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Commercial Concrete Parking Lots and Site Paving Design and Construction—Guide

Reported by ACI Committee 330

ACI PRC-330-21



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Commercial Concrete Parking Lots and Site Paving Design and Construction—Guide

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American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
Phone: +1.248.848.3700
Fax: +1.248.848.3701

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Commercial Concrete Parking Lots and Site Paving Design and Construction—Guide

Reported by ACI Committee 330

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Scott M. Tarr
Eduardo Tartuce
Eldon G. Tipping
Robert L. Varner
Steven M. Waalkes

Consulting Members

Jerry A. Holland

Jon I. Mullarky

David M. Suchorski

Concrete parking lots serve many kinds of public facilities, commercial and retail developments, businesses, and multifamily housing projects. They primarily accommodate parked vehicles but may also provide maneuvering areas and access for delivery vehicles. The design and construction of concrete slabs for parking lots and outside storage areas share many similarities with the design and construction of industrial pavements, streets, and highways, but they also have some very distinct differences. A full appreciation of the differences and the modification of design and construction procedures to take these differences into account can result in economical concrete parking lots that will provide satisfactory service for many years with little maintenance.

This guide includes information on site investigation, thickness determination, design of joints and other details, durability considerations, paving operations, and quality-assurance procedures during construction. Maintenance and repair are also discussed.

Information related to the design and construction of concrete site paving for industrial and trucking facilities is in ACI 330.2R.

Keywords: commercial; concrete pavement; curing; finishing; joints; light duty; parking lot; subgrade; thickness; traffic loads.

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ACI PRC-330-21 supersedes ACI 330R-08 and was adopted and published May 2021.

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CHAPTER 1—INTRODUCTION AND SCOPE

1.1—Introduction

Concrete parking lots serve many different types of facilities and are generally similar in design and construction to other types of concrete pavements. They differ, however, in that the primary role of a parking lot is typically to accommodate storage of vehicles rather than moving traffic, and the pavement loads and geometry differ accordingly. Parking lots tend to be designed for slower vehicle movement, more random traffic patterns, and fewer design load repetitions than streets, highways, airport runways, intermodal yards, and industrial or trucking facility pavements.

The design of concrete parking lots should follow the generally accepted procedures outlined in this guide. Load-bearing capacity, drainage, crack control, life-cycle cost, constructability, safety, sustainability, and material quality are important considerations that impact good design.

Concrete parking lots may be designed to accommodate light vehicles, heavy trucks, or a broad spectrum of vehicle loads as appropriate for the application. Where a variety of loads must be accommodated, the use of traffic controls to separate and channel the heavier trucks away from areas designed for automobiles and light trucks will result in a more economical and sustainable design. Facilities intended to serve only light vehicles may have concrete parking lot panels with thicknesses influenced by constructability and environmental effects rather than by the pavement stress created by vehicle loads. Durability-related distress is often the most critical maintenance concern for lightly loaded concrete parking lot pavements, which are subject to the effects of fuels and lubricants leaked from vehicles, precipitation and drainage, deicer salts, and other environmental influences. Vehicles in parking areas usually travel at low speeds, diminishing the importance of smoothness tolerances. Because parking lots must also accommodate pedestrians, designs and geometrics should reflect pedestrian safety considerations, including crosswalks, a slip-resistant surface texture, and night-time illumination.

Concrete parking lots range in size from small, such as at corner convenience stores, to medium, such as at multi-unit housing projects, to large, such as those for shopping centers and office or commercial developments. Most parking areas include driveways, some of which must accommodate relatively heavy loads. Special consideration may be needed if access to garbage trucks, dumpsters, and/or delivery trucks is to be included. Accordingly, concrete parking lots are constructed with a wide variety of construction equipment, ranging from hand tools and vibratory screeds to large highway paving equipment or laser-guided screeds.

The stiffness of rigid concrete pavements distributes wheel loads over larger areas of the subgrade than do flexible asphalt pavements, resulting in lower subgrade stresses. Thus, thinner total pavement structures are usually possible for a given site when concrete is used. Additional benefits of concrete parking lots include the following:

- a) Concrete surfaces resist deformation from maneuvering vehicles
- b) Concrete surfaces drain well with only minimal slopes
- c) Concrete has relatively simple maintenance requirements
- d) Traffic-lane and parking-stall markings can be incorporated into the jointing pattern
- e) Concrete is minimally affected by leaking petroleum products
- f) The light-reflective surface of concrete can be efficiently illuminated with minimal energy requirements
- g) Concrete parking lots reduce the impacts of the urban heat island effect relative to those of asphalt parking lots by producing lower surface temperatures, thus providing a cooler urban environment and reducing ozone production.

The sustainable construction benefits of concrete are considerable as compared with other pavement materials. Concrete parking lots typically have service lives of 20 years or more, negating the need for more frequent rehabilitation that would use additional aggregates and other nonrenewable resources. In addition to opportunities for

the use of sustainable concrete component materials such as recycled aggregates and supplementary cementitious materials derived from industrial by-products, concrete's light-colored surface helps reduce reflected solar radiation, and its higher reflectivity can reduce illumination requirements considerably. Lower resulting energy requirements are realized throughout the facility's life cycle. Pervious concrete may be useful in reducing storm water runoff from the site (refer to [ACI 522R](#)). At the end of the service life, concrete can be recycled into aggregates and pavement subbase materials. These and other attributes of concrete can be useful in obtaining LEED Green Building certification for a project ([NRMCA 2014](#)).

1.2—Scope

This guide is based on the current knowledge and best practices for the design, construction, and maintenance of concrete parking lots placed on the ground. Some of these practices differ from those used in the design and construction of streets, highways, floors and other types of pavements and flatwork. This guide is not a standard or a specification, and it is not intended to be included by reference in construction contract documents; [ACI 330.1](#) can be used for these purposes.

Parking lots have most loads imposed on interior slabs surrounded by other pavement. Highway and street pavements carry heavy loads along and across free edges and are subjected to greater deflections and stresses. Streets and pavements are usually designed to drain toward an edge where the water can be carried away from the pavement. Parking lots are usually designed so some of the water is collected internally and is conveyed away through underground systems. In urban areas where rainfall runoff from large impervious surfaces is regulated, parking lots often serve as detention basins (not addressed in this guide). This means that the pavement should store water for a period of time without incurring any damage due to loss of support from a saturated subgrade. Parking lots often accommodate appurtenances, such as lighting standards, drainage structures, traffic islands, and landscaped planting areas. Provisions for these appurtenances should be considered in the design of the jointing system and the layout for construction.

