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Guide for the Design and Construction of Concrete Parking Lots

Reported by ACI Committee 330

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Guide for the Design and Construction of Concrete Parking Lots

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Concrete parking lots serve many kinds of public facilities, commercial 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 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.

Keywords: concrete pavement; curing; dowels; finishing; joints; load transfer; parking lot; subgrade; thickness; traffic loads.

CONTENTS

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CHAPTER 1—INTRODUCTION AND SCOPE

1.1—Introduction

Concrete parking lots have many similarities to other types of concrete pavement. On the other hand, parking lots differ from other pavements in that most of the area is intended for storage of vehicles and other goods rather than for movement of vehicles. The design of concrete parking lots should follow generally accepted procedures for concrete pavements as outlined in this guide. Load-bearing capacity, drainage, crack control, life-cycle cost, constructibility, and maintainability are other characteristics that are important in the design and construction of concrete pavements, including parking lots.

Typically, concrete parking lots do not serve the same broad spectrum of traffic loading, from light vehicles to heavy trucks, as highways and arterial streets. Facilities designed to accommodate both light vehicles and heavier delivery trucks may employ traffic controls to separate and channel the heavier trucks away from areas designed for automobiles and light trucks. Facilities designed for heavier vehicles are likely those facilities where relatively accurate predictions of vehicle sizes and numbers are possible. Facilities intended to serve only light vehicles may have concrete parking lot slabs with thicknesses influenced by the practical limitations of the material 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 as well as 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 nighttime 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 need to accommodate relatively heavy loads. Special consideration may be needed if access to dumpsters 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 screeds.

Because of the relatively high stiffness of concrete pavements, loads are spread over larger areas of the subgrade compared with asphaltic pavements. As a result, thinner concrete pavements can be used for the same subgrade material. Additional benefits of using concrete to construct parking lots include the following:

- Concrete surfaces resist deformation from maneuvering vehicles;
- Concrete surfaces drain well with only minimal slopes;
- Concrete has relatively simple maintenance requirements;
- Traffic lane and parking stall markings can be incorporated into the jointing pattern;
- Concrete is minimally affected by leaking petroleum products;
- The light-reflective surface of concrete can be efficiently illuminated with minimal energy requirements; and
- 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 30 years or more, requiring no additional use of aggregates and other nonrenewable materials resources through the period. In addition to opportunities for the use of sustainable concrete component materials such as recycled aggregates and supplementary cementitious materials derived from industrial byproducts, 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 (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 (Portland Cement Association 2005).

1.2—Scope

This guide is based on the current knowledge and practices for the design, construction, and maintenance of concrete parking lots. It emphasizes the aspects of concrete pavement technology that are different from procedures used to design and construct other types of slabs-on-ground, such as streets, highways, and floors. 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, providing some edge support on all sides. 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.

1.3—Background

Design methods for concrete parking lot pavements are somewhat empirical, and are based on the 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 both the stresses in the slab and the reductions in serviceability caused by mixed traffic, including heavy trucks, whereas parking lots usually serve fewer vehicles either parked or traveling at slow speeds. For many parking lots that will serve only light traffic loads, the need for an extensive design process may be less critical. For such projects, a designer can rely on personal 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.

Determining and specifying practical thickness tolerances for pavements is critical. Reduction of the pavement thickness beyond recommendations can significantly increase pavement stresses, reduce pavement structural capacity, and potentially 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.

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 or 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 (mm^2/m) (Section 3.8.1)
ADTT = average daily truck traffic (Section 3.5)
CBR = California bearing ratio (Section 2.2, 3.4, 3.6, 8.1, B.2)
C_f = coefficient of subgrade resistance to slab movement (Section 3.8.1)
f_s = allowable tensile stress in distributed steel reinforcement, psi (MPa) (Section 3.8.1)
h = slab thickness, in. (mm) (Section 3.8.1)
k = modulus of subgrade reaction, psi/in. (MPa/mm) (Section 2.2, 3.4, 3.6, A.1, B.2, B.3)
L = distance between joints, ft (m) (Section 3.8.1)
MOR = modulus of rupture, psi (MPa) (Section 2.2, 3.5, 3.6, A.1)
PI = plasticity index (Section 2.2, B.2)
R = resistance value (Section 2.2, 3.4, 3.6)
SSV = soil support value (Section 2.2, 3.4)
w = density of concrete, lb/ft^3 (kg/m^3) (Section 3.8.1)

2.2—Definitions

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. Note: Used in the design of pavements.

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.

dowels—hardware—usually smooth, parallel steel bars—placed across a joint to transfer vertical load while allowing the joint to open and close.

faulting—the differential vertical displacement of slabs adjacent to a joint or crack.

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 rupture (MOR)—the calculated apparent tensile stress in the extreme tension fiber of a plain concrete beam test specimen at the load that produces rupture when tested in accordance with ASTM C78.

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.

panel—an individual concrete pavement slab bordered by joints or slab edges.

plain pavement—unreinforced concrete pavement.

plasticity index (PI)—the range of water content in which a soil remains plastic, evaluated as the numerical difference between liquid limit and plastic limit, as calculated according to ASTM D4318. (Also referred to as **plasticity**.)

raveling—the tendency for aggregate to dislodge and break away from the concrete along the joint that is being sawed.

resistance value *R*—the stability of a soil determined in accordance with ASTM D2844 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

The design of a concrete parking lot pavement entails selecting dimensions and other details to provide a slab that will adequately carry the anticipated traffic on the subgrade, provide the correct types of joints in the proper locations, channel and segregate traffic where needed, incorporate required drainage features and lighting, and allow for efficient and economical construction. The most important aspect of the structural design for pavement is selecting the appropriate thickness. Excessive thickness can result in unjustifiable construction cost. Inadequate thickness will result in unsatisfactory performance and expense, premature maintenance, or replacement. Selection of the appropriate thickness requires careful evaluation of soil conditions and traffic, as well as the selection of appropriate concrete properties and design life.

Selecting the proper pavement thickness will result in a slab that supports the heaviest anticipated loads by distributing the loads over the subgrade soil without inducing excessive stress in the slab. Joints or cracks between joints produce discontinuities in the slab. Loads crossing these discontinuities cause increased deflections and stresses in the slab and in the subgrade below. Repeated deflections of a slab edge or joint and the resulting displacement of the subgrade can eventually cause fatigue cracking in the slab and faulting at the joint. Proper thickness provides adequate stiffness to minimize fatigue and joint faulting during the design life of the pavement. Faulted joints or occasional cracks are probably not as objectionable in a parking lot as on a street or highway because parking lot traffic moves slowly.

Another inherent characteristic of concrete slabs that affects stresses is the differential volume changes of upper and lower surfaces due to differences in moisture content and temperature. Differential shrinkage or expansion can cause slab corners and edges to deflect up or down relative to the slab center. The tendency for this warping or curling is decreased by reducing the size of individual slabs or by increasing slab thickness. As a practical matter, there is no benefit in building slabs less than 4 in. (100 mm) thick. Thinner slabs do not significantly reduce construction costs, and because of their tendency to warp and curl, are extremely vulnerable to inadvertent overloads and variations in subgrade support. The detrimental effects of concrete thickness variations that result from typical surface irregularities of the prepared subgrade are also magnified.

Methods used to select an appropriate concrete pavement thickness relate concrete stresses and fatigue characteristics to the nature of the underlying subgrade, the strength of the concrete, and the magnitude and location of pavement loadings. They have been developed and refined using experimental and performance data as well as theoretical models. Such methods have generally been intended for the design of street and highway pavements, but are also useful for parking lot design.

Appendix A contains additional information on the methods of concrete pavement analysis and design.

3.2—Pavement stresses

Thickness design of pavement is intended to limit slab tensile stresses produced by vehicular loading. Model studies, as well as full-scale accelerated traffic tests, have shown that maximum tensile stresses in concrete pavement occur when vehicle wheels are close to a free or unsupported edge of the pavement. Stresses resulting from wheel loadings applied near interior joints are generally less severe due to load transfer across the joints. The critical stress condition occurs when a wheel load is applied near the intersection of a joint and the pavement edge. Because parking areas have relatively little area adjacent to free edges and vehicle loads are applied mostly to interior slabs, pavements should be designed assuming supported edges. At the outside edges or at entrances, integral curbs or thickened edge sections can be used to decrease stresses. Thermal expansion and contraction of the pavement and warping or curling caused by moisture and temperature differentials within the pavement cause other stresses that are not addressed directly in thickness design. Proper jointing reduces these stresses.

3.3—Traffic loads

A pavement will be subjected to varying, but predictable, vehicular loads throughout its lifetime. To determine the pavement thickness, 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 for each vehicle type, vehicular loads, and the daily volume or total volume anticipated for the facility over the design life. The owner's projections of the type of traffic expected to use a facility, supplemented by traffic studies or counts for similar facilities, should provide adequate design traffic estimates.

3.4—Subgrade support

The subgrade is the underlying surface of soil or existing pavement on which the parking lot pavement is constructed. The ability of the subgrade soil to uniformly support the loads applied to it 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 by appropriate soils testing on the area to be paved.

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.2). 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*, CBR, resistance value *R*, or SSV should be determined. 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 3.1 shows ranges of values for several types of soil (Portland Cement Association 1984a,b; American Concrete Pavement Association 1982). 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% 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 probably is not economical to use imported subbase material or to chemically treat the subgrade for the sole purpose of increasing *k* values, though such measures are sometimes used to improve the contractor's working platform or to reduce subgrade susceptibility to pumping and erosion. If a subbase or treated subgrade is used, the increased support it provides should be considered in the thickness design. Table 3.2 is indicative of the effects of subbases on *k* values (Portland Cement Association 1984a,b; Federal Aviation Administration 1978). Note that increases in subbase thickness do not result in proportional *k* value improvement. For example, for a subgrade having a *k* value of 100 psi/in. (27 MPa/m), tripling the thickness of a 4 in. (100 mm) granular subbase to 12 in. (300 mm) results in an increase of *k* value from 130 psi/in. (35 MPa/m) to only 190 psi/in. (51 MPa/m).

Additional detailed information on subgrade investigation, subbases, and special subgrade problems can be found in Appendix B.

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 equipment 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

Table 3.1—Subgrade soil types and approximate support values (Portland Cement Association 1984a,b; American Concrete Pavement Association 1982)

Type of soil	Support	k, psi/in.	CBR	R	SSV
Fine-grained soils in which silt and clay-size particles predominate	Low	75 to 120	2.5 to 3.5	10 to 22	2.3 to 3.1
Sands and sand-gravel mixtures with moderate amounts of silt and clay	Medium	130 to 170	4.5 to 7.5	29 to 41	3.5 to 4.9
Sand and sand-gravel mixtures relatively free of plastic fines	High	180 to 220	8.5 to 12	45 to 52	5.3 to 6.1

Notes: CBR = California bearing ratio; R = resistance value; and SSV = soil support value. 1 psi = 0.0069 MPa, and 1 psi/in. = 0.27 MPa/m.

Table 3.2—Modulus of subgrade reaction k*

Subgrade k value, psi/in.	Sub-base thickness			
	4 in.	6 in.	9 in.	12 in.
	Granular aggregate subbase			
50	65	75	85	110
100	130	140	160	190
200	220	230	270	320
300	320	330	370	430
	Cement-treated subbase			
50	170	230	310	390
100	280	400	520	640
200	470	640	830	—
	Other treated subbase			
50	85	115	170	215
100	175	210	270	325
200	280	315	360	400
300	350	385	420	490

*For subbase applied over different subgrades, psi/in. (Portland Cement Association 1984a,b; Federal Aviation Administration 1978).
Note: 1 in. = 25.4 mm, and 1 psi/in. = 0.27 MPa/m.

(MOR) of the concrete is used in pavement design to determine the required thickness.

Flexural strength is determined by the MOR test in accordance with ASTM C78. The 28-day 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 in service until after 28 days. While design of pavements is generally 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 (refer to Eq. (3-1) and (3-2)).

It is a generally accepted principle in concrete mixture proportioning that the coarse aggregate type has a greater influence on the flexural strength than on the compressive strength, and that rough-surfaced and angular-shaped coarse aggregates generally provide increased margins of flexural strengths as compared with smooth-textured and round-shaped coarse aggregates. Goldbeck (1988) noted that the reason for higher margins of flexural strength associated with rough-surfaced and angular-shaped aggregates is the enhanced mechanical bond between the cementitious paste and the aggregates.

For concrete made with most smooth-textured, round-shaped aggregates, an approximate relationship between specified compressive strength f_c' and MOR can be expressed using Eq. (3-1)

$$\begin{aligned} \text{MOR (psi)} &= 8\sqrt{f_c'} \quad \text{(in.-lb units)} \\ \text{MOR (MPa)} &= 0.7\sqrt{f_c'} \quad \text{(SI units)} \end{aligned} \tag{3-1}$$

An approximate relationship between compressive strength f_c' and MOR for concrete made with some rough-textured, angular-shaped (typically crushed) aggregates can be expressed using Eq. (3-2)

$$\begin{aligned} \text{MOR (psi)} &= 10\sqrt{f_c'} \quad \text{(in.-lb units)} \\ \text{MOR (MPa)} &= 0.8\sqrt{f_c'} \quad \text{(SI units)} \end{aligned} \tag{3-2}$$

If no information is available to the designer about coarse aggregates to be used in project concrete, the lower MOR assumptions are recommended as more conservative. Higher MOR values (as produced by Eq. (3-2)) may be used if there is documentation or field experience showing that these higher MOR values can be anticipated with the aggregates to be used, and the resulting pavement section may be slightly thinner. 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 AASHO 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 have been used, such as the Brokaw Method (Brokaw 1973), which is based on surveys of the performance of plain concrete pavements in use throughout the country. 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 3.3 and 3.4 have been developed as the preferred approach. More complete explanations of these design procedures can be found in Appendix A.

Concrete pavements can be classified as plain or reinforced, depending on whether or not the concrete contains distributed steel reinforcement. Plain pavements can be divided into those with or without load-transfer devices at the joints. Those with load-transfer devices are usually referred to as plain-doweled pavements. The aforementioned design methods can be used for plain or reinforced pavements because the presence or lack of distributed steel reinforcement has no useful effect on the load-carrying capacity or thickness. Joint design, however, is affected by the presence of distributed reinforcement. The use of load-transfer devices may sometimes enable pavement thickness to be reduced, but the devices are costly and not normally used in light-duty pavements. The differences between reinforced and plain pavements, with and without load-transfer devices, are discussed in Sections 3.7 and 3.8.

Table 3.3—Traffic categories*

1. Car parking areas and access lanes—Category A
2. Shopping center entrance and service lanes—Category B
3. Bus parking areas, city and school buses
   Parking area and interior lanes—Category B
   Entrance and exterior lanes—Category C
4. Truck parking areas—Category B, C, or D

Truck type	Parking areas and interior lanes	Entrance and exterior lanes
Single units (bobtailed trucks)	Category B	Category C
Multiple units (tractor trailer units with one or more trailers)	Category C	Category D

[*] Select A, B, C, or D for use with Table 3.4.

Tables 3.3 and 3.4 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 3.3 lists four different traffic categories that range from passenger cars and light trucks to heavy trucks. Table 3.4 gives recommended pavement thicknesses for large and small numbers of trucks per day in four different traffic categories and six different categories of subgrade support, ranging from very high to low. The high values of subgrade support can apply to treated subbases or existing flexible pavement. The levels of subgrade support can be related to Table 3.1, which lists the estimated support values for the most commonly occurring subgrade soil types. The thicknesses shown are based on flexural strengths ranging from 500 to 650 psi (3.5 to 4.5 MPa) at 28 days, which correspond to compressive strengths between approximately 3500 and 5000 psi (24 and 34 MPa) based on approximations for relating compressive and flexural strength such as those in Eq. (3-1) and (3-2). Approximate cost comparisons indicate that the lower-strength concrete can sometimes be justified in areas where freezing-and-thawing resistance is not important. Changes in modulus of rupture, however, affect the required concrete thickness and the capacity. A designer should determine whether it is more cost effective to increase strength or thickness, taking into account the other

Table 3.4—Twenty-year design thickness recommendations, in. (no dowels)

		k = 500 psi/in. (CBR = 50; R = 86)				k = 400 psi/in. (CBR = 38; R = 80)				k = 300 psi/in. (CBR =26; R = 67)			
	MOR, psi:	650	600	550	500	650	600	550	500	650	600	550	500
Traffic category*	A (ADTT =1)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.5
	A (ADTT = 10)	4.0	4.0	4.0	4.5	4.0	4.0	4.5	4.5	4.0	4.5	4.5	4.5
	B (ADTT = 25)	4.0	4.5	4.5	5.0	4.5	4.5	5.0	5.5	4.5	4.5	5.0	5.5
	B (ADTT = 300)	5.0	5.0	5.5	5.5	5.0	5.0	5.5	5.5	5.0	5.5	5.5	6.0
	C (ADTT = 100)	5.0	5.0	5.5	5.5	5.0	5.5	5.5	6.0	5.5	5.5	6.0	6.0
	C (ADTT = 300)	5.0	5.5	5.5	6.0	5.5	5.5	6.0	6.0	5.5	6.0	6.0	6.5
	C (ADTT = 700)	5.5	5.5	6.0	6.0	5.5	5.5	6.0	6.5	5.5	6.0	6.5	6.5
	D (ADTT = 700)†	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
		k = 200 psi/in. (CBR = 10; R = 48)				k = 100 psi/in. (CBR = 3; R = 18)				k = 50 psi/in. (CBR = 2; R = 5)			
	MOR, psi:	650	600	550	500	650	600	550	500	650	600	550	500
Traffic category*	A (ADTT =1)	4.0	4.0	4.0	4.5	4.0	4.5	4.5	5.0	4.5	5.0	5.0	5.5
	A (ADTT = 10)	4.5	4.5	5.0	5.0	4.5	5.0	5.0	5.5	5.0	5.5	5.5	6.0
	B (ADTT = 25)	5.0	5.0	5.5	6.0	5.5	5.5	6.0	6.0	6.0	6.0	6.5	7.0
	B (ADTT = 300)	5.5	5.5	6.0	6.5	6.0	6.0	6.5	7.0	6.5	7.0	7.0	7.5
	C (ADTT = 100)	5.5	6.0	6.0	6.5	6.0	6.5	6.5	7.0	6.5	7.0	7.5	7.5
	C (ADTT = 300)	6.0	6.0	6.5	6.5	6.5	6.5	7.0	7.5	7.0	7.5	7.5	8.0
	C (ADTT = 700)	6.0	6.5	6.5	7.0	6.5	7.0	7.0	7.5	7.0	7.5	8.0	8.5
	D (ADTT = 700)†	7.0	7.0	7.0	7.0	8.0	8.0	8.0	8.0	9.0	9.0	9.0	9.0

[*] ADTT = average daily truck traffic. Trucks are defined as vehicles with at least six wheels; excludes panel trucks, pickup trucks, and other four-wheel vehicles. Refer to Appendix A. k = modulus of subgrade reaction; CBR = California bearing ratio; R = resistance value; and MOR = modulus of rupture.

