

ACI 362.1R-12

Guide for the Design and Construction of Durable Concrete Parking Structures

Reported by ACI Committee 362



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Guide for the Design and Construction of Durable Concrete Parking Structures

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ISBN-13: 978-0-87031-785-9
ISBN: 0-87031-785-7

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Guide for the Design and Construction of Durable Concrete Parking Structures

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This guide presents design and construction criteria used to improve the durability of concrete parking structures. Emphasis is placed on key design criteria unique to parking structures, including structural systems, materials, structural design, durability, and construction. Also covered are cast-in-place nonprestressed concrete, cast-in-place post-tensioned concrete, and precast/prestressed concrete structural systems for use in parking structures.

Keywords: concrete durability; construction; corrosion; curing; finishes; freezing-and-thawing resistance; nonprestressed reinforcement; parking structures; post-tensioning; precast concrete; prestressed concrete.

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ACI 362.1R-12 supersedes ACI 362.1R-97 and was adopted and published September 2012.

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This guide addresses the design and construction of durable concrete parking structures.

Parking structures are different from other concrete buildings due to their:

- a) Reduced roofing, cladding, and climate control that result in a more severe direct or indirect exposure to rain, snow, sunlight, temperature variations, and airborne chlorides
- b) Vehicular occupancy that imposes heavy moving loads and deposits deicing salts
- c) Ramps between floors for vehicular circulation and enhanced drainage that present unique structural challenges
- d) Large plan size that magnifies the potential for damage caused by restraint of movements and forces associated with volumetric changes

All are factors that influence the durability of parking structures and require consideration in their design. Maintenance of parking structures is essential to durability and longevity. For more information, refer to ACI 362.2R-00.

1.2—Scope

The purpose of this guide is to provide specific information on several of the design aspects and the construction

of parking structures that differentiates them from other concrete structures. This guide should be used with ACI 318-11, ACI specifications, and ACI standards.

Environmental conditions of the geographic location of a parking structure determine the governing criteria used in this guide. Environmental conditions include structure proximity to sea water and frequency of exposure to direct and indirect applications of deicing salts and freezing temperatures. Once the appropriate environmental conditions are determined, this guide provides the necessary durability criteria for parking structure design and construction. Parking structures integrally constructed with surrounding earth-retaining walls or other restraining structures require additional analysis of the restraining forces and lateral soil loads.

CHAPTER 2—DEFINITIONS

ACI provides a comprehensive list of definitions through an online resource, “ACI Concrete Terminology” (<http://terminology.concrete.org>). Definitions provided herein complement that resource.

corrosion inhibitor—a chemical compound, either liquid or powder, usually intermixed in concrete and sometimes applied to concrete, and that effectively decreases corrosion of steel reinforcement.

deicer—chemical such as sodium or calcium chloride, used to melt ice or snow on slabs and pavements by lowering the freezing point.

guardrail, pedestrian—element at the edge of an open-sided walking surface, intended to restrain a pedestrian from falling from the structure to an adjacent lower surface.

guardrail, vehicle—element at the edge of the driving and parking surface, intended to restrain a vehicle from falling from the structure to an adjacent lower surface.

membrane, traffic-bearing—an elastomeric coating capable of withstanding vehicular traffic.

pour strip—a defined zone of concrete placed after and used to temporarily separate adjoining parts of the structure that have been constructed.

pretopped—plant-manufactured, precast, prestressed concrete floor or roof members that do not require a field-placed concrete topping.

tooled joint—a groove tooled into fresh concrete using a concrete jointer tool to create a weakened plane intended to control the location of cracks.

CHAPTER 3—STRUCTURAL SYSTEMS**3.1—General**

Structural concrete is an ideal material to meet the demands of parking structure construction and maintenance. It is specifically recognized by the International Code Council (ICC) (2009 ICC International Building Code) as an appropriate noncombustible material for parking garage construction. In addition to proper design and construction, a disciplined long-term preventive maintenance program is required from the time a parking structure begins operation to ensure the structure will meet service life goals.

3.1.1 The effects of geographic location; volume changes, which include elastic shortening, creep, shrinkage, and temperature change; and restraint are critical considerations when designing and constructing a parking structure.

3.1.2 The requirements of governing building codes should be considered when selecting a structural system. Special loading criteria, fire resistance, and other local regulations might apply.

