of the site visit. Items or issues of particular concern can be identified, and the relative condition of the various structural elements determined. Note special conditions and established code requirements. It is advisable first to perform the tasks that require the largest amount of time (chain drag and visual examination) so that one can reevaluate the time schedule. Also, it may be advisable to perform reflected ceiling surveys prior to floor slab surveys in certain types of facilities (thin one-way slabs, pan joist systems or waffle slabs, or slabs with a waterproofing membrane system) where (1) the condition of the ceiling holds the key to gaining a quicker appreciation of the facility conditions, and/or (2) the floor slab deterioration is extensive, and the ceiling survey may provide the insight required to expedite the floor survey.

15.4.3 Visual Examination and Documentation

During this phase of the survey, distress in members is identified as potential work items. Perform a visual examination and general review of the structural and operational elements summarized in Figure A-3, in Appendix 15-4. Also note all work item locations on the field sheets and any other forms of distress or features in the various structural members that may help in the evaluation of the structure's performance, but not necessarily identified as potential work items. (refer to Section 15.3 for the cause and significance of typical forms of deterioration.) Also review ACI 201.1R, which contains definitions of terms associated with concrete durability and forms of commonly observed distress.

In most instances, the upper surface of floor slabs receive the first and greatest attention. Because of the presence of embedded reinforcement near the top surface, there is a greater potential for concrete deterioration. Floor surveys consist of two phases: (1) locate deteriorations, and (2) record them.

The person recording data accurately locates and scales the spalled/deteriorated areas onto field survey sheets using the appropriate coding. The square footage of the patch required to repair the deteriorated area should be estimated as carefully as possible. (Refer to Figures A-4 through A-8 in the Appendix for a field survey legend and illustration of procedures to systematically record survey data.) Document the size, location, and depth of scaling and spalling. Use a tape measure if necessary; it is of course better to estimate higher than lower.

Cracks may also be an early indication of corrosion of embedded reinforcement. Refer to ACI 224.1R for determining other causes of cracking. Floor slab areas with cracks oriented parallel to embedded reinforcement should be examined with a pachometer to locate the proximity of the embedded reinforcement to the crack. Also, record crack patterns (if present), types, widths, and lengths. It is important to note whether the cracks are through-slab. Through-slab cracks should be documented during the visual survey of the underside of the slab.

As suggested in the National Cooperative Highway Research Program Report #57, cracks can be classified with respect to width, orientation, and, where possible, cause. Precise measurement of crack widths is neither feasible nor desirable, though a description in the following terms is useful: fine (F), less than 0.01 in.; medium (M), 0.01–0.03 in.; wide (W), greater than 0.03 in.

The crack width may be indicated by the abbreviation F, M, or W beside each crack. If the cracks are described, their orientation is usually classified according to one of the following terms: transverse, longitudinal, diagonal, radial, pattern, or random. Care is required in ascertaining crack widths; cracks usually look wider at the surface because of their broken edges. Consequently, the width (¼ in. below the surface) is often reported. The crack width measurements reported by the petrographer during the microscopic examination of core samples are generally more accurate than those obtained in the field survey. The depth of cracks can be verified by taking core samples. The amount of moisture on the deck has a dramatic effect on the degree of cracking that is visible. Fine cracks are difficult to identify on wet or dry decks. Conversely, if a deck is examined under drying conditions, when moisture is associated with each crack, all the cracks are visible and appear to be wider than they are. The inexperienced observer may produce an exaggerated report.

Active (moving) cracks of any width are much more troublesome than inactive (dormant) cracks because they tend to enlarge and also limit the options when selecting the method of repair. It is often difficult to determine whether or not a crack is active, though a crack that is visible on both the top and bottom surfaces of the deck will tend to be active. In some instances, it may be advisable to use a crack comparator to record crack width accurately. A crack comparator is a small hand-held microscope with a scale on the lens closest to the surface being viewed. Cracks should be recorded simultaneously with floor delaminations, indicating lineal footage and width.

Previously repaired spalls and cracks should also be noted, as well as signs or remnants of previous floor surface sealer or coating applications. It is critical to determine variations in extent of deterioration for floor areas that are protected compared to those areas that are not. It is also important to note variations in the extent of the floor slab deterioration. For instance, the lower (first-supported) level tends to have more deterioration than the roof (exposed) level. This can be attributed to natural wash-down off the roof by rain and periodic removal of the accumulated road salt. In contrast, the first (supported) level surface tends to have a relatively greater accumulation of road salt which is tracked in and deposited by vehicles entering the facility from the street.

Freeze-thaw-related deterioration, such as scaling and shallow subparallel delaminations, should also be noted. Items to consider when quantifying freeze-thaw-related deterioration are as follows:

1. Exposure conditions: top levels, entrance areas, and perimeter parking bays typically exhibit greater levels of freeze-thaw deterioration.
2. Drainage: ponded areas, flat turn aisles or end bays, and gutterlines typically exhibit greater levels of freeze-thaw deterioration.
3. Location of construction joints: resistance to freeze-thaw deterioration can change for different concrete placements.

4. Location and condition of drains: ponding will contribute to increased freeze-thaw deterioration.

As described in ACI 201.1, surface scaling may be qualified as follows:

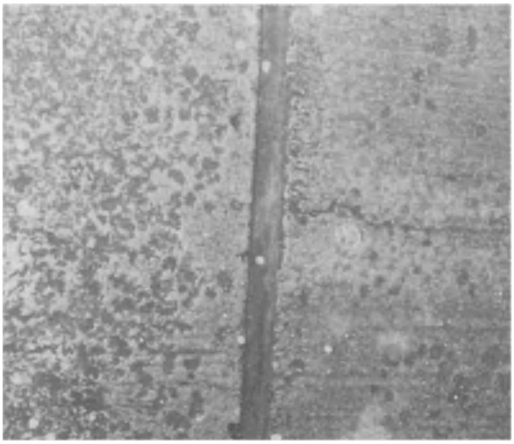
- *Scaling—light:* loss of surface mortar without exposure of coarse aggregate (Figure 15-41(a)).
- *Scaling—medium:* loss of surface mortar up to 5–10 mm in depth and exposure of coarse aggregate (Figure 15-41(b)).
- *Scaling—severe:* loss of surface mortar 5–10 mm in depth with some loss of mortar surrounding aggregate particles 10–20 mm in depth, so that aggregate is clearly exposed and stands out from concrete (Figure 15-41(c)).

Scaling should not be confused with abrasion. Abrasion will typically be concentrated in drive and turn aisles, and will generally appear as a more "smooth" and "polished" surface than that which is evident in scaled floor areas (Figure 15-42). Concrete popouts are also an early indication of freeze-thaw deterioration.

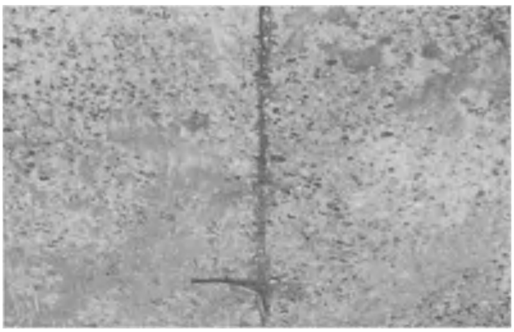
Systematic passes should be made through the structure, concentrating on negative-moment regions, gutterlines, and turns. The slab-on-grade area of the structure should also be inspected for potential problems, such as differential settlement, drainage and scaling concerns, and trip hazards.

The inspection of ceilings is typically the next step in the survey. Beam distress is also recorded in this step. Beam, column, and ceiling delaminations are located by sounding the member with a hammer or tap rod. Longitudinal cracks near beam and column corners are usually reliable indicators of delaminated concrete. Ceilings showing evidence of cracking or salt or water staining should also be sounded. Ceiling deterioration is recorded in the plan view on the reflected ceiling sheets. The next step is to survey the columns to determine the extent of deterioration present on columns, connections, bumper walls, and retaining walls. Since beam, column , and bumper wall distress cannot be shown in plan view, the coding system shown in Figure A-4 in Appendix 15-4 is very helpful in documenting deterioration. Refer to Figure A-5 in Appendix 15-4, where a column spall for example, is denoted as "3C" with an arrow drawn to the appropriate face of the column.

Stair towers are systematically surveyed, followed by electrical and drain system inspection. Finally, a perimeter survey is made to observe conditions not visible from within the structure.



(a)



(b)

(c)

Figure 15-41. (a) Light scaling. (b) Moderate scaling. (c) Severe (heavy) scaling.

Figure 15-42. Surface abrasion and cracking.

Concerning the recording of information during a survey, it may be practical to separate top-of-slab data and ceiling/column data on different sheets, especially where extensive deterioration of slabs is encountered. Color coding can be helpful when separate sheets are not used.

15.4.4 Photographic Recording

It is extremely helpful to record deterioration forms by means of photographs or video cameras. First, the photos and videotapes serve to further qualify distress found. Second, forms of distress that cannot be explained immediately in the field can be presented to other engineers to obtain their opinions. Remember, film is relatively cheap, and a photo may prevent mistakes or an unnecessary return to the job site.

ASA 200V and 400 are good all-around film speeds when variable lighting conditions are encountered. Color film should always be used. Location of photographs should be recorded on field survey sheets or on separate log sheets with an explanation of the subject being photographed.

15.4.5 Delamination Survey

When the steel begins to corrode and before spalls are visible on the deck surface, horizontal cracks, or delaminations, occur at or above the

Figure 15-43. Chain drag delamination survey.

level of the top reinforcing steel. Delaminations need to be detected because they indicate a high level of corrosion activity and represent areas of unsound concrete that must be removed and repaired. It is not uncommon for more than one delamination to occur on different horizontal planes above the reinforcing steel.

Floor slab delaminations are located by sounding the surface with a hammer, iron rod, or chain. When the delaminated area is struck, a distinct hollow sound is heard. Further sounding defines the limits of an area, and the boundaries are then marked with a spray paint or chalk (Figures 15-43 and 15-44).

Delamination surveys are very effective in detecting potential problems with tendon and anchorage corrosion in prestressed structures. The floor slab delamination pattern can be very useful in planning the locations of exploratory excavations to evaluate the condition of prestressing tendons (see Figure 15-45). Just a reminder: any of the older prestressed structures designed in accordance with the ACI Building Code, prior to the 1971 edition, did not require the use of mild steel reinforcement to support the dead load of the slab. The delamination survey results expressed as a percentage of the floor area for these older structures are usually very small in comparison to structures reinforced with mild steel reinforcement. However, any delamination noted is usually attributed to corrosion of prestressing tendons. Even a small

Figure 15-44. Boundaries of delaminated areas marked by spray chalk.

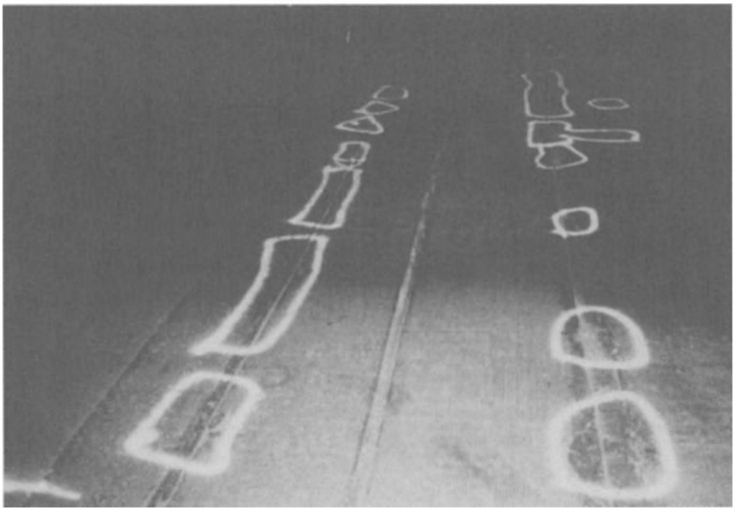
percentage of delaminated area (<2%) could potentially signal severe tendon corrosion and significant loss of structural integrity for these structures.

Detection of delaminated areas by remote sensing through the application of thermograph and radar systems has also been developed. These methods are not currently in routine use for delamination survey of parking structures. These methods have been used successfully in bridge deck surveys.

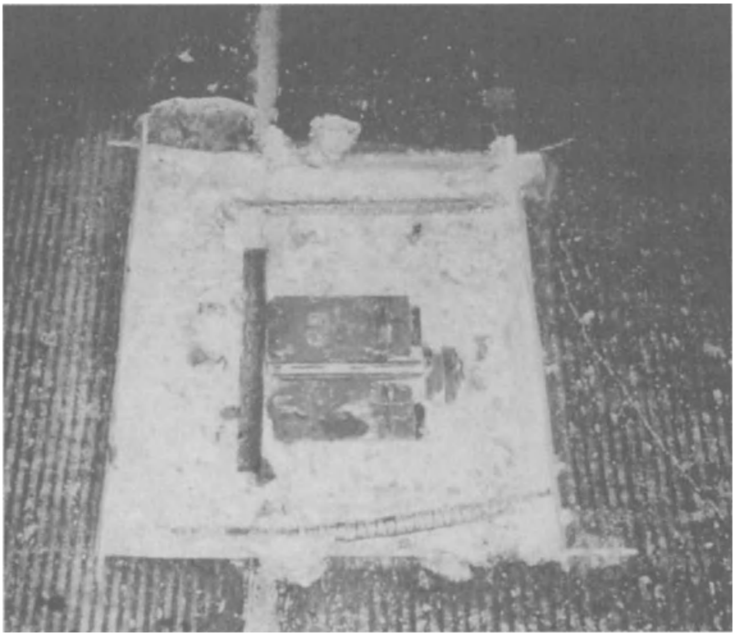
15.4.6 Pachometer Survey

The pachometer magnetically locates the embedded steel and measures the intensity of the magnetic field produced by the embedded steel, which can be correlated to a specific depth from the concrete surface, provided the size of the embedded steel is known (Figure 15-46). It cannot detect the presence of aluminum or PVC conduit. However, it will respond to electric current in its vicinity. One should stay clear of electrical equipment to obtain accurate readings.

Always review available structural drawings prior to performing the survey. The pachometer will give accurate results if the structural mem-



(a)



(b)

Figure 15-45. (a) Chain drag delamination survey at pour strip with tendon end anchorages. (b) Excavation of tendon end anchorage in a delaminated area.

Figure 15-46. A pachometer is used to locate and measure concrete cover over embedded reinforcement.

ber is lightly reinforced. In heavily reinforced members, the effect of secondary reinforcement does not allow accurate measurement of cover. Also, reinforcing bars that run parallel to the bar to be measured will influence the reading if the distance between the bars is less than two or three times the cover distance. The pachometer cannot be accurately used at temperatures below 40°F because of the batteries used in these devices.

When the diameter of the embedded steel is known, the depth of concrete cover can be read from the needle position on the dial of the pachometer. As nearby steel can have an additive influence on needle deflection, the cover reading should be taken at a few locations along a bar. This will help to determine the influence of other elements. Large needle deflection of the meter indicates shallow reinforcement.

Rebar cover measurements should be taken at 10 to 15 random points on each supported tier and recorded on field survey sheets. Extra readings may be required over beams on prestressed decks to locate tendons and measure cover. Pachometer reading should also be taken in the area of coring and in the vicinity of test locations.

It is necessary to locate and determine the depth of concrete cover over the reinforcement for the following four reasons:

1. Establish the chloride ion content of the concrete at the level of the embedded reinforcement.
2. Correlate extent of observed deterioration.
3. Locate areas with shallow cover that would restrict concrete removal by rotary or scarifying equipment.
4. Relate position of reinforcement to concrete removal limits specified in repair details.

15.4.7 Materials Testing

In conjunction with the field survey, it is necessary to perform materials and nondestructive testing to supplement the results of visual observations. Testing should be performed by experienced personnel, and, where necessary, the results evaluated by a materials consultant. The testing assists in verifying the extent of deterioration and in evaluating the condition of the existing concrete. This information is useful in selecting appropriate repair methods and materials. In some instances, test wells are opened to verify the extent of the problem visually. Some of the commonly used laboratory and nondestructive tests for a condition survey of a concrete parking structure along with their applications are listed in Table 15-3. Where applicable, standard test methods are referenced. The testing program for a structure is generally established by considering the following items:

1. The type of structural system involved.
2. The types and forms of deterioration observed, such as corrosion-induced spalling and scaling cracking. The testing should be representative of the type and extent of deterioration noted.
3. The need to qualify previous repairs.
4. Probable repair solutions and repair costs.

Additional information with respect to development of a sampling plan and sample size may be obtained in ASTM C823, "Practice for Examination and Sampling of Hardened Concrete in Construction," and ASTM E122, "Practice for Choice of Sample Size to Estimate the Average Quality of a Lot or Process." Also refer to ACI 364.1R, "Guide to Evalua-

TABLE 15-3. Commonly Used Laboratory and Nondestructive Tests

Tests	Standard Designation	Application
Materials testing		
1. Chloride ion content	FHWA-RD77 or AASHTO T260	Determining the chloride content of concrete to establish potential for corrosion of reinforcement and extent of chloride ion penetration.
2. Compressive strength	ASTM C42	Obtaining and testing drilled core samples to establish quality of concrete.
3. Petrographic examination	ASTM C856	Microscopic examination of concrete core samples to evaluate quality and durability of concrete.
4. Shear bond strength or pull-out test by applying direct tension		Determining bond strength of core sample to evaluate integrity of concrete topping, overlays, and patches.
5. Air-void system of the concrete	ASTM C457	Evaluate surface scaling or freeze- thaw resistance of concrete.
6. Physical and metallurgical examination	Scanning microscopy/X-ray analysis/hardness. Tensile strength.	Examination of prestressing tendons to detect corrosion or embrittlement.
Nondestructive testing		
7. Delamination survey	Chain drag	Determining extent of concrete deterioration in structural members including floor slabs (chain drags often used).
8. Pachometer survey	—	Measuring concrete cover over reinforcement and size.
9. Half-cell testing	ASTM C876	Detection of corrosion activity.
10. Pulse velocity	ASTM C597	Locating internal discontinuities, such as voids, cracking, etc.
11. Radar	—	Locating internal discontinuities and measure size and location of reinforcement.

Figure 15-47. Obtaining concrete powder sample in field.

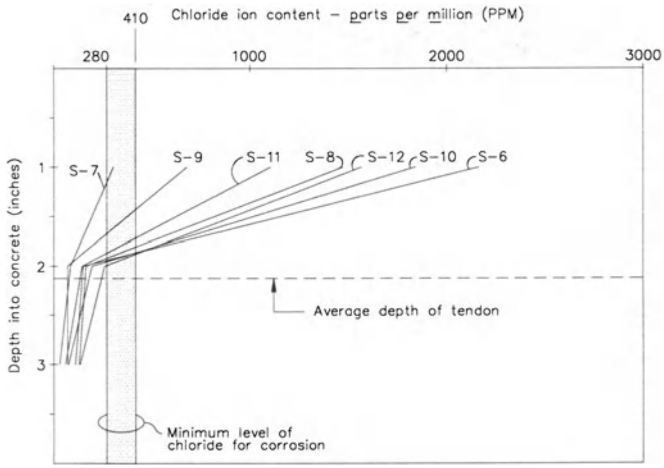
tion of Concrete Structures Prior to Rehabilitation," for practices and methods for assessing the condition and properties of materials in an existing structure.

15.4.7.1 Chloride Ion Content of Concrete

Concrete powder samples are taken at various locations throughout a facility by means of a rotary hammer, and the pulverized samples are taken in equal increments of depth at each location to establish chloride content as a function of depth. This method aids in determining the corrosion potential of the steel at a certain depth within the concrete. The use of the rotary hammer to obtain concrete powder samples has the advantage of portability, light weight, speed, and economy (Figure 15-47). An alternative method to the use of a rotary hammer is to obtain pulverized concrete samples in a laboratory from individual core samples. The use of samples permits the preparation of test samples under controlled conditions and provides better accuracy.

It is generally desirable to sample for chloride content at two or three locations from each level of the structure. Sites should include drive lanes, parking stalls, turns, and speed ramps on all supported levels. In addition, a "baseline" sample from an uncontaminated area should be obtained. Also, determine the minimum depth of the reinforcement in the vicinity of the sample location.

The significance of chloride ion testing is to determine the chloride



SAMPLE NO.	SAMPLE LOCATION
S-6	Supt. tier 4, west bay, drive lane
S-7	Supt. tier 4, east bay, drive lane
S-8	Supt. tier 4, east bay, parking stall
S-9	Supt. tier 3, west bay, drive lane
S-10	Supt. tier 3, east bay, drive lane
S-11	Supt. tier 2, east bay, parking stall
S-12	Supt. tier 2, east bay, drive lane

Figure 15-48. Chloride ion content vs. depth.

ion concentration at the level of the reinforcing steel. High chloride ion concentration at the level of reinforcing steel correlates well with the presence of active corrosion. Research by the Federal Highway Administration (FHWA) has established that an acid-soluble chloride ion content of 280 to 410 ppm at the reinforcing bars results in accelerated corrosion. This information is valuable for investigation of rehabilitation alternatives. A graph is used to interpret chloride ion test results. Parts per million (ppm) are plotted on the horizontal axis, and depth into the concrete is plotted on the vertical axis. A typical plot is shown in Figure 15-48.

Performance of traffic-bearing membranes or coatings can also be established by chloride ion penetration testing. Samples taken from concrete before membrane application and after several years of service provide insight into system effectiveness. Surface sealers can be evaluated for effectiveness in a like manner. Performance of a floor slab

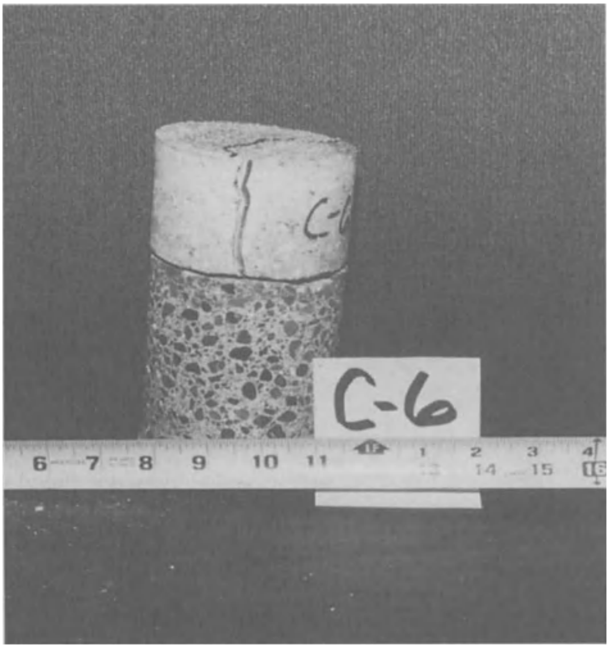
Figure 15-49. Coring for concrete samples.

protection system can be monitored simply by repeating the sampling, analysis, and evaluation of results on an annual basis.

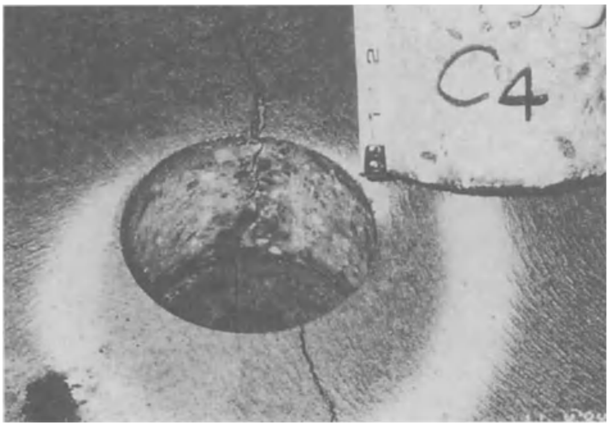
15.4.7.2 Coring and Testing

Drilled concrete cores provide valuable information on the types of deterioration encountered within the structure and to the types of repairs required to return the structure to serviceable condition. Note the location of all cores removed from the structure on the field-survey sheets for future reference. Do not core prestressed structures prior to confirming location of tendons by X-ray examination.

Remove core samples from selected locations after performing the visual observations, delaminations survey, and other nondestructive testing. This assists in correlating, confirming, or resolving conflicting data obtained during the field survey. The majority of the cores should be taken in areas of deterioration, such as delaminations, scaling, and cracking (Figures 15-49 to 15-51). For instance, core through cracks aligned directly over embedded mild steel reinforcement to obtain the depth of concrete cover and the extent of the corrosion of the steel.



(a)



(b)

Figure 15-50. (a) Core sample over crack in overlay to observe depth of cracking. (b) Coring over random crack in concrete topping.

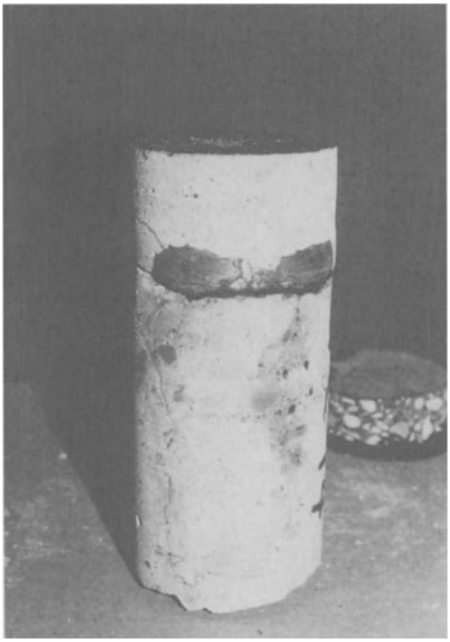


Figure 15-51. Core sample over previously patched areas with a waterproofing membrane and asphalt wearing surface.

However, do not attempt to core through prestressing tendons. Always obtain a few core samples from apparently good areas of the structure to establish a "reference" for comparison of the extent of deterioration in other samples. Locations for coring must be marked by the survey team. Use the pachometer to locate reinforcement in the area. Mark coring location so that the chance of reinforcement damage is minimized, especially when coring near posttensioning tendons. Cores for testing concrete compressive strength should be specifically sited to avoid reinforcing steel. However, it is sometimes desirable to obtain samples of reinforcing steel in cores selected for petrographic examination. Try to obtain core samples by cutting steel near the ends of the rebar (to compromise only the development of the rebar) or in structurally redundant locations of the facility.

The minimum number of samples obtained depends on the type and size of the facility being examined. Visual examination of cores considered useful can generally be gained from three or four samples for a one-level facility, four or five for two levels, five or six for three levels, etc.

Upon return to the office, photograph all the cores taken with a scale reference object. At this time select cores for compressive or petro-

Figure 15-52. Several concrete core samples are obtained from selected locations for laboratory examination and testing.

graphic examination and, if necessary, bond and/or air content testing depending on the type of the deterioration observed (Figure 15-52).

15.4.7.2.1 Concrete compressive strength. Concrete core samples are usually obtained from selected areas of the structure to determine compressive strength. Core samples are obtained and tested in accordance with the Standard Test Method ASTM C42. A minimum of three core samples should initially be tested from a facility to obtain an average concrete compressive strength. Additional cores should be taken when noticeable variations in extent of concrete deterioration is related to different concrete placements or different levels of the structure.

Compressive strengths quantify the relative quality of concrete in the floor slab. They provide confirmation of results obtained by visual observation, materials testing, and nondestructive examination. For instance, extensive floor-slab spalling due to corrosion of reinforcement in a structure with adequate concrete cover may be attributed to poor-quality concrete. This can be confirmed qualitatively by petrographic examination and measured by core compressive strength results. Concrete compressive strength results assist in estimating concrete removal methods and costs. Unit price for concrete removal and preparation is higher for concrete with higher compressive strengths. Also, the selection of concrete removal methods is affected by the concrete compressive strength.

15.4.7.2.2 Petrographic examination. Microscopic examination, sometimes in combination with other techniques, is used to examine samples of concrete. Features that can be evaluated include denseness of cement paste, depth of carbonation, occurrence of bleeding, presence of contaminating substances, air content, and other properties. Standard recommended practice is given in ASTM C 856.

Perform an examination of core samples from deteriorated areas as well as potentially sound areas. Microscopic examination can provide valuable information on the extent of damaged concrete that may require removal, depth and nature of cracks, and presence of other distress that may affect the repairs. When indicated by petrographic examination and visual observations, determine the characteristics of the entrained air void system to evaluate the durability of the concrete. The air void characteristics are determined in accordance with Standard Test Method, ASTM C 457. In accordance with ACI 345, air void characteristics of an adequate system are (1) calculated spacing factor less than 0.008 in.; (2) a surface area of the air voids greater than about 600 sq in./cu in. of air void volume; and (3) a number of air voids per linear inch of traverse significantly greater than the numerical value of the percentage of air in the concrete.

15.4.7.2.3 Shear bond test. Shear bond testing is performed to evaluate the bond strength of concrete overlays, precast topping, and patches to the substrate. The National Cooperative Highway Research Program Report #99 indicates that a value of 200 psi is a desirable bond strength, which has generally been accepted and used as a guide in designing bonding mediums. In areas of questionable bond integrity, microscopic examination of the bond interface should be performed to determine the potential cause(s) of debonding. Debonding of topping in some instances can contribute to a reduction in the load-carrying capacity of structural precast double-tee floor systems.

15.4.8 Nondestructive Testing

The delamination and pachometer surveys described earlier in this section are also a form of nondestructive examination. There are several other nondestructive test methods that can be utilized to evaluate the condition of the structure.

