CONCRETE Information

AMERICAN CONCRETE PAVEMENT ASSOCIATION

Design of Concrete Pavement for Streets and Roads

Design and construction standards for streets and roadways should provide for pavements with both long service life and low maintenance. As a guide in achieving this goal, this publication provides designs that meet traffic requirements and will result in the lowest annual cost when considering both initial construction cost and pavement maintenance.

Following are the factors involved in the design process for concrete streets and roads:

1. Street classification and traffic
2. Geometric design
3. Subgrades and subbases
4. Concrete quality
5. Thickness design
6. Jointing
7. Construction specifications

Several other ACPA publications, *Subgrades and Subbases for Concrete Pavements*(1), *Design and Construction of Joints for Concrete Streets*(2), and *Construction Specification Guideline for Concrete Streets and Local Roads*(3), discuss the details of subgrades and subbases, jointing practices, and specifications in much greater detail.

Street Classification and Traffic

Comprehensive traffic studies have shown that streets of similar character have essentially the same traffic densities and axle load intensities. A practical approach to thickness design is to establish a street classification system that provides an axle load distribution for the various categories of streets. This information sheet has divided street pavements into six different classifications. Descriptions for each classification include traffic volumes, types of vehicles, and maximum axle loadings. These classifications are listed in the Thickness Design section of this document.

Design Considerations

Utilities

During the construction of new subdivisions and commercial developments, utilities are commonly placed in the right-of-way outside the pavement area to facilitate maintenance, possible additions, and upgrades to utility systems. Present and future needs must be evaluated and provisions made for utilities. Forethought can eliminate the tearing up of existing pavements for work on utilities. In some instances, particularly for older infrastructure, underground utilities must be located within the paved area. In these cases, it is usually recommended to incorporate the pavement construction project with utility replacement, such as sewers, water mains, gas lines, and electrical and communications conduits.

Integral Curbs

A practical and economical way to build concrete pavements for streets is with an integral curb section. An integral curb is constructed with the pavement in a single operation — all concrete work being done simultaneously. When using forms, the curb is easily shaped with a template and straightedge as the pavement is placed. Integral curbs can also be constructed to almost any desired cross section using a slipform paver.

Integral curbs offer a structural benefit, providing additional support along the edge of the pavement. When they are used, stresses and deflections at the pavement edge are reduced, thus increasing the structural capacity of the pavement, or conversely, allowing a decrease in the design pavement thickness. Pavement engineers should consider the inherent advantages and economy of integral curb construction for street pavements.

Additional methods of edge support for improved structural capacity include tied curb and gutter, widened lanes, parking lanes, or in rural areas, tied concrete shoulders. Widened lanes are achieved by paving the lane wider than the typical lane width by 1.5 to 2 ft (0.5 to 0.7 m) (create a 13.5 to 14 ft [4.1 to 4.3 m] wide lane) and then striping the pavement at typical lane width to ensure that wheel loads are no closer than 18 inches (0.5 m) from the free edge. By keeping the loads away from the free edge, edge load stresses in the pavement will be lower.

Street Widths

Street widths vary according to the traffic as well as other constraints. The minimum recommended width for 2-lane streets, except in unusual cases, is 25 ft (7.6 m) with a maximum cross slope of 2 percent (1/4 in. per foot [20 mm per meter] of width). Consistent lane widths and cross slope are desirable. See Figure 4 on page 15.

Traffic lanes are customarily 10 to 12 ft (3.0 to 3.7 m) wide. Lanes that are striped to be over 12 ft (3.7 m) are not recommended since experience has shown that drivers will attempt to pass on wider single lanes, decreasing safety.

Parking lanes along the curb are usually 7 to 8 ft (2.1 to 2.4 m) wide. A 7-ft (2.1-m) lane is used where passenger cars predominate, and an 8-ft (2.4-m) lane where trucks must be accommodated. Parking lanes of 6 ft (1.8 m) are not recommended. On major streets, parking lanes are 10 to 12 ft (3.0 to 3.7 m) wide and they can also be used as travel or turning lanes, especially during peak hours (Figure 5).

On streets where parking is prohibited, an extra 2 ft (0.6 m) width is generally provided along the curb as non-traveled space.

Subgrades and Subbases

Unlike other paving materials, the structural strength of a concrete pavement is largely within the concrete itself due to its rigid nature. Because of the remarkable beam strength of concrete, heavy loads are distributed over large areas resulting in very low pressures on the subgrade. This makes it unnecessary to build up subgrade strength with thick layers of crushed stone or gravel; concrete pavements, when designed and constructed properly, will perform well even on poor soils.

Performance records of undoweled highway pavement show that it is necessary to address the potential for pumping and eroding of the subgrade at pavement joints and edges. Granular (aggregate) subbases serve that purpose because they function not so much as a structural layer, but as a non-pumping layer to reduce the soil erosion under the pavement slab. However, since low-volume roads do not typically fail in this manner, they do not require subbases to prevent the subgrade from pumping. Concrete pavements can be placed directly on a compacted subgrade without concern for pumping or erosion, but a 4- to 6-in. (100- to 150-mm) granular subbase may improve long-term performance. Concrete streets with granular subbase have been shown to carry as much as 30% additional traffic/load compared to streets without a subbase. Granular subbases are also beneficial as a platform for construction.

It is important that subgrade soils are uniform, compactable, and stable for satisfactory long-term pavement performance. Abrupt changes in subgrade uniformity can result in heaving subgrade soils from frost action (in northern climates), or shrinking and swelling from moisture changes. Nonuniform heaving in these special cases can be controlled by ensuring uniform soil type and treatment. Changes in volume can be substantially reduced by compacting the soil at 1 to 3% above optimum moisture. Any soft spots caused by organic materials present in the subgrade should be removed and replaced with the same type of materials as the surrounding subgrade. Treatment of the subgrade by chemical stabilization can, in many instances, take the place of aggregate subbase.

Additional information on subgrades and subbases can be found in Reference 1.

Concrete Quality

The primary concern in the selection of quality concrete is the assurance of durability. The concrete must remain durable over its intended life span in order to provide an excellent level of service.

In frost-affected areas, concrete pavements must be able to withstand the many cycles of freezing and thawing and the action of deicing salts. It is essential that the concrete mixture have a low water-cement ratio, an adequate cement factor, sufficient entrained air content, and adequate curing. The quantity of air entrainment necessary for weather-resistant concrete varies with the maximum-size aggregate. Table 1 gives the percentages of air content recommended for durable concrete[4,5]. In addition, a proper air-void spacing factor is necessary to ensure freeze-thaw durability.