3.1.3 In addition to general design requirements for strength and serviceability included in ACI 318-11, there are specific concrete cover and crack control requirements in aggressive environments that are applicable to parking structures.

3.1.4 Structural concrete systems used for parking structures include cast-in-place post-tensioned concrete, cast-in-place nonprestressed concrete, and precast/prestressed concrete.

3.2—Cast-in-place post-tensioned concrete systems

Post-tensioning is achieved by using high-strength steel strand or bar enclosed in sheathing or ducts within hardened concrete to introduce forces into a structure in addition to those induced by gravity, wind, and seismic loads. Post-tensioning forces are used to counteract gravity loads, reduce tensile stresses, and reduce cracking and deflections. Post-tensioned spans may be longer for a given member size compared with concrete with nonprestressed reinforcement only. Post-tensioning typically improves durability by reducing cracking in beams and slabs.

3.2.1 The quantity of post-tensioning and nonprestressed reinforcing steel provided in the structure should be based on the required load-carrying capacity and serviceability requirements. Minimum precompression stresses should meet the provisions of Chapter 6. High average prestressing increases elastic and creep shortening and, where significant restraint exists, increases the probability of cracking in horizontal elements and flexure and shear cracking in columns and walls. The average precompression is typically 200 psi (1.4 MPa) or less in slabs, and 350 psi (2.5 MPa) or less in beams. It is not uncommon to increase precompression to 300 psi (2.1 MPa) in slabs and 500 psi (3.5 MPa) in beams in local regions of long spans or special geometry. Post-tensioning typically improves durability by reducing cracking in slabs and beams.

3.2.2 Cast-in-place post-tensioned slabs with thicknesses less than 5 in. (127 mm) have not performed well in parking structures and should be avoided. Slabs thinner than 5 in. (127 mm) are particularly susceptible to cracking and deterioration, high surface tensile stresses, and loss of flexural capacity due to the tolerance on reinforcement location.

3.2.3 To reduce slab crack widths, nonprestressed reinforcement should be provided in areas of high tensile stress, limited in size (No. 4 [No. 13] or No. 5 [No. 16] in slabs), and uniformly distributed. Refer to Chapter 5 for additional information on restraint and volume change.

3.2.4 Preferably, use products from a certified production facility, including Post-Tensioning Institute (PTI)-certified plants.

3.3—Cast-in-place reinforced (nonprestressed) concrete systems

Cast-in-place concrete without prestressing can be used successfully for parking garage construction. Nonprestressed systems eliminate the volume changes due to elastic shortening and axial creep from prestressing, but remain subject to restraint effects due to volume changes from shrinkage and temperature change. Although the design of nonprestressed concrete systems may be simpler than those with prestressing, additional care is required to provide design for crack control because both gravity loads and volume change restraint can lead to cracking.

3.3.1 Nonprestressed cast-in-place slabs with thicknesses less than 5 in. (127 mm) have not performed well in parking structures. Slabs thinner than 5 in. (127 mm) are particularly susceptible to cracking and deterioration, high surface tensile stresses, and loss of flexural capacity due to the tolerance on reinforcement location.

3.4—Precast/prestressed concrete systems

Precast/prestressed concrete is achieved by casting concrete around high-strength steel strand tensioned before the concrete placement. After concrete is placed and cured to a minimum strength, the prestressing force is transferred to the hardened concrete when the prestressing strands are released from their end supports. This method is applied in manufacturing plants with permanent facilities that allow the economical repetitive fabrication of components. Some components may also be precast in the fabrication plant using only mild steel. Most floor and beam components in precast/prestressed concrete systems are simple span members. The structural systems are assembled using prestressed and precast components with mechanical, welded, or cast-in-place concrete connections.

3.4.1 Preferably, use products from a plant that is a member of the Precast/Prestressed Concrete Institute (PCI) plant certification program. Certification provides additional assurance that the products conform to the requirements of PCI MNL-116-99 and MNL-117-96.

3.4.2 PCI MNL-138-08 and MNL-120-04 are recommended as references for connection design and detailing.

3.4.2.1 *Pretopped precast system*—When precast floors are placed using mechanical connections without a cast-in-place topping or only narrow strips of topping at the ends of horizontal spanning floor components, called tees or double tees, the system is termed untopped or pretopped. A mechanically connected system of precast floor members without cast-in-place topping can be used to create a diaphragm. Flanges should be designed to remain uncracked under service load conditions. An example of a common detail for flange-to-flange connections in a pretopped precast system is provided in Fig. 3.4.2.1.