15.4.8.1 Half-Cell Corrosion-Potential Testing

The half-cell potential method consists of estimating the electrical half-cell potential or reinforcing steel in concrete for the purpose of determining the potential of corrosion activity of the reinforcing steel. The

Figure 15-53. Half-cell potential measurement in field.

method is limited by the presence of electrical continuity. A concrete surface that has dried to the extent that it is a dielectric, and surfaces that are coated with a dielectric material (epoxy, for example), will not provide an acceptable electrical circuit. The testing apparatus consists of a copper-copper sulfate half cell, which is effectively a rigid tube or container composed of a dielectric material that is nonreactive with copper or copper sulfate, a porous wooden or plastic plug that remains wet by capillary action, and a copper rod that is immersed within the tube in a saturated solution of copper sulfate. A detailed description of the apparatus and parameters for use of the apparatus are included in ASTM C876. Means and methods for electrical connections to embedded steel, the half cell, and prewetting of the concrete surface are also described in the test method (Figure 15-53).

Except in very specialized cases, half-cell potential testing should be used to evaluate corrosion potential of floor slab surfaces only. A spacing of 4 ft has been found satisfactory for evaluation of bridge decks and is appropriate in most instances in conventionally reinforced parking structures. A wider spacing is not recommended.

Record the electrical half-cell potentials to the nearest 0.01V. By convention, a negative (–) sign is used for all readings. Report all half-cell potentials in volts and correct the temperature if half-cell temperature is outside the range of 72 ±10°F. The temperature coefficient for correction is given in ASTM C876.

According to ASTM C876, the significance of the numerical value of the potentials measured is as shown below. Voltages listed are referenced to the copper-copper sulfate (CSE) half cell.

- If potentials over an area are less negative than –0.20V CSE, there is a greater than 90% probability that no reinforcing corrosion is occurring at that area at the time of measurement.
- If potentials over an area are in the range of -0.20 to 0.35V CSE, corrosion activity of the reinforcing steel in that area is uncertain.
- If potentials over an area are more negative than -0.35V CSE, there is greater than 90% probability that reinforcing-steel corrosion is occurring in that area at the time of measurement.

Results of half-cell potential testing only indicate probability of corrosion occurring in areas with a potential reading greater than 0.20V. The numerical value of the results is not intended to indicate the relative rate of corrosion. Measurement of corrosion rates requires measuring the corrosion current and the resistance to flow of current.

15.4.8.2 Pulse Velocity Test

The ultrasonic pulse velocity method consists of measuring the time of travel of an ultrasonic pulse passing through the concrete to be tested. The pulse generator circuit consists of electronic circuitry for producing pulses of voltage, and a transducer for converting these pulses into a form of mechanical energy having vibration frequencies of 15–50 kHz. Contact with the concrete is made through a suitable connection; another transducer is connected to the concrete at a measured distance from the first. The time of travel of the pulses between the two transducers is measured electronically. The apparatus requirements are defined in ASTM C597.

There are three ways of measuring pulse velocity through concrete. The best and most accurate method is by direct transmission through concrete where the transducers are held on opposite faces of the concrete specimen. Only personnel experienced in the use of this equipment should be utilized to operate and interpret results of testing.

Some applications of pulse velocity testing for use in the evaluation of concrete structures are listed below:

- Establishing the uniformity of concrete.
- Establishing acceptance criteria for concrete; generally, high pulse velocity readings indicate good-quality concrete.

- Estimating the strength of concrete through correlation of known strengths of core samples.
- Measuring and detecting cracks.
- Inspecting reinforced concrete members.

15.4.8.3 X-Ray Examination

X-ray examination can be helpful to identify the location of embedded reinforcement in very thick structural members where pachometer survey is likely to be ineffective. However, X-ray examination is costly and should be used only if effective data are anticipated. Some of the concerns regarding X-ray examination are as follows:

1. Access to both surfaces of the member is required—one surface for the X-ray source transducer; the opposite surface for the recording film.
2. The X-ray does not distinguish reinforcement placement relative to depth. Images from rebar on the near face of a member may "shadow" an image from rebar deeper in the member.
3. The X-ray signal as it moves through a member is conical; i.e., the range of area the X-ray examines increases with depth of penetration. Careful interpretation of results is required.

X-ray examinations are recommended prior to obtaining core samples from posttensioned decks by locating posttensioning tendons. Other potential uses of X-ray examination are to locate end zone reinforcement in a posttensioned beam or beam column connections, or to locate end zone stem reinforcement in a precast tee beam.

15.4.8.4 Radar Examination

Radar examination is especially useful in locating large areas of embedded reinforcement within a floor slab or structural member. A graphic representation of the reinforcement location is continuously developed during the examination, which can be easily calibrated by coring at predetermined locations to visually record the depth and size of reinforcement.

Welded wire fabric reinforcement can be easily located by radar examination where pachometer examination is generally ineffective. Agencies utilizing radar examination present the opinions that the equipment is capable of detecting voids beneath concrete pavements on grades, determining concrete thickness when only one side is accessible, determining the asphalt overlay thickness, and surveying slab delamination.

In radar profiling, echoes from a pulsed electromagnetic wave are received by an antenna. The penetration and resolution of the signal are a function of the frequency of the electromagnetic pulse. A high-frequency signal provides high resolution but has shallow penetration. Lower-frequency signals have greater penetration but poorer resolution. Depending on the thicknesses of individual layers and the desired penetration, two or possibly three different radar antennas ranging from a few hundred to a thousand or more megahertz may be utilized. The data-recording rate is chosen to yield high-resolution continuous profiles over multiple traverses. Field evaluation and preliminary interpretation of data are generally made from a group of parallel profiles.

Radar profiling detects the presence of delaminated conditions and may indicate deterioration caused by cracking. Chemical deterioration of concrete and consequent changes in the dielectric constant may be detected if radar is used in conjunction with other methods, particularly electrical resistivity. Although radar examination is expensive, it proves to be cost-effective when large areas of floor slabs are required to be surveyed for reinforcement placement, particularly when graphic representation of the survey information is desired.

15.4.9 Exploratory Excavation

Exploratory excavations are very useful to verify conditions of the underlying concrete or embedded reinforcements. In some instances, exploratory excavations may simply consist of coring through the slab surface. In other instances, one may need to perform partial or full-depth excavation of the floor slab to verify conditions. Examples of test wells are shown in Figures 15-54 and 15-55.

15.4.9.1 Waterproofing Membranes

Waterproofing membrane systems quite often have to be removed physically to observe the condition of the underlying slab and to obtain core samples in order to verify the effectiveness of the system. Select test locations in areas with poor drainage conditions and over areas with noticeable water leakage, wet spots, cracks, or efflorescence on the underside of the slab.

Whenever an existing waterproofing membrane is encountered, it is advisable to bring back samples to the office for analysis. The membrane can be observed for weathering, embrittlement, tensile properties, and

Figure 15-54. Test well to observe condition of waterproofing system and underlying concrete.

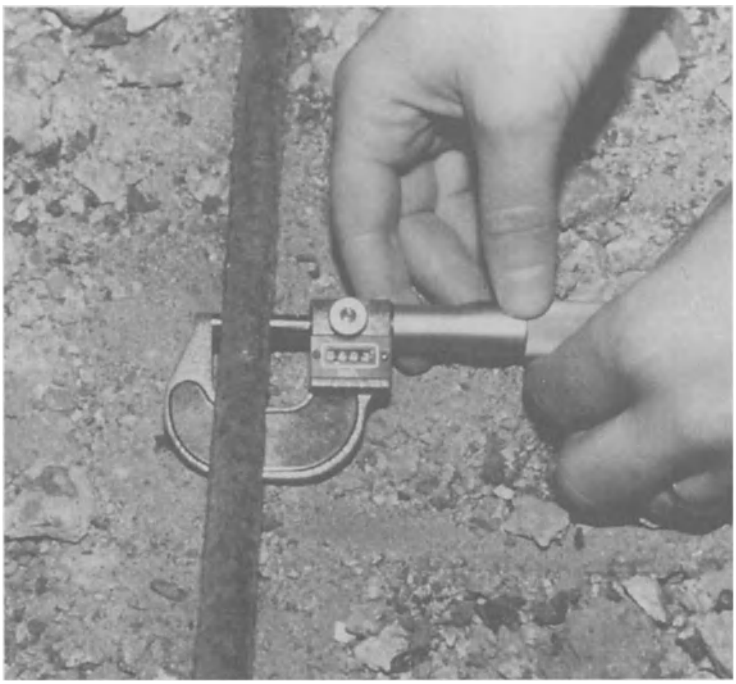


Figure 15-55. Measuring extent of rebar corrosion.

thickness. In the field the membrane should be observed for cracking, adhesion, and excessive wear. Also, obtain information as to the membrane type and the date of its installation.

15.4.9.2 Posttensioning Tendons

Posttensioning tendon conditions, especially in older structures, are visually examined for distress by opening test wells. One has to be extremely careful when attempting to open test wells around posttensioning systems. Also, it is extremely unsafe to stand directly over tendons that are being excavated. These excavations should be directed by an engineer familiar with the design of the structural system and the restoration of prestressed structures.

Locations typically selected for excavations are tendon high points over beams, tendon low points at midspans, intermediate anchorages at construction joints, and end anchorages (Figure 15-56). Also refer to section 15.3.4 for discussion of potential problem areas related to tendon corrosion.

For end anchorage do not remove the concrete behind the bearing plate. Since the concrete behind the embedded-plate assembly is precompressed, concrete removals may result in anchorage failure due to movement or rotation of the anchorage assembly. At each excavated location, note concrete cover of tendons and condition of tendons. If corrosion damage is not apparent and a tendon is broken, a sample of the tendon should be obtained at the fracture location for further metallurgical examination to determine the cause of the failure.

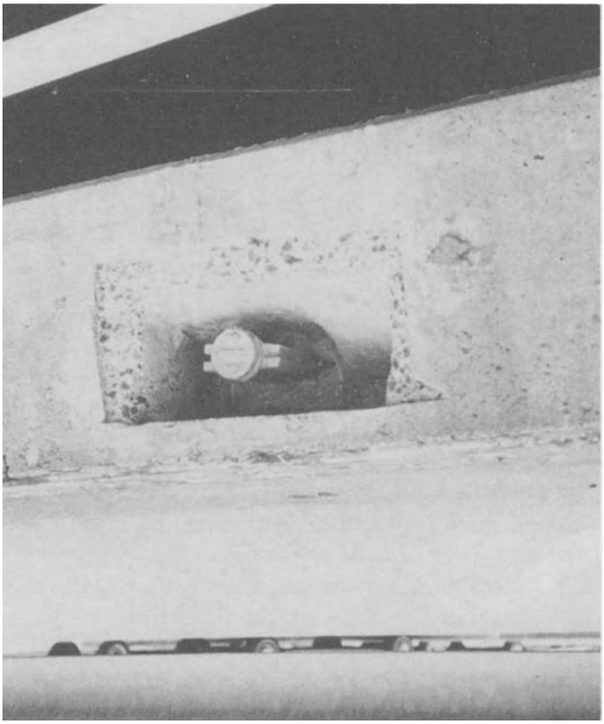
15.4.11 Data Evaluation

The data evaluation consists of (1) analyzing and correlating the results of the field observations, measurements, and testing, and (2) reviewing laboratory test results. The objective is to determine the primary cause(s) of observed deterioration and its impact on structural members. Analysis of the field, laboratory, and testing data requires the application of knowledge and judgment by a restoration specialist in determining the cause(s) of distress.

15.4.11.1 Cause(s) of Deterioration and Contributing Factors

The primary cause of deterioration must be supported by field observations, measurements, and laboratory testing. For example, corrosion-induced deterioration must be verified by results obtained from delami-

(a)



(b)

Figure 15-56. (a) Excavation over intermediate anchorage of a button-head post-tensioning system to determine condition of tendon and anchors. (b) Excavation of tendon end anchorages.

nation, pachometer, and half-cell testing survey and the chloride ion content of the concrete at the level of the reinforcement. Coring and test well can further provide information regarding the extent of reinforcement corrosion. Another observation may be floor slab cracking. Cracking is a symptom of distress, which may have a variety of causes and contributing factors (refer to section 15.3.3). The selection of the correct repair method will depend on determining the primary cause of cracking and the contributing factor(s), if any. The crack pattern, location, and size observed in the structure must be supported by analytical and/or laboratory test results.

Very often there are other factors that also contribute to the observed deterioration; try to determine them. For instance, a primary cause of deterioration is reinforcement corrosion, but contributing factors may also include lack of air entrainment and freeze-thaw deterioration, shallow concrete cover, poor-quality concrete, and inadequate drainage. Understanding the contributing factor will help to recommend better repairs by specifying appropriate repair methods and materials.

Review of original drawings, specifications, inspection reports, and shop drawings can also be useful in determining the cause(s) of a problem. For instance, it is not unusual to find a variation in as-built condition from that specified in structural drawings, which can contribute to distress, such as concrete cracking and spalling in structural elements. For such deficiencies, supplemental reinforcement or strengthening may be required to restore the load-carrying capacity or integrity of the member.

15.4.11.2 Impact of Deterioration

The next step is to determine the impact of the observed deterioration. This is done by tallying quantities of the various forms of deterioration, such as spalling, delaminations, cracking, and scaling from the field-survey sheet on a tier-by-tier basis. For example, determine the extent of floor slab spalling and delaminations. Consider the impact from the standpoint of the extent of present deterioration, as well as the potential for future deterioration. Present floor slab spalling and delaminations may only be 5% of the floor area, but half-cell potential survey may indicate a strong probability for continuing corrosion over most of the remaining floor area. The repairs recommended must correct the present deterioration and address the potential for continuing deterioration of the floor slab due to corrosion of the embedded reinforcement.

The impact of the deterioration observed on the individual elements of the structure can be categorized based on the priority of repairs as follows: (1) structural/safety-related, (2) serviceability/durability-related, or (3) aesthetic/cosmetic in nature.

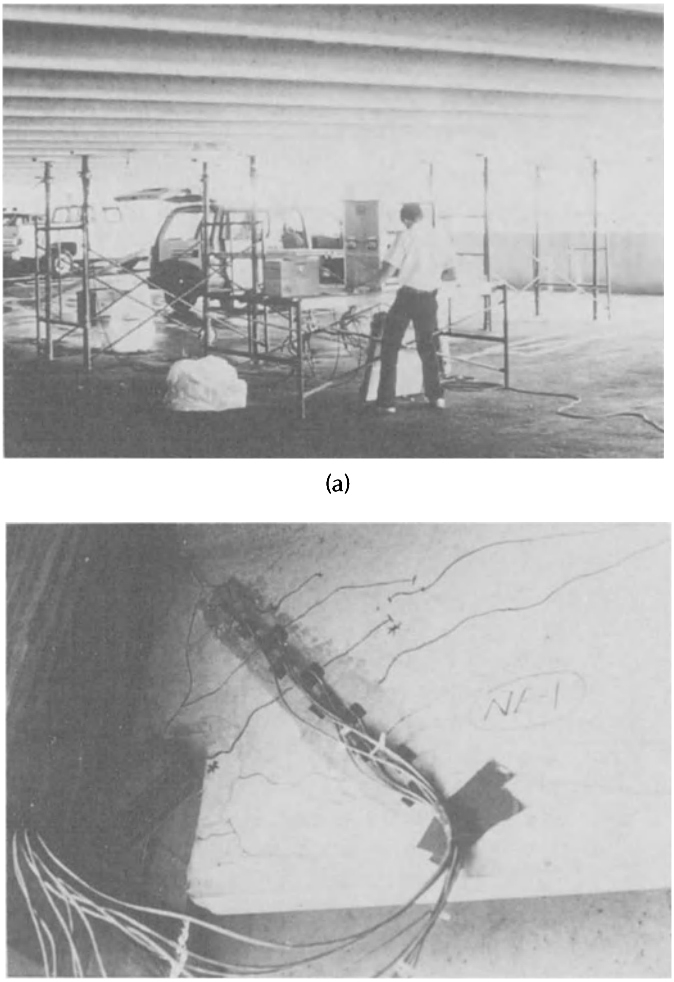
Deterioration can adversely affect structural integrity, safety, and serviceability of members. Estimating the loss of structural integrity due to deterioration is one of the most difficult aspects of an investigation. Structural engineers should consider the effect of cracking, partial loss of the reinforcement bond due to delaminations, loss of the cross-sectional area of primary reinforcement, and loss of strength and toughness. In some cases load testing is the only alternative to determine structural capacity of a deteriorated structure. This will determine the load-carrying capacity of the member at the time of the test. The influence of other large forces, such as those due to restrained volume change or lateral load forces, can be evaluated analytically, according to Chapter 20 of ACI 318, or by modifying the load test to account for such factors (Figure 15-57). The ACI 437R report "Strength Evaluation of Existing Concrete Buildings" provides more information on evaluation procedures to determine the stability, strength, and safety of existing structures, analytically or by load testing.

Repairs correct the effects of deterioration and attempt to return structural elements close to their original condition and serviceability. Measures taken primarily to minimize deterioration and prolong the life of the structure are considered to be maintenance *actions* as opposed to repairs. For example, application of a membrane traffic topping or surface sealer is considered maintenance action, since this is a preventive action to protect the structure from chloride ion penetration. Repairs must be performed when the load-carrying capacity of members is reduced or serviceability of the structure is affected by concrete deterioration. Repair alternatives for strengthening of individual members should be developed, and a cost-effective repair method should be selected for implementation.

15.5 REPAIR METHODS

15.5.1 General

There is a significant amount of literature on concrete repair methods and materials that has been published during the past several years. Many committees of the ACI have now published reports that directly or indirectly relate to the repair and restoration of concrete structures. The results of research and the application of repair methods and materials have been reported in publications presented by the Federal Highway Administration research programs, the Portland Cement Associa-



(a)

(b)

Figure 15-57. (a) Load test of precast members. (b) Load test instrumentation to measure concrete strains.

tion, the Corps of Engineers, and in articles presented in various trade journals. Therefore, this section of the chapter will only attempt to summarize the basic requirements for durable repair techniques that are more commonly used to restore a parking structure. Other, less frequently used techniques have not been included. However, do not be limited by the basic material presented here, and where necessary,

TABLE 15-4. Repair Objectives and Methods

Repair Objective	Repair Method	Primary Application
Restore integrity	Patching	
	a. Partial-depth	Floor slab, beam, column, wall, etc.
	b. Full-depth	Floor slab
	Replacement	Floor slab
Provide protection		
Abrasion	Coating	Floor slab
Freeze-Thaw	Replacement	Floor slab
	a. Partial-depth	
	b. Full-depth	
	Coating	Floor slab
Corrosion	Cathodic protection	Floor slab
	Replacement	Floor slab
	Coating	Floor slab, beam, columns, wall
Waterproofing	Sealing	Floor slab, joints, cracks

attempt to incorporate special repair techniques that are appropriate for your situation.

The restoration of parking facilities require the use of several repair methods to address existing deterioration of structural members and provide effective protection to extend the service life of the restored structure. Table 15-4 summarizes the repair objectives and the methods commonly utilized to repair various structural elements. The horizontal floor slabs generally experience the most deterioration and usually require implementing a combination of repair methods to develop an approach that will effectively restore the structure. For instance, the approach might consist of a combination of repair methods that includes patching to restore floor slab integrity and membrane protection to effectively waterproof and minimize future corrosion-induced concrete deterioration.

Some of the currently available built-in and externally applied corrosion protection systems discussed in Chapter 10 are shown in Figure 15-58. In this figure, the external systems that are applied directly on to the wearing surface are included in the zone designated level 1. The built-in systems are included in the zones designated levels 2 and 3. When repairing existing parking facilities, the depth of concrete removal will usually define the corrosion protection that can be implemented to restore the structure. For instance, regular maintenance actions generally require only limited concrete removals for patching minor floor spalls. Therefore, the options to enhance the corrosion protection for

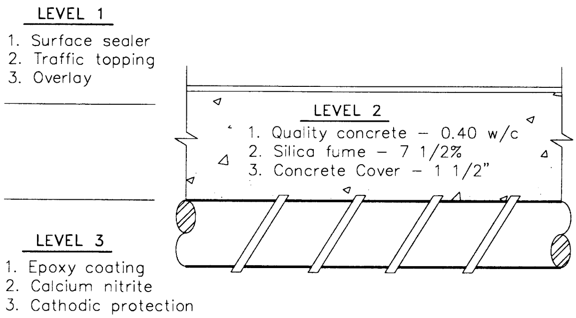


Figure 15-58. Corrosion protection of embedded reinforcement.

this structure is limited only to the surface-applied level 1 systems. Another, other more expensive option is cathodic protection. The type or the combination of the various corrosion protection systems selected will impact the life expectancy of the repairs that are implemented. The consideration of different levels of protection gives the opportunity to develop and evaluate repair alternatives with different life expectancies. (Section 15.7 includes further discussion of development and selection of repair alternatives to restore the floor slabs.)

15.5.2 Basic Requirements for Concrete Repairs

A repair is generally successful if the repair material is compatible with the original substrate and has the required strength and durability. Other considerations are appearance and economy. The four basic requirements for a satisfactory concrete repair are:

- Concrete removal and surface preparation
- Application of bonding medium
- Proper selection of repair material
- Proper material application

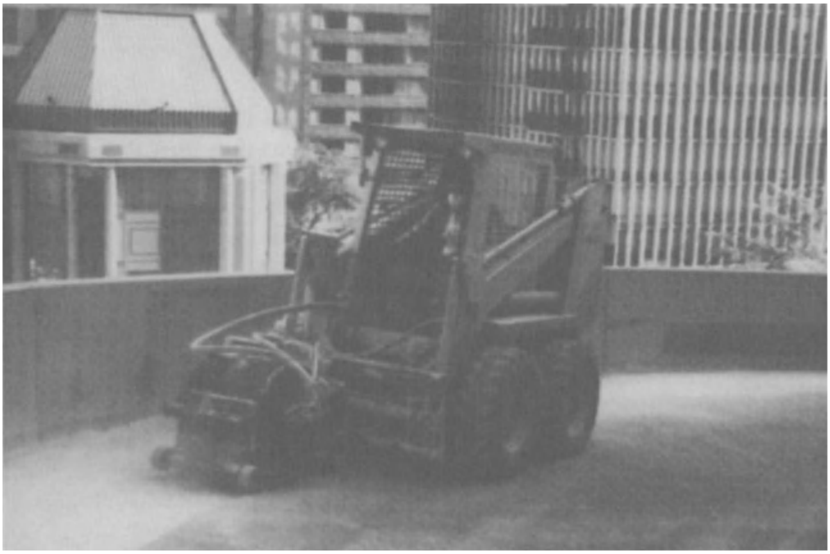
15.5.2.1 Concrete Removal

For all concrete repair situations, regardless of the type of structural member, a basic requirement is to remove all the deteriorated, delaminated, and unsound concrete prior to placing any new patch material. When complete removal of the unsound concrete is not accomplished, there is a good probability of patch failure at the bond interface between the existing concrete and the new patch material.

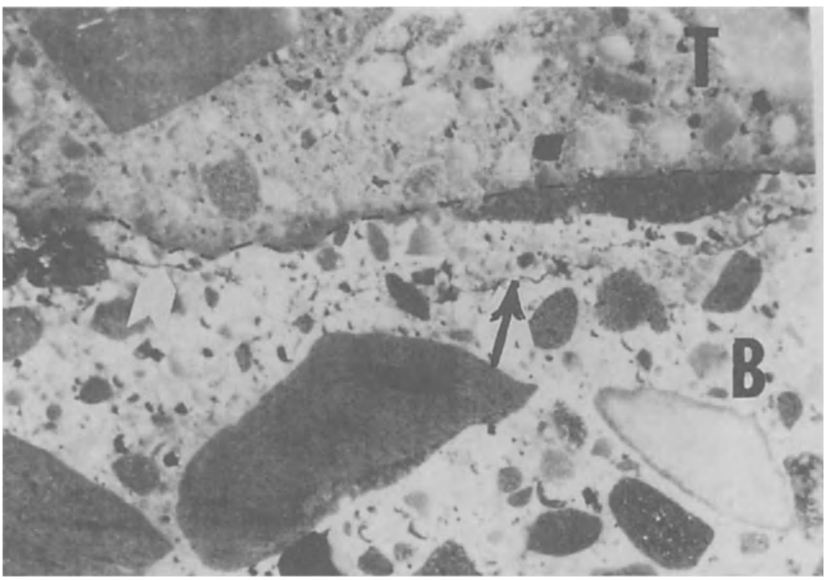
Figure 15-59. Concrete removal prior to patching floor spall.

Concrete removal in parking structures is generally performed by light (15 lb maximum) chipping hammers (Figure 15-59). These light chipping hammers are very convenient for concrete removal around and below the existing reinforcement. The size of the chipping hammer is limited to minimize damage to the surrounding area. Under certain circumstances, such as a relatively thick (8–12 in.) slab, the use of heavier hammers may be permitted by only preapproved operators. Other factors that can influence the selection of hammer size are overall thickness of the member, relative depth of removal to the overall member thickness (partial or full depth) removals, inclination of members (vertical or horizontal), and location (vertical or confined area) of removal. Special care should be applied in removing unsound concrete from around reinforcing steel and embedded anchorages to prevent a loss of bond in the remaining sound concrete.

Large areas requiring the removal of relatively thin layers of concrete, such as concrete removal in preparation for placement of overlay, may be more effectively done with a scabbler, scarifier, or planner than with chipping hammers (Figure 15-60). These machines are particularly effective in cleaning the surface by removing the top surface contamination of traffic oils and greases. In addition, high-pressure sand and water blasters are capable of removing deteriorated concrete and many surface contaminants. Scarification of concrete surfaces using an abraded metal-



(a)



(b)

Figure 15-60. (a) Scarifier. (b) Bruised lightweight concrete substrate due to concrete removal by scabblers. Note failure plane (arrow) just below bond line above.

shot-rebound method has also been used in the preparation of surfaces for installing a membrane or overlay.

The reader is referred to the Corps of Engineers' Manual EM 1110-2-2002 and the National Cooperative Highway Research Program's Report #99 for a more detailed treatment of concrete removal techniques and advantages and disadvantages of the various removal methods.

15.5.2.2 Surface Preparation

Another important step in the repair of concrete structures is the preparation of the surface to be repaired. The repair is only as good as the surface preparation, regardless of the repair method or materials selected. For reinforced concrete structures, repairs must include proper preparation of the reinforcing steel in order to develop a bond with the replacement concrete.

Removal of concrete using mechanical cleaning devices such as scabblers, grinders, and impact hammers may cause "bruising" of the concrete surface remaining in place. Be particularly careful of bruising of lightweight concrete surfaces due to mechanical scarification (see Figure 15.60(b)). The bruising can contribute to the debonding of the patch overlay material. Also, cleaning the surface by sandblasting or high-pressure water is required as a final step to remove any damaged surface material that can potentially contribute to the debonding of the repaired section.

A sample specification for surface preparation is included in the appendix at the end of this chapter. This specification covers requirements for locating and marking work areas on a structure, inspection of the surface and reinforcement after concrete removal, replacement of deteriorated or damaged reinforcement, placement of supplemental reinforcement, cleaning of reinforcement, and preparation of surface for patch/overlay placement.

15.5.2.3 Bonding Medium

Bonding of the new patch or overlay to the concrete substrate is essential for a durable repair. An adequate bond between the patch or overlay material is required to resist stresses due to differential volume change between the patching material and the substrate. The failure can occur either at the bond interface or adjacent to the interface within the section of the lower-strength material.

Once debonding is initiated, the effects of freeze-thaw cycling and dynamic impact of vehicle wheel loads can contribute to the progressive

Figure 15-61. Application of bonding grout precedes concrete overlay placement.

deterioration of the repaired area. Debonded areas are generally prone to cracking. The cracking is usually through the entire thickness of the patch or overlay material, which can permit water leakage to the interface and the underlying substrate.

As indicated in the National Cooperative Highway's Research Report #99, various bonding media have been studied, including sand-cement and water-cement grouts, neat cement, epoxies, and latex. From these studies and field experiences, the sand-cement and water-cement grouts are considered to be the most practical and commonly used bonding mediums. The sand-cement bonding grout consists of one part cement to one part sand by volume, and sufficient water to achieve the consistency of pancake batter. Limit the water-cement ratio of the grout to be at least the same as or better than the concrete repair material. The grout should be applied at a uniform thickness of 1⁄16 in. and should not exceed 1⁄8 in. (Figure 15-61). The grout should be applied to a damp (but not saturated) concrete surface. The surface is dampened to assist in preventing rapid drying of the grout. The bond mechanism consists of the grout penetrating the surface pores of the existing substrate. When the substrate is saturated the pores are filled with water, which can adversely affect the penetration of the bonding grout into the pores of the substrate. See a sample specification for latex-modified concrete or low-slump concrete in the appendix for additional requirements of bonding mediums.

15.5.2.4 Selection of Repair Materials

The selection of the repair materials is covered in section 15.6.

15.5.2.5 Material Application

Concrete repair materials must be properly placed, consolidated, and cured. Follow the appropriate placement and curing procedures of repair materials specified in ACI Recommended Practices or in accordance with each manufacturer's instructions. Also, refer to sample specifications in the appendix for placement, consolidation, and curing requirements for concrete patches and overlay.