The quantity of mixing water also has a critical influence on the durability and weather-resistance of hardened concrete. The least amount of mixing water that will produce a plastic, workable mix will result in the greatest durability in hardened concrete. A cementitious content of 564 lb/yd^3 (335 kg/m^3) or a concrete mixture designed to attain 4,000 psi (27.6 MPa) at 28 days, with a maximum water-cementitious ratio as given in Table 2, will significantly increase freeze-thaw and sulfate resistance of the concrete pavement. References 4 and 5 are excellent resources for further study on this topic.

The gradation of the aggregates used in the concrete mixture are also important. A well-graded combined (both coarse and fine fractions) aggregate will reduce mix water demand, result in higher strengths, and be easier to place and finish. The likelihood of a quality concrete mixture is increased if a more well-graded aggregate blend is used.

Table 1. Recommended Air Contents for Durable Concrete

Maximum size aggregate		Total target air content, percent*		Maximum air-void spacing factor**	
in.	mm	Severe exposure	Moderate exposure	in.	mm
3/8	9.5	7.5	6	0.010	0.25
1/2	12.5	7	5.5		
3/4	19.0	6	5		
1	25.0	6	4.5		
1 1/2	37.5	5.5	4.5		
2	50.0	5	4		

* *A reasonable tolerance for air content in field construction is -1 to +2 percentage points.*

** *Can be measured in hardened concrete according to ASTM C 457, or in fresh concrete with the Air Void Analyzer (AVA).*

Table 2. Maximum Permissible Water-Cement Ratio for Durable Concrete Pavement

Type of exposure	Maximum water-cementitious ratio by weight
Freezing/thawing with deicing chemicals	0.45
Severe sulfate exposure [water-soluble sulfate (SO_4) in soil > 0.20 % by weight]	0.45
Moderate sulfate exposure [water-soluble sulfate (SO_4) in soil of 0.10 to 0.20 % by weight]	0.50

Thickness Design

The design procedure presented in this publication utilizes the method and theories that are outlined in *Thickness Design for Concrete Highway and Street Pavements*[6], and the StreetPave software[7]. The results using typical inputs are listed in Tables 15 (a) and (b).

The ACPA design method determines the thickness for jointed plain concrete pavements. By definition, plain pavements are constructed without any distributed reinforcing steel and are the most common concrete pavement type in the world. Control joints are usually spaced at 15 ft (4.6 m) intervals or less, with load transfer at these joints provided through aggregate interlock or steel dowels. Pavements can be designed with or without edge support (concrete shoulder, integral curb and gutter, or tied curb and gutter).

The method uses two limiting criteria for concrete pavement thickness design. The first is erosion, which models how high-volume roads show distress from pumping and erosion of the subgrade or subbase due to high numbers of multiple axle loadings (tandem & tridem) at or near pavement joints or edges. The second criteria is pavement flexural fatigue. This distress occurs on roadways where repetitive axle loadings produce bending stresses in the pavement, eventually resulting in fatigue cracking in the concrete. It is this latter criteria, flexural fatigue cracking, which most often controls the design of street and local road pavements.

The most influential factors in the determination of thickness design are described in the following sections.

Design Period

The design period is the theoretical life of the pavement before it reaches some level of distress or serviceability, usually requiring either major rehabilitation or reconstruction. It does not necessarily represent the actual pavement life, which is typically far greater than design period. The design tables in this publication assume a 30-year design period. For design periods other than 30 years, the ADTT may be adjusted. For example, if a 20-year design period is desired instead of 30 years, the estimated ADTT value is multiplied by a factor of 20/30.

Reliability

The ACPA design procedure incorporates reliability as an input variable. 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. This 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 roadway that is being designed. A relatively high reliability is used for high-traffic, high-speed roadways, while low-traffic, low-speed roads typically require a lower level of reliability.

The importance of this advancement is that it allows the design professional to use appropriate levels of reliability to produce design thicknesses more practical for the design circumstances, particularly for streets and roads. Table 3 lists the recommended reliability levels for roadway design, dependent on the classification of the facility.

The design tables 15(a) and 15(b) were developed using a reliability value of 80 percent, which is common for most street and local road applications and takes into account the variations in materials and layer thicknesses for each traffic category.

The design procedure also incorporates the percentage of slab cracking as another factor used to evaluate the predicted long-term pavement performance. Primarily, this factor assists in planning future maintenance or pavement preservation activities at the end of the pavement's design period. For Tables 15(a) and 15(b), the percent slabs cracked at the end of the design period was set at 15 percent for all roadway classifications. With the reliability at 80%, this means only a 20% chance of having 15% cracked slabs at the end of the design period. For additional information on concrete pavement preservation or restoration, see ACPA publication *The Concrete Pavement Restoration Guide,* Reference 10.

ACPA-recommended slab cracking levels are shown in Table 4. Table 5 shows examples of the relationship between reliability and slab cracking.

Table 3. Levels of Reliability for Pavement Design (Ref. 13)

Functional classification of roadway	Recommended reliability	
	Urban	Rural
Interstates, freeways, and tollways	85 – 99	80 – 99
Principals arterials	80 – 99	75 – 95
Collectors	80 – 95	75 – 95
Residential and local roads	50 – 80	50 – 80

Note: At higher levels of reliability, typically greater than 90 percent, the design thicknesses obtained using StreetPave closely approximate those pavement thicknesses generated using the PCAPAV software.

Table 4. Design Levels of Slab Cracking by Roadway Type

Roadway type	Theoretical percent of slabs cracked at end of design life
(Default)	15%
Interstate highways, expressways, tollways, turnpikes	5%
State roads, arterials	10%
Collectors, county roads	15%
Residential streets	25%

Table 5. Typical Values of Reliability and Percent Cracking

Street classification	Specified reliability	Percent cracking	Actual average percent cracking at end of design period*
Light residential	75%	15%	7.5%
Residential	80%	15%	6%
Collector	85%	10%	3%
Minor arterial	90%	10%	2%
Major arterial	95%	5%	0.5%

**Average percent cracking = (100 – User-specified reliability) * Percent cracking / 50.*

Classifications of Streets and Local Roads

The StreetPave software incorporates four pre-set traffic categories: residential, collector, minor arterial, and major arterial. This publication includes the additional categories of light residential, business, and industrial (see Table 6). Business streets have traffic loadings similar to collector streets, whereas industrial roadways are similar to major arterials in terms of traffic load.

Light Residential. These streets are not long and are found in subdivisions and similar residential areas. They are typically local streets that may end as dead ends or turn-arounds. They serve traffic to approximately 20 to 30 lots or houses. Traffic volumes are low, less than 200 vehicles per day (vpd) with 2-4 trucks per day (ADTT — average daily truck traffic, two directions, excluding two-axle, four-tire trucks). Maximum loads for these streets are 18 kip (80 kN) single axles and 36 kip (160 kN) tandem axles.