3.4.2.2 *Field-topped precast system*—In a floor diaphragm, when the cast-in-place concrete covers the entire floor surface, the system is called field-topped. In field-topped systems, the topping surface is tooled over each joint between adjacent precast members and a sealant is placed in the joint (PCI Parking Structures Committee 2007). Examples

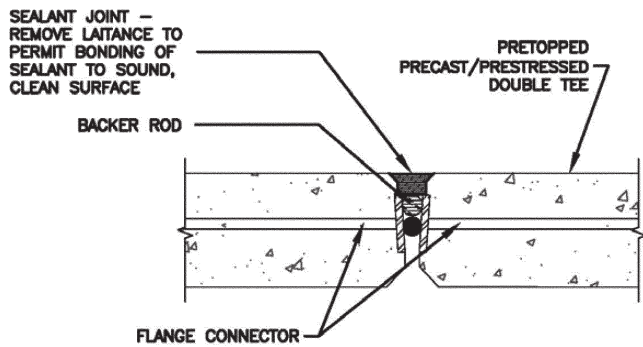


Fig. 3.4.2.1—Flange-to-flange detail for pretopped precast double tee.

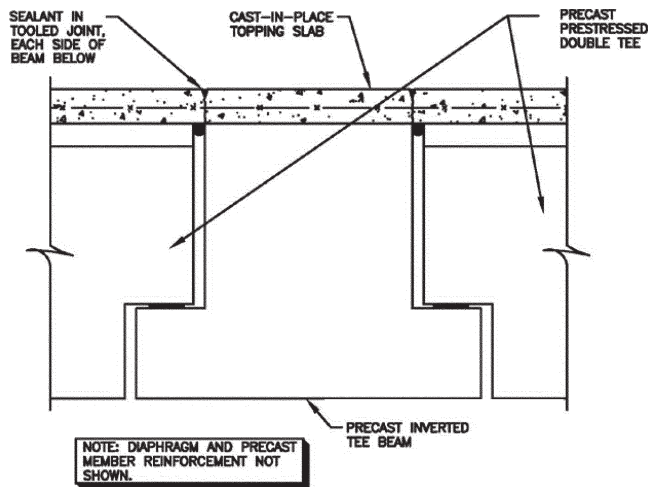


Fig. 3.4.2.2a—Contraction joint detail at inverted tee beam.

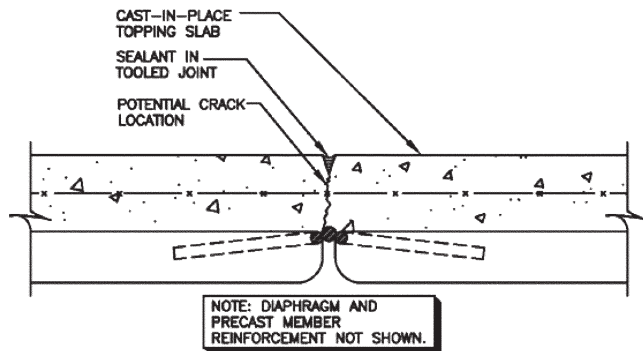


Fig. 3.4.2.2b—Flange-to-flange detail at field-topped double tee.

of typical joints in a field-topped system are shown in Fig. 3.4.2.2a and 3.4.2.2b, and a typical sealant detail at a construction joint shown in Fig. 3.4.2.2c. Joints should be tooled promptly after concrete placement and just before final surface finishing. Do not allow sawn construction joints, including early cut sawn joints, because shrinkage cracking usually occurs in the topping over the flange joints between the double tees before the joint in the topping is sawn. Sawn construction joints that extend fully to vertical elements such as walls, columns, and spandrels are impractical.