Some design methods for concrete parking lot pavements have been based on methods developed for the design of highway pavements such as the [Portland Cement Association \(1984a,b\)](#) method and the [AASHTO \(1993\)](#) design method. These methods are primarily concerned with limiting stresses in the slab (PCA) and the reductions in serviceability caused by mixed traffic (PCA and AASHTO), including heavy trucks, while parking lots usually serve fewer vehicles either parked or traveling at slow speeds. Additionally, AASHTO (1993) is a purely empirical method where the relevant range of vehicle types, subbase and subgrade materials, and pavement repetitions are generally outside of the relevant range for parking lots. Figure 1.2 presents a typical section through a concrete pavement showing subbase and subgrade layers. For many parking lots intended for city light trucks loads, the need for an extensive design process may be less

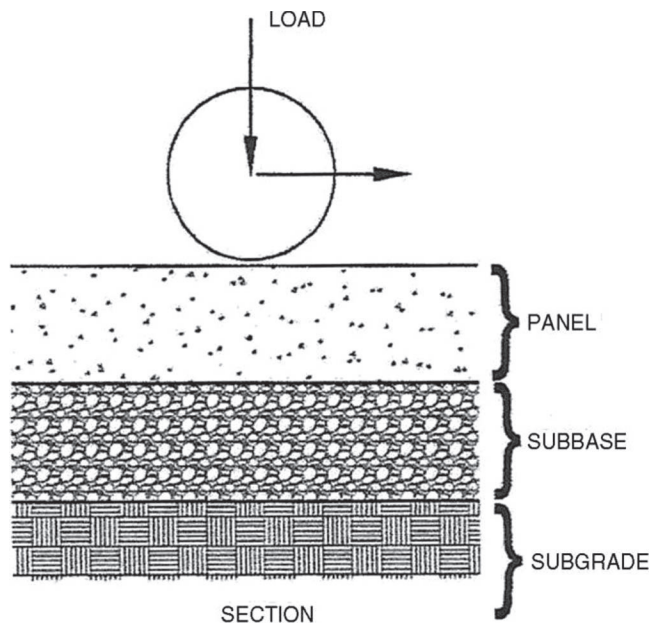


Fig 1.2—Panel support system terminology.

critical. For such projects, a designer can rely on past experience to select conservative values for the design criteria of subgrade soil support and imposed vehicle loads. In these cases, a conservative selection of pavement thickness is prudent practice.

The widely accepted PCA method has been incorporated and extended into the web based Uniform Pavement Design software (PavementDesigner.org) and is the principal design tool used in this guide. Its ability to model traffic spectra typically encountered in parking lots, and its stress/fatigue-based mechanistic-empirical algorithm make it an appropriate procedure for parking lot design. Conversely, the **AASHTO (1993)** procedure is based on limited testing and materials used over a half-century ago for high-volume highway traffic at high speeds. It is not a stress- or fatigue-based method and its applicability is outside the relevant range of vehicle types, base and subgrade materials, and pavement repetitions typically encountered in parking lots. It is not used in this guide and is not recommended for parking lot design.

Although thickness design is important, other aspects of parking lot design are equally critical. Often, if a concrete parking lot has performed poorly, it is due to non-thickness-related design and construction issues. These may include:

- a) Unsuitable subgrade support
- b) Improper joint spacing and patterns
- c) Improper placement and detailing of isolation and construction joints
- d) Inappropriate use of deformed steel reinforcing bars for odd-shaped panels, tying certain panels together, and other specific functions
- e) Poor construction aspects such as concrete mixture proportioning, placement and finishing methods, curing, and saw-cutting
- f) Insufficient maintenance for joints and pavement, as needed

These layout and construction issues are addressed in this guide.

Determining and specifying practical thickness tolerances for pavements is important. Reduction of the pavement thickness beyond tolerance recommendations can unacceptably increase pavement stresses, reduce pavement structural capacity, and reduce pavement life. Although construction smoothness tolerances are not critical for parking areas for low-speed traffic, smoothness is important where concrete surfaces are expected to drain well and carry water long distances across pavements with minimal slope.

Aesthetic considerations of surface texture and crack control in parking lots can be important because of close scrutiny from pedestrians and the owner's desire to project a quality image. In large parking lots, it is important to direct traffic into designated driving lanes and deter heavy vehicles from crossing thin pavements. The future expansion of a parking lot and the facility it serves should also be considered during initial design so that light-vehicle pavements are not required to accommodate future heavy loads. Industries and shopping centers served by public transportation, and schools served by buses are examples where expansion can transform auto parking areas into more robust truck or bus driveways.

Previous versions of this document were intended to address a relatively broad scope of traffic types and loads, including truck traffic up to 700 trucks per day and concrete thickness of up to 9 in. (225 mm). In 2017, however, ACI Committee 330 published **ACI 330.2R**, "Guide for Design and Construction of Concrete Site Paving for Heavy Industrial and Trucking Facilities," which covers the design and construction of pavements for higher volumes of over-the-road trucks, and some special vehicles and applications. Because 330.2R more completely addresses pavements for heavier loadings, including more detailed design of subgrades and subbases, load transfer at joints, and other challenges, the scope of 330R has been reduced relative to design for higher truck volumes and heavier vehicle loads. Therefore, this guide is now written for light-duty, unreinforced, undoweled concrete parking lots. It is applicable for:

- a) Passenger vehicle parking areas, where vehicles other than cars and light-duty trucks are channeled to other areas
- b) Driveways and drive lanes that can include some trucks, busses, or fire trucks
- c) Delivery and trash pickup areas that may see moderate numbers of loaded tractor trailers, delivery trucks, and/or garbage trucks

While there will naturally be some overlap between the two documents, the user is encouraged to consider referring to 330.2R whenever designs approach or exceed the upper limits of loading scenarios, and/or when the designer chooses to incorporate dowels or reinforcing for load transfer.

CHAPTER 2—NOTATION AND DEFINITIONS

2.1—Notation

Notation used in the **Appendixes** are not listed herein but are shown immediately after the corresponding figure.

equation(s); some of these notations may have other meanings in the [Appendix](#).

A = area of distributed steel reinforcement required per unit width of slab, in.²/ft (mm²/m)

f_s = allowable tensile stress in distributed steel reinforcement, psi (MPa)

h = slab thickness, in. (mm)

k = modulus of subgrade reaction, psi/in. (MPa/mm)

L = distance between joints, ft (m)

R = resistance value

w = density of concrete, lb/ft³ (kg/m³)

2.2—Definitions

Please refer to the latest version of ACI Concrete Terminology for a comprehensive list of definitions. Definitions provided herein complement that resource.

articulated bus—a public transportation vehicle composed of two or more rigid sections linked by a pivoting joint.

California bearing ratio (CBR)—the load required to force a standard piston into a prepared sample of soil divided by the load required to force the standard piston into a well-graded crushed stone in accordance with [ASTM D1883](#) and [D1429](#), usually expressed as 100 times the result.

curling—out-of-plane deformation of the corners, edges, and surface of a pavement, slab, or wall panel from its original shape caused by a normally-occurring combination of differences in moisture content and temperature between the two surfaces of the panel; taken independently, temperature differentials result in curling and moisture differentials result in warping. (See also **warping**.)

distributed steel reinforcement—welded wire fabric or bar mats placed in concrete pavements or slabs-on-ground to restrict the width of cracks that form between joints.

frost-susceptible soil—subgrade or subbase material in which segregated ice will form, causing frost heave, under the required conditions of moisture supply and temperature.

modulus of subgrade reaction, k —ratio of the load per unit area of soil to the corresponding settlement of the soil, typically evaluated in place per [ASTM D1196/D1196M](#).

resistance value, R —the stability of a soil determined in accordance with [ASTM D2844/D2844M](#) using the Hveem Stabilometer, which measures the horizontal pressure resulting from a vertical load. (The stability represents the shearing resistance to plastic deformation of a saturated soil at a given density.)

soil support value (SSV)—an index characterizing the relative ability of a soil or aggregate mixture to support traffic loads imposed through a flexible pavement structure.

subbase—a layer in the pavement system between the subgrade and the concrete pavement.

subgrade—the soil prepared and compacted to support a structure or a pavement system.

sympathy crack—an uncontrolled crack influenced by mismatched joints, resulting from tensile stresses that develop in the uncracked section due to normal movement across the unmatched joint and friction between the two sections along the joint that separates them.

warping—out-of-plane deformation of the corners, edges, and surface of a pavement, slab, or wall panel from its original shape, caused by a normally-occurring combination of differences in moisture content and temperature between the two surfaces of the panel; taken independently, temperature differentials result in curling and moisture differentials result in warping. (See also **curling**.)

