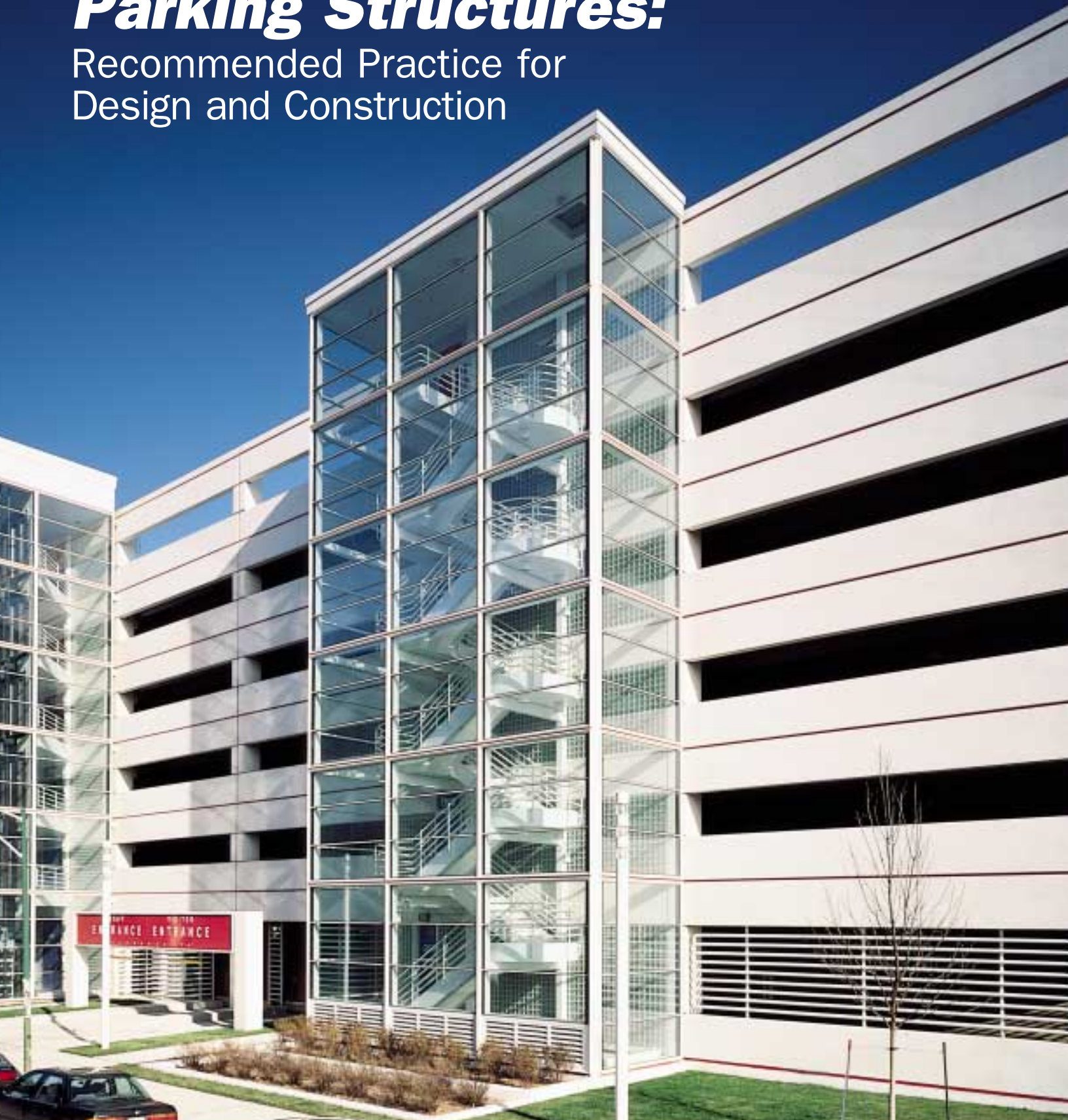




P r e c a s t P r e s t r e s s e d C o n c r e t e

Parking Structures:

Recommended Practice for
Design and Construction



P r e c a s t P r e s t r e s s e d C o n c r e t e

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Recommended Practice for
Design and Construction



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Printed in the United States of America

ISBN 0-937040-58-4

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MNL-129-98

On the cover: Cook County Juvenile Center Parking Garage, Chicago, IL
Photo: William Kildow Photography

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Special thanks to Norm Scott & Tom D'Arcy for their help in revising this publication

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1.0

INTRODUCTION



Boston College Parking Structure, Chestnut Hill, MA

Parking structures have become important elements in today's urban and suburban environments. Owners have realized that parking services represent the first and last impression a visitor receives of the facility, and that can be a pivotal factor when consumers decide where to do business. Even more, owners and designers both are acknowledging that parking structures must be designed specifically for the types of visitors that structure will serve, based on the facilities they support and the flow of daily traffic.

The need to create a parking structure that precisely fits the needs of the users cannot be stressed enough. Unless the facility is user-friendly, projecting a safe, secure, and easy to use environment, parkers will find other options. These needs have become too vital to their peace of mind to be left unmet by the owner and designer.



Pittsburg Technology Center Garage, Pittsburg, PA

photo: Michael Haritan



Pfizer Inc. Parking Structure (Building 290), Groton, CT



Mobile County Parking Garage, Mobile, AL
photo: Thigpen Photography

As a result, creating the best parking structure for the site, users, and budget requires a careful balance of all elements and a logical plan from start to finish. From the initial conception basics are decided until the parking structure opens, a host of choices must be made that will affect the final design and cost of the project—which ultimately will impact its value to the customer.

A PCI-Certified precaster can make a dramatic difference in the final result when allowed to be involved in the process from the beginning while key design decisions

are being finalized. This expertise and input can minimize the cost and time needed to complete the project. By bringing the design professionals and precaster together before drawings are begun, owners can ensure maximum efficiency, speed, and use of funds.



Kravis Center Parking Structure, West Palm Beach, FL

This manual's intent is to show the uniqueness of precast prestressed concrete parking structures and to emphasize areas of special considerations required in the design of these structures. Chapters 1 and 2 explain some of the key considerations an owner/developer must entertain when creating a parking structure. They offer basic explanations of precast's advantages, design options, and techniques to improve functionality. The designer and precaster can elaborate on these elements to provide the most effective solution to each individual element.



Duke Power Co., City of Charlotte Parking Structure, Charlotte, NC

The remaining six chapters are intended for trained personnel who have the basic knowledge of structural and prestressed concrete design. These professionals should be included in any final decisions. The Appendix describes maintenance procedures that are essential in any parking structure.

The information and diagrams are provided as helpful aids to the qualified designer. Actual design details should conform to local practices and code requirements. Architects, engineers, and owners are urged to consult with their local precast and prestressed concrete producer for information on specific local practices and requirements.

1.1

**Parking Structure
Durability**

Durability is the intrinsic value that allows precast prestressed concrete parking structures to outlive competing materials. The difference is quality concrete. The combination of low water-to-cement ratio and heat-cured concrete, achievable only in a factory environment, equals a high-strength, low-permeability, durable parking structure.



Albany Medical Center Parking Structure, Albany, NY



*Carriage Park Parking Garage,
Lincoln, NE*

Concrete exposed to moisture and chlorides perform best with low water/cement ratios and a compressive strength of 5,000 pounds per square inch (psi) minimum. Precast/prestressed concrete is produced with concrete that exceeds these requirements, whereas cast-in-place concrete normally does not meet these requirements. This criteria meets the recommendation of ASTM C94 and also is endorsed by knowledgeable designers. Additionally, research by the Federal Highway Administration (FHWA) has shown that concrete mixes with water/cement ratios that are .40 or lower have relatively high resistance to chlorides, while concrete with this water/cement ratio have much lower absorption characteristics than traditional cast-in-place concrete with water/cement ratios of 0.5 or greater.

A recent study by FHWA concluded that, “There is no doubt that water/cement ratio has a strong influence on chloride ingress into concrete.” Obtaining these strengths and water/cement ratios in a plant is very economical compared to other constructions.

In order to reach its maximum strength, concrete must be cured at the optimum rate, with precise moisture, temperature, and environmental conditions. Precast prestressed concrete products, which use this method, create high strength and impermeability. These optimum conditions are achieved daily in the plant, whereas it is not practical to perform them in the field. Studies of heat-cured concrete as used in the precaster’s plant have shown decreases in water absorption and volume of permeable voids.



Station Plaza Parking Garage, Trenton, NJ

The main reinforcement, prestressing strand and/or reinforcing steel, is located in the bottom of the member. The advantage to this is that chloride concentration decreases with the concrete depth, which indicates that precast members should receive little effect from chlorides. For this same reason, the American Concrete Institute (ACI) recommends a cover of two inches over reinforcing steel in cast-in-place concrete, because some of its main reinforcement is in the top of the structure.

A 1996 report by the engineering firm of Wiss, Janney, Elstner Associates Inc. reports that in many cases, the rapid chloride ion test for determining the level of durability of concrete needed for a project may overstate the results or present potentially misleading comparisons, costing owners money by making them pay for methods and materials that aren't required. Among its findings was that the water/cement ratio was by far the most important indicator of durability, more so than curing method or other factors. Copies of the report are available from the Precast/Prestressed Concrete Institute.



Mall of America Parking Facilities, Bloomington, MN

1.1.1**High-Performance Concrete**

“High-performance concrete” has been part of the day-to-day operation in the production of precast prestressed concrete since the first elements were cast. High cement content and low water/cement ratios result in high early-strength and high ultimate-strength concrete with low permeability thereby providing resistance to chloride ion penetration.

The dramatic and overpowering effect of the water/cement ratio on the chloride permeability of concrete (see 1.1) requires that the potential advantages of “high performance” concrete, such as low water/cement-ratio, heat-cured concretes or those containing admixtures such as silica fume, be examined for comparison using realistic water/cement values for project applications.

One such comparison would be of a conventional cast-in-place concrete parking structure for which no specialty contractors or materials would be required. The concrete used in this hypothetical structure would be 0.46 w/c burlap-cured or 0.46 w/c burlap-cured concrete with 5.0 or 7.5 percent silica fume. A 0.37 w/c heat-cured concrete would be used in the precast prestressed deck, which has been shown by recent studies to be superior to the conventional system.

1.1.2**Past Performance**

Studies have shown that precast parking structures have performed extremely well through the years. The key ingredient for keeping maintenance costs low is to perform regular maintenance procedures as recommended in the Appendix to this manual.

1.2**New Techniques to Improve Performance**

Today’s precast prestressed parking structures supply the standard of excellence against which other parking structures are measured. A major contributor to that excellence is the inherent ability of the structure to “breathe” due to the use of connections between components. This design technique, used in all precast construction, allows the parking structure to relieve pressure from the ordinary expansion and contraction that otherwise would cause cracking in the structural members.



USAA Southeast Regional Office Parking Structure, Tampa, FL

The ability for every structure to breathe is imperative because volume changes in a parking structure will always occur. These result from several factors, including natural shrinkage and creep that take place over time, as well as temperature changes through the year.

With precast concrete, much of the shrinkage and creep occur at the production facility prior to erection. Thus these early volume changes, which account for more than half of all expected volume changes ever to impact the structure, are eliminated with precast construction. Later routine expansion and contraction caused by temperature changes also are mitigated in a precast concrete parking structures due to the connection systems used to absorb these changes.



Monmouth Medical Center Parking Garage, Long Branch, NJ

Most modern precast parking structures are built with double tees, which evolved from earlier tee systems. These earlier designs featured flange-to-flange connections and a field-placed concrete topping as the riding surface. Double-tee structures are mostly factory topped which means the entire deck thickness is integral as cast, although this varies by region. In many cases, pre-topped tees can offer a higher level of quality to resist the elements.

Methods for joining structural members also are evolving. Connections need to meet a number of performance requirements that fall into two main categories: structural and protection from corrosion. The connections must allow for some movement as well as be protected from the elements.

Currently, new techniques are being explored to offer even better connections that withstand the most difficult seismic conditions while still being able to erect the structure quickly by field crews. Precasters in your market will be aware of the latest ideas for available products and techniques that can save money and time while producing a more durable and longer-lasting structure.

1.3

Facade Treatments

The nature and goals of parking facilities have changed in recent years. The fact that these facilities often represent the visitor's first and last impressions is not lost on owners and developers. Making that impression more comfortable and reassuring, as well as helping the structure fit into the neighborhood, have moved aesthetics to the forefront in owners' concerns for the finished construction.

Virtually any desired design can be created on the exterior of precast concrete panels. The panels' versatility can produce a finished look that incorporates brick or tile inlays, exposed aggregate, or creative facings that resemble stone, brick or ribs created from form liners placed in the mold. In addition, virtually any shape, color or texture can be produced.



Chauncey Swan Plaza Parking Facility, Iowa City, IA



Charleston County Health Complex Parking Garage and EMS Station, Charleston, SC



Coliseum Parking Deck, Richmond VA

These variations allow owners to reach any aesthetic goal they desire. They ensure construction of a parking structure that projects a bright, contemporary style or an older, historic look complementing nearby structures. Precast panels also can be designed to blend with existing buildings made of brick or stone, and they even can match closely with other, earlier precast buildings or structures by using the same mix and texture.

1.3.1**Brick & Tile Inlays**

Clay product-faced panels combine the pleasing visual appearance of traditional brick with the strength, versatility, and economy of precast concrete. Clay products bonded directly to precast concrete can include brick or ceramic tile. The facing may cover the entire exposed panel surface or only part of the face, serving as an accent band. Other materials that can be bonded directly or applied to the hardened concrete as accents include granite, glass, and ceramic mosaics.

Brick, stone, or tile can also be constructed in the traditional way and connected to the precast with dovetail anchors.



Camden Waterfront Parking Garage, Camden, NJ

1.3.2**Exposed Aggregates**

Exposed-aggregate finishes are popular for parking structures because they are reasonable in cost and provide a good variety in appearance. The differences in texture are achieved by varying the type, color and size of aggregate, color matrix and depth of exposure.

Sandblasting and chemical surface retarders are the two primary methods of bringing out the full color, texture, and natural beauty of the coarse aggregate.

1.3.3**Shapes**

Various shapes and textures can be created by the shape of the mold itself, forming a bullnose or reveals. Unique textures also can be produced with form liners, including the look of stone, brick, timber, wood paneling, chiseled granites, ribs, shiplaps and other details that reduce the visual scale of larger panels.

1.3.4**Other Finishes**

There are other finishes that may be less costly but can still be attractive. Among these are plain gray concrete and the use of paint on the exterior surfaces. Budget considerations may drive the need for such finishes. Applied coatings are another successful finish applied to the exterior surfaces.



Fairfax Town Center Parking, Fairfax, VA

1.4

Design for Functionality

Security, safety, and ease of use are critical elements for developing a user-friendly atmosphere. Not only must parking structures provide safe, secure locations for visitors, but they must actively exude that atmosphere to reassure parkers. Additional aspects of these elements are discussed in Chapter 2.

1.4.1

Key Elements in Design

Key ingredients in projecting a safe and secure image are high, open spaces inside the parking structure without columns, plus well-lit walkways, elevators, and stairwells that provide high visibility. These elements produce challenges for the designer, because they are difficult to balance with the need for internal structural supports and the cost of higher ceilings. For additional information, see Section 2.7, Security.

1.4.1.1

Passive Security

Passive-security features are those that are designed into the facility and provide a comforting element for parkers through the safe atmosphere they generate. These features include such design elements as creating an overall open space that eliminates possible dark corners, providing plenty of light sources, offering glass walls or an open design for stair and elevator cores, and installing video monitors. Monitors are considered passive because their mere presence can deter predators. In addition, painting the interior ceilings with bright colors can greatly enhance ambient light levels and produce a more comfortable environment. Adding fencing at the lowest level opening will discourage intruders from easily entering the structure.

1.4.1.2**Active Security**

Active security measures prevent or deter crime by their very presence. These include such devices as electronically controlled and rolling steel gates that prevent unauthorized entry. Voice-activated, two-way speaker phones promote immediate response by security forces and reassure parkers that help is readily available in any emergency. The most-effective active security comes from roving patrols, either on foot or in vehicles. These patrols also can serve public-relations functions, answering questions or aiding motorists with car trouble.



*Wayne County Detroit Metropolitan Airport Replacement Structure, Romulus, MI
Albert Kahn Associates, Architects & Engineers Photo: © Lark & Associates, Inc.*

1.4.1.2.1**Framing Systems**

Long-span floor systems, such as provided by double tees and long-span beams, will provide good visibility. In addition, several new concepts for precast structural systems are gaining adherents and can improve the “safe and secure” atmosphere that is desired. Among these are “ladder” walls, and “K” and “H” frames, that can be used on both the interior and the exterior. These systems open the interior of the structure, eliminating some of the columns and shear walls that block visibility and cast shadows. They not only can create an attractive, expansive interior but save costs and allow greater freedom in laying out the space.

“Lite walls” (or “ramp walls”) offer another framing approach that has achieved notable success in some situations. These walls are used on inside column lines when there is a difference in elevation across a column line, as occurs adjacent to ramps. These walls can support one or more double tees per level.

The “lite wall” offers several advantages if designers can take advantage of it in their layout. First, it takes less concrete material than needed for a typical column and beam system, making it more efficient. Second, the walls provide significantly more openness than in a column-to-interior spandrel system. This system sometimes doubles the actual openness of the interior wall lines. Third, they contribute to the lateral load-resisting system, thereby adding functional usability.

1.4.1.2.2**Light Wells**

Light wells, not to be confused with “lite walls”, are a design throwback to older skyscrapers and apartment buildings that provided an interior vertical shaft to allow daylight to reach more interior spaces. This idea now is being applied to parking structures, despite its use of revenue-generating space, because the light well can serve a marketing function as well as a logistical purpose. Not only does a light well create an attractive interior space that reassures parkers, but it reduces the need for daytime lighting.



Cook County Juvenile Center Parking Garage, Chicago, IL Photo: William Kildow Photography

1.4.1.2.3**Floor Height Considerations**

Ceiling height should take into account the fact that higher ceilings provide a more open and attractive environment that can encourage more visitors to use the facility. In addition, lighting systems must be placed at the base of the double tee to provide an unobstructed dispersion of light, and these should not be located so close to the floor that they can be struck by vehicles. The use of tamper-proof lights will help resist vandalism.

Owners should work with their designers and precaster to arrive at the most efficient height to balance cost, visibility, and comfort factors. It cannot be stressed enough that providing the proper level of lighting represents the single most important factor in offering patrons the necessary level of safety and the perception of a secure environment. For more on ceiling and lighting considerations, see Sections 2.3.3, Floor to Ceiling Clearance, and 2.8, Lighting.

1.4.1.3**Floor Layouts**

When possible, designers prefer to lay out floor plans so visitors driving into the facility drive past the elevators and stair access before finding the available parking spaces. This helps them understand the layout of the facility and indicates what direction they should be walking in case there is no immediate sign apparent after leaving the car. Such designs are not always possible, but such techniques should be considered to produce the most secure and visibly reassuring structure possible. For more on this, see Section 2.6, Pedestrian Circulation. For more specifics on floor layouts, see Section 2.5, Parking Configurations.

1.4.1.4**Signage**

The type and amount of signage also directly impacts the security and safety perceptions of a parking structure. These “wayfinding” systems include a variety of directional signs and identification pieces that help traffic flow smoothly and ensure parkers easily can remember where they left their cars. Basic programs include putting directional markers for Elevators and Exits at every corner and along the ceiling in locations visible from many angles as well as coding each floor with a color, a memorable name, or both.

1.4.1.5**Safety Measures**

Safety in a parking structure focuses on the protection of the parkers’ vehicles as well as the patrons’ protection from slips and falls, vehicle accidents, and other mishaps that can occur when a structure is open to the elements and has continuous foot and vehicle traffic around and through it.

Owners should create an on-going program that focuses on key safety needs. Designers and the precaster can help ensure a program is developed that helps the owner achieve these goals.

1.5**Cost Considerations**

First cost considerations include, but are not limited to, land acquisition or rent, construction, and development or enhancement of the infrastructure. Typically the owner will weigh these costs against his projected operating budget, which is influenced by such factors as number of available stalls and the anticipated traffic flow, and available financing arrangements to decide whether to move ahead with the project. Precast prestressed concrete parking structures offer a number of economic advantages, including low cost of construction in comparison to other systems and maximum number of spaces due to the enhanced openness allowed by the clear spans.

Many elements impact the total cost of the structure, regardless of building material. These are addressed in more detail in Chapter 2.

1.5.1**Reduced Construction Cost Due To Early Occupancy/Revenue**

Precast concrete offers a key advantage over other building materials because of its ability to begin casting components as soon as designs are completed—and in some cases, even before the final drawings are prepared. By casting in factory-controlled plants away from the site, work can proceed while other prep work goes on, including digging and constructing foundations and creating access roads.

This not only allows the structure to get a head start on its upper levels, but it ensures the site remains free of obstacles that can slow construction further. In addition, inclement weather can cause significant delays in construction with other materials, whereas precast can be erected through the winter months.

Such a fast-track approach pays off in reduced costs at the site from less labor time and fewer corrections, but it also allows the facility to begin operation more quickly. That means a shorter period before construction bonds can be paid off and faster generation of revenue realized. It also means visitors will be able to use the structure quicker, enticing them to use the adjoining facilities more often, which will provide a multiplier effect for generating revenue.

1.5.2

Reduced Maintenance Cost

The owner's needs – and costs – don't end once the structure is constructed. Maintenance programs are a major part of any parking structure budget, and they should be considered from the beginning to reduce life cycle costs of the project. Once the structure is built, the precast prestressed concrete supplier can help the owner create a maintenance timetable that ensures the structure remains in top condition throughout its service life at a minimum cost for inspections and on-going routine programs.

Detailed information on how to maintain the structure, including information on when to inspect joints and sealants and how often to update caulks or toppings is included in the appendix. In some cases, warranties may be extended as long as the structure is properly maintained. Maintenance handbooks or services to keep the structure working at peak efficiency are often available.

Precast offers many advantages to owners in cost control, from design elements through erection and maintenance during the life of the building. Bringing the precast prestressed concrete supplier onto the design team early provides a host of benefits that may be overlooked otherwise. PCI encourages owners and designers to create a strategic partnership with the precast prestressed concrete supplier to ensure communication remains open throughout the project and that every element is considered so the owner receives the most attractive, useable, and most cost-efficient structure possible.

1.5.3

Design/Build

A good way to build a cost-effective parking structure is to use a construction method using the design/build concept. This concept involves bringing together, from the beginning, all parties to design and construct the most efficient structure. By using design/build, a precast prestressed concrete supplier will be involved early and able to contribute ideas for the most effective solutions. This method will give a single-source responsibility to expedite the time of construction and bring the project within budget.

2.0

PARKING STRUCTURE FUNCTIONAL DESIGN

2.1

Introduction

This chapter provides an overview of many of the non-structural aspects of the design of multilevel parking structures.

Parking structures are unique transportation facilities for vehicle travel, vehicle storage and pedestrian travel, particularly since the personal interchange between vehicles and pedestrians occurs in the relatively confined environment of a structured facility. Because of this uniqueness, the design specialty of parking consulting has evolved. For completeness of detail and quality completion of a project, it is important that the project owner or developer retain a qualified parking consultant.

Functional design involves the development of vehicle and pedestrian flow in a parking structure as well as the parking space layout. Operating and security functions are also considered in functional design.

Parking functional design concerns for self-park structures include:

parking structure type	circulation systems	security
street access design	parking configuration	lighting
revenue control/operating systems	pedestrian circulation	graphics & signage

2.1.1

Types of Parking Structures

2.1.1.1

Operational Types

The two general types of parking structures are attendant-park facilities and self-park facilities. In attendant-park facilities, the car is left at the entrance by the driver and an attendant then parks the car. When the driver returns, the attendant retrieves the car and transfers it to the driver at the exit. Attendant-park facilities maximize the number of cars usually by stacked parking (Figure 2-1). They often are located in high-value areas in larger cities.

Today, the most common type of parking structure in North America is the self-park facility where the driver parks and retrieves his own car (Figure 2-2). This chapter will discuss only the self-park approach to functional design.

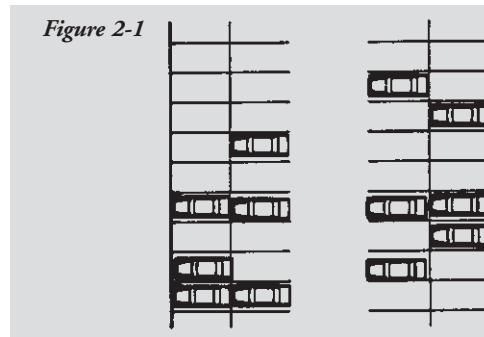


Figure 2-1

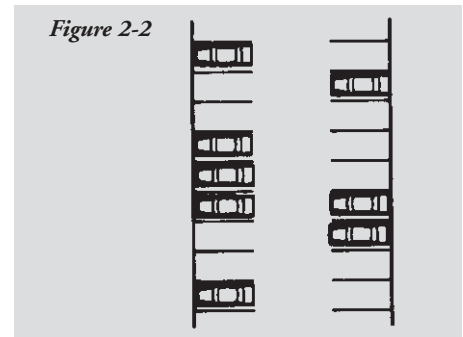


Figure 2-2

2.1.1.2

Building Code Types

The model building codes typically define parking structures in two categories: open parking structures and parking garages.

An open parking structure relies upon facade openness for natural ventilation and does not require a fire sprinkler system when built of concrete. The requirement for openness varies somewhat by what code is used.

Parking structures that don't meet the openness requirements are called closed parking garages and usually require a mechanical ventilation system or air shaft and sometimes a fire-suppression sprinkler system.

Some code jurisdictions classify basement parking areas as open parking structures when adequate natural ventilation is provided by areaways or light wells.

It should be noted that gross floor areas may be limited by openness criteria and the type of structural system. Also, required travel distances to stair exitways vary by code.

2.2

Revenue Control/ Operating Systems

Self-park facilities generally have two operating control locations, one at the entrances and the other at the exits. These control locations serve two types of parkers: the hourly or daily transient parker and the monthly contract parker.

2.2.1

Transient or Hourly Parking

At the entrance, the transient or hourly parker normally takes a time-stamped ticket from an electro-mechanical ticket dispenser or "ticket spitter," the entry control gate opens, and the parker enters the facility and drives to an available parking space. Sometimes two ticket dispensers are installed on the same lane to prevent lane shut-down in case a ticket dispenser malfunctions. After parking, the parker retrieves his vehicle and drives to an exit where he gives the time-stamped ticket to a cashier, who then manually or automatically determines the parking fee. Once the transaction is completed, the exit control gate opens, and the parker enters the street-circulation system. Section 2.2.3 discusses the pay-on-foot method.

2.2.2**Monthly Contract Parking**

The most common method of handling monthly parkers in North America is with a key card system. A magnetic or punched plastic key card, about the size of a credit card, is inserted into or read by the card receiver at the entrance. The system's electronics then activate the entry control gate, and the parker enters the facility. Monthly contract parkers may be directed to use the same entrance as the hourly parker (Figure 2-3), or a different entrance (Figure 2-4). Depending on the traffic circulation pattern, the monthly contract parker may use the same parking spaces as the hourly parker or may be directed to a separate monthly contract parking area. When exiting the facility, the monthly contract parker uses his key card to activate the exit gate.

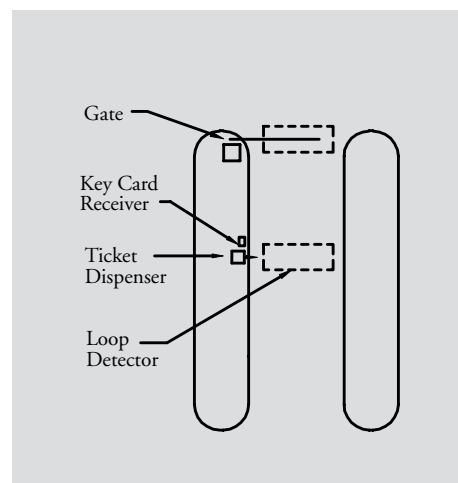


Figure 2-3

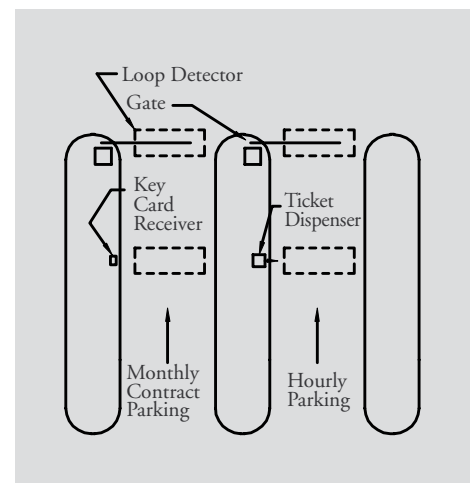


Figure 2-4

More complex systems use an anti-passback feature that prevents the reuse of a key card by another driver if the original user has entered the facility and not yet exited. Computerized systems may use computer inputs to lock-in or lock-out a vehicle if the monthly contract parker has not paid his parking fee.

One method to reserve the more-convenient lower floor parking spaces for hourly parkers is to bar these spaces from monthly parkers in the early morning hours, when the majority of the monthlies arrive (Figure 2-5).

No Parking
Before 9:30 A.M.

Figure 2-5

2.2.3**Cashiering**

The hourly cashiering system is called exit cashiering (Figure 2-6). An alternative is pay on foot or precashiering, in which the parker pays after returning to the parking structure but before retrieving the car. The parker is then given an exit pass with a grace period, usually 15 minutes, in which the parker can retrieve his car and exit the facility. The exit pass then is taken by an attendant at the exit or, more typically, may have a magnetic stripe that is read by a ticket receiver at the exit to activate the exit-control gate.



Figure 2-6



Figure 2-7

An alternative is the automated pay-on-foot precashiering system, which is quite popular in Europe and gaining adherents in North America. This system uses either a magnetic stripe or punch card ticket issued by a ticket dispenser at the entrance. Prior to retrieving his car, the parker inserts the ticket in an automatic cashing machine that computes the fee. The parker then inserts cash or credit card into the machine and receives an exit ticket. (Figure 2-7). This ticket then is used at the exit to activate the exit control gate. (A cashier can also be used for precashiering).

Revenue control is one of the major objectives of parking operating equipment. Automatic-read and semi-automatic cashing systems are commonly used to reduce revenue pilferage and revenue loss by cashier error.

In addition to outbound cashiering and precashiering, inbound cashiering often is used in structures serving event facilities such as convention centers and sports arenas. Inbound cashiering usually is done on a flat parking fee basis and, once the event is over, traffic free-flows outbound.

2.3

Street Access Design

The street traffic configuration—the pattern of adjacent two-way and/or one-way streets—can have a major impact on how a parking structure is used. Parking operators fear having a one-way street direction changed, which immediately reverses all the access directions to the entrances.

2.3.1

Entrances

Generally, entrances are placed on the high-volume streets providing direct access from the parker's origin to the parking destination. Parking facilities generally will have more than one entrance. This provides convenient entering for parkers from various adjacent streets and offers an additional entrance in case operating equipment malfunctions. Entrances should also be located away from street intersections (Figure 2-8).

Where a parking facility is adjacent to a high-volume or high-velocity street, a deceleration lane prior to the entrance helps eliminate rear-ending accidents and street traffic slowdown (Figure 2-9). Entrance ticket dispensers and gates preferably should be set in from the street far enough so that, when a car is at the ticket dispenser or key-card reader, another car can enter behind the first car and be clear of the sidewalk. In any event, a vehicle with a driver taking a ticket from a dispenser must be clear of the adjacent sidewalks and curb lines. When designing the entrances, a large van should be used as the “design vehicle” to check dimensional clearances (Figure 2-10).

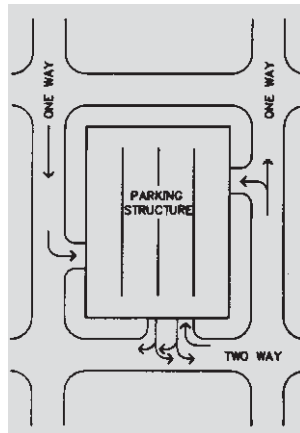


Figure 2-8

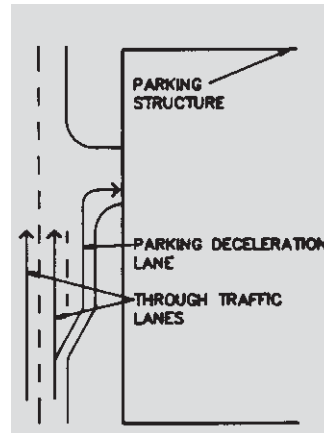


Figure 2-9

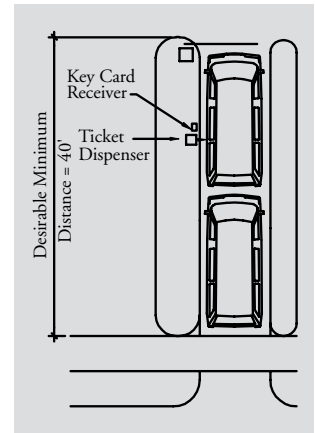


Figure 2-10

Operators often will monitor entrances remote from the cashier and manager's office area with TV cameras. The TV camera, coupled with an audio communication system installed in the ticket dispenser, aids communication if there is an equipment malfunction or if a parker has a question when entering the facility.

The architectural design of entrances impacts a successful parking operation. The entrances should be designed to be obvious and to look different from exits. Special architectural features such as arches, canopies, marquees, and other elements attract attention to the entrance and are encouraged (Figures 2-11 and 2-12).

One inbound lane is the minimum required for a garage with an average turnover of 300 to 500 cars per hour. For larger garages or smaller garages with high turnover, additional entrances will be required. Entrances should be located at least 75 to 100 feet from any corner intersection to prevent conflict with parking garage traffic and street intersection traffic.



Figure 2-11



Figure 2-12

2.3.2

Exits

Exits should be placed on low-volume streets, if possible, to reduce exiting delays caused by street congestion. It is preferable to have all exiting cashier booths grouped together so the parking structure can operate with one cashier during low-volume periods, minimizing operating costs.

The number of cashiering and key-card exit lanes will vary depending on the ratio of monthly contract parkers to transient parkers. Also, a turn to an exit lane can slow down the exiting rate of flow. For a typical municipal combination transient/monthly parking facility, one cashier lane for each 400 cars should be adequate. A minimum of two exit lanes for a parking structure accommodating at least 200 cars is recom-

mended. One lane is used as a primary cashiering lane, and the second lane is used as a secondary or peak-load cashiering lane. The secondary lane, however, is always available for monthly key-card exiting, allowing the monthly parker to bypass any backup that occurs at the cashier's booth. Cashier's booths at exits usually are located to provide space for at least one vehicle that already has completed the cashiering transaction between the cashier's booth and the adjacent street system or sidewalk (Figure 2-13).

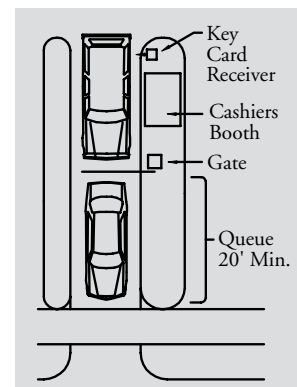


Figure 2-13

2.3.3

Floor-to-Ceiling Clearance

A minimum ceiling clearance of seven feet is recommended and stipulated in several of the codes. Often designers will increase the clearance to the underside of beams and double tee stems to 7'-6" or more to provide a greater feeling of spaciousness and provide better readability of overhead signs. In fact some parking structures have a typical clearance of over nine feet.

In areas providing access to ADA (Americans with Disabilities Act) federally mandated parking spaces, 8'-2" minimum clearance to all overhead obstructions is required. If they can't be located outside the structure, drop off zones particularly for ADA requirements may have as much as 9'-6" clearance.

2.4

Circulation Systems-Level of Service

Some factors affecting the level of service include parking-space angle and width, drive-aisle width, number and radii of turns, ceiling heights, lighting levels, ramp slopes, pedestrian crossings, entry/exit location and design, revenue control systems (exit cashier or pre-cashier), vehicle travel distances, and the traffic circulation system.