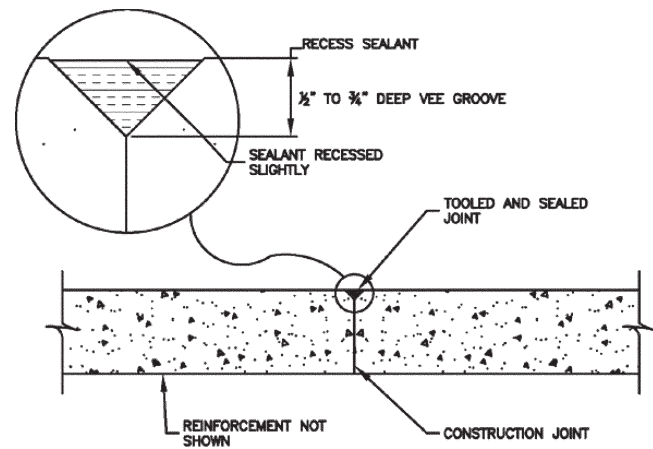


Fig. 3.4.2.2c—Typical sealant detail-at-construction joint. (Note: 1 in. = 25 mm.)

3.4.3 Steel embedments should be protected in accordance with Chapter 6 and exposed connections should provide access for future maintenance.

3.4.4 Because the prestressing steel in horizontally spanning components is placed below the center of gravity to resist positive moments, these components will camber up naturally. Precast/prestressed members should typically have sufficient prestress to maintain a positive camber under service dead loads.

3.5—Steel and concrete hybrid composite systems

Cast-in-place or precast concrete can be combined with structural steel framing for parking structures. Structures of this type require special attention to prevent premature deterioration from steel corrosion.

3.5.1 Steel components should be designed and detailed in accordance with the American Institute of Steel Construction (AISC) Steel Construction Manual (AISC 325-11).

3.5.2 Exposed steel members should be protected against corrosion in accordance with the requirements for exposed steel plates in Table 6.3.2.2a.

3.5.3 Exposed steel members should have fire protection as specified by the local building code. Exposure to weather and physical damage in parking structures should be accounted for in the selection of the fireproofing system. Spray-on systems historically have not performed adequately in this environment and therefore are not recommended.

3.5.4 Durability requirements for cast-in-place reinforced concrete slab, including composite shear connections, should comply with the requirements of Chapter 6. The restraint effects of the structural steel beams and girders on deck slabs should be considered in the design and detailing.

3.5.5 Steel deck, used either as a composite system or as a stay-in-place form, has been used in parking structures to support the fresh concrete, but is not recommended because it has poor corrosion performance characteristics. Stay-in-place form systems other than precast concrete should not be used. Stay-in-place forming systems that are not

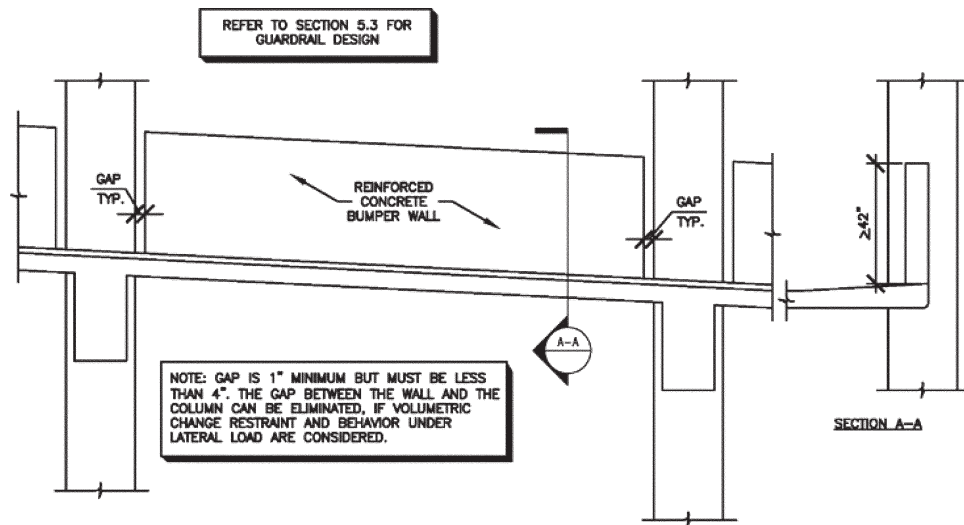


Fig. 3.6a—Concrete vehicular and pedestrian guard at slab edge. (Note: 1 in. = 25 mm.)