Residential. These streets carry similar traffic as light residentials (except more of it) plus an occasional heavy truck. On a grid-type street system, these streets carry traffic serving up to 300 homes as well as collecting all light residential traffic within the area and distributing it into the major street system. Traffic volumes range from 200 to 1000 vpd with approxi-

Table 6. Typical Traffic and Thickness Range for Street and Road Classifications

Street class	Description	Two-way average daily traffic (ADT)	Two-way average daily truck traffic (ADTT)	Typical range of slab thickness
Light residential	Short streets in subdivisions and similar residential areas – often not through-streets.	Less than 200	2 – 4	4.0 – 5.0 in. (100 – 125 mm)
Residential	Through-streets in subdivisions and similar residential areas that occasionally carry a heavy vehicle (truck or bus).	200 – 1,000	10 – 50	5.0 – 7.0 in. (125 – 175 mm)
Collector	Streets that collect traffic from several residential subdivisions, and that may serve buses and trucks.	1,000 – 8,000	50 – 500	5.5 – 9.0 in. (135 – 225 mm)
Business	Streets that provide access to shopping and urban central business districts.	11,000 – 17,000	400 – 700	6.0 – 9.0 in. (150 – 225 mm)
Industrial	Streets that provide access to industrial areas or parks, and typically carry heavier trucks than the business class.	2,000 – 4,000	300 – 800	7.0 – 10.5 in. (175 – 260 mm)
Arterial	Streets that serve traffic from major expressways and carry traffic through metropolitan areas. Truck and bus routes are primarily on these roads.	4,000 – 15,000 (minor) 4,000 – 30,000 (major)	300 – 600 700 – 1,500	6.0 – 9.0 in. (150 – 225 mm) 7.0 – 11.0 in. (175 – 275 mm)

mately 10 to 50 ADTT. Maximum loads for these streets are 22 kip (98 kN) single axles and 36 kip (160 kN) tandem axles.

Collector. These streets collect the traffic from several subdivisions and may be several miles long. They may be bus routes and serve truck movements to and from an area, although they are generally not considered through routes. Traffic volumes vary from 1000 to 8000 vpd with approximately 50 to 500 ADTT. Maximum loads for these streets are 26 kip (116 kN) single axles and 44 kip (196 kN) tandem axles.

Business. Business streets provide land access to stores or commercial areas, and at the same time serve traffic in a central business district. Business streets are frequently congested and speeds are slow due to high traffic volumes, but with a low ADTT percentage. Average traffic volumes vary from 11,000 to 17,000 vpd with approximately 400 to 700 ADTT, with maximum loads similar to collector streets.

Industrial. Industrial streets provide access to industrial areas or parks. Total traffic volumes may be low, but the percentage of trucks is high. Typical traffic volumes are around 2000 to 4000 vpd with an average of 300 to 800 ADTT. Truck volumes are not much different than the business class; however, the maximum axle loads are heavier, 30 kip (133 kN) single axles and 52 kip (231 kN) tandem axles.

Arterials. Arterials bring traffic to and from expressways and serve major movements within and through metropolitan areas not served by expressways. Truck and bus routes are usually on arterials. For design purposes, arterials are divided into major and minor arterials depending on traffic capacity and type. Minor arterials carry about 4000 to 15,000 vpd with 300 to 600 ADTT. Major arterials carry approximately 4000 to 30,000 vpd with 700 to 1500 ADTT and are usually subjected to heavier truck loadings. Maximum loads for minor arterials are 26 kip (116 kN) single axles and 44 kip (196 kN) tandem axles. Major arterials have maximum loads of 30 kip (133 kN) single axles and 52 kip (231 kN) tandem axles.

Truck Traffic Loadings (ADTT) and Axle-Load Distributions

The design method uses the average daily truck traffic in *both* directions (ADTT) to model the loads on the concrete pavement. For the purposes of this document, truck traffic is assumed to be equally distributed in both directions (i.e., 50% each way). The ADTT value can be expressed as ADT (average daily traffic) with percent trucks. Either method can be used for pavement thickness determination.

The default truck axle loadings are distributed according to the roadway classification in Table 7.

Since the ADTT value in the design method represents the average daily traffic over the life of the pavement, the designer must adjust the present ADTT to anticipate any future growth of traffic. When design tables

Table 7. Axle Load Distributions for Street and Road Classifications

Axle load		Axles per 1,000 trucks**				
kips*	kN	Light residential	Residential	Collector	Minor arterial	Major arterial
SINGLE AXLES						
2	9	5000				
4	18	846.15	1693.31			
6	27	369.97	732.28			
8	36	283.13	483.10	233.60		
10	44	257.60	204.96	142.70		
12	53	103.40	124.00	116.76	182.02	
14	62	39.07	56.11	47.76	47.73	
16	71	20.87	38.02	23.88	31.82	57.07
18	80	11.57	15.81	16.61	25.15	68.27
20	89		4.23	6.63	16.33	41.82
22	98		0.96	2.60	7.85	9.69
24	107			1.60	5.21	4.16
26	116			0.07	1.78	3.52
28	125				0.85	1.78
30	133				0.45	0.63
32	142					0.54
34	151					0.19
TANDEM AXLES						
4	18	15.12	31.90			
8	36	39.21	85.89	47.01		
12	53	48.34	139.30	91.15		
16	71	72.69	75.02	59.25	99.34	
20	89	64.33	57.10	45.00	85.94	
24	107	42.24	39.18	30.74	72.54	71.16
28	125	38.55	68.48	44.43	121.22	95.79
32	142	27.82	69.59	54.76	103.63	109.54
36	160	14.22	4.19	38.79	56.25	78.19
40	178			7.76	21.31	20.31
44	196			1.16	8.01	3.52
48	214				2.91	3.03
52	231				1.19	1.79
56	249					1.07
60	267					0.57

* *1 kip = 1,000 lb.*
** *Excludes all two-axle, four-tire trucks.*

[15(a) or 15(b)] are used for pavement design periods greater than 30 years, projection factors from Table 8 may be used to multiply the present-day ADTT to arrive at an estimated average daily truck count over the life of the pavement.

Table 8. Yearly Rates of Traffic Growth and Corresponding Projection Factors*

Yearly rate of traffic growth, %	Projection factor, 40 years	Projection factor, 50 years
1	1.2	1.3
1 1/2	1.4	1.5
2	1.5	1.7
2 1/2	1.7	2.0
3	1.9	2.3
3 1/2	2.1	2.6
4	2.4	3.1
4 1/2	2.7	3.6
5	3.0	4.2
5 1/2	3.4	4.9
6	3.8	5.8

* *Factors represent values at the mid-design period that are widely used in current practice. Another method of computing these factors is based on the average annual value. Differences (both compound interest) between these two methods will rarely affect design.*

Strength of Subgrade or Subbase (k)

The degree of subgrade or subbase support is defined in terms of the Westergaard modulus of subgrade reaction (k). This is determined by ASTM D 1195 (AASHTO T 221) [repetitive] or D 1196 (T 222) [non-repetitive], in which a load in pounds (Newtons) is placed on a 30-in. (760-mm) diameter plate, and the deflection in inches (millimeters) of the plate is measured for that load. The value of k is expressed as pounds per square inch per inch (psi/in.) or more commonly, as pounds per cubic inch (pci) (megapascals per meter or MPa/m).