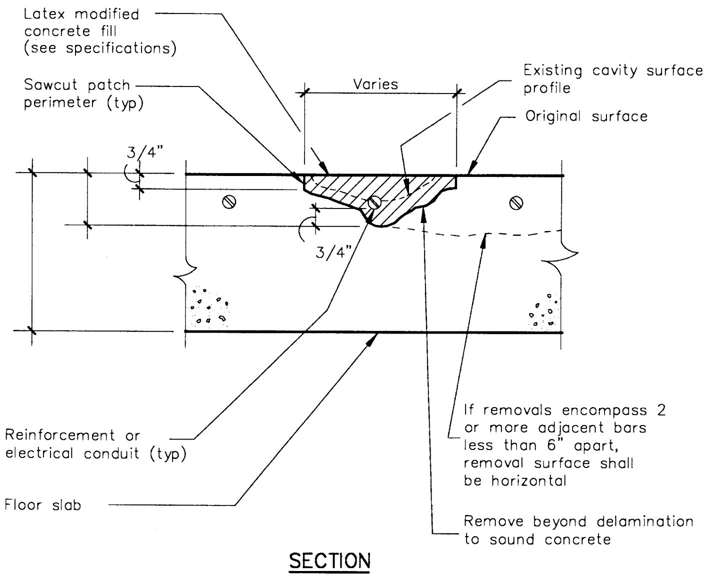
15.5.3 Patching

Patching replaces deteriorated concrete on the surface of horizontal and vertical members. When properly implemented, patching will restore structural integrity as well as improve serviceability or correct cosmetic damage. however, in some instances, this may not be the correct repair approach. Evaluation of appropriate repair approach and methods are discussed in section 15.7.

Patching can be referred to as "partial-depth" or "full-depth" according to the extent of concrete removed. Quite often, for thin slab sections (less than 5 in. thick) it is difficult to perform shallow concrete removals and usually results in full-depth concrete removal. As a general rule of thumb, a full-depth patch is specified when concrete removal equals or exceeds half the slab's thickness.

As shown in Figures 15-62 through 15-65, patching consists of removing the unsound concrete, cleaning reinforcing steel exposed by removals, preparing the exposed surface, and installing a specialty concrete patching material. Patch edges for partial-depth removals are often chipped or saw-cut to near vertical to a depth of at least ¾ in., as opposed to leaving a "feather edge." Refer to the sample specification included in the appendix included at the end of the chapter for more information related to surface preparation and other requirements.

Although patches of high-quality (low-permeability) material are installed, the adjacent surface tends to have lower durability. In chloride-contaminated slabs, the durability of this repair system is adversely affected by delamination and spalling of floor-slab areas due to continuing corrosion of reinforcement beyond patch limits. Patching can, however, rapidly restore the structural integrity of the member and limit



Notes:

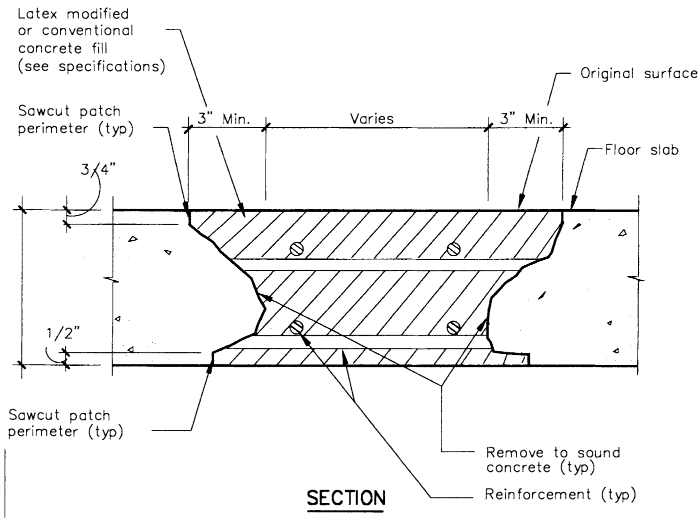
1. Remove and replace all sound and unsound concrete within section shown cross-hatched.
2. Deep removal shall consist of concrete removals that extend beyond two layers of reinforcement.
3. Pay unit = s.f.
4. Detail not to scale.

Figure 15-62. Patch detail with shallow concrete removals.

further damage to embedded reinforcement. The emphasis is on repairs that address only existing damage.

15.5.4 Coating

Coating consists of applying surface sealers, elastomeric traffic-bearing membrane systems, rigid concrete, or specialty concrete overlays. Refer to Chapter 10 for a description of these coatings. Although a sealer can be applied to vertical and overhead surfaces, membranes and overlays are usually applied only on floor slabs. Some of the characteristics of protective coatings are discussed here, relative to their use in repair of parking structures.



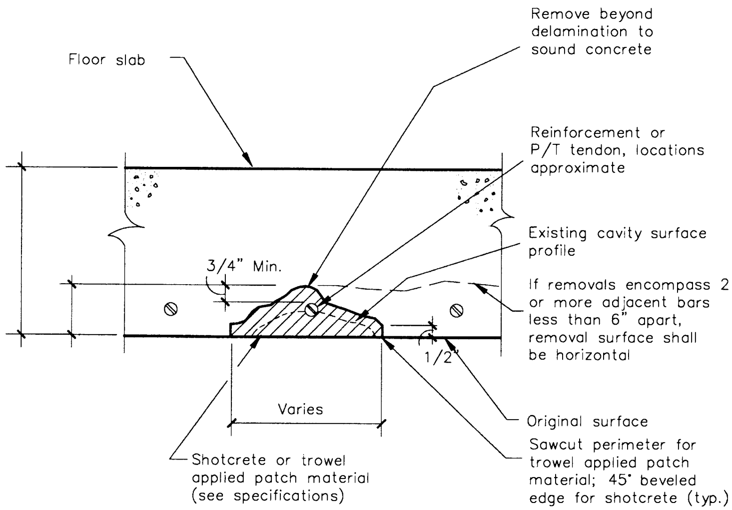
Notes:

1. Remove and replace all sound and unsound concrete within section shown cross-hatched.
2. Deep removal shall consist of concrete removals that extend beyond two layers of reinforcement.
3. Pay unit = s.f.
4. Detail not to scale.

Figure 15-63. Full-depth patch detail.

15.5.4.1 Sealer

A repaired slab surface is usually protected by sealers to minimize moisture and chloride ion penetration by application of a concrete sealer. The original concrete surface requires cleaning by special means, such as high-pressure water-, sand-, or shotblasting to remove all old coatings or sealer, and/or surface laitance. Regular reapplication of the sealer every 3–5 years is to be anticipated depending on the severity of exposure conditions and sealer selection. A sealer is ineffective when applied to a cracked concrete surface, primarily owing to its inability to bridge cracks. Sealers are also relatively ineffective when applied to surfaces of poorly air-entrained concrete or concrete that is chloride contaminated. Sealers are usually most effective when applied to a relatively new structure, primarily as a preventive measure for corrosion-induced deterioration. However, a sealer will eventually permit chloride ions to penetrate to the level of the embedded reinforcement.



SECTION

Notes:

1. Remove and replace all sound and unsound concrete within section shown cross-hatched.
2. Deep removal shall consist of concrete removals that extend beyond two layers of reinforcement.
3. Pay unit = s.f.
4. Detail not to scale.

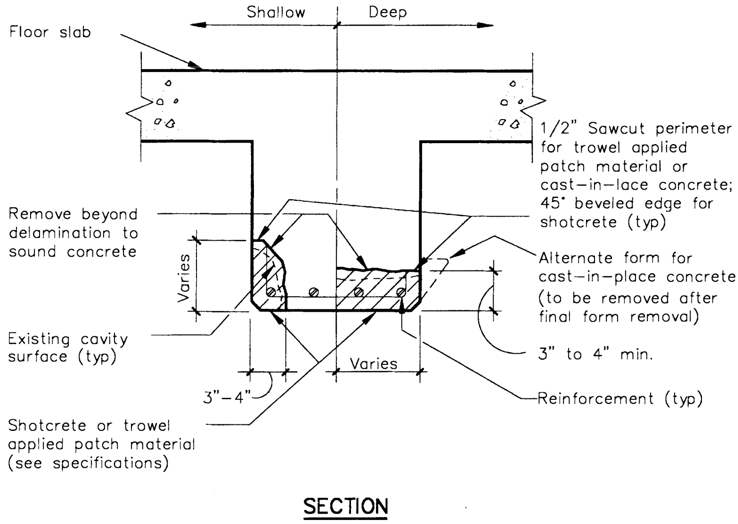
Figure 15-64. Ceiling repair detail.

Regular sealer application only helps to extend the time to corrosion, but is not capable by itself of preventing corrosion-induced deterioration and ensuring long-term durability.

15.5.4.2 Waterproofing Membranes (Traffic Topping)

A traffic-bearing membrane waterproofs the slab and minimizes chloride ion penetration more effectively than a sealer (see Figure 15-66). It also reduces the oxygen supply and moisture that support corrosion and assists in extending the service life of slabs. A membrane can effectively bridge active cracks and is suitable for floor systems with extensive through-slab cracking.

Where membranes have been applied to existing decks, surveys indicate the continuation of corrosion activity if all chloride-contaminated concrete is removed. The long-term effect of membranes on continuing



Notes:

1. Remove and replace all soun and unsound concrete within section shown cross−hatched. Remove minimum 3/4" behind all reinforcement.
2. Forms (if used) shall remain in place until concrete has attained 3000 psi minimum compressive strength.
3. The final coat of shotcrete (if used) shall be troweled to original dimensions and configuration.
4. Cast−in−place concrete may be used for deep repairs at contractors option.
5. Pay unit = s.f. (face of beam for shallow)
   (bottom of beam for deep)
6. Detail not to scale.

Figure 15-65. Shallow and deep beam repair detail.

corrosion of embedded reinforcement is not well established. The performance of these systems on chloride-contaminated decks is highly variable owing to membrane effectiveness, existing deck conditions, and the extent of removal of contaminated concrete. Some future concrete spalling beneath the membrane is to be expected owing to corrosion-induced concrete spalling.

In heavy-traffic areas such as drive aisles, frequent maintenance will be required to extend the life of the membrane system. Use of a "wear-balanced" membrane system consisting of different grades of the membranes will reduce maintenance frequency. Membranes are also susceptible to snow plow damage, but plows can be raised or tipped with rubber guards, and the operator can follow guidelines provided by the manufacturer for snow removal to minimize damage.

Figure 15-66. Membrane installation: Aggregates being broadcast on recently placed membrane.

15.5.4.3 Bonded-Concrete Overlay

A bonded-concrete overlay provides a more durable repair of deteriorated concrete floors. A bonded-concrete overlay requires the removal and preparation of all deteriorated exposed surfaces prior to system installation. The surface is scarified to remove all contaminants, such as oil spots, from the surface. Exposed reinforcing is either cleaned or removed, and replaced with one that is epoxy coated. After surface preparations are complete, a bonded overlay is installed to restore slab integrity while providing a new wearing surface (Figures 15-67 and 15-68; and refer to sample specification for overlay in the appendix included in the end of this chapter).

With overlays, the new surface profile can be adjusted for improved drainage and reduced ponding. Concrete overlays are not appropriate for floor slabs with active cracking. Reflective cracking in overlay is likely to reduce the service life of restored slabs. Where applicable, the additional superimposed load due to the overlay must be evaluated.

The overlay is a coating that can be designed to protect the underlying substrate. In addition, overlays can also be used in partial-depth slab replacement.

The reader should refer to the National Cooperative Highway Research Program's Report #57 for further details regarding surface preparation, placement, and curing of concrete overlays. A more detailed discussion on advantages and disadvantages of overlays is also provided in the report.

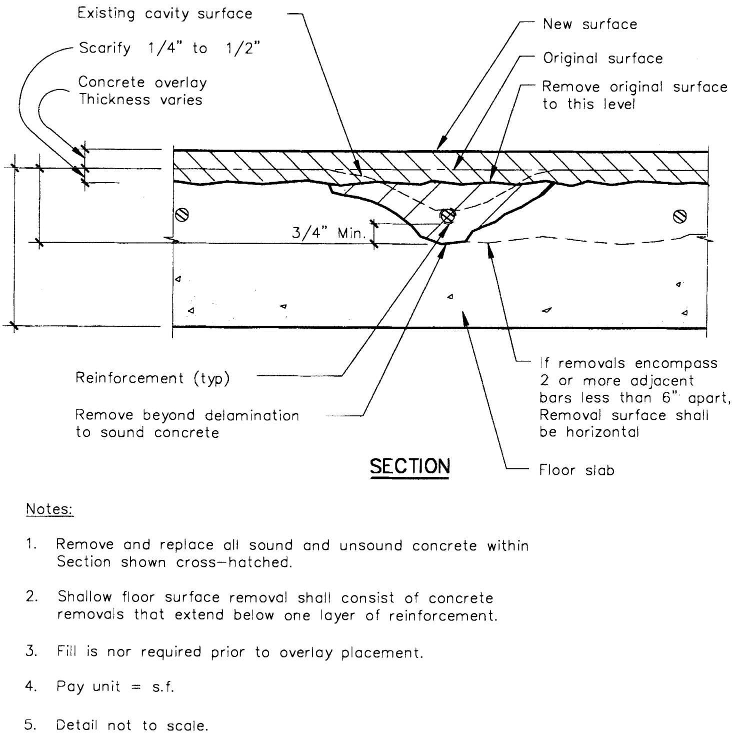


Figure 15-67. Concrete overlay detail.

15.5.5 Replacement

When a floor slab is extensively deteriorated, removal and replacement of the slab may be a viable repair alternative, provided the underlying members are in relatively good condition. This is referred to as "partial-depth" replacement. Floor slabs that are less than 5 in. thick are difficult to repair. Concrete removals on pan-joist, waffle-slab, and one-way slab systems usually result in complete removal of the thin slab (Figures 15-69 and 15-70). The existing underlying beams and waffle or pan-joist ribs are used to support the new slab, provided adequate measures are taken to ensure composite behavior of the rebuilt floor system. The new slab can be reconstructed with durable concrete and epoxy-coated reinforcement and other internally built corrosion protection systems to extend the service life of the facility. However, the new slab is susceptible to cracking due to volume change restraint offered by the existing underlying members. In extreme cases, "full-depth" replacement of the

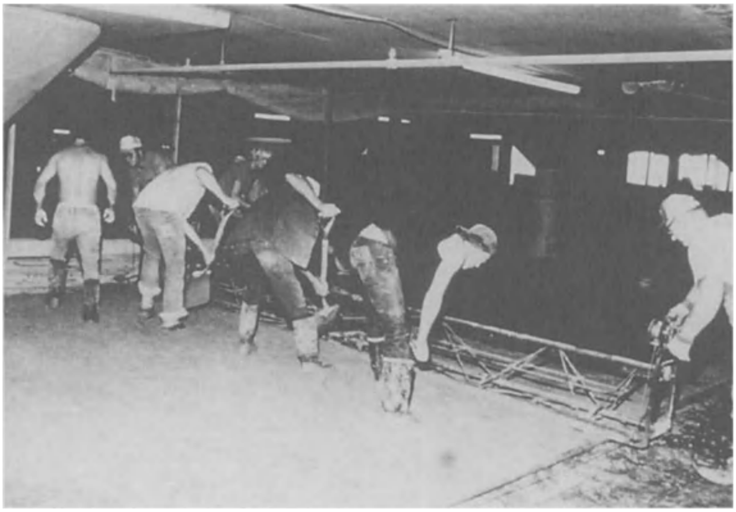


Figure 15-68. Concrete overlay placement with vibratory scroed.

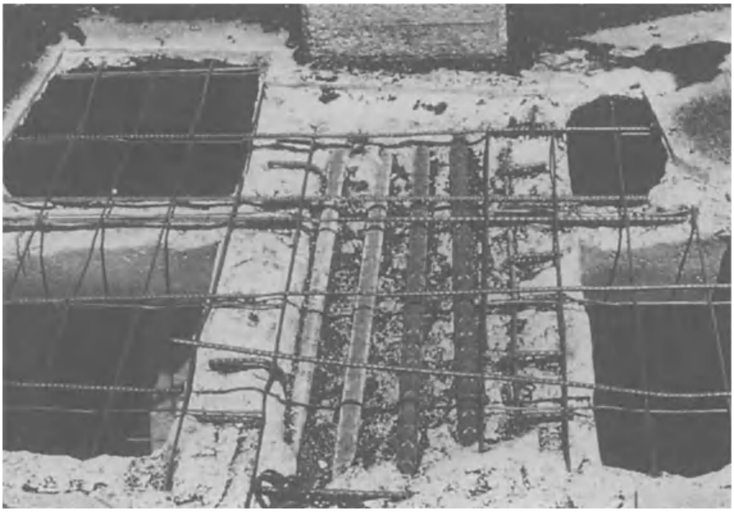
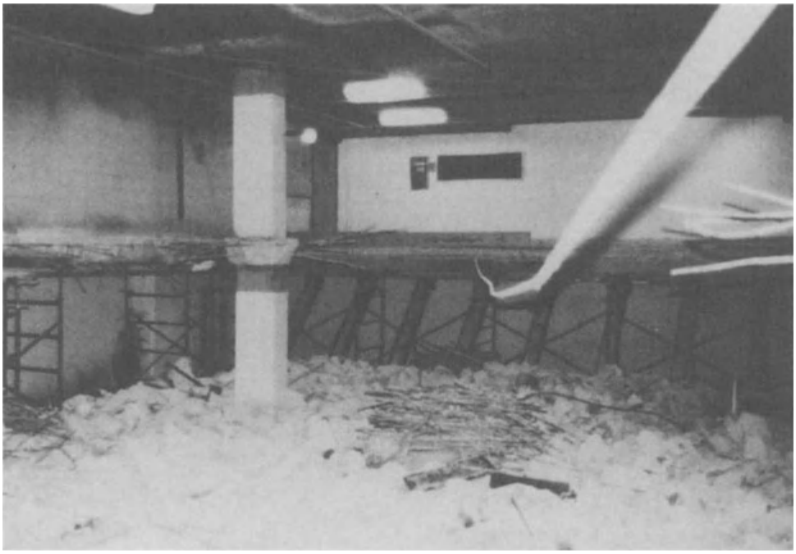
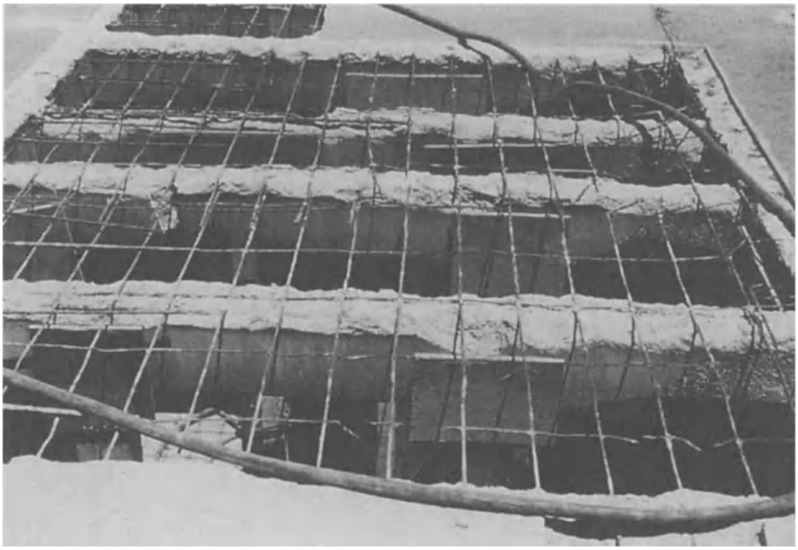


Figure 15-69. Full-depth slab removal over beam.



(a)



(b)

Figure 15-70. (a) Full-depth slab removal (flat slab). (b) Full-depth removal (pan joist slab).

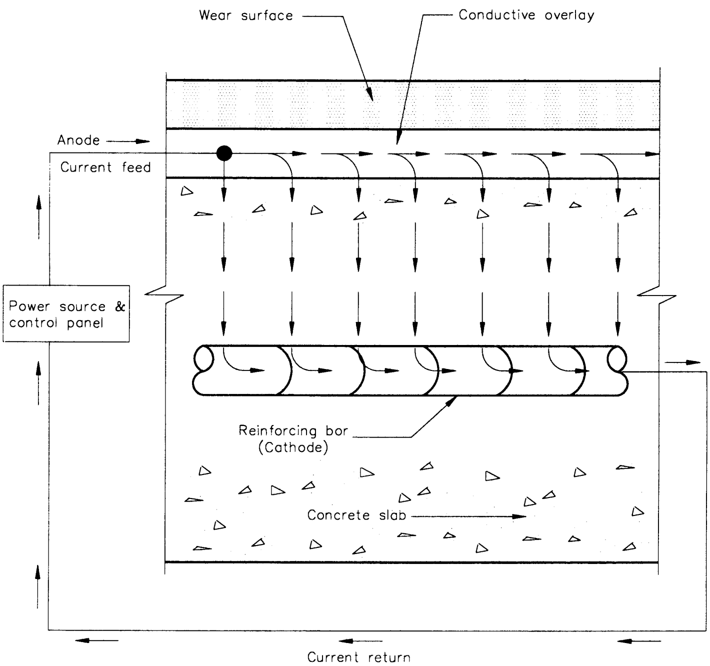


Figure 15-71. Schematic example of cathodic protection.

floor system (slab and underlying elements) or demolition of the entire structure may be necessary.

15.5.6 Cathodic Protection

In concept, the only method that will effectively stop the corrosion of embedded reinforcement in chloride-contaminated slabs is cathodic protection. Cathodic protection works by putting energy in the form of electrical current into the concrete to be protected. The introduced energy prevents corrosion in the steel reinforcement. Corrosion of metal is, put simply, a loss of energy from that metal. Feeding in more energy prevents that corrosion. Cathodic protection is the only protective measure that prevents corrosion from starting. If corrosion has already started before cathodic protection is introduced, it is the only protective measure that will stop corrosion. All other measures described in this chapter are but delaying actions, though some are very effective; they will slow corrosion, but not stop it. See Figure 15-71 for a diagram showing how one cathodic protection system works.

Industry experience in the application of cathodic protection to parking structure floor systems is limited. However, there are several reported applications of cathodic protection to parking structures. The results to date, in general, have been encouraging. Field applications of cathodic-protection systems in bridge decks have been in operation since 1974.

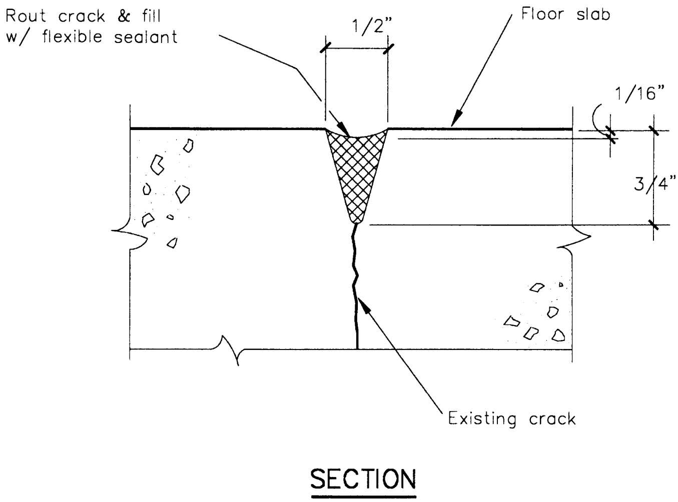
Application of cathodic protection can only mitigate corrosion, and repairs to restore structural integrity and serviceability must still be performed. Therefore, cathodic-protection system is more cost-effective when it is applied to structures having floor slabs in the initial stages of deterioration. Refer to Figure 15-10 for description of the four stages of deterioration. Also, a cathodic-protection system is not economical when applied to structures with less than 10 years of planned or anticipated life expectancy. At present, only conventionally reinforced concrete structures have been cathodically protected. Cathodic protection of prestressing steel is still in the developmental stage. The concern is due to evolution of hydrogen ions as a result of application of cathodic protection to concrete structures. Hydrogen ion can cause embrittlement of the high strength prestressing steel and abrupt tendon failures. Hydrogen embrittlement is not a concern for conventional mild steel reinforcement.

At present, several types of cathodic-protection systems are being marketed. Some of these proprietary cathodic-protection systems have been developed within the last 2 to 3 years, and it is difficult to evaluate the life expectancy and effectiveness of the installed systems over an extended period. Presently cathodic-protection system cost can range from $3 to $5 per square foot. This cost is in addition to that required for concrete repairs. If the floor slab is extensively cracked, a protective coating will also be required to prevent deterioration of other underlying members due to water leakage; therefore, the overall initial repair costs for the structure can sometimes become very high.

15.5.7 Sealing

Sealing consists of performing repairs that will minimize water leakage through floor slab cracks and joints. Since sealing by itself cannot be considered to be a repair approach, it must always be performed in conjunction with the other repair methods described earlier. Potential sources of water leakage are expansion joints, construction joints, control or isolation joints, and construction- or service-related cracks.

Refer to sections 15.3.3 and 15.3.4 for a discussion of the distress associated with cracking and failure of joints. Also, refer to Figures 15-



Notes:

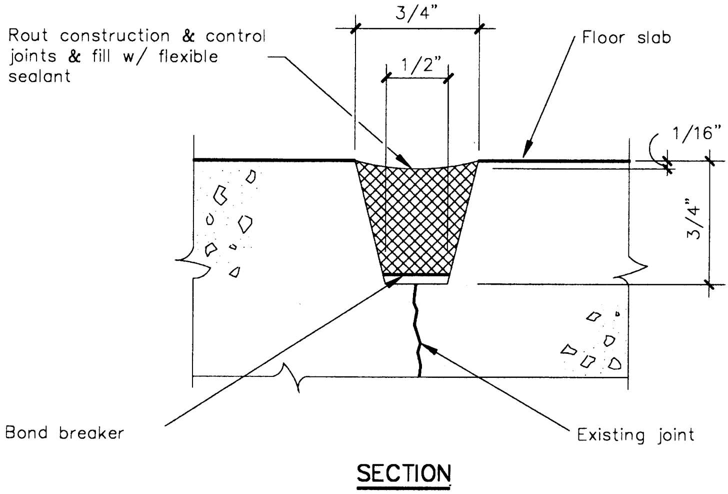
1. Center routed groove on crack.
2. Prepare and allow for primer to cure properly prior to installing sealant.
3. See specifications for approved materials.
4. Install sealant evenly and recess 1/16" below surface. Install sealant flush under traffic topping. Do not overfill joint.
5. Pay unit = l.f.
6. Detail not to scale.

Figure 15-72. Detail for sealing random floor slab cracks.

72 through 15-74 for typical details related to sealing cracks and joints. Design, detailing, material, and installation methods for joint seals are also discussed in detail in ACI 224 1R and ACI 504R.

Under certain circumstances, cracks can be repaired by epoxy injection. The material and its application are described in ACI 224.1R. The procedure for epoxy injection is discussed in ACI 503R and 503.1. Epoxy injection of service-related (active) cracks usually results in cracking adjacent to previously injected cracks. Active cracks should be treated with a flexible-joint sealant material (Figure 15-75).

Surface or pattern cracks that are inactive can be treated by application of high-molecular-weight methacylate (HMWM). The concrete surface is soaked to fill and heal the cracks. These "crack healers" have a viscosity slighting greater than water. Surface cracks can also be treated



Notes:

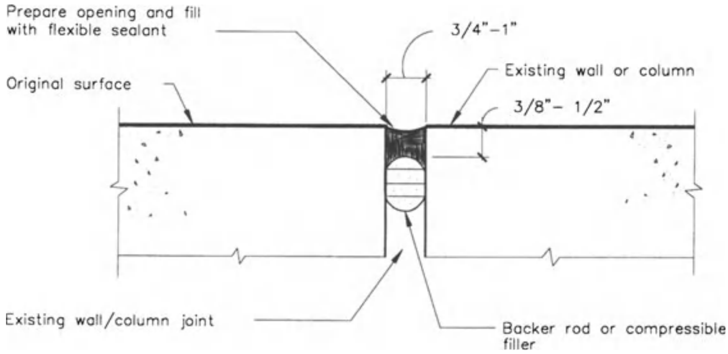
1. Center routed groove on construction/control joints.
2. Prepare and allow for primer to cure properly prior to installing sealant.
3. See specifications for approved materials.
4. Install sealant evenly and recess 1/16" below surface. Install sealant flush under traffic topping. Do not overfill joint.
5. Pay unit = l.f.
6. Detail not to scale.

Figure 15-73. Detail for sealing construction and control joints.

with a traffic-bearing elastomeric membrane. In addition, these membranes also have the ability to bridge and protect the surface from active cracks. Application of silane sealer is also sometimes effective in keeping moisture out of fine hairline surface cracks that are not active.

15.5.8 Posttensioned Structures

An increase has recently been noted in the number of cast-in-place posttensioned structures with performance-related problems due to tendon corrosion. Most of these structures were built in the late 1960s and early 1970s. The performance problems are discussed in section 15.3.1.4. Repairing these prestressed structures requires an understanding of the structural system to provide appropriate shoring and bracing



SECTION

Notes:

1. Remove existing joint sealant material.
2. Grind joint edges.
3. Install backer rod.
4. Prepare and allow for primer to cure properly prior to installing sealant.
5. See specifications for approved materials.
6. Install sealant evenly and recess 1/16" below surface Do not overfill joint.
7. Pay unit = l.f.
8. Detail not to scale.

Figure 15-74. Detail for sealing existing control joints.

during intermediate stages of the construction process. For instance, floor slab removal (dead load) prior to replacement by a new slab may require schemes to counteract the existing beam posttensioning forces. Repair of posttensioned structures should only be attempted by experienced specialists.