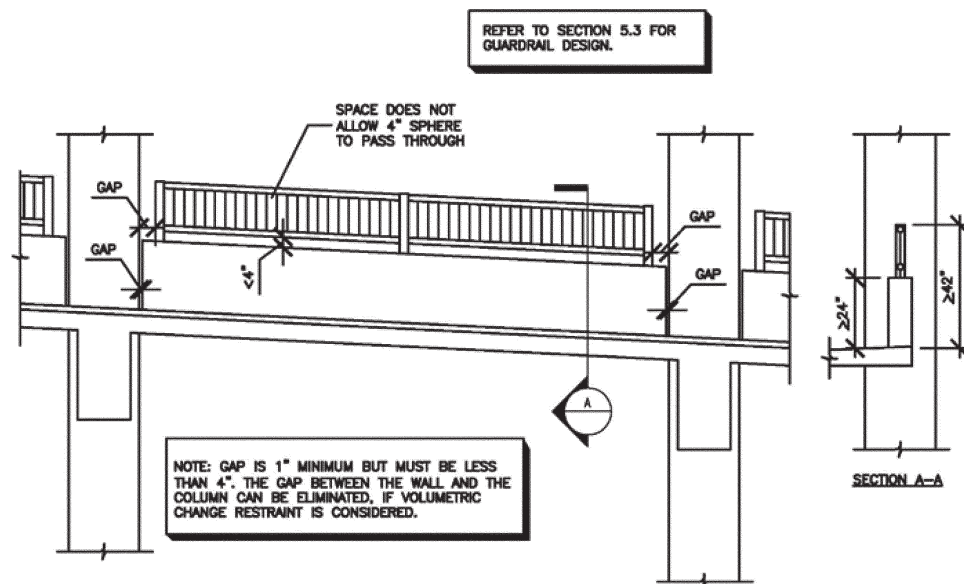


Fig. 3.6b—Concrete vehicular guard with attached pedestrian guard at slab edge. (Note: 1 in. = 25 mm.)

may be considered only if they do not trap water or chlorides between the form and the concrete structure.

3.6—Vehicle guardrail

The perimeter of the structure, as well as any adjacent areas in the interior of the structure with an elevation difference of 12 in. (300 mm) or greater should have a minimum 24 in. (600 mm) high vehicle restraint capable of resisting the horizontal loads in accordance with Chapter 5. Wheel stops are not a vehicle guardrail. Examples of typical vehicle and pedestrian guardrails are provided in Fig. 3.6a through 3.6c.

3.7—Pedestrian guardrail

At the perimeter of all structures or where interior surfaces have abrupt elevation change exceeding 30 in. (750 mm), a

pedestrian guardrail complying with local codes should be provided.

3.8—Below-grade parking structures

The design of below-grade structures should consider:

- a) Volume change and related restraint forces
- b) Higher relative humidity
- c) Groundwater
- d) Lateral earth loads

The horizontal structural slabs and beams are often used as supports or struts for the lateral earth loads on perimeter retaining walls in below-grade parking structures. Design connections between the walls and slabs should consider the effects of slab and beam volume changes, particularly in corners. Restrained walls, slabs, and lateral systems should be designed for at-rest earth pressures at a minimum. The

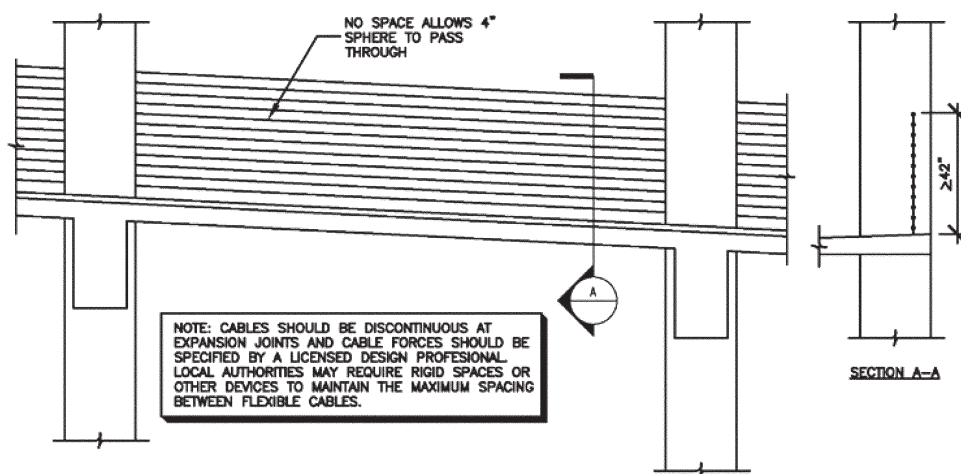


Fig. 3.6c—Steel cable vehicular and pedestrian guard at slab edge. (Note: 1 in. = 25 mm.)

presence of expansive clays outside basement walls or long interior distance for the accumulation of thermal expansion that can create higher pressures should be accounted for in the design. Eliminating the reinforced connection between slabs and retaining walls and using a sliding-bearing connection can reduce slab restraint cracking.