Table 9 gives typical ranges in k values for different soil types. However, since the plate-loading test is both expensive and time consuming, the value of k is usually correlated to other subgrade support values as shown in Table 10. When a subbase layer is used, the corresponding k-value is improved, and Tables 11, 12, 13, and 14 can be used to estimate the improvement in subgrade support and determine the composite k-value for different subbase types and thicknesses.

Flexural Strength (MR)

Concrete pavements bend under axle loads, producing both compressive and flexural stresses. Since the ratio of compressive stress to compressive strength is relatively small compared to the ratio of flexural stress to flexural strength, the flexural strength of concrete is the controlling factor in pavement design. The flexural strength of concrete is determined by modulus of rupture (MR) tests, usually made on a 6 x 6 x 30-in. (150 x 150 x 760-mm) beam (ASTM C 78 or AASHTO T 97).

(continued on page 11)

Table 9. Subgrade Soil Types and Approximate k-Values

Type of soil	Soil	k-value range
Fine-grained soils in which silt and clay-size particles predominate	Low	75 – 120 pci (20 – 34 MPa/m)
Sands and sand-gravel mixtures with moderate amounts of silt and clay	Medium	130 – 170 pci (35 – 49 MPa/m)
Sands and sand-gravel mixtures relatively free of plastic fines	High	180 – 220 pci (50 – 60 MPa/m)

Table 10. Correlated k-Values for Subgrade Support

Type	Amount of support	Typical k-values, pci (MPa/m)	California bearing ratio (CBR), % (ASTM D 1183)	Resistance value (R-value) (ASTM D 2844)
Fine-grained with high amounts of silt/clay	Low	75 – 120 (20 – 34)	2.5 – 3.5	10 – 22
Sand and sand-gravel with moderate silt/clay	Medium	130 – 170 (35 – 49)	4.5 – 7.5	29 – 41
Sand and sand-gravel with little or no silt/clay	High	180 – 220 (50 – 60)	8.5 – 12	45 – 52

Table 11. Approximate k-Values of Different Base/Subbase Types

Type	Modulus (psi)	Historical k-values (pci)
Silts and clays	3,000	50 – 110
Granular	30,000	150 – 250
Bituminous treated	100,000	300 – 450
Cement treated	1,000,000	400 – 550
Lean concrete (Econocrete)	2,000,000 +	500 +

Table 12. Typical Composite k-Values for Unbound Granular, Aggregate, or Crushed Stone Subbase

Subgrade k-value (pci)	Thickness of unbound granular or crushed stone subbase			
	4"	6"	9"	12"
50	65	75	85	110
100	130	140	160	190
150	176	185	215	255
200	220	230	270	320

Table 13. Typical Composite k-Values for Bituminous Treated/Asphalt Subbase

Subgrade k-value (pci)	Thickness of bituminous treated/asphalt subbase			
	4"	6"	9"	12"
50	85	112	155	200
100	152	194	259	325
150	217	271	353	437
200	280	345	442	541

Table 14. Typical Composite k-Values for Cement Treated/Econocrete Subbase

Subgrade k-value (pci)	Thickness of cement treated/Econocrete subbase			
	4"	6"	9"	12"
50	103	148	222	304
100	185	257	372	496
150	263	357	506	664
200	348	454	634	823

Table 15(a). Concrete Thickness (inches), 30-Year Design WITH Concrete Curb and Gutter or Concrete Shoulders

Traffic classification	k = 100 pci Modulus of rupture (psi)			k = 150 pci Modulus of rupture (psi)			k = 200 pci Modulus of rupture (psi)			k = 300 pci Modulus of rupture (psi)		
	550	600	650	550	600	650	550	600	650	550	600	650
Light residential												
2-lane ADTT = 3	5.0	5.0	4.5	5.0	4.5	4.5	4.5	4.5	4.0	4.5	4.0	4.0
Residential												
2-lane ADTT = 10	5.5	5.5	5.0	5.5	5.0	5.0	5.0	5.0	4.5	5.0	4.5	4.5
ADTT = 20	6.0	5.5	5.5	5.5	5.5	5.0	5.5	5.0	5.0	5.0	5.0	4.5
ADTT = 50	6.0	6.0	5.5	5.5	5.5	5.0	5.5	5.0	5.0	5.0	5.0	4.5
Collector												
2-lane ADTT = 50	6.5	6.0	6.0	6.0	6.0	5.5	6.0	5.5	5.5	5.5	5.5	5.0
ADTT = 100	6.5	6.5	6.0	6.5	6.0	6.0	6.0	6.0	5.5	6.0	5.5	5.5
ADTT = 500*	7.0	6.5	6.5	6.5	6.5	6.0	6.5	6.0	6.0	6.0	6.0	5.5
Business												
2-lane ADTT = 400*	7.0	6.5	6.5	6.5	6.5	6.0	6.5	6.0	6.0	6.0	6.0	5.5
ADTT = 700*	7.0	7.0	6.5	7.0	6.5	6.0	6.5	6.0	6.0	6.0	6.0	5.5
Minor arterial												
4-lane ADTT = 300*	7.5	7.5	7.0	7.5	7.0	6.5	7.0	6.5	6.5	6.5	6.5	6.0
ADTT = 600*	8.0	7.5	7.0	7.5	7.0	7.0	7.5	7.0	6.5	7.0	6.5	6.5
Industrial												
4-lane ADTT = 300*	8.0	8.0	7.5	8.0	7.5	7.0	7.5	7.0	7.0	7.0	7.0	6.5
ADTT = 800*	8.5	8.0	8.0	8.0	7.5	7.5	8.0	7.5	7.0	7.5	7.0	7.0
Major arterial												
4-lane ADTT = 700*	8.5	8.0	7.5	8.0	7.5	7.5	8.0	7.5	7.0	7.5	7.0	6.5
ADTT = 1100*	8.5	8.0	8.0	8.0	8.0	7.5	8.0	7.5	7.0	7.5	7.0	7.0
ADTT = 1500*	8.5	8.5	8.0	8.5	8.0	7.5	8.0	7.5	7.5	7.5	7.5	7.0

* Dowels recommended when ADTT is greater than or equal to 80:

1. If pavement thickness is 6" or less dowels not recommended
2. If pavement thickness is 6.5" to 7.5" use 1" dowels
3. If pavement thickness is 8" or greater use 1¼" dowels

CONVERSIONS

1 in. = 25.4 mm

100 psi = 0.689 MPa

100 pci = 27.15 MPa/m

NOTES FOR BOTH TABLES 15(a) and 15(b):

1. *Concrete pavement thicknesses rounded up to the nearest ½ inch. In some cases this will increase the design life significantly. If exact thicknesses and design life are desired, the StreetPave software program[7] should be used to develop a complete pavement analysis.*
2. *The ADTT value listed includes both directions of travel, over all lanes of traffic.*
3. *For light residential, residential, and collector, a 2-lane design was used with each lane carrying a total of 50 percent of the traffic.*
4. *For business, minor arterial, industrial, and major arterial a 4-lane category was chosen with 90 percent traffic used in the drive lane for thickness design. If multiple lanes are used between 6 to 10 total lanes, the pavement thickness will likely be reduced.*
5. *The total percent slabs cracked for the design period listed above is set at 15 percent for all designs. If the reliability (set at 80% for these Tables) is decreased or if the allowable percent slabs cracked is increased, the resulting pavement cross-sections will be reduced.*

Table 15(b). Concrete Thickness (inches), 30-Year Design WITHOUT Concrete Curb and Gutter or Concrete Shoulders

	k = 100 pci			k = 150 pci			k = 200 pci			k = 300 pci		
	Modulus of rupture (psi)			Modulus of rupture (psi)			Modulus of rupture (psi)			Modulus of rupture (psi)		
Traffic classification	550	600	650	550	600	650	550	600	650	550	600	650
Light Residential												
ADTT = 3	6.0	5.5	5.5	5.5	5.5	5.0	5.5	5.0	5.0	5.0	5.0	4.5
Residential												
2-lane ADTT = 10	6.5	6.5	6.0	6.5	6.0	6.0	6.0	6.0	5.5	6.0	5.5	5.5
ADTT = 20	7.0	6.5	6.0	6.5	6.0	6.0	6.5	6.0	5.5	6.0	5.5	5.5
ADTT = 50	7.0	7.0	6.5	7.0	6.5	6.0	6.5	6.0	6.0	6.0	6.0	5.5
Collector												
2-lane ADTT = 50	7.5	7.0	7.0	7.0	7.0	6.5	7.0	6.5	6.5	6.5	6.5	6.0
ADTT = 100	8.0	7.5	7.0	7.5	7.0	6.5	7.0	7.0	6.5	7.0	6.5	6.0
ADTT = 500*	8.0	8.0	7.5	8.0	7.5	7.0	7.5	7.0	7.0	7.0	7.0	6.5
Business												
2- or ADTT = 400*	8.0	8.0	7.5	7.5	7.5	7.0	7.5	7.0	7.0	7.0	7.0	6.5
4-lane ADTT = 700*	8.5	8.0	7.5	8.0	7.5	7.0	7.5	7.5	7.0	7.5	7.0	6.5
Minor Arterial												
4-lane ADTT = 300*	9.0	8.5	8.0	8.5	8.0	7.5	8.0	8.0	7.5	8.0	7.5	7.0
ADTT = 600*	9.5	9.0	8.5	9.0	8.5	8.0	8.5	8.0	7.5	8.0	7.5	7.5
Industrial												
4-lane ADTT = 300*	9.5	9.0	8.5	9.0	8.5	8.0	8.5	8.5	8.0	8.5	8.0	7.5
ADTT = 800*	10.0	9.5	9.0	9.5	9.0	8.5	9.0	9.0	8.0	8.5	8.0	8.0
Major Arterial												
4-lane ADTT = 700*	10.0	9.5	9.0	9.5	9.0	8.5	9.0	8.5	8.0	8.5	8.0	8.0
ADTT = 1100*	10.0	9.5	9.0	9.5	9.0	8.5	9.0	8.5	8.5	8.5	8.5	8.0
ADTT = 1500*	10.0	9.5	9.0	9.5	9.0	8.5	9.0	9.0	8.5	9.0	8.5	8.0

* Dowels recommended when ADTT is greater than or equal to 80:

1. If pavement thickness is 6" or less dowels not recommended
2. If pavement thickness is 6.5" to 7.5" use 1" dowels
3. If pavement thickness is 8" or greater use 1¼" dowels

CONVERSIONS

1 in. = 25.4 mm

100 psi = 0.689 MPa

100 pci = 27.15 MPa/m

(continued from page 8)

For thickness determinations using Table 15, the average modulus of rupture at 28 days should be used. The average 28-day strength is usually at least 10 to 15 percent greater than the minimum strengths commonly specified for accepting concrete at 28 days.

If compressive strength tests (ASTM C 39, AASHTO T 22, or CSA A23.2-9C) are used to evaluate the quality of the concrete, the relationship between the flexural strength and the compressive strength should be determined for the mix design under consideration. An approximate relationship between flexural and compressive strength is (8):

$$MR = K\sqrt{f'_c}$$

where:

MR = flexural strength, (in psi or MPa), for third-point loading

K = constant, usually between 7.5 and 10 (for psi) or between 0.7 and 0.8 for metric (MPa) (See Figure 1)

f'_c = compressive strength (in psi or MPa)

Concrete continues to gain strength with age as shown in Figure 2. Strength gain is shown for two different types of cement, representing average strength values for several series by laboratory tests, field-cured test beams, and sections of concrete taken from pavements in service.

In this design procedure the effects of variations in concrete strength from point to point in the pavement and gains in concrete strength with age are incorporated in the design charts and tables. The designer does not directly apply these effects but simply selects the average 28-day strength value.

Jointing

Joints must be carefully designed and constructed to ensure good performance. Except for construction joints, which divide paving work into convenient increments, joints in concrete pavements are used to keep stresses within safe limits and to prevent formation of irregular cracks. Guidelines for jointing can be found in *Design and Construction of Joints for Concrete Streets*(2), and joint layout procedures for streets and intersections are given in *Intersection Joint Layout*(11). See Figure 1 for details and cross-sections of joint types.