CHAPTER 3—PAVEMENT DESIGN

3.1—Introduction

This document is intended to facilitate the design of parking lots subjected to a relatively small number of moderate loads. As such, the concepts contained herein do not consider the complexity associated with other types of concrete pavements. Should the project entail heavier loads and/or higher modulus of subgrade reaction, it is recommended the designer use of [ACI 330.2R](#) and/or computerized design concepts.

Design of parking lot pavement entails selecting dimensions and other details to provide a system of concrete panels that will:

- Carry the anticipated loads to the subgrade
- Provide proper joint stability and performance
- Channelize and segregate traffic where needed
- Incorporate required drainage features and lighting
- Allow for efficient and economical construction

The designer should consider all factors that influence the performance of a concrete pavement. Such factors include traffic loads, patterns and frequencies, subgrade/subbase support, concrete strength, pavement panel thickness, joint spacing, joint stability, the use of curbs and widened lanes, and ambient effects (humidity and temperature).

Ambient effects on pavement during construction and throughout its design life have a significant effect on the magnitude of warping and curling in the pavement panels and, therefore, the stresses in the concrete under load. The analysis of ambient effects on the pavement design adds a level of complexity that this guide does not consider.

After the estimation of traffic levels, the most influential factors in the design of concrete pavements are thickness, joint spacing, and joint detailing. Compared to concrete material strength and subgrade/subbase support, the pavement thickness, joint spacing, and joint detailing have a far greater impact on the load-carrying capability of the pavement. There is a significant interaction between joint spacing, thickness, and joint stability, which is the load transfer efficiency between adjacent panels, so all three requirements should be considered together as part of the design system.

Methods used to determine concrete pavement design are based on theoretical (mechanistic) and field (empirical) studies that relate the following to the required performance of concrete stresses, fatigue characteristics, and required design life:

- Applied loads (truck traffic)
- Material properties, including the subgrade/subbase support and concrete strength
- Pavement panel geometry, including thickness, panel length, and panel width

d) Edge support, such as joint stability and curb and shoulder details

This chapter addresses design from the point of view of accommodating loads, shrinkage, and thermal effects, but does not address concrete durability, which influences the long-term performance of concrete pavement. Those considerations are addressed in [Chapter 4](#).

3.2—Pavement stresses and cracking

Selecting the proper pavement subgrade/subbase, thickness, materials, and details will result in a pavement system that supports the most critical loads without inducing excessive stress in the pavement panels over the intended life of the pavement. The most critical loads are determined by magnitude, contact area, and frequency. Thicker slabs have lower load-induced deflections and flexural stresses. A decreased joint spacing will result in reduced magnitudes of warping and curling, and joint detailing will provide joint stability and reduce edge and corner stresses. Inadequate thickness or joint detailing could result in unsatisfactory performance, an increase in maintenance expenses, or even require early replacement.

Joints, or cracks between joints, produce discontinuities in the pavement system. Loads crossing these discontinuities can cause increased deflections and stresses in the pavement panels and the supporting subgrade/subbase. Repeated deflections of a panel edge or undoweled joint, and the resulting displacement or pumping of the subgrade/subbase, can eventually cause cracking in the central portion of the panel and faulting at the joint. The relatively short joint spacings recommended herein are intended to lower joint movement by utilizing aggregate interlock.

Whenever the designer cannot be assured of positive long-term load transfer at the joints through aggregate interlock, the committee recommends referring to load transfer guidance provided in [ACI 330.2R](#).

3.3—Traffic loads

A pavement will be subjected to varying, but predictable, vehicular loads throughout its lifetime. To accurately determine the pavement thickness required to manage cracking to the desired design percent of slabs cracked, the designer needs to know the types of vehicles that will use the pavement (such as passenger cars, light trucks, heavy trucks, and school or commuter buses), the number of trips (including multiple passes of the same vehicle) for each vehicle type, vehicular loads, axle types and spacings, and the daily volume or total volume anticipated for the facility over the design life. In the absence of thorough traffic spectrum and vehicle count data with which to conduct an accurate pavement thickness determination, the simplified tables herein can be used to estimate thickness requirements.

3.4—Subgrade support

The subgrade is the underlying surface of soil on which the parking lot pavement is constructed. The ability of the subgrade soil to uniformly support the loads applied through the pavement is extremely important and affects both the

required pavement thickness and the performance of the pavement. Uniform subgrade support is the goal of site preparation. For example, a designer can require grading operations to blend soil types to improve uniformity. Information on the engineering properties of the soil on a particular project can be obtained from foundation investigations for buildings constructed at the site, the U.S. Department of Agriculture Soil Survey, or geotechnical investigations conducted for adjacent roads or buildings. It is recommended, however, that actual soil conditions and subgrade properties be determined on the area to be paved by appropriate soils testing.

The extent of the geotechnical investigation will be determined by the magnitude of the project. A geotechnical investigation should include the identification and the properties of in-place soils and their suitability for use as a subgrade. The soil should generally be classified according to one of the standardized systems such as the Unified or AASHTO systems (refer to Appendix B and Chapter 3 of ACI 330.2R-17). Soil properties such as liquid and plastic limits, moisture-density relationships, expansion characteristics, susceptibility to pumping, and susceptibility to frost action should be determined by standard ASTM or AASHTO tests. The relative bearing capacity expressed in terms of modulus of subgrade reaction *k*, California bearing ratio (CBR), resistance value *R*, or soil support value (SSV) should be determined by means of a site-specific geotechnical investigation. For projects designed for light traffic loads only or where extensive soil testing is impractical or economically unjustified considering the project scope, the selected value can be estimated. Conservatism is advised in making such estimates. Table 3.4 shows ranges of values for three soil classifications ([ACPA 2006](#)). The value used will be for the subgrade compacted to the specified density. Fine-grained soils, such as clays or silts, are usually compacted to 95 percent of maximum dry density using standard effort as determined by [ASTM D698](#). A higher density may sometimes be specified for heavier traffic pavements or for materials that are more easily compacted and, alternatively, a maximum dry density using modified effort as determined by [ASTM D1557](#) may be specified, resulting in a higher soil unit weight.

It typically is not economical to use imported subbase material or to chemically treat the subgrade for the sole

Table 3.4—Modulus of subgrade reaction (*k*) for typical subgrade soils (ACPA 2006)

Soil type	Support	Typical <i>k</i> -values,* pci (MPa/m)
A: Fine-grained with high amounts of silt/clay	Low	75 to 120 (20 to 34)
B: Sand and sand-gravel with moderate silt/clay	Medium	130 to 170 (35 to 49)
C: Sand and sand-gravel with little or no silt/clay	High	180 to 220 (50 to 60)

**k*-values exceeding 300 pci (81 MPa/m) are outside the scope of this document. When higher *k*-values are used, it is recommended that the designer use [www.PavementDesigner.org](#).

purpose of increasing k -values. However, such measures can be helpful to 1) provide a stiffer working platform to mitigate subgrade deformations during construction operations; 2) reduce weather delays due to poor subgrade conditions from rain (cementitious stabilization is best for this); and 3) reduce subgrade susceptibility to pumping and erosion. Additionally, for expansive soils, cementitious stabilization with portland cement or lime can help reduce the susceptibility of soils to differential heave due to varying moisture conditions.

If a subbase is used, the increased support it provides should be considered in the thickness design. Table 3.4 is indicative of the effects of subbases on k -values (ACPA 2006). Note that increases in subbase thickness do not result in proportional k -value improvement. Furthermore, a thicker subbase layer can experience secondary consolidation that can be detrimental to the uniform support of the pavement.

Additional detailed information on subgrade investigation, subbases, stabilization, and special subgrade problems can be found in Appendix B and Chapter 3 of ACI 330.2R-17.