Again, most of the posttensioning repairs are directed at the floor slab tendons. Occasionally, beam tendon repairs are necessary owing to end anchorage corrosion. The types of tendon repair that may be utilized are as follows:

1. *Partial Tendon Replacement.* Partial tendon replacement is possible when the corrosion of floor slab tendons is localized and limited to an area such as the tendon high points or construction joints (see Figures 15-76 through 15-78. Corrosion-induced damage of the high points may be attributed to shallow concrete cover and/or tendon that is exposed to traffic abrasion at open floor slab spalls. Tendon

Figure 15-75. Routed and sealed random cracks.

corrosion at construction joints is attributed primarily to continued water leakage through the joint. The affected section of the tendon is replaced by a new section attached to the existing tendon by couplers. The actual splice detail will vary depending on the type of the prestressing element in the existing tendon, the stressing method, and the manufacturer of the prestressing system.

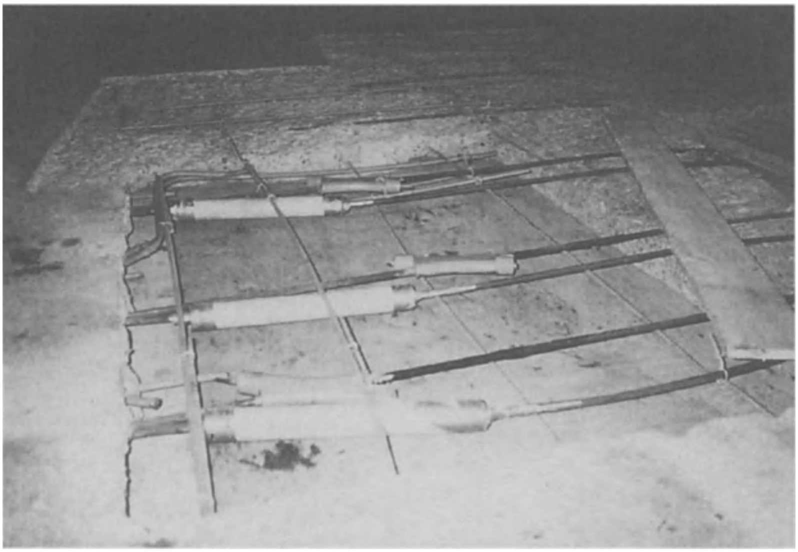
2. *Complete Tendon Replacement.* It becomes cost-effective to replace a tendon that has been affected by corrosion at several points along the tendon. The tendon replacement requires threading a new tendon through the existing chase. The same-diameter prestressing strand or wire or a little smaller than the diameter of the original tendon can be threaded through. Sometimes, one can choose to replace the existing tendon with epoxy-coated strands for added protection.

   Another method that has been used for tendon replacement is the trenching method. The trenching method is a patented system of replacing posttensioning tendons in existing concrete structures. The method utilizes short trenches cut into the top and bottom surfaces of the slab. These trenches overlap so new 1/2-in.-diameter, totally encapsulated tendons can be installed in a parabolic profile, identical to the original design. The trenches are then patched with a latex-modified or low slump dense concrete, and the tendons are stressed to appropriate levels. Additional top-reinforcing steel can be added

(a)

(b)

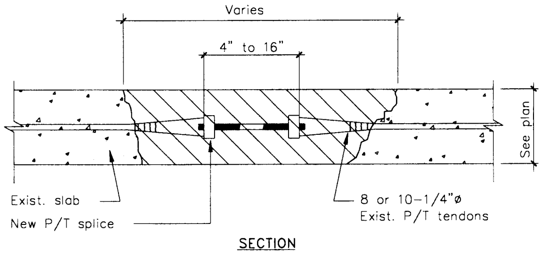
Figure 15-76. (a) Field button-heading of wire tendons. (b) Partial tendon replacement at slab high point.



(a)

(b)

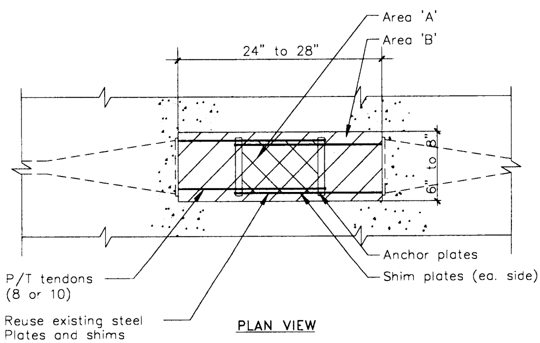
Figure 15-77. (a) Partial strand replacement at tendon profile high point. (b) Tendon splice at construction joint.



NOTE:

1. See Specification for concrete removal and patch.
2. Detension tendons prior to splice installation.
3. Grease and wrap tendons.
4. Install splice(s) and new tendons if required and retension.
5. Pay units:
   A. New splice(s) = EA.
   B. New tendons = L.F.

(a)



Notes:

1. Remove all sound and unsound concrete within sections shown cross-hatched. Remove concrete in area 'A' first, taking care not to disturb existing steel shims, place hydraulic jack then remove concrete in area 'b'.
2. Do not sawcut patch perimeter until all P/T tendons have been expossed by chipping for examination by engineer.
3. Detention P/T tendons for associated repairs, then retension tendons per specifications.
4. Sandblast all exposed steel plates, shims and wires and epoxy coat steel plates and shims, grease and wrap tendons.
5. Place patch in accordance with specifications.
6. Pay unit = ea.

(b)

Figure 15-78. (a) Tendon splice detail. (b) Center-stressing detail.

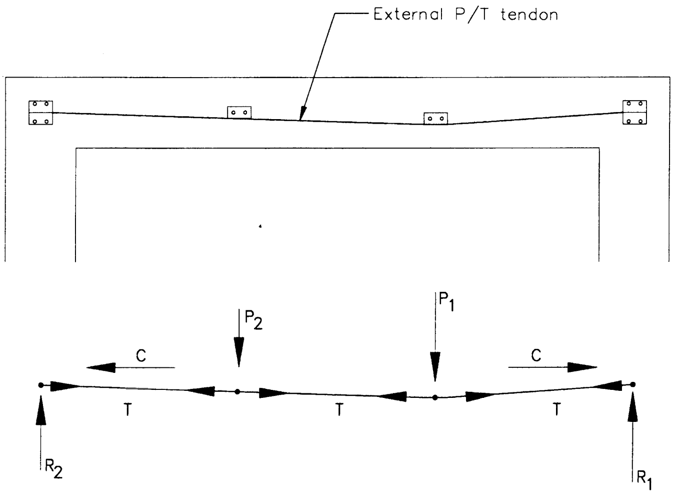


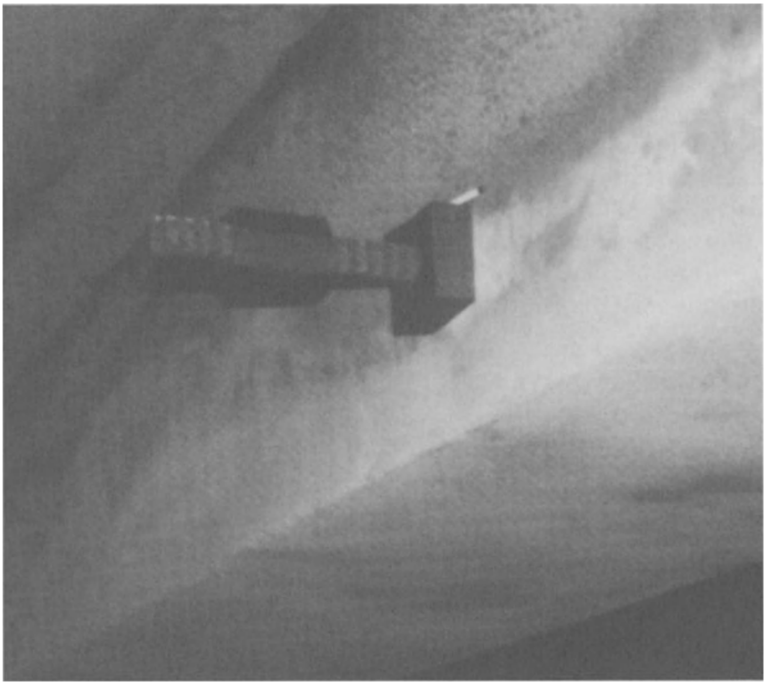
Figure 15-79. Application of external prestressing to structural members.

to the slab in the trenches to update the structure to meet current minimum requirements. This system has been successfully used in several parking ramps in the Midwest. The trenching method of repair is considered a long-term repair.

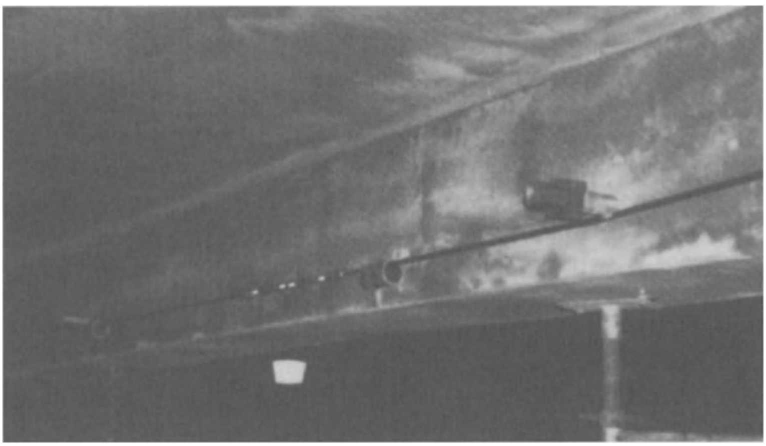
3. *External Tendons.* External tendons are more commonly used in repair and strengthening of beams as opposed to repair of slabs (See Figures 15-79 and 15-80). The strength capacity of the beam is restored by adding tendons to the outside of the existing beam section. After it is installed and stressed, the externally applied tendons have to be encased in concrete or other noncombustible material for fire protection.
4. *Full-Depth Slab Removals.* In extreme cases, it may be necessary to remove and replace the entire slab section. This can be a design as well as a construction challenge. The beam section will require in-depth analysis for all the load conditions encountered during the slab reconstruction with cross sections that are altered by concrete removal and replacement. Also, removal of the slab dead load from the existing beam will result in uplift forces that have to be controlled during the repairs.

15.5.9 Summary

The intent of these sections has been to discuss the commonly used repair approach and methods for restoring parking structures. Construc-



(a)



(b)

Figure 15-80. (a) Deflectors installed to maintain tendon profile. (b) Strand installed with deflector.

tion and design deficiencies, along with errors in design or construction, may require strengthening or stiffening of the structural element. Also, severely deteriorated structural elements in a parking facility may require strengthening. In these instances, the primary cause of the distress must be determined first, and then appropriate corrective actions must be taken by following the approach discussed in section 15.4. Also, refer to ACI 437R "Strength Evaluation of Existing Buildings." These situations are generally uncommon. If construction and design deficiencies are present, then repair and/or strengthening method must address the specific conditions encountered.

15.6 REPAIR MATERIALS

15.6.1 Patching Materials

The selection of patching and concrete material is based on the consideration of the following five characteristics, as they relate to the member being repaired:

- Thermal compatibility or incompatibility
- Shrinkage
- Strength of repair material and the substrate
- Durability of the repair material and the substrate
- Ability to permit vapor transmission

The compatibility of the repair materials with the existing concrete is an important concern in the selection of appropriate repair materials. Since parking structures are exposed to temperature extremes, a difference in thermal properties of the repair material and the existing concrete will contribute to the debonding and failure of repaired areas. For instance, failure of epoxy-mortar patches can often be attributed to the thermal incompatibly. Even for sand-filled epoxy mortars, the thermal coefficient of expansion may be four to five times that of the underlying concrete. The high stress developed between the epoxy patch and the underlying concrete is less forgiving of deficiencies in workmanship related to patch preparation and placement, resulting in more frequent failures.

For parking structures, Portland cement-based patching and overlay materials generally perform better than any other material. Even in moderate climatic regions, the use of Portland cement-based material should be preferred over other polymer concrete materials. Portland cement-based materials also minimize failures associated with a difference in the modulus of elasticity of the repaired material and existing concrete.

The differential shrinkage between the original concrete and the repair material can also contribute to debonding and cracking due to development of shear stresses along the interface. Minimize shrinkage of concrete repair materials by using a low water-cement ratio concrete, the maximum permissible size of coarse aggregate, and the lowest slump that will permit proper consolidation and finishing of the concrete. Minimizing the shrinkage potential of the concrete repair material is particularly important for full-depth patches and floor slab replacements. Cracking of full-depth patching and floor slab replacements is a common occurrence. The use of additional reinforcement and control joints is another effective way to control, but not eliminate, concrete cracking. Also refer to ACI 224R.

Always specify a strength of the repair material that is equal to or exceeds the strength of the underlying concrete. Also, patches placed over poor-quality concrete with less than 3000 or 4000 psi concrete-compressive strength are susceptible to debonding. In such instances, the failure may occur in the underlying concrete. The extent of the failure will be affected by the concrete removal method, bonding medium, and patch material used. For suspect or questionable quality of the underlying concrete, verify performance of the repair technique by field-testing various concrete removal methods, surface preparation, and placement methods based on shear-bond test results.

A substrate that is marginally or inadequately air entrained is susceptible to progressive deterioration due to freeze-thaw damage if enough moisture is available or trapped at the interface to critically saturate the underlying concrete. Under these conditions the repair material selected should not behave as a vapor barrier. Also, cracking or defects in the repair material that permit water to reach the interface will contribute to deterioration of the repair. For instance, an elastomeric-waterproofing membrane system (traffic topping) placed over a non-air-entrained concrete surface is likely to be subjected to progressive deterioration at pinholes and defects due to scaling of the underlying concrete. Another example is the reduced life expectancy of the patches and overlays ($<3/4$ in. thick) due to cracking that extends through to the underlying substrate.

The repair material itself must be durable enough to resist freeze-thaw cycling. The patch or overlay material should be properly air entrained. For the horizontal floor slab surfaces, low-slump, high-density, and microsilica-modified concrete patching materials that are properly proportioned and adequately air entrained tend to perform well.

Figure 15-81. Severe deterioration of underlying concrete covered by asphaltic material overlay.

Also, latex-modified concrete patching materials perform well since they are not as susceptible to freeze-thaw damage. Refer to the appendices at the end of the chapter for sample specifications of patching materials. For full-depth floor slab replacements, specify a concrete mix with low potential for shrinkage.

Performance of rapid-setting prepackaged patching materials has generally been poor owing to its inability to control air entrainment. However, prepackaged Portland cement and polymer concrete-based patching materials have been used to maintain serviceability for a limited time as a temporary measure to reduce safety hazards. In some instances, asphalt has been used. Since asphalt tends to trap moisture and chlorides, patching with asphalt material may accelerate damage to the underlying concrete due to freeze-thaw and corrosion. (See Figure 15-81.)

The patching material for overhead and vertical surfaces is less susceptible to freeze-thaw deterioration than the floor slab or horizontal surface. For areas that are protected from direct exposure to moisture, such as the ceiling, rapid-setting prepackaged Portland cement-based repair materials have been used successfully (Figure 15-82). Other successfully but not widely used patching materials are various epoxy and polymer concretes. Polymer concretes are classed as thermosetting and hydrating. Examples of thermosetting polymer concretes are those containing epoxy and those containing methyl methacrylate. Examples of hydrating polymer concretes are those containing styrene-butadene

Figure 15-82. Overhead patching.

("latex") additives which enhance the bond and reduce permeability. Limit the use of these materials only to address cosmetic or aesthetic repairs. For large shallow areas, pneumatically applied (shotcrete) concrete has also been used effectively. Specify the wet process with air entrainment when there is a potential for saturation of the surface by moisture (Figure 15-83).

15.6.2 Sealers

There are many types of generic sealers available in the market today. The silanes and the siloxanes have emerged to be more effective than other generic types. However, not all silanes and siloxanes perform equally. The desirable properties of a good sealer are:

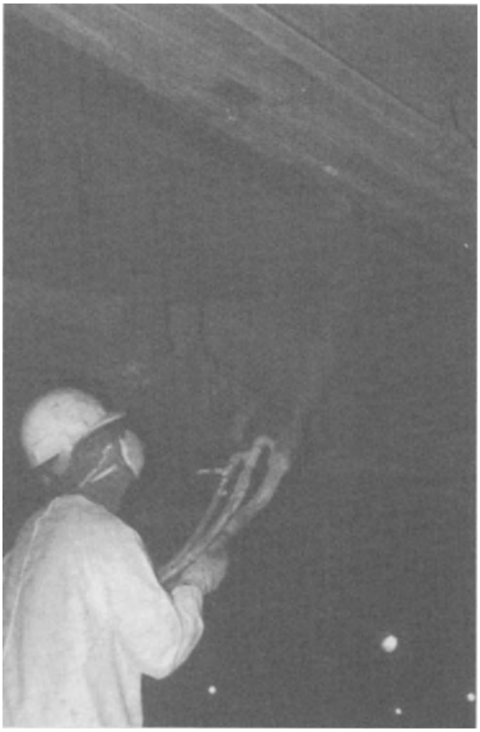


Figure 15-83. Shoicrete repair.

- Reduce water absorption
- Effective chloride ion screen and chemical stability when exposed to road salt
- Ability to "breathe," which permits moisture vapor transmission
- Resist ultraviolet exposure
- Provide a skid-resistant surface after application
- Ability to penetrate in to the concrete surface

Some of the more commonly accepted laboratory test procedures that are available to evaluate sealer performance are summarized in Table 15-5. A combination of several of the test methods that are listed is necessary to properly distinguish sealer performance.

The better performance of silanes and siloxanes is due to its smaller molecular structure. These sealers can penetrate as much as 1/8 in. into the concrete surface. Depth of penetration is obviously related to the concrete porosity and permeability. Concrete with higher water-cement

TABLE 15-5. Sealer Testing

Test Objective	Standard Designation	Remarks
Chloride screening ability	NCHRP 244 Series II	Sealer performance evaluated based on water absorption and chloride ion content of test specimens that are submerged in salt water.
Chloride ion intrusion	AASHTO T259 AASHTO T260	Slab test specimens are ponded with saltwater for the test period. Chloride ion content of concrete is determined at various increments of depth to evaluate sealer performance.
Water absorption	ASTM C642	Water absorption of core samples. Absorption permitted only from the slab top side or bottom. Effectiveness of sealer application can be evaluated by comparison of water absorption for sealed slab top surface and the unsealed slab bottom surface.
Impact of surface abrasion (penetration)	Alberta DOT (Canada) 1989	Abraded samples are tested for chloride ion screening ability to simulate impact of traffic abrasion on horizontal surfaces. Penetrating sealers perform better than sealers that only tend to form a film on the surface.
Ultraviolet exposure	NCHRP 244 Southern exposure test	Stability to UV exposure.
Scaling resistance	ASTM C672	Must be performed on non-air-entrained concrete test specimens. Evaluates ability to keep moisture away from the concrete surface.
Moisture vapor transmission	ASTM E96	Measures the ability of the sealer to "breathe."
Skid resistance	ASTM C303	Generally not a concern with penetrating sealers such as a silane. Film forming sealers tend to "glaze" which can be a slip hazard.

ratio is more porous and will permit greater sealer penetration than a concrete that is less porous. Also, the sealer effectiveness is influenced by the sealer application rate and the concrete porosity. Some other factors that can affect sealer performance are condition of the surface at the time of sealer application, surface preparation, moisture content of the concrete, and sealer concentration. The effectiveness of the sealer under service condition and/or frequency of reapplication can be monitored by chloride ion testing. See Chapter 14 for chloride ion monitoring.

One recent development is the use of water-based solvents for silanes. The more volatile, alcohol-based solvent carriers that were traditionally required have been replaced by water-based solvents. This is due to the very stringent regulations for the Volatile Organic Compounds (VOC) that have been imposed by several states. These state standards exceed the current Environmental Protection Agency's Clean Air Act Amendment standards. It is anticipated that many more states will adopt these current regulations and some will tighten them even more. Therefore, some manufacturers have already developed solvent-free 100% silane sealers. This highly concentrated sealer is obviously more expensive than the current sealers that are packaged at 20% to 40% silane content. The new sealers can potentially last longer and provide better corrosion protection owing to their high solids content.

15.6.3 Membranes (Traffic Topping)

The present ASTM test methods for testing properties of traffic-bearing membranes are not adequate to evaluate the performance and the abrasion resistance of systems. There are many manufactures that supply the membrane, but not all membrane systems perform equally. Some basic characteristics that help to evaluate the systems are:

- Impermeability—Should be impermeable to water under normal use.
- Tear resistance—Membrane should be capable of bridging cracks under normal as well as cold-weather conditions.
- Adhesion—Intercoat as well as adhesion to the substrate.
- Moisture vapor transmission—The membrane should be capable of breathing.
- Material stability—Stability under service exposure conditions to perform over extended time period.
- Chemical resistance—Should be resistant to gasoline, oil, and antifreeze spills.

- Ease of installation—The waterproofing material and installation procedures must be tolerant of site conditions, as opposed to ideal laboratory conditions.

Select membrane systems based on performance history, compatibility with other sealant systems, cost, and the manufacturer's reputation to properly install and service the topping. Improper application of polyurethane membranes can result in localized imperfections, such as blistering and pinholes. Therefore, the performance of the membrane systems is affected by the care taken to install the systems. These systems require more frequent maintenance in high-traffic areas. The service life and the level of maintenance are affected by the abrasion resistance of the system. Current ASTM abrasion test methods are not effective in distinguishing the performance of membranes manufactured by the various vendors.

A proprietary test that has gained considerable acceptance in the industry is the comparison of the abrasion resistance of the membrane systems when tested against oak blocks. The oak blocks are placed in a specially designed wear test machine that can apply a constant predefined pressure against membrane samples cast on an aluminum strip. The test samples (strips) are clamped onto a bed that moves back and forth underneath the stationary oak blocks. This wear test machine was originally designed and developed by the 3M Company, Minneapolis, Minn. The author has successfully used this tester to evaluate the performance of the various membrane systems over the last eight years, based on a detailed membrane performance specification developed by Walker Parking Consultants of Kalamazoo, Mich.

The stricter VOC regulation imposed by several states has led to the recent development of some solvent-free (100% solids) membrane systems. Currently, most of the urethane membrane systems are solvent based. Also, low-odor systems are offered by many manufacturers for membrane installation in enclosed areas or areas adjacent to occupied spaces in buildings. At present, there are no standards to measure or compare the odor characteristics. After all, odor is a very subjective issue and cannot be defined very easily.

15.6.4 Overlays

The most widely used specialty concrete overlay systems that have demonstrated a satisfactory long-term performance history are latex-modified concrete (LMC) and low-slump, high-density concrete (LSDC). LMC is more effective at preventing additional water and salt penetrations into the base slab than LSDC; however, long-term durability appears to be equivalent in the two systems. Polymer-concrete overlays have been used only on a limited scale and have not been fully evaluated. Such systems, whether referred to as polymer or epoxy concrete, can offer solutions to surface deterioration problems and should not be excluded from consideration. Another specialty concrete overlay utilizing silica-fume-modified, high-density concrete is currently available. Its performance history is limited to about 10 years; however, the potential for the long-term durability of this system is excellent. Also, the installation cost of the silica-fume-modified overlay is lower than that of the LMC system. Refer to sample specifications for overlay included in the appendices at the end of this chapter.

15.7 SELECTION OF REPAIR APPROACH AND METHOD

15.7.1 General

Floor slab surfaces experience the most deterioration due to more direct exposure to the service environment. The deterioration is accelerated by design deficiencies or construction practices that contribute to poor-quality concrete, shallow cover over embedded reinforcement, inadequately air-entrained concrete, cracking, and ponding. The repair objective is to correct many of these deficiencies and improve other adverse conditions. This will reduce the deterioration rate of the restored structure and extend the service life of the facility. Several repair alternatives are developed to extend the service life of the facility, and then the most cost-effective repair approach is selected.

It is not unusual for floor slab repairs to consume as much as 50% to 80% of the total restoration cost. Therefore, floor slab repairs generally offer the greatest potential for cost savings. In most instances repairs to underlying members such as columns, haunches, bearing ledges, and walls represent a much smaller portion of the total restoration cost. Repair of the structural members other than the floor slab are performed by patching, strengthening, or replacement. The selection of a repair scheme to restore the floor slab of a parking structure is related to the following six basic issues:

- Nature of distress
- Extent of deterioration
- Type of structure
- Repair strategies
- Life expectancy of the repaired structure
- Economics

15.7.2 Repair Approach

The same repair approach cannot be used for all structures. The repair scheme selected to restore a structure damaged by corrosion of embedded reinforcement will be different from that selected for a slab damaged by freezing and thawing. In addition, the repair approach selected must address the adverse effect of other contributing factors, such as the quality of the concrete, poor drainage, floor slab cracking, shallow concrete cover over reinforcement, and lack of adequate air entrainment.

The extent of the deterioration and type of structural system will also influence the selection of the repair scheme. For instance, if a 4-in.-thick slab of a pan-joist system is extensively damaged owing to corrosion, then patching, sealing, or cathodic protection may not be an acceptable solution. The appropriate repair scheme in this instance is probably going to be the replacement of the slab of the floor system. Slab replacement will be required, since it is difficult to perform partial-depth repair of slabs that are less than 5 in. thick. On the other hand, if the 4-in. slab is damaged by surface scaling, an elastomeric waterproofing membrane or an overlay may be acceptable solutions. However, if the extent of the freeze-thaw damage extends 1–2 in. below the surface, replacement may be a more appropriate repair method.

In summary, from a technical standpoint, consider the nature and extent of the deterioration, the pros and cons or the repair methods that are technically acceptable, and the impact of the repair on factors contributing to the deterioration. Also, make certain that the structure can be repaired (as opposed to replaced) and that all elements of the structure will support additional loads imposed by the repair work.

15.7.3 Repair Strategies

It is not uncommon to develop several technically acceptable repair alternatives based on the following overall repair strategies:

1. Do nothing and use up the remaining useful life of the structure.
2. Perform repairs to address only potentially unsafe conditions that exist. This amounts to performing only "Band-Aid-type" repairs prior to either implementing a comprehensive restoration program or demolishing the structure.
3. Perform necessary repairs to extend the life of the structure by 5 to 10 years.
4. Perform necessary repairs to extend the life of the structure by 10 to 20 years.
5. Perform repairs to extend the life of the structure by 20 years or more.

The selection and evaluation of repair alternatives are important elements of the restoration process. Select repair alternatives based on the overall strategies. This assists in selecting schemes that will address future plans for use of the structure based on funds that are available or obtainable. However, do not consider technically unacceptable alternatives primarily to limit restoration costs.

The nature and the extent of the deterioration will also limit the selection of repair alternatives. For instance, it may not be appropriate to extend the life of a structure by 5 to 10 years simply by patching, if the slab is likely to undergo progressive damage due to freezing and thawing. Also, it may not be possible to assure safe operating conditions by performing only limited repairs to a structure that is extensively damaged.

15.7.4 Life Expectancy of Repairs

The life expectancy of repair methods is at best an estimate. Also, estimating the service life of repaired structures is only an educated opinion, based on experience gained from conditions observed in structures with a similar framing system. Therefore, difficulty in estimating the service life of repaired structures complicates the selection of a cost-effective repair method. For instance, removal of sound but contaminated concrete has a significant impact on the life expectancy of repairs. The impact of concrete removal on the various repair methods can be best illustrated by considering the life expectancy of structures repaired by patching.

A distinction can sometimes be made between temporary and permanent repair patches. However, because of the progressive nature of corrosive processes, the service life of even a "permanent" patch is limited. As shown in Figure 15-84, in a temporary patch the concrete is removed only to the level of reinforcement. This situation contributes to progressive deterioration within and adjacent to the patch boundary, as illustrated in Figure 15-85. Also, the life expectancy of the patch may be limited to only 1 or 2 years. This method of patch repair may be appropriate for structures when serviceability is to be maintained for a limited time, or when constraints are imposed owing to available funds or weather conditions.

In the instance of a relatively permanent patch, the concrete is removed below the existing reinforcement to minimize potential for corrosion within the patch boundary (Figure 15-86). Also, to control accelerated corrosion adjacent to the patch boundary, the existing reinforcement may be epoxy coated. The entire floor surface is then

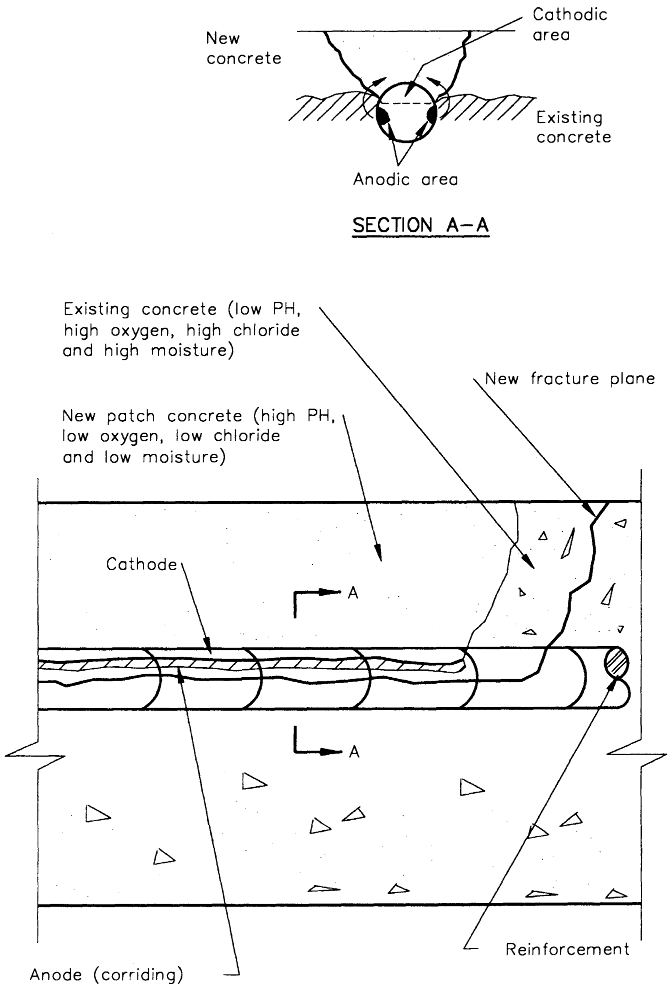


Figure 15-84. Development of corrosion cell in repair with shallow concrete removal.

sealed to reduce the deterioration rate of areas beyond the patch boundary. Under these conditions, patching can extend the service life of the structure by 3 to 5 years.