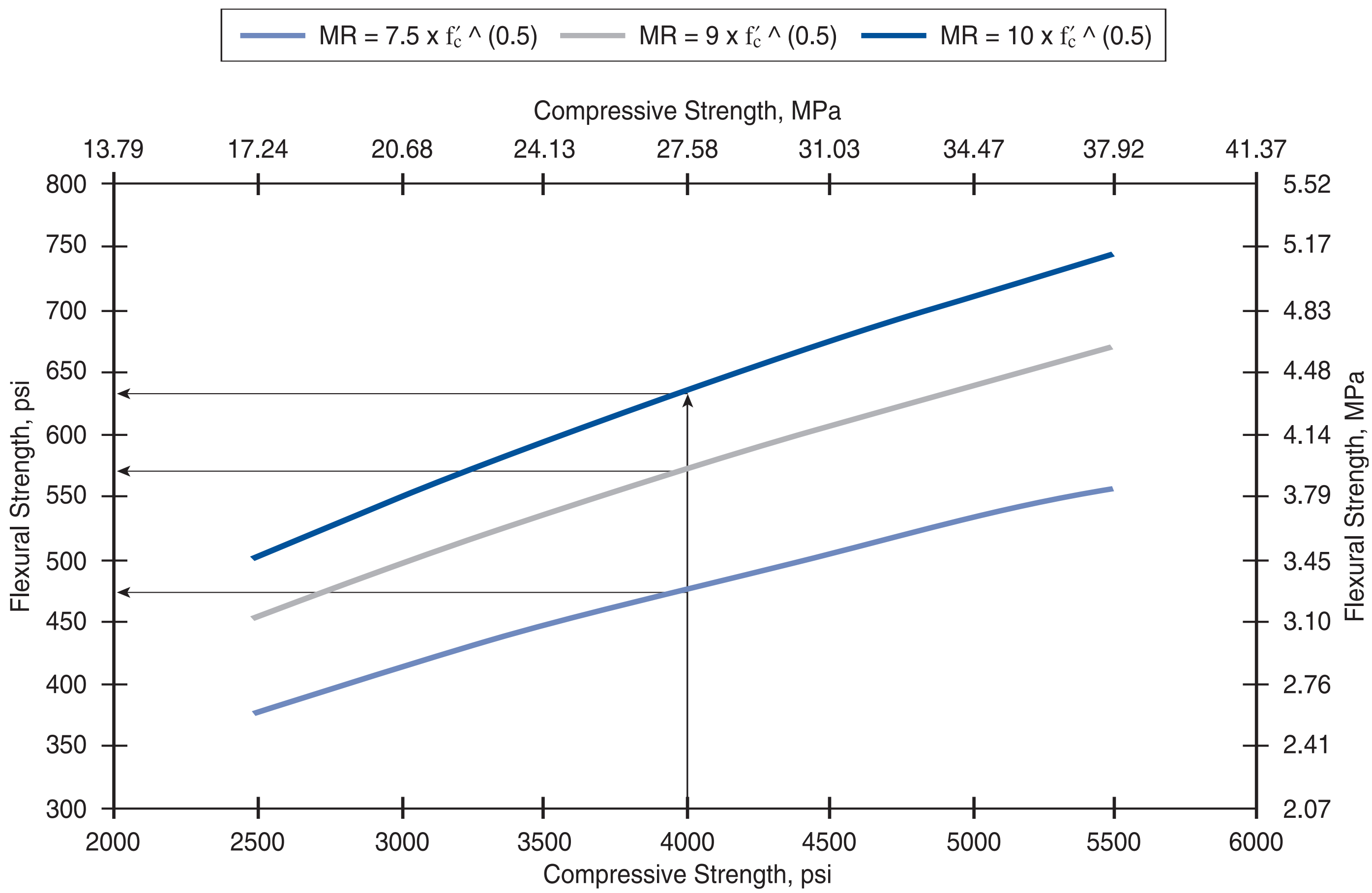

Figure 1. Plot showing the range in correlation constants for compressive to flexural strength conversion. Exact correlation constant will be mix-specific.

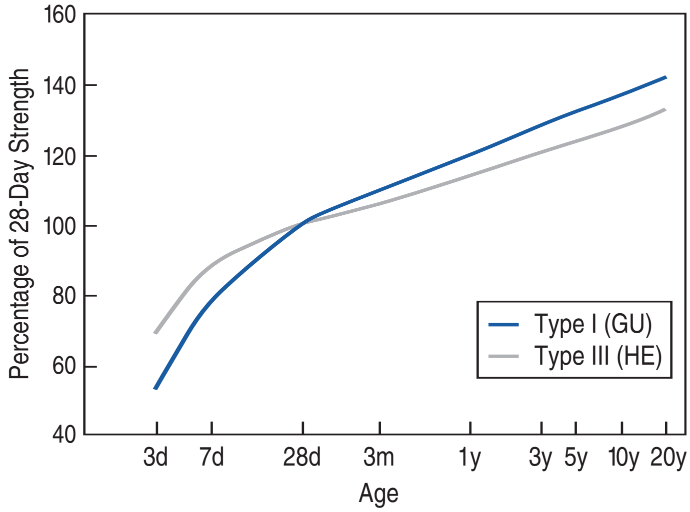

Figure 2. Representation of concrete strength gain with age for two different cement types. (Ref. 9)

Longitudinal Joints

Longitudinal joints are installed to control longitudinal cracking and to divide the pavement into paving lanes. They are often spaced to coincide with travel lane markings — at 8- to 12-ft (2.4- to 3.7-m) intervals — but are not required to do so (see Figures 4, 5 and 6). Longitudinal joint spacing should not be greater than 14 ft (4.3 m) unless local experience has shown that the pavements will perform satisfactorily. With thinner pavements 6 in. (150 mm) and less, slab widths may need to be less than 14 ft (4.3 m) to prevent cracking. The depth of longitudinal joints should be one-third of the pavement thickness (D/3) when using conventional saws. Street pavements with curb and gutter are restrained by the backfill behind the curbs, which can eliminate the need for tying longitudinal joints with deformed tiebars.

Transverse Joints

Transverse contraction joints are used to control transverse cracking. Contraction joints (1) relieve tensile stresses that occur when the slab contracts and (2) limit curling and warping stresses caused by differential temperatures and moisture contents within slab. Most contraction joints are constructed by sawing after the concrete has achieved initial set. Selection of the jointing method to be used is normally based on the economies of the operation. In any case, the depth of the joints in streets and roads should be a minimum of one-fourth (D/4) of the as-built pavement thickness when using conventional saws, unless the pavement is built on stabilized (cement or asphalt) subbase, in which the depth should be one-third (D/3). Early-entry saws do not require saw cuts to be as deep.

Distributed steel or wire mesh is not needed in concrete pavements. It only serves to hold the edges of uncontrolled cracks tightly together. Distributed steel and wire mesh do not add to the structural strength of the pavement. If transverse contraction joints are properly spaced, no intermediate cracking should occur and distributed steel should be omitted. Thus it is necessary to determine the contraction-joint spacing that will control cracking.

In general, for plain jointed concrete street pavements, the ***transverse joint spacing should not exceed 24 times the pavement thickness, with a maximum spacing of 15 ft. (4.6 m)***. Table 16 lists recommended joint spacings for street pavements. However, data from a large number of surveys have shown significant variations in joint spacing; therefore, local service records are the best guide for establishing a joint spacing that will effectively control transverse cracking and yield a well-performing concrete pavement.