3.5—Concrete properties

Concrete mixtures for paving should be designed to produce the required flexural strength, provide adequate durability, and have appropriate workability considering the placement and finishing techniques to be used. Loads applied to concrete pavement produce both compressive and flexural stresses in the slab. However, flexural stresses are more critical because heavy loads will induce flexural stresses that may be a significant percentage of the concrete flexural strength, whereas compressive stresses remain small in relation to the compressive strength of the concrete. Consequently, flexural strength or modulus of rupture (MOR) of the concrete is used in pavement design to determine the required thickness.

The MOR is determined by ASTM C78/C78M. The 28-day average in field strength is normally selected as the design strength for pavements, but this is conservative because concrete usually continues to gain strength, and the pavement may not be placed into service until after 28 days. While design of pavements is based on flexural strength of concrete, compressive strength testing is typically used for quality control in the field, and is preferred because it is less costly, with less testing-induced variability. The correlation between compressive strength and flexural strength for a given concrete mixture is consistent and should be understood. On projects designed for heavy traffic that are large enough to economically benefit from refinement of the MOR value used in thickness design, a correlation between flexural strength and compressive strength should be developed from laboratory tests on the specific concrete mixture to be used. On other projects, especially those that will accommodate little truck traffic or where the mixture of traffic loads may not be well known, it may be more practical to assume an approximate, but conservative, relationship between compressive strength f'_c and flexural strength MOR using equation Eq. (3.5).

$$\text{MOR} = C \times \sqrt{f'_c} \quad (3.5)$$

where C is between 8 and 10, in in.-lb units (0.64 and 0.8 in SI units), depending on the mixture constituents and mixture performance. Additional discussion of approximations of MOR appears in various pavement design resources (Goeb 1989).

3.6—Thickness design

3.6.1 Basis for design—Thickness designs for concrete pavements are based on laboratory studies, road tests, and surveys of pavement performance. Commonly used procedures include the AASHTO method, which was developed from data obtained at the AASHTO Road Test (Highway Research Board 1962), and methods based on calculated stresses and fatigue resistance such as the Portland Cement Association Design Procedure (Portland Cement Association 1984a,b). Other methods such as the Brokaw Method (Brokaw 1973), which is based on surveys of the performance of plain concrete pavements in use throughout the country, have been used. While most of these design methods were developed for analyzing and designing pavements for streets and highways, the research behind them has included thin pavements, and they can be used for parking lot design. The different design procedures generally give similar thicknesses. Huang (2004), however, noted that the AASHTO method values are unconservative for lightly-trafficked pavements, and produce less reasonable results than Portland Cement Association methods. For thickness design of parking lot pavements, Tables 3.6a and 3.6b have been developed as the preferred approach utilizing the American Concrete Pavement Association's PavementDesigner.org web-based design tool.

Tables 3.6a and 3.6b have been prepared to facilitate the selection of an appropriate pavement thickness for the types of traffic and soil conditions most frequently encountered in parking lots. Table 3.6a lists five different traffic categories that range from passenger cars, buses, heavy trucks, and garbage trucks. Table 3.6b gives recommended pavement thicknesses for the five different traffic categories and three different categories of subgrade support for various moduli of subgrade reaction. The levels of subgrade support can be related to Table 3.4, which lists the estimated support values

Table 3.6a—Traffic categories*

Category	Description
A†	Car parking areas and access lanes
B	Entrance and truck service lanes
C‡	Buses
D	Heavy-duty trucks
E	Garbage or fire truck lane

*Select A, B, C, D, or E for use with Table 3.6b.

†Category A contains a wide variety of axle distributions. Not every truck is a fully loaded 18-wheeler. Refer to Appendix A for axle loading distribution for each Category.

‡Category C does not include large, articulated buses.

Notes: k is modulus of subgrade reaction; MOR is modulus of rupture of the concrete; E is modulus of elasticity of the concrete. 1 in. = 25.4 mm; 1 psi = 0.0069 MPa; 1 pci = 0.27 MPa/m.

Table 3.6b—Twenty-year design thickness: no dowels; edge support provided*

		<i>k</i> = 100 pci (27 MPa/m)		
		MOR, psi (MPa)	450 (3.1)	550 (3.8)
		<i>E</i> , psi (MPa)	3,037,500 (20,960)	3,712,500 (25,620)
Category [†]	Trucks [‡]	<i>D</i> , in. (mm)	<i>D</i> , in. (mm)	<i>D</i> , in. (mm)
A	1	5.00 (125)	4.25 (105)	4.00 (100)
A	10	5.50 (140)	4.75 (120)	4.50 (115)
B	10	6.00 (150)	5.25 (135)	4.75 (120)
B	25	6.25 (160)	5.50 (140)	5.00 (125)
B	50	6.50 (165)	5.75 (145)	5.25 (135)
C	5	8.75 (220)	8.00 (200)	7.25 (185)
D	1	5.25 (135)	5.25 (135)	4.75 (120)
D	10	6.25 (160)	5.50 (140)	5.00 (125)
D	25	6.75 (170)	5.75 (145)	5.75 (145)
E	1	7.75 (195)	6.75 (170)	6.25 (160)
		<i>k</i> = 200 pci (54 MPa/m)		
		MOR, psi (MPa)	450 (3.1)	550 (3.8)
		<i>E</i> , psi (MPa)	3,037,500 (20,960)	3,712,500 (25,620)
Category	Trucks [†]	<i>D</i> , in. (mm)	<i>D</i> , in. (mm)	<i>D</i> , in. (mm)
A	1	4.50 (115)	4.00 (100)	4.00 (100)
A	10	5.00 (125)	4.25 (105)	4.00 (100)
B	10	5.50 (140)	4.75 (120)	4.50 (115)
B	25	5.75 (145)	5.00 (125)	4.50 (115)
B	50	5.75 (145)	5.25 (135)	4.75 (120)
C	5	8.00 (200)	7.25 (185)	6.50 (165)
D	1	5.25 (135)	4.75 (120)	4.25 (105)
D	10	5.75 (145)	5.00 (125)	4.75 (120)
D	25	5.75 (145)	5.50 (140)	5.25 (135)
E	1	7.25 (190)	6.50 (165)	6.00 (150)
		<i>k</i> = 300 pci (81 MPa/m)		
		MOR, psi (MPa)	450 (3.1)	550 (3.8)
		<i>E</i> , psi (MPa)	3,037,500 (20,960)	3,712,500 (25,620)
Category	Trucks [†]	<i>D</i> , in. (mm)	<i>D</i> , in. (mm)	<i>D</i> , in. (mm)
A	1	4.25 (105)	4.00 (100)	4.00 (100)
A	10	4.75 (120)	4.25 (105)	4.00 (100)
B	10	5.00 (125)	4.50 (115)	4.25 (105)
B	25	5.25 (135)	4.75 (120)	4.25 (105)
B	50	5.50 (140)	5.00 (125)	4.50 (115)
C	5	7.75 (195)	7.00 (175)	6.75 (170)
D	1	5.00 (125)	4.50 (115)	4.00 (100)
D	10	5.50 (140)	4.75 (120)	4.50 (115)
D	25	5.50 (140)	5.25 (135)	5.00 (125)
E	1	7.00 (175)	6.25 (160)	5.50 (140)

*Table formulated using the Uniform Pavement Design (www.PavementDesigner.org) with a minimum thickness of 4.0 in. (100 mm).[†]Refer to Appendix A for axle loading distribution for each Category.[‡]Trucks = trucks/day. Trucks are defined as vehicles with at least six wheels; excludes panel trucks, pickup trucks, and other four-wheel vehicles.

for the most commonly occurring subgrade soil types. Note that this document is intended to be used for k -values less than or equal to 300 pci (81 MPa/m). Thickness of pavements on stiffer subbases can be determined utilizing the Uniform Pavement Design (www.PavementDesigner.org). The thicknesses shown in Table 3.6b are based on flexural strengths ranging from 450 to 650 psi (3.1 to 4.5 MPa) at 28 days, which correspond to compressive strengths between approximately 3000 and 5000 psi (20 and 34 MPa) based on approximations for relating compressive and flexural strength such as those in Eq. (3.5). The recommended thickness presented in Table 3.6b assumes that the pavement has adequate edge support in the form of extending the limits of the pavement, thickening the edge, or providing a tied curb. Approximate cost comparisons indicate that the lower strength can be used in areas where durability concerns, such as freezing and thawing, are not important. Changes in modulus of rupture, however, affect the required concrete thickness and pavement capacity. Attempting to artificially increase concrete strength in order to utilize a thinner pavement is not recommended.