In certain instances, where longer life expectancy is desirable, concrete removal along the entire length of reinforcement is specified. For conditions shown in Figure 15-87, the life expectancy of the strip-patch repair may be estimated at 10–20 years, limited primarily by other

Figure 15-85. Delamination due to continuing corrosion within and beyond patch.

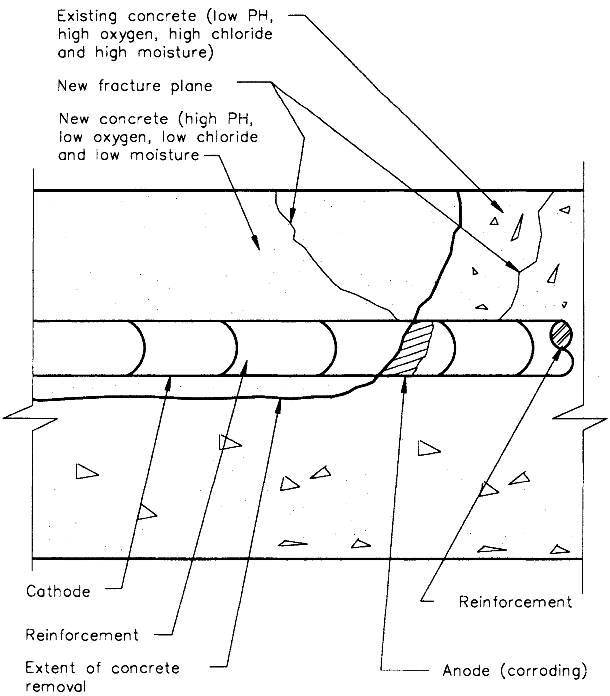
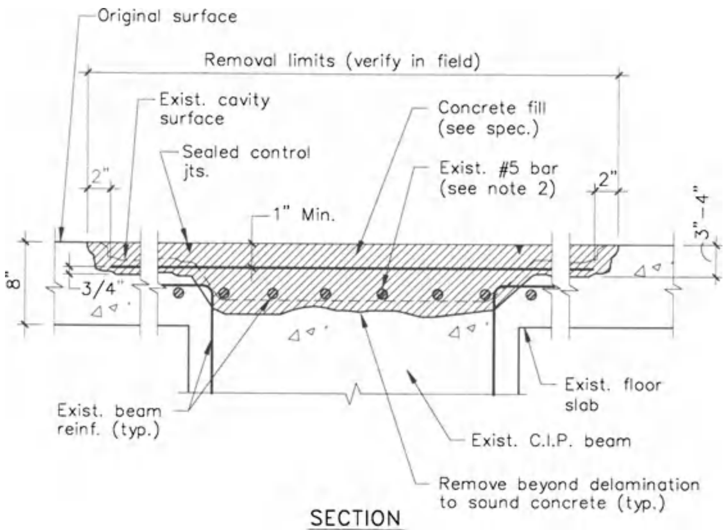


Figure 15-86. Development of corrosion cell in repair with deep concrete removal.



Note:

1. Remove and replace all sound and unsound concrete within sections shown cross-hatched.
2. Remove existing top reinforcement and replace with new epoxy coated reinforcement of same size.

Figure 15-87. Strip patch repair detail.

contributing factors such as cracking, lack of air entrainment, and poor drainage that may adversely affect the service life of the structure. However, it is not feasible to implement the strip-patch-repair approach in structures with relatively thin slabs. Therefore, considerations such as the structural system involved and the existing reinforcement pattern will limit the practical service life of structures that can be realized.

At present, the only way to be assured of a "permanent" repair requiring minimal maintenance is to remove all concrete that contains chlorides in excess of the corrosion threshold. However, in most instances, this can amount to complete removal of the floor slab (Figure 15-88). The emphasis should be on selective, but cost-effective, removals of chloride-contaminated concrete, based on consideration of overall repair strategies and the desired life expectancy of the repairs. Refer to section 15.3.1 for an explanation of the corrosion-mechanism process, chloride contamination, and continuing corrosion.

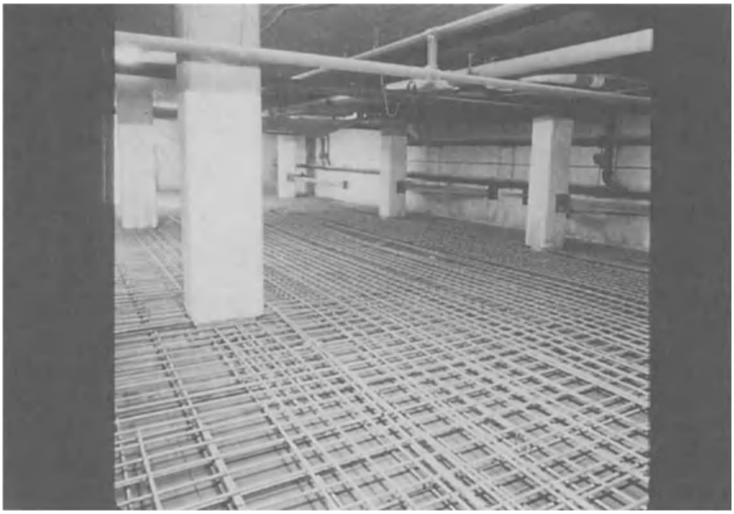


Figure 15-88. Full-depth slab replacement for long-term life expectancy.

Based on the extent of concrete removals, the structural system involved, and the concrete cover over existing reinforcements, patching and then coating floor slab with a waterproofing membrane is likely to extend the service life of the structure by 5 to 10 years. An overlay can extend the service life of structures by 10 to 20 years. In concept, the only method that will mitigate corrosion of the embedded reinforcement without removal of sound concrete is cathodic protection. Application of cathodic protection is estimated to extend the service life of structures beyond 20 years. Full-depth slab and floor removal can be designed to be rebuilt with a life expectancy of 20 to 40 years.

15.7.5 Economics

The selection of a cost-effective repair method consists of (1) preparing cost estimates of technically acceptable repair alternatives, and (2) estimating the service life of the repaired structure. Repair costs can vary significantly even for the same method of repair. Factors contributing to cost variations are geographic location of the structure, scope of the overall contract, size and volume of the repair work, and availability of materials and qualified contractors. Constraints associated with maintaining traffic during construction and the overall volume of construction work at the time of bidding can also vary the overall repair costs. Realistic estimates are obtained by using costs from an historical record and assigning appropriate contingency factors to the total cost of the work.

In some instances life cycle cost analysis of repair methods is also performed to select an economical repair method. Once again, the economics are difficult to estimate owing to the possible inaccuracy in assessed costs and assumed service life of the repaired structure.

15.7.6 Selection of Repair Approach

The advantages and disadvantages of the various schemes were discussed in sections 15.5.3 to 15.5.7. This information can be conveniently qualified to assist in the selection of technically appropriate repair approach by using a decision matrix as shown in Table 15-6. The concept of the decision matrix was developed by the Ontario Ministry of Transportation, Research and Development Branch, primarily for selection bridge deck rehabilitation methods. The decision matrix presented in Table 15-6 has been adapted from the material published in the Ministry of Transportation's manual. The table assists in the selection of a repair approach with the least amount of technically unfavorable elements. Note that patching or sealing as a repair approach by itself will be ineffective in restoring the slab. Patching and sealing are usually done in conjunction with application of a surface sealer, traffic topping, or an overlay.

The decision matrix leads, by elimination, to the selection of repair schemes with the fewest disadvantages. In some cases, most of the schemes considered may be inappropriate. For instance, a structure that is extensively cracked, consisting primarily of active cracks and delaminated over 30% of the floor area, will necessitate working through the selection process and examining the implication of violating each criterion in turn for the selected alternatives. If the structure is considered to be important, then the scheme may consist of slab replacement with a liquid-applied membrane to minimize leakage through active floor slab cracks. The criteria contained in Table 15-6 are not rigid, but serve as a useful starting point from a technical standpoint. As previously mentioned, repair strategies, life expectancy, and economic issues usually influence the selection of the final repair scheme.

15.8 REPAIR DOCUMENTS AND CONSTRUCTION OBSERVATION

Repair documents implement the findings of the condition appraisal. The four tasks associated with document preparation and implementation of the repairs are as follows:

TABLE 15-6. Selection of a Floor Slab Repair Approach

Criterion	Patching (Partial or Full-Depth)	Sealer	Protective Coatings Traffic Topping	Overlay	Replacement (Partial or Full-Depth)	Cathodic Protection[a,b]
1. Corrosion-induced deterioration—10% of the floor area	No	No				
2. Corrosion-induced deterioration—30% of the floor area	No	No	No	No		No
3. Moderate scaling—10% of the floor area	No	No				Yes/no
4. Non-air-entrained concrete	No	No	No			Yes/no
5. High concrete permeability	No	No				
6. Need to improve drainage	No	No	No			Yes/no
7. Shallow concrete cover	No	No				
8. Limited structural capacity				No		Yes/no
9. Limited floor clearance				No		Yes/no
10. Remaining life less than 10 yr				No	No	No
11. Active cracks	No	No		No	No	

[a]Items 3, 4, and 7 are appropriate if the C.P. system selected consists of anode embedded in a concrete overlay.
[b]Items 8 and 9 will be appropriate if the C.P. system consists of anode embedded in slots cut in the structure or applied to the soffit.
Adapted from "Bridge Deck Rehabilitation Manual," Part 2: Contract Preparation, Ontario Ministry of Transportation.

TABLE 15-7. Repair Work Items

Work Item	Description
1.0	Repair damaged floor slab
2.0	Repair damaged beams and columns
3.0	Install new electrical conduit
4.0	Paint exposed structural steel
5.0	Install new control joints
6.0	Repair bumper guards
7.0	Apply concrete surface sealer
8.0	Install new drain system

- Development of plans, details, and specifications
- Priority assignments and preparation of cost estimates
- Contractor selection and bidding or negotiation
- Construction observation

The two most common contract forms are the negotiated contract and the lump sum contract, both based on unit prices and quantities. The lump sum contract is preferred for restoration work. Using the unit-price approach, repair procedures are identified as separate work items (Table 15-7). They are repair procedures that will correct the distress in structural members. The plan sheets are usually condition appraisal field sheets converted to work items based on the field survey observations. The specifications contain the description of the scope of individual work items, material specifications, and repair procedures. Details describe concrete removal limits and provide dimensions and material requirements. Refer to several sample repair details contained in section 15.5.

For owners facing budget constraints, assign priority to repair items to allocate available funds. Also, when repair costs are high, restoration work may sometimes be planned to be phased over several years. The first priority is to repair structural defects to assure a safe and serviceable condition. Except for emergency repairs, priorities are assigned on a tier basis, not a work-item basis. A tier (or area) of a parking deck should be closed only once for repairs. Contract priorities assigned by work items, instead of areas or tiers, can be more annoying to the facility users. Also, confining the work to a designated area minimizes the disruption of traffic circulation during construction.

Cost estimates are prepared using the work-item listing developed earlier, and estimated quantities for each item. Quantities should be estimated on a tier-by-tier basis to aid the contractor in planning and

TABLE 15-8. Repair Cost Estimate

Work Item	Description	Estimated Cost
1.0	Repair damaged floor slab	$325,000
2.0	Repair damaged beams and columns	75,000
3.0	Install new electrical conduit	25,000
4.0	Paint exposed structural steel	30,000
5.0	Install new control joints	24,000
6.0	Repair bumper guards	28,000
7.0	Apply concrete surface sealer	42,000
8.0	Install new drain system	30,000
	Subtotal	$579,000
	Plans and specifications	30,000
	Resident services	30,000
	Materials testing	18,000
	Contingency	100,000
	Total	$757,000

scheduling the work with minimum disruption to the operation of the facility (Table 15-8). Always provide funding for contingencies; otherwise, latent conditions found during the repairs may contribute to cost overruns.

When restoration work is planned and phased over several years, repair costs will be higher for the following reasons:

1. Contractor must move on and off site more than once.
2. Smaller repair quantities each year will have higher unit costs.
3. Items not repaired in the first stage will continue to deteriorate, so volume of repairs will increase.
4. Inflation normally results in an annual repair cost increase.

Where possible, only experienced general and specialty contractors should be permitted to bid on restoration projects. Qualifications should be closely examined to determine if the contractor is able to perform the work according to specifications. Such an experienced contractor is one who has performed the type of restoration work being bid on, or has personnel who have completed similar work in the past. Evaluate contractors based on the number of similar projects completed, size of projects completed, experience and skill of personnel, bonding capacity, and reputation.

A qualified project resident should observe repair work, verify repair areas, and document actual work-item quantities. The resident can also monitor the compliance to material requirements, repair procedures, equipment, and construction load restrictions specified by the contract documents. Field problems can be resolved promptly with the assistance of a project resident maintaining the construction schedule and minimizing any inconvenience to facility users.

15.9 MAINTENANCE PROGRAM

Effective maintenance can prolong the life of a restored facility by minimizing the deterioration of the structure, thus protecting the owner's investment. The essential elements of a comprehensive maintenance program for parking facilities are discussed in Chapter 14.

APPENDIX 15-1

SAMPLE SPECIFICATION FOR SURFACE PREPARATION

PART 1 GENERAL

1.01 WORK INCLUDED

This work consists of furnishing all labor, materials, equipment, supervision, and incidentals necessary to locate and remove all delaminated and unsound concrete, and preparing the cavities created by said removal to receive patching or overlay material. Also included in this work is the preparation of existing surface spalls and potholes to receive patching or overlay material.

1.02 RELATED WORK

The following is directly related to, and shall be coordinated with, surface preparation for patching:

1. Concrete formwork
2. Concrete shores and reshores
3. Concrete reinforcement
4. Cast-in-place concrete
5. Preplaced aggregate concrete

6. Low-slump dense concrete
7. Latex-modified concrete and mortar
8. Trowel-applied mortar

1.03 REFERENCES

A.—"Specifications for Structural Concrete for Buildings" (ACI 301), American concrete Institute.

B.—Comply with the provisions of the following codes, specifications, and standards except where more stringent requirements are shown on the drawings or specified herein:

1.—"Guide for Repair of Concrete Bridge Superstructures" (ACI 546.1R), American Concrete Institute.

PART 2 PRODUCTS (NOT USED)

PART 3 EXECUTION

3.01 LOCATION AND MARKING OF WORK AREA

A.—Floor slabs

1.—Floor slab delaminations shall be located by sounding the surface with a hammer, rod, or chain drag.

2.—When a delaminated area is struck, a distinct hollow sound is heard.

3.—The contractor shall sound all designated floor for delaminations.

B.—Vertical and overhead surfaces

1.—Vertical and overhead surface delaminations shall be located by sounding the appropriate member with a hammer or rod.

2.—Cracks, usually horizontal in orientation along beam faces and vertical in orientation near column corners, are indicators of delaminated concrete.

3.—The contractor shall only sound vertical and overhead surfaces that show evidence of cracking and/or salt and water staining.

C.—Delaminated areas, once located by the contractor, will be further sounded to define their limits. These limits or "boundaries" once defined shall be marked with chalk or paint.

D.—The contractor shall locate spalls by visual inspection and mark their boundaries with chalk or paint after sounding the surface.

E.—The engineer may define and mark additional unsound concrete areas for removal, if required.

F.—Areas to be removed shall be as straight and rectangular as practical to encompass the repair and provide a neat patch.

G.—The contractor shall locate all embedded posttensioning tendons in the repair area and mark these locations for reference during concrete removal.

3.02 CONCRETE REMOVAL AND CAVITY PREPARATION

A.—Temporary shoring may be required at concrete floor repair areas exceeding 5 sq ft in area and at any beam, joist, or column repair. Contractor shall review all marked removal and preparation areas and request clarification by the engineer of shoring requirements in questionable areas. Shores must be in place prior to start of concrete removal and cavity preparation in any area requiring shores.
(Note 1: Five-square-foot area of concrete removal can be increased based on evaluation of the structural framing system.)

B.—Delaminated, spalled, and unsound concrete floor areas shall have their marked boundaries sawcut to a depth of 3/4 in. into the floor slab unless otherwise noted. For vertical and overhead surfaces the marked boundary may be saw-cut, ground, or chipped to a depth of ½ to ⅝ in. into the existing concrete, measured from the original surface. All edges shall be straight, and patch areas square or rectangular. A diamond blade saw or grinder with abrasive disk suitable for cutting concrete is acceptable for performing this work. The edge cut at the delamination boundary shall be dressed perpendicular to the member face. It shall also be of uniform depth for the entire length of the cut. Extra caution shall be exercised during saw-cutting operations to avoid damaging existing reinforcement (especially posttensioning tendons and sheaths) near the surface of concrete. Any damage to existing reinforcement, posttensioning tendons, or sheaths during removals shall be repaired by the contractor with engineer-approved methods at no cost to the owner.

C.—All concrete shall be removed from within the marked boundary to a minimum depth of 3/4 in. using 15- to 30-lb chipping hammers equipped with chisel point bits. When directed by the engineer, chipping hammers less than 15 lb shall be used to minimize damage to sound concrete. If delaminations exist beyond the minimum removal depth, chipping shall continue until all unsound and delaminated concrete has been removed from the cavity.

D.—Where embedded reinforcement is exposed by concrete removal, extra caution shall be exercised to avoid damaging it during removal of additional unsound concrete. If bond between exposed embedded reinforcement and adjacent concrete is impaired by the contractor's removal operations, the contractor shall perform additional removal around and beyond the perimeter of the reinforcement for a minimum of ¾ in. along the entire length affected at no cost to the owner.

E.—If rust is present on embedded reinforcement where it enters sound concrete, additional removal of concrete along and beneath the reinforcement will be required. Such additional removal shall continue until nonrusted reinforcement is exposed, or removal may be terminated as the engineer directs.

3.03 INSPECTION OF THE CAVITY SURFACES AND EXPOSED REINFORCING

A.—After removals are complete, but prior to final cleaning, the cavity and exposed reinforcement shall be inspected by the contractor and verified by the engineer for compliance with the requirements of section 3.02. Where the engineer can detect unsatisfactory cavity preparation, the engineer may direct the contractor to perform additional removals. The engineer shall reverify that the additional removals have been performed as directed.

B.—The contractor shall inspect embedded reinforcement exposed within the cavity for defects due to corrosion or damage resulting from removal operations. Replacement of damaged or defective reinforcement shall be performed according to this section and as directed by the engineer.

3.04 REINFORCEMENT IN REPAIR AREA

A.—All embedded reinforcement exposed during surface preparation that has lost more than 15% of the original cross-sectional area owing to corrosion shall be considered defective. All nondefective exposed reinforcement that has lost section (to the extent specified above) as a direct result of contractor's removal operations shall be considered damaged.

(Note 2: Loss percentages may be filled in only after analysis of the structural capacity of the as-built structure to see if any loss of reinforcing at all is permissible.)

B.—Supplement defective or damaged embedded reinforcement with a reinforcement of equal diameter having a class C minimum splice (ACI 318) beyond the damaged portion of the reinforcement. Secure the new reinforcement to the existing reinforcement with wire ties and/or approved anchors. Supplemental reinforcing bars shall be epoxy coated, ASTM A615 grade 60 steel. Tendon supplement or repair materials, when applicable, shall be as required by the specifications.

C.—Loose reinforcement exposed during surface preparation shall be securely anchored to the original floor prior to patch placement. Loose reinforcement shall be adequately secured by wire ties to bonded reinforcement or shall have drilled-in anchors installed to the original deck. The engineer shall determine adequacy of wire ties and approve other anchoring devices prior to their use. Tying loose reinforcement to bonded reinforcement is incidental to surface preparation, and no extras will be allowed for this work. Securing loose reinforcement with drilled anchors shall be paid for at the unit price bid for that work item.

D.—Concrete shall be removed to provide a minimum of ¾ in. clearance on all sides of defective or damaged exposed embedded reinforcement that is left in place. A minimum of 1½ in. concrete cover shall be provided over all new and existing reinforcement. Concrete cover over reinforcement may be reduced to 1 in. with engineer's approval if coated with an approved epoxy resin.

E.—Supplemental reinforcement and concrete removals required for repairs of defective or damaged reinforcement shall be paid for as follows:

1.—Concrete removals and supplemental reinforcement required for repairs of defective reinforcement shall be paid for by the owner at the unit price bid.

2.—Concrete removals and supplemental reinforcement required for repairs of damaged reinforcement shall be paid for by the contractor.

3.05 CLEANING OF REINFORCING WITHIN DELAMINATION AND SPALL CAVITIES

A.—All exposed steel shall be cleaned of rust to bare metal by sandblasting. Cleaning shall be completed immediately before patch placement to ensure that the base metal is not exposed to the elements and further rusting for extended periods of time.

B.—Paint exposed steel with an approved epoxy resin and protect from damage prior to and during concrete placement.

3.06 PREPARATION OF CAVITY FOR PATCH PLACEMENT

A.—Cavities will be examined prior to commencement of patching operations. Sounding the surface wall be part of the examination. Any delamination noted during the sounding shall be removed as specified in this section.

B.—Cavities shall be sandblasted. Airblasting is required as a final step to remove sand. All debris shall be removed from the site prior to the start of patching or placement of overlay.

APPENDIX 15-2

SAMPLE SPECIFICATION FOR LATEX-MODIFIED CONCRETE AND MORTAR FOR PATCHING AND OVERLAY

PART 1 GENERAL

1.01 WORK INCLUDED

This work consists of furnishing all labor, materials, and equipment necessary for the production and installation of latex-modified concrete or mortar for patching floor spalls and delamination voids.

1.02 RELATED WORK

The following work is directly related to and shall be coordinated with the placement of the latex-modified concrete and mortar:

1. Surface preparation for patching and overlay
2. Concrete shores and reshores
3. Concrete reinforcement
4. Concrete accessories
5. Concrete curing

1.03 REFERENCES

A.—"Specifications for Structural Concrete for Buildings," American Concrete Institute, herein referred to as ACI 301, is included unabridged as specification for this structure except as otherwise specified herein.

B.—Comply with the provisions of the following codes, specifications, and standards except where more stringent requirements are shown on the drawings or specified herein:

1.—"Building Code Requirements for Reinforced Concrete," American Concrete Institute, herein referred to as ACI 318.

2.—"Hot Weather Concreting," reported by ACI Committee 305 (ACI 305R).

3.—"Cold Weather Concreting," reported by ACI Committee 301 (ACI 306R).

4.—"Guide for Concrete Floor and Slab Construction," reported by ACI Committee 302 (ACI 302.1R).

C.—The contractor shall have the following ACI publications at the project construction site at all times:

1.—"Specifications for Structural Concrete for Buildings (ACI 301) with selected ACI and ASTM References," ACI Field Reference Manual, SP15.

2.—"Hot Weather Concreting," reported by ACI Committee 301 (ACI 305R).

3.—"Cold Weather Concreting," reported by ACI Committee 306 (ACI 306R).

4.—"Guide for Concrete Floor and Slab Construction," reported by ACI Committee 302 (ACI 302.1R).

1.04 QUALITY ASSURANCE

A.—The Testing Agency will be an independent testing laboratory employed by the owner and approved by the engineer.

B.—The testing agency is responsible for conducting, monitoring, and reporting to the owner the results of all tests required under this section with copies of all reports sent to the engineer and contractor. Testing agency has authority to reject concrete not meeting specifications.

C.—Submit the following information for field testing of concrete unless modified in writing by the engineer:

1.—Project name and location

2.—Contractor's name

3.—Testing agency's name, address, and phone number

4.—Concrete supplier

5.—Date of report

6.—Testing agency technician's name (sampling and testing)

7.—Placement location within the structure

8.—Elapsed time from batching at plant to discharge from truck at site

9.—Concrete mix data (quantity and type)

a.—Cement

b.—Fine aggregates

c.—Coarse aggregates

d.—Water

e.—Water/cement ratio

f.—Latex emulsion

g.—Latex emulsion/cubic yard of concrete

h.—Other admixtures

10.—Weather data

a.—Air temperatures

b.—Weather

c.—Wind speed

11.—Field test data

a.—Date, time, and place of test

b.—Slump
c.—Air content
d.—Unit weight
e.—Concrete temperature
12.—Compressive test data
a.—Cylinder number
b.—Age of concrete when tested
c.—Date and time of cylinder test
d.—Curing time (field and laboratory)
e.—Compressive strength
g.—Type of break

1.05 SUBMITTALS

A.—Submittals shall be in accordance with requirements of the specifications.

B.—Before beginning patching or overlay operations, the contractor shall submit to the engineer a mix design reviewed by a representative of the latex manufacturer. Include the following information for each concrete mix design:

1.—Submittals shall be in accordance with requirements of the specifications.

2.—Before beginning patching or overlay operations, the contractor shall submit to the engineer a mix design reviewed by a representative of the latex manufacturer. Include the following information for each concrete mix design:

a.—Method used to determine the proposed mix design (ACI 301, article 3.9).
b.—Gradation of fine and coarse aggregates—ASTM C33.
c.—Proportions of all ingredients, including all admixtures added either at the time of batching or at the job site.
d.—Water-cement ratio.
e.—Slump—ASTM C143.
f.—Certification of the chloride content of admixtures.
g.—Air content: Of freshly mixed concrete by pressure method, ASTM C173.
h.—Unit weight of concrete—ASTM C138.
i.—Strength at 3, 7, and 28 days—ASTM C39.
j.—Chloride ion content of the concrete.

PART 2 PRODUCTS

2.01 MATERIALS

A.—Portland cement shall be type 1, ASTM C150 non-air-entraining.

B.—Latex emulsion shall be:

1.—"Dow Modifier A," Dow Chemical Company of Midland, Mich.
2.—Dylex 1186 as manufactured by Polysar, Incorporated, Chattanooga, Tenn.
3.—Approved equivalent used in accordance with the manufacturer's recommendations.

C.—Concrete aggregates for all concrete work exposed to the weather shall be gravel or crushed limestone, containing a maximum of 2% clay lumps; friable particles and chert shall not exceed 3% in accordance with ASTM C33, class designation 5S. All other concrete aggregates shall be in accordance with ASTM C33. Aggregates not meeting the requirements of ASTM C33 may be used only upon written approval from the engineer who will require additional information and data.
1.—Concrete fine aggregate shall be natural sand conforming to ASTM C33 and having the preferred grading shown for normal weight aggregate in ACI 302.1R, Table 4.2.1.
2.—Concrete coarse aggregate shall be nominal size as indicated below and as specified by ASTM C33, Table 2:
a.—3/8 in. for patch cavities 3/4 to 1½ in. deep.
b.—½ in. for patch cavities greater than 1½ in. deep and overlays.
3.—Concrete shall be produced using an approximate 1:1 ratio by volume of fine and coarse aggregates listed above.

2.02 MIX DESIGN

A.—The selection of concrete proportions shall be in accordance with ACI 301, article 3.9. Before any concrete is placed for the project, the contractor shall submit to the engineer data showing the method used for determining the proposed concrete mix design, including fine and coarse aggregate gradations, proportions of all ingredients, water-cement ratio, slump, air content, 28-day cylinder breaks, and other required data for each different concrete type specified. The mix design shall meet the following minimum requirements:

Mix Design Requirements

Compressive strengths	4500 psi at 28 days 2500 psi at 3 days
Water-cement ratio	0.25–0.40
Latex content per sack of cement	3½ gal
Slump	4 in. ± 2 in.
Minimum cement content	658 lb/cu yd
Air content	4–8%

B.—For concrete placed and finished by vibrating screeds the slump shall be limited to 4 in.

C.—The water-soluble chloride ion content of the concrete shall not exceed 0.15% by weight of cement in the mix; perform test to determine chloride content of concrete in accordance with AASHTO Test Method T260.

D.—Bonding grout: The bonding grout shall consist of a sand, cement, and latex emulsion in proportions similar to the mortar in the concrete with sufficient water to form a stiff slurry to achieve the consistence of "pancake batter."

PART 3 EXECUTION

3.01 PRODUCTION OF MORTAR OR CONCRETE

A.—Production of latex-modified mortar or concrete shall be in accordance with requirements of ACI 301, Chapter 7, except as otherwise specified herein.

B.—Concrete shall be produced by on-site volumetric batching done in accordance with requirements of ASTM C685.

C.—On-site mortar or concrete batching in a mixer of a least 1/3 cu yd capacity shall be permitted only with approval of the engineer. On-site concrete batching and mixing shall comply with requirements of ACI 301, Chapter 7.

3.02 PREPARATION (PATCH AND OVERLAY INSTALLATION—FLATWORK)

A.—Cavity surfaces shall be clean and dry prior to beginning of patch or overlay installation. Preparation of surfaces to receive new concrete shall be in accordance with the requirements of the specification.

B.—Bonding grout shall be applied to a damp (but not saturated) concrete surface in uniform thickness of ¹⁄₁₆ to ⅛ in. over all surfaces to receive patching or overlay. Grout shall not be allowed to dry or dust prior to placement of patch or overlay material. If concrete placement is delayed and the coating dries, the cavity or surface shall not be patched or overlaid until it has been recleaned and prepared as specified in section 02530. Grout shall not be applied to more area than can be patched or overlaid with ½ hr by available manpower.