[†] Thickness of Category D (only) can be reduced by 1.0 in. (25 mm) if dowels are used at all transverse joints (that is, joints located perpendicular to direction of traffic).

Note: 1 in. = 25.4 mm; 1 psi = 0.0069 MPa; and 1 psi/in. = 0.27 MPa/m.

benefits of high strength such as improved durability. Table 3.4 can be used to assist the designer in this determination.

3.7—Jointing

Joints are placed in concrete pavement to minimize random 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 3.5). This spacing depends on the thickness of the pavement, the strength of the concrete, the type of aggregates, climatic conditions, and whether distributed steel reinforcement is used. Distributed steel reinforcement helps minimize the width of intermediate temperature and drying shrinkage cracks that can occur between joints. Experience is often the best guide for determining the optimum joint spacing to control temperature and drying shrinkage effects. Closer joint spacings can result in smaller joint openings that provide increased load transfer between panels in the form of aggregate interlock. 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.

3.7.1 *Contraction joints*—A contraction joint predetermines the location of cracks caused by restrained shrinkage of the concrete and by the effects of loads and warping or curling. Hardened concrete will shrink almost 1/16 in. (2 mm) for every 10 ft (3 m) of length while drying. If this shrinkage is restrained, tensile stresses develop that can reach the tensile strength of the concrete, and the concrete cracks.

Contraction joints create planes of weakness that subsequently produce cracks as the concrete shrinks. The planes of weakness can be created while the concrete is still plastic by using a grooving tool or by inserting a premolded filler strip. Concrete can also be cut with saws after it has hardened enough to support the saws and avoid raveling. The depth of the joint should be at least 1/4 of the slab thickness when using a conventional saw, or 1 in. (25 mm) when using early-entry saws on slabs 9 in. (230 mm) or less in thickness (refer to Section 5.7.1). The width of a cut depends on whether the joint is to be sealed. A narrow joint width, generally 1/10 to 1/8 in. (2.5 to 3 mm) wide, is common for unsealed joints. Cuts at least 1/4 in. (6.5 mm) wide are required for sealed joints, and a 3/8 in. (9.5 mm) wide cut is commonly recommended. Joint sealant manufacturers' recommendations should be followed for the depth and width of joints that are to be sealed.

Contraction joints are normally called transverse joints or longitudinal joints in streets. In parking areas, longitudinal joints refer to those parallel to the direction of paving. Transverse joints divide the paving lanes into panels. Contraction joint patterns should divide pavements into approximately square panels. The length of a panel should not be more than 25% greater than its width. Joint patterns across lanes should be continuous. In unreinforced parking lot pavements, maximum spacing should be about 30 times the thickness of the slab up to a maximum of 15 ft (4.5 m) (Table 3.5). In many instances, jointing patterns can be used to delineate driving lanes and parking stalls.

Table 3.5—Spacing between joints

Pavement thickness, in. (mm)	Maximum spacing, ft (m)
4, 4.5 (100, 113)	10 (3.0)
5, 5.5 (125, 140)	12.5 (3.8)
6 or greater (150 or greater)	15 (4.5)

3.7.2 *Construction joints*—Construction joints provide the interface between areas of concrete placed at different times during the course of the project. A common use is the longitudinal joints along placement lanes. Butt-type joints without special load-transfer features are usually recommended for parking lots serving light vehicles, but the need for load transfer should be considered for heavier traffic loads. Keyways of half-round or trapezoidal shape have, at times in the past, 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. Refer to Section 3.8.2 for information on the use of dowels for load transfer.

Transverse 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.

When transverse construction joints are needed, they should be installed at contraction joint locations, if possible. If the slab thickness was established based on the assumption of load transfer by aggregate interlock at transverse joints, slab edges at any butt-type joints should be thickened approximately 20%. In emergency situations, such as lack of materials, sudden changes in weather, or equipment breakdown, it may not be possible to place the joint where planned. A construction joint can be made in the middle third of a panel if deformed tie bars are used across the joint to prevent joint movement.

Longitudinal construction joints between paving lanes deserve the same considerations concerning load transfer. Longitudinal construction joints along the periphery of a parking area can be tied with deformed bars if joint tightness is critical where heavy vehicles are expected. It is usually sufficient to tie only the first joint inward from the exterior edge. Tying additional joints will restrict movement and can cause undesirable cracks. Refer to Section 3.8.3.

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. Measures should be taken to prevent or minimize such cracking.

Where slabs of different thicknesses come together at construction joints, such as between automobile parking and truck lanes, the subgrades under the thinner pavements should be shaped to provide gradual thickness transition over a distance of 4 ft (1.2 m) or more.

3.7.3 *Isolation (expansion) 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 isolate the pavement from these structures, such as light standard foundations, drop inlets, and buildings. They are full-thickness, vertical joints usually filled with a compressible material. While sometimes referred to as expansion joints, they are rarely needed to accommodate concrete expansion. When they must be located in areas that encounter wheel and other loads, the pavement edges at the joint should be thickened by 20% or 2 in. (50 mm), whichever is greater (refer to Fig. C.4 in Appendix C). 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 fillers prevent the new slab from bonding to other structures during and after concreting operations. The joint filler should extend through the slab thickness to the subgrade and be recessed below the pavement surface or used with void caps so that the joint can be properly sealed with closed-cell backer rod and joint-sealant materials. The types of joint filler materials available include bituminous mastic, bituminous impregnated cellulose or cork, sponge rubber, recycled tire rubber, and resin-bound cork. Joint-filler materials should be installed in accordance with the manufacturer's recommendations.

Isolation joints are not recommended for routine use as regularly spaced joints. They are difficult to construct and maintain, provide no load transfer, and can be 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.

3.8—Steel reinforcement in parking lot pavements

3.8.1 *Distributed steel reinforcement*—When pavement is jointed to form short panel lengths that will minimize intermediate cracking, distributed steel reinforcement 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. In areas where deicing salts and similar materials are used, distributed steel also presents a risk of corrosion. Shorter unreinforced panels are generally more economical and provide better performance. 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.

When joint spacings are in excess of those that will effectively control shrinkage cracking or when uncorrectable subgrade conditions are liable to provide nonuniform support, distributed steel reinforcement can be used to control the opening of intermediate cracks between the joints. The sole function of the distributed steel reinforcement is to hold together the fracture faces if cracks form. The quantity of steel varies depending on joint spacing, slab thickness, the friction between the concrete and the subgrade expressed as the coefficient of subgrade resistance, and the allowable tensile stress of the steel. The area of steel required per unit width of slab is computed by the following drag formula (Portland Cement Association 1955)

$$A\ (\text{in.}^2/\text{ft}) = (LC_f wh)/24(f_s) \quad \text{(in.-lb units)}$$
$$A\ (\text{mm}^2/\text{m}) = (LC_f wh)/204(f_s) \quad \text{(SI units)} \qquad (3\text{-}3)$$

where

A = area of distributed steel reinforcement required per unit width of slab, in.^{2}/ft (mm^2/m);

L = distance between joints, ft (m);

C_f = coefficient of subgrade resistance to slab movement (a value of 1.5 is most commonly used in design);

w = density of concrete (145 lb/ft^3) (2320 kg/m^3);

h = slab thickness, in. (mm); and

f_s = allowable tensile stress in distributed steel reinforcement, psi (MPa) (a value of 2/3 yield strength is commonly used for example 40,000 psi (280 MPa) for Grade 60 steel).

Distributed steel reinforcement may be needed in pavements with transverse joints spaced more than 30 times the slab thickness. Because contraction joints should be free to open, distributed steel reinforcement is interrupted at the joints. Because increased spacing between joints will increase joint openings and reduce aggregate interlock load transfer, pavements designed for truck traffic that use such joint spacing typically require load-transfer dowels. Distributed steel reinforcement should be supported on chairs or precast concrete blocks to hold it in position, usually 2 in. (50 mm) below the top of the slab.

3.8.2 *Dowels*—Experience has shown that dowels or other load-transfer devices are not needed for most parking lot conditions. They may be economically justified where there are poor subgrade support conditions or heavy truck traffic if improved joint performance would allow a significant reduction in thickness.

Dowels across pavement joints can provide load transfer while permitting the joints to move. When dowels are used, their correct alignment and lubrication is essential for proper joint function. Dowel baskets (Fig. 3.1) should be used at contraction joints to maintain alignment, or dowel bar inserters can be used on slipformed placements. The dowels should be epoxy coated in areas where deicing salts are used. The dowel size should be in proportion to the pavement thickness. Table 3.6 gives recommended sizes of smooth, round dowel bars for different slab thicknesses (American Concrete Pavement Association 2007). Dowels should not be placed closer than 12 in. (300 mm) to a joint intersection to minimize the potential for corner cracking (ACI 360R; Schrader 1987, 1991). In thinner pavements of 7 in. (180 mm)

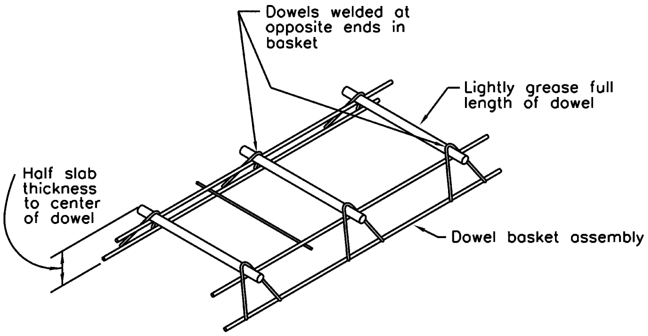

Fig. 3.1—Dowel basket assembly.

Table 3.6—Sizes of smooth, round dowels*

Slab thickness, in. (mm)	Dowel diameter, in. (mm)
7 (180)	1 (25)
8 (200)	1-1/4 (32)
9 (230)	1-1/4 (32)

*All dowels spaced at 12 in. (300 mm) centers, with minimum total length of 14 in. (360 mm) and minimum embedment length of 6 in. (150 mm) on each side of joint, with allowance made for joint openings and for minor errors in positioning dowels.

and less, round dowels can be impractical or counterproductive. Usually, it is more economical to keep joint spacing close, using aggregate interlock, and thicken the pavement slightly, if necessary, to reduce deflections.

The use of alternative dowel geometries and shapes has become common in the construction of industrial floor slabs, and some of these have been used successfully in parking and site pavements (Keith et al. 2006). These have most often been diamond- or trapezoid-shaped steel plate dowels, which may also be useful in some of the thinner sections (7 in. [180 mm] and less) for which traditional round dowels are impractical. There are other potential benefits to this type of dowel design as well. Less steel is required because the increased bearing area reduces the stress on both the concrete and the dowel. This geometry is also less sensitive to construction tolerances, and some differential movement of adjacent slab panels is afforded longitudinally along the joint. Special attention is recommended to consolidation of concrete around plate dowels.

3.8.3 *Tie bars*—Tie bars should be used to tie only the first longitudinal joint from the pavement edge to keep the outside slab from separating from the pavement (for location, refer to Fig. C.1 of Appendix C). Tie bars are not required in the interior 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 3.7.

3.8.4 *Irregular panels*—In unreinforced parking lots, distributed steel reinforcement should be considered for irregular panels. An irregular panel is considered to be one in which the slab tapers to a sharp angle, when the length-to-width ratio exceeds 1.7, or when the slab is neither square nor rectangular. Distributed steel reinforcement should be calculated based on the drag formula (Eq. (3-3)). Even with distributed steel reinforcement, a greater incidence of out-of-joint cracking should be anticipated in irregular panels.

Table 3.7—Lengths and spacings for No. 4, 1/2 in. (13 mm) diameter tie bars

		Tie bar spacing, in. (mm)		
		Distance to nearest free edge or to nearest joint where movement can occur		
Slab thickness, in. (mm)	Tie bar length, in. (mm)	12 ft (3.7 m) or less	14 ft (4.3 m)	16 to 24 ft (4.9 to 7.3 m)
5 (125)	24 (610)	30 (760)	30 (760)	28 (710)
5-1/2 (140)	24 (610)	30 (760)	30 (760)	25 (630)
6 (150)	24 (610)	30 (760)	30 (760)	23 (580)
6-1/2 (165)	24 (610)	30 (760)	30 (760)	21 (530)
7 (180)	24 (610)	30 (760)	30 (760)	20 (510)
7-1/2 (190)	24 (610)	30 (760)	30 (760)	18 (460)
8 (200)	24 (610)	30 (760)	28 (710)	17 (430)
8-1/2 (215)	24 (610)	30 (760)	26 (660)	16 (410)
9 (230)	30 (760)	36 (910)	30 (760)	24 (610)

3.9—Joint filling and sealing

Joints are often left unfilled without affecting performance, but joint filling and sealant material should be used to minimize the infiltration of water and solid materials into the joint openings where local experience has shown this to be necessary. 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 preventing 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 the pavement surface. Refer to ACI 504R for additional information on joint sealing.

3.10—Pavement grades

3.10.1 *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.

3.10.2 *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 storm water for regulated release using pervious concrete. Refer to ACI 522R for additional information.

3.10.3 *Pavement slope*—To prevent puddling of water, the minimum pavement slope used should be 1% or 1/8 in./ft (3 mm/300 mm); 2% or 1/4 in./ft (6 mm/300 mm) is recommended wherever possible. 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% without the use of vertical curves. Driveways and entrances may be sloped up to 12%, but a maximum slope of 6% is generally recommended for areas where vehicles park. Disabled accessible (handicapped) spaces should be designed in accordance with the Americans with Disabilities Act (ADA).

3.11—Other design features

3.11.1 *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 mountable (roll type) curbs and barrier (straight) curbs. Mountable curbs are preferred by many people 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 Appendix C.

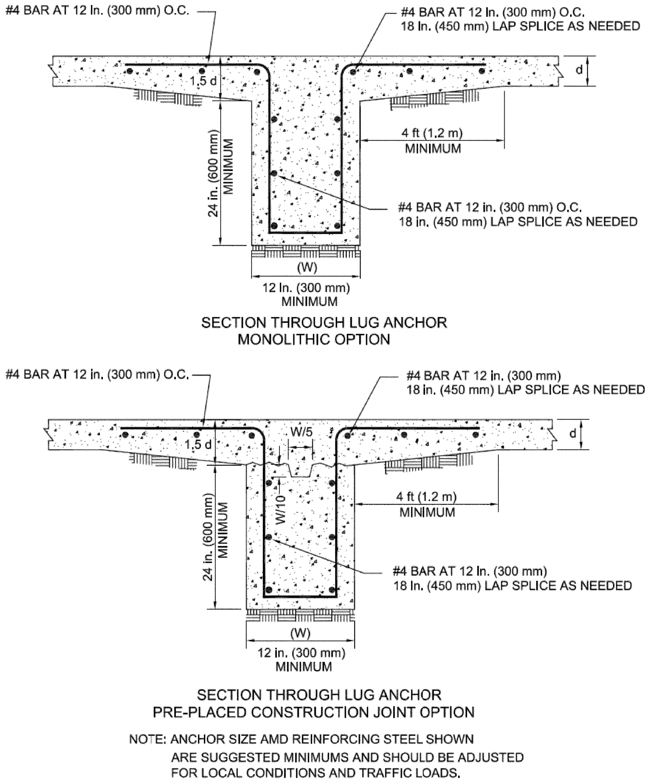

Fig. 3.2—Example sections of typical lug anchors.

3.11.2 *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 this movement (Section 3.8.3), but this practice alone may not be sufficient where these influences are extreme, and especially where sliding forces are present over larger areas.

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. 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. Figure 3.2 shows example section details of typical lug anchors (American Concrete Pavement Association 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).

CHAPTER 4—MATERIALS

4.1—Introduction

Concrete used to construct parking lot pavements should be batched, mixed, and delivered in accordance with ASTM C94/C94M or C685/C685M. Components of the mixture should follow the requirements contained in other appropriate ASTM specifications. Proportioning concrete by the methods used in ACI 211.1 will help to ensure that the concrete used in parking lot paving will provide the required strength, long-term durability, economy, and workability envisioned by the owner, designer, and contractor. ACI 301 may also provide useful guidance. ACI 304R contains guidance on batching, mixing, and placing.

The proportions for the concrete can be established on the basis of previous field experience or laboratory trial batches. For most small parking lot projects, the effort and expense required to establish proportions by laboratory trials may not be justified if commercial concrete with the requisite performance history is available. Commercial mixtures proportioned and approved for use in state, city, or county paving will usually be adequate for parking lots. Concrete producers normally have standard mixtures with performance records that are appropriate for parking lot projects.

4.2—Strength

Flexural strength is a critical property of concrete used for paving. Concrete strength is a function of the cementitious material content and the water-cementitious material ratio (*w/cm*) selected for the mixture. Angular-shaped coarse aggregates have been shown to increase flexural strength compared with rounded aggregates. Water-reducing admixtures can also be used to increase strength by reducing the amount of water needed to achieve a desired slump. Mixtures designed for high early strength can be provided if the pavement is to be used by construction equipment or opened to traffic very soon after construction (refer to Section 5.9).