For parking lots designed for ages other than 20 years, simply ratio the anticipated traffic spectrum. For example, for a 30-year design and Category B with 10 trucks per day, enter the table at $30/20 \times 10 = 15$ trucks per day. Enter the table 25 trucks per day.

3.7—Jointing

Joints are placed in concrete pavement to minimize out-of-joint cracking and facilitate construction. The three types of joints that are commonly used in concrete pavement are contraction joints, construction joints, and isolation joints. To effectively control cracking due to tensile stresses created by restrained shrinkage and warping or curling caused by moisture or temperature differentials, it is important to have the joints properly spaced. Table 3.7 recommends a simplified joint spacing. Further joint spacing analysis can be performed using PavementDesigner.org. This spacing depends on the thickness of the pavement, the modulus of subgrade reaction, the strength of the concrete, the aspect ratio of the panels created by joints, the type of aggregates, and climatic conditions. Closer joint spacings can result in smaller joint openings that provide increased load transfer between panels in the form of aggregate interlock while limiting the opportunity for water infiltration of the supporting soil support system. Spreading the joints farther apart can result in wider openings and diminished aggregate interlock. Joints in the pavement slabs should be carried through adjacent curbs or curb and gutter sections to prevent

sympathy cracks. Establishing joint spacing, joint layout, and joint details is the responsibility of the designer.

3.7.1 Contraction joints—Contraction joints are intended to predetermine the location of cracks caused by restrained shrinkage of the concrete and by stresses induced from warping and curling. Hardened concrete will shrink almost 1/16 to 1/8 in. (2 to 4 mm) for every 10 ft (3 m) of length while drying. If movement of the concrete in response to this shrinkage is restrained, tensile stresses develop that can exceed the tensile strength of the concrete, and the concrete cracks.

Contraction joints create planes of weakness that subsequently encourage cracks to form under the joint as the concrete shrinks. While properly made tooled joints of appropriate depth or insert joints installed vertically and surface-flush have been successfully used, the most common choice for contraction joints is saw cuts. Concrete should be sawn after it has hardened enough to support the saws and avoid raveling. The depth of the joint should be at least one-fourth the slab thickness when using a conventional saw, or a minimum 1 in. (25 mm) when using early-entry technology on pavements 9 in. (230 mm) or less in thickness. A narrow joint width, generally 1/16 to 1/4 in. (1.6 to 3 mm) wide, is initially sawn to induce cracking under the joint. The initial joint can be left unfilled, filled, or widened for sealing. Joint sealant manufacturers' recommendations should be followed for the depth and width of joints that are to be filled or sealed.

Contraction joint patterns should divide pavements into approximately square panels. When odd-shaped panels are necessary, the length of a panel should not be more than 50 percent greater than its width. Joint patterns across lanes should be continuous. For parking lot pavements, maximum spacing should conform to Table 3.7. In many instances, jointing patterns can be used to delineate driving lanes and parking stalls.

3.7.2 Construction joints—Construction joints provide the interface between areas of concrete placed at different times during the project. The designer should consider pavement drainage patterns when locating construction joints. Butt-type joints without special load-transfer features are recommended for parking lots serving the light vehicles considered in this document. Keyways of half-round or trapezoidal shapes have been used as a load-transfer design feature across construction joints, but this practice is no longer recommended for pavement designs within the scope of this document due to poor performance histories of this type of detail. Steel leave-in-place forms with keyed shapes should not be used.

Construction joints are designed for interruptions in paving operations, such as those that occur at the end of a day or when placing is stopped for other reasons, such as weather or equipment breakdown. Whenever work is interrupted, a construction joint should be used.

Where construction joints occur, they should be installed at contraction joint locations, if possible. In emergency situations, such as lack of materials, sudden equipment failure, or equipment breakdown, it may not be possible to place the

Table 3.7—Spacing between joints*

Pavement thickness, in. (mm)	Maximum spacing, ft (m)
4 to less than 5 (100, 125)	10 (3.0)
5 to less than 6 (125, 150)	12.5 (3.8)
6 or greater (150 or greater)	15 (4.5)

*If subgrade treatments are likely to produce a k -value in excess of 300, the joint spacing should decrease to 80 percent of the values shown above.

joint where planned. In these cases, concrete can be removed back to the nearest contraction joint or a tied construction joint can be made in the middle third of a panel.

Designers should recognize that when new concrete, with an inherent tendency to shrink, is tied to older concrete, which has already gone through the shrinkage process, stresses will develop that can cause cracking. To overcome these stresses, the construction joint should be designed to accommodate shrinkage.

Where slabs of different thicknesses come together at construction joints, such as between automobile parking and a garbage truck lane, the subgrades under the thinner pavements should be shaped to provide gradual pavement thickness transition over a distance of 4 ft (1.2 m) or more at a maximum slope of 1 in. in 12 in. (25 mm in 300 mm).

3.7.3 Isolation joints—Concrete slabs should be separated from other structures or fixed objects within or abutting the paved area to offset the effects of expected differential horizontal and vertical movements. Isolation joints are used to separate the pavement from these structures, such as light pole bases, manhole inlets, and buildings. A compressible material should be used for isolation joints and should be applied to the full thickness of the pavement. While sometimes referred to as expansion joints, they are rarely needed to accommodate concrete expansion. Isolation joints are not recommended along the face of curb and gutter abutting a pavement, but pavement joints of any type that intersect this junction should extend through the curb and gutter.

Premolded joint isolation materials prevent the new slab from bonding to other structures during and after concreting operations. The isolation material should extend through the slab thickness to the subgrade. Should the designer require the joints to be sealed or filled, a portion of pre-molded isolation material should be removed to accommodate the joint sealant or filler per the manufacturer's recommendations. Isolation joints, including wooden strips, are not recommended for routine use as regularly spaced joints. They are difficult to construct and to maintain, and often are a source of pavement distress, distortion, and premature failure.

Isolation joints are not needed to accommodate expansion when contraction joints are properly spaced; their use should be limited to the role of isolating other structures or fixed objects. Designers are cautioned that wheel loads at isolation joints cause distresses similar to those at pavement free edges unless additional support is provided by features such as thickened pavement edges along the joint. At the juncture of a new entrance panel and an existing pavement such as a street (a T intersection), provide an isolation joint with a thickened edge as per Section 3.7.2 and shown in Fig. C.1d(b) or C.1d(c) in [Appendix C](#).

3.7.4 Expansion joints in parking lot pavements—When pavement is jointed in accordance with Table 3.7, expansion joints are not necessary.