The most common circulation system used in free-standing parking structures in North America is the continuous ramp, where sloping floors with aisles and parking off both sides of the aisle offer access to the parking spaces and the circulation route. The basic continuous sloping floor configuration is called the single-helix or scissors ramp. This configuration is used with 90-degree parking and two-way traffic (Figure 2-14).

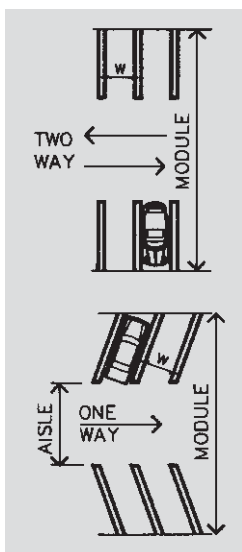


Figure 2-20

There are a number of systems using combinations of the single-helix continuous ramp, such as the two-bay end-to-end (Figure 2-15), the double-threaded helix (Figure 2-16), the three-bay double-thread (Figure 2-17), and the four-bay side-by-side (Figure 2-18). All of these circulation patterns lend themselves to one-way traffic and angled parking, although two-way traffic and 90° parking may also be accommodated in certain cases. The two-bay split-level is sometimes used to maintain a horizontal facade, but the added interfloor ramps usually add cost and are uncomfortable for drivers to negotiate (Figure 2-19).

While 90-degree parking could be used with a one-way system, it is not recommended because the 90-degree or perpendicular parking space does not provide the one-way traffic direction that angled parking creates (Figure 2-20). Advantages of angle parking include the ease of entering a parking space in a one-way traffic angle parking pattern and the elimination of two-way traffic conflicts and possible congestion.

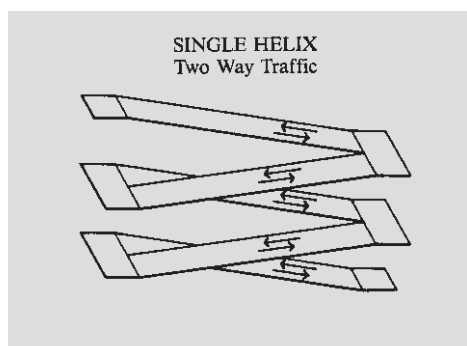


Figure 2-14

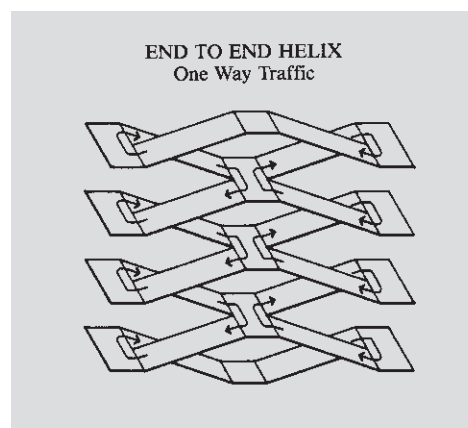


Figure 2-15

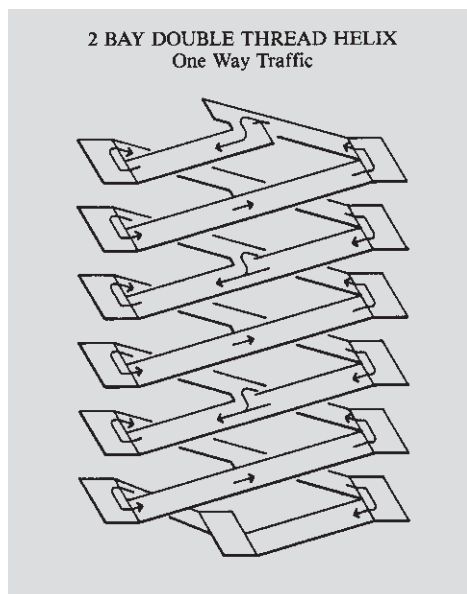


Figure 2-16

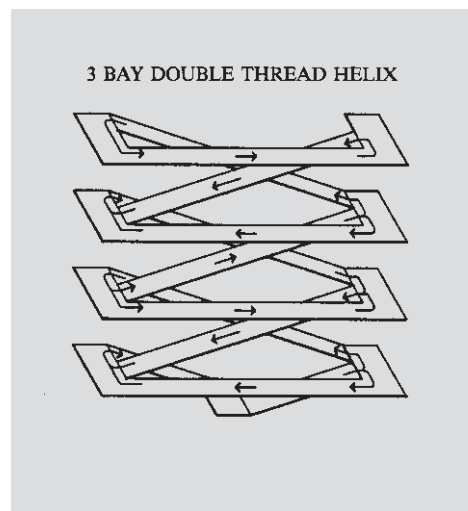


Figure 2-17

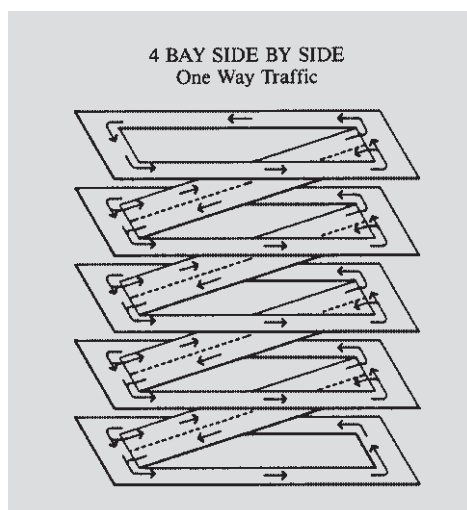


Figure 2-18

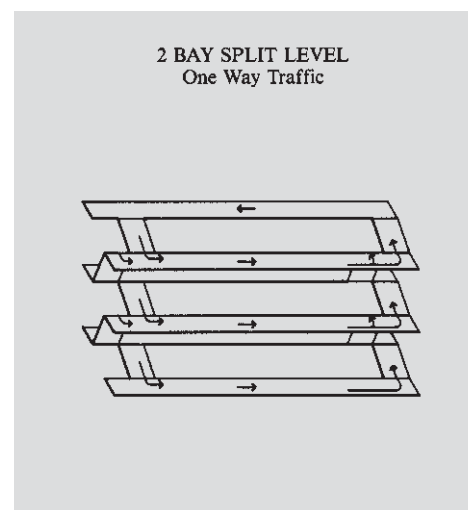


Figure 2-19

With certain types of peak period flows, a 90-degree, two-way traffic pattern can operate similarly to a one-way traffic layout. A facility with high inbound traffic in the morning and high outbound traffic in the evening, such as an employee-parking facility, will operate effectively as a one-way traffic facility.



Figure 2-21

Large-capacity parking structures, such as for airports or regional entertainment parks, often use flat-deck storage ramps with spiral express entrance and exit ramps so the parker doesn't have to search the entire parking facility for a parking space (Figure 2-21). Sloped, straight ramps also are used as entering and exiting express ramps (Figure 2-22). Large parking structures often will use electronic counting systems and displays to show the parking availability on different parking floors or locations.



Figure 2-22

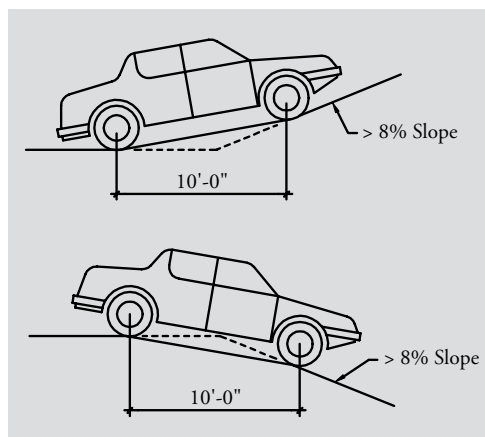


Figure 2-23

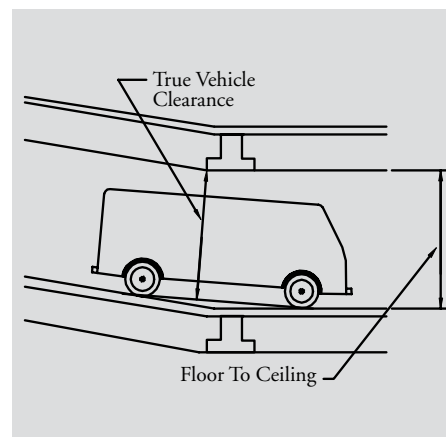


Figure 2-24

Typical grades in continuous ramp facilities on the parking floors generally do not exceed 6% (6 inches in 100 inches). However, continuous ramp grades up to 7% have been used successfully. Speed ramps (non-parking) should be limited to a 12% grade unless pedestrians specifically are excluded from the ramp by signage. Ramp grades greater than 15% can be psychological barriers to some drivers, particularly when the ramp is down-bound. When the ramp's break over slope exceeds 8%, a vertical-curve transition or a transition slope of half the ramp slope should be used (Figure 2-23).

With the popularity of vans and over-height recreational vehicles and the requirements of the Americans with Disabilities Act (ADA), some parking structures are developed with special high-clearance areas. Often this is done on the first or grade tier, where the grade slab can be lowered to create the additional clear height required at minimal additional cost. Generally for passenger vehicles, a 7'-0" minimum clear height is used, although 7'-4" to 7'-8" and even greater may provide a more spacious feeling. For over-height vehicles and ADA van-accessible spaces, clear heights of 8'-2" or greater are used. Height clearances on ramp breaks should be checked from the wheel line, not from the floor surface (Figure 2-24).

2.5

Parking Configuration

One of the major advantages of using precast prestressed concrete to construct a parking structure is its ability to provide economical clear spans of the parking bay. This creates a number of advantages. First, it eliminates columns between parking spaces, thus promoting the ease of entering the parking space without the "fender bender" stigma. Second, the columns take space used for parking in a clear-span structure. Third and most important, the clear span allows for future restriping of the parking spaces.

The advantages of being able to restripe in a clear span facility can be seen easily in light of the historical decline in car size. The average new car in North America reduced considerably from 1975 to 1985 due to gasoline efficiency laws. In 1975, a common parking space width and module was 9'-0" x 62'-0", while in 1985, 8'-6" x 58'-0" was quite adequate and remains generally adequate today (Figure 2-25).

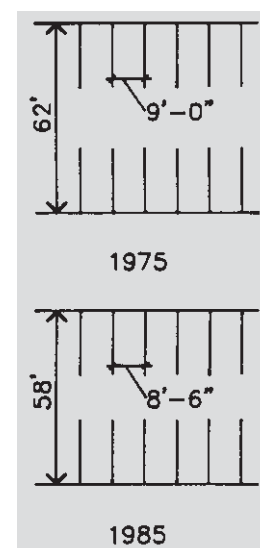


Figure 2-25

Some designers attempt to space columns along the bumper walls at a multiple of the parking space width so columns projecting into the structure do not interfere with parking. In other words, if a typical parking space is 8'-6" wide, columns would be spaced at 17'-0", 25'-6" or 34'-0". Since car lengths vary greatly and cars park randomly, column projections seldom cause problems. Typically, it is more economical to space columns on a double tee width module such as 8'-0", 9'-0", 10'-0" or 12'-0".

In angle-parking facilities, the restriping advantages can be even greater, because gains are achieved by rotating the parking-space angle as well as decreasing the space width (Figure 2-26).

The most efficient parking structure in terms of square feet per space is not necessarily developed with a 90-degree parking stall. Properly designed angle-parking layouts with one-way end crossovers can be more efficient than 90-degree layouts (Figure 2-27). The ease of parking and improved safety with a one-way traffic angle parking layout often offsets any decrease in efficiency when compared to 90-degree parking.

Parking-space width and parking module (bumper wall to bumper wall dimension) vary based on the desired level of comfort. Some parking structure designers provide separate sizes of spaces for large and small cars, while other designers use one size for all. It is not uncommon to see a one-size-fits-all parking space of 8'-6" (Figures 28 and 29) in width compared to a large car space of 9'-0" wide and a small car space of 7'-6" wide (Figure 2-30). The ratio of large cars to small cars varies throughout North America.

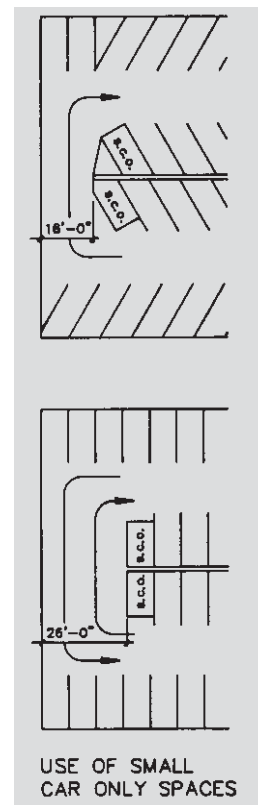
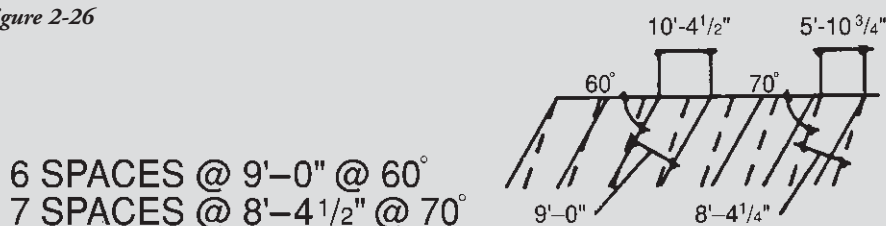


Figure 2-27

Figure 2-26



Even with the “one-size-fits-all” concept, it is common to place small-car-only (SCO) spaces at the end of parking rows adjacent to turns. This ensures that a large vehicle doesn’t project into the drive lane (Figure 2-29). To control the size of vehicles using SCO spaces, a closure line is placed across the end of the space with a notation on the “small car only” sign of “Don’t overhang rear line.”

Vehicle turnover in a parking space is a factor in selecting parking-space width. A low turnover facility for all-day parkers may have an 8'-2" width; 8'-6" may be provided for an average turnover and 8'-10" for a turnover of more than five vehicles per day.

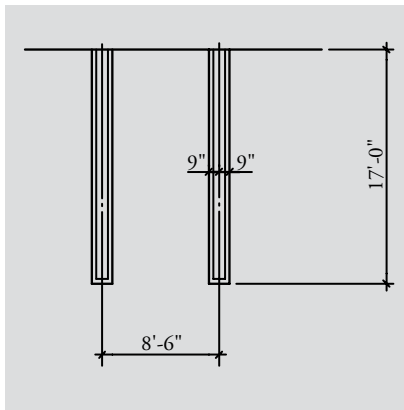


Figure 2-28

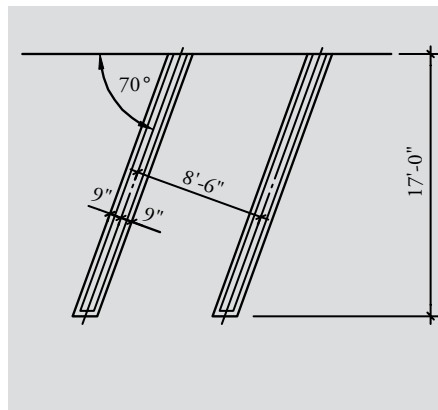


Figure 2-29

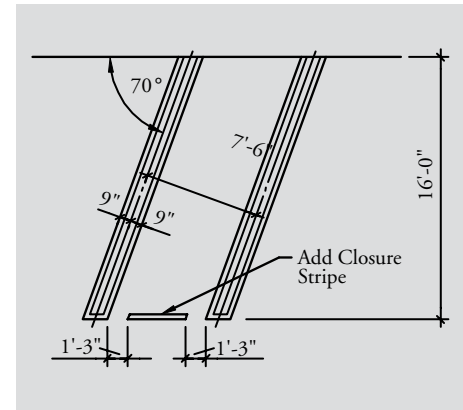


Figure 2-30

Parking-space module and space dimensions as recommended by the Parking Consultants Council of the National Parking Association are shown in Table 2-1. Note that where large and small cars are mixed, a one-size-fits-all space is developed as determined by the weighted average of the small-and large-car space dimensions.

Dimensional efficiencies can be achieved with angle parking by interlocking the spaces as shown on Table 2-1. Again, one-size-fits-all spaces can be developed by using a weighted average on the dimensions shown.

2.5.1

Accessible Parking

With the advent of the Americans with Disabilities Act of 1990 (ADA), more emphasis is required in hiring practices to eliminate discrimination in employment and in the physical design of new and renovated facilities. This translates into mandated improvements to create accessibility for the disabled in existing and new parking structures.

In new parking facilities, barrier-free provisions are required as follows:

- Minimum number of accessible parking spaces. See Table 2-2.
- Minimum sizes and clearances for accessible parking spaces along with requirements for “van-accessible” spaces.
- Types of accessible routes including stairs, slopes, ramps, etc.
- Types and capacities of elevators.
- Accessibility standards for employees such as barrier-free offices, washroom facilities, and hardware accessories.

Table 2-2

ADA Accessibility Guidelines:
Space Requirements

Total Spaces In Facility	Minimum # of Accessible Spaces
1 to 25	1
26 to 50	2
51 to 75	3
76 to 100	4
101 to 150	5
151 to 200	6
201 to 300	7
301 to 400	8
401 to 500	9
501 to 1,000	2% of total
1,001 and over	20 plus 1 for every 100 over 1,000

*Care should be taken to design for accessibility according to the guidelines of ADA and also according to local and state codes or ordinances that may require more restrictive designs (Figures 2-31). Health care facilities may have more stringent requirements under ADA.

Table 2-1

Typical Parking Dimensions

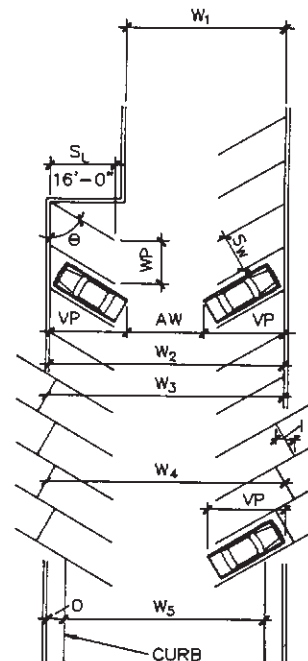
Small Cars

Angle	Interlock Reduction i	Overhang o	Vehicle Projection VP	Aisle Width AW	W ₁	W ₂	Module Widths W ₃	W ₄	W ₅
45°	2'-0"	1'-5"	15'-3"	11'-6"	26'-9"	42'-0"	40'-0"	38'-0"	39'-2"
50°	1'-10"	1'-6"	15'-9"	12'-0"	27'-9"	43'-6"	41'-8"	39'-10"	40'-6"
55°	1'-8"	1'-8"	16'-1"	12'-10"	28'-11"	45'-0"	43'-4"	41'-8"	41'-8"
60°	1'-5"	1'-9"	16'-4"	13'-4"	29'-8"	46'-0"	44'-7"	43'-2"	42'-6"
65°	1'-2"	1'-10"	16'-6"	14'-0"	30'-6"	47'-0"	45'-10"	44'-8"	43'-4"
70°	1'-0"	1'-11"	16'-7"	14'-10"	31'-5"	48'-0"	47'-0"	46'-0"	44'-2"
75°	0'-9"	1'-11"	16'-6"	16'-0"	32'-6"	49'-0"	48'-3"	47'-6"	45'-2"
90°	0'-0"	2'-0"	15'-6"	20'-0"	35'-6"	51'-0"	51'-0"	51'-0"	47'-0"

Large Cars

Angle	Interlock Reduction i	Overhang o	Vehicle Projection VP	Aisle Width AW	W ₁	W ₂	Module Widths W ₃	W ₄	W ₅
45°	2'-4"	2'-1"	18'-0"	13'-0"	31'-0"	49'-0"	46'-8"	44'-4"	44'-10"
50°	2'-1"	2'-4"	18'-8"	13'-8"	32'-4"	51'-0"	48'-11"	46'-10"	46'-4"
55°	1'-10"	2'-5"	19'-2"	14'-8"	23'-10"	53'-0"	51'-2"	49'-4"	48'-2"
60°	1'-8"	2'-7"	19'-6"	16'-0"	35'-6"	55'-0"	53'-4"	51'-8"	49'-10"
65°	1'-4"	2'-9"	19'-9"	17'-0"	36'-9"	56'-6"	55'-2"	53'-10"	51'-0"
70°	1'-1"	2'-10"	19'-10"	18'-4"	38'-2"	58'-0"	56'-11"	55'-10"	52'-4"
75°	0'-10"	2'-11"	19'-9"	20'-0"	39'-9"	59'-6"	58'-8"	57'-10"	53'-8"
90°	0'-0"	3'-0"	18'-8"	24'-8"	43'-4"	62'-0"	62'-0"	62'-0"	56'-0"

- θ Parking angle
 W₁ Parking module width (wall to wall), single loaded aisle
 W₂ Parking module width (wall to wall), double loaded aisle
 W₃ Parking module width (wall to interlock), double loaded aisle
 W₄ Parking module width (interlock to interlock), double loaded aisle
 W₅ Parking module width (curb to curb), double loaded aisle
 AW Aisle width
 WP Stall width parallel to aisle
 VP Projected vehicle length measured perpendicular to aisle
 S_L Stall length
 S_w Stall width
 o Overhang clearance
 i Interlock reduction



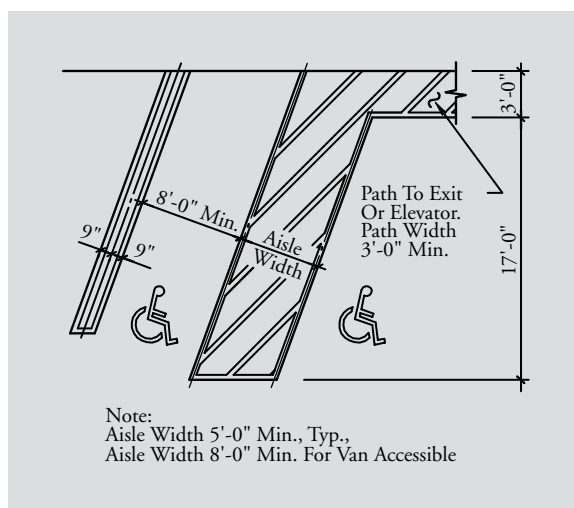


Figure 2-31

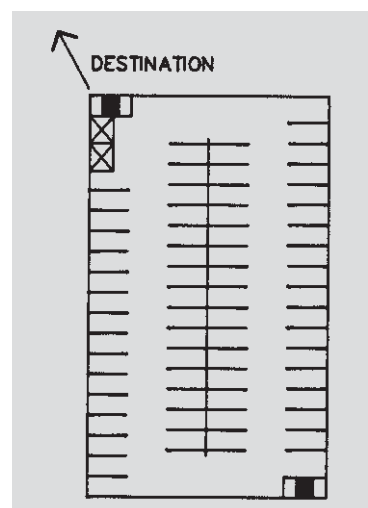


Figure 2-32

2.6

Pedestrian Circulation Stairs and Elevators

Stairs generally are located as required by fire-safety codes. Elevators generally are located in the direction of travel to the walking destination of the parker (Figure 2-32). The number of elevators is dictated by the number of parking spaces but influenced by the type of use as well. Many parking structures of 600 cars or fewer will have at least two elevators, with an additional elevator in the same bank for each additional 500 spaces. It is good practice to locate a stair next to the elevators. Single elevators should be used only with low-height parking structures where stair use is encouraged and the elevator is supplied for visitors with difficulty using stairs, or as required by ADA or the local building code.

Where high peak-load pedestrian traffic is anticipated, such as for major-event parking, extra-wide stairs are recommended. Wide stairs may require a center handrail. Sometimes, escalators are used for high-volume pedestrian traffic.

Single-run precast tread and riser units are an economical way to install stairs in a precast concrete parking structure (Figure 2-33). Also, special wide-spaced stem double tees are sometimes used to, accommodate precast stairs with an intermediate landing (Figure 2-34). Metal pan, structural steel stairs and landings with precast wall panels can also be used for stair towers.

Some model building codes allow stairs used as fire exits to be constructed without walls to provide openness and better passive security. In northern climates, while maintaining openness on the interior, it may be desirable to provide glass walls on the exterior side of the stairs and a roof over the stair on the upper deck, to provide a wind break and prevent ice and snow accumulation.



Figure 2-33



Figure 2-34

2.7**Security**

Security is a specialized field. Owners may find it prudent to retain a security consultant to review the design documents during the design review stage. Typical security features are divided into two categories, passive and active.

2.7.1**Passive Security**

Passive-security features are those designed into the facility to create a feeling of comfort on the part of the user and to create an atmosphere that deters criminals. Passive security features include designing for general openness, designing to eliminate nooks and corners that create hiding places, providing good lighting, including glass walls on stairs and elevators to promote openness and visual access, and installing video monitors. Solid walls should be avoided whenever possible. Precast “lite walls” (Figure 2-35) may be an economical way to achieve openness. Locating stair and elevator shafts on the exterior where they are exposed is also a good practice for passive security.

Video-TV monitoring (Figure 2-36) is classified as passive security because the mere presence of cameras creates a deterrent to the criminal even though there is no guarantee that the criminal activity will be seen by the person who is supposed to be watching the TV monitor. However, a motion sensor integrated with a video tape usually is used to record activity. Periodic scanning of floors by a security officer viewing a TV monitor is a good security feature and also can aid in traffic control during high-volume periods.



Figure 2-35



Figure 2-36

2.7.2**Active Security**

Active security measures are those which actively prevent or deter criminal actions. Lower-level fencing (Figure 2-37) and rolling steel gates prevent unauthorized entry into the parking facility. Audio two-way speaker microphones (Figure 2-38), which are voice-activated, promote immediate response by security forces. The best active-security feature, however, is the roving patrol, either on foot or in a vehicle. The patrol also serves a public-relations function by aiding people with dead batteries or flat tires.

2.8**Lighting**

Pedestrians and vehicles simultaneously use the same aisle, requiring special attention to adequate visibility of people, objects, and vehicles. Adequate lighting also is required for ambient illumination of signage, deterring crime and user comfort.



Figure 2-37



Figure 2-38

In parking structures, ceiling heights are low compared to the large floor areas, requiring light fixtures that produce a wide distribution of light without excessive glare to the driver. But they also must provide adequate distribution of light over and between vehicles and for overhead signage. Structural-system elements often dictate fixture placement, limiting the flexibility for locating fixtures. The coffers created by double tee stems may obstruct the light if fixtures are not positioned properly. Specially designed reflectors now can provide even light distribution for double tee systems. The goal is to develop an economical lighting system that minimizes operating and maintenance costs at a reasonable first cost.

2.8.1

Lighting Design Criteria

The Illuminating Engineering Society of North America (IES) design guidelines for parking facility lighting are:

Source: RP-20 Lighting for Parking Facilities, Illuminating Engineering Society of North America, August, 1984.

Notes: (1) Sum of electric lighting and daylight.

- (2) Entrance area is defined as the portal or physical entrance to the covered portion of the parking structure to a point 15 meters (50 feet) beyond the edge of the covering into the structure.
- (3) Vertical illuminance at 1.8 meters (6 feet) above the pavement should equal above values.
- (4) Emergency lighting should provide a minimum of approximately ten percent of the above lighting levels or as required by local code.
- (5) Footcandles is the unit of measure of total light on a surface. One lumen falling on a surface of one square foot produces one footcandle.

2.8.2

Fixture Selection

There are three basic types of lighting fixture: cutoff, semi-cutoff, and non-cutoff.

Cutoff fixtures enclose the lamp within the fixture housing and distribute a cone of light below the fixture by a reflector (Figure 2-37). These fixtures do not illuminate the ceiling and must be placed at very close spacings to provide good three-dimensional illumination at driver's eye level and for overhead signage. They are not recommended in covered parking facilities where the mounting height is less than 10 feet. They are used extensively for surface parking lots and on the roofs of parking structures where the mounting height is 20 feet or more and where spilling light onto adjacent properties is a concern.

Table 2-3
IES Lighting Design Recommendations

	Day	Night	
Areas	Footcandles, average on pavement (1)	Footcandles, average on pavement	Uniformity Ratio (Average/Minimum)
General parking and pedestrian areas	5	5	4:1
Ramps and corners	10	5	4:1
Entrance areas (2)	50	5	4:1
Stairways	Range of Illuminances Footcandles 10-15-20		

A semi-cutoff fixture encloses the lamp within the fixture housing (Figure 2-40). However, additional uplight is provided by a prismatic lens attached to the bottom of the fixture, or by placing “windows” in the top of the fixture to better illuminate vertical surfaces at and above driver’s eye level compared to cutoff fixture.

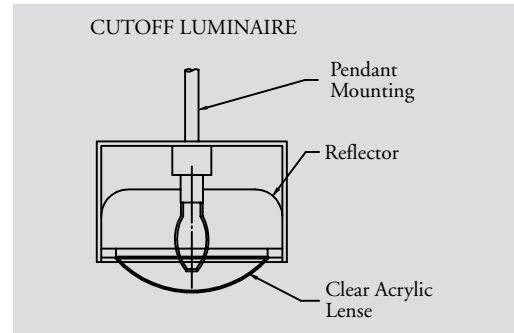


Figure 2-39

A non-cutoff fixture has the lamp or bulb mounted below the fixture housing and is enclosed in a wraparound clear-plastic or glass prismatic lens (Figure 2-41). The lens design often redirects the light output to minimize glare to the driver. An internal reflector also sometimes is used to

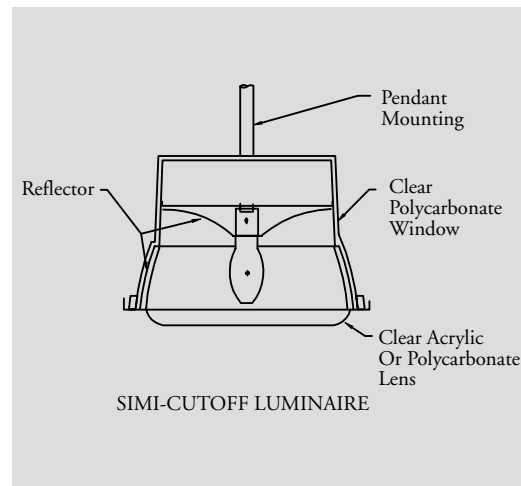


Figure 2-40

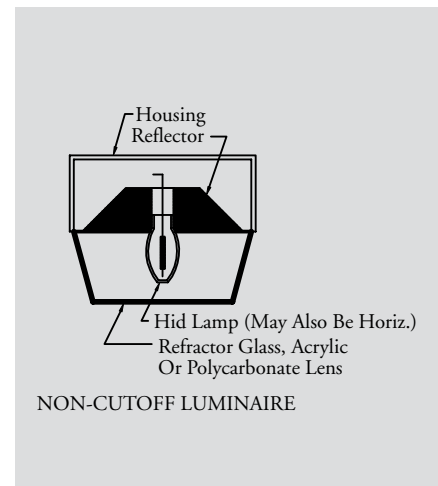


Figure 2-41

redirect the light output from the exposed lamp to minimize glare. These fixtures provide the best three-dimensional distribution of light, but there is greater potential for glare discomfort and point source of brightness when visible from outside the parking facility.

Bare-tube fluorescent fixtures or fluorescent fixtures with a wraparound lens are non-cutoff fixtures. The preferred orientation of fluorescent fixtures is for the long dimension of the tube to be parallel to the centerline of the drive aisle. This orientation dictates a 4-foot-long tube where the tee stem spacing is 5 feet.

2.8.3

Light Source Selection

The most common types of lamps used in parking facilities are high-pressure sodium, metal-halide, and fluorescent.

For interior areas, lamp wattage typically ranges from 60 to 175 watts. Higher lamp wattages produce excessive heat and glare from the low mounting heights typical in covered parking facilities. Therefore they are not recommended except for use for roof lighting.

Aesthetically, the color of the light source is the biggest difference between these lamps. Fluorescent and metal-halide lamps emit a white light, while high-pressure sodium lamps produce a yellowish light. The effect of this color difference has often been exaggerated. While high-pressure sodium lamps slightly distort the hue of many colors, the full spectrum of colors can be identified. Users still can identify their vehicle with HPS lighting. Paint colors for signage and graphics can be selected to result in a more true color rendition under HPS lighting.

Fluorescent lamps are subject to significant reduction in light output where exposed to wind and low temperatures. Therefore, exposed fluorescent lamps should not be used in outdoor environments except in the southern part of the United States. In colder climates with average winter temperatures of +40°F or less, a wraparound clear lens should be used for protection from wind and low temperatures. The most energy-efficient and cost-effective fluorescent systems consist of T8 fluorescent lamps with electronic ballasts.

In northern climates, metal-halide lamps should be used when a “white” light source is desired. Metal-halide lamps have approximately 80 percent of the light output and only 35 to 50 percent of the lamp life of high-pressure sodium lamps. Maintenance costs for relamping of metal-halide lamps typically will be approximately double that of high-pressure sodium lamps.

High-pressure sodium lighting remain the most cost-effective light source for parking facility lighting. Although color-improved versions of HPS lamps have recently become available, those lamps have reduced light output and reduced lamp life similar to metal-halide lamps.

2.8.4

Fixture Placement

The spacing of precast concrete double-tee stems most often dictates the placement of light fixtures. A 10-foot-wide double-tee with a tee stem spacing of five feet will result in a light fixture spacing on a five-foot module. However, placement of light fixtures below the flange joint of the double tees is not recommended, as inadequate

maintenance of the joint sealant may result in water leakage that will damage the lighting system. If fixture placement in the flange joint soffit is necessary, the light fixture should be offset to the uphill side of the joint. It is typical to cast openings in the double tee stems above the prestressing strand to allow for placement of continuous electrical conduit for lighting.

In order to minimize blockage of light, the light fixture should be mounted so the bottom of the fixture is approximately level with the bottom of the double-tee stem. The proper mounting height is determined by drawing a straight line from the center of the light source to a point midway between the fixtures at an elevation of six feet above the floor without intersecting the bottom of the tee stem. (Figure 2-42).

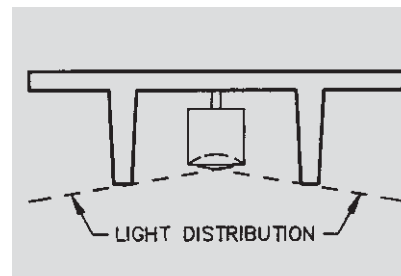


Figure 2-42

Figures 2-43, 2-44 and 2-45 show typical lighting configurations for covered parking facilities. The single row of light fixtures on the centerline of the drive aisle (Figure 2-43) generally is not recommended, as it is difficult to meet the IES average-to-minimum uniformity ratio or the vertical-illuminance criteria. The configuration in Figure 2-44 or 2-45 is recommended for precast concrete double tee parking structures. The staggered configuration in Figure 2-45 illuminates more of the double tee stem soffits and thus provides for a brighter ceiling appearance.

FIXTURE LOCATIONS

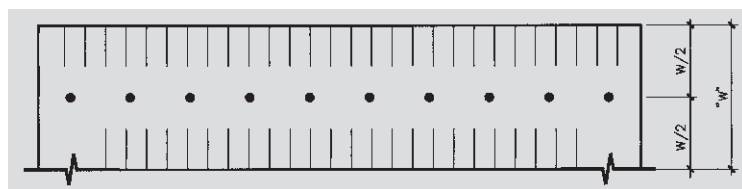


Figure 2-43
Single Row Lighting

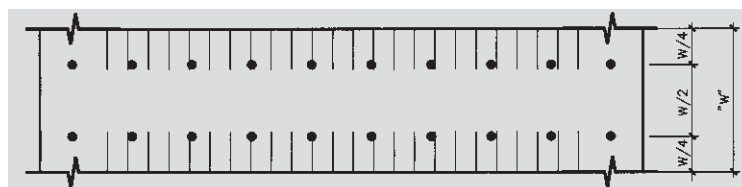


Figure 2-44
Double Row Lighting

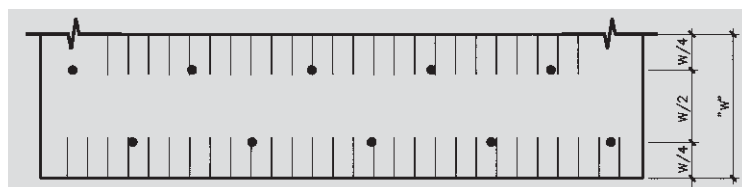


Figure 2-45
Staggered Row Lighting

2.8.5

Electrical Equipment Room

Electric metering and switching often requires a separate area or room in a parking structure. This room may be a partitioned section of a storage room where maintenance equipment and supplies are kept. If the equipment room is not readily accessible to operating areas (cashier booths and office), remote switching of the lighting from the office or a cashier booth may be desirable.