4.3—Durability

Freezing-and-thawing climates present very hostile environments for concrete pavements in parking lots. Traffic loads, freezing-and-thawing cycles, deicing salts, and sometimes soil sulfates or potential alkali-silica reactivity can cause pavement deterioration unless the concrete mixture is carefully proportioned to maximize durability. For heavy traffic loads or when durability is critical, a compressive strength of at least 4000 psi (28 MPa) should be specified. The use of reinforcing steel in areas where deicing salts or air-born salts are present may necessitate a higher compressive strength for the concrete to reduce permeability and increase durability. Concrete used in parking lots should be designed to meet the durability requirements for their particular exposure conditions as specified in ACI 318-08, Chapter 4.

Concrete subjected to freezing and thawing should be air entrained. Table 4.1 provides recommended air contents based on three exposure classifications. Mild exposure is a climate where the concrete will not be exposed to freezing or deicing salts. Moderate exposure is a climate where freezing is expected, but where the concrete will not be continually exposed to moisture or free water for long periods before freezing, and will not be exposed to deicing agents. Severe climates expose the concrete to deicing chemicals or possible saturation by continual contact with moisture or free water before freezing. Excessive soluble sulfates in the soil may lead to chemical reactions between the hydrated cement and the sulfate ions. These reactions can lead to deterioration of the concrete, causing a progressive loss of strength and loss of mass. When sulfates in the soil exceed the limits given in ACI 201.2R, Type II or V cement or equivalent should be specified and used. The use of pozzolans or blended cements may be economical mitigation methods. Aggregates selected for paving should be durable for freezing-and-thawing exposures, and should not contain porous cherts in excess of applicable specification limits. Coarse aggregates meeting ASTM C33 or local highway department specifications for concrete paving normally provide acceptable in-service performance (refer to ACI 221R for additional guidance). Potential alkali-silica reactivity (ASR) has become an important durability consideration for aggregates. Aggregates that test positive for potential ASR should only be used with mitigation procedures. These include the use of low-alkali cements, pozzolans, slag cement, and blended cements that have proven effectiveness in ASR test programs. The best evidence of an aggregate's potential ASR properties is its service record for 10 or more years (ACI 221R).

Table 4.1—Recommended air contents

Nominal maximum size aggregate, in. (mm)	Typical air contents of non-air-entrained concrete, %	Recommended average air content for air-entrained concretes, %		
		Mild exposure	Moderate exposure	Severe exposure
3/8 (10)	3.0	4.5	6.0	7.5
1/2 (13)	2.5	4.0	5.5	7.0
3/4 (19)	2.0	3.5	5.0	6.0
1 (25)	1.5	3.0	4.5	6.0
1-1/2 (38)	1.0	2.5	4.5	5.5

Note: Tolerances: ±1.5%. There is conflicting opinion on whether air contents lower than those given in the table should be permitted for high-strength (over 5500 psi [38 MPa]) concrete. This committee believes that where supporting experience or experimental data exist for particular combinations of material, construction practices, and exposure, the air contents can be reduced by approximately 1%.

Poor construction practices such as indiscriminate addition of water, late sawcuts of joints, and lack of curing will reduce the durability of concrete, and should be avoided. Additional information on curing is available in Section 5.6.

4.4—Economy

Economy is an important consideration in selecting the concrete to be used for paving. Well-graded aggregates, minimum cement contents consistent with strength and durability requirements, and admixtures are all factors that should be considered in proportioning economical concrete. Commonly available commercial mixtures proportioned with locally available materials are usually more economical than custom-designed mixtures. Concrete costs can be reduced by the incorporation of supplementary cementitious materials. If the concrete will be exposed to deicing salts in service, however, replacement factors should be limited as specified in ACI 318-08, Table 4.4.2.

4.5—Workability

Workability is an important consideration in selecting concrete for a parking lot paving project. Slump for slipform paving is usually 1-1/2 in. (38 mm) or less. Concrete to be placed by hand or with vibrating screeds will require a higher slump, generally 4 in. (100 mm) or less. Water content, aggregate gradation, admixtures, and air content are all factors that affect workability. The maximum aggregate size should be no greater than 1/3 the thickness of the slab.

4.6—Material specifications

ACI 330.1 contains a complete reference specification for unreinforced concrete parking lots that can be incorporated in project specifications, with material specifications included in Section 2. Additional guidance for specifying concrete can be found in ASTM C94/C94M. This comprehensive standard specification covers concrete manufacturing and delivery procedures and quality-control procedures. In the absence of specific specification requirements, the purchaser of concrete for paving projects should provide the producer with the size or sizes of coarse aggregate, slump desired at the point of delivery, and air content. In addition, one of the following should be given: strength requirements at 28 days or other specified age, strength requirements and the minimum acceptable cement content, or prescription for the mixture.

ASTM C33 defines the requirement for grading and the quality of fine and coarse aggregate used in concrete. In some areas, highway standard specifications for aggregates may vary slightly from ASTM C33, but may be used because they are likely to conform more closely to local supplies, and should produce acceptable paving concrete.

Requirements for air-entraining admixtures used in concrete are specified in ASTM C260. Water-reducing, retarding, and accelerating admixtures are usually specified by ASTM C494/C494M. Requirements for fly ash used in concrete are in ASTM C618, and ASTM C989 specifies requirements for slag cement used in concrete. ASTM C150, C595, and C1157 are specifications for portland and other hydraulic cements. Each of these cementitious material specifications includes several types of cements and various mineral admixtures designed for specific uses and conditions, and should be carefully selected to meet the needs of a particular project. The availability of a cement type in a particular geographical location should be verified.

Liquid membrane-curing compounds offer the most simplistic method of curing concrete pavements. ASTM C309 and C1315 are the standard specifications for these materials.

Specification requirements for steel products used for paving projects can be found in: ASTM A185/A185M, A497/A497M, A615/A615M, A706/A706M, and A820/A820M.

Specification requirements for expansion joint material are found in ASTM D994, D1751, or D1752. Those for joint-sealing materials are found in ASTM D3406 for hot-poured elastomeric type sealants, or Federal Specification TT-S-001543a and TT-S-00230c.

CHAPTER 5—CONSTRUCTION

5.1—Introduction

Construction of parking lots should be accomplished in compliance with adequate plans and specifications to provide a pavement that will meet the owner's needs. Because the contractor is responsible for providing quality workmanship, ACI-certified finishers and compliance with ACI 121R are recommended. This is especially important on small projects that are likely to be constructed with little or no inspection. Construction starts with thorough planning, such as coordinating with other contractors on the site, determining the optimum size equipment for the project, arranging for a realistic delivery rate of concrete, determining the construction sequence, and arranging delivery routes for concrete trucks. A good way to accomplish this is to conduct a preconstruction conference attended by the architect/engineer, general contractor, excavator, utility subcontractor, paving subcontractor, concrete supplier, and testing agency. A recommended agenda for a preconstruction conference is presented by the National Ready Mixed Concrete Association (1999).

5.2—Subgrade preparation

A well-prepared, uniform subgrade at the correct elevation is essential to the construction of a quality pavement. Uniformity provides consistent support, and the proper elevation determines that the pavement will be the required thickness. The subgrade should support not only the pavement but also the paving equipment and construction traffic as well.

Earthwork operations should be coordinated with the installation of utilities to avoid conflict. The subgrade should be excavated or filled with suitable material to produce the required subgrade elevations. All uncompactable and otherwise unsuitable materials should be blended with other soils if possible, or removed and replaced with suitable material. Various techniques using cementitious materials can also be used to improve or remediate existing subgrade material (refer to Section 3.4 and Appendix B). Good practice dictates that filled sections be compacted in layers to the specified density and should extend at least 12 in. (300 mm) beyond the formlines. The subgrade should not be uncompacted, disturbed, muddy, or frozen when paving starts. The subgrade should be prepared far enough ahead of the paving operation to permit uninterrupted paving. The subgrade should have a dense, firm, and uniformly smooth surface when concrete is placed on it.

Sand cushions should not be used as a construction expedient instead of proper subgrade preparation. Granular aggregate subbases are not normally used for concrete parking lots. If a subbase is specified for some special reason, it should be placed on the prepared subgrade, compacted, and trimmed to the elevation called for in project plans.

All utility trenches and other excavations in the area to be paved should be backfilled to finish grade and compacted to meet project specifications in advance of the normal subgrade preparations. Backfill materials should be compacted with mechanical tampers in approximately 6 in. (150 mm) lifts. Controlled low-strength material—a mixture of granular and cementitious materials and water—is recommended for use instead of compacted backfill (refer to ACI 229R). If subsidence of compacted trench backfill is evident before the paving covers it, it should be excavated and recompacted before paving.

The final fine grading should be checked with a template or other positive means to ensure that the surface is at the specified elevations. Suggested tolerances for fine grading are no more than 1/4 in. (6 mm) above or 1/2 in. (13 mm) below the design grade. Deviations greater than these tolerances can jeopardize pavement performance because small variations in thickness of thin pavements affect load-carrying capacity. Such variations in thickness are indicative of poor control of grading or concrete placement.

5.3—Layout for construction

A layout to permit efficient use of paving equipment, to provide easy access for concrete delivery trucks, and to ensure good drainage of the site can expedite construction operations.

The contractor and engineer should agree on joint layout and construction methods before paving begins. A drawing showing the location of all joints and the paving sequence is helpful in establishing the agreement. Locations of drainage fixtures, lighting supports, and other fixed objects should be established with the joint pattern and construction methods in mind. Paving should be done in lanes. Paving-lane widths should be done in multiples of the joint spacings. The width will depend on the equipment and method selected by the contractor. Checkerboard placing is not recommended and should be avoided because it requires more time and forming materials, and usually results in less consistent surface tolerances and poorer joint load transfer.

5.4—Paving equipment

5.4.1 *Forms*—If forms are used, they should be straight, of adequate cross section and strength, and held in place securely to resist the pressure of concrete and support the paving equipment without springing or settling. Forms can be made of wood, steel, or other accepted materials. Stay-in-place forms are not recommended for outdoor parking lots.

5.4.2 *Setting forms*—The subgrade under the forms should be compacted, cut to grade, and tamped to furnish uniform support to the forms. Enough form pins or stakes should be used to resist lateral movement. All forms should be cleaned and oiled as necessary to obtain neat edges on the slab. Lines and grades of forms should be checked immediately before concrete placement and preferably after form-riding equipment has been moved along the forms.

5.4.3 *Strike-off and consolidation*—Concrete can be struck off and consolidated using a straightedge and a hand-held vibrator, or by use of a vibrating screed, mechanical paving machine, or laser screed. Vibrating screeds should be heavy enough that they do not ride up over stiff mixtures and rigid enough that they do not sag between the forms. They should also be adjustable to produce any specified crown.

5.4.4 *Slipform paving*—Instead of using fixed forms, the contractor can use a slipform paver designed to spread, consolidate, and finish the concrete in a single pass. The slipform paver should be operated with as nearly a continuously forward movement as possible. All delivery and spreading of concrete should be coordinated so as to provide uniform progress without stopping and starting the machine. Coordination with the concrete supplier is especially important. When the slipform paver is to ride on the edge of a new concrete pavement, the concrete strengths should be greater than 2000 psi (14 MPa). String lines or other means for setting grade should be checked frequently.

5.5—Placing, finishing, and texturing

5.5.1 *Placing and consolidation*—The subgrade (or subbase, if used) should normally be dry when concrete is placed. Only if concrete is placed in very dry conditions should the subgrade be lightly dampened with water. There should be no free water standing on the subgrade, nor should there be any muddy or soft spots when the concrete is placed. When dowels in baskets are called for, the baskets should be carefully located at joint locations and secured to the subgrade so as to prevent possible movement during concrete placement operations. The concrete should be deposited as uniformly as possible ahead of the paving equipment, and as close to its final position as possible, so as to require minimum rehandling. The concrete should be consolidated along the faces of the forms and struck off to the required elevation and cross section. If slipform equipment is used, the concrete should be of the consistency necessary to prevent noticeable edge slump.

5.5.2 *Finishing*—Immediately following the strike-off, the surface should be leveled with a bullfloat or a scraping straightedge. The surface should be finished no more than necessary to remove irregularities. All edges, tooled joints, and isolation joints should be rounded to the specified radius with appropriate tools. The use of hand or power floats and trowels is not necessary and is not recommended, as this can result in scaling.

5.5.3 *Texturing*—As soon as the finished concrete has set sufficiently to maintain a texture and no bleed water remains on the surface, the surface can be dragged with a short length of damp burlap or other material such as synthetic turf carpeting. Drags are sometimes attached to paving machines or screeds. As an alternative, the surface can be broomed to develop a skid-resistant surface and uniform appearance.

5.6—Curing and protection

5.6.1 *Curing*—Use of white-pigmented membrane-forming curing compounds meeting ASTM C309 or C1315 (Type II) requirements should follow the normal curing procedure as recommended by the manufacturer. After finishing and texturing operations have been completed and immediately after free water has evaporated, the surface of the slab and any exposed edges should be uniformly coated with a high-solids curing compound. The application rate should be at least that recommended by the manufacturer. A second application at 90 degrees offset is recommended on windy days or whenever a single application results in coverage that is not uniform. Other acceptable curing materials and methods can be used. These methods are described in more detail in ACI 308R-01, Section 2.4.2.3.

5.6.2 *Cold-weather protection*—Cold-weather curing should provide protection from freezing while retaining moisture for the time necessary to achieve the desired physical properties in the concrete. Curing blankets or polyethylene sheets sandwiching hay or straw serve both purposes. For additional information, refer to ACI 306R.

Plastic shrinkage cracking during or immediately after finishing can occur in cold weather as well as hot weather, especially when air temperature is lower than concrete temperature. Low humidity and wind further contribute to this possibility. When such conditions are present, extra measures should be taken to minimize evaporation from concrete surfaces, finishing should be completed as soon as possible, and curing should begin immediately.

If the pavement is built in the fall in an area where deicer salts are routinely used and will be put into service before it dries for 30 days (above 40° F [4° C]) after curing, a linseed oil or other surface treatment is recommended. The materials used should allow water vapor to escape. *NCHRP Report* No. 244 (Transportation Research Board 1981) presents a thorough appraisal of the effectiveness of many sealers used to prevent the intrusion of deicing salts into concrete. Additional information on materials to protect vulnerable concrete from freezing-and-thawing damage is found in Section 7.2.

5.6.3 *Hot-weather precautions*—In hot weather, transporting, placing, and finishing of concrete should be done as quickly as practical. It is important to schedule concrete deliveries that will help ensure no placement delays.

Plastic shrinkage cracking sometimes occurs during or soon after finishing operations under the influences of differential temperatures (concrete temperature higher than air temperature), low relative humidity, high wind velocity, or a combination of these. When concrete is placed during such conditions, extra precautions should be taken to reduce the time between placing and finishing and to protect the concrete to minimize evaporation. Refer to ACI 305R for additional information on preventing problems during hot weather.

5.6.4 *Protection against rain*—When rain is imminent during paving operations, paving should be stopped, and all steps necessary to protect the hardening concrete should be taken. The contractor should have enough plastic sheeting available on the project site to completely cover any surfaces that may be damaged in the event of rain. There should also be adequate weights available to keep the plastic sheeting from blowing away. If the pavement is being constructed along a slope, the fresh concrete should be protected from water above washing across the surface.

5.6.5 *Minimizing warping*—The most damaging warping or curling tendencies are usually those that result from the drying out of the concrete surface while the bottom surface remains wet. The flexural strength of the concrete near the panel center may be exceeded due to the unsupported dead load of the panel edges, vehicle loads near the edges, or both, and midpanel cracking occurs. There are a number of precautions that can be taken to reduce or minimize this type of warping:

1. Using a concrete mixture with low-shrinkage characteristics, that is, a concrete mixture with large maximum-size coarse aggregate at the highest quantity consistent with the required workability. Such mixtures minimize water content by minimizing paste content;
2. Control of slump. Water in excess of that required to restore design slump should not be added to the concrete on the job site. The higher the water content of a concrete mixture, the more shrinkage it will experience after placement. Water-reducing admixtures may be used to lower water content. Slump should be adjusted only up to the design slump of the mixture (refer to ASTM C94/C94M for allowable tolerances in slump);
3. Avoiding delays in placement that tend to increase the demand for retempering water;
4. Placing concrete on a dry (or almost dry) subbase or subgrade; and
5. Providing effective curing, particularly during early ages, in accordance with ACI 308.1. Timely use of continuous moist curing or a high-solids curing compound can greatly reduce the rate of water loss from the concrete and help reduce moisture differentials during the most critical period of concrete strength gain.

5.7—Jointing

5.7.1 *Contraction joints*—Contraction joints can be formed to the dimensions in Section 3.7.1 by sawing, tooling, or using inserts. If inserts are used, they should be installed vertically, flush with the surface, and continuous between edges. Sawing transverse joints should begin as soon as the concrete has hardened sufficiently to avoid raveling of the coarse aggregate. Two types of saws can be used to form contraction joints: early-entry dry-cut saws, and conventional (either wet- or dry-cut) saws. The early-entry dry-cut process is normally used when early sawing is desired. The timing of the early-entry process allows joints to be in place before development of tensile stresses that are great enough to initiate cracking, thus increasing the probability of cracks forming at the joint.

The depths of joints, using a conventional saw, should be at least 1/4 of the slab thickness. When early sawing is desired, an early-entry dry-cut saw should be used, and the depth of the sawcut should be at least 1 in. (25 mm) for slabs that are less than 9 in. (230 mm) thick. Typically, joints produced using conventional processes are made within 4 to 12 hours after the slab has been finished in an area—4 hours in hot weather to 12 hours in cold weather. For early-entry dry-cut saws, the time of cut is immediately after initial set of the concrete in that joint location, which will typically vary from 1 hour after finishing in hot weather, to 4 hours after finishing in cold weather. Timing of the sawing operations will vary with the manufacturer and equipment. The goal of sawcutting is to create a weakened plane as soon as the joint can be cut without creating raveling at the joint. The sawing of any joint should be discontinued or omitted if a crack occurs at or near the joint location before or during sawing, and future joint sawing on the project should be accomplished earlier in time, relative to finishing. If extreme conditions make it impractical to prevent erratic cracking by early sawing, the contraction joints should be formed by other methods. For additional jointing guidance, refer to "Concrete Intersections—A Guide for Design and Construction" (American Concrete Pavement Association 2007).