Often, below-grade parking structures are under high-rise structures such as office buildings and hotels, and the interior columns, shear walls, and walls around stair and elevator shafts are large in plan section. The restraining effects of these stiff elements should be considered in structural design.

CHAPTER 4—MATERIALS

4.1—General

The selection of materials for use in parking structures is intended to enhance the constructibility and improve long-term performance of the structure. Reducing permeability and cracking should be two main objectives in determining the mixture design for structures exposed to chlorides. In addition to proper material selection, proper placing, finishing, and curing practices are critical in obtaining a durable finished concrete structure. The material recommendations of this document may be more restrictive than the requirements of ACI 318-11 and ACI 301-10.

4.2—Concrete

Concrete serves as a main structural component, a wearing surface, and the primary corrosion protection element in most parking structures. Low-permeability concrete is of paramount importance in reducing corrosion of embedded steel because of its increased resistance to penetration of water, chloride, and oxygen—the elements required to induce corrosion.

4.2.1 Portland cement complying with ASTM C150/C150M-11 is recommended. Due to variations in fineness and chemical composition, different cements will yield varying results for strength, finishability, durability, and color. Once initial qualification testing of the concrete is performed, changes in the cement source should not be

allowed without the written consent of the licensed design professional.

4.2.2 Supplemental cementitious materials such as fly ash, silica fume, slag cement, and metakaolin can enhance the mixing, placing, and hardened properties of concrete. Variations in these materials and the other components of the concrete mixture can have a significant effect on the final results. Testing should be used to evaluate the benefits of supplemental cementitious materials in the mixture.

4.2.2.1 Typically, fly ash doses have been limited to 25 percent of total cementitious materials in elevated parking structure slabs. Fly ash typically retards the early strength gain of the concrete and reduces the heat of hydration. The reduced heat of hydration could be beneficial in hot weather conditions and detrimental in cold weather conditions. The retarding effect of fly ash could delay prestressing and extend the required duration of heating, covering, and curing concrete. Fly ash should comply with ASTM C618-08 and used in accordance with the manufacturer's recommendations.

4.2.2.2 Silica fume has been used in parking structures since the 1980s to reduce the permeability and to increase the strength of concrete with the intent of reducing the potential for corrosion of reinforcement and other embedded metals. Adding silica fume makes the concrete mixture less permeable than an equivalent concrete without it. Silica fume increases the heat of hydration and the 28-day compressive strength while decreasing the available bleed water. Particular attention should be paid to the effect of silica fume on the surface of fresh concrete. Fogging and other special procedures are usually required with silica fume concrete (ACI 234R-06 and ACI 308R-01). The use of silica fume may require modification of the timing of finishing processes because bleed water is reduced or eliminated. Early-stage curing of silica-fume concrete is critical to reduce plastic shrinkage. Trial slabs and consultation with the material supplier and concrete subcontractor before making the first structural concrete placement are recommended. Silica fume should comply with ASTM C1240-11 and be used in accordance with the manufacturer's recommendations.

4.2.2.3 Slag cement has properties similar to fly ash. Slag cement should comply with ASTM C989/C989M-11 and be used in accordance with the manufacturer's recommendations.

4.2.2.4 Finely ground metakaolin is a highly reactive pozzolan. Metakaolin should be used in accordance with the manufacturer's recommendations.

4.2.3 Chemical tests of concrete mixing water should be reviewed for chloride content. Concrete mixing water should not contain deleterious amounts of chloride ions or other substances. Reclaimed wash water can contain high amounts of chlorides and other deleterious materials and should be used only after verifying that the chemical content of the concrete mixture complies with specifications. Water should comply with ASTM C94/C94M-11. The source of the mixing water should remain constant throughout the term of the project.