3.8—Steel reinforcement in parking lot pavements

3.8.1 Secondary reinforcement—When a pavement is jointed to form short panel lengths that will reduce warping and curling, and relieve internal stresses, mid-panel rein-

forcement is not necessary. The practice of adding distributed steel to increase panel lengths has largely been discredited and generally leads to excessive joint movements and interior panel cracks that deteriorate over time. Shorter unreinforced panels are generally more economical and provide better performance. In jointed pavement designs, the use of distributed steel reinforcement will not add to the load-carrying capacity of the pavement and should not be used in anticipation of poor construction practices or soil conditions. When construction practices require that fully loaded concrete trucks and screeding equipment must traffic the subgrade, then the presence of reinforcement can prevent the contractor from recompacting and leveling the grade during the construction process. Its presence would be counterproductive to quality construction and the mitigation of out-of-joint random cracking. In areas where deicing salts and similar materials are used, distributed steel also presents a risk of corrosion.

3.8.2 Continuously reinforced concrete pavements (CRCPs)—In the rare condition where contraction joints cannot be tolerated, they may be eliminated with the inclusion of a minimum steel ratio of 0.7 percent ([Federal Highway Administration 2016 \[ISO 144044:2006\]](#)) of the pavement cross-sectional area in the direction where the contraction joints are eliminated. The significant increased cost of materials and construction makes this design extremely rare in parking lots. This document does not cover the design and construction of continuously reinforced concrete pavements.

3.8.3 Odd-shaped panels—The designer should provide a layout of joints and joint details. Pavement panels should be as square as possible with a maximum aspect ratio of 1.5 to 1. Odd-shaped panels such as L- and T-shaped panels should be avoided to minimize reentrant corner cracking. Where odd-shaped panels cannot be avoided, or special circumstances require the use of panels with an aspect ratio of greater than 1.5 to 1, designers should consider the use of reinforcement, with an area of steel of approximately 0.1 percent, so that should the odd-shaped panels crack, they will remain functional. This reinforcement is normally furnished in the form of deformed steel bars, welded wire reinforcement, or macrosynthetic fibers. Steel reinforcing bars or welded wire reinforcement should be positioned in the upper one-third of the pavement thickness and should be adequately chaired in place to support the reinforcement during all placing and finishing operations. The use of macrosynthetic fibers in dosages as high as 7.5 lb/yd³ (4.5 kg/m³) has proven to be successful in limiting crack widths in pavements with odd-shaped panels or in locations where the aspect ratio of panels must exceed 1.5 to 1.

3.8.4 Dowels—This document is based on non-doweled pavements. If the designer believes load transfer in the form of dowels is necessary, it is recommended that [ACI 330.2R](#) or the Uniform Pavement Design (www.PavementDesigner.org) be consulted.

3.8.5 Tie bars—Tie bars, if needed, should be used to tie only the first joint from the pavement edge to keep the outside slab from separating from the pavement. For more information, refer to Fig. C.1). Tie bars are not required in the interior

Table 3.8.5—Lengths and spacings for No. 4 (1/2 in. [13 mm] diameter) tie bars

Slab thickness, in. (mm)	Tie bar length, in. (mm)	Tie bar spacing, in. (mm)	
		Distance to nearest free edge or to nearest joint where movement can occur	
		14 ft (4.3 m) or less	16 to 24 ft (4.9 to 7.3 m)
5 (125)	24 (610)	30 (760)	28 (710)
5.5 (140)	24 (610)	30 (760)	25 (630)
6 (150)	24 (610)	30 (760)	23 (580)
6.5 (165)	24 (610)	30 (760)	21 (530)
7 (180)	24 (610)	30 (760)	20 (510)
7.5 (190)	24 (610)	30 (760)	18 (460)
8 (205)	24 (610)	30 (760)	17 (435)

joints of parking lots and other wide, paved areas because they are confined by surrounding slabs. Tie bars should be used on centerline joints of entrance drives and access roads that have a single longitudinal joint. Tie bar dimensions are shown in Table 3.8.5. Note that tie bars are only recommended for pavement thicknesses greater or equal to 5 in. (127 mm). Alternate slab movement preventive measures are discussed in 3.13.2.

3.9—Fiber reinforcement in parking lot pavements

Fiber-reinforced concrete (FRC) is a composite material that includes the use of fibers alone, instead of traditional reinforcement, or in addition to it. Concrete parking lots have been successfully designed and placed for many years without any type of secondary/temperature reinforcement, including both temperature steel and fiber reinforcement. Fibers of many types have been used in concrete parking lots and pavements for over 30 years. **ASTM C1116/C1116M** classifies these fibers into four different categories: 1) steel; 2) alkali-resistant glass; 3) synthetic fibers; and 4) natural fibers. The benefits of FRC in parking lot pavement applications are dependent on fiber type, length, and dosage, and may include crack and crack width control, increased joint spacing, and increased flexural toughness and flexural fatigue resistance.

3.9.1 Fiber performance contributions—Microfibers made of synthetic materials such as polypropylene, polyethylene, and nylon, and natural materials such as cellulose, are used to reinforce concrete against plastic shrinkage stresses and to provide control of random plastic shrinkage cracking. These fine microfibers with diameters less than 0.012 in. (0.30 mm) are typically used at low volume addition rates of 0.03 to 0.20 percent by volume, equating to fiber dosage rates of 0.50 to 3.0 lb/yd³ (0.3 to 1.8 kg/m³).

Macrofibers made of steel or synthetics are used at higher concentrations and, as a result, offer contributions to a wide range of both plastic and hardened concrete properties. Macrofibers add elements of crack control, crack width control, and flexural toughness to concrete pavements, with improvements directly related to fiber type and dosage. Synthetic macrofibers with diameters greater than 0.012 in. (0.30 mm) are typically used in dosages representing 0.20 percent by volume—3 lb/yd³ (0.89 kg/m³) and higher—depending on the desired performance values. Steel fibers

are added to concrete in quantities typically ranging from 0.06 to 1 percent by volume—approximately 17 to 60 lb/yd³ (10 to 36 kg/m³)—again dependent on desired performance. Flexural toughness, the measure of the post-cracking energy-absorbing capacity or ductility of FRC, is one of the most valuable contributions of FRC to concrete pavements. Macrofibers, in sufficient dosage, also offer considerable contributions to fatigue performance, especially for repeated, low-stress loading that is typical for pavement applications ([Mulheron et al. 2015](#)).

3.9.2 Fiber-reinforced pavement design principles—Several existing pavement design methods are available for determining the thickness of FRC pavements, such as [PavementDesigner.org](#) and OptiPave. These design methods depend on the FRC attaining a minimum level of residual strength and are therefore applicable to both steel and synthetic macrofibers.

3.9.3 Fiber-reinforced pavement joint practices—The performance of fibers at sawn contraction joints depends on slab thickness, contraction joint spacing, joint opening width, saw-cut depth, and mixture components. Sawn contraction joint details and spacing for FRC containing synthetic microfibers or other fibers used specifically for control of plastic shrinkage cracking are the same as those used for unreinforced concrete. For sawcut joints in steel or synthetic macrofiber FRC pavements, the steps outlined in **ACI 544.3R** should be followed. Depending on their effectiveness in holding cracks tight, steel and synthetic macrofibers may offer additional shear load transfer through fiber-enhanced aggregate interlock compared to plain unreinforced concrete.

3.9.3.1 Joint spacing—Sawn-cut contraction joint spacing for FRC pavement slabs with quantities of steel fibers less than 0.25 percent by volume—approximately 33 lb/yd³ (20 kg/m³)—or synthetic macrofibers less than approximately 5.0 lb/yd³ (3 kg/m³) should follow the same guidelines as those for plain concrete or slabs with minimum conventional reinforcement (Table 3.7). Steel and synthetic macrofibers are very efficient at crack control and, as a result, have been used in some cases to extend joint spacing beyond conventional recommendations when sufficient dosages are used. Refer to **Appendix E** for alternate joint spacing options with FRC pavements.