If joint sealing is required (Section 3.9), the joints should be thoroughly cleaned and the sealing materials installed without overfilling, in accordance with the manufacturer's instructions, before the pavement is opened to traffic.

5.7.2 *Isolation joints*—Isolation joints should be used to separate drainage structures, existing islands, light standards, building foundations, and existing approach pavements from the parking lot pavement. Joint material should be continuous from form to form, extend from top of slab to the subgrade, and be shaped to the curb section.

5.8—Pavement markings

When stall striping and other pavement markings are applied to concrete, it is important to have a clean surface that is free of dirt, loose materials, laitance, grease, and oil. The marking materials should be applied in accordance with the manufacturer's recommendations and be compatible with the curing compound used.

5.9—Opening to traffic

Automobile traffic should not be allowed on the slab for at least 3 days, and all other traffic should be kept off the slab for at least 7 days. This, however, assumes normal summer temperatures above 60° F (15 °C). In colder weather, more time will be required. Preferably, tests of field-cured cylinders should be made to determine that the concrete has gained adequate strength (usually 3000 psi [21 MPa]) to resist damage from construction equipment or traffic.

CHAPTER 6—INSPECTION AND TESTING

6.1—Introduction

The scope of the inspection and testing program for any given project is most often stipulated in the project specifications. An adequate quality-assurance program should be developed regardless of project size. The inspection and testing program should be designed so that it ensures compliance with the contract requirements, but does not add unnecessary costs or delays during the construction process. ACI Certified Inspectors and Field Testing Technicians should be used. Refer to ACI 311.4R and 311.5 for guidance on development of the inspection and testing program.

While the contractor is the one who bears the full responsibility for compliance with all contract requirements, the owner may hire testing and inspection services to monitor contract compliance. The agency providing these services should be accredited and in full compliance with ASTM C1077 and E329. These services may vary from occasional visits to full-time inspection. ACI SP-2 (ACI Committee 311 1999) is a good reference for both the contractor and inspector.

6.2—Subgrade preparation

Inspection of the subgrade and subbase is an important part of any concrete parking lot construction project. The subgrade is the foundation upon which the concrete is supported. Poor preparation of the subgrade can result in detrimental effects on performance. Pavement thickness is based on subgrade support capacity when it has been compacted as specified. The soils at the parking lot site and the intended borrow areas should be observed and, if necessary, sampled and tested to confirm the soil types and identify any problem conditions that may require special treatment, such as stabilization or removal. If the soils to be used are different from those that were expected based on the design investigation, they should be tested to determine their supporting capacities and necessary compaction requirements. At the start of construction, the moisture content and the moisture-density relationships for the soils to be used in the subgrade and subbase should be checked to aid in determining the amount of water that needs to be added to the soil or the amount of drying necessary to achieve the required compaction. In-place density tests should be performed to confirm that the contractor is obtaining the required compaction in accordance with ASTM D698 or D1557. A full-scale testing program may require at least one test per 2000 yd^2 (1670 m^2) of area per 6 in. (150 mm) lift, with a minimum of three tests per lift in accordance with ASTM D6938 (nuclear method), D1556 (sand-cone method), D2167 (rubber balloon method), or D2937 (drive-cylinder method).

Subgrade (or subbase) elevations should be checked throughout the grading operations to verify that the grades are correct. The final elevation should allow forms and stringlines to be set within the specified tolerances.

6.3—Concrete quality

Ensuring that the concrete meets the specified quality can be accomplished if all parties have an understanding with the concrete supplier and the contractor as to everyone's concerns before the paving operations begin. An inspector should visit the concrete production facility and look at the batching equipment and the delivery trucks to verify that they meet the requirements for the project. Current certification of plant and equipment in accordance with a recognized program, such as that of the National Ready Mixed Concrete Association, can preclude such a visit. The sources and types of aggregates, cement, and admixtures should be identified. The production facility should have the capability to check aggregate gradations daily as well as the capability to periodically check the moisture contents of the aggregates and adjust the batch proportions as necessary. The information required on the delivery tickets by ASTM C94/C94M and the distribution of these tickets should be confirmed. The location and sequence of testing concrete should also be coordinated at this time. The anticipated delivery rates should be discussed. The contractor should give the inspector and the concrete supplier adequate notice that paving is going to take place to allow them to do their jobs.

Checking the properties of the fresh concrete is especially important in the early stages of the project, particularly on a small project that will probably be complete before any of the acceptance strength test results are received. The slump, air content, density, and temperature of the fresh concrete should be checked at least once for every 5000 ft^2 (460 m^2)

of pavement, and at least once a day. Strength specimens should be molded for testing at least at the same frequency.

While the design of pavements is generally based on the flexural strength of the concrete, it is more practical to use some other type of test in the field for acceptance testing. Compressive strength (ASTM C39/C39M) or splitting-tensile strength (ASTM C496/C496M) can be correlated with the flexural strength. The correlations required for a project can be determined in the laboratory at the time the concrete mixture is evaluated. The test specimens for acceptance strength testing should be stored and cured in accordance with ASTM C31/C31M before testing, particularly during the first 24 hours. All test results should be recorded and reported to the contractor and supplier as soon as possible so that any problems can be corrected in a timely manner. While most concrete is accepted based on the strength at 28 days, determined with standard-cured cylinders, it may be necessary to test field-cured specimens at earlier ages to determine when the pavement has adequate strength to allow traffic on it. It is essential that the contractor does not allow traffic on the pavement until it has adequate strength and curing. This determination should be made by the engineer or owner's representative. The required curing time can be estimated based on prevailing temperatures and experience, but a more accurate determination can be made using field-cured cylinders (refer to Section 5.9).

The performance of all sampling, testing, and inspection should be in accordance with standardized procedures that are spelled out in the project specifications. The specifier should require that all sampling and testing be performed by personnel who have met the requirements of the appropriate ACI or equivalent certification program and have proof of certification.

6.4—Construction operations

It is important to check stripping of topsoil and vegetation in both the borrow areas and in the parking lot areas to confirm that significant amounts of organic materials are not incorporated in the subgrade. Proof rolling all areas to receive fill, as well as those areas that have been cut, should be conducted to confirm that adequate subgrade support is available for filling operations and in cut areas. The proof rolling should be accomplished with a minimum 7-1/2 ton (6800 kg) roller or loaded dump truck with equal weight, and any areas that are observed to deflect greater than 1/2 in. (13 mm) should be stabilized or removed and replaced with well-compacted materials. If rutting or pumping is evident during the preparation of the subgrade, corrective action should be taken. Rutting normally occurs when the surface of the subgrade or subbase is wet and the underlying soils are firm. Pumping normally occurs when the surface is dry and the underlying soils are wet.

The spreading of the fill materials should be checked to confirm that the lifts are thin enough to be compacted as required by the project specifications. The final elevations of the subgrade should be carefully checked to verify that the grades are according to plans and that there are no deviations that will result in any concrete thickness deficiency greater than 1/4 in. (6 mm). No grading work should be done when the subgrade is wet or frozen.

If a granular aggregate subbase is specified, it should be of proper gradation to allow the material to be spread with minimal segregation and to allow compaction to the grades specified. The in-place moisture content and density of the granular subbase course should be determined in a manner and frequency similar to that specified for the subgrade if the material lends itself to density testing. If the granular subbase is a well-draining and open-graded material, then conventional density testing is not applicable. A heavy vibrating roller should be used to ensure that such materials have been adequately densified.

Before placing concrete, forms should be checked to see that they are at the called-for elevation and that they have the proper alignment. If forms are not used in small or irregularly shaped areas, a series of construction stakes driven in the subgrade can be used to provide the contractor with the necessary elevation references. The construction stakes should be driven into the subgrade to the top of the slab elevations at various locations. Control is critical because insufficient thickness due to poor grade control can be the source of pavement failures.

The concrete arriving at the job site should be tested as outlined in Section 6.3. Adjustments to the mixture should not be made unless approved by the engineer or owner's representative.

It is also important to check that the curing compound is placed or curing actions are taken as soon as the concrete has attained final setting. The curing procedures should cover all of the concrete placed. If joints are tooled or formed with premolded inserts, alignment should be verified. If sawing is to be used, the concrete should be checked periodically to see when joints can be cut. Finally, it is essential that the contractor does not allow traffic on the pavement until it has achieved adequate strength and curing (refer to Sections 5.9 and 6.3).

Even with the best construction techniques, there may be occasional uncontrolled shrinkage cracks. As long as load transfer can be maintained across such cracks, these panels should be acceptable. As long as the pavement is still structurally sound, it will not be worthwhile to resort to slab removal to improve the aesthetics of the parking lot. Workmanship defects, such as over-finishing, can be very important if durability is affected, but not if the only result is some variation in surface texture.

CHAPTER 7—MAINTENANCE AND REPAIR

7.1—Introduction

Concrete parking lot pavements generally perform for many years with minimal maintenance and few repair costs. There are exceptions, however, and well-intended designs and construction efforts may result in occasional defects and distress. This chapter provides guidance on acceptable maintenance procedures and repair techniques for concrete parking lot pavements.

7.2—Surface sealing

Deicing chemicals and moisture intrusion can contribute to deterioration of concrete parking lot pavements in freezing-and-thawing environments. Specified air entrainment and adequate curing are essential before the surface is exposed to deicing chemicals and freezing-and-thawing cycles. If these steps are neglected, durability may be affected.

If concrete starts to show signs of poor durability, protection is necessary because surface spalling from freezing-and-thawing action and steel corrosion from salt intrusion can result. Research studies and field trials indicate that there are several protective coatings available that protect against salt attack on concrete pavements. It is imperative to use a sealer that allows water vapor to escape from the pavement. Perhaps the most economical protective coating with the longest history of use is a mixture of 50% boiled linseed oil and 50% mineral spirits. Rates of application for this mixture should be the same as given in Section 5.6.2. Some studies have shown that the boiled linseed oil/mineral-spirits mixture is not effective in protecting concrete for long periods of time (Transportation Research Board 1981). There is also a darkening of the concrete caused by the linseed oil mixture.

Other materials are suitable for protecting concrete, including acrylics, epoxies, urethanes, methylmethacrylates, and siloxane/silane water repellents. The siloxane/silane repellents have the advantage of allowing the substrate to dry out normally, therefore preventing damage from a buildup of moisture below the film-forming material. They have also been proven effective in restricting chloride ion penetration, protecting the concrete from deicing chemicals in northern states and airborne salt in marine and coastal areas.

In the case of proprietary products, the manufacturer should provide independent testing laboratory documentation to establish conformance with ASTM C672/C672M and E303, AASHTO T 259 and T 260, and *NCHRP Report* No. 244 (II & IV) (Transportation Research Board 1981).

Before specifying one of these products, its performance under similar conditions of use should be determined. Application should always be in accordance with the manufacturer's instructions.

Before applying any sealer, the concrete should be cleaned by pressure-washing or other means recommended by the product manufacturer and allowed to dry for at least 24 hours at temperatures above 60 °F (15 °C) and humidities below 60%. Some old, especially dirty, concrete may require a more aggressive preparation of the surface.

7.3—Joint and crack sealing

Joints in concrete parking lots are frequently sealed, but in many successfully performing parking lots, the joints are not sealed. Closer joint spacing and adequate drainage will minimize the infiltration of water through joints into the subgrade. Light traffic (automobile traffic with only an occasional truck) will not cause pumping of unsealed joints under most conditions. Pumping is not usually an issue with automobile traffic.

In the event that poor subsoil conditions and frequent heavy truck traffic warrant extra precautions, either cold-poured or hot-poured sealing materials can be used to seal the joints. Preformed materials, common in highway pavements, are seldom used in parking lots.

ACI 504R provides guidance in selecting joint sealants. Before sealing, the joint opening should be cleaned with compressed air to remove all foreign matter. All contact faces of the joint should be cleaned to remove loose material, and should be surface dry when hot-poured sealing materials are used. Sealing materials should be carefully installed so that sealants will not be spilled on exposed concrete. Any excess material on the surface of the concrete should be removed immediately, and the pavement surface cleaned. Manufacturers' instructions for mixing and installing the joint materials should be followed explicitly. The top of the sealing compound is normally 1/8 to 1/4 in. (3 to 6 mm) below the adjacent concrete surface.

Cracks can be routed (widened and deepened using special bits) and sealed. This will reduce concrete spalling at the crack faces and reduce water penetration. Section 3.3 of ACI 224.1R offers detailed guidance on routing and sealing cracks. It is often more cost effective to remove and replace badly cracked panels than to attempt crack repair.

7.4—Full-depth repair

The most effective repair method for badly cracked and deteriorated pavement panels is full or partial replacement. It is important to determine and correct the cause of the slab failure before starting repairs. Localized subgrade problems should be corrected. If the pavement panels failed because of heavier-than-anticipated loads, replacement panels should be thickened to provide additional load-carrying capacity.

7.4.1 *Repair location and joint types*—The engineer should determine the boundaries and joint type for each repair. For parking lots carrying light traffic, a rough-faced joint (created by jackhammered concrete removal below a shallow sawcut around the repair area) that relies on aggregate interlock for load transfer is adequate. Repairs in parking lots carrying heavy truck or bus traffic should be doweled to the existing pavement. Repair boundaries should be selected so that all of the underlying deterioration is removed. Minimum length for undoweled repairs is 6 ft (2 m). The repair should not be less than half the panel width.

7.4.2 *Preparation of the repair area*—Preparation requires sawing boundaries if they do not follow existing joint patterns. Partial-depth cuts, approximately 1/4 to 1/3 of the pavement thickness, are recommended, followed by removal of the remaining concrete extending vertically below the partial-depth cut by chipping with a light jackhammer of 15 lb (7 kg) or less (American Concrete Paving Association 1995a). This procedure for completing the boundary cut is less expensive than full-depth cutting, and provides some aggregate interlock due to a rough face. Concrete inside the repair boundary to be removed should be broken up with a pavement breaker or jackhammer. Wrecking balls should not be used because shock waves will damage adjacent concrete. Breakup should begin at the center of the repair area, not at sawcuts. Broken concrete can be removed with a backhoe.

After the concrete has been removed, the subgrade should be examined to determine its condition. All material that has been disturbed or that is loose should be removed and replaced with similar or improved materials. If standing water exists in the repair area, it should be removed and the subgrade dried before new concrete is placed.

It is difficult to obtain adequate compaction of new subgrade or subbase materials in a confined repair area. Replacement of the deteriorated subgrade with concrete or controlled low-strength material (ACI 229R) can be the best alternative.

7.4.3 *Dowels*—If dowels are required, they can be installed by drilling holes into the exposed face of the existing slab. A quick-setting, nonshrinking mortar or a high-viscosity epoxy should be used to grout the dowels into the existing slabs.

If panel joints include dowels or ties from the original slab, they should be straightened or realigned as necessary for correct positioning. For additional information on procedures for installing dowels in a joint between an existing slab and new concrete, refer to American Concrete Pavement Association (1995a).

7.4.4 *Concrete placement*—The concrete placement and finishing techniques should follow acceptable procedures found in previous sections of this document. Extra attention should be given to ensure that the repair is well vibrated around the edges and that it is not overfinished. If the repair will be opened to traffic early, consideration should be given to the use of specially designed, high-early-strength concrete mixtures. Repairs should be properly cured to ensure satisfactory performance.

7.5—Undersealing and leveling

Loss of support beneath concrete pavement slabs is a major factor in accelerating deterioration. Loading is also a factor in this type of deterioration. Generally, pavements carrying less than 100 heavy trucks per day are not subject to pumping and loss of subgrade support. This type of failure may, however, occur in truck and bus parking lots constructed on poor subgrade. Techniques for injecting grout mixtures under the slab to restore subgrade support and leveling depressed slabs (Federal Highway Administration 1984) may be used as a maintenance procedure for parking lots. The cost of undersealing and leveling should be compared with the cost of full-depth repairing.

7.5.1 *Undersealing*—A variety of grout mixtures, including cement/loam topsoil slurry, cement/limestone dust slurry, cement/pozzolan slurry, and cement/fine-sand slurry have been used. Success of cement grout undersealing depends on the experience of the contractor. Undersealing of parking lot pavement should be performed on a localized basis. Jointed concrete pavements typically pump at joints and transverse cracks that have visibly opened. Holes are drilled through the slab approximately 2 ft (0.6 m) away from the joint or crack. The grout mixture is carefully pumped under the slab to fill voids. Care should be taken not to raise the slab above grade. Traffic should be kept off the slab long enough to allow for adequate curing.

7.5.2 *Leveling*—Leveling, or slab-jacking, consists of pumping cement grout under pressure beneath the slab to raise the slab slowly until it reaches the desired elevation. Settlement can occur anywhere along the pavement, but is usually associated with fill areas.

Experience is important in determining the best location for grout holes. A general guideline is that the holes should be placed in about the same location as hydraulic jacks would be placed if it were possible to get them under the pavement. Holes should be placed not less than 12 in. (300 mm) or more than 18 in. (450 mm) from slab edges or transverse joints. The distance between holes should not be more than 6 ft (2 m). A taut stringline secured at least 10 ft (3.0 m) from the end of the depression should be used to monitor the raising of the slab as the grout is injected. To minimize cracking, no portion of the slab should be raised more than 1/4 in. (6 mm) at a time. Once the slab has been raised to proper position, traffic should be kept off until the grout has set.