2.9

Graphics and Signage

Graphics and signage play a significant role in how both vehicles and pedestrians circulate through a parking structure.

Entrances and exits should be well designated, not only architecturally but also with signage such as “Enter,” “Entry,” or “Entrance.”

The signage can be developed using reflective material, neon, backlit, or Light Emitting Diode (L.E.D.). The signage must be “user friendly” and make the entrances and exits to the facility as identifiable as possible.

Entry signage also must list minimum clearance designation, which is often developed with a “headknocker” (Figure 2-46). This can be made from chains, plastic pipe, or some other device that will hit the top of the vehicle and alert the driver if the vehicle is too high to enter the facility without causing damage to the vehicle. Barrier-free parking spaces require additional headroom for van-accessible spaces and may require the use of two “headknockers,” one set for van-accessible height (8'-2") and an additional bar located beyond the van spaces for the rest of the facility.



Figure 2-46

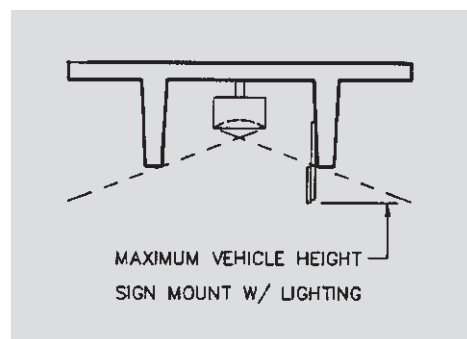


Figure 2-47

If vehicles are entering a structure at the top level, or if the posted clearance is greater than 7'-0", it is suggested that a weight limit also be posted at the entrance to prohibit entrance by vehicles of excessive weight such as service vehicles, dual wheel snow plows, and semitrailer trucks. Since some model building codes require designing for a 2,000-pound concentrated floor load, a 7,000-pound maximum vehicle load limit is appropriate, since the axle weights are typically disproportionate.

Wayfinding in parking structures can be confusing to some patrons. The ideal functional design (layout) should reduce confusion by minimizing directional decisions and reinforce wayfinding by circulating past readily identifiable landmarks such as elevators and stairs. Signage is used to reinforce the natural inclination of drivers and pedestrians to find their way. Generally, vehicular signage is of primary concern and pedestrian signage is secondary.

Vehicular signage should direct the driver into the facility to a parking space and provide adequate signage to direct the user to the exit. This signage should be centered on the path of travel and placed as low as possible for visibility, but not lower than the maximum allowable vehicle height (Figure 2-47). Signage in precast double tee construction must be placed so that the stems of the double tee will not interfere with the driver's view of the sign. This may require additional floor-to-floor height above the minimum.

Secondary or pedestrian signage should direct the users from their parking space to the appropriate stair and elevator. This signage should be over the drive-aisle end of the parking space and placed in the direction of the pedestrian flow. In addition to stair/elevator directional signs, pedestrian signs should be provided to direct the parker to emergency assistance call boxes, sound monitors, etc., as well as to specific destinations. Both vehicular and pedestrian signage should minimize or eliminate conflicts between vehicles and pedestrians and reinforce the individual's natural directional inclination.

One problem that occurs in parking structures, especially in a continuous sloped structure, is the confusion for the parker in retrieving his car. Large graphics in the stair and elevator lobbies denoting the floor and an indication for the parker to remember his floor level should be provided. Memory joggers to help the parkers remember their parking location are often used. Themes such as colors, athletic teams, or animals designating each floor.

Also, ADA (Americans with Disabilities Act) signage including braille markings must be mounted in appropriate locations. Signage should be provided at each parking module to further assist the user in larger multi-module garages. Some parking facility operators number each space to aid in vehicle control.

Signs should be mounted securely to the supporting structure. Lighting should be coordinated with signage so special sign lighting is not generally required. However, lighting should be located so the light's brightness doesn't create glare and interfere with reading a sign (Figure 2-47).

Typical signage in parking structures can be developed using reflective materials enhanced by adjacent light fixtures. Illuminated signage such as L.E.D. or neon signs can be developed at critical decision points in the structure and must be analyzed on each project for their cost/benefit, including the additional maintenance cost involved. Variable message signs or space available count signs may be helpful in large parking structures.

2.10

Other Items to Consider

The above discussion is aimed at the open-parking structure, which requires no mechanical ventilation or fire sprinkler system (although dry standpipes are often provided in open parking structures). If a parking structure is enclosed or underground and does not meet the open parking requirements for natural ventilation, then mechanical ventilation and sprinklers may be required. Ventilation at a rate of one cfm per square foot of area usually is adequate for a parking structure, except where a great deal of queuing is expected, such as in major event facilities. Carbon-monoxide sensors are recommended for underground facilities.

When required by the building code, sprinkler systems for fire protection are installed in a conventional manner. However, in freezing climates, a dry-type system is required.

Locating fire extinguishers in the parking areas is discouraged, as they are often stolen. The overall experience and low likelihood of fire in a parking structure has shown that keeping fire extinguishers in the cashier's booth and in the manager's office is usually sufficient fire protection. However, the building code may require otherwise.

Curbs in the vicinity of stair and elevator towers are tripping hazards, and their use is discouraged. Precast or plastic wheel stops are not recommended (Figure 2-48), as they provide an area for trash and debris to collect, are trip hazards, and are often dislodged by cars and snowplows. Also, curbs should not be expected to act as edge

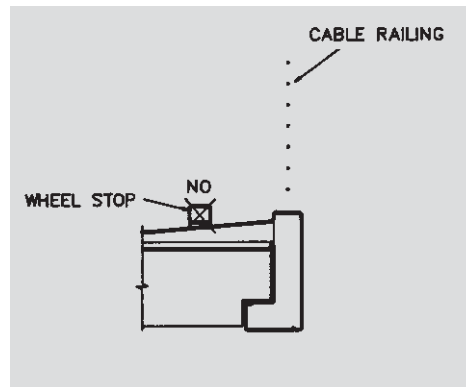


Figure 2-48

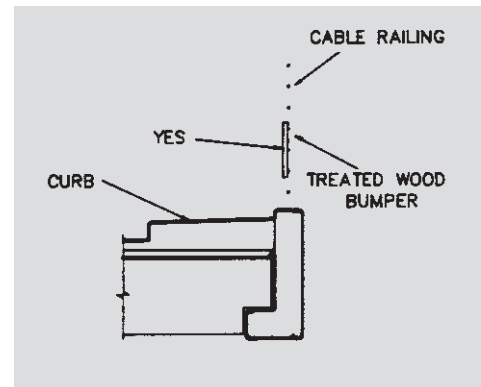


Figure 2-49

restraints to stop a car. If curbs or wheel stops are used, they should be painted a contrasting color from the floor such as traffic yellow to enhance visibility. Often curbs will be used as wheel stops when rails are used in lieu of concrete bumper walls (Figure 2-49). When curbs are not used with rails, some type of guard rail, possibly wood planking, should be installed on the rail at bumper height to prevent bumpers from catching in the rail. Cable rails should be adequately stressed and properly anchored to maintain tightness.

Recent revisions to some of the model building codes have banned metal railings with horizontal elements that create a ladder effect. Also, the maximum opening dimension in a railing is as low as four inches. To meet these requirements, it may be most economical to design railings with horizontal prestressing strand to resist the bumper load of the vehicle (10,000 pounds ultimate point load at 18 inches above the floor surface unless otherwise required by the local code) and attach cyclone fencing to the cables to meet the openness requirements. It should be recognized by the designer that these strands impart significant forces that may create problems due to restraint to volume change movement.

2.11

Summary

The objectives of the functional design of a parking structure are to create a facility with a simple continuous traffic flow, parking spaces that are easy to park in, and an atmosphere that gives the user the feeling of safety and comfort, it also should operationally insure that the revenue collected from the parker is revenue received by the operator and owner.

For additional information regarding parking functional design, one may contact:

National Parking Association
1112 16th Street, N.W., Suite 2000
Washington, DC 20036
Phone: 1-800-647-PARK
Fax: 202/331-8523

International Parking Institute
P.O. Box 7167
Federicksburg, VA 22404
Phone: 540/371-7535
Fax: 540/371-8022

3.0

DURABILITY CONSIDERATIONS

3.1

Introduction

Precast prestressed concrete parking structures have been proven to be durable and are well suited to areas where corrosion and freeze-thaw damage are potential problems. But in order to provide reliable service, they must be designed, fabricated, erected, and maintained according to principles of good practice.

The precast prestressed concrete parking structure can be thought of as a lightly-loaded bridge built in the configuration of a building. Parking structures differ from bridges in that they are usually constructed on a building site, regulated by building codes, and designed by engineers with building design experience. Like highway bridges, however, they encounter dynamic loadings, severe temperature changes, weathering, and often chloride penetration from deicing salts or ocean-generated airborne salts. The engineer must keep in mind the uniqueness of the structure, especially that it is exposed to the weather.

3.2

Durability Factors

The major factors affecting parking-structure durability are restraint to volume changes, deterioration from freeze-thaw cycles, and corrosion damage from chloride exposure.

In precast prestressed concrete parking structures, dimensional-volume changes occur due to concrete shrinkage and creep and temperature changes. Shrinkage and creep shorten the members, but most of these strains occur before precast products are erected, so their effects are minimized. Volume changes due to temperature variations, both daily and seasonal, will either shorten or elongate a member. Distress can occur if the resistance to natural volume change induces excessively large forces. The effects of volume changes on a parking structure are a structural design concern covered in Chapter 4.

Climatic durability relates to the structure's ability to withstand the effects of freeze-thaw action and deicing salts in colder climates, and the effects of airborne salt in coastal areas. Moderate-climate regions may experience more freeze-thaw cycles than where temperatures stay below freezing for longer periods. It also should be recognized that salt application can cause concrete-surface scaling, particularly when the concrete is relatively young. A map identifying different exposure conditions is presented in Figure 3-1.

Durability Zones

ZONE I: The mildest conditions, where freezing is rare and salt is not used.

ZONE II: Areas where freezing occurs but deicing salts are not or rarely used.

ZONE III: Areas where freezing and deicing salts are common.

ZONE CC (Coastal Chloride) I: Areas within Zone I within five miles of salt-water bodies (the Atlantic Ocean, Gulf of Mexico, Pacific Ocean and the Great Salt Lake).

ZONE CC I (Coastal Chloride) II: Areas within Zones I and II within 1/2 mile of the salt-water bodies listed in Zone CC I.

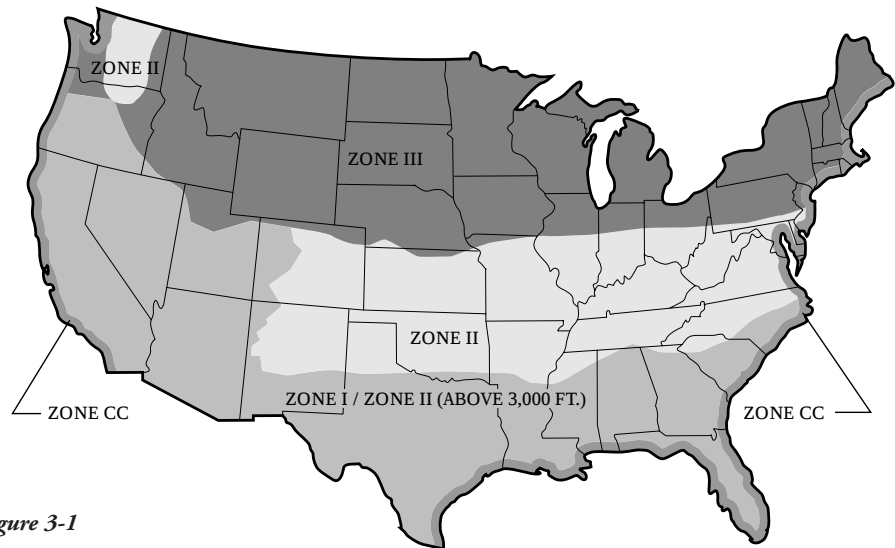


Figure 3-1

3.3

The Corrosion Deterioration Process

Corrosion is an electrochemical process that requires an anode (or area of oxidation), and a cathode (or area of reduction). In the case of concrete reinforcement, the anodes and cathodes are elements of steel-reinforcing bars, welded-wire fabric, or strand. The process requires oxygen and an electrolyte—in this case, water-soluble chloride ions, and is the major cause of premature corrosion of reinforcing steel in parking structures. In simple terms, the bars or portions of bars that are anodes rust, but the steel that becomes a cathode does not. Generally, anode steel is near the top surface and cathode steel is lower in the member.

There are several potential sources of chloride ions in concrete. Chloride may exist in cement compounds or in aggregates. Certain concrete admixtures contain chlorides as can mixing water, but these sources do not normally contain significant amounts of corrosion-causing chloride. In northern climates, the most common source of chlorides is deicing salts; more than 10 million tons are used on North American streets and highways every winter. In coastal areas, airborne salt from the ocean can also cause corrosion.

Deicing salts are carried with snow and ice on the undersides of automobiles. The salty water that melts from these cars falls to the floor, often ponding on surface depressions (Figure 3-2). The chloride-laden moisture seeps into the concrete through tiny capillaries formed when the concrete cured. If the concrete surface is cracked, chlorides can rapidly penetrate the slab. If the concrete is sufficiently permeable and the reinforcing steel is close enough to the surface, the steel eventually will come into contact with the chloride-laden moisture.



Figure 3-2

Since the corrosion rate of steel is reduced as the pH of the surrounding concrete increases, the relatively high alkalinity of concrete normally protects reinforcing steel from corrosion. (pH is a chemical term expressing the acidity or alkalinity of a solution. A low pH is acidic, a high pH is alkaline.) The presence of free chlorides, however, reduces concrete's pH to a level impairing the protection given by concrete's inherent alkalies, and, with water, increases its electrochemical conductivity.

Federal Highway Administration research indicates that in moist-cured concrete, corrosion begins when the acid-soluble chloride content at the level of reinforcing bars reaches a range of 0.18 to 0.26% by weight of Portland cement. This value is called the corrosion threshold. Other measures are 1.2 to 1.6 pounds of chloride per cubic yard or 300 to 400 parts per million (ppm) of concrete. (The ACI Building Code, ACI 318, establishes limits for new concrete of 0.20% of acid-soluble chloride ions by weight of cement to weather-exposed reinforced concrete poured in the field, but only 0.08% for prestressed concrete). Once the corrosion process begins, the only way to slow or stop it is to apply electric current to the reinforcing steel to reverse the electrochemical process - a costly procedure known as cathodic protection. Rehabilitation is typically required to restore the integrity of the structure. Corrosion inhibitors, breathable barriers, and coatings are other methods that can significantly slow but not entirely stop the process.

As corrosion proceeds, iron ions migrate away from the corrosion site and react with oxygen to form oxides. As steel rusts, the volume increase can be substantial and the resultant pressures can cause cracking, spalling, and delaminations in the surrounding concrete. This in turn can accelerate chloride penetration (Figure 3-3).

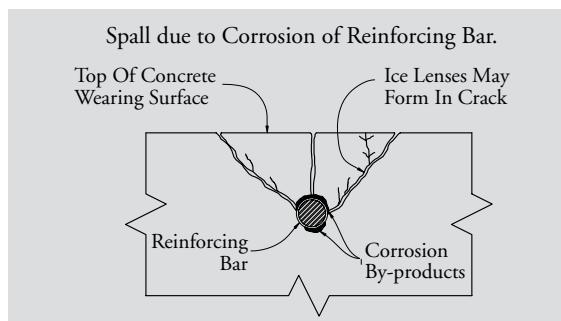


Figure 3-3

Corrosion and concurrent concrete deterioration can weaken structural members by causing loss of concrete cross section, loss of reinforcement cross section, loss of member ductility, loss of bond between the reinforcement and the concrete, and loss of monolithic behavior of the member. With time, structural distress can occur in addition to the aesthetic problems associated with rust and the deteriorating concrete.

3.4

Designing for Climatic Deterioration

Major deterioration occurs in harsher climates due to freeze/thaw action and the corrosive effects of deicing salts. These corrosive effects also are prevalent in areas where ocean salts are carried inland by air movement. Criteria to be considered in the design of any parking structure include:

- concrete quality
- proper surface drainage
- concrete cover over reinforcement
- surface sealers
- crack-prevention design
- construction joint and control-joint sealants

3.4.1**Concrete Quality**

Concrete performance is generally defined in terms of durability. The primary criterion for durability is high-quality concrete—i.e., a minimum of 5,000 psi compressive strength, made with durable hard-rock aggregates for good abrasion resistance. In more definitive terms, high-quality concrete design must incorporate considerations for the following parameters: Strength, permeability, durable aggregates, and air entrainment.

Concrete strength above 5,000 psi can be obtained through the proper balance of cementitious content and water/cement ratio. While geographical differences in material availability and performance exist, cementitious contents in the 600-700 lbs. per cubic yard range and water/cement ratios in the 0.40-0.45 range will usually result in strengths above 5,000 psi. Higher strength, with a corresponding lower permeability, is achieved with high cementitious content and a lowered water/cement ratio, sometimes augmented by the use of fly ash or microsilica.

To effectively limit permeability of floor-slab concrete, the water/cement ratio should not exceed 0.40-0.45. For even lower permeability in corrosive environments, water/cement ratios between 0.32 and 0.40 can be achieved readily through the use of superplasticizers (high-range water reducers) or other water reducers in the concrete mix. This is common practice for those plants that produce pretopped double tee members. A recent study¹ confirmed a previous FHWA corrosion study² showing that the concrete water cement ratio is the dominant factor in reducing chloride permeability. Lowering the water cement ratio from a level between 0.46 to 0.51 to a level between 0.37 to 0.40, reduced the chloride at a depth of 1" after severe 1-year saltwater exposure by about 80 percent (Table 3-1).

Table 3-1

Study	Change in w/c	Reduction in chloride at 1-in (25-mm) depth (%)
1987 FHWA	0.51 to 0.40	80
Present	0.46 to 0.37	80
1987 FHWA	0.51 to 0.28	95
Present	0.46 to 0.32	94

Aggregates play a major part in the determination of concrete quality. Durable aggregates possessing proper hardness, soundness, and low absorption are recommended for both compressive strength and abrasion resistance. Air entrainment should be in accordance with American Concrete Institute standards (5% to 7% in cold climates). In addition, good concrete placement practices as defined in American Concrete Institute Standards are necessary.

3.4.1.1**Topping Quality**

In order to provide durability, field-cast, concrete-wear surfaces should have the qualities described above and should be placed using proper methods. Specifications need to be strictly adhered to. The recommended alternative to using topping concrete is to specify a plant-produced, pretopped precast structure. Pretopped precast concrete members generally have air-entrained concrete with strengths in excess of 5,000 psi

and the greater durability associated with the lower water/cement ratio. Proper adherence to good concreting practices, including proper curing to reduce shrinkage, cracking, and crazing, is necessary to create durable concrete surfaces. Minimum strength for field placed toppings should be 4,000 psi.

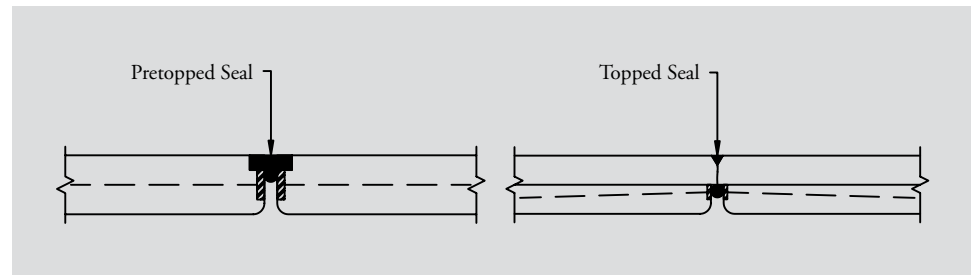


Figure 3-4

Prior to placing topping concrete, the joints between the tee flanges and tee ends should be covered or sealed to prevent concrete leakage. The precast deck unit must be cleaned thoroughly and wetted prior to placing the concrete. To control shrinkage cracking, which typically occurs at the flange-to-flange joints, the topping must be hand-tooled at the flange-joint locations (Figure 3-4). The joints then are filled with an elastomeric joint sealant to provide watertightness. It's recommended that all precast joints covered by topping receive a tooled joint in the topping.

3.4.1.2

Finishing

Finishing the concrete is also critical. The key to durability is to minimize finish working of the concrete and to maximize curing so as not to disrupt the matrix at the surface and drive out moisture needed to hydrate the cement at the surface. Minor roughness is desirable to improve traction. A hard-troweled finish should be avoided. Precast surfaces that are field-topped are typically roughened by using a rake on the semi-plastic surface. Pretopped tees usually have a medium broom finish.

Final finishing of field-placed topping concrete should not commence until the bleed water has disappeared. Early finishing results in driving the bleed water back into the surface, increasing the water/cement ratio in the critical top layer and greatly increases the probability of surface scaling later. The low water/cement mix used in the plant minimizes this problem, because very little bleed water exists and finishing can proceed quite rapidly. When a bridge-deck finishing machine is employed, screeding and finishing are combined into a single operations. If silica fume is used in the mix, finishing should be done quickly, as bleed water is much reduced. The use of an evaporation retarder is required to avoid plastic shrinkage cracking.

3.4.1.3

Curing

Curing methods depend on weather conditions. Enough moisture must be present to hydrate the cement, but excess moisture must be allowed to escape prior to sealing the concrete surface. With low water/cement-ratio concrete, an evaporation retarder often is applied to the concrete surface during the finishing stage to reduce evaporation and prevent plastic shrinkage cracking. The curing temperature is best kept below 160°F, based on industry recommendations.

The ability to achieve high durability through various curing methods has been studied in a recently released report.¹ Various durability properties were measured in concretes cured in different ways and mixed with different water/cement ratios. Each tested concrete specimen was cured in a water tank, under wet burlap, or by heat-curing. Concretes incorporating admixtures of silica fume were cured under wet burlap only.

A portion of that paper is reprinted here, which presents conclusive evidence that plant-cast heat-cured concrete exhibits superior durability characteristics to concrete poured in the field:

“The results of this study show that heat-cured conventional concretes at 0.32, 0.37, and 0.46 w/c produced water absorptions and volume of permeable voids that were much lower than the 12 moist- and tank-cured mixtures that were moist-cured for 7 days and contained 0, 5, and 7.5 percent silica fume. In fact, at all water/cement ratios the silica fume concretes had volume of permeable voids that were on average 100 and 50 percent greater than the heat-cured conventional concretes for the 5 and 7.5 percent silica fume additive rates, respectively. The highest volume of permeable voids for heat-cured conventional concrete was only 7.97 percent, a value lower than the 9.62 percent voids of the best performing silica fume mixture (0.33 w/c with 7.5 percent silica fume). These high absorption values for all of the silica fume concretes may explain the high surface chloride concentrations for these silica fume concretes observed during the long-term ponding tests.

“The long-term ponding tests showed that the AASHTO grade 0.46 w/c heat-cured concrete had the lowest near surface chloride concentration when compared to the 0.46 w/c moist-cured concretes, including the 5.0 and 7.5 percent silica fume mixtures. These surface chlorides for the 0.46 w/c heat-cured concrete averaged about 36 percent less than the four other moist-cured 0.46 w/c concretes with or without silica fume. The long-term ponding tests also indicate that the heat-cured conventional concretes at 0.32, 0.37, and 0.46 w/c had lower or essentially equal chloride contents at all measured depths when compared to the burlap- or water tank-cured conventional concretes at the same w/c.

“These current observations confirm similar conclusions about the beneficial effects of heat-curing on chloride profiles in 0.44 w/c AASHTO grade concrete studied in the 1987 FHWA study of heat-cured versus moist-cured w/c concrete. This current study also showed that the 28-day compressive strength of properly heat-cured concrete was not lowered by heat-curing, even when the cylinders did not receive any supplemental wet- or moist-curing after the initial overnight heat-curing. This conclusion, in conjunction with the lower water and chloride absorption, lower volume of permeable voids, lower 1-year chloride content profiles, and comparable estimated time to corrosion values, indicates that heat-cured conventional concretes are far more impervious to water and chloride ingress than identical moist-cured AASHTO grade 0.46 w/c concretes. The 0.37 and 0.32 w/c heat-cured concretes also had equal or better resistance to water and chloride ingress than moist-cured concretes with equal w/c levels.”

3.4.2**Drainage**

Proper drainage of the parking structure floors is mandatory, to eliminate the ponding water which promotes the absorption of deleterious chlorides into the concrete. Minimum slopes in two directions are necessary to achieve positive drainage to avoid ponding water, further See Section 4.4 for design criteria and floor-slope details regarding drainage.

Vertical drain lines (downspouts) should be protected from vehicle bumper damage with a bumper guard around the drain line or by locating the drain line in a protected location (Figure 3-5). In hurricane areas, edge-relief scuppers can prevent structural overloading if a floor drain is clogged. When locating drain lines, architectural appearance also must be considered.



Figure 3-5

3.4.3**Concrete Cover**

The amount of concrete cover over the reinforcing steel has a great effect on the concrete's ability to resist deicing salt's deteriorating effect. Horizontal deck surfaces and vertical surfaces potentially exposed to deicing salts are those surfaces that should be taken into consideration. Tests have shown that concentrations of deicing salt in older parking structures may be above 1,000 parts per million (ppm) in the upper surfaces of the concrete but will decrease with depth into the concrete. As mentioned above, the threshold level for the initiation of corrosion in reinforcing steel is approximately 300-400 ppm of chloride ion in the concrete, so the objective is keep the concentration below that level.

The ACI Building Code (ACI 318) recommends a cover of 2 inches for reinforcing steel in cast-in-place concrete subject to deicing salts and 1-1/2 inches in precast concrete. In areas where slabs are not exposed to deicing salts but are exposed to the weather, the cover recommendation is 1 inch. If the net design tensile stress is greater than $6\sqrt{f'_c}$, concrete cover should be increased 50 percent. This cover requirement applies to welded-wire fabric as well as mild steel-reinforcing bars, but the fabric is less likely to corrode with the same cover.

Double tee floor members have their primary reinforcement - the strand - located in the stems, well below the deck surface. Consequently, chloride penetration does not present a problem for this reinforcement and increasing concrete cover by 50% when net tensile stress exceeds $6\sqrt{f'_c}$ is not required.

3.4.4**Concrete Surface Sealers**

Concrete surface sealers reduce moisture and salt penetration into parking structure floor surfaces or other concrete members being treated. While these sealers can enhance the durability characteristics of any concrete topping to which they are applied, they do not provide a substitute for basic durable concrete design. They also do not provide protection against penetration of moisture and chlorides through cracks. Since precast prestressed concrete design benefits from good concreting practices, the durability gains associated with using a concrete sealer may not be as great

as the gains achieved when used on cast-in-place concrete parking structures. Nevertheless, use of surface sealers can enhance durability performance and should be considered when decreased concrete permeability is desirable. It is advisable to seal the deck where a cooling tower is present at the roof level.

Research has shown the performance characteristics of concrete sealers will vary greatly depending on the particular product used as well as other variables. Products should be evaluated against the criteria established in the NCHRP 244 Study.³

Sealers generally may be classified into two groups: penetrants and surface sealers.

3.4.4.1

Penetrants

Penetrants, generally silanes or siloxanes, provide protection by penetrating the surface, reacting with the cementitious materials in the concrete, and creating a thin hydrophobic layer on the surface, but they do not have crack-bridging capabilities. Silane and siloxane sealers are longer lasting and less subject to wear under traffic and from exposure than other sealer alternatives. For optimum wear forty percent solids usually is recommended. Because both finish and appearance are generally unaffected by application of these sealers, it is difficult to monitor their performance visually. Under heavy use, the hydrophobic layer may deteriorate, requiring retreatment (refer to the maintenance section in the appendix.) Powder samples at incremental depths may be taken every year or two to monitor performance.

3.4.4.2

Surface Sealers

Surface sealers are generally polymer resins such as urethanes, epoxies, acrylics or other proprietary blends. Manufacturers' recommendations should be followed so that proper traction is achieved. They protect by penetrating slightly into surface pores and/or by providing a tough continuous film over the surface to which they are applied, but they do not bridge cracks. Surface sealers generally are less expensive than penetrants, and performance characteristics of many of the products compare favorably with the silanes and siloxanes. These sealers are more likely to change the appearance and traction of the floor surface and are subject to wear under traffic. They provide an alternative for areas where traffic or sunlight exposure isn't a factor, such as in covered parking-stall areas and secondary-traffic aisles. Because a surface film generally is in evidence, performance can be monitored visually and areas can be resealed on a spot basis as needed.

3.4.4.3

Geographic Considerations

The decision to use a concrete sealer on a precast prestressed concrete project typically depends on its geographic location, whether a topping is incorporated into the design, and its service environment. Sealers generally are used when the structure will be exposed to freeze-thaw conditions, deicing salts, or ocean salt water. These conditions generally diminish in severity as one moves south to warmer climates or inland from the coast.

3.4.5

Crack Prevention, Control Joints and Sealing

Deterioration of slabs and corrosion of reinforcing steel are accelerated in areas where cracking occurs. Cracking may accelerate the deterioration of concrete slabs by allowing rapid access of deicing salts to the reinforcing steel, particularly through cracks in line with the bars. Perpendicular cracks are less of a problem. Typically, precast pre-

stressed concrete parking structures have exhibited a higher degree of durability than cast-in-place concrete parking structures. Precast concrete strengths of 6,000 psi are common, promoting higher durability through denser concrete. Also, it is found that these higher-strength precast slabs maintain their integrity and function as uncracked sections in the service load range, creating greater durability. A recent PCI funded report⁴, showed this to be true in a survey of existing structures.

The presence of cracks does not necessarily lead to corrosion of reinforcing. Studies have shown that while cracks may accelerate the onset of corrosion, such corrosion is localized, particularly where the crack is perpendicular to the reinforcement. Further, studies have shown that cracks less than about 0.012 inches wide have little influence on the corrosion process.

3.4.5.1

Construction and Control Joints

Structures often must be built with control joints and construction joints. Topping pours must have control joints over joints between the precast units. These joints should be tooled into the plastic concrete, not saw cut at a later time, and have the proper cross section to ensure proper joint action. A high quality traffic-bearing polyurethane or silicone sealant is necessary to prevent intrusion of salts into these joints and to prevent subsequent deterioration of embedded metals. Depending on the degree of exposure silicone sealants may provide greater longevity. As a backup in case of sealant failure, all metal passing through the joint may be coated with rust inhibiting primer, hot-dipped galvanized, painted with cold galvanizing compound, or made of stainless steel.

3.4.5.2

Isolation Joints

Isolation joints (expansion joints) are provided in parking structures to relieve the stresses associated with volume-change forces (see Section 4.3.3). These joints are characterized by a complete break through the full cross section of the structure, allowing substantial movement to occur without harmful effects. Deterioration of underlying structural elements and leakage can be expected when these expansion joints are not sealed properly. Vertical shear should be transferred across these joints to extend the life of the joint.

3.4.6

Additional Durability Measures

Where the deteriorating effects of deicing and ocean salts are prevalent, additional protective measures should be considered. The best first line of defense, as discussed elsewhere in this chapter, is dense concrete. Lowering the water cement ratio has greater impact and is more economical than any of the alternatives. Also, allowing for more concrete cover on the reinforcing steel has been shown to increase durability in parking structures. In fact, a recent study has shown that an increase in cover is significantly more effective when low water cement concretes are used. This compounds the benefits offered by a precast system in several ways. The flange reinforcing in a pretopped double tee is utilized to distribute the concentrated loads a relatively short distance to the vertical stems. This reinforcement is well protected by the dense concrete in which it is contained and by the generous cover accommodated by the small cross section of steel and the four inch thickness of concrete flange. The stems contain the primary flexural reinforcing, typically prestressing strands, which are located well below the deck surface and thus, well away from exposure to the corrosive elements. As they are cut flush to the end, strands are typically coated with a galvanizing compound or bitumastic material for protection.

Other protective measures which may be employed include: epoxy-coated reinforcement, application of traffic-bearing membranes, or the use of corrosion inhibitors or microsilica within the concrete mix. The use of each of the above is only for those members which may be in contact with chloride laden moisture, such as the deck double tee flanges and stems of inverted tee beams. Since it would not be practical to pour the same member with different mixes, for the stems and flange of a tee for example, the entire member would receive concrete containing the additive. It has been exhibited that the use of microsilica in prestressed precast concrete products is of small incremental value, and therefore typically avoided for reasons of cost and difficulties within the fabrication process.

3.4.6.1

Epoxy-Coated Reinforcement

Electrostatic, fusion-bonded epoxy coating insulates the reinforcing steel and prevents the migrating chloride ions from coming into direct contact with steel. This prevents the development of corrosion cells and greatly reduces the possibility of rusting. When epoxy-coated reinforcement is used, tie wire and other accessories also must be epoxy-coated. Caution should be exercised in using any epoxy-coated reinforcement. Increased bond lengths are required due to the smooth surface finish that is created. Also, due to low melting temperatures, epoxy coatings should not be used in members subject to fire. Epoxy-coated strand is not used for parking structure applications, even in severe exposure conditions. Due to the distance from the surface to the strand location. Where additional protection is desired for the deck, other methods may be more beneficial than using epoxy coatings and should be considered (e.g., increasing cover low water/cement ratio, corrosion inhibitors, and silica fume).

3.4.6.2

Traffic-Bearing Membranes

Elastomeric deck-coating and membrane systems (**Figure 3-6**) protect concrete against deterioration from the intrusion of water-borne chloride ions and freeze-thaw action as well as against leakage. These systems have gained widespread use in protecting cast-in-place reinforced-concrete structures because of the high incidence of corrosion related deterioration with this type of structural design. Because precast prestressed parking structures have high durability characteristics, using these membrane systems to protect against deterioration and leakage generally is not required. Sometimes, situations arise where occupied space exists immediately beneath the parking area and the use of an elastomeric traffic-bearing coating system is desirable to ensure long-term watertightness.

Traffic-bearing membranes typically consist of a multi-layer elastomeric polyurethane material with an integral, nonskid traffic topping. In addition to providing superior waterproofing protection to concrete sealers, the elastomeric properties of these systems allow them to successfully bridge small cracks. Due to potential movement of the joints, membranes are advisable only for site-topped conditions. They must be inspected periodically to ensure any tears or through wear of the membrane are repaired to prevent the seepage of water and deicing salts into the concrete being protected.

If a lower-cost alternative is desired (at greater risk of leakage), only overlaying each double tee edge joint with a 6 inch wide strip of waterproofing membrane will add protection to the typical sealant-joint detail.



Figure 3-6

3.4.6.3

Corrosion Inhibitors

Corrosion inhibitors offer protection to embedded reinforcement and prestressed strand. These admixtures either act on the steel surface to inhibit chloride-induced corrosion electrochemically (anodic, cathodic, mixed-inhibitor) or chemically (chemical barrier). A corrosion inhibitor delays the initiation of corrosion, reduces the corrosion rate, and may extend the structure's service life. Corrosion inhibitors are being used by some highway departments as an admixture to protect precast concrete structural elements for bridges and cast-in-place concrete decks against deterioration due to deicing salts. It also is a corrosion-protection method for parking and marine structures.

One type of corrosion inhibitor that has seen extensive use is calcium nitrite, which reacts with the steel in the concrete and creates a protective electrochemical barrier. Quantities of calcium nitrite can be varied in proportion to the level of corrosion protection desired. At the time of this writing, there is one domestic producer of this material.

Other compounds reported as corrosion-inhibiting additives include borates, chromates, molybdates, nitrites, and hypophosphates. They offer varying levels of protection depending upon their application and formulation. In all instances, the manufacturer should be contacted to verify appropriateness of applications and level of performance.