3.03 PLACING AND FINISHING

A.—Do not place concrete when the temperature of the surrounding patch area or the air is less than 50°F or when mix temperature is above 85°F unless the following conditions are met:

1.—Place concrete only when the temperature of the surrounding air is expected to be above 45°F for at least 36 hr.
2.—When the above conditions are not met, concrete may be placed only if insulation or heating enclosures are provided in accordance with ACI 306, "Recommended Practice for Cold Weather Concreting," and are approved by the engineer.
3.—When air temperature exceeds 80°F or any combination of high temperature, low humidity, and high-wind velocity, which causes rate of evaporation in excess of 0.10 lb/sq ft/hr as determined by Figure 2.1.5 in ACI 305 R, "Hot Weather Concreting," requirements shall be met.

B.—The concrete shall be manipulated and struck off slightly above final grade. The concrete shall then be consolidated and finished to final grade with surface vibration devices. Consolidation equipment used shall be approved by the engineer.

C.—Fresh concrete 3 in. or more in thickness shall be vibrated internally in addition to surface vibration.

D.—For overlays the vibrating device shall consist of vibrating screeds meeting the following requirements:

1.—Placing and finishing equipment shall not exceed a maximum weight of 6000 or 3000 lb per axle.
2.—The screed shall be designed to consolidate the concrete to 98% of the unit weight determined in accordance with ASTM C 138 . A sufficient number of identical vibrators is provided for each 5 ft of the screed length.
3.—The bottom face of screeds shall not be less than 4 in. wide and shall be metal covered with turned up or rounded leading edge to minimize tearing of the surface of the plastic concrete.
4.—The screed shall be capable of forward and reverse movement under positive control. The screed shall be provided with positive control of vertical position and angle of tilt.
5.—The screed shall be capable of vibrating at controlled rate, adjustable to between 3000 and 6000 vpm.

E.—Concrete shall be deposited as close to its final position as possible. All concrete shall be placed in continuous operation and terminated only at bulkheads or a designated control joint.

F.—On ramps with greater than 5% slope, all concreting shall begin at the low point and end at the high point. The contractor shall make any necessary adjustment to slump or equipment to provide a wearing surface without any irregularities or roughness.

G.—When a tight uniform concrete surface has been achieved by the screeding and finishing operation, the surface shall be textures using a coarse broom, as approved by the engineer from sample panels.

H.—Brooming shall not tear out or loosen particles of coarse aggregate. Finishing tolerance: ACI 301, paragraph 11.9; class B tolerance.

I.—Finish all concrete slabs to proper elevations to ensure that all surface moisture will drain freely to floor drains, and that no puddle areas exist. The contractor shall bear the cost of any corrections to provide for positive drainage.

3.04 CURING

Latex-modified mortar and concrete shall be cured according to the latex manufacturer's recommendations and according to the following minimum requirements:

A.—The surface shall be covered with a single layer of clean, wet burlap as soon as the surface will support it without deformation. Cover the burlap with a continuous single thickness of polyethylene film for 24 hr.

B.—After 24 hr remove the polyethylene film and allow the burlap to dry slowly for an additional 24–48 hr.

C.—Remove the burlap and allow the concrete to air dry for an additional 48 hr.

D.—Curing time shall be extended, as the engineer directs, when the curing temperature falls below 50°F.

E.—If shrinkage cracks appear in the overlay when the initial 24-hr curing period is completed, the overlay shall be considered defective, and it shall be removed and replaced by the contractor at no extra cost.

3.05 FIELD QUALITY CONTROL

A.—Mortar and concrete cylinders 3 in. in diameter by 6 in. long will be fabricated, cured, and tested in accordance with ACI 301 except as noted in this specification. Six cylinders will be made for each 10 cu yd of mortar prepared or each day's concrete pour, whichever is less. Cylinders shall be field cured for 3 days, two at 7 days and two at 28 days. Compressive strength at 3 days shall be 2000 psi minimum. Two additional cylinders shall be fabricated for reach 20 cu yd of concrete produced. These shall be field-cured until needed.

B.—The patch and overlay areas shall be sounded by the contractor with a chain drag after curing for 7 days. The contractor shall repair all hollowness detected by removing and replacing the patch or affected area at no extra cost to the owner.

APPENDIX 15-3

SAMPLE SPECIFICATION FOR MICROSILICA CONCRETE FOR PATCHING OR OVERLAY

1.01 WORK INCLUDED

This work consists of providing all materials, labor, equipment and supervision to furnish and install cast-in-place microsilica concrete overlay.

1.02 RELATED WORK

The following work is directly related to, included in, and coordinated with placement of silica modified concrete patch on overlay.

A.—Surface preparation for patching
B.—Surface preparation for overlay
C.—Concrete reinforcement
D.—Concrete accessories
E.—Concrete curing
F.—Waterproofing system
G.—Sealants and caulking
H.—Pavement marking

1.03 QUALITY ASSURANCE

A.—Work shall conform to requirements of ACI 301 and ACI 318 except where more stringent requirements are shown on Drawings or specified in this Section.

B.—Testing Agency:

- **1.**—Independent testing laboratory employed by Owner and acceptable to Engineers.
- **2.**—Accredited by AASHTO under ASTM C1077. Testing laboratory shall submit documented proof of ability to perform required tests.

C.—Sampling and testing of concrete shall be performed by ACI certified Concrete Field Technicians Grade I. Certification shall be no more than three years old.

D.—Testing Agency is responsible for conducting, monitoring, and reporting results of all tests required under this Section. Testing Agency has authority to reject concrete not meeting Specifications.

E.—Proportioning, production, placement, and finishing of microsilica concrete shall be reviewed by, and have approval of, microsilica manufacturer.

F.—Microsilica admixture supplier must make available qualified individual, experienced in placement of microsilica concrete, to aid Contractor. Qualification of supplier's representative shall be acceptable to Engineer. Supplier's representative must attend preconstruction meeting and must be present for all trial placements, initial startup and then as required by Engineer.

G.—Submit following information for field testing of concrete unless modified in writing by Engineer:

1.—Project name and location
2.—Contractor's name
3.—Testing Agency's name, address, and phone number
4.—Concrete supplier
5.—Date of report
6.—Testing Agency technician's name (sampling and testing)
7.—Placement location within structure
8.—Elapsed time from batching at plant to discharge from truck at site
9.—Concrete mix data (quantity and type)
  a.—Cement
  b.—Fine aggregates at SSD
  c.—Coarse aggregates at SSD
  d.—Water
  e.—Water/cementitious material ratio
  f.—Air-entraining admixtures
  g.—Water-reducing admixture and high-range water-reducing admixture
  h.—Microsilica admixtures
  i.—Other admixtures
10.—Weather data
  a.—Air temperatures
  b.—Weather
  c.—Wind speed
  d.—Relative humidity
11.—Field test data
  a.—Date, time, and place of test
  b.—Slump
  c.—Air content
  d.—Unit weight
  e.—Concrete temperature
12.—Compressive strength test data
  a.—Cylinder number
  b.—Age of concrete when tested
  c.—Date and time of cylinder test

- **d.**—Curing time (field and lab)
- **e.**—Compressive strength
- **f.**—Type of break

13.—Rapid chloride permeability test results

1.04 REFERENCES

A.—American Concrete Institute (ACI)

- **1.**—ACI 214, "Recommended Practice for Evaluation of Strength Test Results of Concrete"
- **2.**—ACI 301, "Specifications for Structural Concrete for Buildings"
- **3.**—ACI 302.1R, "Guide for Concrete Floor and Slab Construction"
- **4.**—ACI 305R, "Hot Weather Concreting"
- **5.**—ACI 306R, "Cold Weather Concreting"
- **6.**—ACI 306.1, "Standard Specification for Cold Weather Concreting"
- **7.**—ACI 308, "Standard Practice for Curing Concrete"
- **8.**—ACU 318, "Building Code REQUIREMENTS for Reinforced Concrete"
- **9.**—ACI 347, "Recommended Practice for Concrete Formwork"

B.—American Society for Testing and Materials (ASTM)

- **1.**—ASTM C31, "Method of Making and Curing Concrete Test Specimens in the Field"
- **2.**—ASTM C33, "Specification for Concrete Aggregates"
- **3.**—ASTM C39, "Test Method for Compressive Strength of Cylindrical Concrete Specimens"
- **4.**—ASTM C94, "Specification for Ready-Mixed Concrete"
- **5.**—ASTM C109, "Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 20in. or 50-mm Cube Specimens)"
- **6.**—ASTM C138, "Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete"
- **7.**—ASTM C143, "Test Method for Slump of Portland Cement Concrete"
- **8.**—ASTM C150, "Specification for Portland Cement"
- **9.**—ASTM C172, "Method of Sampling Freshly Mixed Concrete"
- **10.**—ASTM C173, "Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method"
- **11.**—ASTM C231, "Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method"
- **12.**—ASTM C260, "Specification for Air-Entraining Admixtures for Concrete"
- **13.**—ASTM C457, "Practice for Microscopical Determination of Air-Void Content and Parameters of the Air-Void System in Hardened Concrete"
- **14.**—ASTM C494, "Specification for Chemical Admixtures for Concrete"

15.—ASTM C666, "Test for Resistance of Concrete to Rapid Freezing and Thawing"
16.—ASTM C685, "Specification for Concrete Made by Volumetric Batching and Continuous Mixing"
17.—ASTM C1040, "Standard Test Method for Density of Unhardened and Hardened Concrete by Nuclear Methods"
18.—ASTM C1077, "Standard Practice for Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation"
19.—ASTM C1116, "Standard Specification for Fiber-Reinforced Concrete and Shotcrete"
20.—ASTM C1202, "Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration"
21.—ASTM C1240, "Standard Specification for Silica Fume for Use in Hydraulic-Cement Concrete and Mortar"

C.—AASHTO
1.—AASHTO Method T260

D.—Concrete Reinforcing Steel Institute (CRSI)
1.—CRSI MSP, "Manual of Standard Practice"

E.—Contractor shall have following ACI publications at Project construction site:
1.—ACI SP-15, "Specifications for Structural Concrete for Buildings ACI 301-84 (Revised 1988) with selected ACI and ASTM References"
2.—ACI 302.1R, "Guide for Concrete Floor and Slab Construction"

1.05 SUBMITTALS

A.—Make submittals in accordance with requirements of this Specification, and as herein specified.

B.—Submit mix designs as defined in ACI 301 article 3.9. Mix design shall be reviewed by microsilica manufacturer prior to submitting to Engineer. Include following information for reach concrete mix design:
1.—Method used to determine proposed mix design (per ACI 301 Article 3.9)
2.—Gradation of fine and coarse aggregates: ASTM C33
3.—Proportions of all ingredients including all admixtures added either at time of batching and at job site
4.—Water/cementitious material ratio
5.—Slump: ASTM C143
6.—Certification of chloride content of admixtures
7.—Rapid chloride permeability test results
8.—Air content
a.—Of freshly mixed concrete by pressure method, ASTM C231, or volumetric method, ASTM C173

b.—Of hardened concrete by microscopical determination, including parameters of air-void system, ASTM C457

9.—Unit weight of concrete, ASTM C138

10.—Strength at 7 and 28 days, ASTM C39

11.—Water-soluble chloride ion content of concrete per AASHTO method T260

12.—Mill Test Report of Silica Fume Admixture: Provide report for each 400 cu yd or fraction thereof, of concrete placed on project. Provide to Engineer from independent testing lab showing chemical analysis in percent by weight of silica fume solids supplied and used.

a.—Silica fume concrete admixture: Shall comply with ASTM C1240 and following additional requirements:

1)—Silicon dioxide content: 90% minimum

2)—LOI: 6% maximum

C.—Contractor shall submit the following:

1.—Microsilica concrete mix proportions and batching, transporting, handling, placing, finish, and curing procedures

2.—Procedures to protect fresh concrete from rain and hot and cold weather conditions

D.—Testing Agency shall submit the following:

1.—Unit weight of concrete, ASTM C138

2.—Slump, ASTM C143

3.—Air content of freshly mixed concrete by pressure method, ASTM C231, or volumetric method, ASTM C173

4.—Air content and parameters of air-void system by microscopical determination, ASTM C457

5.—Concrete temperature (at placement time)

6.—Air temperature (at placement time)

7.—Strength determined in accordance with ASTM C39 at 7 and 28 days

8.—Rapid chloride permeability test of core samples in accordance with Test Method ASTM C1202, as and when directed by Specifications

9.—Freeze-thaw resistance, ASTM C457 and C666: If concrete cannot meet hardened air content requirements, submit laboratory results of specimens with concrete mix similar to proposed mix for project. Report air void parameters (spacing factor and specific surface area) of specimens with concrete mix similar to proposed mix for project. Report air void parameters (spacing factor and specific surface ares) of specimens in accordance with ASTM C457. Test specimens shall contain specified entrained air content, silica fume admixture and superplasticizer.

PART 2 PRODUCTS

2.01 AGGREGATES

A.—General

1.—Coarse aggregates for all concrete work exposed to the weather shall be gravel or crushed limestone containing a minimum 2% clay lumps; friable particles, and the sum of clay lumps, friable particles, and chert shall not exceed 3% in accordance with ASTM C33, Class Designation 5S.

2.—All other concrete aggregates shall meet requirements of ASTM C33 and additional requirements as specified in this section.

3.—Aggregates not meeting the requirements of ASTM C33 may be used only upon written approval from the engineer who will require additional information and data.

B.—Coarse aggregates

1.—Concrete coarse aggregates shall meet gradation requirements as specified by ASTM C33, Table 2.

2.—Coarse aggregate shall be nominal maximum size as indicated below:

a.—⅜ in. for patch cavities ¾ to 1½ in. deep.

b.—½ in. for patch cavities greater than 1½ in. deep and for overlay work. Maximum size of aggregate shall be limited to one-third the thickness of the patch or overlay. Also use the largest practical size aggregate to minimize shrink-related concrete cracking.

C.—Fine aggregates: Fine aggregates shall be natural sand conforming to ASTM C33 with respect to soundness and control of deleterious materials. Gradation shall be as shown for normal weight aggregates in ACI 302.1R, Table 4.2.1.

2.02 CEMENT (ACI 301, ARTICLE 2.1). Use one brand throughout the project.

2.03 WATER (ACI 301, ARTICLE 2.3)

A.—Mixing water for concrete shall meet requirements of ASTM C94.

2.04 ADMIXTURES (ACI 301, ARTICLE 2.2)

1.—Microsilica admixture shall be:

a.—"FORCE 10,000" or "EMSAC," by W. R. Grace & Co., Cambridge, MA.

b.—"MB-SF Slurry," Master Builders, Cleveland, OH.

c.—Use of dry densified silica fume product is not acceptable unless approved in writing by Engineers.

2.—Use of any admixtures must be approved in writing by Engineer prior to its use.
3.—Use approved admixtures in strict accordance with manufacturer's recommendations.
4.—Air entraining admixture—ASTM C260.
5.—Prohibited Admixtures: Calcium chloride, thiocyanates or admixtures containing more than 1% chloride ions, by weight of admixture, are *not* permitted. Additionally, each admixture shall not contribute more than 5 ppm, by weight, of chloride ions to total concrete constituents.
6.—Water-reducing admixtures: ASTM C494, type A.
7.—High-range, water-reducing admixture (superplasticizer):
- **a.**—ASTM C494, type F or G.
- **b.**—Use shall not change requirements for:
  - **1)**—Maximum water/cement ratios
  - **2)**—Concrete strength
  - **3)**—Air content of placed concrete
  - **4)**—Minimum cement content

8.—Non-corrosive, non-chloride accelerator
- **a.**—ASTM C494, type C or E
- **b.**—Admixture manufacturer must have long-term non-corrosive test data from an independent testing laboratory (of at least a year's duration) using an acceptable accelerated corrosion test method such as that using electrical potential measures.

2.05 STORAGE OF MATERIALS (ACI 301, ARTICLE 2.5)

2.06 (NOT USED)

2.07 CONCRETE MIX DESIGN (ACI 318, CHAPTER 4)

A.—Selection of concrete proportions shall be in accordance with ACI 301, article 3.8. Mix design shall meet following minimum requirements:

Mix Design Requirements

Compressive strength (28 days)	6000 psi
Water/(cement + silica fume) ratio	0.35–0.40
Microsilica content	7½% by wt of cement
Slump (maximum)*	6″
Cement content	610 lb/cu yd
Maximum size of aggregate	¾″
Air content	7½% ± 2%

*For consolidation with vibratory screeds, concrete slump at point of placement shall be limited to 4 inches maximum.

B.—When desired mix properties are achieved, two 12″ × 12″ × 4″ slabs shall be prepared for each mix design drilling four 4″ diameter cores. Drilled cores shall be tested for rapid chloride permeability in accordance with Test Method ASTM C1202. Slab shall be moist cured for 28 days and cores removed and kept at 50% relative humidity until testing at 35 to 42 days. Concrete mix design submitted shall have average chloride permeability result of less than 800 coulombs for four cores tested, with no single test result exceeding 1000 coulombs.

C.—Target value for air entrainment

1.—Hardened concrete shall have air void system spacing factor of 0.0080 in. maximum as determined by ASTM C457. For concrete with higher than 0.0080 in. spacing factor, additional laboratory test data acceptable to Engineer must be provided to verify that concrete mixture is durable for intended use when subjected to freezing and thawing.

D.—All concrete containing high-range water-reducing admixture (superplasticizer) shall have 6″ maximum placement slump with range 4½″ ± 1½″. Concrete shall arrive at job site at 4″ maximum slump, be verified, then high-range water-reducing admixture added to increase slump to approved level of placement.

E.—Bonding grout shall consist of sand, cement, and microsilica in proportions similar to mortar in concrete to form stiff slurry. Consistency shall be such that it can be applied to old concrete in thin, even coat using stiff broom or brush without running or puddling.

PART 3 EXECUTION

3.01 PRODUCTION OF CONCRETE (ACI 301, CHAPTER 7)

A.—Concrete shall be produced by on-site volumetric batching or ready-mixed concrete batched at Contractor's option.

B.—Proportioning and mixing equipment

1.—Silica modified concrete, mixed at site, shall be proportioned by continuous mixer used in conjunction with volumetric proportioning. Volumetric batching/continuous mixers shall conform to ASTM C685. In addition, self-continuous mixers shall conform to ASTM C685. In addition, self contained mobile, continuous type mixing equipment shall comply with the following:

a.—Mixer shall be capable of producing batches of not less than 6 cubic yards.

b.—Mixer shall be capable of positive measurement of cement being introduced into mix. Recording meter visible at all times and equipped with ticket printout shall indicate this quantity.

c.—Mixer shall provide positive control of flow of water into mixing chamber. Water flow shall be indicated by flowmeter and shall be readily adjustable to provide for minor variations in aggregate moisture.

d.—Mixer shall be capable of being calibrated to automatically proportion and blend all components of indicated composition on continuous or intermittent basis, as required by finishing operation, and shall discharge mixed material through conventional chute into transporting device or directly in front of finishing machine. Sufficient mixing capacity or mixers shall be provided to permit intended pour to be placed without interruption.

e.—Mixer shall be calibrated to accurately proportion specified mix. Yield is required to be within tolerance of 1.0%.

C.—At Contractor's option, silica modified concrete may be ready-mixed concrete batched, mixed and transported in accordance with ASTM C94. In addition, following requirements shall also apply:

1.—Volume of concrete in truck mixer shall not exceed 63% of total volume of drum.

2.—No water shall be added to concrete batch at site. Addition of high-range water reducers (superplasticizer) at site shall be as directed by concrete manufacturer and approved by microsilica manufacturer. Truck shall be equipped with admixture dispenser or other auxiliary dispensing equipment, capable of adjustment for variation of dosage, calibration and accurate measurement.

3.—Sequence and method of charging mixer shall be as recommended and approved by microsilica manufacturer. Engineer may request mixer evaluation as specified in ASTM C94 to verify uniformity of concrete mix.

D.—Placing and finishing equipment

1.—Placing and finishing equipment shall include adequate mechanized and hand tools for placement of plastic concrete and for working down to approximately correct grade for striking off with vibrating screed.

3.02 TRANSPORTATION AND DISCHARGE

A.—Concrete transported by truck mixer or agitator shall be completely discharged within 1 hour after water has been added to the cement or cement has been added to the aggregates. During hot weather concreting, the discharge time shall be limited to 45 min. The discharge time shall not be extended without written approval from the Engineer.

3.03 PREPARATION

A.—Cavity surfaces shall be clean and dry prior to commencement of overlay installation. Preparation of surfaces to receive new concrete shall be in accordance with project specification.

B.—Bonding grout

1.—Bonding grout shall be applied to damp (but not saturated) concrete surfaces and cavities on floor. Slurry shall be applied to all surfaces to receive overlay. Apply grout evenly to uniform thickness 1⁄16″ to 1⁄8″ throughout. Grout shall not be allowed to dry or dust prior to placement of overlay material.

2.—If overlayment is delayed and coat of grout dries, surface shall not be patched until it has been recleaned and prepared as specified in section 02030. Grout shall not be applied to more surface area than can be overlaid within ½ hour by available manpower.

C.—Receive Owner's and Engineer's written approval of concrete surface finish used on flatwork before beginning construction.

3.04 INSTALLATION

A.—Placing (ACI 301, Chapter 8)

1.—Do not place concrete when temperature of surrounding concrete or air is less than 50°F. unless following conditions are met:

a.—Place concrete only when temperature of surrounding air is expected to be above 45°F for at least 36 hours.

b.—When above conditions are not met, concrete may be placed only if insulation or heating enclosures are provided in accordance with ACI 306, "Recommended Practice for Cold Weather Concreting." Submit proposed protective measures in writing for Engineer's review prior to concrete placement.

c.—Costs for precautionary measures required shall be borne by Contractor.

2.—For hot weather concrete placements, the following conditions shall apply:

a.—Do not place concrete if mix temperature exceeds 90°F.

b.—Do not place concrete under hot weather conditions. Hot weather is defined as air temperature which exceeds 80°F. or any combination of high temperature, low humidity and high wind velocity which causes evaporation rate in excess of 0.10 pounds per square foot per hour as determined by ACI 305R, Figure 2.1.5.

3.—Concrete shall be manipulated and struck off slightly above final grade. Concrete shall then be consolidated and finished to final grade with internal and surface vibration devices. Proposed consolidation method used shall be submitted for Engineer's review prior to concrete placement.

4.—Fresh concrete 3 inches or more in thickness shall be vibrated internally in addition to surface vibration.

5.—For overlays, vibrating device shall consist of vibrating screeds meeting following requirements:

a.—Placing and finishing equipment shall not exceed maximum weight of 6000 pounds or 3000 pounds per axle.

b.—Screed shall be designed to consolidate concrete to 98% of unit weight determined in accordance with ASTM C138. Sufficient number of identical vibrators shall be effectively installed such that at least one vibrator is provided for each 5 feet of screed length.

c.—Bottom face of screeds shall not be less than 4 inches wide and shall be metal covered with turned up or rounded leading edge to minimize tearing of surface of plastic concrete.

d.—Screed shall be capable of forward and reverse movement under positive control. Screed shall be provided with positive control of vertical position and angle of tilt.

e.—Screed shall be capable of vibrating at controlled rate, adjustable to between 3000 to 6000 vpm.

6.—Concrete shall be deposited as close to its final position as possible. All concrete shall be placed in continuous operation and terminated only at bulkheads or designated control or construction joints.

7.—On ramps with greater than 5% slope, all concreting shall begin at low point and end at high point. Contractor shall make any necessary adjustment to slump or equipment to provide wearing surface without any irregularities or roughness.

B.—Finishing (ACI 301, Chapters 10 and 11)

1.—Flatwork (Broom Finish ACI 301, 11.7.4)

a.—All flatwork finishers shall hold current ACI Concrete Flatwork Finishers certification.

b.—Contractor shall adequately protect concrete surfaces after concrete placement and between initial and final finishing operations to minimize moisture loss from surface by misting and use of approved evaporation retardant. Protection materials and equipment must be in place, ready to use, prior to beginning of placement.

1)—No spraying of water directly on flatwork will be allowed. Fogging is not to be used to lubricate surface for finishing purposes.

2)—Fogging shall continue after finishing operation until covered by wet burlap cure.

c.—Screed and bullfloat surface of concrete to desired elevation.

d.—Immediately after bullfloating, give slab surfaces coarse transverse scored texture by drawing broom across surface. Texture shall be as approved by Owner and Engineer from sample panels.

e.—Other finishing operations may be accepted by Owner and

Engineer based on demonstration of procedures with sample panels.

f.—Finishing tolerance: ACI 301, paragraph 11.9: class B tolerance.

g.—Before installation of overlay and after submittal, review, and approval of concrete mix design, Contractor shall fabricate two acceptable test panels simulating finishing techniques and final appearance to be expected and used on Project.

h.—Finish all concrete slabs to proper elevations to insure that all surface moisture will drain freely to floor drains, and that no puddle areas exist. Contractor shall bear cost of any corrections to provide for positive drainage.

C.—Joints in concrete (ACI 301, Chapter 6)

1.—Construction, control, and isolation joints are located and detailed on Drawings:

a.—Tool joints at time of finishing. Saw-cut joints are prohibited.

b.—Isolation joints—interrupt structural continuity resulting from bond, reinforcement, or keyway.

D.—Curing

1.—Microsilica concrete shall be cured to meet following requirements:

a.—Surface shall be covered with single layer of clean, wet burlap as soon as surface will support it without deformation. Cover burlap with continuous single thickness of 4 mil polyethylene film. Maintain burlap in moist condition for 7 days.

b.—Curing time shall be extended, as Engineer directs, when curing temperature falls below 50°F.

c.—Curing compounds are prohibited.

d.—Protect microsilica concrete from surface drying and plastic shrinkage by:

1)—Continuous water fogging over slab area between finishing operations.

2)—Use of evaporative retardants immediately after screeding in accordance with manufacturer's recommendations.

E.—Repair of surface defects (ACI 301, Chapter 9)

1.—Repair all defects exceeding ¼ inch width or depth.

2.—Match color of concrete to be repaired.

3.—Submit samples of materials and relevant literature and test data on proprietary compounds used for adhesion or patching ingredients to Engineer for his review before patching concrete.

4.—Receive written approval of Engineer of method and materials prior to making repairs to concrete.

3.05 FIELD QUALITY CONTROL BY TESTING AGENCY (ACI 301, CHAPTER 16)

A.—Air content

1.—Sample freshly-mixed concrete per ASTM C172 and conduct one air content test per ASTM C231 or ASTM C173 for each truck of ready-mix, air-entrained concrete delivered to Project. For concrete produced on site by volumetric batching and continuous mixing, air content test shall be conducted for every 10 cu yd of concrete produced.

2.—Sample fresh concrete immediately following placement and screeding and conduct air content tests per ASTM C231 or ASTM C173 at rate of one per every 10 truck loads of ready-mix, air-entrained concrete delivered to Project. For concrete produced on site by volumetric batching and continuous mixing, air content test shall be performed for every 100 cu yd of concrete produced.

3.—Core and test hardened concrete topping for air content per ASTM C457 at rate of one core per 15,000 square feet of topping or structural slab, unless directed otherwise by Engineer.

B.—Compressive strength

1.—Mold test cylinders in accordance with ASTM C31 as follows:

a.—Take minimum of six cylinders for each 30 cubic yards, or fraction thereof, of each mix design of concrete placed in any one day. Use of 4″ × 8″ cylinders in lieu of standard cylinders is acceptable.

b.—Additional two cylinders shall be taken under conditions of cold weather concreting, and when directed by Engineer.

2.—Sample plastic concrete for testing, at point where it is finally placed, in accordance with ASTM C172-82. Prior to placement, Engineer will select sampling locations which may include points where plastic concrete has already been screeded and floated.

3.—Cure test cylinders per ASTM C31 as follows:

a.—To verify compressive strength of test cylinders required due to cold weather concreting conditions:

1)—Store test specimens on structure as near to point of sampling as possible and protect from elements in same manner as that given to portion of structure as specimen represents.

2)—Transport to test laboratory no more than 4 hours before testing. Remove molds from specimens immediately before testing.

b.—To verify 28-day compressive strength:

1)—During first 24 hours after molding, store test specimens under conditions that maintain temperature immediately adjacent to specimens in range of 60 to 80°F. and prevent loss of moisture from specimens.

2)—Remove test specimens from molds at end of 20 ± 4 hours and store in moist condition at 73.4 ± 3°F until moment of test. Laboratory moist rooms shall meet requirements of ASTM C511.

4.—Compression tests

a.—Test 2 cylinders at 7 days.

b.—Test 2 cylinders at 28 days.

c.—Hold 2 cylinders in reserve for use as Engineer directs.

5.—Unless notified by Engineer, reserve cylinders may be discarded without being tested after 56 days.

C.—Slump test

1.—Conduct one slump test per truck load or 10 cubic yards of concrete delivered to Project.

2.—When high-range water-reducing admixture (superplasticizer) is added at job site, initial slump must be verified by Testing Agency.

D.—Chloride permeability

1.—Mold two 4-in.-diameter cylinders for every 20,000 square feet of overlay, unless directed otherwise by Engineer. Mold cylinders in accordance with ASTM C31.

2.—Cylinders shall be cured and tested in accordance with requirements stated in section 2.07.B and results reported to Engineer.

E.—Yield and proportioning tests (ASTM C685)

1.—When concrete placements involve more than 100 cubic yards, accuracy of on-site batching equipment output indicators shall be verified at 50 cubic yard intervals.

2.—Accuracy of on-site batching equipment proportioning of concrete mixture shall be verified at 100 cubic yard intervals.