The need for dowels in transverse contraction joints depends on the service to be required of the pavement. Dowel bars are not needed in residential pavements or other light traffic streets, but they may be needed on arterial streets carrying significant amounts of truck traffic with pavement thicknesses less than 6.5 in. (165 mm). Pavements 6.5 in. (165 mm) and greater should follow dowel recommendations in Tables 15(a) and 15(b). ***Isolation joints are not required except at fixed objects and asymmetrical intersections***[12]. See Reference 2 for additional information on jointing practices for concrete streets.

Table 16. Recommended Maximum Transverse Joint Spacing for Plain Concrete Pavements

Pavement thickness	Max. joint spacing*
4 in. (100 mm)	8 ft (2.4 m)
5 in. (125 mm)	10 ft (3.0 m)
6 in. (150 mm)	12 ft (3.7 m)
7 in. (175 mm)	14 ft (4.3 m)
8 in. (200 mm) or more	15 ft (4.6 m)

** Can vary if local experience indicates; depends on climate, base types, and concrete properties. Shorter joint spacing is always better to reduce potential of cracking and to reduce joint opening.*

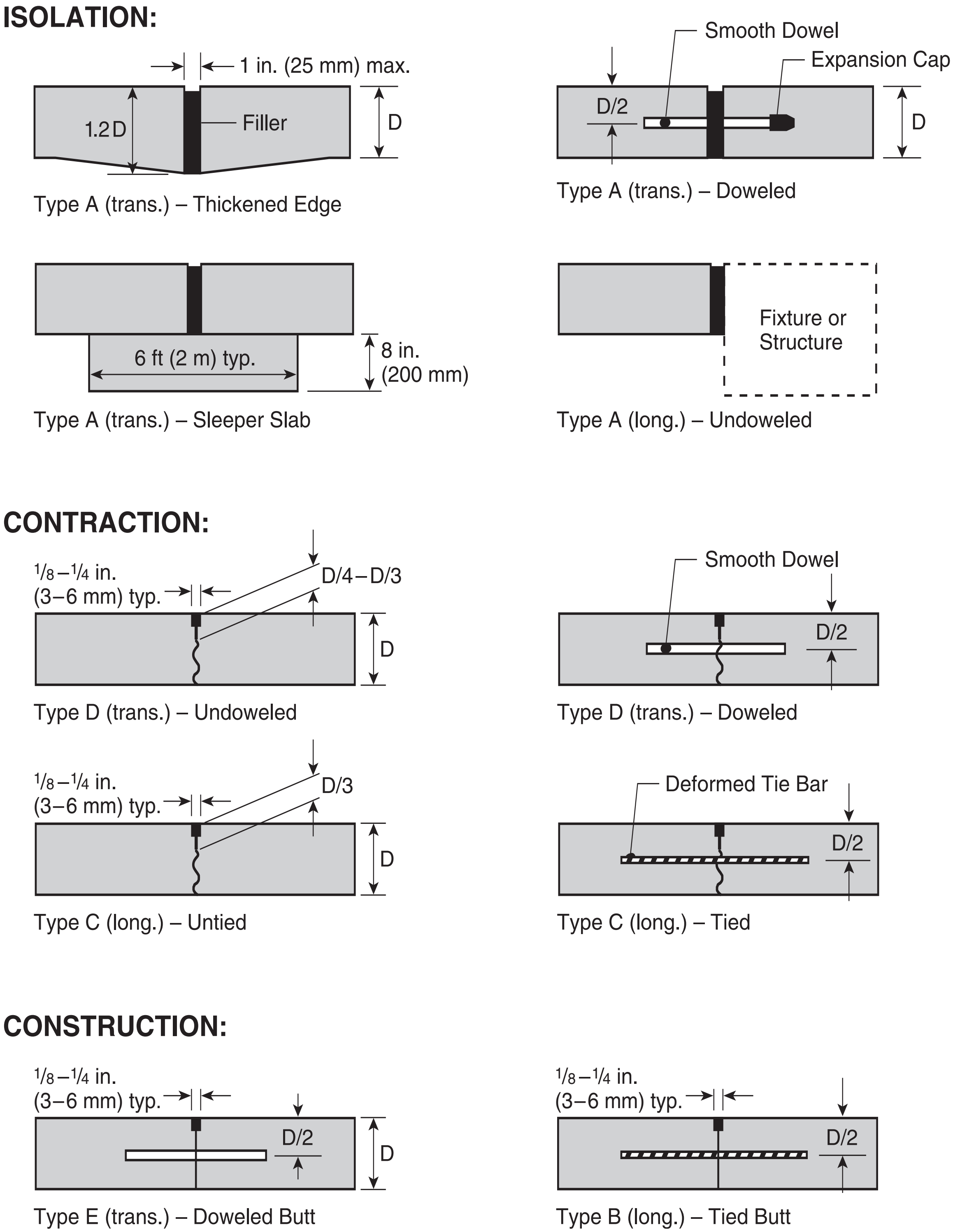

Figure 3. Cross sections of different joint types.