3.4.6.4

Microsilica

Concrete mixed with microsilica (silica fume) can exhibit high strength with a very high density. The high-density concrete creates low permeability that prevents the chloride ions from migrating into the concrete and protects the reinforcing steel. The microsilica concrete does not prevent structural cracking. The low-permeability advantages of microsilica concretes can be used best in areas where cracking can be minimized. Its application as a topping over precast slabs or in closure pours should be considered in lieu of conventional concrete toppings to create a drive surface of comparable durability characteristics to that of a pretopped double tee.

When specified for precast concrete, two factors should be considered. First, use of microsilica may present difficulties with the finishing and curing process. Second, dosages as high as 10 percent (per weight of cement) have been a problem in heat-cured concrete, causing fine cracks. Dosage rates should be held to 5 percent, but special precautions are still necessary.

3.4.7

Protection for Precast Connections

Depending on the degree of exposure, plates should be coated with rust inhibitive paint, epoxy painted, galvanized, or made from stainless steel to prevent long-term deterioration. The protection should be mandatory where plates cannot be reached in the future for protective maintenance. Where welding of galvanized occurs, the weld slag should be removed and the weld coated with a liquid galvanizing coating after the steel has been scoured with a stiff wire brush.

Some designers have specified the use of stainless-steel connections to prevent long-term corrosion. While this may appear to be the ultimate in corrosion protection, users are cautioned that welding produces heat that can create adverse hardware expansion adjacent to the assembly being welded. This can cause cracking in the adjacent concrete and promote accelerated long-term deterioration. This can be resolved by keeping the edges free from adjacent concrete to allow expansion during welding without spalling the concrete.

3.4.8

Electrical Accessories

Electrical wiring conduits and boxes should be surface-mounted on pretopped structures. On wide double tees, it may be advantageous to place blockouts in the stems just under the flange to allow transverse-conduit runs and save conduit length. When conduit crosses an expansion joint, movement in the three dimensions must be accommodated.

In deicing-salt areas, metallic electrical conduits should not be placed in toppings. They should be surface-mounted as with a pretopped system.

In non-deicing salt areas, non-metallic conduit may be placed in the topping. However, concrete covers must be maintained to reduce shrinkage cracking over the conduit.

3.5

Durability Considerations Summary

All of the protection systems noted above can be added on top of the other to provide the ultimate in protection redundancy to the parking-structure floor slab. This will not be justified economically in most cases.

It is recommended that a basic protection system for deicing salt and ocean atmosphere areas includes:

1. Good quality, air-entrained, high-strength concrete that is properly placed, finished, and cured.
2. Adequate drainage slope with 1-1/2 percent slope desired and one percent minimum. Camber must be considered for the determination of the final slope.

3. Depending on the level of exposure, bearing plates and other exposed plates may be galvanized or epoxy-painted. Flange weld-plate connections may be galvanized or painted with a cold-galvanizing compound, or they may incorporate stainless steel, as dictated by climate and local preference. Flange reinforcement may be epoxy-coated in heavy deicer-use regions, or corrosion inhibitors may be utilized in the concrete mix for the flat deck elements.
4. Minimum concrete covers recommended by ACI 318, consisting of 1-1/2 inches in precast concrete and 2 inches in cast-in-place concrete. If for some reason the cover requirement cannot be met, other protection systems should be employed.
5. High-quality sealants at construction and control joints.
6. A high-quality concrete sealer which can be periodically reapplied.
7. A housekeeping, maintenance, and repair program that ensures any distress will be repaired immediately upon detection and that sealers, sealants, and membranes are replaced periodically to minimize the intrusion of deicing salts into the concrete.

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2. Pfeifer, D.W., Landgren, J.R., and Zoob, A.B., "Protective Systems for New Prestressed and Substructure Concrete", FHWA Final Report No. FHWA/RD-86/193, National Technical Information Service, Springfield, Va., April 1987.
- 3 National Cooperative Highway Research Program 244, "Concrete Sealers for Protection of Bridge Structures".
4. The Consulting Engineers Group, Inc., "Durability of Precast Prestressed Concrete Structures", Prestressed/Precast Concrete Institute, Chicago, Ill., 1996.

4.0

STRUCTURAL DESIGN

4.1

Introduction

The structural design of a parking structure includes the determination of gravity and lateral loads, the selection of a framing system, provisions for proper drainage, and the detailing and sizing of components and connections. (Refer to Chapter 8 for additional contractual responsibilities.) For additional information regarding overall structural integrity, refer to Chapter 3 of the *PCI Design Handbook*.

The structural engineer's contribution to ensure proper performance requires that the structure's behavior be examined not only for the code specified loads but also for the realistic live loads that actually exist. For instance, while local building codes may state that the mandated load for a parking structure is 50 psf, the actual static load in a fully occupied parking structure is in the range of 25-30 psf. It is recommended for service-load analysis that the engineer use the live-load reduction methods found in the applicable code. In order to ensure proper performance, this manual suggests reasonable criteria for design for such realistic loads, which also must be used in conjunction with the strength requirements of the code.

4.2

Gravity Loads

Gravity loads are derived from the structure's weight and code-specified live loads. As noted previously, a realistic live load for even a fully occupied parking structure is typically 25 psf to 30 psf.

4.2.1

Live Loads

For any parking level exposed to the sky, some codes require that the design live load be the sum of the code-specified parking load and the full-snow load, which is unrealistic. Designing for live loads that are significantly larger than actual loads may not be beneficial for prestressed concrete members. On occasion, this can result in detrimental behavior, such as excessive camber and increased member shortening. On the other hand, it also may be detrimental to permit tensile stresses for realistic loads greater than the tensile capacity of concrete in prestressed concrete members subjected to deicing salt exposure.

Recommended design criteria for passenger-car loading are as follows:

1. The ultimate strength of the member must satisfy the code-specified factor for live (including load for snow and drift as required) and dead loads.

- When deicing chemicals are used, the level of prestress for prestressed members should be chosen such that, under a realistic live load, the flexural tensile stress in the precompressed tensile zone won't exceed $7.5\sqrt{f'_c}$. (A realistic live load of 25 psf is recommended. An additional 5 psf may be added to account for dynamic effects. In areas of average snow loads, the snow load may be added to this realistic live load. In areas of heavy snow loads, engineering judgment should be used in combining the loads, since it is unlikely automotive traffic will exist with an appreciable snow load.)
- Where deicing chemicals are used, the extreme fiber tension at the top surface should not exceed $3\sqrt{f'_c}$ under dead loads, and under dead loads plus realistic live loads should not exceed a tensile stress of $6\sqrt{f'_c}$.
- Where deicing chemicals aren't used, the extreme fiber-tension values given in the ACI Building Code, ACI 318, are appropriate using realistic live loads. Under code-specified loads, higher tension values are appropriate if deflection limits and ultimate strength criteria are satisfied.

4.2.2

Dead Loads

It is recommended that under dead load only, precast members should be designed to conform to the following:

- For prestressed members, the level of prestress should prevent downward deflection.
- For nonprestressed reinforced concrete members where crack width is an important consideration (e.g., architectural finished spandrels) the z-factor, as defined by ACI 318, should not exceed 55. Note that this requirement will produce steel-reinforcing amounts that usually exceed the flexural steel requirements.

4.2.3

Torsional Loads

Load-bearing members loaded non-symmetrically may be subject to both internal and external torsion. A typical example is a load-bearing spandrel beam. If the resulting applied load is not coincident with the member's shear center, torsion will exist along the span of the member (Figure 4-1). When a connection is provided at the ends that resist the "roll", localized equilibrium forces will develop in the end regions (external torsion or torsional resistance).

Conventionally reinforced concrete members subject to torsion should be designed in accordance with the applicable provisions of ACI-318, Chapter 11. Prestressed members subject to torsion should be designed in accordance with the applicable provisions of the *PCI Design Handbook*, Chapter 4, *PCI SFRAD Research Project No. 5* and ACI-318.

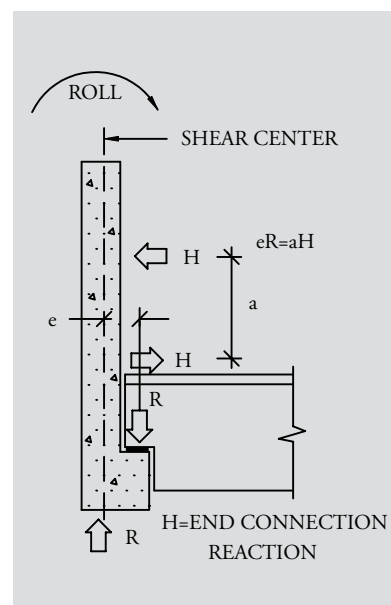


Figure 4-1

Experience indicates that when members are designed in accordance with these provisions, proper performance can be expected, and proper strength achieved. Precast prestressed concrete beams subjected to torsion should be designed for the torsional loads on the member regardless of where the loads occur on the member, as substantiated by *PCI Research Project No. 5*. Distance limitations of “d” (as given in ACI 318) shouldn't be used on precast ledger beams with concentrated loads.

Internal torsion may be minimized by locating the applied loads close to the shear center. This can be achieved by using small bearing pads of a type that permit higher bearing stresses and are carefully placed in the field. Another advantage of small bearing pads is that the dead load stress on the bearing generally will be high enough to prevent the phenomena of bearing pad “walking”. To ensure an adequate bearing pad area, sizing of bearing pads must consider production and erection tolerances. Refer to Chapter 6 of the *PCI Design Handbook* for a discussion of the design of bearing pads.

Another way to locate applied loads close to the shear center, essentially eliminating torsion, is by pocketing the supporting member, such as a spandrel, and bearing the double tee stem or joist in the pocket close to the spandrel shear center (Figure 4-2). Refer to Section 4.8 for other considerations when utilizing pocketed spandrels.

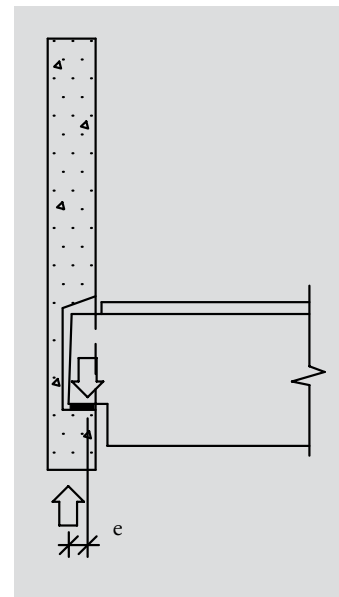


Figure 4-2

4.2.4

Concentrated Loads

Members with applied concentrated loads should be investigated for shear and torsion at the location of these loads.

In parking structures, these concentrated loads most often focus on individual wheel loads. Most codes require a concentrated wheel load of 2,000 lbs. A wheel load is imposed over a footprint of approximately 20 square inches or as otherwise specified. For double tee structures, the flange (slab) must be checked for flexure and shear that is perpendicular to the span of the double tee. This analysis includes considering the flange plus any composite topping as a continuous span between stems and as a simple cantilever or propped cantilever outside the stem. The consideration of the slab as a cantilever outside the stem is based on the assumption that a through crack at the joint between double tees may occur, and that this crack could interrupt the slab continuity provided by the structural topping. For structures utilizing pretopped double tees, this slab is considered to be a propped cantilever because of the close spacing of the flange connections (e.g., the 2,000 lb. load is taken on each adjacent tee as a 1,000 lb. load on a simple cantilever).

The distribution of the concentrated wheel loads should follow standard practice. Figure 4-3 shows a commonly assumed distribution. Reference 4 provides a more in-depth analysis and has shown this distribution to be conservative. Flange steel that resists a 2,000 lb. load is shown in Figures 4-4 and 4-5.

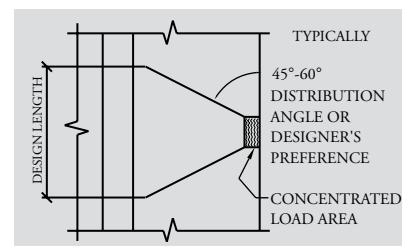


Figure 4-3

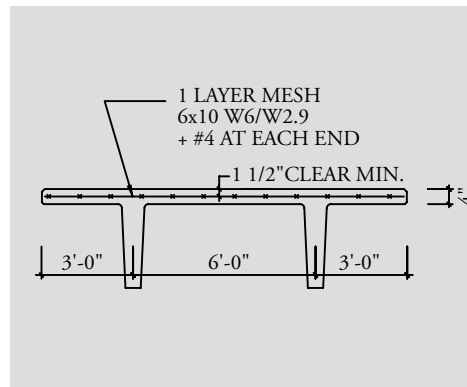


Figure 4-4

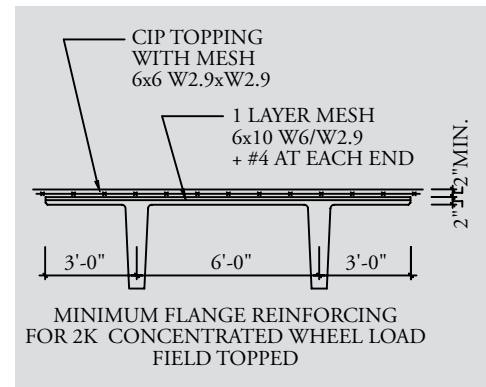


Figure 4-5

4.2.5

Additional Points to Consider

- (1) Analysis must evaluate axial loads that may develop due to restraint of volumetric change.
- (2) Unsymmetrical members with reduced depth at the support (dapped beams) are particularly sensitive to cracking in the region of the support. The *PCI Design Handbook* and *PCI Research Report No. 6*, "Strength of Members with Dapped Ends," is recommended to the designer for reference. Reinforcing steel at the bearing region should be provided to transfer the applied loads from the full-depth section to the reduced-depth section, using, for example, vertical reinforcement to "hang" the load (Figure 4-6).

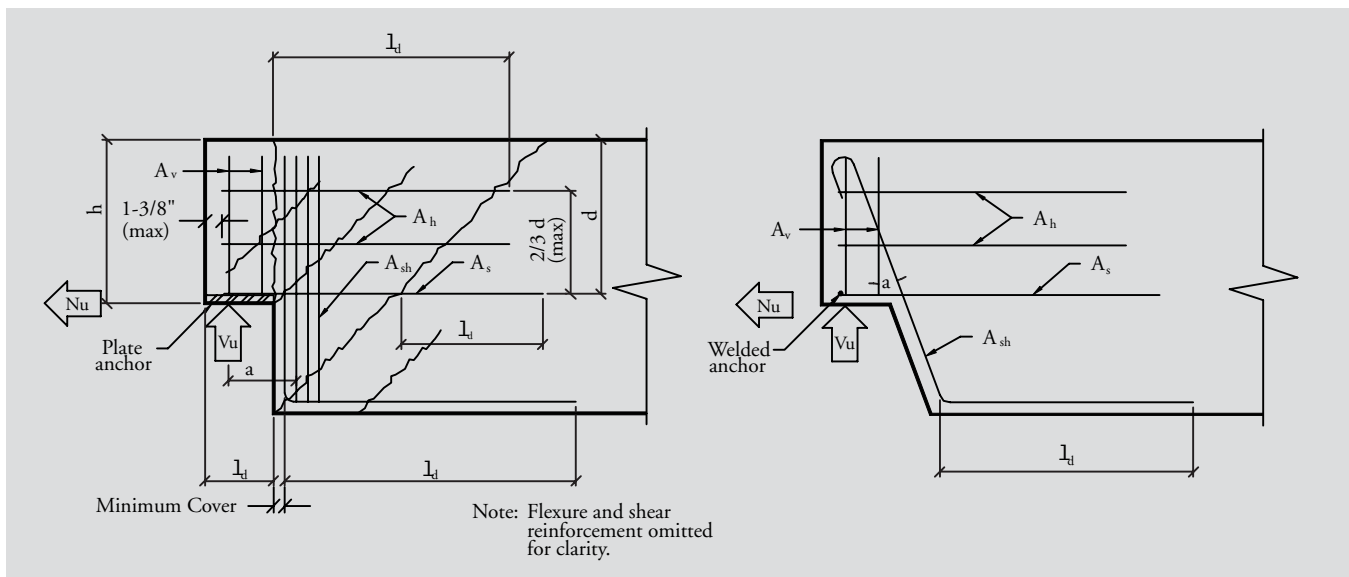


Figure 4-6 Dapped End Potential failure modes and required reinforcement

- (3) ACI 318, Chapter 11
- (4) Consideration must be given to the type of connection used between the spandrel and the column and its relationship to the center of structural stiffness of the spandrel.

4.2.6**Vehicle Impact**

Members projecting above the riding surface must be designed to resist lateral loads from vehicular impact. Local codes specify different lateral load values, and it often is difficult to determine the rational basis for some of these values. The National Parking Association recommends using an ultimate point load of 10,000 pounds applied on a one-foot square area at a distance of 18 inches above the riding surface, located at any point on the length of the bumper wall. This load may be distributed rationally.

The lateral load may be taken directly into the deck (by various types of common connections). The moment induced by the eccentricity of the load above the riding surface can be transferred to the columns at each end by torsion in the spandrel beam (bumper wall). The spandrel beam also can be treated as a horizontal beam between columns, subjected to the specified load (Figure 4-7).

The bumper wall also can be laterally attached to the floor at intervals (usually not more than 10 feet), and the connection and adjacent floor can be designed to resist the impact force (Figure 4-7A).

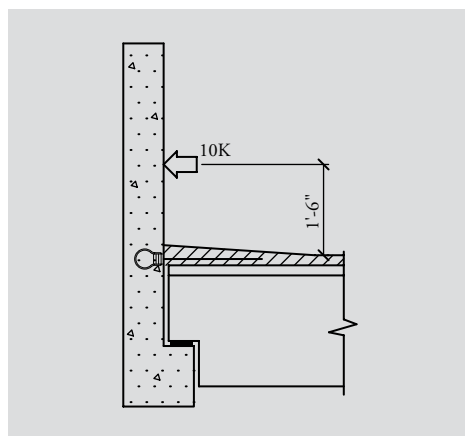


Figure 4-7

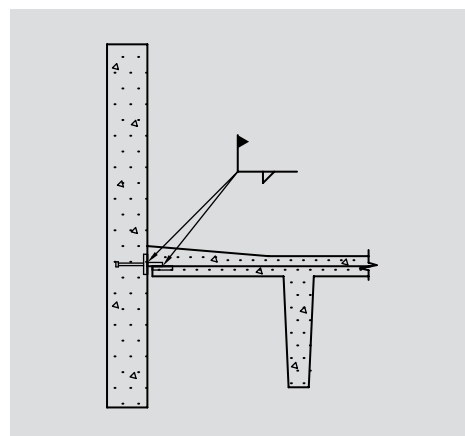


Figure 4-7A

4.2.7**Earth Pressure**

When parking structures are built partially or totally below grade, it may be possible to use the floor system as a diaphragm to brace the retaining walls. The interaction of the soil, wall, and diaphragm must be known to predict the correct magnitude of force applied to the diaphragm. Any changes over time, such as retaining wall drains that become inoperable, will affect the magnitude of these factors. Also, if the retaining wall is very rigid, temperature expansion of the floor diaphragm may produce large forces in the wall and in the floor diaphragm. When these floor diaphragms are below grade and not directly exposed to the sky, the temperature ranges will be less than in an exposed floor diaphragm.

The point of application of load transfer from the wall to the diaphragm is important. When contact bearing exists between the deck and the wall, the earth pressure is applied directly to the diaphragm. As a flat plate, the deck is stiffened at intervals (e.g., 4, 5, or 6 feet) by the stems when the load is parallel to the span of the tee. When the load is transverse to the tee span, the magnitude of the soil pressure will dictate whether stiffeners are necessary perpendicular to the stems. In most cases, they won't be necessary.

Topping applied at the perimeter may need to be thickened depending on the load, although the wash for drainage may already meet the requirement. It is preferable not to directly transfer force from wall to floor at the bearing point of the floor members. If it is necessary, a detail must be used that permits contraction of the floor under volumetric shortening. Such a detail could include dry-packing or shimming behind the double tee legs and the adjacent wall, ideally near the center of gravity of the cross section.

For these reasons, and to facilitate construction sequencing, retaining walls should be free-standing and independent of the supported floor system. Lateral-load resistance can be achieved by cantilevering the wall or by transferring forces to adjacent cast-in-place retaining walls, counterforts, or other means. When this is not possible, consideration must be given to the forces that realistically can develop. Parking structures have been constructed using the walls and precast floors as a system to transfer earth pressures, demonstrating that this solution is feasible when attention is given to the factors discussed above.

4.3

Lateral Loads

Lateral loads include wind, earth pressure, seismic, and those forces induced by restrained volumetric changes. Methods of analysis and design are given in the *PCI Design Handbook*. Wind and seismic loads are specified by the governing design code. For wind-load analysis, most codes apply wind to an assumed solid-exterior surface that develops windward pressures and leeward suctions. Earth pressures are obtained from a geotechnical investigation of site conditions. Localized lateral loads, such as car impact, also must be considered.

4.3.1

Volume Changes

Volume change is defined as a change in dimension of structural elements due to the forces associated with shrinkage, temperature change, elastic shortening, and creep. Restraint of volume-change forces can result in cracking of floor slabs, beams, columns, or walls. If left unprotected, these can allow the ingress of water and/or contaminants resulting in ongoing deterioration of the structure.

In a cast-in-place concrete structure, restraint forces tend to induce cracking spaced along the length of a member, while in a precast structure, these forces tend to accumulate at the connections. These restraint forces must be provided for either by designing the connections and members to resist the full value of the force, determined by classical methods assuming full rigidity, or by designing the connections with some degree of flexibility, so the fully restrained value of the forces will not develop. The forces developed are related to the stiffness/flexibility of the supporting structure and the connection type.

The use of flexible or ductile connections is preferred. It is very important the design recognize that rigid (e.g., welded) connections inhibit the structure's ability to react to volume changes. The use of bolted or "slip" connections for beams-spandrels is recommended wherever possible.

4.3.1.1

Shrinkage and Creep

Time-dependent volume changes, such as shrinkage and creep, are not as severe in precast prestressed concrete parking structures as in other types of structural systems,

such as cast-in-place and post-tensioned concrete structures. In post-tensioned structures, all of the volume change must be absorbed by the structure. In precast concrete, elastic shortening and much of the creep and shrinkage take place in the precast plant prior to erection of the structural members at the job site. As a result, these early volume changes prior to erection do not affect the structure. The only effects of volume change on a precast concrete structure are the incremental volume changes that occur after erection (Figure 4-8).

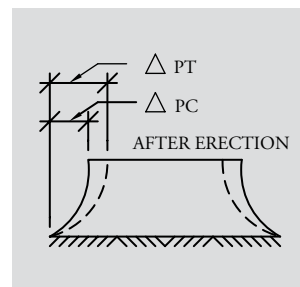


Figure 4-8

The effects of shrinkage and creep will cause a sustained shortening load. But the concrete columns also will creep to relieve themselves of the load created by the shortening. Due to this relieving factor, the computed volume change can be divided by a factor K_1 to obtain an equivalent volume change for design purposes. As noted in the *PCI Design Handbook*, Chapter 3, the K_1 reduction factor for precast prestressed concrete structures is 4, while it is only 2 for cast-in-place post-tensioned structures. Post-tensioned structures have a smaller volume-change reduction factor because the post-tensioning compression in the concrete prevents any relief of the volume-change forces within the structure itself. The precast prestressed concrete structure tends to “breathe” as the joints between the various precast elements open and close. It is therefore important to detail these connections with ductility in mind in order to relieve volume-change forces.

The rate of creep and shrinkage decreases over time. Approximately one half of the creep and shrinkage that will occur in a member takes place in the first 28 days. To allow initial shrinkage and creep to take place, it is desirable that the precast prestressed elements be at least 28 days old before final field connections are completed. In the case of tight construction schedules where a newly cast prestressed element must be placed in a structure prior to the end of the recommended 28-day storage period, the element should not be connected firmly to adjacent elements by welding or bolting until the 28-day period has elapsed.

4.3.1.2

Temperature-Related Volume Changes

Volume changes due to seasonal and daily temperature changes vary with geographical location. Smaller temperature variations occur in coastal areas where the oceans have a moderating effect on the temperature changes, while northern plains areas have annual mean temperature changes as high as 130 degrees F. Roof surfaces can have seasonal temperature changes as high as 160 degrees F. Volume changes due to temperature will cause loads to columns that aren't relieved to the same extent as time-dependent volume changes. The K_t reduction factor for temperature-induced dimensional change is 1.5 for precast prestressed concrete structures and 1.0 (no reduction) for post-tensioned or normally reinforced cast-in-place concrete structures.

The engineer also should realize that protected parts of a structure may behave differently than portions directly exposed to the elements. For example, the top level of a parking structure will be subjected to a higher amplitude of temperature-related cyclical movement (particularly horizontal movement of vertical members and vertical movement of deck members) than the levels below because of direct sunlight (Figure 4-9). It is important that connection design consider the effects of temperature and

not be so rigid as to inhibit temperature-related cyclical movement. The sun's heating of the roof slab while the undersides of the members remain cooler in the shade can cause "sun cambering." This causes rotation at the supports, so the bearings of roof members must be free to move to relieve any adverse stresses that might occur if this bearing were fixed (welded). If relief is not provided at the bearing point and allowed by the connections, the designer should consider volumetric induced moments, which are greatest at the lowest level as shown in **Figure 4-9**.

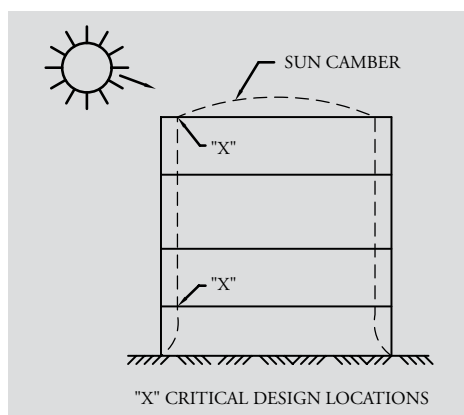


Figure 4-9

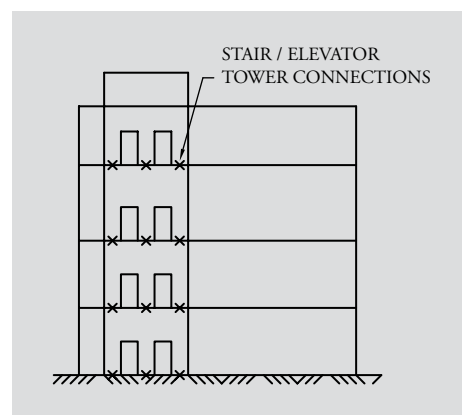


Figure 4-10

4.3.1.3

Volume-Change Effects on Frames

Volume-change effects tend to change the length of a parking structure as a unit. The forces associated with volume change may be controlled effectively by (1) inserting isolation joints at appropriate locations, (2) isolating the moment frame from stiff walls, or (3) reducing the rigidity of certain members or connections.

Stair and elevator towers may be kept free of the structural frame. On tall structures, one can attach the tower to the deck diaphragm for lateral support. Attachments may be left out at the roof deck level if sun heating causing independent roof expansion is anticipated to be a problem (**Figure 4-10**).

The effects on the columns are the most severe between the foundation and the first supported slab. Grade slabs and retaining walls may be kept free of the structure to prevent detrimental restraint.

Because of the shortening differential between the foundation and the first supported slab, tensile forces are introduced into the connection between the horizontal members and the columns at the first supported level. This should be considered in the design if significant.

Closure strips, which are often used on post-tensioned structures, generally are not used on precast prestressed concrete parking structures because of the reduced effect of shrinkage and creep on a precast structural frame.

4.3.2

Structural Strategies

Methods are available to the designer to reduce the effects of volumetric restraint. The best method is the proper detailing of connections to reduce such restraint. Also, reducing the size of exterior columns in the direction in which it is desired to minimize restraint, and considering rotational capacity at the foundation are other methods. Such deliberate ways of increasing flexibility still must provide sufficient strength to resist lateral forces and meet drift requirements. Two methods of resisting lateral loads include the use of frame action and shear walls (Figure 4-11).

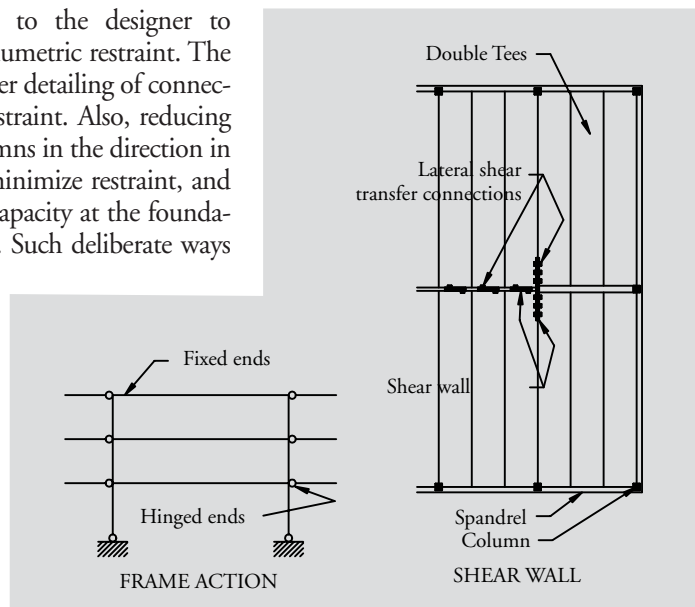


Figure 4-11

4.3.2.1

Frame Action

In developing frames to resist lateral loads, special wind beams at the columns are not commonly used, although this solution has been employed where lateral movements are particularly high. Exterior spandrels and interior beams are typically attached to columns for frame action or may be cast monolithically as “H” or “Tree” shape elements. It is common to create frame details with beams and columns that allow for one way frame action at the end of the member to minimize volume change forces. When stemmed floor members are used as part of the frame in one or two story non-seismic structures, the moments at the ends of the members must be transferred to the columns. The load path generally will be from the floor member through its connection to the supporting beam, then transferred along the length of that beam to the columns. The beam-to-column connection must resist the lateral forces, shears torsion, and moments attributable to that bay. It is preferable for the designer to limit the location of moment connections to those double tee stems immediately adjacent to the columns. Another option is to assume that all floor members resist an equal moment and connect all floor members to the beam.

There are some further considerations when treating the floor members as part of a frame:

1. It is desirable to make the tension connection between floor member and supporting member at the top of the floor member only, so no tensile forces from volumetric restraint are imposed in the bearing region of the floor member. If a compression transfer such as dry-packing is provided near the bottom, the connection can resist imposed moments from lateral loads, but only in one direction (Figure 4-12).
2. In one- or two-level structures, columns cantilevering from the foundation without beam fixity can resist lateral-wind loads and low-seismic loads.

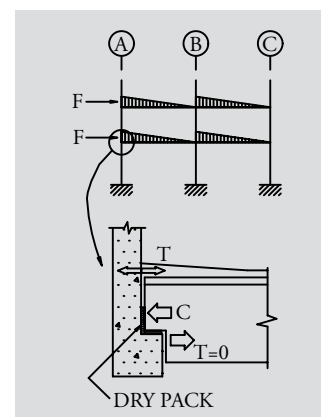


Figure 4-12

4.3.2.2**Ramp Truss Action**

In a continuously ramped structure, the lateral resistance can be achieved by truss action, with the floors acting as web members and the columns acting as chord members. Web members should be connected at the lowest extremity of the structure, and proper detailing is essential to transferring loads through the load path. Special consideration should be given to the chord members and also to force reversals within the load path.

4.3.2.3**Shear Walls**

Shear walls are the most common system used to resist lateral loads in parking structures. For economy, shear walls can support stair or elevator towers and serve as load-bearing walls for double tees or beams. Vertical loads are beneficial for reducing uplift forces created by lateral loads. Design considerations for shear wall structures are shown in **Figure 4-13**. Depending on the climate and overall length of structure, placing rigid walls at or near the ends should be avoided if build up of restraint forces may be significant.

Openings in shear walls commonly are provided for improved visibility, security, air-flow, and openness. Reduced stiffness created by openings or connecting separate wall elements should be considered in deflection calculations.

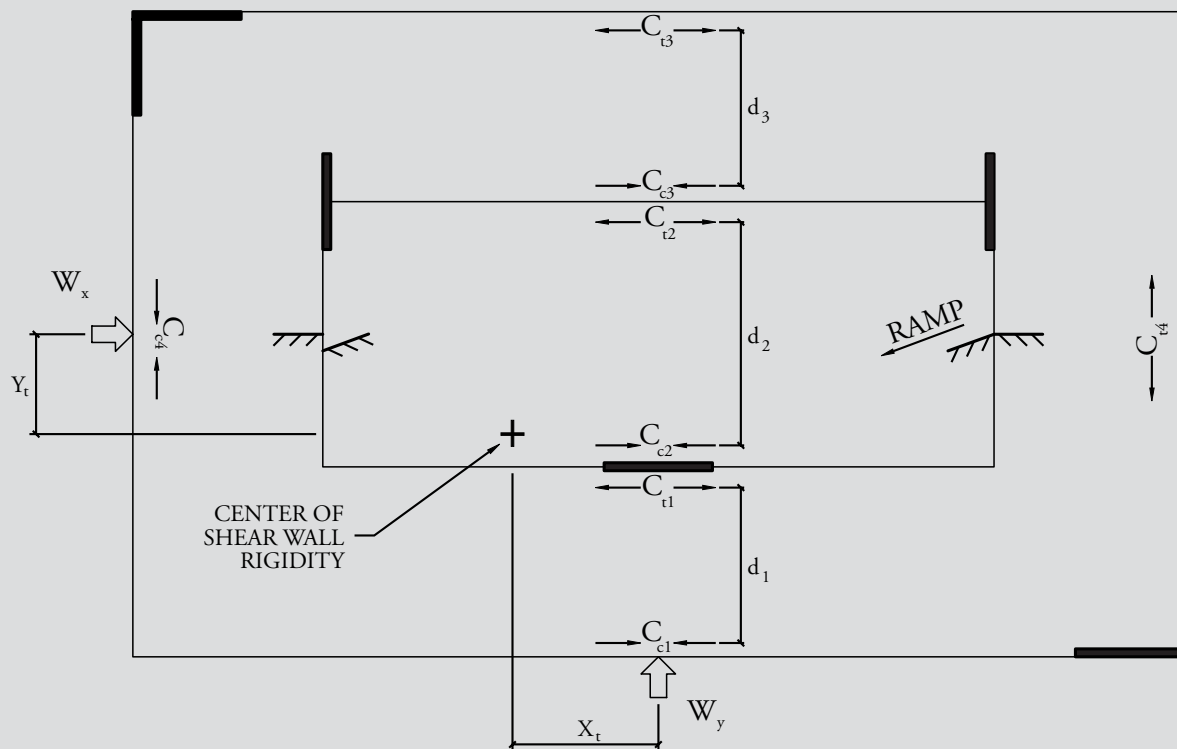
4.3.2.4**Floor Diaphragms**

A common procedure treats the floor as a rigid diaphragm, transferring the lateral forces to appropriately located shear walls or frames. Diaphragm connections should be designed to transfer the resulting shear and the tension forces created from beam action. Such tension forces can be resisted in several ways, such as by using reinforcing steel in the topping or by using pour strips or transverse reinforcing steel in the top flange of the deck members made continuous by connections between adjacent members. The diaphragm connections may be designed in accordance with the *PCI Design Handbook*, Chapter 3. When reinforcement is placed in the topping, the size of such reinforcing steel should be appropriate to the thickness of topping to ensure proper cover.

When diaphragms are designed as part of a lateral force-resisting system for seismic loads, the engineer should carefully consider the appropriate load factors and load combinations. The diaphragm is not a suitable location for yielding in a seismic system. Such yielding could change the behavior of a rigid diaphragm into one with flexibility or even create a failure mechanism. For this reason, it is appropriate to design the diaphragm either for the elastic level of load from the earthquake or to ensure the development of the probable strength of the frame or wall system which will resist the loads inelastically.