F.—Evaluation and acceptance of concrete (ACI 301, Chapter 17, and ACI 318, article 4.7)

1.—Concrete compression tests will be evaluated by Engineer in accordance with ACI 301, Chapter 17. If number of tests conducted is inadequate for evaluation of concrete or test results for any type of concrete fail to meet specified strength requirements, core tests may be required as directed by Engineer. Air content and parameters of air-void system shall meet requirements of this section.

2.—Core tests, when required, per ACI 301, article 17.3.

3.—Should tested hardened concrete meet these specifications, Owner will pay for coring and testing of hardened concrete. Should tested hardened concrete not meet these specifications, concrete contractor will pay for coring and testing of hardened concrete and for any corrective action required for unaccepted concrete.

G.—Acceptance of structure (ACI 301, Chapter 18)

1.—Acceptance of completed concreted Work will be according to provisions of ACI 301, Chapter 18.

2.—Patched and overlaid areas shall be sounded by Contractor with chain drag after 7 days cure and any hollowness detected shall be corrected by removing and replacing unsound areas at no extra cost to Owner.

3.—If plastic or early drying shrinkage cracks appear in overlay within first 72 hours of curing period, overlay shall be considered defective. Contractor will remove and replace defective overlay at no extra cost.

4.—Concrete rejected due to entrained air content below specified limit will be accepted if any of following conditions are met:

a.—ASTM C457: Three concrete specimens tested in accordance with ASTM C457 meet specified air void parameters.

b.—ASTM C457: Three concrete specimens tested in accordance with ASTM C457 meet preapproved air void parameters of concrete.

c.—ASTM C666: Test three concrete specimens removed from structure.

APPENDIX 15-4

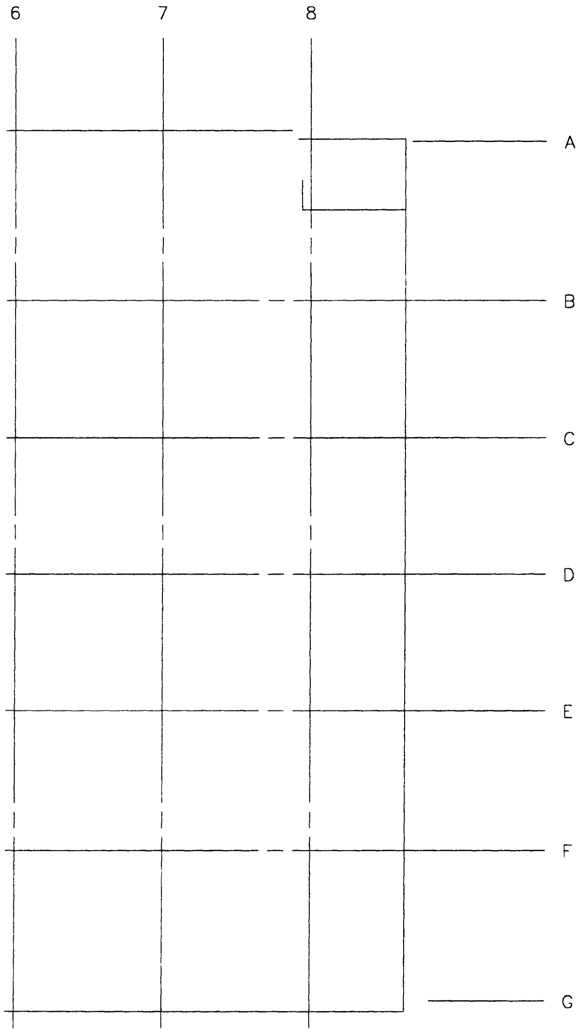


Figure A-1. Field survey blank sheet to record data (example 1).

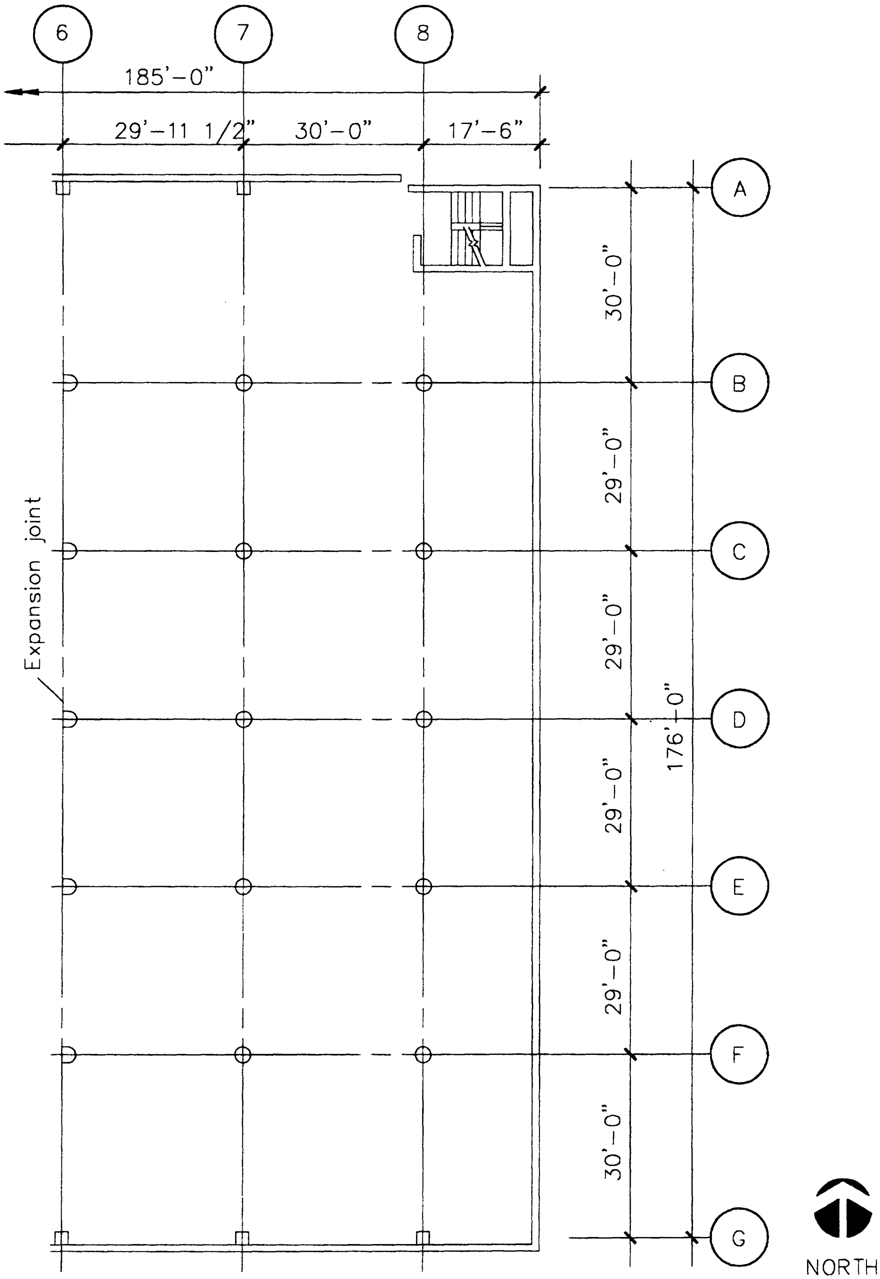


Figure A-2. Field survey blank sheet to record data (example 2).

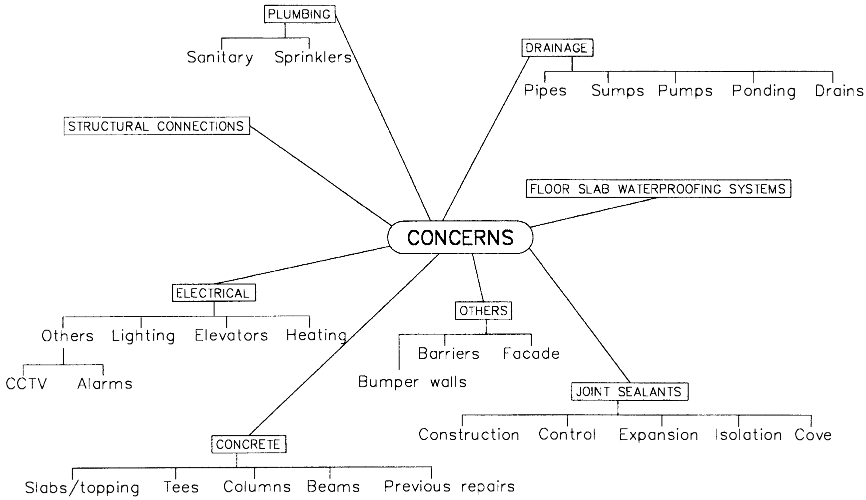


Figure A-3. Parking structure structural and operational elements.

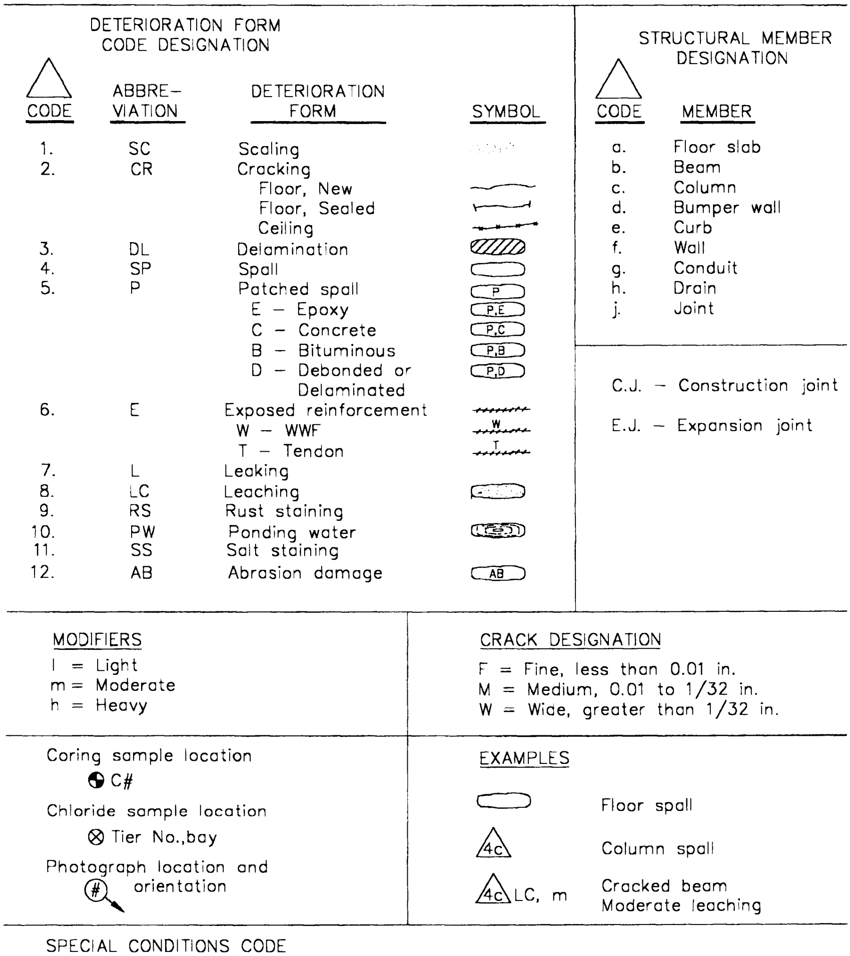


Figure A-4. Field survey legend.

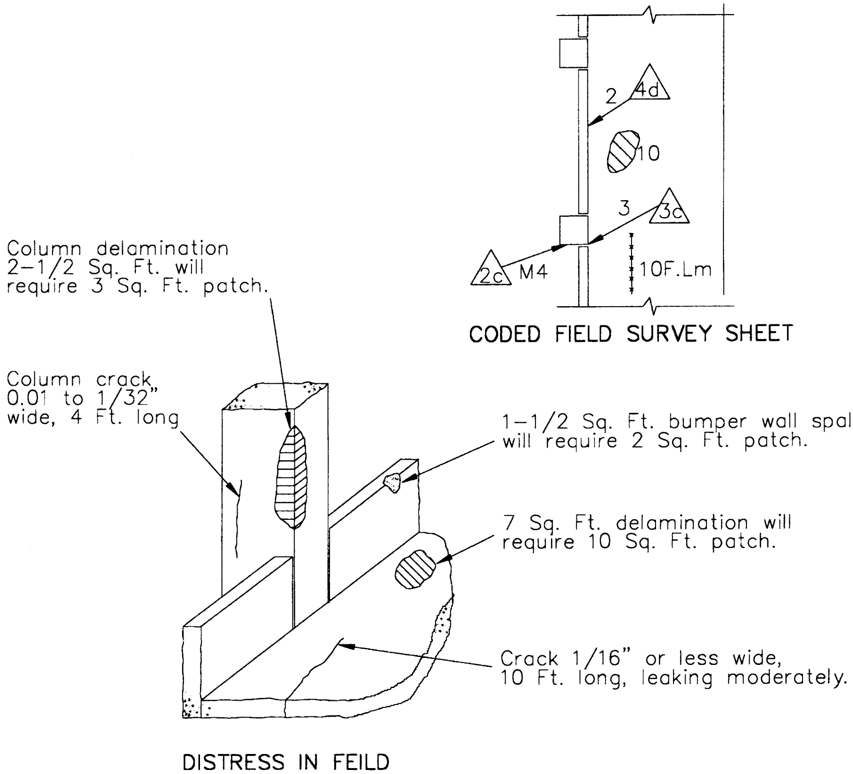


Figure A-5. Use of field survey legend to record data systematically.

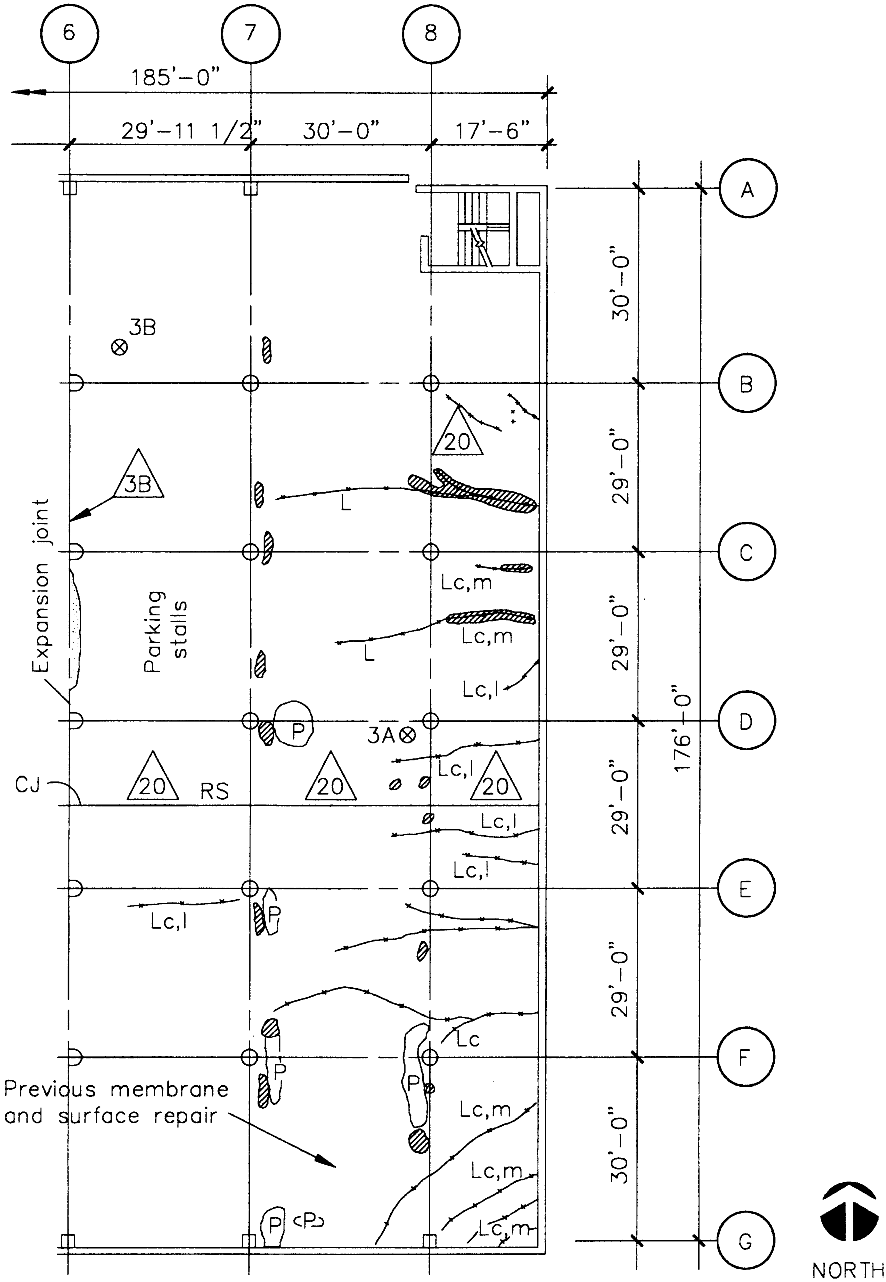


Figure A-6. Sample of data recorded on survey sheets.

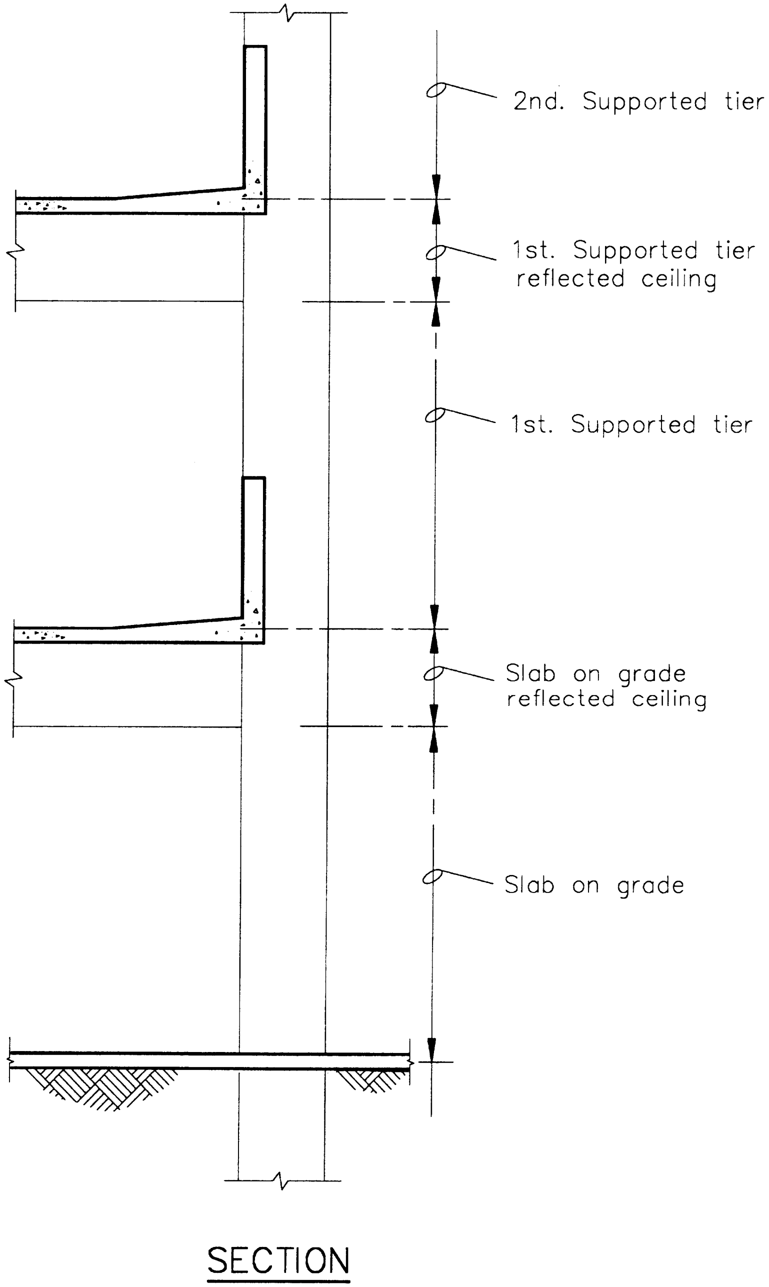


Figure A-7. Procedure for recording floor slab surface and ceiling distress.

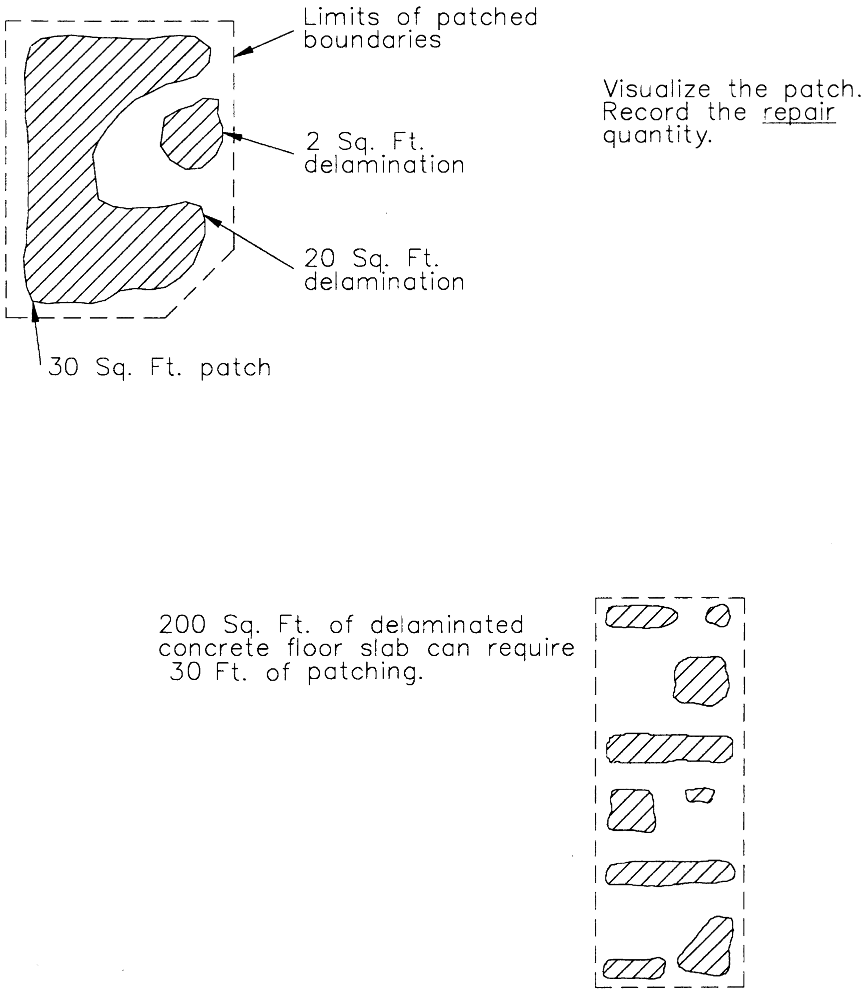


Figure A-8. Procedure for estimating and recording floor slab deterioration.

GLOSSARY

ABRASION RESISTANCE—Ability to resist being worn away by rubbing and friction.

ABRASIVE NOSING—A strip with a roughened surface cast in, or adhesive applied to, the edge of a stair step to provide traction and minimize slipping.

ACCESS DESIGN—The design of the connection points between the parking facility and the adjacent roadways or streets.

ACTIVE SECURITY—Measures or systems that promote good security by providing a means of alerting the management/employees of the facility to an incident in progress.

ARCHITECTURAL GRAPHICS—The integration of wayfinding messages into the physical design, including wall treatments, flags, banners, etc.

ADHESIVES—The group of materials used to join or bond similar or dissimilar materials—for example, in concrete work, the epoxy resins.

ADMIXTURE—Material other than water, aggregate, or cement used as an ingredient of concrete and added to concrete during mixing to modify the concrete properties.

AGGREGATE—Granular material, such as sand, gravel, or crushed stone, used with cement, water, and admixtures to form concrete.

AIR ENTRAINING—The capability of a material to develop a system of minute bubbles of air in concrete during mixing.

AIR-ENTRAINING AGENT—An admixture for concrete that causes entrained air to be incorporated into the concrete during mixing, usually to increase its workability and frost resistance.

AIR ENTRAINMENT—The inclusion of air in the form of minute bubbles (generally smaller than 1 mm) during the mixing of concrete.

ALKALI-AGGREGATE REACTION—Chemical reaction in mortar or concrete between hydroxyl associated with alkalies (sodium and potassium) from Portland cement or other sources and certain constituents of some aggregates; under certain conditions, deleterious expansion of the concrete or mortar may result.

ALKALI REACTIVITY (OF AGGREGATE)—Susceptibility of aggregate to alkali-aggregate reaction.

ANCHORAGE—In posttensioning, a device used to anchor a tendon to a concrete member. In pretensioning, a device used to anchor a tendon during hardening of the concrete.

ANGLED—Parking stalls not perpendicular to the driving aisle.

ANTIPASSBACK—Controls that prevent several users from sharing one card. The antipassback controls can be either *firm*, which reject the card outright when it is "out of mode," or *soft*, which open the gate but print out an error message for later action by management.

AUDIT TRAIL—Data in the memory of the fee computer or on the journal tape of a cash register that is used for auditing the cash revenues of the system.

AUTOGENOUS HEALING—A natural process of closing and filling of cracks in concrete or mortar when the concrete or mortar is kept damp.

AUTOMATED PAY STATION—A fully automated revenue collection machine similar to an automated teller machine (ATM).

AUTOMATIC VEHICLE IDENTIFICATION—A system that identifies individual vehicles through various technological means, including radio frequency transponders, laser reading of bar codes, etc.

BREAKOVER EFFECT—The tendency for vehicles to "bottom out" when a change in slope is too abrupt. See TRANSITION SLOPE.

BUFFER—A device that holds a task until the computer can process it.

CAMBER—Upward deflection intentionally built into a structural element or form to improve appearance or to nullify the deflection of the element under loads, shrinkage and creep. Camber may also be produced by prestressing.

CAPACITY—Used as a short form for either flow capacity or static capacity. The distinction will be determined by the context.

CARD READERS—A system allowing regular parkers to enter or exit. The readers decipher cards similar to credit cards and, if valid, send a signal to open the gate.

CAST-IN-PLACE CONCRETE—Concrete that is deposited in the place where it is required to harden as part of the structure, as opposed to precast concrete.

CCTV—Closed-Circuit Television. A system of television cameras, monitors, and other devices, connected by cable, carrying the signals only within the circuit.

CENTRAL FACILITY COMPUTER (CFC)—A computer that processes an FMS for one facility or a group of facilities.

CHALKING—Disintegration of coatings such as cement paint, manifested by the presence of loose powder evolved from the paint at, or just beneath, the surface.

CHARGE-COUPLED DEVICE (CCD)—A solid-state imaging sensor in which the television scanning function is accomplished by moving the video signal on a silicon chip.

CHECKING—Development of shallow cracks at closely spaced but irregular intervals on the surface of mortar or concrete.

CIRCULAR HELIX—See EXPRESS HELIX.

CLEARANCE BAR—A device set at the posted clearance height to warn drivers whose vehicles are too tall to drive through the parking facility. Due to bouncing and the BREAKOVER effect, the posted clearance must generally be 2 to 4 in. less than the minimum straight vertical clearance at any point.

COMMERCIAL FACILITIES—Under ADA, privately owned buildings where commerce occurs.

COMPUTERIZED COUNT CONTROLLER (CCC)—Generally a small microprocessor that replaces the electromechanical CONTROLLER MONITOR.

CONCRETE—Mixture of Portland cement, fine aggregate, coarse aggregate, and water, with or without admixtures.

CONTRACT DOCUMENTS—Project drawings and specifications.

CONTROLLER/MONITOR (CM)—A board that indicates the status of various peripherals (gate up, ticket supply low, etc.), the current occupancy (see DIFFERENTIAL COUNTER), and the various NON-RESETTABLE COUNTERS.

CORROSION—Disintegration or deterioration of concrete or reinforcement by electrolysis or by chemical attack.

CPU—Central Processing Unit, which is the brain of any computer.

CRACK COMPARATOR—A viewer capable of magnifying surface cracks with a graduated linear scale in the viewer, which assists in crack width measurements.

CRAZE CRACKS—Fine, random cracks or fissures caused by shrinkage which may appear in a surface of plaster, cement paste, mortar, or concrete.

CRAZING—The development of craze cracks; the pattern of craze cracks existing in a surface. (See also CHECKING.)

CREDIT CARD OPTION—On a machine-readable system, either card or ticket, a system to track usage and issue a monthly bill for parking charges in the prior period.

CROSSOVER—A route to go from an up thread to a down thread or vice versa.

DAILY FEE PARKER—A parker who pays the appropriate parking fee each time he or she visits the facility. In most cases, a new fee is charged with each visit, even with multiple visits on the same day. Also called TRANSIENT parker. Daily fee parkers can be either SHORT- or LONG-TERM parkers.

DATA MANAGEMENT or DATA BASE SOFTWARE—Handles the organization, storage, and retrieval of data. Allows the CPU to search for certain data events and patterns.

DEBIT CARD—A card similar to a credit card, but which deducts the amount from a checking account as soon as the transaction is reported to the bank. A debit card is essentially a paperless check.

DECLINATING—A prepaid system that subtracts the fees for each use until the prepaid amount is used up. It eliminates the need for cashiers for these users.

DECREMENTING—A prepaid system that allows a predetermined number of parking stays, regardless of the length of stay.