7.6—Overlays

Both concrete and asphalt parking lot pavement can be rehabilitated with concrete overlays. To ensure satisfactory performance of the overlay, factors that caused the deterioration and failure of the original pavement should be determined and either corrected or recognized in the design of the concrete overlay. Parking lot pavement failures can usually be attributed to one or more of the following factors: drainage problems, traffic overload, subgrade conditions, inadequate pavement section, poor construction, inappropriate concrete mixtures, or substandard materials. ACI 325.13R provides more complete guidance on the selection of overlay types and designs, based on the existing pavement's characteristics and condition.

7.6.1 *Concrete overlay on existing concrete parking lot pavement*—Portland-cement concrete overlays on existing parking lots will normally be jointed, although continuously reinforced overlays might be considered for lots carrying large volumes of heavy vehicles. Jointed overlays can be unbonded, partially bonded, or fully bonded. Joints in overlays should always match joints in bonded and partially bonded overlays. Cracks in existing pavements will tend to reflect through fully or partially bonded concrete overlays.

7.6.1.1 *Unbonded overlays*—Unbonded overlays are achieved only if steps are taken to prevent bonding of the overlay to the existing slab. A separation layer of asphalt concrete has been used for this purpose. There is evidence, however, that layers of asphalt of less than 1 in. (25 mm) do not provide an adequate bondbreaker for completely independent action of the slabs. Unbonded overlays are the only overlay type that should be considered for existing concrete pavements that are badly broken.

7.6.1.2 *Partially bonded overlays*—Partially bonded overlays result whenever fresh concrete is placed directly on existing slabs with little or no surface preparation. Unless steps are taken to prevent bond, it is usually assumed some degree of bond will be achieved between the overlay and the existing pavement, so the overlay is assumed to be a partially bonded overlay, and some reflective cracking is to be expected. Thus, this option should be used only when the existing pavement is relatively sound with no major distresses.

7.6.1.3 *Fully bonded concrete overlay*—To achieve a fully bonded overlay, it is necessary to carefully prepare the surface of the existing pavement before placing the overlay. This preparation should include removing all oil, grease, surface contaminants, paint, and unsound concrete. Refer to ACI 546R for information on equipment and techniques for concrete removal and surface preparation.

Field and laboratory tests should be conducted to ensure that the bonding techniques used will provide a good bond. Bonded overlays should not be placed during times of high temperature changes (such as early spring and late fall), or they can experience early debonding problems.

Fully bonded overlays should be used only when the existing pavement is in good condition or where serious distress has been repaired. Joints in the overlay should be sawed directly above the joints in the existing slab as soon as possible. The joint should be cut completely through the overlay to avoid secondary cracking (ACI 325.13R).

7.6.2 *Concrete overlay on asphalt pavement*—The thickness required for a concrete overlay on an existing asphalt pavement is a function of the type and volume of traffic, strength of the subgrade below the new overlay, and the properties of the concrete used.

Areas of the parking lot that exhibit deterioration and failure should be considered for special treatment before they are resurfaced. Special treatments could involve subgrade strengthening, improved drainage, or replacement of the asphalt in the affected area. Jointing and other aspects of design are similar to those for parking area pavements on traditional subgrades. For guidance on design of concrete pavement overlays on asphalt pavement, refer to ACI 325.13R and American Concrete Paving Association (1998).

7.7—Parking lot cleaning

Oil and grease dripping from vehicles can cause unsightly dark stains on concrete parking areas. Generally, petroleum stains do not harm the concrete or cause deterioration. Given enough time, oxidation and weathering will make the stain less noticeable. If the stains are aesthetically unacceptable, there are several physical and chemical methods that can remove oil and grease from concrete (National Ready Mixed Concrete Association 1984). If the stains are particularly heavy or jelled, as much residue should be scraped off as possible before further cleaning. Dry portland cement or other absorbent materials can be used to absorb wet oil before starting other cleaning operations.

7.7.1 *Abrasive blasting*—Sandblasting or shotblasting are effective means of removing some stains from concrete parking lots. (Shotblasting will not remove heavy grease.) Blasting is less time-consuming than chemical methods. It will remove approximately 1/16 in. (2 mm) of the concrete surface. Blasting should be done by a specialty contractor and can be more expensive than chemical cleaning. High-pressure water equipment can also be effective.

7.7.2 *Chemical cleaners*—There are a variety of commercial driveway cleaners available. Many contain sodium metasilicate and petroleum distillate. Generally, these cleaners are poured over the area to be cleaned and scrubbed in with a stiff brush. Rinsing the surface with water removes the cleaner and oil stains.

Scrubbing the stain with a strong soap solution, scouring powder, or trisodium phosphate (TSP) will also remove oil and grease.

For particularly stubborn stains, spread a stiff paste of 5% sodium hydroxide (NaOH) solution mixed with ground limestone over the discolored area. After 24 hours, the paste can be scraped off, and the area thoroughly rinsed with warm water.

CHAPTER 8—REFERENCES

8.1—Referenced standards and reports

Applicable documents of the various standards-producing organizations referred to in this committee report are listed below with their serial designations. The users of these documents should check directly with the sponsoring groups for the latest revisions.

AASHTO

T 259	Resistance of Concrete to Chloride Ion Penetration
T 260	Sampling and Testing for Total Chloride Ion in Concrete and Concrete Raw Materials

American Concrete Institute

121R	Quality Management System for Concrete Construction
201.2R	Guide to Durable Concrete
211.1	Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete
221R	Guide for Use of Normal Weight and Heavyweight Aggregates in Concrete
224.1R	Causes, Evaluation, and Repair of Cracks in Concrete Structures
229R	Controlled Low-Strength Materials
230.1R	Report on Soil Cement
301	Specifications for Structural Concrete
304R	Guide for Measuring, Mixing, Transporting, and Placing Concrete
305R	Hot Weather Concreting
306R	Cold Weather Concreting
308R	Guide to Curing Concrete
308.1	Standard Specification for Curing Concrete
311.4R	Guide for Concrete Inspection
311.5	Guide for Concrete Plant Inspection and Testing of Ready-Mixed Concrete
318	Building Code Requirements for Structural Concrete
325.13R	Concrete Overlays for Pavement Rehabilitation
330.1	Specification for Unreinforced Concrete Parking Lots
360R	Design of Slabs-on-Ground
504R	Guide to Sealing Joints in Concrete Structures
522R	Pervious Concrete
546R	Concrete Repair Guide

ASTM International

A185/A185M	Standard Specification for Steel Welded Wire Reinforcement, Plain, for Concrete

A497/A497M	Standard Specification for Steel Welded Wire Reinforcement, Deformed, for Concrete
A615/A615M	Standard Specification for Deformed and Carbon-Steel Bars for Concrete Reinforcement
A706/A706M	Standard Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement
A820/A820M	Standard Specification for Steel Fibers for Fiber-Reinforced Concrete
C31/C31M	Standard Practice for Making and Curing Concrete Test Specimens in the Field
C33	Standard Specification for Concrete Aggregates
C39/C39M	Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens
C78	Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
C94/C94M	Standard Specification for Ready-Mixed Concrete
C150	Standard Specification for Portland Cement
C260	Standard Specification for Air-Entraining Admixtures for Concrete
C309	Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete
C494/C494M	Standard Specification for Chemical Admixtures for Concrete
C496/C496M	Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens
C595	Standard Specification for Blended Hydraulic Cements
C618	Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
C672/C672M	Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals
C685/C685M	Standard Specification for Concrete Made by Volumetric Batching and Continuous Mixing
C989	Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars
C1077	Standard Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation
C1157	Standard Performance Specification for Hydraulic Cement
C1315	Standard Specification for Liquid Membrane-Forming Compounds Having Special Properties for Curing and Sealing Concrete
D698	Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3))
D994	Standard Specification for Preformed Expansion Joint Filler for Concrete (Bituminous Type)
D1196	Standard Test Method for Nonrepetitive Static Plate Load Tests of Soils and Flexible Pavement Components, for Use in Evaluation and Design of Airport and Highway Pavements
D1429	Standard Test Methods for Specific Gravity of Water and Brine
D1556	Standard Test Method for Density and Unit Weight of Soil in Place by the Sand-Cone Method
D1557	Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))
D1751	Standard Specification for Preformed Expansion Joint Filler for Concrete Paving and Structural Construction (Nonextruding and Resilient Bituminous Types)
D1752	Standard Specification for Preformed Sponge Rubber Cork and Recycled PVC Expansion Joint Fillers for Concrete Paving and Structural Construction
D1883	Standard Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils
D2167	Standard Test Method for Density and Unit Weight of Soil in Place by the Rubber Balloon Method
D2487	Standard Test Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
D2844	Standard Test Method for Resistance *R*-Value and Expansion Pressure of Compacted Soils
D2937	Standard Test Method for Density of Soil in Place by the Drive-Cylinder Method
D3282	Standard Practice for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes
D3406	Standard Specification for Joint Sealant, Hot-Applied, Elastomeric-Type, for Portland Cement Concrete Pavements
D4318	Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
D6938	Standard Test Method for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)
E303	Standard Test Method for Measuring Surface Frictional Properties using the British Pendulum Tester
E329	Standard Specification for Agencies Engaged in Construction Inspection and/or Testing

Federal Specifications

TT-S-001543a	(COM-NBS) Sealing Compound: Silicone Rubber Base (for Caulking, Sealing and Glazing in Buildings and Other Structures)
TT-S-00230c	(COM-NBS) Sealing Compound, Elastomeric Type, Single Component (for Caulking, Sealing and Glazing in Buildings and Other Structures)

The above publications may be obtained from the following organizations:

American Association of State Highway and Transportation Officials (AASHTO)
444 N. Capitol St. NW
Suite 225
Washington, DC 20001
www.transportation.org

American Concrete Institute
P.O. Box 9094
Farmington Hills, MI 48333-9094
www.concrete.org

ASTM International
100 Barr Harbor Dr.
West Conshohocken, PA 19428
www.astm.org

Federal Specifications
Business Service Center
General Services Administration
7th and D Street SW
Washington, DC 20407

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APPENDIX A—PROCEDURES FOR CONCRETE PAVEMENT DESIGN

A.1—Pavement stress determination and fatigue consumption

Several established design methods for rigid pavement have used calculation of the stresses induced by pavement loadings and other influences. Fatigue of concrete occurs with repetitions of loads that result in a stress ratio (induced stress/MOR) greater than approximately 0.50, and the rate of fatigue consumption is greater as the stress ratio increases. Fatigue consumption over time can thus be approximated using projected traffic loads and frequencies for any candidate pavement design. One such method is the Portland Cement Association design method (Portland Cement Association 1984a,b), which was used to generate nomographs (Fig. A.1 and A.2) to determine the stresses that result from the applications of various single and tandem axle loads to slabs of different thicknesses. The other variable needed to use the nomographs is the modulus of subgrade reaction, or *k*. Both nomographs were prepared for interior slabs with a load transfer by aggregate interlock on all sides—the prevailing condition in a parking lot.

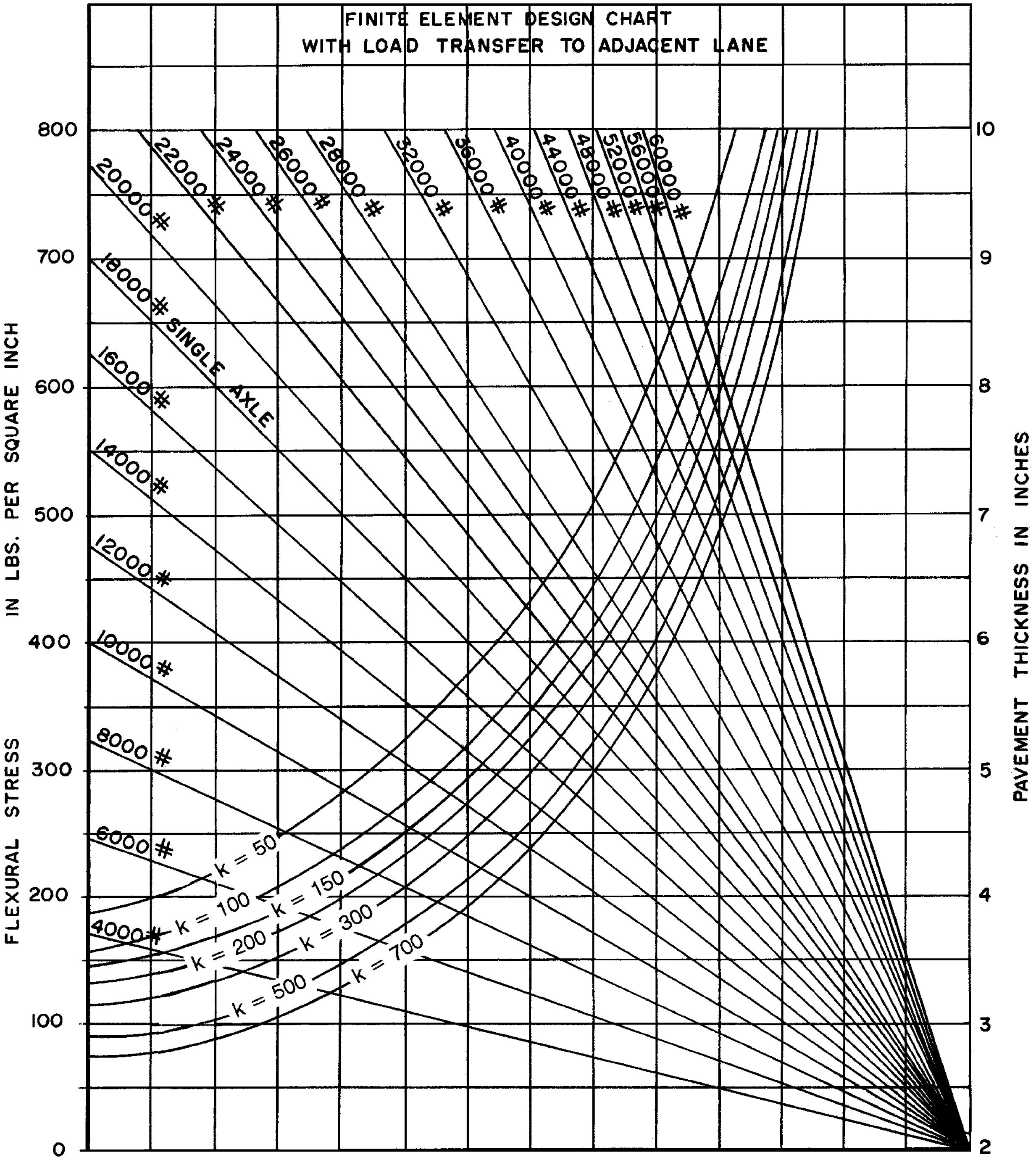


Fig. A.1—Nomograph for estimating flexural stress (psi) in slab of given thickness (in.) on subgrade of given k *value (psi/in.) for single axle load in pounds (#). Note: 1 in. = 25.4 mm; 1 lb = 4.45 N; 1 psi = 0.0069 MPa; and 1 psi/in. = 0.27 MPa/m.*

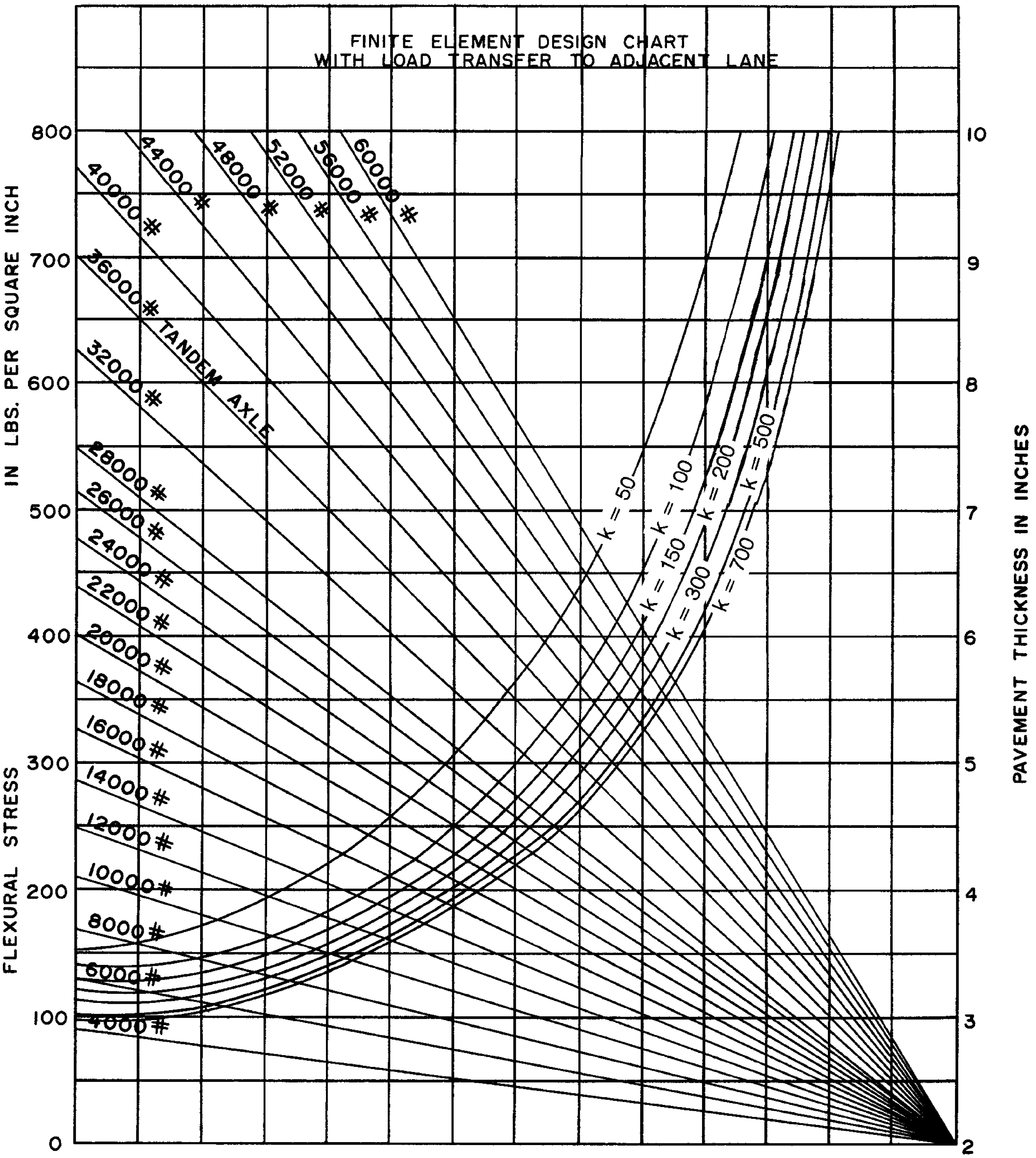


Fig. A.2—Nomograph for estimating flexural stress (psi) in slab of given thickness (in.) on subgrade of given k *value (psi/in.) for tandem axle load in pounds (#). Note: 1 in. = 25.4 mm; 1 lb = 4.45 N; 1 psi = 0.0069 MPa; and 1 psi/in. = 0.27 MPa/m.*

To determine the required thickness using the nomographs, an iterative process is used. First, a trial thickness is assumed. For each class of axle, a line is drawn from the assumed thickness shown on the right ordinate to the diagonal line representing the applied axle load. From there, a line is drawn vertically to the curve representing the subgrade support, and then a line is drawn to the left ordinate to find the induced stress. The stress ratio is then calculated by dividing the induced stress by the MOR of the concrete to be used in the candidate design and used to estimate the allowable load repetitions (Fig. A.3 or Eq. (A-4)). The estimated number of loads during the pavement's design life is divided by the allowable number of loads to find the percentage of the slab fatigue capacity that has been used. This process is repeated for all anticipated load levels, and the amount of fatigue life that has been used is totaled. A slab is considered to have satisfactory thickness if less than 125% of the fatigue is used. Total fatigue can exceed 100% because the concrete will continue to gain strength beyond the design strength.