4.2.4 The size, shape, strength, and chemical makeup of aggregates have a significant impact on the properties of the concrete in both the plastic and cured states. A well-graded aggregate tends to produce more-durable concrete because the concrete has less cement paste for a given volume than concrete that has a predominance of one aggregate size.

Absorptive aggregate particles such as chert and lignite can create surface popouts from freezing and thawing, and are more susceptible to promoting concrete shrinkage than hard, nonabsorptive aggregates. ASTM C33/C33M-11 sets maximum limits on the amount of chert in the coarse aggregate for various environmental regions. When specifying architectural concrete or where local experience shows excessive popouts, it might be desirable to set lower limits for chert content than those required by ASTM C33/C33M-11.

Combinations of cement and aggregate subject to deleterious alkali-aggregate reactions should not be used in parking structures. Evaluating aggregates for their abrasion resistance characteristics might also be required.

Aggregates, particularly those obtained from areas exposed to seawater, may contain chlorides that can become available to promote corrosion of reinforcement and other metals within the concrete. The effect of such aggregates on the total amount of chlorides within a concrete mixture should be investigated (ACI 222.3R-10).

In addition to the freezing and thawing aspects of aggregates discussed previously, other properties, such as those covered in ACI 201.2R-08, might also have an effect on durability and should be considered.

Aggregates should comply with ASTM C33/C33M-11 for normalweight aggregates and ASTM C330/C330M-09 for lightweight aggregates. The source of the aggregates should remain constant throughout the term of the project.

4.2.5 Admixtures (ACI 212.3R-10) may be used to impart the desired properties into the plastic or finished concrete if included in the mixture design and accepted by the licensed design professional. Water-reducing, accelerating, and retarding admixtures should comply with the requirements of ASTM C494/C494M-11. Compatibility of the admixtures should be investigated and confirmed before use. Admixtures should not contain more than trace amounts of chlo-

rides so the concrete mixture meets the chloride limits of ACI 318-08. The effect of admixtures on the mixing, placing, and finishing of concrete should be thoroughly investigated before their use. Admixture substitutions should not be allowed after mixture proportioning and initial testing are performed unless prior approval is granted by the licensed design professional and additional tests are performed to confirm the adequacy of concrete properties.

4.2.5.1 Maximum dosages and allowable field dosages of water-reducing admixtures should be in accordance with the manufacturer's recommendations and applicable testing. Maximum allowable time from addition of water until final placement should account for the expected effective life of the water-reducing admixture. High-range water-reducing admixtures may be needed in concrete with low water-cement ratios (w/c) to provide workable concrete. The reduction of water in the mixture may tend to reduce shrinkage, but reduced water could also reduce bleed water, resulting in increased plastic shrinkage cracking, which could be minimized with proper curing. Concrete that uses ASTM C494/C494M-11 Type F or G high-range water-reducing admixtures may still be resistant to freezing and thawing, although it does not meet the typically recommended hardened air content size and spacing factors of 0.0008 in. Water-reducing admixtures should comply with ASTM C494/C494M-11.

4.2.5.2 Types B, C, D, and E retarding and accelerating admixtures may be used to control setting characteristics of concrete during abnormally hot or cold temperatures, and they should comply with ASTM C494/C494M-11.

4.2.5.3 *Air-entraining admixtures*—Deterioration of saturated non-air-entrained concrete may occur when water within the cured concrete expands as it freezes. This change in volume causes stresses to develop, sometimes resulting in a rupture of the concrete at the wet surface (ACI 201.2R-08). Freezing and thawing deterioration can be reduced by the proper use of entrained air in the concrete. Air entrainment is achieved by adding an air-entraining admixture to the concrete mixture. The type and quantity of air-entraining admixture should be selected and batched for compatibility with other admixtures and additives. Dosages for air-entraining admixtures should be determined to yield the proper air content at the point of placement. This is not at the concrete truck.

Each batch of concrete should be tested for air content at the point of discharge from the concrete truck per ASTM C173/C173M-11 or C231/C231M-10. For the first three concrete trucks and periodically thereafter, the air content should be checked at the point of placement. A correlation should be developed to enable verification of proper air content at the point of placement based on air-content tests performed at the point of discharge from the concrete truck. Concrete cylinders should be taken at the point of placement. Slump tests should also be taken at the point of placement unless a correlation is established between the slump at the point of placement and the slump at the point of discharge from the concrete truck. Air-entraining admixtures should comply with ASTM C260/C260M-10.