BASIC TWO-LANE SECTION
Not to scale

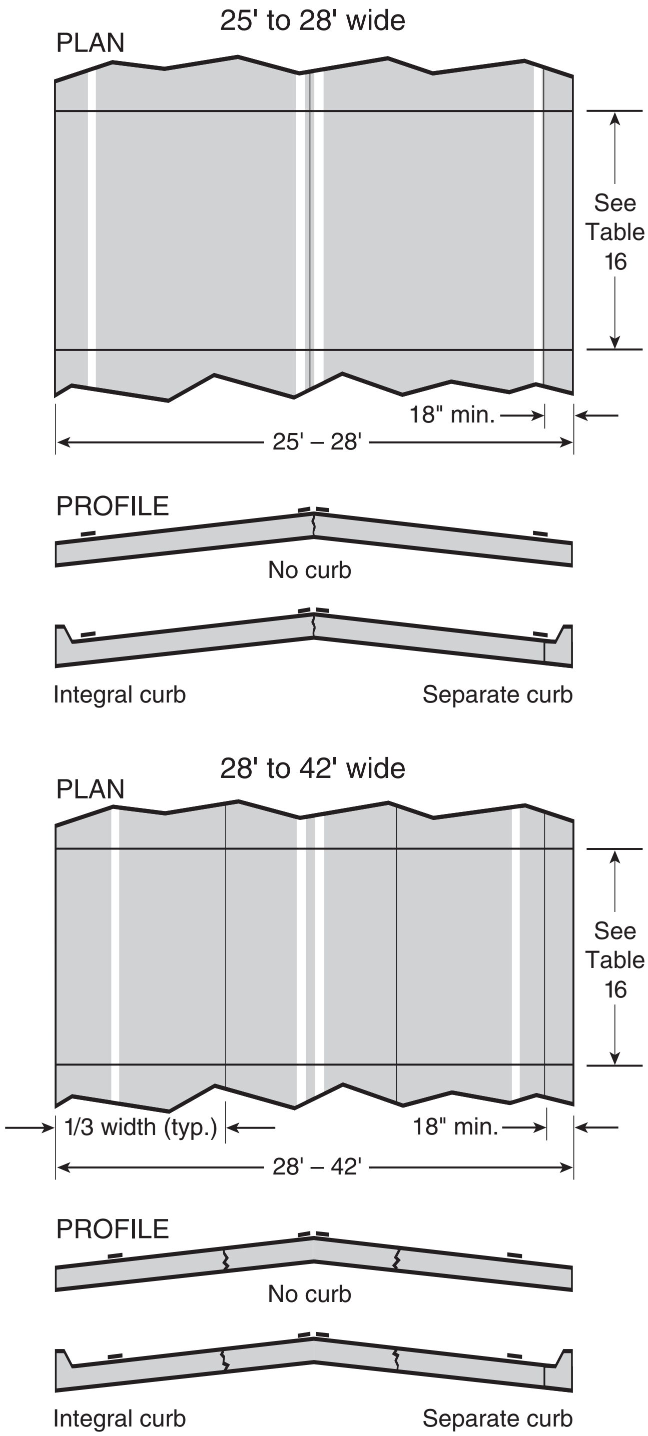

Figure 4.

BASIC SECTION WITH PARKING
Not to scale

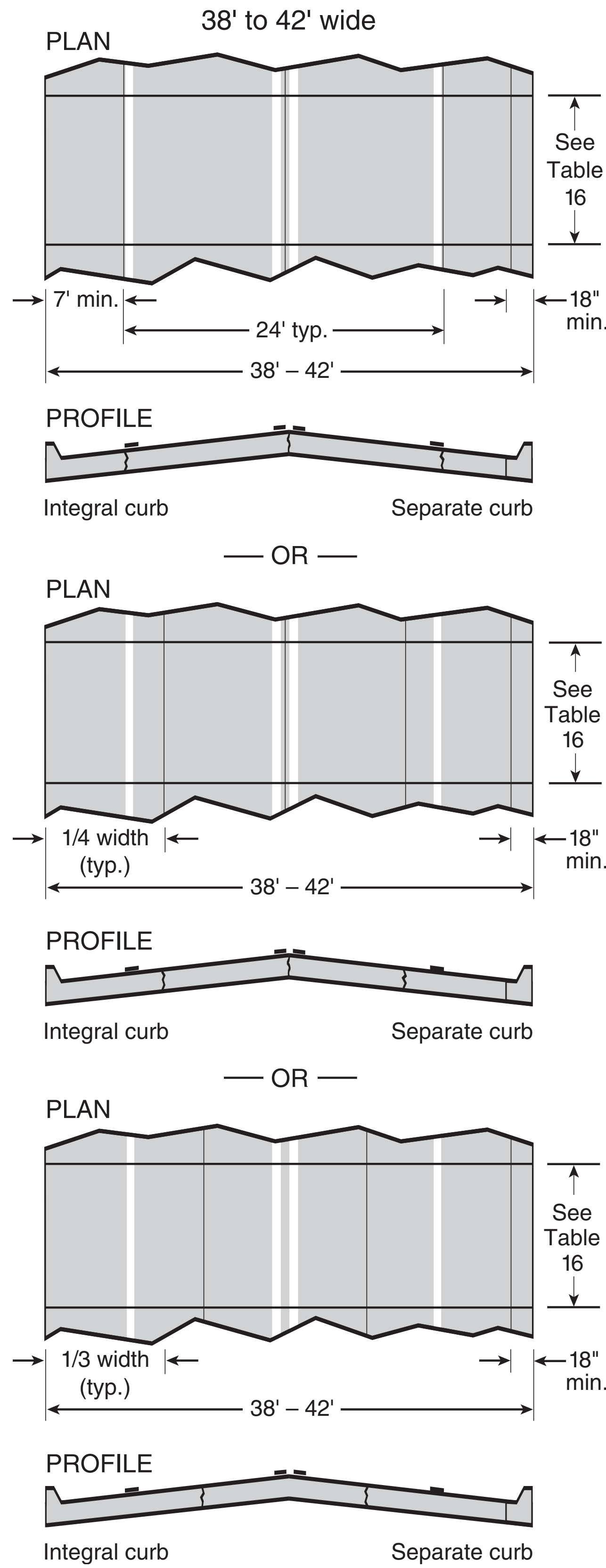

Figure 5.

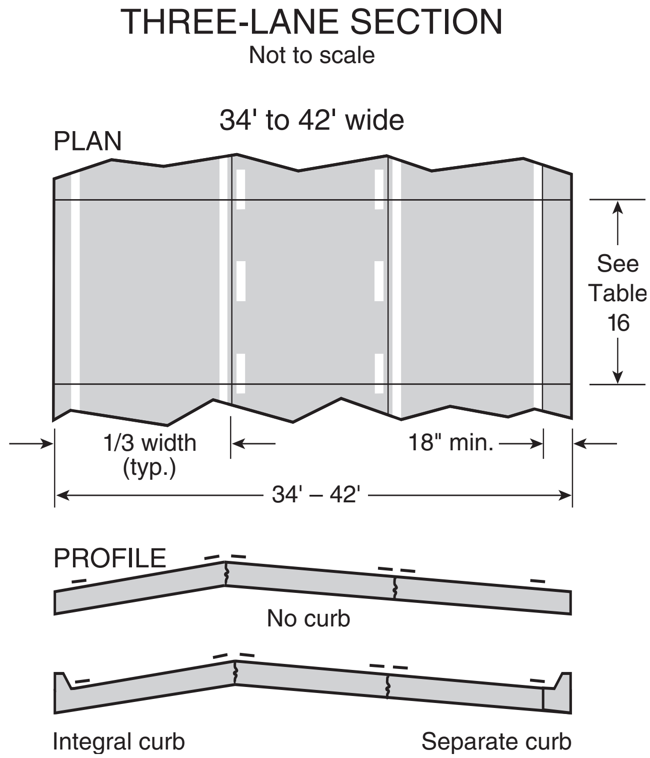

Figure 6.

Construction Specifications

Although it is not the intent of this document to cover construction specifications, it should be emphasized that a good performing pavement depends not only on its design and materials, but also on adequate specifications and quality workmanship. Suggested specifications(3) are available from the ACPA for streets and roads.

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