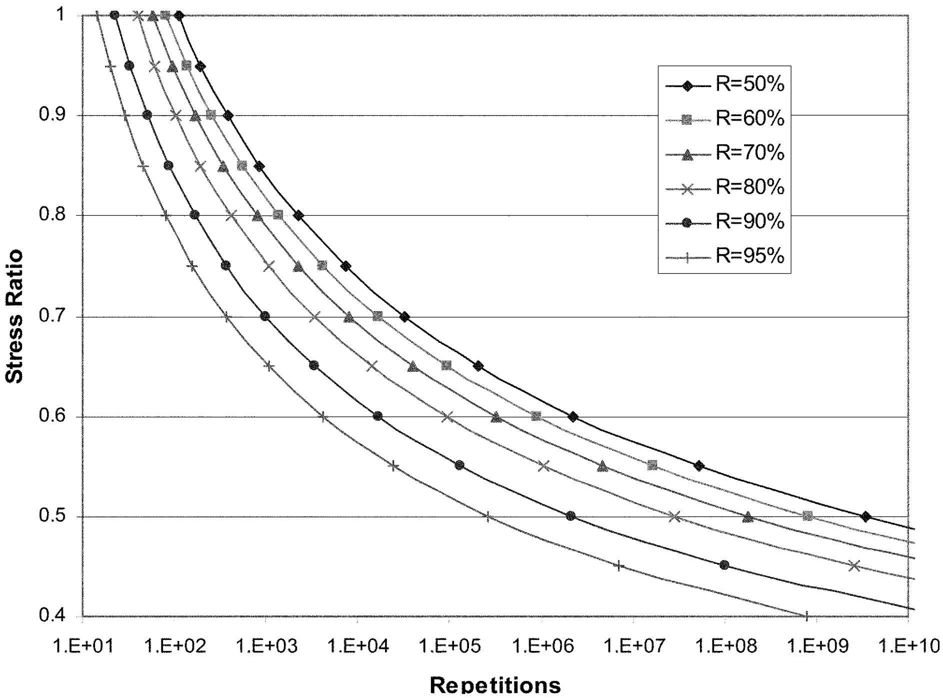


Fig. A.3—Fatigue relationships for varying overall reliability.

Required concrete thickness can also be determined using direct calculation of induced stresses and calculated or graphically-determined relationships between stress ratio and allowable load repetitions. Equations (A-1) through (A-4) were developed for this purpose by Titus-Glover et al. (2004) and Gotlif et al. (2004). The equations apply only to interior slabs (that is, no free edge loading) with load transfer by aggregate interlock on all sides. Equation (A-1) applies to single axles, (A-2) to tandem axles, and (A-3) to tridem axles. Each equation is presented in two forms for calculating equivalent stress in either psi ($\sigma_{eq\ in.\text{-}lb}$) or MPa ($\sigma_{eqSI}$).

$$\sigma_{eq_{in.-lb}} = \frac{6 \times (-970.4 + 1202.6 \times \log[\ell_{in.-lb}] + 53.587\ell_{in.-lb}) \times (0.8742 + 0.01088 \times {k_{in.-lb}}^{0.447})}{{h_{in.-lb}}^2} \times \left[\left(\frac{24}{SAL_{in.-lb}}\right)^{0.06} \times \frac{SAL_{in.-lb}}{18}\right] \times 0.894$$

$$\sigma_{eq_{SI}} = \frac{6 \times (-2659.85 + 1202.6 \times \log[\ell_{SI}] + 2.10972\ell_{SI}) \times (0.8742 + 0.427338 \times {k_{SI}}^{0.447})}{{h_{SI}}^2} \times \left[\left(\frac{106.757}{SAL_{SI}}\right)^{0.06} \times \frac{SAL_{SI}}{80.068}\right] \times 3.97672 \qquad \text{(A-1)}$$

$$\sigma_{eq_{in.-lb}} = \frac{6 \times (-2005.4 + 1980.9 \times \log[\ell_{in.-lb}] + 99.008\ell_{in.-lb}) \times (0.8742 + 0.01088 \times {k_{in.-lb}}^{0.447})}{{h_{in.-lb}}^2} \times \left[\left(\frac{48}{TAL_{in.-lb}}\right)^{0.06} \times \frac{TAL_{in.-lb}}{36}\right] \times 0.894$$

$$\sigma_{eq_{SI}} = \frac{6 \times (-777.437 + 1980.9 \times \log[\ell_{SI}] + 3.89794\ell_{SI}) \times (0.8742 + 0.427338 \times {k_{SI}}^{0.447})}{{h_{SI}}^2} \times \left[\left(\frac{213.515}{TAL_{SI}}\right)^{0.06} \times \frac{TAL_{SI}}{160.136}\right] \times 3.97672 \qquad \text{(A-2)}$$

$$\sigma_{eq_{in.-lb}} = \frac{6 \times (-88.54 + 134.0 \times \log[\ell_{in.-lb}] + 0.83\ell_{in.-lb}) \times (11.3345 + 0.2218 \times {k_{in.-lb}}^{0.448})}{{h_{in.-lb}}^2} \times \left[\left(\frac{72}{TriAL_{in.-lb}}\right)^{0.06} \times \frac{TriAL_{in.-lb}}{54}\right] \times 0.894$$

$$\sigma_{eq_{SI}} = \frac{6 \times (-276.788 + 134.0 \times \log[\ell_{SI}] + 0.0326771\ell_{SI}) \times (11.3345 + 8.78356 \times {k_{SI}}^{0.448})}{{h_{SI}}^2} \times \left[\left(\frac{320.272}{TriAL_{SI}}\right)^{0.06} \times \frac{TriAL_{SI}}{240.204}\right] \times 3.97672 \qquad \text{(A-3)}$$

where

$\sigma_{eq_{in.\text{-}lb}}$ = equivalent stress, psi;

$\sigma_{eq_{SI}}$ = equivalent stress, MPa;

$\ell_{in.\text{-}lb}$ = radius of relative stiffness, in. = $\sqrt[4]{\dfrac{E_{in.-lb}{h_{in.-lb}}^3}{12k_{in.-lb}(1-\mu^2)}}$;

ℓ_{SI} = radius of relative stiffness, mm = $\sqrt[4]{\dfrac{E_{SI}{h_{SI}}^3}{12k_{SI}(1-\mu^2)}}$;

$E_{in.\text{-}lb}$ = modulus of elasticity of the concrete, psi = 6750 × MOR;
E_{SI} = modulus of elasticity of the concrete, N/mm^2;
$h_{in.\text{-}lb}$ = slab thickness, in.;
h_{SI} = slab thickness, mm;
$k_{in.\text{-}lb}$ = modulus of subgrade reaction, psi/in. or lb/in.^{3};
k_{SI} = modulus of subgrade reaction, N/mm^3;
μ = Poisson's ratio for concrete, usually 0.15;
$SAL_{in.\text{-}lb}$ = single axle load, kips;
SAL_{SI} = single axle load, kN;
$TAL_{in.\text{-}lb}$ = tandem axle load, kips;
TAL_{SI} = tandem axle load, kN;
$TriAL_{in.\text{-}lb}$ = tridem axle load, kips; and
$TriAL_{SI}$ = tridem axle load, kN.

Again, an iterative process is used to determine the required thickness. First, a trial thickness is assumed. For each axle class, the stress imposed on the slab by that load is determined. The stress ratio is calculated and can be used with Fig. A.3 to estimate the allowable load repetitions by drawing a horizontal line at the calculated stress ratio and finding the intersection with the curve that represents the desired reliability level. From the intersection, a line is drawn downward to estimate the total number of those loads that can be applied before the slab fails. An alternative is to use the following equation to determine the allowable loads

$$N = 10^{\left[\frac{-89.2857 \times \log(1-p)}{SR^{10.24}}\right]^{0.217}} \qquad \text{(A-4)}$$

where
N = number of allowable load repetitions;
SR = stress ratio;
p = probability of failure; and
$(1 - p)$= probability of survival, that is, overall reliability.

Reliability, simply stated, is the factor of safety of the pavement design. It is a measure of how likely the specified design will perform before needing rehabilitation. The design procedure predicts when the pavement will reach the limits of fatigue (a crack will form) or erosion (the subgrade material will pump out from underneath the pavement). The recommended level of reliability depends on the type of pavement that is being designed. A relatively high reliability is used for high-traffic, high-speed roadways, whereas low-traffic, low-speed facilities typically require a lower level of reliability. This concept is now used in AASHTO design and the benefit is that it allows the design professional to use appropriate levels of reliability to produce design thicknesses more practical for the design circumstances.

The estimated number of loads during the design life of the slab is divided by the allowable number of loads to find the percentage of the slab fatigue capacity that has been used. This process is repeated for all anticipated load levels, and the amount of fatigue life that has been used is totaled. A slab is considered to have satisfactory thickness if less than 125% of the fatigue is used.

This procedure is illustrated by the following example:

A driveway is to be built to carry two delivery trucks per day for 20 years. Each truck is expected to have a single front axle with a load of 10 kips (44 kN) and a tandem rear axle of 26 kips (115 kN). The subgrade is a clay with k = 100 psi/in (27.2 MPa/m).
Two trucks per day for 20 years = 2 × 20 × 365 = 14,600 repetitions
Assume a 4.5 in. (115 mm) pavement with MOR = 650 psi (4.5 MPa)

Using the single-axle equation (Eq. (A-1)), the stress for each front axle is found to be 317 psi (2.2 MPa).
The stress ratio = stress/MOR = 317/650 = 0.53
Using the tandem-axle equation (Eq. (A-2)), the stress for each rear axle is found to be 332 psi (2.3 MPa).
The stress ratio = 332/650 = 0.55

From the curve in Fig. A.3 (or Eq. (A-4)), allowable load repetitions for single axles equal 59,000, and for the tandem axles equal 20,000.
Fatigue consumption = expected loads/allowable loads
Fatigue consumption, single axles = 14,600/59,000 = 25%
Fatigue consumption, tandem axles = 14,600/20,000 = 71%
Total fatigue consumption = 96% (< 125%)
The 4.5 in. (115 mm) pavement is acceptable.

A.2—Source of thickness tables

Table 3.4 was generated using the principles outlined in A.1. A computer program that applies the finite-element method to these principles (American Concrete Pavement Association 2005) was used to facilitate the calculations. It performs iterations similar to the previous example for the specific input axle-load distributions. The four distributions of vehicles used to set up the four traffic categories in Table 3.3 are shown in Table A.1. Categories B and C, developed by the Portland Cement Association, are composites of data averaged from several loadometer tables representing appropriate pavement facilities. Category A is the same as Category B, except that the heaviest axle loads have been eliminated. Category D consists only of tractor semitrailer trucks with gross weights of 80 kips (360 kN). The assumed design life used in Table 3.4 was 20 years, with an overall reliability of 95%.

Table A.1—Axle-load distributions used for preparing design Tables 3.3 and 3.4

Axle load, kips (kN)	Axles per 1000 trucks[*]			
	Category A	Category B	Category C	Category D
Single axles				
4 (18)	1693.31	1693.31	—	—
6 (27)	732.28	732.28	—	—
8 (36)	483.10	483.10	233.60	—
10 (44)	204.96	204.96	142.70	—
12 (53)	124.00	124.00	116.76	—
14 (62)	56.11	56.11	47.76	—
16 (71)	38.02	38.02	23.88	1000
18 (80)	—	15.81	16.61	—
20 (89)	—	4.23	6.63	—
22 (98)	—	0.96	2.60	—
24 (107)	—	—	1.60	—
26 (116)	—	—	0.07	—
28 (125)	—	—	—	—
30 (133)	—	—	—	—
32 (142)	—	—	—	—
34 (151)	—	—	—	—
Tandem axles				
4 (18)	31.90	31.90	—	—
8 (36)	85.59	85.59	47.01	—
12 (53)	139.30	139.30	91.15	—
16 (71)	75.02	75.02	59.25	—
20 (89)	57.10	57.10	45.00	—
24 (107)	39.18	39.18	30.74	—
28 (125)	68.48	68.48	44.43	—
32 (142)	69.59	69.59	54.76	2000
36 (160)	—	4.19	38.79	—
40 (178)	—	—	7.76	—
44 (196)	—	—	1.16	—
48 (214)	—	—	—	—
52 (231)	—	—	—	—
56 (249)	—	—	—	—
60 (267)	—	—	—	—

[*] Excluding all two-axle, four-tire trucks.

A.3—AASHTO procedure

The other widely used pavement design method is the AASHTO procedure (AASHTO 1993). This empirical procedure addresses both rigid and flexible pavement design, and was developed based on pavement performance at the AASHO Road Test (Highway Research Board 1962), which was conducted during the period of 1958 to 1960. The 1993 AASHTO guide followed three interim versions of the guide, and it constitutes a major revision of previous versions.

A computer program is also available to implement the AASHTO procedure (American Concrete Pavement Association 2006). The program will compute the required pavement thickness for design traffic, or it will analyze a selected thickness for traffic-carrying capacity.

Refer to Section 3.6.1 for additional information comparing results of the AASHTO procedure with those of other design methods.

APPENDIX B—SUBGRADE

B.1—Introduction

The designer should give careful consideration to the specific subgrade soils at the site. Troublesome subgrade conditions should be accommodated in the design. The engineer should make the best use of the soil information available.

B.2—Soil classification

Unlike manufactured products, such as concrete or steel, the properties of subgrade soils are highly variable from site to site, and even within a job site. Over time, geotechnical engineers have developed a number of standard classification systems to characterize the engineering properties of soils.

The most commonly used classification is the Unified System (Corps of Engineers 1953), originally developed by Arthur Casagrande, and later standardized by ASTM D2487. In this system, the division point between coarse-grained and fine-grained soils is the No. 200 (0.075 mm) sieve. If more than 50% of the soil passes the No. 200 (0.075 mm) sieve, it is classified as fine-grained. If more than 50% of the soil is retained on the No. 200 (0.075 mm) sieve, it is classified as coarse-grained. Other components of the classification system are the liquid limit (LL) and the plasticity index (PI), which are physical tests to distinguish between silts and clays.

The soils are identified in the Unified System using letter combinations from the following list of letter symbols:

G = gravel;
S = sand;
M = silt;
C = clay;
W = well graded;
P = poorly graded;
L = low-liquid limit;
H = high-liquid limit; and
O = organic.

In the AASHTO system, soils are divided into two major groups: granular materials containing 35% or less, passing the No. 200 (0.075 mm) mesh sieve, and clay and clay-silt materials containing more than 35% passing the No. 200 (0.075 mm) mesh sieve. The soil components are further classified as gravel, coarse sand, fine sand, silt, or clay. The final classification parameter is the group index (GI), computed from sieve analysis data, the liquid limit (LL), and the plasticity index (PI). The AASHTO system and its GI formula are described in ASTM D3282.

Soils described by a unique description of a classification system generally exhibit similar engineering properties, regardless of location. Table B.1 shows general properties for soils classified in the ASTM system.

B.3—Problem soils

Unfortunately, parking lots cannot always be built on coarse-grained soils, which generally provide excellent subgrades. The designer may need to use less desirable soils that are subject to frost action and soil expansion; therefore, the designer should understand how to minimize problems these soils can cause.

Various cementitious materials can be used to improve or stabilize existing subgrade material, in many cases producing a strong, stable subbase with significant enhancement of the soil's k value. Refer to ACI 230.1R for guidance on related materials and procedures.

Portland cement has a long history of use in soil-cement construction of pavement subbases and in modification of soil properties. Design and construction guidance can be found in IS411.02 (Portland Cement Association 2003) and other Portland Cement Association publications. Fly ash is also successfully used as a stabilizer in many areas (Federal Highway Administration 2003; Ferguson and Levorson 1999), and lime can be effective in the modification and stabilization of plastic clays and some other soils types (National Lime Association 2004; Little 1999).

B.4—Expansive soils

Expansive soil types and the mechanisms that cause soil volume change are well known by geotechnical and highway engineers. Test procedures for identifying expansive soils are also well known and commonly used. Table B.2 shows the approximate relationships between soil plasticity and expansion. Normally, a soil with a high degree of expansion potential is needed to cause bumps, depressions, or waves in the pavement.