4.3.3**Isolation
(Expansion) Joints****4.3.3.1****Structural
Considerations**

Isolation (expansion) joints are provided in parking structures to relieve the stresses associated with volume-change forces (e.g. shrinkage, thermal cycling, elastic shortening, and creep—in precast structures the primary consideration is temperature). They are placed to reduce the length of a slab, where a change of direction of the structure's predominant shape occurs, and to separate other buildings from the main structure. Minor isolation joints also may be used to separate grade beams from the superstructure and to isolate columns from the slab-on-grade.



1. Determine magnitude and location of wind and seismic loads at each level W_x , W_y .
2. Determine stiffness of each shear wall and center of rigidity of shear wall group.
3. Distribute shear and torsional forces to each wall based on wall stiffness. Torsion = $W_y X_t$ or $W_x Y_t$ (or minimum required by code).
4. Determine moments in each shear wall based on distributed shear at each level. Design shear wall connections to resist tension from moments and axial loads.
5. Determine diaphragm loads, moments and shears. Diaphragms interrupted by ramps should be designed as separate units. (Interior diaphragms may not be required to resist wind loads.)
6. Determine chord forces required to resist diaphragm moments.
7. Design diaphragm connections to resist chord forces, diaphragm shears and for shear transfer between diaphragm and shear wall.
8. In seismic zones design of vertical members must consider deformation of diaphragm units. Deformation direction of individual units can be equal or opposite to each other.
9. All elements stabilized by the diaphragm should be connected to resist all code specified loads.

Figure 4-13

Design Example: Lateral Load Resistance Using Shear Walls

Expansion joints are characterized by a complete break through the full cross section of the structure, allowing substantial movement to occur without harmful effects. Related isolation joints for earthquake design are referred to as seismic joints and are characterized by a larger dimension across the opening than otherwise desirable. The *PCI Design Handbook* provides detailed guidelines for spacing isolation joints

(1) Types of Isolation Joints

The most reliably performing structural isolation joint is the double-column isolation joint (**Figure 4-14**). The double-column joint is more expensive than other types of isolation joints, but it truly allows the building to be separated into independent sections without relying on the adjacent structure for support.

The cantilevered isolation joint (**Figure 4-15**) provides architectural continuity. However, careful attention must be given to placing negative moment-reinforcing steel and to detailing and construction, if required, of negative moment connections.

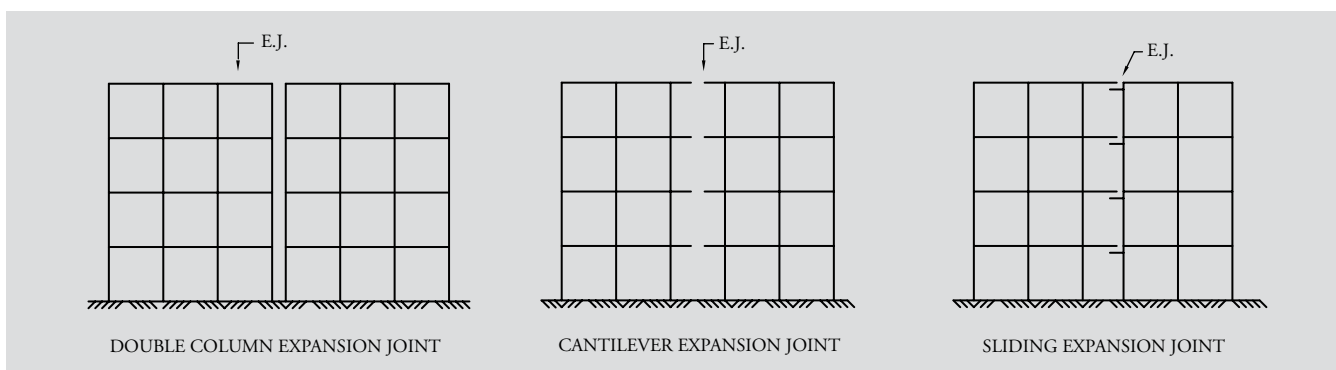


Figure 4-14

Figure 4-15

Figure 4-16

The lap-type sliding isolation joint (**Figure 4-16**) also provides architectural continuity and eliminates the possibility of differential deflection that may occur with a cantilever joint. This joint requires a slide-bearing mechanism to ensure freedom of movement in the joint. The lap-type joint is the most economical joint to achieve movement. Care must be taken to properly align the slide bearings so that they operate correctly. The slide bearing must be protected to prevent the accumulation of dirt in the joint (**Figure 4-17**).

The possible replacement of the slide bearing over the long term also must be considered. Where small horizontal joint movements are anticipated, elastomeric (unreinforced neoprene) bearing can provide for the movement by distortion (**Figure 4-18**). However,

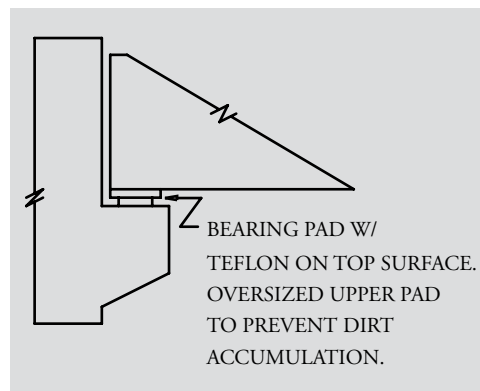


Figure 4-17

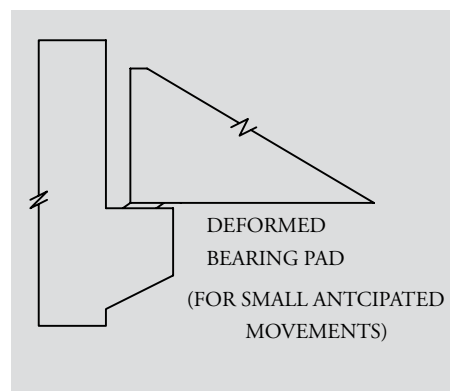


Figure 4-18

it is often preferable to use slide-bearing connections, particularly when the maximum movement will exceed 1/2 inch. These slide connections consist of low-friction material such as teflon bonded to neoprene or neoprene-impregnated duck as well as stainless steel attached to the structural member. These permit uninhibited movement in the direction intended (Figure 4-17).

The proper functioning of slide bearings depends on proper design, accurate installation, and continued maintenance.

In the design of these bearings, the designer must consider the bearing stresses for the case where the bearing area would be minimized in the expansion-contraction cycle.

(2) Location of Isolation Joints

Isolation joints are seldom used in a precast concrete parking structure, unless the structure exceeds 300 feet in length (150 feet from the center of restraint) (Figures 4-20 and 4-21). Isolation joints also may be used around structural elements the designer chooses to isolate from the main structure. There are no fixed rules for locating isolation joints. The structure's flexibility, desired maximum movement within the joint, shape of the structure, direction of prestressed element span, and type of isolation joint seal all will affect the joint's spacing.

Typically, one- or two-story structures may require smaller distance between isolation joints.

Isolation joints should be located at the high point of the drainage system so water flows away from the joint (Figure 4-22). It is prudent for the portion of the joint directly exposed to traffic to be arranged so it can be replaced.

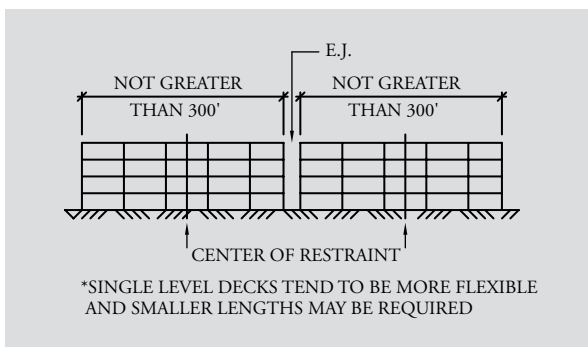


Figure 4-20

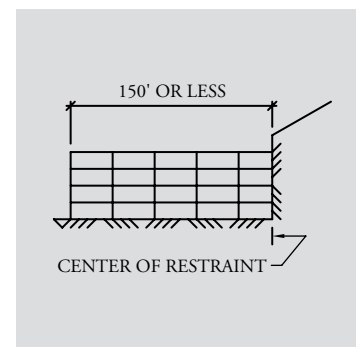


Figure 4-21

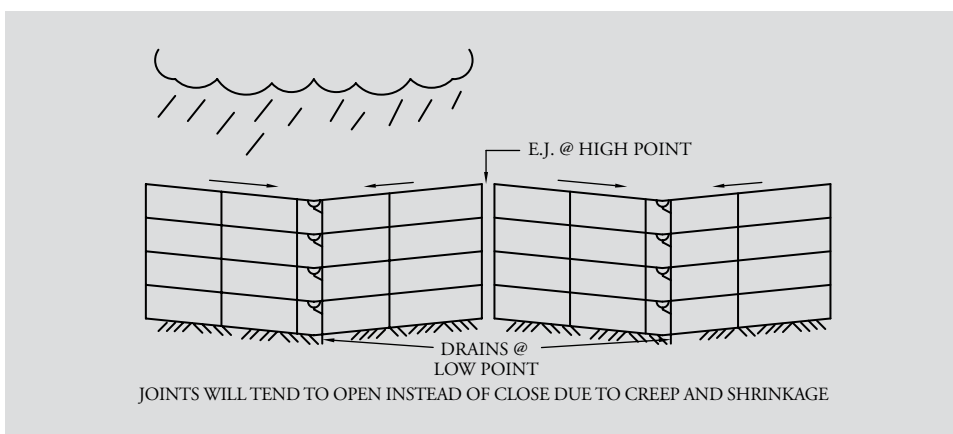


Figure 4-22

Isolation joints must continue through the entire superstructure so there is total separation. They may be offset in plan as necessary to bypass columns or other elements. If they are offset, this portion of the joint seal must accept the movement in horizontal shear (Figure 4-23).

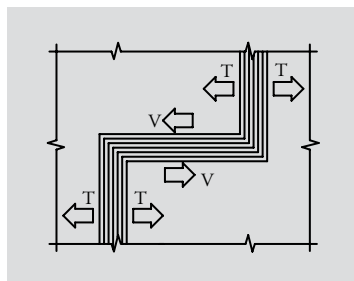


Figure 4-23

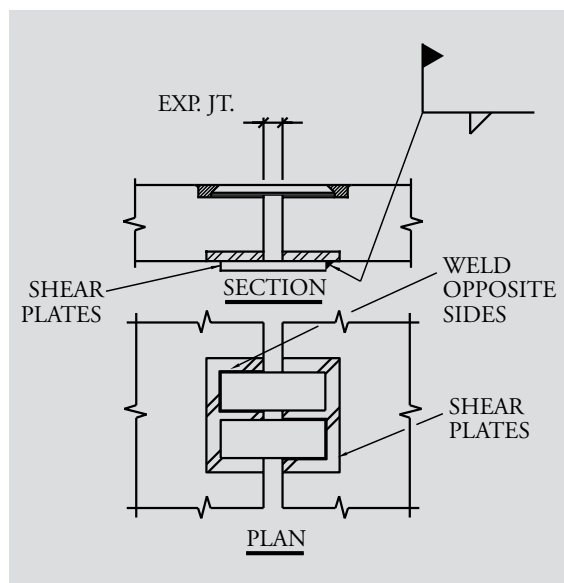


Figure 4-24

Alternatively, if leakage is not a problem, this portion could be reduced in width to perhaps 1/2 inch, requiring no joint material.

(3) Additional Considerations

A variety of isolation joint types are presently in use. Although materials and methods vary, all will function only if:

1. The joint width is related correctly to actual movement.
2. The installation is done under close supervision.
3. Joints are detailed to prevent intrusion of foreign materials.
4. Joints are maintained continuously.
5. Vertical shear connections transmit the forces across the joints.
6. Joints tend to open 1/2 inch to 2 inches (Refer to Section 4.3.1.1).

In order to minimize relative vertical movement at an isolation joint between flexible members, it is desirable to provide a vertical joint-transfer connection across the joint that equalizes vertical deflection while permitting the intended expansion/contraction movement (Figure 4-24).

The designer should verify the bearing strength of supporting members using those values of extreme anticipated travel that he deems appropriate to determine what the expected minimum bearing length would be. To ensure the bearing area required by design is maintained at this usually critical location, the erection drawings should specify that the correct plan location of members adjacent to isolation joints will be "held". It also may be appropriate to specify closer-than-usual erection tolerances for members that will move at the isolation joint.

4.3.3.2

Isolation Joint Details

Isolation joints are the best way to relieve volume-change forces. However, the hardware and seals normally required to prevent leakage through the isolation joint usually require significant maintenance over the life of the structure.

When isolation joints are not sealed, deterioration of underlying structural elements and leakage can be expected. Successfully sealing isolation joints is a function of several factors. These include exposure to traffic, exposure to weather, and the amount of annual and total movement expected (represented by the cumulative estimates of thermal movement, shrinkage, elastic shortening, and creep).

Assuming these joints are provided in a manner that successfully meets the structure's volume-change needs, leakage can be minimized by selecting the proper seal for the various service conditions encountered. Joints should be placed at high points wherever possible and in no case located where ponded water may stand. Good practice further dictates that the seal element should be exposed to view while in service so performance can be monitored and maintenance or replacement easily undertaken.

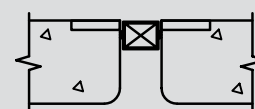
A common method of sealing isolation joints in parking structures is to install a factory-molded urethane sealant over a traffic plate by adhering into place with polymeric nosings. This provides an effective, economical means of successfully sealing these joints. The resultant seal is flush to the driving surface, eliminating tripping hazards and places for dirt and debris to collect. The seals adapt readily to the contours of the surface and may be provided continuously in any length without a break in the seal. This feature allows the seals to be turned up over curbs, walls, or around columns and corners without any loss of function.

The distinction is important between factory-molded seals and field-poured sealant's. Field-poured sealants are subjected to many variables, including inconsistent cure, uneven thicknesses, and inability to provide a bond-free zone beneath the seal. Factory molded seals eliminate these problems and greatly improve performance potential.

Some performance limitations have been observed with this type of surface-mounted isolation-joint seal. These systems frequently have been subjected to damage when exposed to snowplows and/or high-speed or heavy-duty traffic, or movement at the top level. In particular, problems are caused by exposure to truck and bus-traffic conditions frequently encountered in the large, one-level decks surrounding shopping centers. Other conditions where performance problems have been observed include the tops of ramps, spots where traffic can "bottom out," locations at entrances or exits near ticket spitters where cars stop and then apply power to wheels while directly on the seal, and at turns where stresses from power steering occur. In these cases, other systems should be considered to minimize performance problems.

When conditions such as these are likely to be encountered, the extra expense of a sealing system based on a continuous, folded-elastomeric gland secured by metal-retaining strips, polymeric nosings, or both is well justified. These systems have evolved to solve some of the problems related to the use of compression seals and their inability to remain in place and provide an effective seal (see **Figure 4-25** for typical seals of this type). The folds in the elastomeric gland allow it to take movement without stressing the joint edges, a feature that extends the seal's useful life. The folds also allow a smaller dimension to be exposed at the driving surface, minimizing the potential for damage from traffic or snowplows. However, the complexity of the seal's shape makes it more difficult to provide effective seals at butt joints in the gland as well as to make transitions in direction, changes of plane, or terminations.

Figure 4-25



TYPICAL GENERAL
ELASTOMERIC GLAND SEAL

4.4 Drainage

4.4.1 Slope

The camber of the main floor members, usually double tees, requires careful study regarding drainage. This is particularly true when the designer desires to minimize the number of floor drains. Designers cannot depend on camber of the prestress members to provide drainage slopes.

Parking decks should be pitched for drainage. Slopes of 1-1/2% are common with 1% being the minimum acceptable field-limit after construction tolerances are considered. (Figure 4-26). Pitch is necessary to help ensure positive drainage and to overcome the effects of finishing tolerance, camber, and surface irregularities. Cross-bay drainage can best be achieved by raising one end of floor members. At the low end, lateral movement of water to the drains can be achieved by:

1. Pitching the supporting girder or spandrel.
2. Sloping structural topping.
3. Twisting or warping the precast floor units, provided they are sufficiently flexible. 1%-1-1/2% can be used for pretopped members that span over 50 feet. Thin flanged, topped tees can be warped to a greater degree.
4. Sloping the bearing support of the floor double tees.

When pretopped double tees are used, care must be taken to eliminate differential camber offsets at the edges of members that may trap water.

On continuous ramp parking structures, the drains and drain lines typically are kept on the interior column lines to minimize the architectural impact of the vertical drain line on the exterior. This also minimizes the cost of the drainage system.

4.4.2 Drains

Positive drainage slopes in the immediate vicinity of floor drains is important. Floor drains often are set lower (1/2 inch to 1 inch) than the surrounding floor slab to ensure the concrete finishers will slope the floor positively down into the drains rather than leaving a “bird bath” adjacent to the floor drain. Drains generally are located near columns and at the bottom of the ramps throughout the structure. Coordination is required to ensure drains and drain lines do not interfere with structural connections between the column and the floor members. Also, if lateral runs are required, they must not fall within the critical bearing area of structural member (see Figure 4-27).

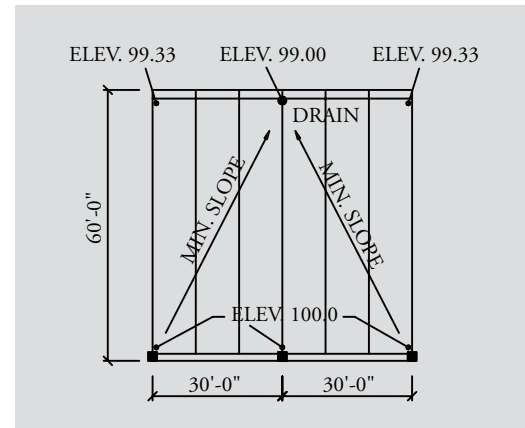


Figure 4-26

Note: The deck elevation at the center column in the bottom of the sketch could be lowered such that the transverse slopes at the ends of the tees would be identical. This would preclude any potential for cracking due to an out of plane condition of the flange in place.

Floor-drain openings provided in the precast-member flanges should be totally within one member if possible. Trying to match portions of precast openings cast into adjacent members creates match-tolerance problems and usually is not feasible unless sufficient tolerance is provided. The slab portion of stemmed members should be reinforced locally where large drains are installed. Square or round floor-drain openings are preferred to trench drains, which cut a large structural section out of the precast member's flange. Trench drains may be used at the bottom of a roof level ramp, but full-length trench drains are not recommended.

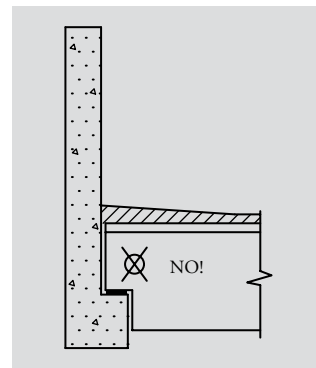


Figure 4-27

4.5

Precast Products

The following precast concrete products have been used as floor members in parking structures (Figure 4-28):

1. Stemmed members
 - a. double tees, topped and pretopped
 - b. quad tees, topped and pretopped
 - c. single tees, topped
2. Slabs
 - a. solid slabs, topped and pretopped
3. Joists with cast-in-place slabs

All have shown acceptable performance when designed and constructed in accordance with the procedures of the *PCI Design Handbook*, and this manual.

4.5.1

Stemmed Floor Members

For stemmed members, the following points are pertinent:

1. Generally, the bearing area of stemmed members should be reinforced with properly anchored bearing plates. The length of bearing over a support as erected should typically not be less than 4 inches. Careful consideration must be given to production and erection tolerances and to anticipated long-term movements while designing and detailing bearings.
2. The strength of the precast flange and composite topping should be verified for transverse bending and shear, when subjected to the code specified concentrated wheel loads. The cast-in-place topping reinforcement also should be used to support and distribute these loads.
3. Longitudinal cracking at the juncture of stem and flange sometimes occurs. The history of topped precast parking structures indicates that such cracking will not deteriorate with time and will not affect the strength at this location. Through flange cracks in double tees require repair and sealing in pretopped members.

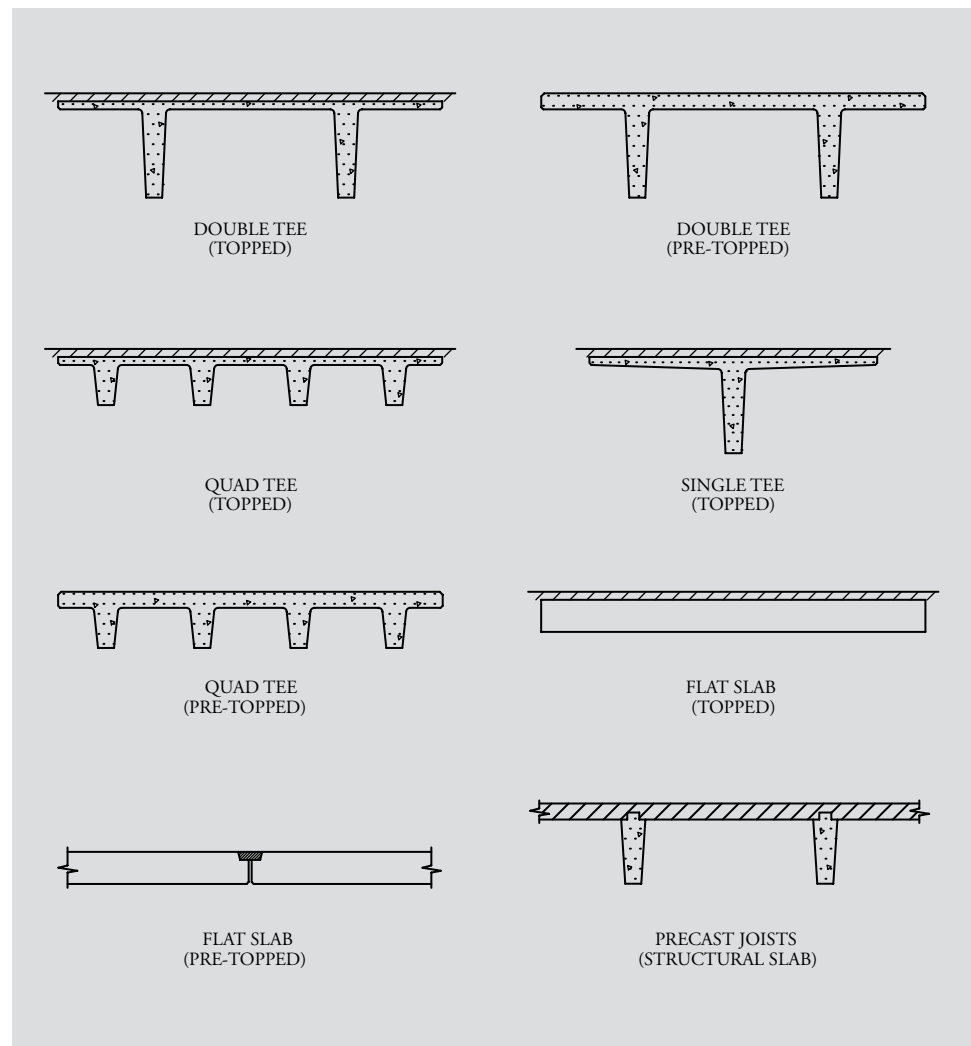


Figure 4-28

4. Flange connectors should be investigated for strength under the application of a wheel load at the connector. Flange connectors should be spaced approximately 8 to 10 feet apart for the full length of the member when structural topping is used and, in a drive aisle, 4 to 6 feet apart for pretopped floor members. Chord forces from diaphragm loading may require smaller spacings.
5. Cracking of structural topping at the joint between adjacent flanges of stemmed members cannot be prevented. If not sealed, these shrinkage-created cracks may cause deterioration. Commonly, a tooled joint filled with a flexible sealant has been used effectively to prevent leakage and deicing salt-related deterioration (Figure 4-29). (See Chapter 3 for additional information.)
6. The bearing of stemmed members should not be welded to their supports. Connections to support members should be made at the flanges of stemmed members (Figures 4-30).
7. Normal-weight concrete is preferable for durability reasons. Light-weight concrete can be used for precast members, but it requires rigid quality controls for camber, camber differential, shortening, and rotation.

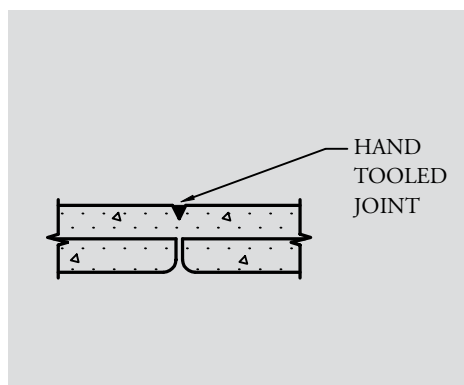


Figure 4-29

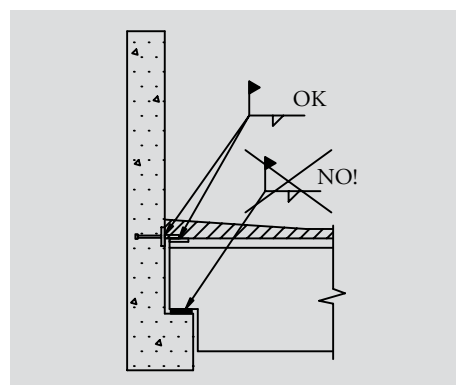


Figure 4-30

4.5.2

Composite Topping for Stemmed and Slab Floor Members

The thickness of structural concrete topping should be no less than 2 inches at all locations, including mid-span of the cambered tees. Where deicing chemicals are commonly used, the thickness should be no less than 3 inches at supports. Topping thickness also may be governed by fire ratings, floor diaphragm stresses, or flexure under large concentrated loads (e.g. fire trucks).

When reinforcing bars are to be placed in the topping, such as when required for continuity or connections, the design topping thickness at that location must consider the size and cover for the reinforcing steel. This is especially true for the covers recommended for deicing salt regions (2 inches in cast-in-place concrete). See Section 3 and ACI 362 for other durability considerations.

See ACI Building Code and Commentary, Sec. 17.5 for discussion on horizontal shear strength between composite topping and precast members.

4.5.3

Beams

For beams, the following points are pertinent:

1. The bearing area of beams should be reinforced with properly developed bars.
2. The structural topping may be used compositely in conjunction with support beams to permit design of these as T-beams, even if the topping slab thickness is partially reduced due to tooling. The requirements of ACI 318, Sect. 8.10, relating to effective width of flange may be used with adequate transverse reinforcing steel across tooled joints.
3. For members receiving final load from both sides, torsion resulting from loading one side during erection should be considered. Erection connections can also be used to control torsion and beam rotation (see Figure 4-31).
4. For torsion stirrup steel requirements, see *PCI Research Project No. 6* recommendations.
5. Deep beams (such as spandrels) require longitudinal steel adjacent to each vertical face. As a minimum, the values of ACI 318, Sect. 10.6.7 should be provided. It has been observed that once a flexural or shear crack develops in such a beam, it tends to travel vertically unless such reinforcing steel is provided.
6. Provide beam ledge reinforcement per *PCI Design Handbook*, and *PCI Research Project No. 6* recommendations (Figure 4-32).

7. Providing a lateral support near mid-depth of a member, such as a spandrel to the diaphragm, will provide the lateral support required to satisfy ACI 318, Chapter 10 (Figure 4-33).
8. While it is preferable that beams align with the column centerline, this often is not architecturally desirable at the exterior. Eccentric loading on columns resulting from offsetting spandrel beams will result in column bending (Figure 4-34). During erection, there is a tendency for such columns to laterally displace. Care must be taken to provide proper erection bracing to compensate.

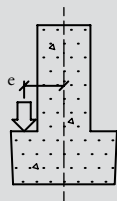


Figure 4-31

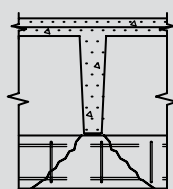


Figure 4-32

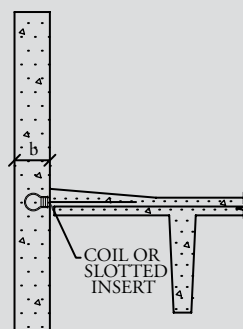


Figure 4-33

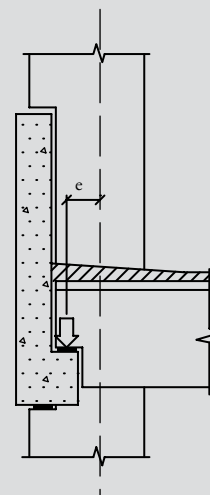


Figure 4-34

4.6

Pretopped Double Tees

Pretopped double tees are a recommended alternative to field-placed concrete topping. Among the advantages of this structural system is that it produces an excellent, 5,000 psi minimum concrete strength, plant-produced wearing surface instead of a typical field-placed concrete topping with lower strengths. In some areas, it is possible to achieve concrete strengths of 6,000-8,000 psi, producing an even more durable traffic-wearing surface. The top flange surface typically is broom-dragged to provide improved driving traction. With this system, special considerations are critical for adjacent camber differential, joint treatments, erection stability, and drainage.

4.6.1

Differential Camber

Differential camber between adjacent pretopped double tees must be controlled to create a reasonably smooth driving and walking surface. A maximum 1/4 inch differential is permitted in the driving-lane area. This can be accomplished by minimizing the prestress force in design and, most importantly, by field adjustments using jacking and shimming procedures.

4.6.2

Sealing Joints

Since there is no topping spanning the double tee joints, details similar to the detail on page 5-13 should be used to create a watertight system. A 1/4 inch tooled radius or eased edge is used to prevent small joint spalls which could ultimately make the sealant fail.

4.6.3**Drainage**

Positive drainage should be accomplished by properly using elevation control and details. Drains should be placed at low points of flanges but should not split a flange joint. A drain located in the recessed pour strip area and surrounded by cast-in-place concrete sloped to the drain helps to create a positive water flow. Sloped cast-in-place pour strips and/or preformed washes also minimize water ponding.

Positive drainage can be developed with the use of raised washes that are integral with the pre-topped double tee. Drain frames can be cast directly into the precast tees, with the drain body mounted to the frame after stripping from the form. This practice can eliminate all cast-in-place concrete topping or pour strips and provide greater control over durability and positive drainage. Additional protection can be gained by placing drains in pairs on either side of an interior inverted tee beam so that water does not have to pass over the beam to tee joints. This approach has resulted in improved performance and the absence of puddles in the vicinity of the drains.

4.6.4**Connections**

In a pretopped system, the most critical double tee connection is the flange-to-flange connection. This connection must transfer diaphragm shear and distribute wheel loads. The detail on page 5-13 is typical.

Microcracking at the surface behind these connections has sometimes been observed in field practice. The condition of these cracks deteriorates over time and can result in leakage. Investigation of this problem suggests the primary cause comes from the restrained expansion of the weld plates generated by the heat of the welding process.

The single most-important method of minimizing or eliminating this problem appears to be to provide a flange weld-plate detail that allows unrestrained thermal expansion of the plate when heat is applied during the welding process.

Another helpful suggestion is to wire brush or grind the weld area to ensure bare metal contact, thus reducing the heat required to successfully complete the weld. The nature of this problem should be explained to the welder, and he should be encouraged not to over-weld the connection. Some have suggested that the use of stainless steel connections also may contribute to the problem because of the higher coefficient of thermal expansion associated with this material. Further discussion of welding practice can be found in Chapter 7.

4.7**Special Loading Considerations**

Some parking decks require consideration of special vehicle loading. Shopping-center or plaza-parking decks surrounding a building may be serviced by special vehicles, such as garbage trucks or delivery trucks. In addition, the local building department may require fire-truck access on a portion of the parking structure to provide fire protection to adjacent buildings.

The Colorado Prestressers Association has published a design guide for use in designing typical prestressed members supporting heavy vehicles. Its analysis indicates that the use of large uniform equivalent loads (250 psf) as recommended by various building codes is not conservative.

The proposed design methodology uses influence value charts to determine bending moments and end shears in the supporting members. For the slab design, they recommend a 0.3% isotropic reinforcement in two layers similar to that provided in the Province of Ontario, Canada, Highway Bridge Design Code.

4.8

Erection Considerations During Design

The erection process must be considered during the design stage. Temporary connections to stabilize the partially completed structure must be studied carefully to determine their effect on the completed structure. Consideration should be given to define the temporary connection details that are acceptable and also how they are to be incorporated into the completed structure.

The most common methods of stabilizing the structure during the erection sequence involve diagonal cables, bracing the columns, and connecting to shear walls and stair and elevator shafts. However, cables obstruct the continuing erection process and could become a hazard.

In no case should both ends of the bottom of a double tee stem be welded in the final structure. It cannot be emphasized too strongly that careful study must be given to the structure's temporary condition during erection with regard to the long-term performance and service of the building.

It should be noted that the use of pocketed spandrels and vertical “lite walls” for the mutual support of double tees requires special procedures for the installation of the tee. More conventional erection procedures are followed for horizontal walls and/or ledged spandrels.

4.9

Design Examples

Detailed design is beyond the scope of this publication. The *PCI Design Handbook*, provides additional detailed examples and information on structural systems and member and connection design.

5.0

CONNECTIONS

Most parking structures are unheated, framed buildings exposed to weather. In addition, those located in coastal regions or northern climates are exposed to the corrosive actions of salt spray and deicing chemicals. Therefore, in selecting connections, the designer must pay particular attention to location, protection, and choice of material.

Connection design is dealt with extensively in the *PCI Design Handbook*. Some of the connections used in precast concrete parking structures are subject to significant and cyclic movement. Such connections must be detailed and installed to ensure that these movements are accommodated during the structure's service life. This is a particular challenge for the designer, but, it can be accomplished with proper selection of the connection type and arrangement of connection material.

It is far more economical to accommodate movement than to attempt to resist it fully. Bolts in sleeves and limited slip-type connections are commonly used to accommodate movement. Steel plates or angles used as connecting hardware may be designed so the resisting section has a small-enough cross section that any yielding (and deformation) occurs before any appreciable force is built up. Movement will be impeded to the point of causing damage if welding is in excess of that specified, bolt nuts are installed under a higher than intended torque, or exposed connections rust.

As previously discussed (Sections 4.3.2.1, 4.3.2.2 and 4.3.2.3), the lateral rigidity of precast parking structures is obtained either by frame action or by the use of stabilizing elements, such as shear walls or internal trussing of the members. The characteristic behavior of each of these systems, as related to connections, is discussed below.

5.1

Structural Frames

Structural frames used in parking structures can be braced or unbraced. They typically are made up of beam/column elements, with floor and roof elements connected to form a diaphragm. Connection methods include bolting, welding, post-tensioning, grouting, or a combination of these. The floor system can have a structural topping or not. For a braced frame, bracing members may be individual shear walls and/or stair or elevator shaft walls. Frame action depends on the ability of joints to transfer applied loads. It is imperative that such joints be designed with allowances made for these forces, especially since large forces can develop due to restraint of volume-change primarily caused by temperature in precast decks if the joint is fully fixed.

5.2

Braced Frames or Shear Walls

Braced frames or shear walls rely on individual stiff elements to provide the lateral rigidity. This generally permits the majority of the structural beams to be designed as simply supported members. The stiffening elements may be load-bearing or non-load-bearing. In the former case, advantage can be taken of the superimposed load's ability to resist overturning. The location of the structure's bracing elements can have a major influence on the magnitude of forces resulting from volume-change effects. Such elements located at the structure's extremities may require connections detailed to permit significant movement due to shrinkage and temperature change. To minimize the force induced by movement, it generally is preferable to locate these stiff elements as close to the center of the structure as possible. Again, flexible connections are the key to success.