DEFLECTION—A variation in position or shape of a structure or element due to effects of loads or volume change, usually measured as a linear deviation from an established plane.

DEGRADATION—The deterioration or damage to the coding on a card or ticket that naturally occurs in everyday use.

DELAMINATION—A separation along a plane parallel to a surface, as in the separation of a coating from a substrate or the layers of a coating from each other, or, in the case of a concrete slab, a horizontal splitting, cracking, or separation of a slab in a plane roughly parallel to, and generally near, the upper surface. Found most frequently in bridge decks and caused by corrosion of reinforcing steel or freezing and thawing. Similar to spalling, scaling, or peeling, except that delamination affects large areas and can often only be detected by tapping.

DESIGN VEHICLE—The 85th percentile vehicle among the mix of expected vehicle sizes.

DETERIORATION—Disintegration or chemical decomposition of a material during test or service exposure. (See also DISINTEGRATION.)

DIAGONAL CRACK—An inclined crack caused by shear stress, usually at about 45 degrees to the neutral axis of a concrete member; or a crack in a slab, not parallel to the lateral or longitudinal dimensions.

DIFFERENTIAL COUNTER—A resettable counter that is increased 1 digit with each entry and decreased 1 digit with each exit to show current occupancy of the facility.

DISCOLORATION—Change of color from that which is normal or desired.

DISINTEGRATION—Deterioration into small fragments or particles.

DISKS—The permanent storage system for the operating system, software, and data for a personal computer. May be either *floppy,* which are inserted and removed from the computer as needed, or *hard,* which are permanently fixed in the computer.

DOUBLE-LOADED—An aisle with parking spaces on both sides.

DOWNLOAD—To send downstream from the CPU to the peripheral.

DROP SAFE—A safe with a special slot that allows a cashier to deposit revenues without having the combination/key to open the safe.

DRY-MIX SHOTCRETE—Pneumatically conveyed shotcrete in which most of the mixing water is added at the nozzle.

DRY-PACKING—Placing of zero slump, or near zero slump, concrete, mortar, or grout by ramming into a confined space.

DURABILITY—The ability of concrete to resist weathering action, chemical attack, abrasion, and other conditions of service.

DURESS ALARM—An alarm, usually silent, that a cashier can depress to summon assistance in the event of a problem at an exit lane.

DUSTING—The development of a powdered material at the surface of hardened concrete.

EFFICIENCY—The GROSS PARKING AREA divided by the STATIC CAPACITY.

EFFLORESCENCE—A deposit of salts, usually white in color, formed on a surface, the substance having emerged in solution from within concrete or masonry and deposited by evaporation.

EMERGENCY TELEPHONE—A special telephone, without a dial, that connects directly with a manned security station or police force. Although emergency telephones are generally "hard wired," microwave signal transmission can also be used to eliminate the need to run wires to every unit.

ENCROACHMENT—The protrusion of columns, piping, light poles, and other appurtenances into a parking stall or module.

END BAY PARKING—Stalls placed along the TURNING BAY, using that area for access into and out of the stalls.

ENTRAINED AIR—Microscopic air bubbles intentionally incorporated in concrete during mixing; typically between 10 and 1000 μm in diameter and spherical or nearly so.

ENTRAPPED AIR—Air voids in concrete that are not purposely entrained and that are significantly larger and less useful than those of entrained air, 1 mm or larger in size.

EXCEPTION TRANSACTION—A transaction that does not follow the normal procedure. Includes lost tickets, validation for parking without an account number, or other transactions where the cashier has circumvented procedures.

EXPOSED CONSTRUCTION—Exposed to public view.

EXPOSED TO PUBLIC VIEW—Situated so that it can be seen from eye level from a public location after completion of the building. A public location is accessible to persons not responsible for operation or maintenance of the building.

EPOXY CONCRETE—A mixture of epoxy resin, catalyst, fine aggregate, and coarse aggregate. (See also EPOXY MORTAR, EPOXY RESIN, and POLYMER CONCRETE.)

EPOXY MORTAR—A mixture of epoxy resin, catalyst, and fine aggregate. (See also EPOXY RESIN.)

EPOXY RESIN—A class of organic chemical bonding systems used in the preparation of special coatings or adhesives for concrete, or as binders in epoxy resin mortars and concretes.

EVALUATION—Determining the condition, degree of damage or deterioration, or serviceability, and, when appropriate, indicating the need for repair, maintenance, or rehabilitation. (See also REPAIR, MAINTENANCE, and REHABILITATION.)

EXPRESS HELIX—A ramp wound in a tight circle. Also called a CIRCULAR HELIX, it has no parking on it, and provides an extremely fast route up or down.

EXPRESS RAMP—A straight or gently curved ramp between two tiers.

FACILITY MANAGEMENT SYSTEM (FMS)—A SOFTWARE package that analyzes and reports activity and runs on a computer of appropriate size and capability. With an FMS, all information about transactions, card uses, etc. is transmitted periodically to a central host computer.

FEATHER EDGE—Edge of a concrete or mortar placement such as a patch or topping that is beveled at an acute angle.

FEE COMPUTER—An electronic cash register that calculates the fee due from an input of the "in" time and date. The internal clock provides the "out" time and date.

FEE INDICATOR—A device designed to display the fee as entered into the fee computer to the driver of the exiting vehicle.

FIELD OF VISION—The normal range of vision without turning one's head.

FLOOR—The surface at the bottom of any volume of space such as a room, an ocean, etc. See also TIER. Because all parking and drive areas must be designed for proper drainage (see Chapter 10), a floor area in a parking facility will be either sloped only as required for drainage, in which case it is nominally *level,* or sloped for floor-to-floor circulation, in which case it is nominally *sloped.*

FLOOR-TO-FLOOR HEIGHT—The vertical dimension from the top of one floor surface to the top of the floor surface on the tier above or below.

FLOW CAPACITY—The ability to accommodate expected traffic VOLUMES without excessive congestion and delay.

FLUORESCENT—A lamp that emits light when an arc passes though gas and then refracts through a phosphor coating.

FOOTCANDLE—A measure of the intensity of ILLUMINANCE; 1 footcandle is equal to 1 LUMEN per square foot.

FOOTPRINT—The outline of the structure viewed from directly above, such as would be seen in an aerial photograph.

FULL SIGN—An illuminated sign at each entry lane that is automatically turned on when the occupancy of the facility reaches the preset full level.

FUNCTIONAL DESIGN—The consideration of pedestrian and vehicular flow through a parking facility.

GENERATOR—Land use that creates a demand for parking.

GEOMETRICS—The dimensions of various components of a parking facility, including aisles, stalls, and MODULES.

GRAPHICS—The way in which a message is presented on a SIGN.

GROOVE JOINT—A joint created by forming a groove in the surface of a pavement, floor slab, or wall to control random cracking.

GROSS FLOOR AREA (GFA)—The sum of the floor area on each tier using out-to-out dimensions.

GROSS PARKING AREA (GPA)—The sum of the floor area on each tier, calculated using outside to outside of exterior walls, less enclosed areas devoted to auxiliary uses, such as stair towers, elevator shafts and lobbies, and storage and equipment rooms. Any other uses, such as retail or office space, should be excluded from GPA.

HAIRLINE CRACKING—Small cracks of random pattern in an exposed concrete surface.

HALATION—A "halo" effect in which light letters on a dark background appear larger than they are.

HANDSHAKING—Coordination of communication between computer and device. Some handshaking is part of the hardware, such as the timing and speed of transmission.
HELIX—A coiled shape or a spiral. In a parking structure, a series of PARKING BAYS and/or ramps that provide floor-to-floor circulation.
HIGH-INTENSITY DISCHARGE—A type of lamp for lighting fixtures that has high light output in a relatively small bulb.
HINGE POINT—The point at which two different slopes meet.
HONEYCOMBING—Voids left in concrete due to failure of the mortar to effectively fill the spaces among coarse aggregate particles.
HYBRID PAY STATION/CENTRAL CASHIERS—A system that combines central cashiers with AUTOMATED PAY STATIONS.
HYBRID PAY STATION/EXIT CASHIERS—A system that combines central AUTOMATED PAY STATIONS with cashiers at the exits.

ILLUMINANCE—The intensity of light falling on a surface or plane.
INBOARD—Locating a stair/elevator tower in a row of parking stalls, displacing those stalls, or tucking it into an unused corner. Towers placed OUTBOARD are outside the perimeter of the parking area.
INTEGRATION—Combining peripherals and/or computer systems from one or more manufacturers into a complete, properly functioning system.
INTERFACES—The physical connection and electronic circuits that connect the computer to a peripheral. Several different types of devices connect the CPU to the peripherals: a *bus* (a line that moves data), a *board* (onto which chips are mounted with plug-in connections), or a *port* (which is the computer equivalent of an electrical outlet).
INTERLOCKED—A parking layout where the ANGLED parking stalls in two adjacent MODULES are perfectly aligned.
INTERMODAL—A facility that allows transfer between modes of transportation, especially between personal vehicles (by providing parking) and public modes of transportation such as local, regional, and/or intercity fixed-route buses; fixed or variable route shuttles, car or van pools, and light or commuter rail.

JOURNAL TAPE—A paper tape in the fee computer that records each step of each transaction.
JOINT SEALANT—Compressible material used to exclude water and solid foreign material from joints.

LAITANCE—A layer of weak and nondurable materials containing cement and fines from aggregates brought by bleeding water to the top of overwet concrete. The amount is generally increased by overworking or overmanipulating concrete at the surface by improper finishing or by job traffic.
LAND USE—The intended type of activity in or functional use of a building.

LAMP DEPRECIATION—The degradation of ILLUMINANCE over the life of a lamp.

LATEX—A water emulsion of a synthetic rubber or plastic obtained by polymerization and used in coatings and adhesives.

LEGIBILITY—Ability to distinguish letters and symbols.

LEVEL OF SERVICE—A qualitative measure of the conditions in a particular traffic-carrying component. Applied to geometrics, other design parameters, flow capacity, and queuing at entry/exit points herein.

LICENSE PLATE INVENTORY (LPI)—A listing of the license plates of all vehicles parked in a facility at a certain time.

LIGHT WELL—An airshaft open to the sky providing natural light and ventilation to spaces at some distance from the building exterior.

LOAD, DEAD—Dead weight supported by a member, as defined by a general building code.

LOAD, LIVE—Live load specified by a general building code.

LOAD, SELF—Weight of the member itself.

LOCAL FACILITY COMPUTER (LFC)—When multiple facilities are connected to an FMS, a computer making decisions and monitoring the activity at one facility.

LONG SPAN—A structural system which spans the full width of the MODULE.

LONG-TERM PARKER—A parker who stays in a facility more than 3 hours. May be either a daily-fee or monthly parker.

LOOP DETECTOR—Loops of wire placed in floor slabs connected to a device that magnetically detects vehicle presence.

LUMEN—The measure of light from a source.

LUMINANCE—The output of light from an object, such as a lamp.

MACHINE-READ TICKETS—Tickets from which all data required to perform a complete transaction are automatically recognized by technological means.

MAINTENANCE—Taking periodic actions that will either prevent or delay damage or deterioration or both. (See also REPAIR.)

MAP CRACKING—See CRAZING.

MATCHLINES—Markings on floor plans depicting where one tier stops and another begins. When owners and other construction laymen are to view the plans, it helps if the matchlines are located near the center of the sloping bay or ramp. However, on drawings to be used in construction, matchlines should be placed at natural breaks in construction, such as the end of a concrete pour.

MEAN INHIBITING PERIOD—The average spacing of vehicles at capacity flow in time units.

MEANS OF EGRESS—A term in building codes referring to the mode and route of exit during an emergency.

MEMORY—The storage/retrieval system for the operating system, software, and data currently in use on a computer. Memory in microprocessors is provided either in ROM or RAM. ROM stands for Read Only Memory and is permanently electrically fixed on the *chip.* RAM (Random Access Memory) is temporary and can be modified or overwritten during use.

METER—A device that accepts a parking fee and denotes how much purchased time remains. One meter is placed at each stall. Originally mechanical, electronic meters are now available that have microprocessors to calculate the remaining fee and keep track of how much money is in the cash box.

METER BOX—A device that accepts parking fees for a number of spaces and has a means of letting the enforcement official know which stalls are paid and/or not paid. Originally, was as simple as a box with a slot for each stall; now, electronic and computerized online meters are available.

MICROCRACKS—Microscopic cracks within concrete.

MICROPROCESSOR—Essentially a computer each on its own *silicon chip.* A computer such as the popular personal computer that uses a microprocessor for its CPU is generically called a microcomputer. (Larger, more powerful computers have labels such as mini- and mainframe.) A microprocessor can also be designed for just one task.

MINICOMPUTER—A computer class that is larger and faster than a personal computer but smaller than a *mainframe* which, in turn is smaller than a *supercomputer.* Most minicomputers are multiuser and multitasking.

MODEM—Changes the computer's language into audible frequencies so that it can be sent over telephone lines.

MODULE—The wall-to-wall dimension of a PARKING BAY. The combination of one or two rows of parked vehicles and the driving aisle providing access thereto. A module may be SINGLE LOADED, with parking on only one side of the aisle, or DOUBLE LOADED, with parking on both sides.

MONOMER—An organic liquid of relatively low molecular weight that creates a solid polymer by reacting with itself or other compounds of low molecular weight or with both.

MONTHLY PARKER—A parker who pays, usually in advance, for a month or more of parking at a time. A monthly parker is usually allowed to come or go as often as he or she pleases within the paid period.

MOTION DETECTOR—A device that detects the presence of a person in a normally "quiet" area.

MULTITASKING—Capable of processing different tasks or programs at the same time. Only the most recent and most powerful microprocessors can perform even limited multitasking.

MULTIUSER—A single computer that can run tasks for several users, each at a different terminal.

NESTING—A sequence of gates that must be passed through in the proper order for continued authorization.

NETWORK—Interconnection of several computers without multiuser capabilities so that data processed by one computer may be used by another.

NONRESETTABLE COUNTER—A digital or electronic counter that increases 1 digit with each transaction. When it reaches the maximum number of the counter (usually 99,999), it starts back over at zero. Similar to the odometer on a car, which records total miles driven.

OFFLINE—Not ONLINE. Offline systems can still be computerized by other means of data communication.

ONLINE—Generally, a device that is hard-wired to a CPU of some sort.

OPERATING SYSTEM—Set of software that controls the reading, writing, and placing of data in the memory on the disks. The most popular operating system for personal computers compatible with the IBM PC is known as MS DOS, and various versions have been developed similar to the Intel family of microprocessors.

OUTCLOCK—See TICKET DISPENSER.

OVERBOOKING—The practice of either selling 10% to 20% more monthly passes than the number of spaces allocated, or allowing transient parkers to use spaces allocated to monthly parkers when the latter are absent.

OVERHEAD CLEARANCE—The straight vertical clearance encountered by pedestrians.

OVERLAY—A layer of concrete or mortar, seldom thinner than 1 in., placed on and usually bonded to the worn or cracked surface of a concrete slab to either restore or improve the function of the previous surface.

PACHOMETER—Instrument for nondestructively locating and estimating concrete cover and/or diameter of embedded reinforcement.

PAN AND TILT—A device that allows a camera to rotate vertically and horizontally to change the view of an area.

PANIC BUTTON—A button placed on an intercom unit or emergency telephone that sounds an alarm at the master intercom station.

PARATRANSIT—Specialized transportation services for the disabled.

PARKING ACCESS AND REVENUE CONTROL (PARC). Any device or combination of devices that controls access, utilization, and/or revenues for a parking space.

PARKING BAY—Rows of parking with an aisle in between. A parking bay may be SINGLE-LOADED (parking on one side only) or DOUBLE-LOADED (on both sides).

PARKING GARAGE—A parking facility that does not meet code requirements for openness and therefore must have mechanical ventilation.

PARKING STRUCTURE—A multistory parking facility that meets code requirements for natural ventilation. May be called a parking deck or parking ramp.

PASSIVE SECURITY—Physical features of a parking facility that promote good security, usually by providing increased visibility.

PATTERN CRACKING—Fine openings on concrete surfaces in the form of a pattern; resulting from a decrease in volume of the material near the surface, an increase in volume of the material below the surface, or both.

PAY-ON-FOOT—A system where the patron pays "on foot" upon returning to the facility but before retrieving his car. An exit ticket or token is issued that is surrendered at the gate.

PEAK HOUR—The 60 consecutive minutes that together have the highest total volume of traffic.

PEAK-HOUR FACTOR (PHF)—The ratio of the total hourly volume to the maximum 15-minute RATE OF FLOW within the hour.

PEELING—A process in which thin flakes of mortar are broken away from a concrete surface, such as by deterioration or by adherence of surface mortar to forms as they are removed.

PERIPHERAL—Any device connected to the CPU and memory, including the keyboard, video display, and printer. In PARC systems, peripherals also include gates, ticket dispensers, etc.

PERSONAL COMPUTER (PC)—A version of the microcomputer designed to sit on a desk and process everyday assignments for one user.

PETROGRAPHY—Chemical and microscopic examination mainly in laboratory of concrete samples.

PITTING—Development of relatively small cavities in a surface, due to phenomena such as corrosion or cavitation, or, in concrete, localized disintegration. (See also POPOUT.)

PLASTIC CRACKING—Cracking that occurs in the surface of fresh concrete soon after it is placed and while it is still plastic.

PLASTIC SHRINKAGE CRACKING—See PLASTIC CRACKING.

POLYETHYLENE—A thermoplastic, high-molecular-weight organic compound used in formulating protective coatings or, in sheet form, as a protective cover for concrete surfaces during the curing period, or to provide a temporary enclosure for construction operations.

POLYMER—The product of polymerization; more commonly, a rubber or resin consisting of large molecules formed by polymerization.

POLYMER CONCRETE—Concrete in which an organic polymer serves as the binder; also known as resin concrete. Sometimes erroneously employed to designate hydraulic cement mortars or concretes in which part or all of the mixing water is replaced by an aqueous dispersion of a thermoplastic copolymer.

POLYMER-CEMENT CONCRETE—A mixture of water, hydraulic cement, aggregate, and a monomer or polymer, polymerized in place when a monomer is used.

POLYMERIZATION—Reaction in which two or more molecules of the same substance combine to form a compound containing the same elements in the same proportions, but of higher molecular weight, from which the original substance can be generated, in some cases only with extreme difficulty.

POLYURETHANE—Reaction product of an isocyanate with any of a wide variety of other compounds containing an active hydrogen group; used to formulate tough, abrasion-resistant coatings.

POPOUT—The breaking away of small portions of concrete surface due to internal pressure which leaves a shallow, typically conical, depression.

POSTTENSIONED—See PRESTRESSED CONCRETE.
POT LIFE—Time interval after preparation during which a liquid or plastic mixture is usable.
POULTICE—A smooth paste usually made by mixing some essentially inert fine powder with the solvent or solution to be used and applied to the surface for cleaning concrete stains.
PRECAST CONCRETE—Concrete cast somewhere other than in its final position.
PRESTRESSED CONCRETE—Concrete in which stresses of such magnitude and distribution are introduced that the tensile stresses resulting from the service loads are counteracted to the desired degree. PRETENSIONED concrete is prestressed concrete in which the method of prestressing is to tension the tendons before the concrete hardens. POSTTENSIONED concrete is prestressed concrete in which the method of prestressing is to tension the tendons after the concrete hardens.
PROTOCOL—A set of control characters that define what information is coming next in a stream of data.
PROXIMITY—A system that is able to read a card presented in close (6 to 10 in.) proximity to a reader.
PUBLIC ACCOMMODATIONS—Under ADA, privately owned buildings or areas thereof where the public may go to receive goods and services.
PVC—Polyvinyl chloride—a stiff, strong plastic that is commonly used for pipe and conduit.

QUEUE—The line of waiting vehicles in the reservoir.

RATE OF FLOW—The equivalent hourly rate at which vehicles pass a given point, determined by observing VOLUMES in a time interval less than 1 hour, such as 15 minutes.
REACTIVE AGGREGATE—Aggregate containing substances capable of reacting chemically with the products of solution or hydration of the Portland cement in concrete or mortar under ordinary conditions of exposure, resulting, in some cases, in harmful expansion, cracking, or staining.
READABILITY—Ability to perceive a message.
REDIAL—A software subprogram that overrides the antipassback control for one card use.
REENTRY—The path of travel allowing a driver who is nearing the exit but has not found a parking space to reenter the inbound circulation path.
REFLECTANCE—The ability of a surface to reflect light.
REHABILITATION—Making major repairs or modifications, which if not performed could result in unserviceability; during rehabilitation, a facility or area is normally out of service. (See also REPAIR.)
REINFORCEMENT—Bars (smooth or deformed), wires, strands, and other elements that are embedded in concrete in such a manner that reinforcement and concrete act together in resisting forces. CONVENTIONAL reinforce-

ment is nonprestressed smooth or deformed bar or wire reinforcement with yield strengths in the 40,000–75,000 psi range. PRESTRESSED reinforcement is steel bars, wires, or strands with ultimate strengths in the 250,000–270,000 psi range, strong enough to permit effective pre- or posttensioning.

REPAIR—Restoring damaged or deteriorated elements to serviceable condition; repair work can normally be performed while a structure remains in service. (See also REHABILITATION and MAINTENANCE.)

RESIN—A natural or synthetic, solid or semisolid organic material of indefinite and often high molecular weight having a tendency to flow under stress; usually has a softening or melting range and usually fractures conchoidally.

RESIN MORTAR (or CONCRETE)—See POLYMER CONCRETE.

RESOLUTION—In CCTV systems, the detail and clarity of the picture.

RESERVOIR—The space for waiting behind the vehicle being serviced. Without a vehicle in the reservoir, there is "dead time" when no vehicle is being serviced.

RESTRAINT (OF CONCRETE)—Restriction of free movement of fresh or hardened concrete following completion of placing in formwork or molds or within an otherwise confined space; restraint can be internal or external and may act in one or more directions.

REVENUE COLLECTION EFFICIENCY (RCE)—The percent of potential revenue that actually makes it to the owner's bank account.

RISE—The dimension of the vertical component of a sloping element.

RUN—The dimension of the horizontal component of a sloping element.

RUBBER STUD FLOORING—A flooring system designed for commercial applications that has raised "studs" about 1 in. in diameter closely spaced throughout the pattern.

SANDBLASTING—A system of cutting or abrading a surface such as concrete by a stream of sand ejected from a nozzle at high speed by compressed air; often used for cleanup of horizontal construction joints or for exposure of aggregate in architectural concrete.

SCALING—Local flaking or peeling away of the near-surface portion of hardened concrete or mortar; also of a layer from metal. (See also PEELING and SPALLING.) (Note: Light scaling of concrete does not expose coarse aggregate; medium scaling involves loss of surface mortar of 5–10 mm in depth and exposure of coarse aggregate; severe scaling involves loss of surface mortar of 5–10 mm in depth with some loss of mortar surrounding aggregate particles 10–20 mm in depth; very severe scaling involves loss of coarse aggregate particles as well as mortar generally to a depth greater than 20 mm.)

SECURITY AUDIT—The process of assessing the risk of incidents in the parking facility as a whole and in specific locations within the facility.

SERVICE RATE (μ)—The maximum number of vehicles that can be processed through a lane in 1 hour under a constant heavy load. It is therefore the capacity.

SHEAR WALL—A wall reinforced to carry the lateral loads placed on a building by wind, earthquakes, and other horizontal forces.

SHORT CIRCUIT—An extra turning bay in a long structure which allows the drivers to turn back into the adjacent bay without going all the way to the end of the structure.

SHORT SPAN—A structural system that does not span the full module, resulting in columns between parked vehicles.

SHORT-TERM PARKER—A parker who stays in a facility 3 hours or less.

SHOTCRETE—Mortar or concrete pneumatically projected at high velocity onto a surface; also known as air-blown mortar; also pneumatically applied mortar or concrete, sprayed mortar, and gunned concrete. (See also DRY-MIX SHOTCRETE and WET-MIX SHOTCRETE.)

SHRINKAGE—Volume decrease caused by drying and chemical changes; a function of time but not of temperature or stress due to external load.

SHRINKAGE CRACK—Crack due to restraint of shrinkage.

SHRINKAGE CRACKING—Cracking of a structure or member due to failure in tension caused by external or internal restraints as reduction in moisture content develops, as carbonation occurs, or both.

SIGNS, SIGNAGE—The system of signs providing directions, warnings, and commands to the user.

SINGLE-LOADED—An aisle with parking spaces on one side only.

SOFTWARE—Any set of instructions that tells the CPU what to do.

SOLID STATE—A device using transistors, which are electronic semiconductor devices that control current flow.

SPALL—A fragment, usually in the shape of a flake, detached from a larger mass by a blow, by the action of weather, by pressure, or by expansion within the larger mass; a small spall involves a roughly circular depression not greater than 20 mm in depth or 150 mm in any dimension; a large spall may be roughly circular or oval or, in some cases elongate, more than 20 mm in depth and 150 mm in greatest dimension.

SPALLING—The development of spalls.

SPEED RAMP—Connects two PARKING BAYS with a grade differential of 2 to 5 ft.

STATIC CAPACITY—The number of parking spaces in a parking facility.

STIRRUP—Reinforcement used to resist shear and torsion stresses in a beam; typically bars, wires, or welded wire fabric (smooth or deformed).

STRUCTURAL CLEARANCE—The straight vertical clearance between the underside of the deepest structural member and the top of the floor slab, without adjustment for washes, curbs, and structural deflection.

STRUCTURAL STEEL—Rolled steel structural shapes, plates, and assemblies, as opposed to steel reinforcement.

SWITCHER—In CCTV systems, a device that controls which picture is shown on the monitor at any particular time. Switchers can sequence from one camera to another automatically with manual override when the observer wishes to continue to view the scene from one specific camera.

TENDON—A steel element such as a wire, cable, bar, rod, strand, or group of such elements used to impart prestress to concrete when the element is tensioned.

THERMOSETTING—Becoming rigid by chemical reaction and not remeltable.

TICKET DISPENSERS—Located at entry lanes to issue a ticket stamped or coded with date and time. In first-generation equipment, the ticket is imprinted with a *rate ring* which rotates like a clock with the time of issue. An *out clock* (much like an old-fashioned employee time clock) at the exit lane cashier station punches the ring in the appropriate fee range, indicating the fee to be charged. In the second-generation system, the ticket is merely stamped with the date and time.

TICKET TRACKING—A system recognizing each ticket as it is issued and monitoring its status until it is presented at exit.

TIE—Loop of reinforcing bar or wire enclosing the longitudinal reinforcement in a column.

TIER—One story. A tier in a parking facility is defined by the way it is depicted on the construction drawings; because of the sloping PARKING BAYS and ramps, it is sometimes difficult to decide where one tier stops and another begins. The most important thing is to ensure that all floor areas are shown once and only once on the plan views.

TIDAL FLOW CAPACITY—The ability to accommodate traffic flow that is almost all inbound or outbound in a particular hour.

TOKEN—See VALIDATION.

TRANSIENT—A parker who comes in occasionally, not every day.

TRANSIT—Local public transportation, including bus, commuter rail, etc.

TRANSITION—An area that softens the change in slope at which HINGE POINTS are joined. Minimizes BREAKOVER effect.

TRANSVERSE CRACKS—Cracks that develop at right angles to the long direction of a member.

TURNING BAY—The space used to turn from one PARKING BAY to another parking bay.

TURNING RADII—The dimension from the center to the edge of the circle traced by the outside front wheel of a design vehicle.

TURNOVER—The average number of times a parking space is used by different vehicles over a 24-hour period. Calculated by dividing the number of parkers in a facility each day by static capacity.

TURNOVER CAPACITY—The ability to accommodate traffic flow that mixes both arriving and departing vehicles in the same hour.

TWO-WAY INTERCOM—A unit that allows someone at any one of the substations to talk to and listen to the operator at the master station. Communication between substations, however, is not possible. Two-way intercoms are hard wired to each other.

TWO-WAY RADIOS—A unit that allows communication between substations and the master unit, using radio frequency waves for transmission. Usually, all communications are heard on all units.

UNIFORMITY RATIO—In lighting design, the ratio of average to minimum maintained illuminance.

VALET PARKING—System in which attendants (rather than customers) park and retrieve vehicles.
VALIDATIONS—A system of validating the ticket of a daily-fee parker for a reduced charge or a period of free parking. Validations come in many forms: stickers, credit-card-like imprints, ink stamps, an authorized signature, etc. *Tokens* are a form of validation but eliminate the need for tickets and a cashier.
VEHICULAR CLEARANCE—The safe clearance encountered by vehicles driving through the structure.
VEHICLE DETECTOR—See LOOP DETECTOR.
VISIBLE SPECTRUM—Those wavelengths of electromagnetic radiation visible to the human eye.
VISIBILITY—Ability to see and recognize.
VISUAL ACUITY—Ability to see clearly.
VOICE-ACTIVATED INTERCOM—An intercom that filters out background noise but carries conversations and unusual noises to the master unit without depression of a button or other device at the substation. Generally, the voice activation capability at the master unit can be turned off, which reduces the effectiveness of the system.
VOLUME—The total number of vehicles passing a point in a certain period; unless otherwise noted, volumes discussed herein are for a full hour.
VOLUME CHANGE—In this context, primarily a change in horizontal dimension due to elastic shortening, drying shrinkage, creep, and temperature change.

WAYFINDING—The ability to find one's way in an unfamiliar environment.
WET-MIX SHOTCRETE—Shotcrete wherein all ingredients, including mixing water, are mixed before introduction into the delivery hose; it may be pneumatically conveyed or moved by displacement.

ZOOM—A device that automatically refocuses a camera lens for the desired distance and detail.

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