Documents

Document Sharing Hub



3.10—Joint filling and sealing

Joints are often left unfilled without affecting performance, but joint-filling and sealant material may be used to minimize the infiltration of water and solid materials into the joint openings. Proper surface grading and closer joint spacings with narrower openings minimize the amount of water that can drain through a joint and the amount of solid materials that can enter the joint. If a sealant is used, it should be able to withstand repeated movement while minimizing the intrusion of water and solids. This requires proper width and depth of the sealant reservoir, as recommended by the sealant manufacturer, and careful application to minimize material deposited on or above the pavement surface. Consult the joint filler/sealer manufacturer and [Appendix C](#) for installation recommendations and details.

3.11—Pavement grades

3.11.1 Establishing grades—Project drawings should designate critical elevations in parking areas, such as changes in grade, to designate crown, and at all intake structures. It is vital that grades be established in sufficient detail to provide positive drainage in all gutters, around all islands and structures, and especially in intersections and pedestrian walkways. The construction layout crews should make sure that grade stakes are set at each change in slope.

3.11.2 Surface drainage—It is vital to establish grades that will ensure drainage of parking lots. The design and construction should provide a parking area that is fast-draining, quick-drying, and puddle-free. The drainage design plan should be coordinated with the jointing plan to avoid the channeling of surface water along a joint. Where environmental conditions dictate, parking lots can be designed to hold stormwater for regulated release using pervious concrete. Refer to [ACI 522R](#) for additional information.

3.11.3 Pavement slope—Where the pavement is sloped for drainage, the minimum pavement slope used should be 1 percent, or 1/8 in./ft (3 mm/300 mm). To minimize puddling, a 2 percent, or 1/4 in./ft (6 mm/300 mm), slope is recommended. Minimal slopes can be used because a concrete surface maintains its shape, provided that the subgrade support remains uniform. Minimal slopes can reduce the amount of earthwork during construction and can result in greater spacing of inlets. To prevent vehicles from dragging on the pavement, entrance slopes should not abruptly change by more than 8 percent without the use of vertical curves. Driveways and entrances may be sloped up to 12 percent, but a maximum slope of 6 percent is generally recommended for areas where vehicles park.

3.12—ADA/ABA-AG surface profile requirements

It is important that the designer not produce a design requiring the maximum permissible ADA/ABA-AG tolerances because expected construction variances can result in the work not complying with the ADA/ABA-AG requirements. [ACI 117.1R-14](#) Chapter 5.8 provides the designer with recommended design strategies.

3.13—Other design features

3.13.1 Curbs and islands—Large parking lots require special features to control, channel, and segregate traffic; to keep parked vehicles on the pavement; to collect runoff; and to provide spaces for landscaping. These functions are usually fulfilled by edge curbs and islands formed by interior curbs. Islands can be paved or landscaped.

Curbs on any parking lot confine traffic to the paved surfaces and can direct the flow of runoff. Curbs can perform the function of confining the pavement structure. Preferably, curbs are constructed monolithically with pavement slabs, but they can be constructed separately. Curb and gutter sections are sometimes constructed first and then used as side forms for paving parking slabs. When used with concrete pavement, monolithic curbs or curb and gutter sections tied to the pavement with tie bars provide structural stiffness to the edges of the pavement.

Joints in the pavement slabs should be carried through adjacent curbs or curb and gutter sections. Thorough planning is necessary before separate curb and gutter sections are constructed. Longitudinal reinforcing steel is not needed in curbs if they are properly jointed and placed on a well-compacted subgrade. Joint locations should be coordinated to ensure that the contraction joints line up and contribute to effective performance of the concrete paving system.

Islands can provide some separation between pedestrians and vehicles. Islands can be placed to restrict turns of long vehicles and segregate trucks and buses to areas with heavy-duty pavement. Where landscaping is desired, islands can be made large enough to provide areas for plantings.

The locations of islands should be established to facilitate construction without disrupting the parking lot jointing pattern if feasible. In some instances, it is desirable to establish final locations of islands after the jointing pattern is determined. Small islands that require fixed forms and finishing with hand tools can be constructed after paving operations if sufficient areas in the pavement are boxed out during initial paving.

Curbs are constructed in many shapes, but the predominant types are rollover or mountable curbs (monolithic or tied), and barrier curb. Curbs can be placed before, with, or after the parking pavement. Mountable curbs are preferred by many for their appearance, and they are easier to construct by the slipform method. Barrier curbs can also be slipformed, but the process is easier if there is a slight batter to the exposed faces of the curbs. A description of the most commonly used curb sections is found elsewhere (Canadian Portland Cement Association 1978), and cross sections of typical curbs are shown in Fig. C.5 in Appendix C.

3.13.2 Details for minimizing panel sliding—In some cases, conditions such as fine-grained subgrade soils, steep pavement grades, and the forces of braking and turning vehicular traffic can result in the in-plane sliding of pavement panels over time. Such movement can result in deterioration through loss of load transfer at joints, sealant failure, and faulting. Tie bars are often used across joints that connect the edge panels of parking lots to minimize movement (Section 3.8.5), but this practice alone may not be

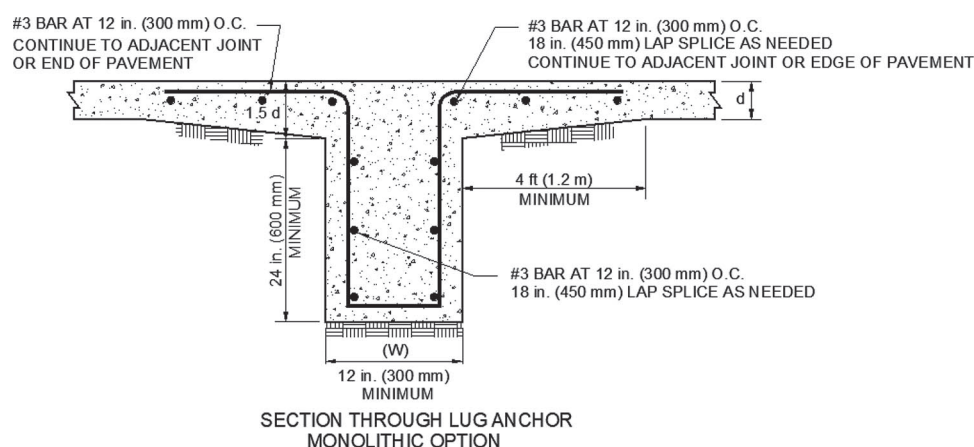


Fig. 3.13.2a—Lug anchor section (monolithic).