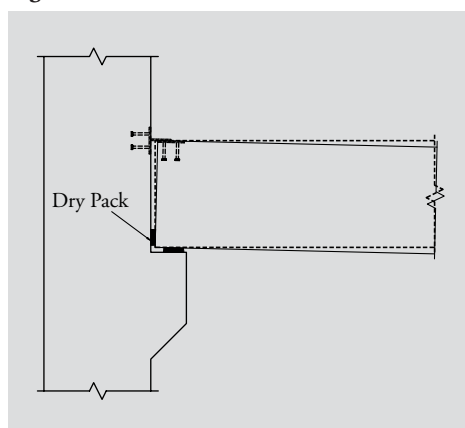
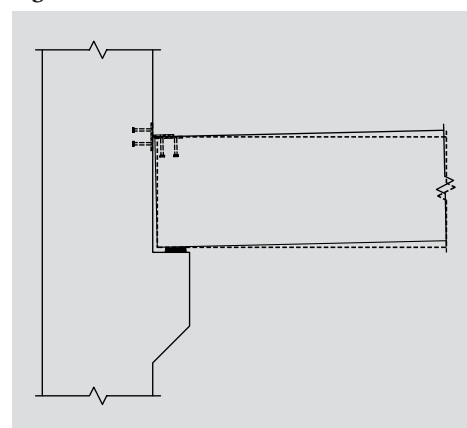
As has been demonstrated over the years, braced construction by use of shear walls and shaft walls is indeed economical. A combination of bracing elements in one direction and frame action in the perpendicular direction also can be done. Generally, the choice will depend on the parking layout and structure shape. To provide visibility and air flow for security and ventilation purposes, bearing walls can be pierced with openings.

5.3

Unbraced Frames

Unbraced frames depend on member and connection stiffness for rigidity and can be sensitive to differential foundation settlement. For one- or two-story structures, columns may be designed as cantilevers. For taller structures, cantilever action isn't feasible, and rigidity will depend on the connections. A certain amount of flexibility is inherent in a typical column-to-foundation connection due to deformation of the soil and base plate, and to anchor-bolt extension capability. Design ramifications and analytical models are discussed in the *PCI Design Handbook*.

Since a frame joint generally consists of a top and bottom connection, the stiffness of that joint is a function of the relative movement of these top and bottom elements. The conceptual behavior of a frame connection in a precast concrete structure is indicated in **Figure 5-1**. Note that this one-way braced frame connection can develop a moment capacity for applied loads only in one direction. An opposite hand connection is used to take the applied forces in the opposing direction. These connections are used in only those joints where moment capacity is required.

Figure 5-1*Figure 5-2*

The top connection can transmit both tension and compression. With the end of the member dry-packed at the bottom (Figure 5-1), The bottom connection also can transmit compressions. For negative moment, the point of zero translation probably will be near the midheight of the member. Under positive moment, the only tensile resistance available at the bottom is due to friction between member and bearing pad, which typically is very small. Figure 5-2 shows a typical connection that allows for movement and rotation of the bearing surface. This joint is not designed for frame action.

5.4

Galvanizing-Special Precautions

As noted in Chapter 3, in regions where deicer salts or coastal airborne salt are present, the components of exposed connections sometimes are hot-dip galvanized. In order to ensure that the strength of the elements of a connection are not reduced by embrittlement during the hot-dip galvanizing process, several precautions are recommended.

When parts in a connection assembly require welding, such as anchor bars to plates, the following recommendations have been found to produce satisfactory results and are recommended by the American Hot Dip Galvanizers Association:

1. An uncoated electrode should be used whenever possible to prevent flux deposits.
2. If a coated electrode is used, all welding-flux residues must be removed by wire brushing, flame cleaning, chipping, grinding, needle gun, or abrasive blast cleaning. This is necessary because welding flux residues are chemically inert in the normal pickling solutions used by galvanizers; their existence will produce rough and incomplete zinc coverage.
3. A welding process such as metal-inert gas (MIG), tungsten-inert gas (TIG), or CO₂ shelled arc is recommended when possible, since it produces essentially no slag.
4. If special-process welding is not available, select a coated rod specifically designed for self-slugging, as recommended by welding equipment suppliers, and refer to Item 2.
5. The welding procedure utilized should be prequalified per AWS D1.1.

It also should be recognized that many parts of connection components are fabricated using cold-rolled steel or cold-working techniques, such as bending of anchor bars. In some instances, cold-working may cause the steel to become strain-age embrittled. The embrittlement may not be evident until after the work has been galvanized. This occurs because aging is relatively slow at ambient temperatures but is more rapid at the elevated temperatures of the galvanizing bath.

It is recognized that any form of cold-working reduces the ductility of steel. Operations such as punching holes, notching, producing fillets of small radii, shearing, and sharp bending may lead to strain-age embrittlement of susceptible steels.

The following precautions are recommended by the American Hot Dip Galvanizers Association:

1. Select steel with a carbon content below 0.25%.
2. Choose steel with low-transition temperatures, since cold-working raises the ductile-brittle transition temperature, and galvanizing (heating) may raise it even further.
3. For steels with a carbon content between 0.1% and 0.25% a bending radius of at least three times the section thickness ($3t$) should be maintained. In some cases, $6t$ yields even better results. If less than $3t$ bending is unavoidable, the material should be stress-relieved at 1,100 degrees F for one hour per inch of section thickness.
4. Drill, rather than punch, holes in material thicker than $3/4$ inch. If holes are punched, they should be punched undersize then reamed an additional $1/8$ inch overall or drilled to size.
5. Edges of steel sections greater than $5/8$ inch thick and subject to tensile loads should be machined or machine cut.
6. In critical applications, the steel should be hot worked above 1,200 degrees F in accordance with the steel maker's recommendation. Where cold-working cannot be avoided, stress-relieve as recommended in Item 3 above.

ASTM A143, "Recommended Practice for Safeguarding Against Embrittlement of Hot Dip Galvanized Structural Steel Products and Procedure for Detecting Embrittlement" and CSA Specification G164, "Galvanizing of Irregularly Shaped Articles," provide guidance for cold-working of susceptible steels is better avoided, if at all possible.

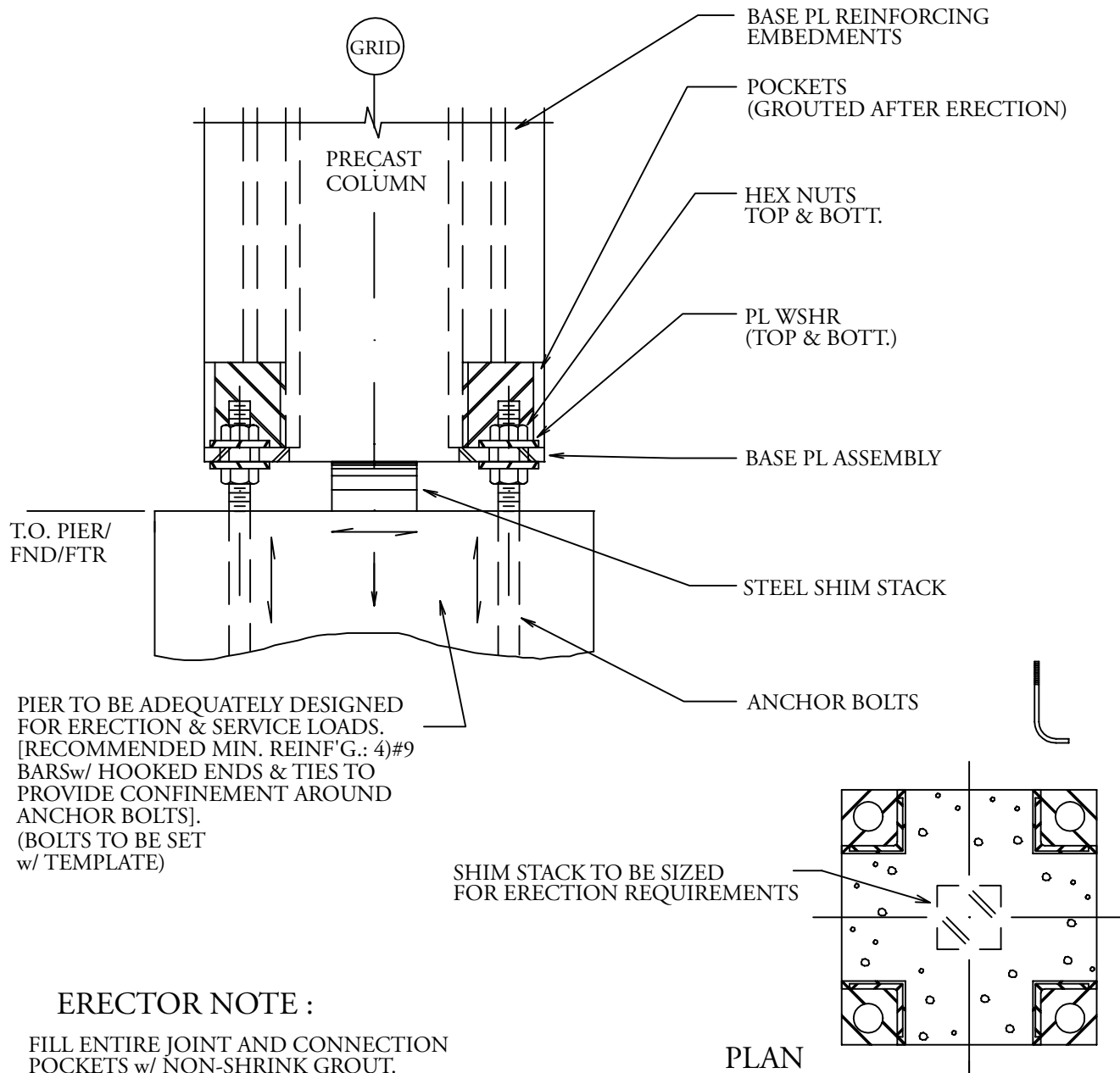
Another area of concern is hydrogen embrittlement. This is a ductile-to-brittle change occurring in certain high-strength steels. Hydrogen released during the pickling operations, prior to hot dipping, can cause this embrittlement. The hydrogen can be absorbed into the steel during the acid pickling, but at galvanizing temperatures it is generally expelled from the steel.

Hydrogen embrittlement is not common, but precautions should be taken if the steel involved has an ultimate tensile strength exceeding approximately 150,000 psi or if the pickling process is poorly controlled, resulting in long exposure in HC1. In those cases, grit blasting is recommended instead of acid pickling.

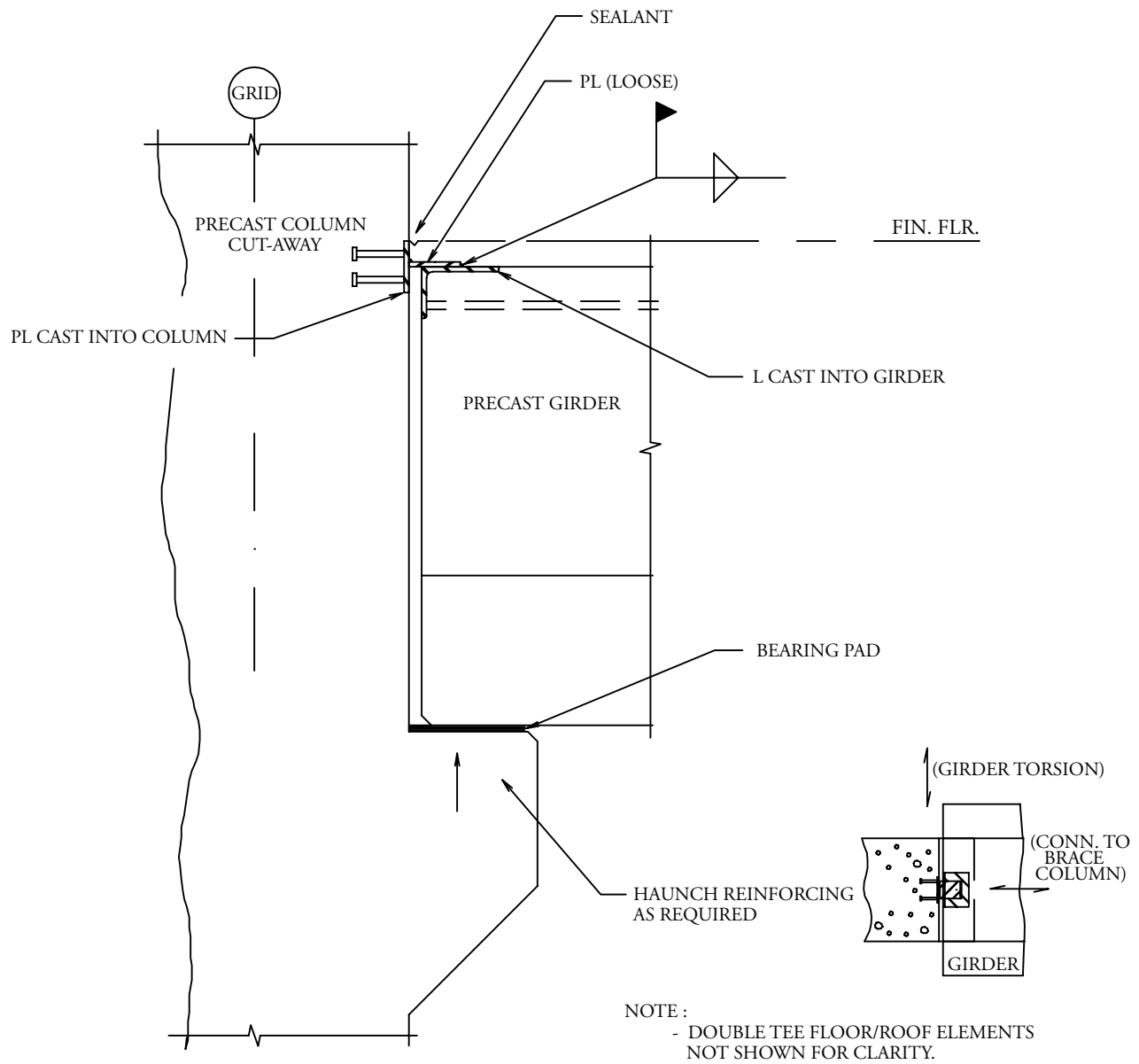
5.5

Typical Details

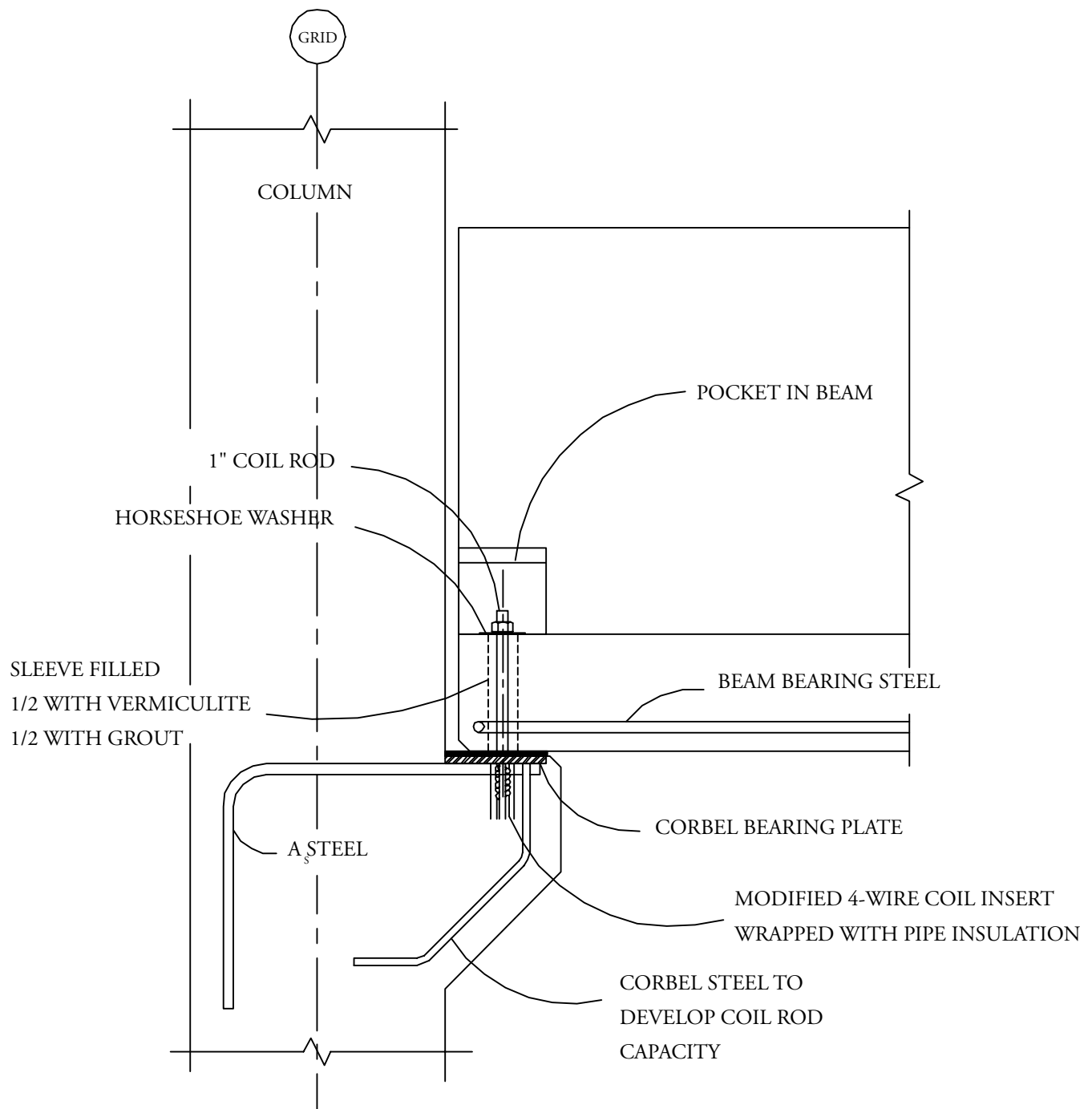
The following pages include schematics of details typically used on parking projects. The designer must select and design each connection depending on the requirements of the particular project. It is advised that the designer check with the producers in the geographical region of the project to determine if local connection preferences exist.



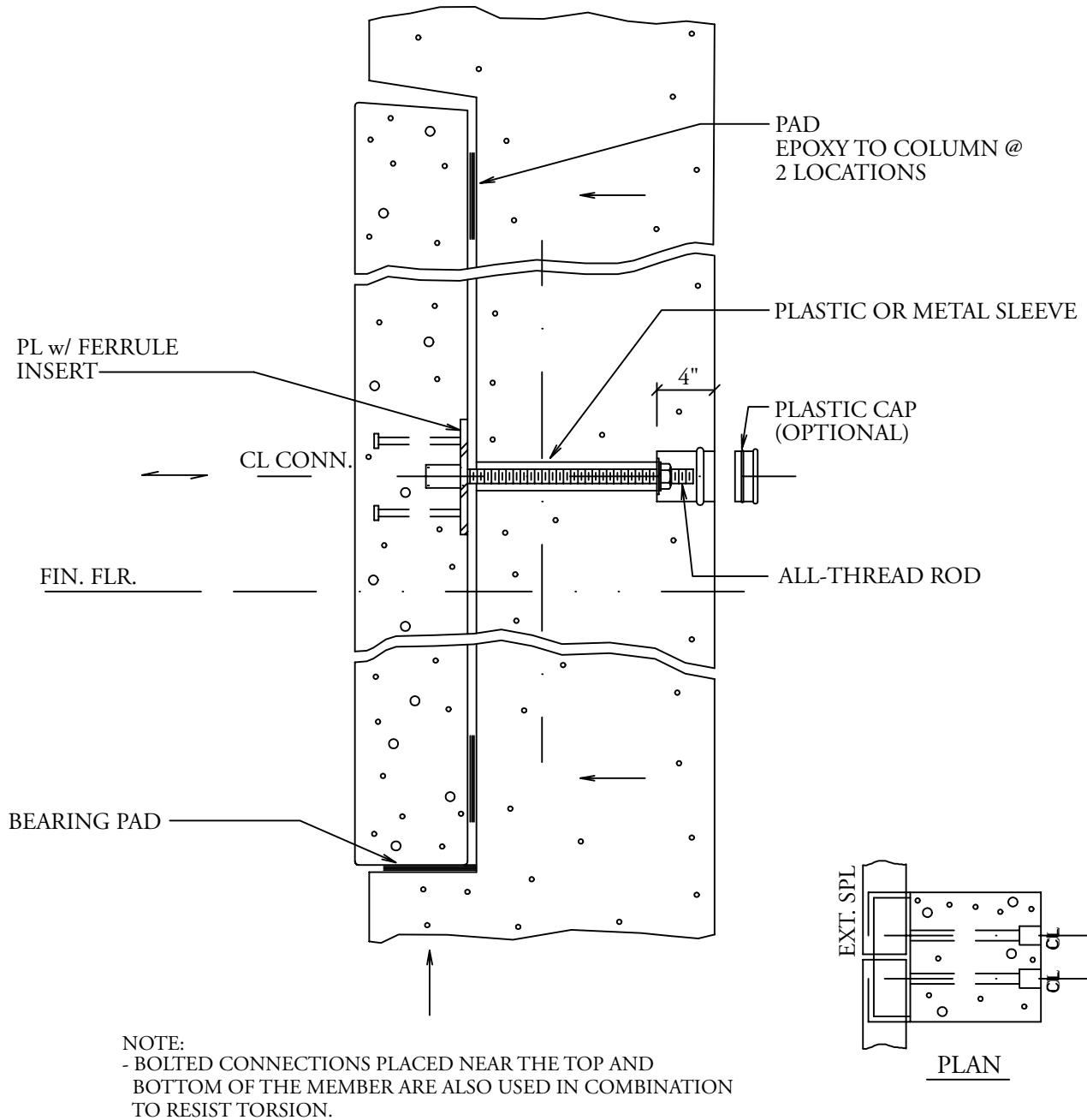
COLUMN BASE CONNECTION



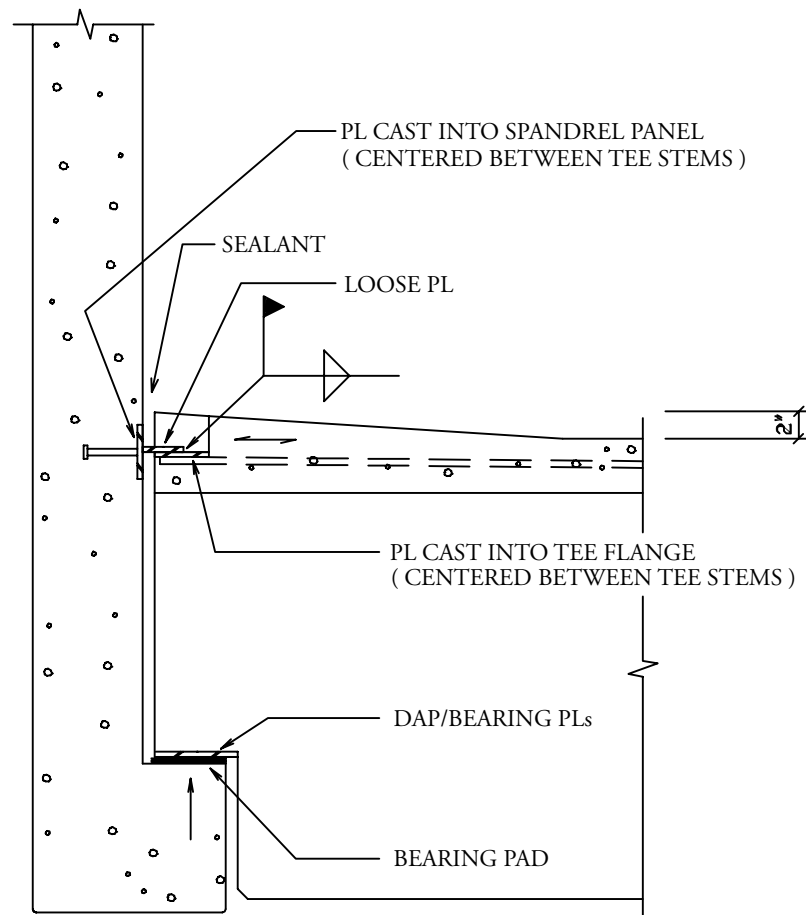
BEAM TO COLUMN CONNECTION



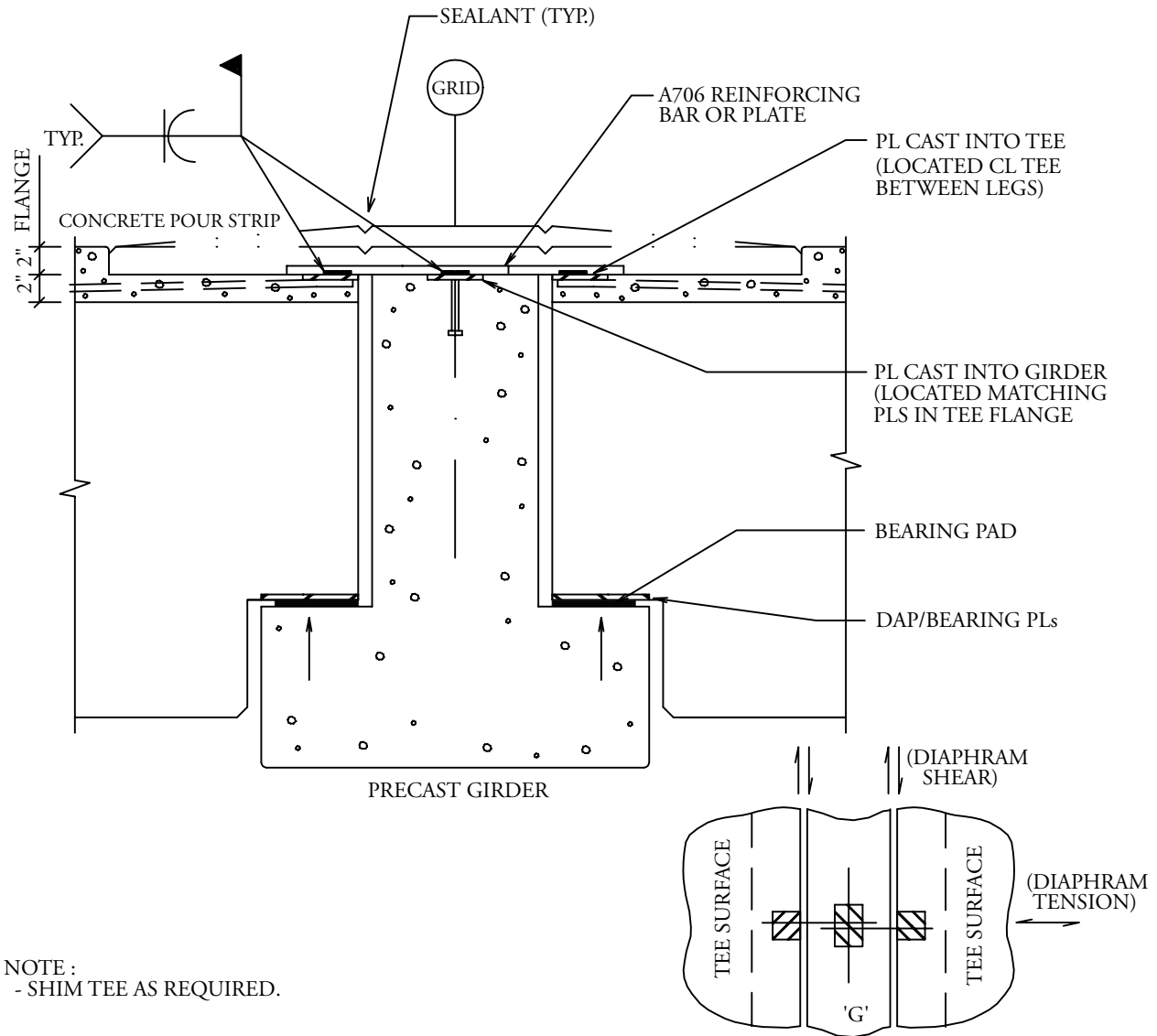
BEAM TO COLUMN CONNECTION



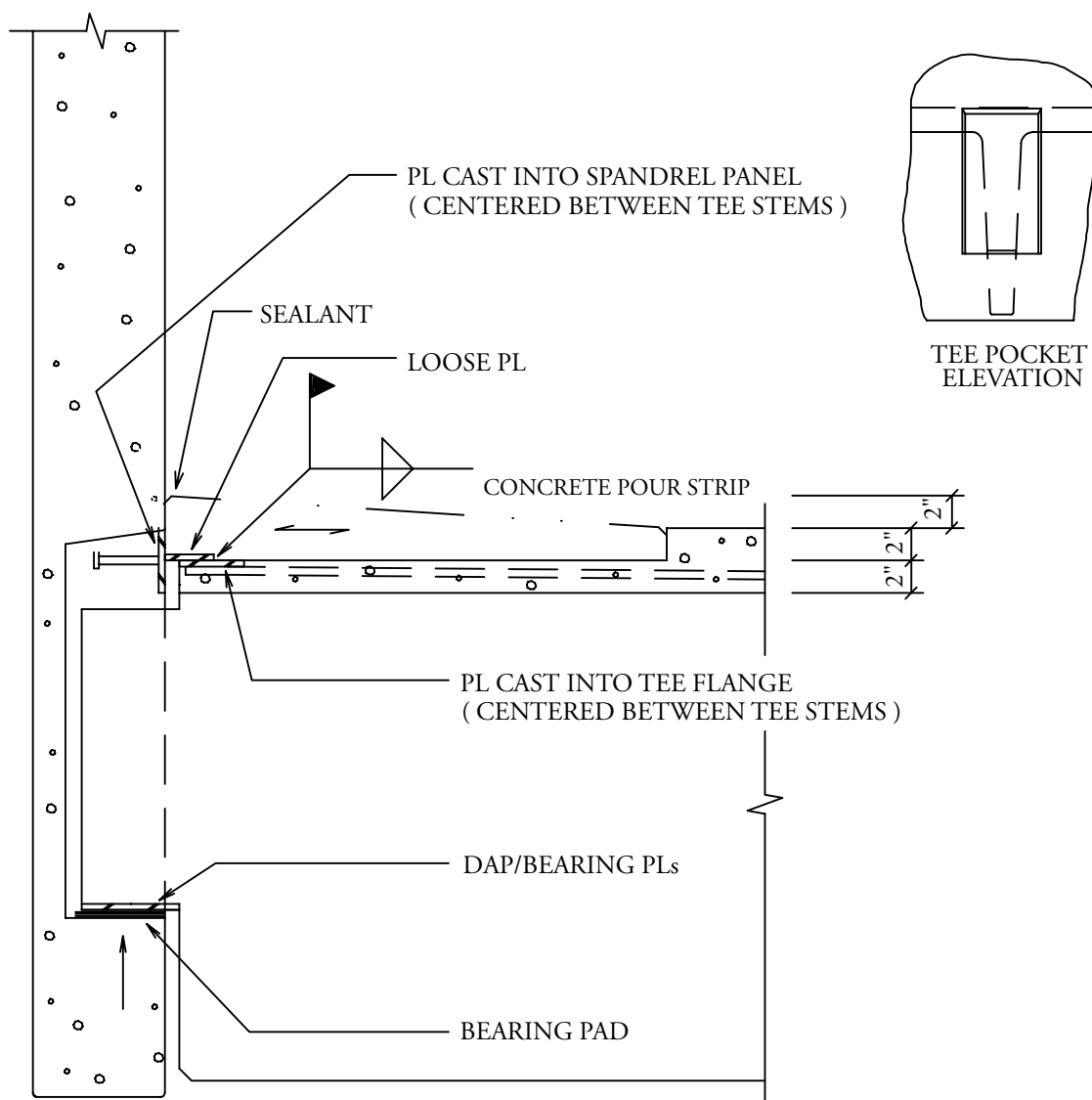
SPANDREL TO COLUMN CONNECTION



DOUBLE TEE TO 'L' SPANDREL CONNECTION



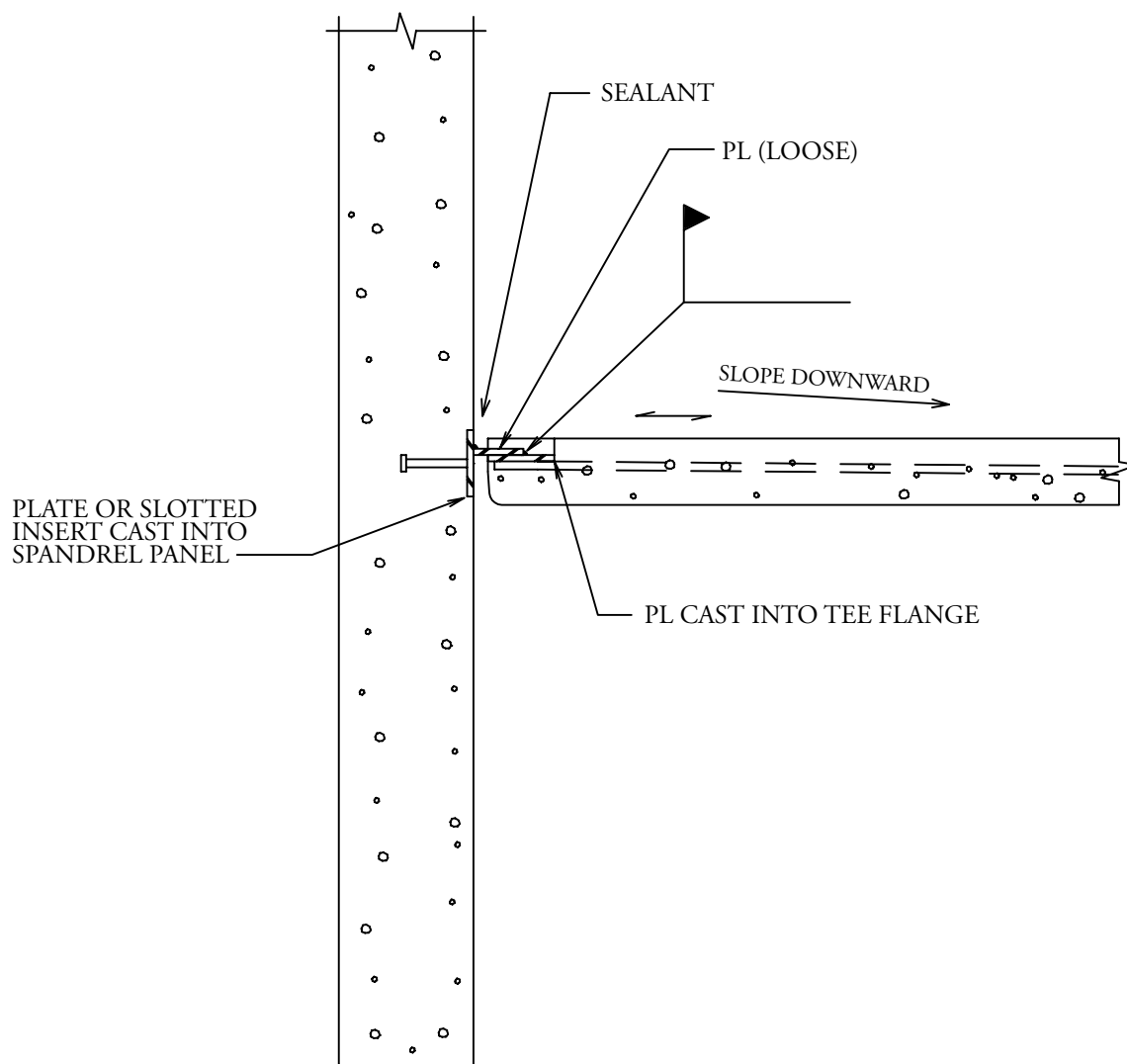
DOUBLE TEE TO GIRDER CONNECTION



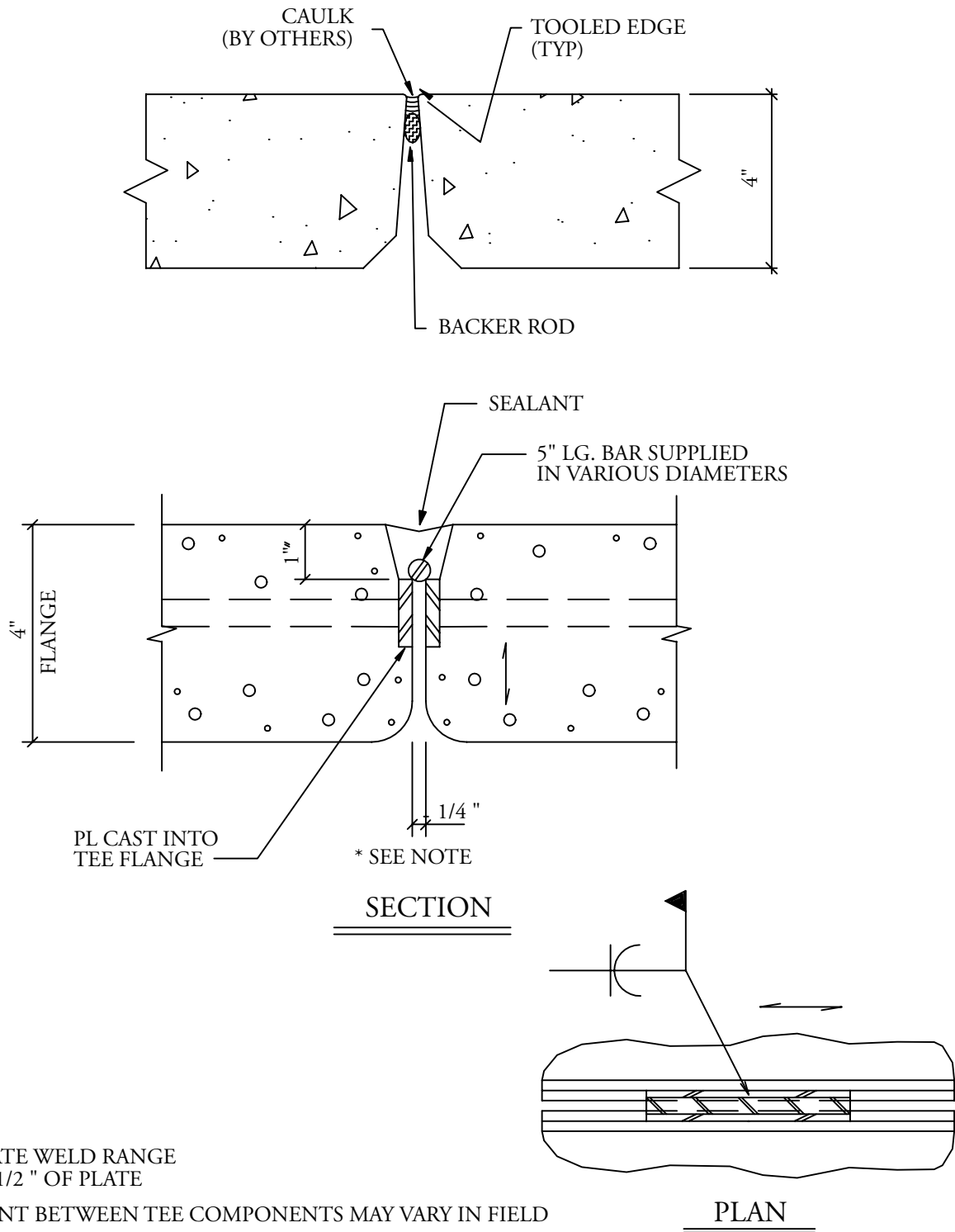
NOTE:

- CLOSURE REQ'D. @ TOP OF POCKET TO PREVENT CONCRETE FROM POUR STRIP SEEPAGE
- SHIM TEE AS REQUIRED.