Most soils sufficiently expansive to cause distortion of pavements are in the AASHTO A-5 or A-7 groups. In the Unified Soil Classification system, these soils are classified as CH, MH, or OH. Soil survey maps prepared by the USDA Soil Conservation Service can be helpful in determining soil classifications at the parking lot site. When highly expansive soils are believed to be present, additional soil tests should be used to better define the expected volume changes and subsequent pavement movement.

Expansive soils can be controlled effectively and economically by the following:

- *Subgrade grading operations*—Swelling can be controlled by placing the more expansive soils in the lower parts of embankments and by cross-hauling or importing less expansive soils to form the upper part of the subgrade. Selective grading can create reasonably uniform soil conditions in the upper subgrade and will help ensure gradual transitions between soils with varying volume change properties. In deep cuts into highly expansive soils, a great deal of expansion can occur because of the removal of the natural surcharge load and absorption of additional moisture. Because this expansion usually takes place slowly, it is advisable to excavate deep cuts well in advance of other site-grading work;
- *Compaction and moisture control*—Soil volume changes can also be reduced by adequate moisture and density controls during subgrade compaction. It is very important to compact highly expansive soil at 1 to 3% above optimum moisture content, as determined by ASTM D698. Expansive soils compacted slightly wet-of-optimum expand less, have higher strengths after wetting, and absorb less water; and

Table B.1—Soil characteristics pertinent to parking lot pavements

Major divisions		Letter		Name	Compress-ibility and expansion	Drainage characteristics	Compaction equipment	Typical design values	
								CBR	Subgrade modulus k, psi/in.
(1)	(2)	(3)		(6)	(11)	(12)	(13)	(15)	(16)
Coarse-grained soils	Gravel and gravelly soils	GW		Well-graded gravels or gravel-sand mixtures, little or no fines	Almost none	Excellent	Crawler-type tractor, vibratory compactor, rubber-tired roller, steel-wheeled roller	40 to 80	300 to 500
		GP		Poorly graded gravels or gravel-sand mixtures, little or no fines	Almost none	Excellent	Crawler-type tractor, vibratory compactor, rubber-tired roller, steel-wheeled roller	30 to 60	300 to 500
		GM	d	Silty gravels, gravel-sand-silt mixtures	Very slight	Fair to poor	Rubber-tired roller, sheepsfoot roller; close control of moisture	40 to 60	300 to 500
			u		Slight	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	20 to 30	200 to 500
		GC		Clayey gravels, gravel-sand-clay mixtures	Slight	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	20 to 40	200 to 500
	Sand and sandy soils	SW		Well-graded sands or gravelly sands, little or no fines	Almost none	Excellent	Crawler-type tractor, vibratory compactor, rubber-tired roller	20 to 40	200 to 400
		SP		Poorly graded sands or gravelly sands, little or no fines	Almost none	Excellent	Crawler-type tractor, vibratory compactor, rubber-tired roller	10 to 40	150 to 400
		SM	d	Silty sands, sand-silt mixtures	Very slight	Fair to poor	Rubber-tired roller, sheepsfoot roller; close control of moisture	15 to 40	150 to 400
			u		Slight to medium	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	10 to 20	100 to 300
		SC		Clayey sands, sand-clay mixtures	Slight to medium	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	5 to 20	100 to 300
Fine-graded soils	Silts and clays, LL < 50	ML		Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity	Slight to medium	Fair to poor	Rubber-tired roller, sheepsfoot roller; close control of moisture	15 or less	100 to 200
		CL		Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Medium	Practically impervious	Rubber-tired roller, sheepsfoot roller	15 or less	50 to 150
		OL		Organic silts and organic silt-clays of low plasticity	Medium to high	Poor	Rubber-tired roller, sheepsfoot roller	5 or less	50 to 100
	Silts and clays, LL > 50	MH		Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	High	Fair to poor	Sheepsfoot roller, rubber-tired roller	10 or less	50 to 100
		CH		Inorganic clays of high plasticity, fat clays	High	Practically impervious	Sheepsfoot roller, rubber-tired roller	15 or less	50 to 150
		OH		Organic clays of medium to high plasticity, organic silts	High	Practically impervious	Sheepsfoot roller, rubber-tired roller	5 or less	25 to 100
Highly organic soils		Pt		Peat and other highly organic soils	Very high	Fair to poor	Compaction not practical	—	—

Notes:
1. Extracted from MIL-STD-619B (U.S. Department of Defense 1967, revised).
2. In Column (3), division of GM and SM groups into subdivisions of “d” and “u” are for roads and airfields only. Subdivision is on the basis of Atterberg limits: suffix “d” (such as GM) is used when the liquid limit is 25 or less, and the plasticity is 5 or less; suffix “u” is used otherwise.
3. In Column (13), the equipment listed will usually produce the required densities with a reasonable number of passes when moisture conditions and thickness of lift are properly controlled. In some instances, several types of equipment are listed because variable soil characteristics within a given soil group may require different equipment. In some instances, a combination of two types may be necessary.
4. 1 psi/in. = 0.27 MPa/m.

Table B.2—Approximate relationship between soil plasticity and expansion[*]

Data from index tests[†]			Probable expansion and total volume change[‡] (due to saturated condition), %	Degree of expansion
Colloid content, % minus 0.001 mm	Plasticity index	Shrinkage limit, %		
28	35	11	30	Very high
20 to 31	25 to 41	7 to 12	20 to 30	High
13 to 23	15 to 28	10 to 16	10 to 20	Medium
15	18	15	10	Low

[*] Derived from Holtz and Gibbs (1956). Copied from the National Research Council (1965).

[†] All three index tests should be considered in estimating expansive properties.

[‡] Based on a vertical loading of 1.1 psi (7.6 kPa).

- *Nonexpansive cover*—In areas with prolonged periods of dry weather, highly expansive subgrades may require a cover layer of low-volume change soil. This layer will help minimize changes in the moisture content of the underlying expansive soil. A low-volume-change layer with low to moderate permeability is usually more effective and less costly than permeable, granular soil. Highly permeable, open-graded subbase materials are not recommended as cover for expansive soils because they allow more moisture to reach the subgrade.

Local experience with expansive soils is always an important consideration in pavement design.

B.5—Frost action

Field experience with concrete pavements has shown that frost action damage is usually caused by abrupt, differential heave rather than subgrade softening during thawing. Design of concrete pavement projects should be concerned with reducing nonuniformity of subgrade soil and moisture conditions that could lead to differential heaving.

For frost heave to occur, three conditions are required: a frost-susceptible soil, freezing temperatures penetrating the subgrade, and a supply of water. Heaving is caused by the growth of ice lenses in the soil. As freezing temperatures penetrate the subgrade, water from the unfrozen portion of the subgrade is attracted to the frozen zone. If the soil has a high capillary suction, the water moves to ice crystals initially formed, freezes on contact, and expands. If a supply of water is available, the ice crystals continue to grow, forming ice lenses that will eventually lift or heave the overlying pavement. The worst heaving usually occurs in fine-grained soils subject to capillary suction. Low-plasticity soils with a high percentage of silt-size particles (0.05 to 0.005 mm) are particularly susceptible to frost heave. These soils have pore sizes that are small enough to develop capillary suction, but are large enough for rapid travel of water to the freezing zone.

To a large degree, frost heave can be mitigated by appropriate grading operations, as well as control of subgrade compaction and moisture content. If possible, grade lines should be set high enough that frost-susceptible soils are above the capillary range of the groundwater table. Pockets of highly frost-susceptible soil should be removed and backfilled with soils like those surrounding the pocket. Fine-grained soils should be compacted to a moisture content slightly higher than ASTM D698 optimum. Where high grades are impractical, subgrade drainage or non-frost-susceptible cover should be considered. The thawing of frozen subgrade reduces subgrade support of the pavement. Because rigid pavements distribute loads over large areas, there is usually no damage from these short-term conditions.

B.6—Mud-pumping

Mud-pumping is the forced displacement of fine-grained subgrade soil and water from slab joints, cracks, and pavement edges. It is caused by frequent deflection of slab edges by heavy wheel loads. Highway studies have shown that the following three factors are necessary for mud-pumping to occur: a subgrade soil that will go into suspension, free water between the pavement and subgrade or subgrade saturation, and frequent passage of heavy loads (American Concrete Pavement Association 1995b).

Normally, pavements that carry less than 200 heavily loaded trucks (18,000 lb [80 kN] axle weights) per day will not be damaged by pumping, especially if speeds are low; therefore, they do not require subbases. Most parking lots do not have this traffic volume and, therefore, are not susceptible to mud-pumping.

If a subbase is required, 4 to 6 in. (100 to 150 mm) of well-compacted granular material is normally adequate. Cement, lime, Class C fly ash or other stabilization agents can also be used. Unstabilized subbases have little influence on pavement thickness design. They cannot be economically justified on the basis of reduced pavement thickness in most cases. On the other hand, stabilized subbases improve pavement support and influence pavement thickness.

B.7—Support uniformity

Uniformity of support for a concrete pavement is key to its longevity. Only the most often-used methods for achieving subgrade uniformity will be discussed herein. One of the more common methods is through the use of subgrade moisture control. During the compaction process of soils, either natural to the location or haul-in materials, good control of moisture content is important. For medium- and light-duty traffic, the optimum moisture content and desired compaction characteristics are usually determined by ASTM D698. Typical variations that should be achieved with fine-grained soils (silts and clays) are moisture contents within 3% of optimum. An exception to this rule is for expansive clays that are more appropriately compacted with the moisture at the upper end of the optimum range and at a density approximately 3% less than would be used for nonexpansive, fine-grained soils.

Subgrade uniformity can also be enhanced with natural subgrade soils by ripping the material to a depth of 4 to 6 in. (100 to 150 mm), adjusting the moisture content, if appropriate, and recompacting at a more uniform moisture and density. Methods of adjusting the moisture content include aeration of the soil, mixing in drier soil, watering, and then disking or blading for uniformity of distribution.

Compaction uniformity will occur with good moisture contents and watchful operation of compaction equipment. By making approximately the same number of passes on each area of the subgrade, the compaction densities will be similar. With uniform moisture contents, it is possible to obtain compacted densities in a range of ±5% of target density.

Solid rock is not a desirable material for either the establishment of subgrade elevations or as an immediate pavement foundation. The first effort should be to raise the subgrade elevation to avoid the rock. If this is not possible, the rock should be removed to a depth of approximately 6 in. (150 mm) below the pavement subgrade elevation and replaced with compacted soil.

APPENDIX C—SUGGESTED DETAILS

C.1—Pavement jointing and design feature details

Pavements are jointed to control cracking due to tensile stresses caused by shrinkage, to provide for slab movement and load transfer, and to facilitate construction. Other design features such as thickened edges and curbs may be used to enhance pavement performance or function. The description and use of the types of joints and features are discussed in Sections 3.7 and 3.11. Figures C.1 to C.6 provide details for the various joint types and features.

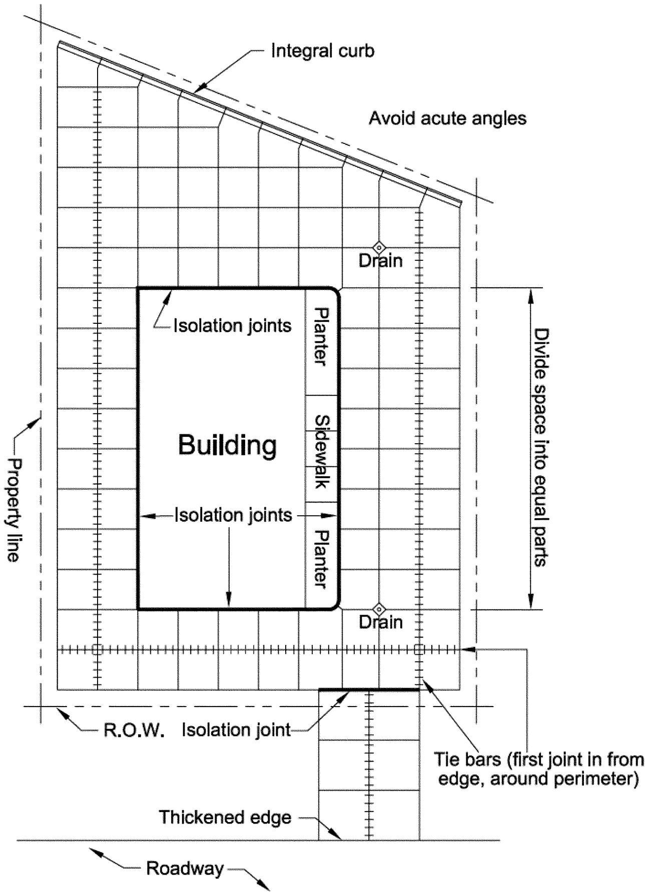
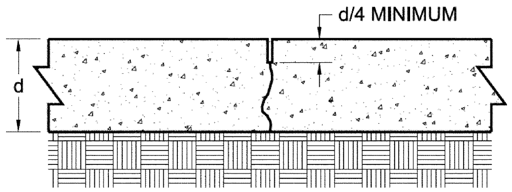
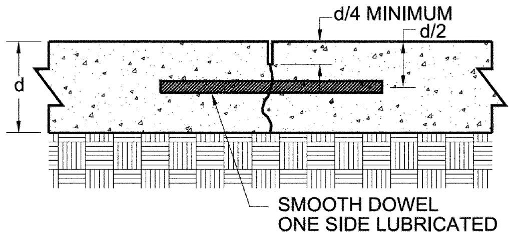


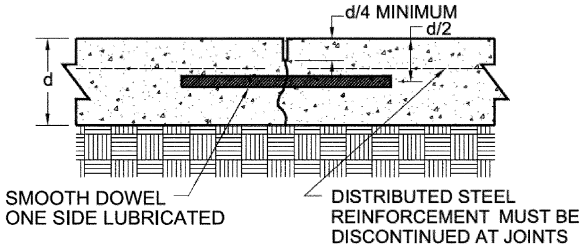
Fig. C.1—Typical joint layout for parking area.



PLAIN PAVEMENT
CONTRACTION JOINT, UNDOWELED
(ALL PAVEMENTS - SHORT JOINT SPACING)

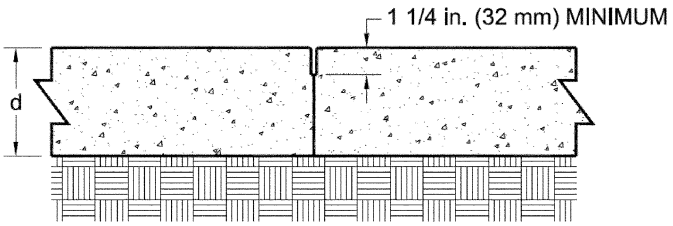


PLAIN PAVEMENT, DOWELED
(USED FOR HEAVY DUTY PAVEMENT,
7 in. (180 mm) OR THICKER

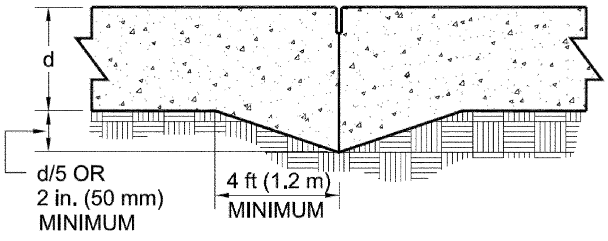


REINFORCED PAVEMENT DOWELED JOINT
(LONG JOINT SPACING)

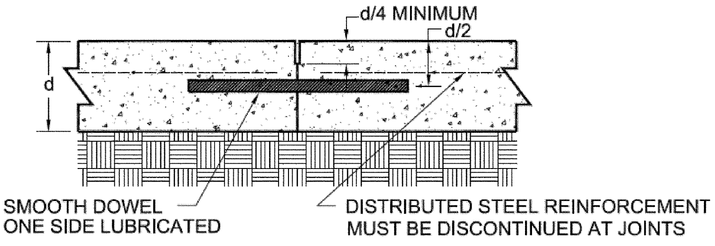
Fig. C.2—Example contraction joint details (longitudinal or transverse); refer to 3.7.1 for additional design information.



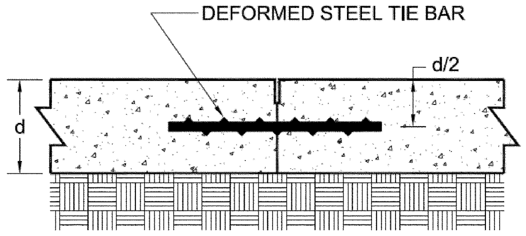
BUTT JOINT



THICKENED EDGE BUTT JOINT



REINFORCED PAVEMENT
DOWELED BUTT JOINT
(LONG JOINT SPACING)



TIED BUTT JOINT

MAY BE USED FOR A LONGITUDINAL JOINT NEAR PAVEMENT
EDGE OR FOR A TRANSVERSE JOINT THAT DOES NOT ALIGN
WITH THE REGULARLY SPACED JOINTS IN ADJACENT LANES.

Fig. C.3—Construction joint details (longitudinal or transverse).