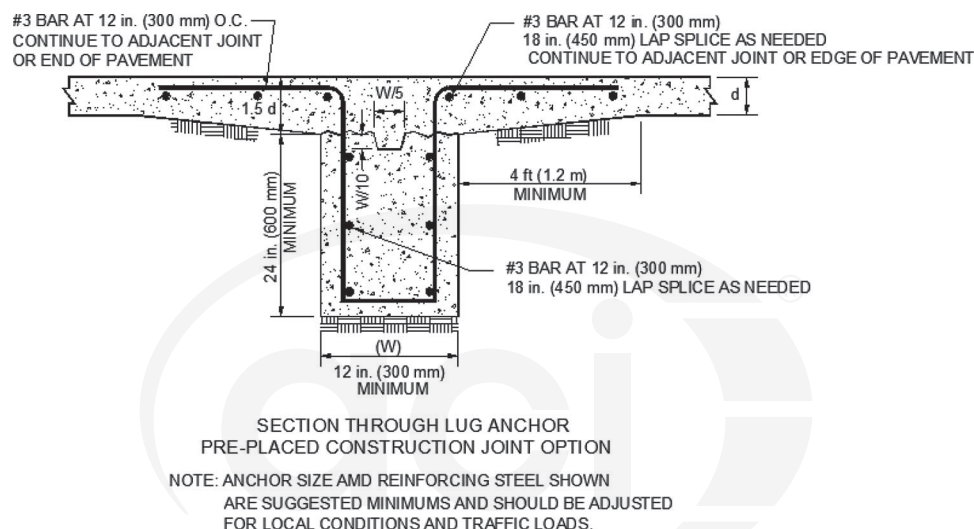


Fig. 3.13.2b—Lug anchor section (preplaced construction joint).

sufficient where these influences are extreme, and especially where sliding forces are present over larger areas. Properly backfilled curbs can assist in limiting slab movement. Areas that are particularly susceptible to panel sliding include driveways where vehicles must brake or turn at intersections, aprons where trucks must turn or maneuver near loading docks, and areas where vehicles frequently brake while moving downhill or approaching pavement edges. Flexible pavement that abuts concrete at street intersections or facility boundaries may provide little resistance to concrete panel movement. However, where such conditions and influences are envisioned, consideration should be given to additional details designed to minimize panel movement.

Some pavement designers have successfully used integral subgrade key details or lug anchors to resist these panel movement tendencies. Such designs may incorporate preset or integrally placed trench footings at the interior of selected pavement panels, individual post-style anchors, or thickened edges. Figures 3.13.2a and 3.13.2b show example section details of typical lug anchors (ACPA 2003; Georgia Department of Transportation 2005; Saint Louis County Department of Highways and Traffic 2004). Some roadway agencies have used similar full-width transverse lug anchors

through areas with steep slopes at spacings of less than 40 ft (12 m) up to as much as 200 ft (61 m).

3.14—Design examples

Appendix E contains a parking lot design example.

CHAPTER 4—CONCRETE MATERIALS AND MIXTURE PROPORTIONING

4.1—Introduction

4.1.1. Concrete should be batched, mixed, and delivered in accordance with [ASTM C94/C94M](#) or [C685/C685M](#), and the proportions for the concrete mixture can be established based on previous field experience or laboratory trial batches, in accordance with [ACI 325.14R](#). Mixtures proportioned on the bases of laboratory trial batches should be field verified using the contractor's methods and procedures to ensure the mixture will produce the required concrete properties.

4.2—Cementitious materials

4.2.1 Introduction to cementitious materials—Both ordinary portland cements (OPCs) and blended cements are used in parking lot concrete. These hybrid cements use supplementary cementitious materials (SCMs) such as fly

ash and slag cement provide the primary cementing material in concrete mixtures. Hydraulic cement reacts with water and produces calcium silicate hydrate and other cementing compounds that cause concrete to set and gain strength. A by-product of this reaction is calcium hydroxide, which remains suspended in the concrete matrix and may be available to react with SCMs. SCMs are materials that may have little cementing value by themselves but will react with calcium hydroxide to provide more cementing compounds. Each of the cementitious material specifications include several types of cements and various SCMs designed for specific uses and conditions, and should be carefully selected to meet the needs of each project.

4.2.2 Hydraulic cements—Portland cement meeting requirements of **ASTM C150/C150M** is hydraulic cement made to conform to specific chemical and physical property limits per this specification. Type I or Type II is commonly used for parking lot pavements. While Type I is considered general-purpose, Type II has moderate sulfate resistance for pavements exposed to soil or water containing sulfate ions. Type III cement is ground finer so it reacts quicker and can be used where early opening to traffic is required. Type V cement could be used in areas of high sulfate exposure.

Blended cement meeting requirements of **ASTM C595/C595M** is also hydraulic cement made to conform to specific chemical and physical property limits. This specification provides for blending hydraulic cements with other cementitious materials and could eliminate the need for multiple cement storage silos.

Hydraulic cement meeting performance requirements of **ASTM C1157/C1157M** can also be used for parking lot pavements. This cement may contain other blended or interground materials, including fly ash, slag cement, limestone, or other related materials. It is produced to conform to performance limits essentially without specific chemical requirements. There are six types of cements established in **ASTM C1157/C1157M** and the type used is selected according to application.

Portland-limestone cements (PLCs) may also be used. Recognized for their sustainability benefits, with lower associated greenhouse gas emissions and embodied energy, they are used interchangeably with ordinary portland cements, with or without SCMs. Portland-limestone cements containing up to 15 percent limestone may be supplied under **ASTM C595/C595M** (Type IL or IT) or **ASTM C1157/C1157M**.

4.2.3 Supplementary cementitious materials (SCMs)—Some concrete pavements incorporate SCMs in the mixture, particularly slag cement and Class C or Class F fly ash. SCMs may be added to concrete to improve plastic and/or hardened properties of the concrete while optimizing the mixture. SCMs may have both hydraulic and pozzolanic value in concrete. SCMs may offer benefits such as less shrinkage, lower permeability, and mitigation for alkali reactivity with aggregates. Testing must be performed on specific materials and mixture proportions to determine the magnitude of the benefits provided by the SCMs. SCMs commonly used in parking lot pavements are listed in the following sections.

Other SCMs may also be used when approved by the engineer. As SCMs typically have a delayed reaction, the curing period (retaining moisture) may need to be extended to develop the full strength properties at the exposed surface.

4.2.3.1 Fly ash—Fly ash is finely divided residue of burned ground coal, captured from the flue gases of a coal combustion device, usually at a coal-burning electric power plant. The combustion by-product is usually harvested with electrostatic precipitators, conveyed to storage and shipping, and is commonly used as a cementitious component of concrete without further processing; however, some fly ash is enhanced by separation of particle sizes and chemical treatment of carbon residue in the ash. Class C and Class F fly ash conform to the provisions of **ASTM C618**. The distinction between the two classes is usually related to the type of coal burned in production of the ash. Class C fly ash can contain a total calcium content (expressed as CaO) higher than 10 percent. Both classes of fly ash are predominately pozzolanic. Functionally, a Class F fly ash is typically more nearly pure pozzolan than a Class C fly ash. A Class C fly ash may have slight hydraulic cementitious reactivity and other reactive chemical components. It is possible for a fly ash source to conform to both Class C and Class F fly ash designations. Fly ash is commonly used to replace up to 25 percent of the hydraulic cement. Fly ash normally provides similar strengths at 28 days, but lower earlier strengths compared to concrete mixtures made of 100 percent hydraulic cement.

4.2.3.2 Slag cement—Slag cement conforming to **ASTM C989/C989M** is produced from water-quenched molten slag from an iron-making blast furnace. It is hydraulic cement with additional pozzolanic properties. Slag cement is the molten mineralogical by-product of iron ore from the blast furnace but must be processed through granulation (rapid water quenching), drying, and grinding in a ball mill or roller press. Slag cement may be used to replace up to 50 percent of the hydraulic cement. Slag cement normally provides higher strength at 28 days, but lower earlier strengths compared to concrete mixtures made of 100 percent hydraulic cement.

4.3—Mixing water

Mixing water should meet requirements of specification **ASTM C1602/C1602M**.

4.4—Aggregates

Aggregates meeting the requirements of **ASTM C33/C33M** or the local state DOT requirements are suitable for use in parking lot pavements. Crushed limestone or natural gravel aggregates are commonly used in concrete for parking lots. In general, the use of the largest practical nominal maximum aggregate size is recommended in an effort to minimize the required paste content and corresponding drying shrinkage potential and associated curling/warping. It is important, however, to use a well-graded aggregate blend to maintain workability and finishability when the paste content is minimized. **ACI 325.14R** includes details on mixture proportioning methods, including optimizing the grading distribution of the combined aggregates.