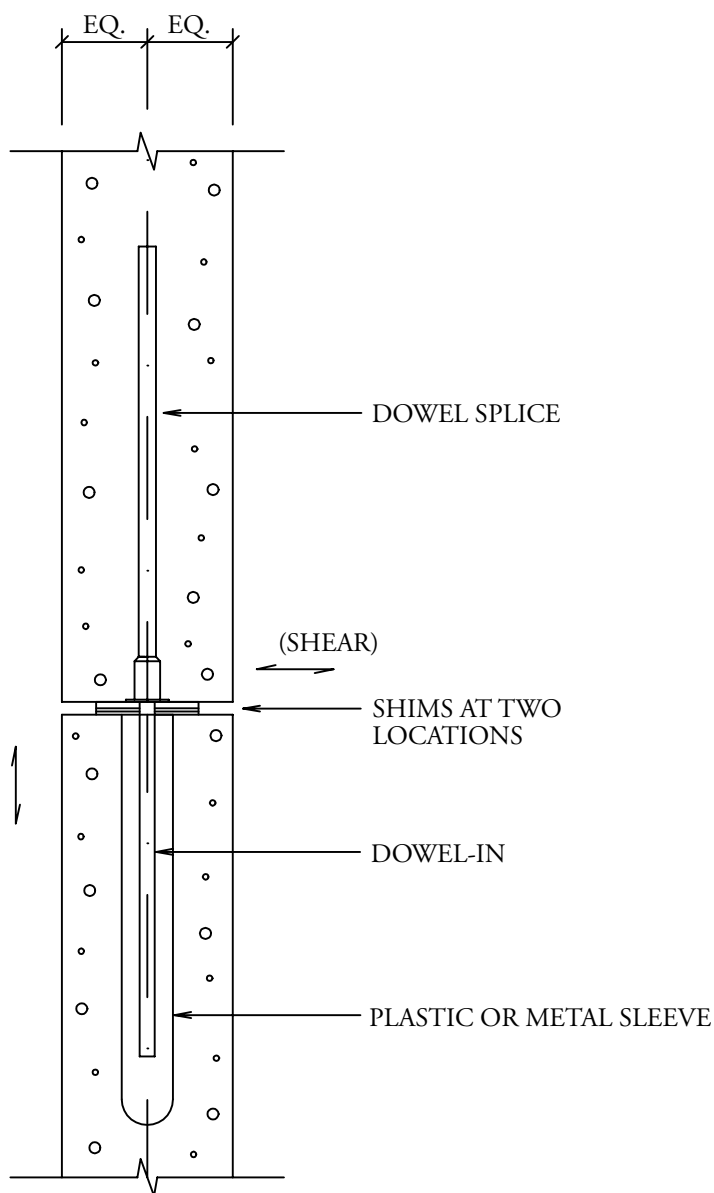
DOUBLE TEE TO SPANDREL CONNECTION



DOUBLE TEE EDGE CONNECTION TO SPANDREL



DOUBLE TEE FLANGE CONNECTION

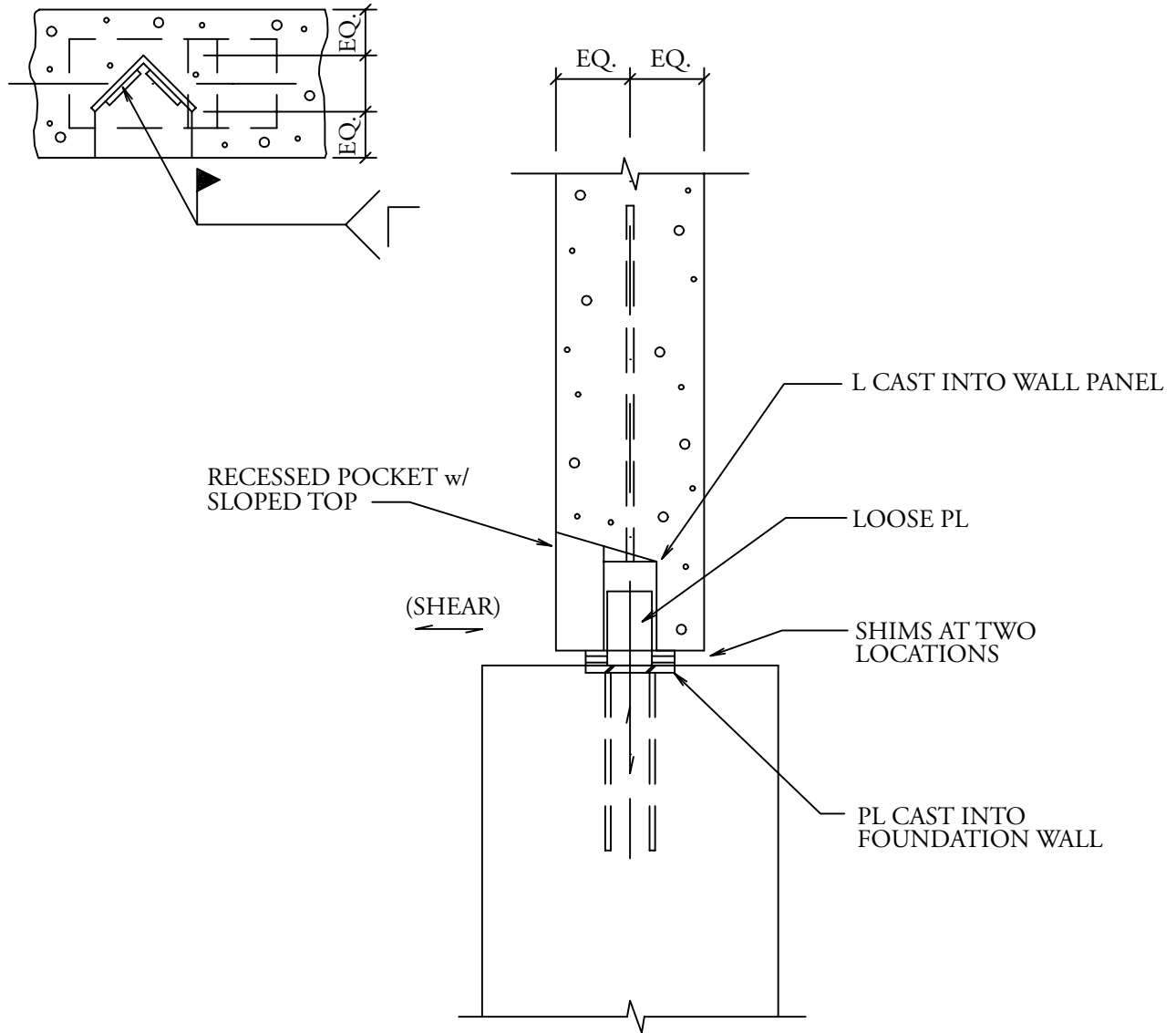


ERECTOR NOTE :

FILL ENTIRE JOINT AND CONNECTION
SLEEVE w/ NON-SHRINK GROUT.

CONNECTION BETWEEN WALL PANELS

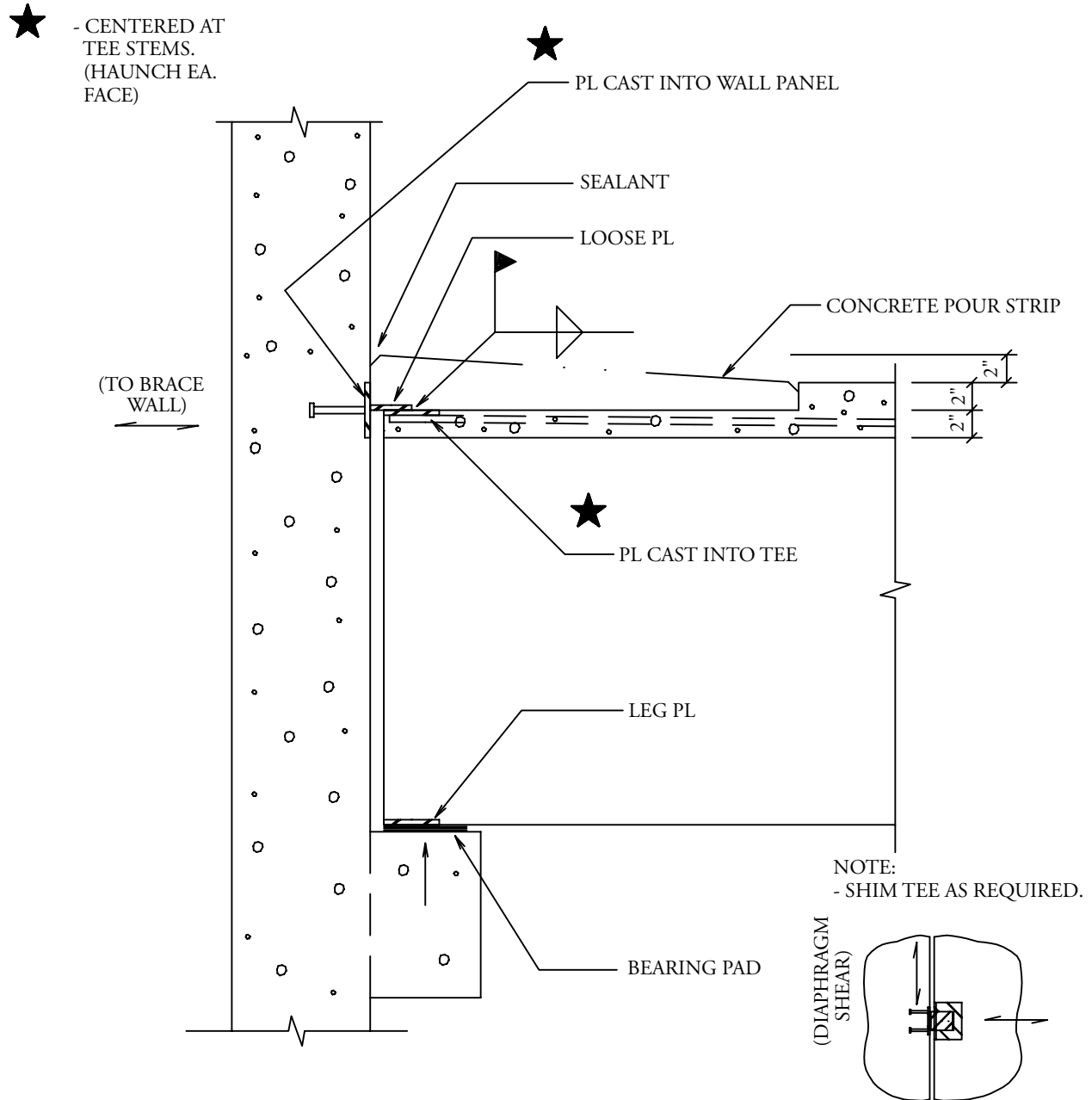
(NOTE: THIS CONNECTION CAN BEHAVE AS A HINGE
AND MAY REQUIRE LATERAL BRACING.)



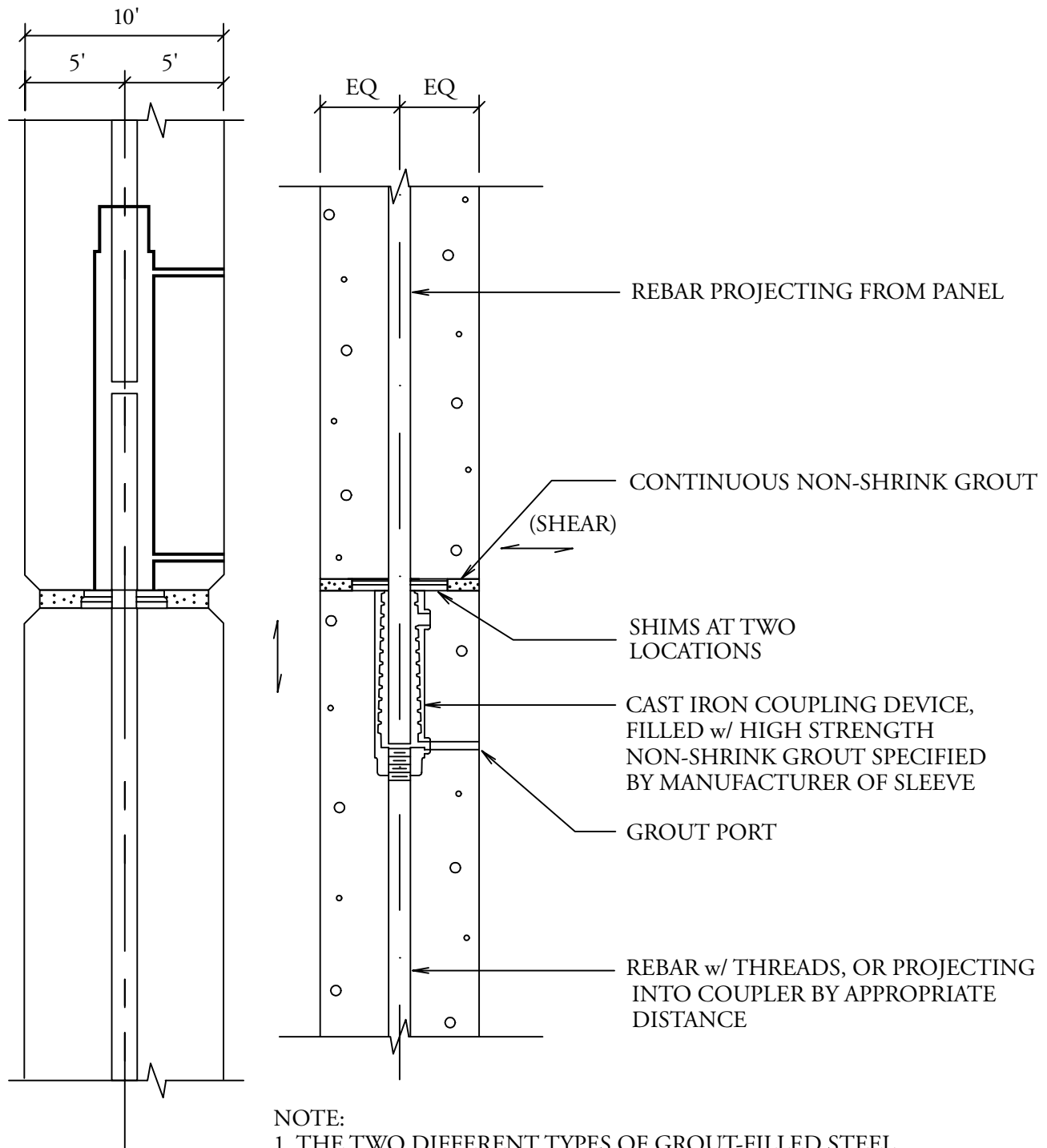
ERECTOR NOTE :

FILL ENTIRE JOINT AND CONNECTION
POCKET w/ NON-SHRINK GROUT.

WALL PANEL TO FOUNDATION CONNECTION



DOUBLE TEE CONNECTION TO WALL PANEL WITH HAUNCH



CONNECTION BETWEEN WALL PANELS

6.0

PRODUCTION

6.1

Concrete Quality

A precast, prestressed concrete parking structure requires high-quality, low-maintenance materials and connections. This can best be ensured by careful consideration of all aspects of the design and construction phases and by employing products produced by a PCI Plant-Certified Manufacturer.

The concrete compressive strength and mix design should be in accordance with contract documents, and materials used in the manufacture of the concrete should meet all applicable ASTM specifications. The recommendation for initial concrete compressive strength for precast prestressed concrete is typically 3,500 psi. Concrete cylinder samples should be taken in accordance with the *PCI Quality Control Manual*, MNL 116, and cylinder breaks should be monitored for release, stripping, and final conditions.

A summary of ASTM specifications for concrete materials and reinforcing steel is listed in Division IV of the *PCI Quality Control Manual*, MNL 116.

6.1.1

Admixtures

Admixtures may be incorporated to accomplish the following:

1. Air entrainment
2. Set retardation
3. Set acceleration
4. Water reduction
5. Water reduction and set retardation
6. Corrosion inhibition

Air entraining admixtures should be used in climates where resistance to freezing and thawing is required (refer to Chapter 3). They also may be used in certain applications to improve workability.

Superplasticizers are types of water reducers that increase workability but are more expensive than ordinary water reducers. They are ideal for parking structure applications where it's desirable to have fluidity for placing concrete around heavily reinforced connections and low water/cement ratios.

Admixtures can have negative results if not used properly. Color differences and strength problems can occur if consistency is not maintained. Only admixture manufacturers with successful field experience should be considered in product selection. Admixtures should be stored properly to avoid freezing or exposure to contaminants that would adversely affect the chemical ingredients. Admixtures from different manufacturers should be checked for compatibility.

Grout and dry-pack materials, when employed, should be produced and tested in accordance with ACI.

The precast manufacturer should be prepared to submit certificates of compliance for all materials used in the manufacturing process, if requested.

6.2

Casting Standardization

6.2.1

Products

6.2.1.1

Double Tees

The current trend is away for 8'-0" wide double tees and toward the use of double tees 10'-0" to 15'-0" wide for reasons of economy. Tee depths should be constant throughout a project and only vary when extremely heavy loads (such as cooling towers) are encountered. Contact area producers for availability of sections that meet the project's requirements. If possible, it is preferable to maintain the depth of stems but vary the width. Bay widths should be such that full-width tees can be moduled easily (e.g., three at 10'-0" = 30'-0" or three at 12'-0" = 36'-0", instead of odd bay widths of 28'-0" or 22'-6"). When narrow-width tees must be used, the designer should pay special attention to minimizing differential cambers. Bay widths that match double-tee width multiples yield the optimum in deck economy and decrease the potential for engineering, production, and erection errors. Joint width may be increased to maintain the module when ramps are created by running tees across the slope.

6.2.1.2

Beams

Beams for exterior and interior grid lines should be kept the same depth for each application. The depth limitation will be controlled by the clearance heights in the drive cross-overs or entrances. To reduce overall structural depth, the supported double tees are frequently dapped. Inverted tee beams typically are used on interior-spans. Exterior beams are either L beams or pocketed rectangular beams.

It should be noted that some recently published codes eliminate the beam live load-reduction options, making it more difficult to support the required loads with limited depths. Two potential means to augment capacity of the section are to utilize non-prestressed reinforcement for flexure and horizontal shear reinforcement to cause the field applied topping to behave compositely with the beam section.

6.2.1.3

Spandrels

Spandrels are essentially perimeter beams that extend both above and below the deck surface. They are either ledged, pocketed, or have individual corbels to support the tee stems (Figure 6-1). Often articulation of the exterior surface by means of reveals, indentations, or projections is used for aesthetic affect. The local precaster should be contacted to determine the most economical solutions available. Closure spandrels may have the same cross section as load-bearing spandrels without ledges or pockets.



Figure 6-1 Ledged spandrel in form.

It is recommended that handrails, when utilized, should be attached with field drilled anchors.

6.2.1.4

Columns

For exterior columns, straight-shaft columns with blockouts for beam or spandrel support are preferred to haunches (Figure 6-2). Minimizing different column sizes is desirable and ideally, all exterior and all interior columns will be the same size. Increasingly, columns are prestressed or reinforced with a combination of prestressing strand and normal reinforcement. Prestressing makes it possible to cast the columns in longer lengths and reduces the possibility of cracking during handling. Column splicing in tall parking structures may be desirable to the erector to control stability. Utilization of high strength concrete typically allows for the reduction of cross section, thereby enhancing the “openness,” and reducing the stiffness which helps with volume changes.



Figure 6-2

6.2.1.5

Walls and Openings

Load-bearing panels are used frequently for interior-ramp framing. The panels are either a series of single-story horizontal panels or tall, narrow, vertical panels. Both architects and owners favor openings in these walls because they allow light to pass through, and, they increase the visibility within the garage. These openings enhance the appearance and improve the ventilation and security of the garage.

The walls support double tees on ledges, button haunches, or pockets. Eccentric loading normal to the haunch projection is typically not a problem, provided the stem bears sufficiently on the haunch or pocket. When stemmed members are used, the width of the load-bearing wall should modulate with the double-tee spacing. These walls may add to the lateral stability of the structure. The amount these walls will help in the lateral stability of the structure will depend on their degree of openness.

6.2.1.6**Other Panels**

Stair and elevator wall panels are frequently produced using precast concrete. Walls can be prestressed or normally reinforced with haunches for stairs along with button haunches or pockets for tee stems. Pockets cannot be used at both ends of a tee for erection reasons. Coordination is required with elevator subcontractors for block-outs to accommodate call buttons, floor indicators, etc. Alternatively, the door opening may be oversized, and the section filled in with concrete masonry block. Elevator guidrails should be attached with field-drilled anchors.

6.2.1.7**Shear walls**

Precast shear walls frequently are used for lateral restraint of precast parking structures. Since tolerances are usually stringent, special attention needs to be given to grouted splice connections or inserts in the precast units that need to match up with connections in foundations or other panels. Openings may be cast into these walls for improved visibility.

6.2.2**Daps, Blockouts and Haunches**

To minimize floor-to-floor height, beams and double tees are frequently dapped. (See *PCI Design Handbook* for design methods). Particular care must be taken in detailing dapped connections to minimize congestion of reinforcement, provide proper anchorage, and insure well-consolidated concrete placement. Unless special design considerations dictate, such as the use of embedded steel shapes, daps should be limited to no more than one-half of the member depth.

Column haunches are cast in a variety of ways. These include up-in-form, up-and-down-in-form, on both sides of member, or in some cases up-in-form plus a second step of welding on the down-in-form haunch in a plant-finishing operation. Unless haunches are parallel with the length of a wall panel, they are usually cast on the up-in-form face. In this position, they can be adjusted to match ramp slopes.

Generally, it is preferred to use individual button haunches instead of continuous haunches. Button haunches (also known as spot corbels), if cast up-in-form, can be precast previously and hung in the form during casting with their anchor bars engaging the body of the panel. Steel shapes and plates can be used to reduce haunch height and, therefore, floor-to-floor height. Blockouts in wall panels can be used to support floor members (Figure 6-3). These pockets require substantial draft on their sides (a minimum of 1/4 inch for every 6 inches in depth) and should have at least 2 inches cover to the exposed face. More cover may be required if the exterior surface has an architectural finish.



Figure 6-3

6.3**Non-Prestressed Reinforcing**

Special attention should be given to reinforcing to avoid interference with the connections, which are often recessed. In many products requiring cages, which are pretied and set in molds, interferences may result in costly changes.

Different types of reinforcing are optimum for various products. For example both a fully prestressed ledged spandrel with closed stirrups and a prestressed pocketed spandrel with mesh and mesh caps are illustrated here for comparison.

Development and lap lengths, bends, and hook dimensions must meet all applicable code requirements.

6.4

Cast-In Materials

6.4.1

Standardization

Standardization of cast-in materials (e.g., plates, inserts, and assemblies) is important. Standardization improves quality control in the plant and contributes to production economies. For example, when some details require no. 6 reinforcing bars and others require no. 5 bars for similar conditions, it is better to use the no. 6 bar throughout. In more general terms, where the majority of haunches are required to support a 100 kip load, and a few are subject to only 60 kips, all haunches should be designed for the 100 kip load. Plate sizes, anchor studs, and product dimensions should be identical if possible.

6.4.2

Inserts

It is recommended that inserts for connecting other materials to precast concrete, such as handrails or lighting fixtures, be installed in the field by the trade requiring the insert. This has proven to be the most economical and time-saving solution, because the information required to cast in the material is seldom available to meet production schedules. In addition, proper location and jiggling of small fasteners is difficult and expensive during casting. If inserts must be used, it is recommended that a thin mounting plate be used to improve dimensional control and allow attachment to form.

6.4.3

Sleeves

It is recommended that any grout filled steel sleeve be introduced into the molds as intended or recommended by the manufacturer. It should be noted that proprietary splicing sleeves are systems and generic parts should not be introduced. Appropriate hardware should be used to secure sleeves during pouring and vibration of the concrete. Jigs are often used to accurately locate and hold in place sleeves and/or reinforcing for field pours. Bar embedment and protrusion dimensions should be verified prior to the pour.

6.4.4

Plate Assembly Anchorages

To prevent any interference, particular care must be taken in the design and detailing stage to properly size and locate reinforcing bar and stud anchorages.

Large bars may be impractical due to their longer required embedment length, the difficulty in obtaining proper bend geometry to conform to the connection hardware, or the limited space available within a precast member to properly contain large bars. Attention also must be given to locate welds away from cold bar bends. While ASW D1.4 suggests allowing a cold bend at two bar diameters from a weld, experi-

ence shows that a minimum distance of 3 inches is prudent with the small bars commonly used in precasting.

When designing a connection, it is important to verify that the anchorage and reinforcement are positioned to allow proper casting and vibrating of low to average slump concrete in and around the connection region. When large quantities of reinforcement cross each other, the concrete may contain honeycombing and voids. Such production problems can be reduced by checking the connection region for dimensions and clearances prior to casting and considering the size of aggregate to be utilized. Half-size or full-size drawings are helpful in eliminating such potential problems.

To ensure proper performance, it is essential that cast-in assemblies (plates, anchors, steel shapes, inserts) be properly attached to the form. If they are not held securely during casting, they can become skewed, recessed or misaligned. To accommodate attachment to the form or jiggling, it is suggested that two 1/4 inch holes be drilled into plates, angles or steel shapes so that they can be held in place by screwing or nailing to the form or blockout surface. Glue and double-faced tape are two other methods of attachment. To avoid pockets or honeycombing under top-of-form assemblies, it is suggested that a 3/4 inch air-release hole be drilled in the top surface of elements that have a surface area larger than 16 square inches.

Plates located on the surface of precast units, particularly in areas where deicing salts are used, should be protected by special coatings such as epoxy or zinc enriched paints or galvanizing. Stainless steel also may be utilized. Note that special care should be taken when galvanized assemblies are used in conjunction with mild steel reinforcement. To avoid possible strain-age embrittlement and hydrogen embrittlement, adherence to the practices given in ASTM A153 is mandatory (also see section 5.4).

The amount of field welding may dictate a thicker plate, but in no case should an embedded plate be less than 1/4 inch thick.

6.5

Molds/Formwork

When the precaster is given more flexibility in sizing and panelizing product, standardization will result in uniformity and economy. Minimizing the number of molds and mold changes will reduce production costs. Standardizing strand designs will enable efficient long-line production. Mold materials can be tailored to the number of casts, such as opting for a concrete or steel mold to cast 50 similar pieces rather than a wood form that would require maintenance. Two-part casts with a cold joint may be more efficient. In architectural precast, the condition of molds and tolerances of dimensions is especially critical. The precast scheduler should familiarize himself thoroughly with the products, design, erection requirements, etc. in order to issue the best possible casting sequence.

Attention should be given to types of lifting and connecting inserts or hardware that reduce the modification of molds or rails. For example, if a haunch is required on the face of a spandrel, the welded-on haunch plate is more attractive in order to avoid building up the mold face. Also, placing stripping inserts on the back face of the panel will preclude having to remove side rails to strip a panel.

6.6**Manufacturing,
Interfacing and
Erection Tolerances**

Three groups of tolerances should be established as part of the precast concrete design: tolerances for manufacturing, tolerances for interfacing, and tolerances for erection. This section will deal with the first two; erection tolerances are discussed in Chapter 7. When tolerances are understood and appropriate allowances made in the design, the task of determining and specifying them becomes fairly simple. The pre-caster, contractor, and erector must in turn carefully monitor tolerances in order to construct the structure as designed.

6.6.1**Product Manufacturing
Tolerances**

The economics, ease, and speed of erection require accuracy in the dimensions of precast units. Product-manufacturing tolerances relate to the dimensions and dimen-

sional relationships of the individual precast concrete units. They are normally determined by economical and practical production considerations, as well as functional and appearance requirements. Manufacturing tolerances are applied to physical dimensions of units such as thickness, length, width, square, camber, and opening size and location.

Production tolerances should comply with the industry tolerances published in the *Design Handbook* (PCI MNL 120). The PCI Tolerance Committee report also provides suitable industry standards. These tolerances form a range of acceptability in common use in the industry. However, if the design or appearance of the parking structure is not affected, exceeding such tolerances should not be cause for arbitrary rejection.

The Architect/Engineer should be responsible for coordinating the tolerances for precast work with the requirements of other trades whose work adjoins the precast construction. In all cases, the specified tolerances must be reasonable, realistic, and within industry standards.

6.6.1.1**Structural Conditions**

The consequences of accumulation of tolerances permitted on a particular project should be investigated to determine whether a change is necessary in the design or in the tolerances applicable to the individual components. For example, there should be no possibility of minimum tolerances accumulating so that the bearing length of members is reduced below the required design minimum. The designer should specify the minimum bearing dimensions and conditions.

6.6.1.2**Connection Tolerances**

Ample tolerances must be provided in sizing connection materials to allow for both production and field tolerances. For example, to connect a 4 inch plate, it is recommended that the cast-in connection plates be oversized to 6 inches. When detailing bolted connections, provide for oversized holes in the connection plate or angle at least twice the size of the bolt but no less than 1 inch larger than the bolt diameter. A washer plate also must be used.

For corbels or plates receiving tee stems or beams, stems may be offset as much as 2 inches laterally, especially on parking structure ramps. This should be considered in designing the hardware and detailing the corbel.

6.6.1.3**Visual Effects**

The degree of deviation from theoretical visual requirements will be controllable. Large deviations are objectionable, whether they occur suddenly or cumulatively.

6.6.2**Interfacing Tolerances**

Performance and fit of interfacing materials (e.g., doors, louvers, rails) require determination of acceptability of standard precast tolerances. To avoid encroaching on property lines, reasonable tolerances with respect to those lines should be identified.

6.6.2.1**Door and Window Blockouts**

Where door openings are required in wall panels, particular attention should be made in sizing the opening. To allow for production tolerances, at least 1/2 inch extra should be allowed on all sides.

6.7**Quality Control**

Each plant should be PCI certified and establish a Quality Control Program based on guidelines given in the *PCI Quality Control Manual*, MNL 116.

6.7.1**Inspections by the Precaster****6.7.1.1****Pre-Pour Inspection**

A pre-pour inspection should be performed by a qualified inspector to check mold dimensions, plate locations, reinforcing, etc. prior to pouring concrete. At this time, any corrections may be made and interferences resolved.

6.7.1.2**Post-Pour Inspection**

A post-pour inspection should be performed to double check the above and ensure that no adverse changes have taken place during the placement of the concrete. Finishes can be reviewed at this time.

6.7.1.3**Miscellaneous Inspections**

Other checks as specified in the *PCI Plant Certification Manual* are required. These include inspecting concrete cylinder breaks, checking concrete mix and placement procedures, stressing operations, and record keeping.

Quality Control personnel should keep good communication with Production personnel so problems can be corrected promptly.

6.7.2**Inspections by the Designer**

To ensure proper quality during production, it is recommended that the designer review the quality control program employed in the manufacturing plant. PCI Plant Certification is preferred and may not require such a review. The designer also should inspect the plant during the first casts of each product to be satisfied that the stated

procedures are being employed. Periodic inspections are available to the designer as well. It is suggested that the inspections be conducted by someone familiar with precast plant production procedures to ensure that appropriate items are inspected.

6.8

Finishes

6.8.1

Floor Members Finishes

A double tee surface receiving composite topping should be roughened by transverse-raking or brooming. Tie bars are required to transfer shear across the two surfaces in composite beams but usually not in double tees because the horizontal stress levels are low.

6.8.2

Exposed Surface Finishes

On surfaces exposed to view (spandrels, flat walls, etc.) it is recommended that a light broom finish, or a smooth, floated surface be used. In some cases manufacturers prefer a light wet sand-blasted finish.

Hand-troweled surfaces should be avoided since they are expensive to produce and frequently darken the surface in uneven patterns. The producer should be consulted and invited to furnish samples of his preferred treatment for approval. If a hand-troweled finish is selected, the precaster should take special care when covering the finished concrete before curing. Allowing insulated blankets or polyethylene covers to come in contact with the finished concrete can produce discolorations.

6.8.3

Architectural Finishes

Occasionally architectural finishes, such as exposing aggregate by sandblasting or use of a retarder, are used in parking structures. Because the members with such finishes are frequently also structural members, such surface treatments should be kept relatively simple. It should be noted that architectural product tolerances are not always possible for large structural members employing architectural finishes.

6.8.4

Facade Samples

From an aesthetic standpoint, one of the more critical steps in the construction process is establishing an agreed-upon measure of the level of finish of a facade. This normally requires quality control samples to establish a range of acceptability resulting in an agreed upon facade finish. A suggested process would be as follows:

Step 1.

The precast fabricator provides samples from previous projects to establish the types of finishes and colors that are readily available. If a special finish has been specified, samples will be limited to that type of finish.

Step 2.

Once a finish type is selected and a color or colors (if any) is chosen, specific samples about 2'-0" x 2'-0" are cast and finished as agreed. This process should use a minimum of two samples to establish a range. One set of approved samples should be kept in the plant and one set in the field to be used for control.

Step 3. (Optional)

Once the custom finish samples have been selected the next step should be to produce an approximately 6'-0" long section of spandrel panel usually representing the end of the panel. Reveals and face mixes (if any) can be better viewed, and it will present a better overview of the degree of variability that will naturally occur in concrete.

Step 4.

The final step is to cast a fully prototypical panel. This panel or paired set of panels will set the standard for the rest of the precast facade panels. By the time a full-scale panel is made, all issues of color, finish, and sharpness of features should be resolved. One full-scale panel can be left at the plant and one at the site to act as the quality control for the rest. It is advisable that panel inspection be performed at the plant where, if defects are found, better tools are available to remedy the condition. Inspection in the field then is limited to damage from shipping and handling.