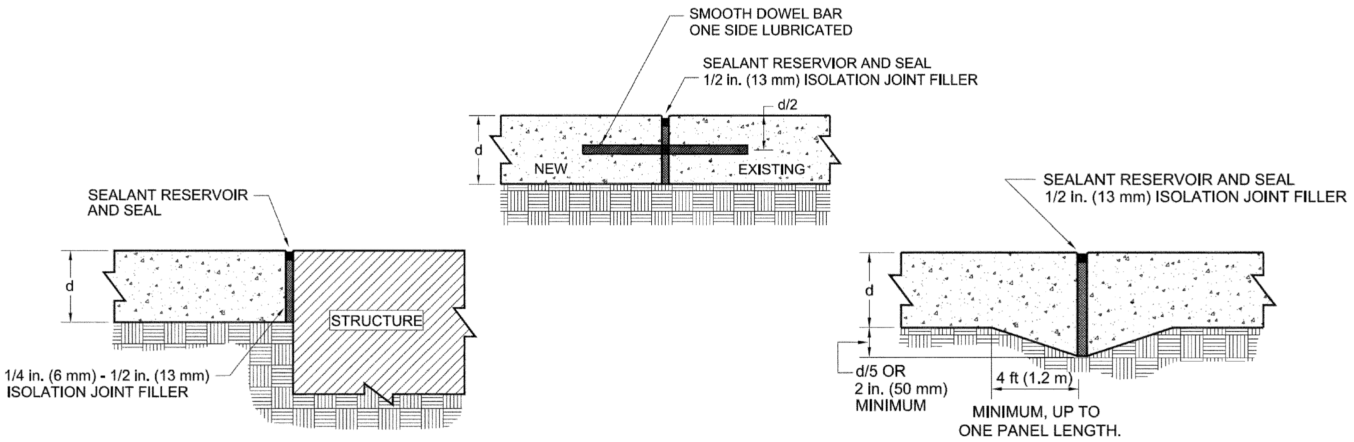


Fig. C.4—Isolation joints.

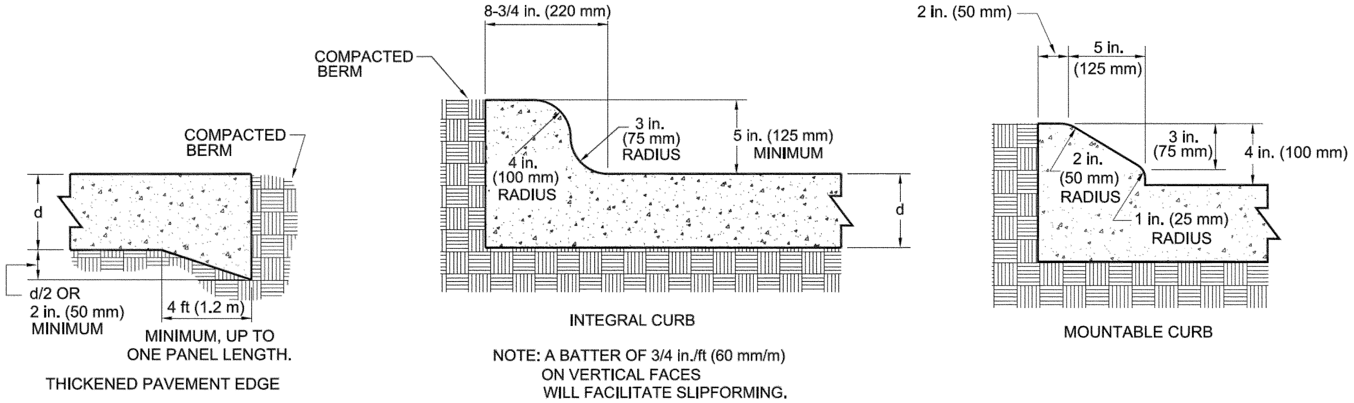


Fig. C.5—Curbs and thickened edges.

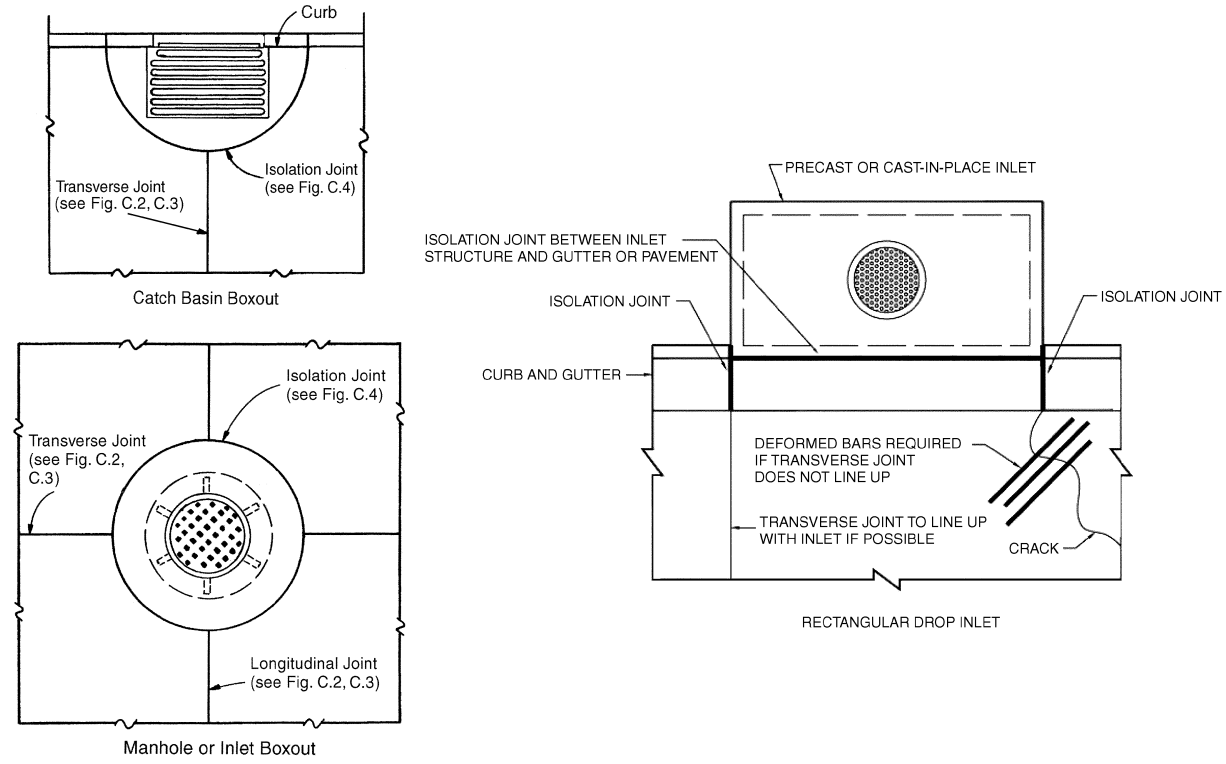


Fig. C.6—Fixture details.

APPENDIX D—PARKING LOT GEOMETRICS

D.1—Parking requirements

Local zoning regulations usually dictate the minimum numbers of parking spaces required for various types of buildings. Many local regulations also specify minimum sizes of parking spaces. The parking space requirements in Table D.1(a) are typical. "Recommended Zoning Ordinance Provisions" (Parking Consultants Council/National Parking Association 2006) contains additional information. Table D.1(b) and Fig. D.1 show dimensions for parking spaces of common widths and various angles. Aisles should be 24 ft (7.3 m) wide for two-way traffic. Aisle width will depend on parking angle for one-way traffic.

Right-angle, or 90-degree, parking, permits two-way travel in aisles and is considered to be the most economical arrangement. A 90-degree pattern is the simplest to lay out, but parking is more difficult than parking at smaller angles.

One-way travel is used with parking angles less than 90 degrees. Wider parking spaces allow the use of narrower aisles. For the optimum layout of parking spaces for any given size and shape of a parking lot, several trial-and-error layouts will probably be necessary. Tables are available (Parking Consultants Council/National Parking Association 2006) to facilitate the calculation of critical stall dimensions.

D.2—Entrances and exits

Entrances and exits should be well-defined and located so as to have as little effect as possible on traffic movement on adjacent streets. Local standards usually prescribe lengths of acceleration-deceleration lanes at entrances and minimum distances from intersections. Reservoir space is important at entrances and exits on busy streets. Figure D.2 gives dimensions for curb returns.

D.3—Truck-parking facilities

Dimensions to allow adequate space for maneuvering and parking trucks vary greatly depending on the size and types of trucks. A truck terminal used by a single type of vehicle may have standard-sized spaces. A service area adjacent to a highway that will cater to trucks of all sizes can be designed for the entire parking lot to handle the largest and heaviest trucks, or it may be advantageous to segregate single units, tractor semitrailers, and twin trailer units. Parking-space length and width, and driving-lane turning radii requirements (as well as pavement thickness) can be tailored to the different types of traffic. Table D.2 gives suggested dimensions for maneuver areas for typical sizes. These dimensions should be checked before designing the parking lot. Trailer lengths vary; widths up to 102 in. (2.6 m) are used.

D.4—Additional information

There are many sources for information to aid in providing adequate spaces for parking and maneuvering vehicles. These include trade associations and parking lot equipment suppliers. Information from some of these sources is included in this appendix, and several publications are listed in Section 8.2.

Table D.1(a)—Typical parking space requirements

Type of building	Parking ratio, number of spaces per
Multi-family dwelling, rental	1.0/dwelling unit for efficiency units; 1.5/dwelling unit for the first bedroom in units with one or more bedrooms, plus 0.25 space for each additional bedroom
Cinemas	Single screen: 0.5/seats; 2 to 5 screens; 0.33/seat; 5 to 10 screens; 0.3/seat; more than 10 screens: 0.27/seat
Theaters, auditoriums, churches	0.4/seat
Commercial lodgings	1.25/sleeping room or unit plus 10/1000 ft^2 GFA restaurant lounge plus the following for meeting/banquet space: less than 20 ft^2/sleeping room, none: 20 ft^2/sleeping room: 30/1000 ft^2 GFA; 20 to 50 ft^2/sleeping room: scaled between 20 and 50 ft^2/sleeping room; over 50 ft^2/sleeping room: 20/1000 ft^2 GFA
General and convenience retail, stand-alone	2.75/1000 ft^2 GFA
Grocery stores, stand-alone	6.75/1000 ft^2 GFA
Discount superstores, stand-alone	5.5/1000 ft^2 GFA, including outdoor sales areas
Fast food, stand-alone	15/1000 ft^2 GFA
Restaurants, fine/casual dining (with bar)	20/1000 ft^2 GFA
Industrial/manufacturing	1.85/1000 ft^2 GFA plus required parking spaces for office, sales, or similar use where those uses exceed 10% GFA
Storage/wholesale	0.67/1000 ft^2 GFA
General business offices	3.8/1000 ft^2 GFA up to 25,000 ft^2; scaled between 25,000 to 100,000 ft^2; 3.4 for 100,000 ft^2; scaled between 100,000 and 500,000 ft^2; 2.8/1000 ft^2 GFA over 500,000 ft^2
Secondary schools	Higher of 0.3/seat in auditorium or gym and 0.3/student
Shopping center, not more than 10% GLA in non-retail sales and services uses	4.0/1000 ft^2 GLA up to 400,000 ft^2 GLA; scaled between 400,000 to 600,000 ft^2 GLA; 4.5/1000 ft^2 of GLA over 600,000 ft^2

Selected table entries reprinted with permission from the National Parking Association and the Parking Consultants Council. Source: "Recommended Zoning Ordinace Provisions" (Parking Consultants Council/National Parking Association 2006). Notes: GFA = gross floor area; GLA = gross leasable area; 1 ft^2 = 0.093 m^2.

Table D.1(b)—Recommended parking space dimensions

Angle of parking, degrees	Stall width		Module	Vehicle projection	Aisle	Interlock		Overhang	Wall offset	Stripe offset
	9’0”	8’6”				9’0”	8’6”			
θ	WP	WP	M	VP	A	i	i	o	WO	SO
45	12’9”	12’0”	48’0”	17’8”	12’8”	3’2”	3’0”	1’9”	10’8”	16’6”
50	11’9”	11’1”	49’9”	18’3”	13’3”	2’11”	2’9”	1’11”	9’5”	13’10”
55	11’0”	10’5”	51’0”	18’8”	13’8”	2’7”	2’5”	2’1”	8’3”	11’7”
60	10’5”	9’10”	52’6”	19’0”	14’6”	2’3”	2’2”	2’2”	7’2”	9’6”
65	9’11”	9’5”	53’9”	19’2”	15’5”	1’11”	1’10”	2’3”	6’1”	7’8”
70	9’7”	9’1”	55’0”	19’3”	16’6”	1’6”	1’5”	2’4”	5’0”	6’0”
75	9’4”	8’10”	56’0”	19’1”	17’10”	1’2”	1’1”	2’5”	3’10”	4’5”
Angles of parking between 76 and 89 degrees not permitted.										
90	9’0”	8’6”	60’0”	18’0”	24’0”	0’0”	0’0”	2’6”	1’0”	0’0”

Notes:

1. Add 1 ft to stall width where adjacent to walls, columns, and other obstructions to door opening and turning movement into the stall.
2. 9’0” stalls shall be used except that 8’6” stalls may be used for the following uses as defined herein: residential, general business offices, data processing/telemarketing/operations offices, industrial, storage/wholesale, utility, and educational (except for spaces serving cultural/recreational/entertainment uses at educational campuses).
3. Add 1 ft to stall width for stalls next to curbs and islands to reduce trip hazard.
4. Dimensions may be interpolated for angles between 45 and 75 degrees.
5. Deduct 1 ft from aisle, and corresponding module, for parking in structures or where guides (columns, guardrails, bumper walls) or curbs are provided for at least 25% of the stalls.
6. All dimensions based on design vehicle of 6’7” by 17’3”, parked 9 ft from front of stall.
7. Light poles and columns may protrude into a parking module a maximum of 2 ft combined as long as they do not impact more than 25% of the stalls. For example, either a 1 ft encroachment on both sides of the aisle, or a 2 ft encroachment on one side only, is acceptable.
8. Interlock reductions cannot be taken where there is encroachment by columns, light poles, or other obstructions for more than 25% of the stalls in the bay.
9. All dimensions rounded to the nearest inch.
10. Aisles and corresponding modules are for two-way traffic flow for 90-degree parking and one-way traffic flow for angled parking between 45 and 75 degrees.
11. For two-way traffic flow and angled parking, a minimum 24 ft aisle is required.
12. Parallel parking stalls to be 8 x 22 ft, with 12’0” travel lane. For parallel parking along a two-way drive, a minimum aisle of 24 ft is required.

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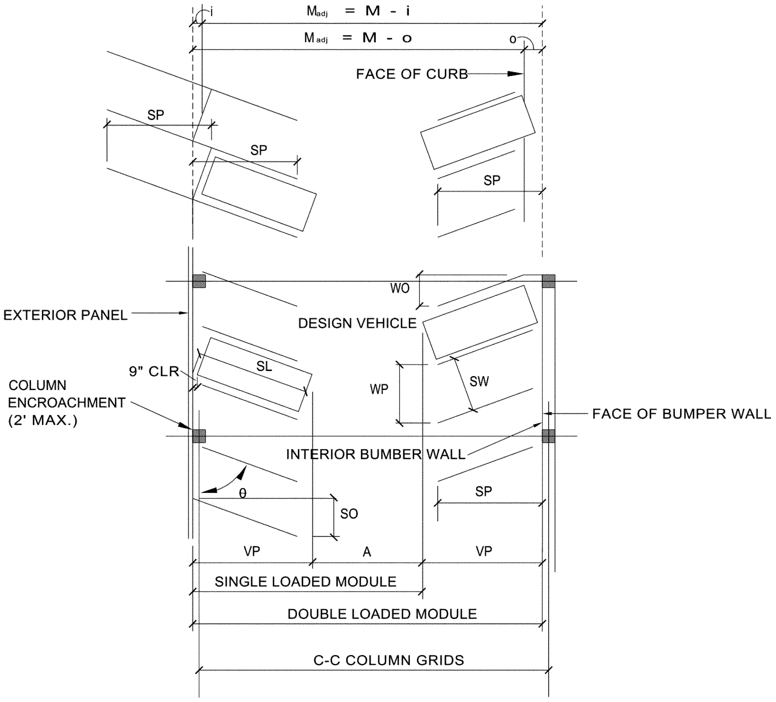

DEFINITION OF BASIC LAYOUT DIMENSIONS

θ = Angle of Park
M = Module
A = Aisle Width
i = Interlock
o = Overhang
SP = Stripe Projection = 16'-6"
VP = Vehicle Projection
WP = Width Projection
SW = Stall Width
SL = Stall Length
WO = Wall Offset
SO = Stripe Offset

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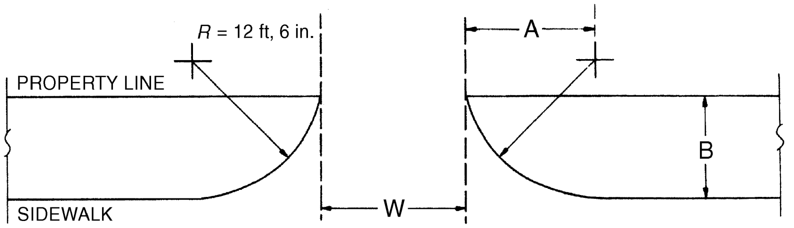
Fig. D.1—Parking space layout plan view and notation used in Table D.1(b).

Table D.2—Suggested dimensions for maneuver areas (Federal Sign and Signal Corp. 1974)

Type	Vehicle width, in. (m)	Wheelbase, in. (m)	Overall length, ft (m)	Minimum turn radius, ft (m)*
Single	96 (2.4)	250 (6.3)	33 (10.0)	45 (13.7)
Tractor-semitrailer	96 (2.4)	138 (3.5)	55 (16.8)	50 (15.2)
Double trailer	96 (2.4)	104 (2.6)	65 (19.8)	50 (15.2)

*Turning radius is measured from the turning center to the outside front wheel of the truck.



A	B	ENTRANCE W	EXIT W
9′9″	4′6″	14′9″	11′6″
10′6″	5′6″	14′0″	10′9″
11′0″	6′6″	13′6″	10′0″
11′6″	7′6″	13′0″	9′6″
12′0″	8′6″	12′6″	9′3″

Table gives curb returns required to permit a car traveling 1 ft from curb to turn into parking lot and clear parked cars by 1 ft. Exit dimensions permit the reverse.

Fig. D.2—Entrance and exit curb returns for parking lots (Federal Sign and Signal Corp. 1974). Note: 1 ft = 1' = 0.348 m; 1 in. = 1" = 25.4 mm.

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Guide for the Design and Construction of Concrete Parking Lots

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