Traditionally, due to the cost of prototype panels, they are incorporated into the building as one of the last panels erected.

6.9**Production Summary**

Precast concrete offers many advantages and is the clear material of choice for parking structures. The contractor performs relatively little site work in preparation for the erection of the structure, which reduces total time on site. The precaster is able to produce the members offsite, employing economies beneficial to overall project costs and at the same time greatly improving conditions for quality.

Standardization of products, hardware, designs, etc. are all important in capitalizing on the overall economies of precast structures.

7.0

ERECTION CONSIDERATIONS

7.1

Introduction

Erection considerations for precast concrete parking structures vary to some degree from erection considerations for other precast concrete structures. Some of the unique aspects of these structures include the high percentage of long, heavy members; the exposed nature of the structural frame; the relative instability of the structure during erection until the topping is poured and/or all connections are completed; and the special access conditions created by tight construction sites.

Precast concrete parking structures tend to be multi-story and contain vertical-load supporting members, such as columns and wall panels. These usually are manufactured in the maximum length reasonable to cast, handle, and transport. This minimizes field splices, joints, and the number of pieces to erect. The desire for open floor spans in precast concrete parking structures also requires long, heavy horizontal load-carrying members.

7.2

Erection Procedures

Erection procedures vary in accordance with the size and shape of members, engineering design, and the overall complexity of the structure. The sequence of erection (Figure 7-1) should be established as early as possible, and a schedule of delivery, preferably by load list, should be determined in sufficient time. This creates time to



*Figure 7-1
Crane in middle bay setting three bays at a time – bringing the building out in one sequence.*

properly organize the loading and do needed cleaning or preparing of members prior to shipping. More definitive procedures are outlined in *PCI's Erectors Manual-Standards and Guidelines for the Erection of Precast Concrete Products* (to be published in 1997 or early 1998). Safety issues are addressed in *Erector's Safety Manual for Precast and Prestressed Concrete*.

Prior to beginning erection a field check of the project must be performed by the precast concrete supplier or erector. This will establish that there are no errors in the foundations or anchor bolt locations and that the members can be erected in their proper locations in the structures. Special conditions created by tight construction sites require early evaluation of access for erection equipment and trucks. A final check prior to the move-in of equipment should be also completed.

Probably the most important step of the preconstruction planning process is a review of the plans and details by the designer with the erector.

7.3

Stability

Evaluating how to stabilize the structure during construction is essential for properly planning the erection. As this is a common requirement for each of the three types of load-bearing members to be covered in detail, the following considerations for temporary bracing and guying apply to (a) deck members, (b) long columns, (c) wall panels. Stability during erection is paramount, since parking structures are typically multi-story, and stiffening floor diaphragms may not be complete until composite topping is placed.

During construction, the members are exposed to wind, possible seismic shock, temporary torsion due to applied loads and possible impact from construction equipment or adjacent members while being erected. At this stage, the designed structural framing is not complete, so temporary bracing and/or connections is required. In particular, the erection stability must account for the eccentric loading frequently created by the location of the exterior spandrels on the columns. Special requirements for stability during various stages of construction should be determined in advance of the erection process. A preplanning meeting between the erector and the precast engineer (or other competent personnel) should be held to identify special requirements for the installation and removal of bracing, the sequence of member placement and the percentage of completed connections necessary to tie the structure together.

Erection stability sometimes can be built into the design. It may be possible to design the foundations and anchor bolts to withstand the forces generated by wind and the temporary forces caused by construction procedures. Since cost is a factor in providing adequate stability, column base connections may not provide sufficient stability, and therefore temporary guying and/or bracing must be provided until final structural stability is achieved in the completed structure. It is desirable to start erection from a laterally stable element, such as a corner wall or stair tower.

A wide range of bracing options is available. Conventional steel pipe, tilt-up braces are most commonly used. These devices combine strength, flexibility and adjustment into one unit. Braces should be used per the manufacturer's specifications regarding load, length, and inclined angle. Special care must be given to the location and the capacity of both the insert in the panel and the deadman or ground anchor. Ground anchors, are particularly susceptible to displacement during rainy conditions, and

their stability under these conditions must be considered. Temporary bracing should be arranged so as not to interfere with other members being erected. Cable guys are frequently required for greater heights, but these are slow and expensive to install and usually are more cumbersome to work around. When used, long cable guys can stretch under a load and should be adjusted as required.

7.4

Deck Members

Double tees are commonly used as floor or roof slabs. They are manufactured in a wide range of sizes, providing a high degree of design flexibility for long or short spans. Single tees, cast in the double tee form to maintain similar cross section also are used occasionally.

The manufacturer's handling instructions must be followed, particularly for long-span, deep-leg members where torsional stresses generated by hauling over uneven ground can cause cracking of flanges along the stems.

Strand lifting loops are typically used for hoisting the members. Slings and spreaders should be of adequate length so the lifting loops are not overstressed. The spreader angle should always be greater than 45 degrees.

Double tees have plates cast in the bottom ends of the legs for armoring end-bearing conditions. Such plates typically should not be used to weld the tees to beams, columns, walls, or spandrels. Welding such plates eventually could cause structural damage due to later shrinkage, creep and thermal effects.

Variation in camber and warp can be eliminated with intermediate flange connections. Shimming of the tee stems also can achieve better camber match between adjacent long span and short span tees or ramp tees. Unsymmetrical tee units, with a varying width of deck, must be maintained in a stable condition until final connections are completed.

Camber corrections must be done before the flange connections are welded. Care must be exercised in making camber corrections so the flange connectors don't become overstressed and cause serious spalling of the flanges.

After the units are set in their final positions, lifting loops should be cut off below the deck surface for pretopped tees. Special lifting anchors, locating lifting anchors in pour strip areas or special patching procedures should be considered. For a field topped deck, joints should be taped, sealed with roofing felt or grouted prior to placing floor topping.

When utilized, single tees must always be handled in an upright position to prevent buckling and rolling. Saddle brackets, fastened to steel or wooden bunks, are required for transporting these units. Erection criteria for long-span single tees are the same as for long-span double tees, except that single tees must be braced to prevent tipping over from bumping or wind loading until they are permanently connected in the structure.

7.5

Columns

Prior to erecting structural columns, elevations may be established at the top of shim pack or leveling nuts. If the design calls for a base detail other than anchor bolts, elevations should be established at the top of shim packs, and the column must be stabilized. They can be held plumb with pipe bracing or guys. Long columns placed in this manner also may have to be guyed or may require longer and stronger braces.

The designer's instructions must be followed closely in the unloading and turning of columns (**Figure 7-2**). Columns up to 40 feet in length normally can be picked up directly from the truck with the crane load line hooked to a lifting loop in the top of the column or to a pin and lifting frame through a hole in the column.



Figure 7-2
Rotating a column into position.

Long columns of more than 40 feet usually will have to be turned using multiple lines and multiple pick points. Columns in the 60- to 90-foot length require further special handling for hauling and erection, and a rolling block system is required for turning the columns into the vertical position. Guying or bracing also is required for these long lengths. Long columns can be spliced when it is not practical to erect them in one piece.

Sufficient access is required to allow anchor bolts to be tightened. If the columns are to be loaded immediately, sufficient shims must be installed to transfer the load. If the columns are erected far enough ahead of placing the rest of the structure, dry-packing or grouting of bases with non-shrink grout should follow directly behind erection. Continuous-thread, high-strength Dywidag bars and nuts also can be used instead of standard anchor bolts.

Columns should be plumbed by using two transits placed at 90 degrees. Column plumbness should be rechecked after load is applied. Column plumbness should be checked periodically throughout the erection process. Spandrels frequently produce eccentric loads on the columns when they are used to support floor members, especially when using pretopped tees. These eccentric loads make it difficult to keep the columns plumb. One solution is to erect the columns a measured amount out of plumb as load is applied. To maintain a plumb condition, the columns should be braced (**Figure 7-3**).

7.6

Wall Panels

Several types of bearing wall panels are commonly used, depending on design and architectural features. All types must be handled with care in order to prevent damage.



Figure 7-3
Braced "lite walls" during erection.

Single-story panels should be shipped on frames in an upright position when possible to eliminate the need for extra handling at the jobsite.

Offset lines normally are marked on the foundation. Elevations are established by using shim packs. Care should be taken when using steel shims, as the compressive modulus of a steel shim is six times that of the dry-pack. Consequently, the grout will compress more readily than the steel, and the principal load-transfer path will remain concentrated through the steel shim rather than along the grout bed. High load concentrations at the shims can cause spalling at panel surfaces or crack panels vertically. Plastic shim material is often used because of its compatibility in terms of stiffness with the grout. Guidance for locations and type of shim material should be provided in the plans and details.



Figure 7-4
Story height wall panels "Stacked."

Panels should be plumbed using transits or hand levels. While the crane is still holding most of the weight of the panel, bracing/guys should be installed. Inserts for attaching bracing/guys normally are cast into the back of the panel and drilled into the floor slabs at the required location. All bracing must remain in place until stability is achieved for that portion of the structure. For multi-story structures, the walls can be post-tensioned vertically using post-tensioning bars coupled in pockets at the panel base on each floor level. Welding or grouted splice sleeve connections of reinforcements offer other ways to transfer force at the horizontal story.

The base of the panels either bracing/guys should be dry-packed before the next level of floor slabs is erected or the applied stresses should be checked carefully. When vertical post-tensioning is used, walls must be dry-packed in advance.

7.7**Beams and Spandrels**

Beams are generally erected on or between columns. If the columns were erected in their correct locations, further layout for the beams should not be required other than to monitor their length prior to erection and to keep joint widths constant. Beam-to-column connections will vary depending on design requirements and/or architectural details. Special precaution must be taken to avoid rigidly fixing beams to columns, such as by welding both the top and bottom of the beam, unless specifically called for in the design. If it is done, specific procedures must be followed. Special precautions should also be taken when erecting double tees on pocketed spandrels opposing vertical "lite walls"

7.7.1**Beam Connections**

Spandrels commonly are connected to columns by bolts projected through sleeves cast into the column and anchored in the side of the spandrel by cast-in anchor nuts. A bearing material, usually neoprene or reinforced masticated rubber, provides uniform bearing for the spandrel-to-column bearing condition. This connection handles thermal movement quite well.

Corbels frequently are used on interior columns at intermediate floor levels. Beam stability normally is achieved with connections between steel plates cast into the column face and the top of the beam or by bolting through the ledge to the corbel surface; bearing pads are used at the bearing surface. If expansion must be provided at one end of a beam, a neoprene pad of proper thickness to accommodate the anticipated movement or a specially designed expansion bearing of stainless steel and teflon must be used. The top connection must not be welded unless double columns are used.

If welded spandrel-to-column connections are used, it is recommended that the connections be designed to allow for flexure in the spandrel's length. This can be achieved by using an angle welded only at the end of the leg attached to the column.

Structural steel brackets encased in concrete may be used where a small sized corbel is required. The amount of welding used for beam-to-column connections should be minimized, and the need for parking decks to expand and contract over a wide temperature range should be taken into account.

7.7.2**Structural "L" and "T" Beams**

Structural "L" and inverted "T" beams must be checked for rotation when loaded eccentrically. Wedging behind the stems of the double tees or single tees using temporary hardwood wedges may help prevent rotation. Care should be taken to ensure that the bottom of the beam does not translate and the columns rechecked for plumb. If one side only of an inverted "T" beam must be loaded, it may be necessary to install temporary shores under the loaded edge until rotational stability is achieved. A bolted connection detail for preventing roll is shown in Chapter 5.

7.8**Field Considerations for Connections****7.8.1****Introduction**

When considering the erection efficiency of any precast concrete project, the type of connection details is of prime importance. Thus designers in the early stages of the project must ensure that connections are economical and workable in the field.

Connections should recognize the necessary tolerances between precast elements and foundations and should be simple in detail and easily adjustable in the field to meet job conditions not accounted for in the plans.

Repetition of the same connection improves quality control in the field, leading to better structural performance. In general, common hardware, even if heavier, should be used at lightly loaded units if it will eliminate a special piece mark or make welds more uniform in size. This practice prevents the possibility of the lighter piece being used where the heavy one is required.

Standardization also applies to dimensioning connection details. Little is gained by slight changes in dimensions, since the savings in materials may be more than offset by the extra labor needed to develop the modifications. Furthermore, if the changes in connection dimensions and materials are not in increments large enough for visual recognition, there is a greater chance that an improper connection may be used.

All items, materials, and procedures involved in making connections should be standard to the industry and readily available. Efficient connections also should minimize the pieces of hardware.

In general, grouting and dry-packing should proceed as members are erected. Composite topping typically is poured on top levels first, proceeding to lower floors, in multi-bay pours. Topping usually takes place after the deck has been erected completely or to a natural dividing point such as an expansion joint.

Adjustments or changes in connections that could place additional stress in the products or connections are not permitted without approval by the precast designer. He should be alerted as soon as a discrepancy is apparent. The precast designer should be contacted early enough to provide input into the remedial detail rather than be faced with an accomplished fact difficult to change. This benefits all parties. Particular care should be taken to prevent damage to the precast members when adjustments bring the unit into final position.

In general, lifting anchors should be compatible with the method of shipping (flat, on edge, etc.). They should be located so there will be no interference with the structural frame during the precast setting operations. If possible, they also should be hidden from view.

7.8.2

Temporary Connections

To provide the appropriate stability, the need for a required number of temporary connections should be determined by the number of floors or floor area, if the erector wants to erect in a structure before making final connections. This is especially important for grouted connections, floor diaphragms and cold weather conditions. For pretopped structures, it may be necessary to use temporary shear ties from the pretopped double tees to shear walls to produce erection stability if the final connections are achieved in closure pours.

7.8.3**Types of Connections** (as related to erection)**7.8.3.1****Bolted Connections**

Bolted connections when designed with proper tolerances simplify and speed erection, because the connection is immediately positive. Final alignment and adjustment are made later without tying up valuable crane time. When using bolted connections, it is desirable to standardize the size of attachment hardware (clip angles and bolts). This minimizes errors, reduces hardware inventory, and improves productivity. With bolted connections 3/4 inch, 7/8 inch or 1 inch diameter bolts are considered standard in the precast industry.

Clip angles should have slotted or oversized holes to provide adequate adjustment and movement caused by expansion and contraction of the precast units and supporting members. All bolts should be verified as being of proper length and diameter. When bolts are attached the depth of the units recess should be checked to ensure required thread engagement.

Following erection of a precast unit where slotted connections are used, bolt position and tightness should be checked. The bolt to the spandrel should be tight but not so tight that it can't move within the connection angle slot. Regular steel washers may be required to ensure the bolt has been developed adequately. Low friction washers (e.g., teflon) are necessary to ensure movement if rough surfaces exist between the connection elements. Such connections should be coated to prevent rusting.

Design of bolted connections must allow reasonable erection tolerances. Alternative connections should be developed when the connection can't be made because the insert is out of place or missing. Expansion bolts, when used, should be inserted into pre-drilled or self-drilled bored holes in hardened concrete. For connection reliability, the importance of correct installation and quality control cannot be overemphasized. For expansion bolts, the minimum distance to the edge of the concrete should be five times the bolt diameter.

7.8.3.2**Welded Connections**

Welded connections are efficient and adjust easily to different field conditions. Their strength depends on reliable workmanship and compatibility of welding materials with the metals to be joined.

Welding should be performed by qualified welders in accordance with the erection drawings. The drawings should clearly specify type, size and length of the weld, sequence and types of electrodes, minimum preheat and interpass temperatures, and location of welds as required, particularly if reinforcing bars are to be welded in the field.

Welding should be avoided in enclosed or confined areas, especially where hardware is galvanized. If galvanized materials must be welded, all weld areas should be coated with zinc-rich paint, or cold galvanizing compound, immediately after inspection. Welding of galvanized bent plates should be avoided or given special consideration due to embrittlement (Ref. to Sect. 5.4).

Care should be taken when welding in the vicinity of neoprene bearing pads to avoid damaging the pads. When welding or burning with a welding electrode, the ground should be attached directly to the base metal. Under no circumstances should the member be used as a conductor for the ground, as internal arcing on principal reinforcement may occur.

Potential damage to the concrete surrounding the connections always must be evaluated for possible effect upon performance of the connection. When welding a structural steel component embedded in concrete, thermal expansion and transformation of moisture into steam in the concrete may induce spalling or cracking in the surrounding concrete.

The steel's expansion and distortion also may destroy the bond between the embedded component and the concrete. This is particularly true where expansion of the heated metal is restrained by concrete. Inserts should be given adequate cover, and the steel shapes should be well anchored into the concrete to resist local distortion.

The extent of cracking of concrete and distortion of the metal is dependent on the amount of heat generated during welding. Heat may be reduced by selecting low heat rods of small size. The amount of weld metal may need to be controlled, as excessive continuous welds can be detrimental to the unit and to the connection. Long welds should be made in stages or designed as a series of intermittent welds, allowing the heat to dissipate. It also may help to use wet rags to absorb heat from the area surrounding the weld.

Note: The higher coefficient of thermal expansion associated with stainless steel components has created cracking in adjacent concrete surfaces. Thus, it requires special precautions and care as listed above.

7.8.3.3

Post-Tensioned Connections

Post-tensioning both vertically and horizontally, utilizing bonded tendons or bars, may be used for field connection of precast members. Bonded tendons are installed in preformed voids or ducts. They are made monolithic with the member and protected from corrosion by grouting after the stressing operation is completed.

Grout provides corrosion protection to the post-tensioning steel and develops a bond between the steel and the surrounding concrete. To accomplish this, the grout has to fill all the voids in and around the post-tensioning tendon for its entire length. Grouting procedures should follow the *PCI Recommended Practice for Grouting of Post-Tensioned Prestressed Concrete*.

Post-tensioning operations call for extreme care by all those involved. Personnel involved in the tensioning operation should be properly qualified and experienced with the stressing procedures and the equipment. No one should stand directly in back of the jack or around the dead end of the member being stressed.

7.8.3.4

Grout, Mortar and Dry-Pack

Grouts and mortars are used primarily as a load-transferring material and as a patching or void-filling material. When patches or non-critical void filling is the objective, job-mixed grouts or mortars are acceptable. However, when the purpose is to achieve a positive, protective or load-transferring capability, proprietary non-shrink or factory-controlled components should be used, or sufficient testing should be done of job-mixed grouts, to assure uniform results.

Dry-pack is a term associated with a method of placing rather than a description of material. Dry-packing uses only enough water in the mix to produce a stiff but damp granular material that must be packed into place. Both proprietary and factory-

controlled grouts and mortars used for dry-packing generally will yield higher compressive strengths. This is due in part to the selection and quality control of materials and the inclusion of special additives.

Panels set in a bed of grout can either be set on shim stacks and grouted later or set immediately in fresh grout with the elevation controlled by previously placed shim stacks.

Column base plates, in most cases, should be grouted before loading the frame with precast decking or additional shim stacks added.

Cold-weather grouting is critical due to the possibility of the grout freezing. Grouting is permitted at 40 degrees F and rising. Concrete or grout strength increases very slowly when exposed to low temperatures. Cold-weather protection and additional curing are necessary if ambient temperatures are below 40 degrees F. A space enclosure and heating should be used if early strength is required. Additives that increase early set and strength are advantageous, but they must be controlled carefully. Calcium chloride as an additive should not be allowed.

7.9

Field Erection Tolerances

Final erection tolerances should be verified and agreed on before erection commences. If they are different from those originally planned, it should be stated in writing and noted on erection drawings.

Erection tolerances are of necessity largely determined by the actual alignment and dimensional accuracy of the building foundation and frame. The general contractor is responsible for the plumbness, levelness, and alignment of the foundation of the cast-in-place concrete or structural steel frame. This includes the location of all bearing surfaces and anchorages for precast products. Many architects or engineers fail to recognize the critical importance of controlling foundation and building frame tolerances. If the precast units are to be installed reasonably plumb, square, and true, the actual location of all surfaces affecting alignment must be known before erection begins. This includes the levels of floor slabs and beams, the vertical alignment of floor slab edges, and the plumbness of columns or walls.

Erection tolerances are less critical in structures consisting entirely of precast concrete units than for combination precast and cast-in-place concrete or for steel frame structures. Ample erection tolerances are particularly required where precast units connect to site work, such as at footings or foundation walls.

7.9.1

Clearances

A good rule of thumb for joints is that at least 3/4 inch clearance be maintained between precast members, except flange-to-flange connections and wall panels-to-precast members. One inch is the minimum clearance between precast members and cast-in-place concrete. It also is the minimum clearance required between precast members and a steel frame. At least 1-1/2 to 2 inch clearance should be allowed in tall structures, regardless of the structural framing materials. The minimum clearance between column covers and columns is 1-1/2 inches. Three inches is preferred because of the possibility of columns being out of plumb or dimensions causing interference with completion of the connection. If clearances are realistically assessed, they will solve many tolerance problems.

7.9.2**Connection Tolerances**

All connections should be provided with the maximum adjustability in all directions in which it is structurally or architecturally feasible. Where a 1 inch clearance is needed, a 2 inch clearance should be selected. Closer tolerances are required for bolted connections than for grouted connections.

7.9.3**Hardware**

Location of hardware items, cast into or fastened to the structure by the general contractor, steel fabricator, or other trades, should be determined with specified tolerances for placement. Unless some other value is specified, tolerances for such locating dimensions should be 1 inch in all directions (vertical and horizontal), plus a slope deviation of no more than 1/4 inch in 12 inches for the level of critical bearing surfaces.

Connection details should consider the possibility of bearing surfaces being misaligned or warped from the desired plane. If the misalignment from horizontal plane exceeds 1/4 inch, adjustments can be provided with dry-pack concrete, non-shrink grout, shims, or elastomeric pads, if approved by the precast engineers.

Where a unit is not erected within the tolerances assumed in the connection design, the structural adequacy of the installation should be checked and the connection design should be modified if required. No unit should remain in an unsafe support condition. Any adjustments affecting structural performance, other than adjustments within the prescribed tolerances, should be made only after approval by the design engineer.

Small width variations between adjacent joints, can be accommodated by setting out joint centerlines equally spaced along an elevation and centering units between them. The resulting joint width may vary considerably—within specified tolerance—from the theoretical width, but a smaller variation between adjacent joints should be possible.

7.9.4**Protection of Work,
Patching and Cleaning****7.9.4.1****Protection of Work**

All precast concrete should be furnished to the jobsite in a clean and acceptable condition with embed plates cleaned and inserts free of obstruction. It should be kept in this condition until erected. The erector is normally responsible for any chipping, spalling, cracking, or other damage to the units after delivery to the jobsite and until erected and connected. The erector should take necessary precautions to protect the erected precast concrete as well as the work and materials of other trades, from damage during erection.

The general contractor should assume responsibility for protection of the work after final erection of any portion of precast work to acceptable alignment and appearance, including completion of all connections and joints. Any cleaning or repair of precast concrete work after acceptance should be done by the erector or precaster, but it remains the responsibility of the general contractor. Specifications should state this responsibility clearly. It is wholly impractical for the precaster or erector to police the work against damage by others after it is put in place. There should be a carefully established and implemented program of protection and later cleaning for each job under the responsibility of the general contractor, who alone can control all the potential sources of damage.

At the end of each working day, all necessary measures should be taken to protect the installation from damage. For example, adequate temporary protection should be provided where precast units in partially completed buildings could be damaged by weather such as by freezing water in holes, pipe sleeves, and inserts.

7.9.4.2

Patching

Immediately after erection, the erection supervisor or the precaster's representative should make a thorough inspection of the precast concrete installation and arrange for final repairs, cleaning where needed, joint treatment and final acceptance by the architect/engineer.

A certain amount of product repair is to be expected as a routine procedure. Jobsite repair may be necessary although fully acceptable elements may be superficially damaged during handling, transportation, or erection, resulting in minor chipping and spalling. Major repairs should not be attempted until an engineering evaluation is made to determine whether the unit will be structurally sound, and the method must be approved or provided by the precast engineer.

When required, all temporary lifting and handling anchors cast into the precast concrete units should be removed completely and the surfaces patched. Alternatively, if the devices are protectively treated, they need be removed only where they interfere with the work of any other trade or when exposed to view. Plastic plugs are often used where a hole is not covered, such as in a beam or column.

Responsibility for repair work normally is resolved between the precaster and the erector. It is recommended that the precaster execute all repairs or approve the methods proposed for such repairs by other qualified personnel. The decision on the time of patching should be left up to the precaster.

Since the techniques and materials for repairing precast concrete are affected by a variety of factors, including mix ingredients, final finish, size and location of damaged area, temperature conditions, age of member, surface texture, etc., precise methods of repairing cannot be detailed in this manual.

The selection of techniques or materials for the repair will depend on:

1. Extent of damage
2. Function of the product
3. Availability of equipment and skilled manpower
4. Economic considerations
5. Need for speed of repair
6. The importance of appearance

Cracks may be repaired by the injection of a low-viscosity, 100 percent solid epoxy under pressure if cracking has occurred and if repair is required for the restoration of structural integrity, prevention of general deterioration, or aesthetics. Care should be taken to select an epoxy color (amber, white, or gray) most closely matching the concrete surface. Epoxy grout may be mixed either by batch or continuous mixing and injected by using paint pressure pots, air or hand-actuated caulking guns, or hydraulic pumps.

The first step in filling a crack by injecting epoxy adhesive is to clean the areas adjacent to the crack as thoroughly as possible. Then a temporary surface seal should be provided on the adjacent areas and over the crack front and back (or top or bottom) so the liquid resin won't leak and flow out of the crack prior to gelling and curing. If unexposed faces of the concrete cannot be reached, crack repair by pressure injection is extremely difficult unless special steps are taken.

If cracks are moist or wet, or members are cold, ensure that epoxy being used will cure under the adverse conditions.

If the crack is vertical, the injection takes place from the bottom up through adjacent ports. Care must be taken not to trap air pockets. With horizontal cracks, injection proceeds from one end of the crack to the other through adjacent ports.

The crack is considered full when pumping pressure can be maintained. After the injected epoxy adhesive has cured, the temporary surface seal and ports are scraped off. This leaves the face of the concrete smooth and unmarred except for the trace outline of the crack.

The easiest repair is to simply glue the piece back in place using an epoxy bonding agent if a spalled piece is available and surfaces will mate, and the engineer approves for structural integrity. Both the broken surfaces of the unit and piece should be painted with the adhesive. Enough epoxy should be applied to the surfaces to have some of it squeeze out of the joint when the mated pieces are clamped together. An epoxy with a thick enough consistency should be selected to prevent sagging or running on a vertical surface. Self-leveling formulations should be used on horizontal surfaces. In some cases, it may be preferable to drill into the element itself to get some anchorage for bonding broken pieces.

7.9.4.3

Cleaning

As erection of exposed precast work progresses, all dirt, mortar, plaster, grout, fireproofing, or other construction droppings should be removed by brushing or water washing where required. The precast units should be given a final cleaning only after all installation procedures, including joint treatment, are completed and at least three to seven days after patching. Refer to section 7.9.4.1 for guidelines on responsibility.

To ensure that no permanent damage to the precast work or adjacent materials is likely to occur, it is recommended that the precaster and/or erector assist where possible in the final cleaning by checking the cleaner's procedures, prior to actual execution.

INTRODUCTION Precast/Prestressed concrete is highly resistant to abrasion, impact, corrosion, vandalism, and other ravages of time which make it an ideal solution for parking structures that receive minimal maintenance. Minimal maintenance to sustain parking can be interpreted to mean many different type of maintenance programs. However, the maintenance program selected has a definite effect on the operating characteristics and costs of all parking structures, regardless of type of construction. Precast concrete parking structures that receive specific periodic maintenance and care have shown decades of use with moderate cost.

This appendix has been prepared to serve as a maintenance guide to owners and operators of precast, prestressed concrete parking structures. It is recommended that the owners and operators have a good understanding of the goals of a maintenance program being used or recommended. The maintenance goals for a new facility can often be summarized in a maintenance procedures manual prepared by the design engineer. This appendix can present the design features and expected maintenance for the parking structure owner and operator prior to occupancy. The maintenance goals for older facilities may benefit from an examination of basic conditions in the facility and an analysis of the options for maintenance, protection, or deferred action.

TYPES OF MAINTENANCE Maintenance which is required due to public use, weathering, and traffic wear is divided into three categories:

- Housekeeping
- Preventive Maintenance
- Repairs

Housekeeping Housekeeping is usually performed by the parking structure operator and includes:

- Sweeping and trash pickup
- Window cleaning
- Elevator maintenance and cleaning
- Parking space restriping
- Lighting fixture cleaning and relamping
- Lavatory, office, and waiting area janitorial services
- Graffiti removal
- Cleaning, repair, and maintenance of signs
- Parking equipment and revenue control system maintenance
- Security systems check

These duties generally fall to the parking structure operator, that has a primary interest in maximizing operating revenues and keeping operating expenses within budget while providing safe and convenient parking to attract the user. The housekeeping items listed above should be performed by the operator on a periodic schedule as suggested in Table A. The following additional comments should be noted:

Lighting fixtures lose much of their effectiveness due to dirt accumulation in the lens or clear covers. Therefore, it is recommended that all fixtures be cleaned annually, immediately following the spring washdown.

Highly visible parking striping promotes centering of the parked car in the parking space, thus minimizing space overlap.

Security systems must be checked frequently to insure proper functioning at all times.

Oil stains are generally not detrimental to the structure, but their removal improves facility appearance. Heavy stains may be slippery and hazardous.

Preventive Maintenance General preventive maintenance is performed on a periodic basis and includes:

- A twice-a-year washdown
- Sealing cracks
- Reapplying of floor sealers and cleaning necessary reapplication
- Maintaining sealants (caulking)
- Maintaining roofing and related sheet material
- Painting/repainting
- Maintaining masonry, including repointing and recaulking
- Tightening guard rail bolts and guard rail strand

The owner has basic control over the durability of a parking structure. If the owner chooses to invest in durability features in the original construction, the future preventive maintenance and repair costs will be small. Therefore, it is prudent that the owner, not the operator, be responsible for preventive maintenance and repairs to protect his investment.

The following preventive maintenance schedule, when used diligently, will help in extending the parking structure's useful life and reduce costly repairs.

Table A
Housekeeping Schedule

	Daily	Weekly	Semi-Annually	Annually	As Required
Sweeping	d				
Trash Pickup	d				
Window Cleaning			sa		
Elevator Cleaning	d				
Elevator Maintenance			sa		
Parking Space Restriping				a	
Remove Oil Stains					as
Relamp		w			
Light Fixture Cleaning				a	
Floor Drain Cleaning			sa		
Lavatory, Office, Waiting	d				
Room, Janitorial service					
Graffiti Removal		w			
Graphics Cleaning			sa		
Graphics Repair & Maintenance				as	
Parking Equipment Maintenance					as
Security Systems Check	d				
Landscaping	d				

Preventive Maintenance Schedule

The objective of preventive maintenance is to keep the parking structure protective system at a high level in order to minimize the intrusion of water and deicing salts into the concrete.

1. Semiannually

- a. Flush all floor surfaces (use a fire hose or 1-1/4" hose; garden hose water volumes are not sufficient). Start from roof and work down. In deicing salt areas, a spring flushing should be done immediately after the spring thaw.
- b. Inspect floor surfaces for excessive wear and cracking. Cracks should be routed and sealed with a high quality sealant.
- c. Inspect floor surfaces for delaminations, structural cracking or potholes. These type of problems indicate the need for repairs prior to the usual maintenance. The scope and type of repairs required will vary depending on the cause of the problem which is discussed further in the repairs section that follows.
- d. Inspect floor expansion and control joints for deterioration, wear, or abuse (from snow plows, etc.). Repair as required.
- e. Inspect and clean floor drains, and repair downspouts where required.
- f. Elastomeric traffic-bearing membranes should be patched when visual inspection indicates ripping, tearing, and excessive wear.

2. Once Each Year (Spring)

- a. Inspect mortar joints, remove loose mortar, and repair with new mortar or a sealant.
- b. Inspect each sealant joint and replace sealant as required.
- c. Inspect all structural connections and surrounding concrete area. Seal cracks with epoxy injection and/or clean out all loose concrete and rebuild with appropriate material. If the crack is a "moving" crack, an engineer should be consulted to determine if the crack has any structural implications.
- d. Inspect parapets and guard rails for impact damage and repair as required. Tighten rail bolts and strand guard rails.
- e. Inspect all elastomeric bearing pads. If the pads are deteriorating or if concrete is cracked in the vicinity of the pad, an engineer should be consulted.
- f. Check for rust. Clean and recoat all exposed metals with epoxy or zinc rich coating. Rust is usually an indication that moisture intrusion is occurring in the vicinity.

3. Periodic Maintenance

- a. If a surface sealer such as a penetrating silane or siloxene sealer was applied, it should be reapplied every 5-8 years. Areas of abrasion such as turns and acceleration areas may require reapplication more often.
- b. If other sealing material was applied as floor surface water repellent it should be evaluated for reapplication to meet the needs of the structure. Schedules are generally not more than every 3 to 5 years.
- c. Other elements to be inspected periodically in a parking structure are:

• Doors and Hardware	• Electrical System	• Elevators
• Stair Rails	• Landscaping	• Painting
• Parking Operating Equipment	• Roofing and Flashing	• Plumbing System
• HVAC System	• Signs (Graphics)	

See Table B for inspection schedule.

Table B
Preventive Maintenance Schedule

	Daily	Weekly	Semi-Annually	Annually	As Required
Floor Wash Down			sa		
Floor Cracking				a	
Scaling				a	
Joint Sealants				a	
Isolation Joints				a	
Parapets and Guard Rails		w			
Bearing Pads				a	
Rust, Exposed Steel				a	
Floor Surface sealer				a	
Doors and Hardware		w			
Stairs		w			
Plumbing		w			
HVAC Equipment		w			
Roofing and Flashing		w			

Parking Structure Repairs

Repairs may be necessary in aggressive environments. The repairs can vary from minor surface repairs to structural reconstruction. Structural deterioration in parking structures is most often related to water leakage, corrosion, freeze/thaw or scaling deterioration and volume change movements. Surface deterioration is often related to weathering, ultraviolet deterioration of sealants, and coatings. Repairs may include patching of potholes, removal and replacement of reinforcing steel, floor slab overlays, replacement of expansion joints, and the replacement of bearing pads.

A comprehensive preventive maintenance program will often include a cycle of annual preventive maintenance planned to keep the repair program to a 5 or 10 year cycle.

Repair procedures for parking structures are beyond the scope of this Manual. It is recommended that the owner secure the services of a qualified engineer experienced in parking structure restoration work for appropriate repair methods.

MAINTENANCE FOR A REPAIRED PARKING STRUCTURE

A parking structure that has required structural repairs will have special maintenance requirements. Protection systems are often provided to help mitigate the recurrence of the deterioration. The protection is usually related to keeping water and chlorides out of the concrete and materials often include the following: concrete surface sealers, joints sealants (caulking and expansion joint sealants), surface applied membranes, and concrete overlays.

**PERIODIC
CONDITION AUDIT**

It is strongly recommended that the parking structure owner retain an engineer experienced in parking structure design and restoration to periodically (e.g., once every three years) perform a condition audit of the parking structure. The deterioration of parking structures due to deicing salts and ocean salts is a complex electrochemical phenomenon. Some remedial actions, such as overlaying a slab with an asphalt wearing course without an underlying waterproof membrane, can actually accelerate the deterioration of a parking structure slab. An engineer with confirmed capability in restoration of parking structures will see potential problems that will not be apparent to the inexperienced or untrained person. Some parking structure owners have a “walk-through” condition audit conducted by an independent consultant annually.

**SNOW AND
ICE REMOVAL**

Many of the deterioration problems in parking structures are due to salts from highway de-icing. Highway departments are considering changes to less damaging materials such as CMA.

Garage owners and operators can switch to CMA for snow and ice removal. In high traffic areas that bring in high volumes of road salt, the maintenance funds are probably best spent on protecting the concrete from salt penetration.

**DOCUMENTATION
AND PLANNING**

Effective maintenance requires a good record of the inspections, service, repairs, and maintenance procedures.