ASCE STANDARD

ASCE/T&DI/ICPI 58–10

Structural Design of Interlocking Concrete Pavement for Municipal Streets and Roadways

This document uses both the International System of Units (SI) and customary units

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ICPI INTERLOCKING CONCRETE PAVEMENT INSTITUTE

T&DI TRANSPORTATION & DEVELOPMENT INSTITUTE

American Society of Civil Engineers

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ASCE/EWRI 2-06 Measurement of Oxygen Transfer in Clean Water
ANSI/ASCE 3-91 Standard for the Structural Design of Composite Slabs and ANSI/ASCE 9-91 Standard Practice for the Construction and Inspection of Composite Slabs
ASCE 4-98 Seismic Analysis of Safety-Related Nuclear Structures
Building Code Requirements for Masonry Structures (ACI 530-02/ASCE 5-02/TMS 402-02) and Specifications for Masonry Structures (ACI 530.1-02/ASCE 6-02/TMS 602-02)
ASCE/SEI 7-10 Minimum Design Loads for Buildings and Other Structures
SEI/ASCE 8-02 Standard Specification for the Design of Cold-Formed Stainless Steel Structural Members
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ASCE/EWRI 13-05 Standard Guidelines for Installation of Urban Subsurface Drainage
ASCE/EWRI 14-05 Standard Guidelines for Operation and Maintenance of Urban Subsurface Drainage
ASCE 15-98 Standard Practice for Direct Design of Buried Precast Concrete Pipe Using Standard Installations (SIDD)
ASCE 16-95 Standard for Load Resistance Factor Design (LRFD) of Engineered Wood Construction
ASCE 17-96 Air-Supported Structures
ASCE 18-96 Standard Guidelines for In-Process Oxygen Transfer Testing
ASCE 19-96 Structural Applications of Steel Cables for Buildings
ASCE 20-96 Standard Guidelines for the Design and Installation of Pile Foundations
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SEI/ASCE 32-01 Design and Construction of Frost-Protected Shallow Foundations
EWRI/ASCE 33-01 Comprehensive Transboundary International Water Quality Management Agreement

EWRI/ASCE 34-01 Standard Guidelines for Artificial Recharge of Ground Water
EWRI/ASCE 35-01 Guidelines for Quality Assurance of Installed Fine-Pore Aeration Equipment
CI/ASCE 36-01 Standard Construction Guidelines for Microtunneling
SEI/ASCE 37-02 Design Loads on Structures during Construction
CI/ASCE 38-02 Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data
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ASCE/EWRI 42-04 Standard Practice for the Design and Operation of Precipitation Enhancement Projects
ASCE/SEI 43-05 Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities
ASCE/EWRI 44-05 Standard Practice for the Design and Operation of Supercooled Fog Dispersal Projects
ASCE/EWRI 45-05 Standard Guidelines for the Design of Urban Stormwater Systems
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ASCE/SEI 55-10 Tensile Membrane Structures
ASCE/T&DI/ICPI 58-10 Structural Design of Interlocking Concrete Pavement for Municipal Streets and Roadways

FOREWORD

Interlocking concrete pavers can provide a durable and effective pavement system, but, as with any pavement, proper design, construction, and maintenance procedures are required. This standard guideline has been prepared by the ASCE/T&DI Structural Design of Interlocking Concrete Pavement Standards Committee. It establishes guidelines for developing appropriate pavement structures for various traffic and subgrade conditions. The overall goal of this standard guideline is to assist the industry and public by establishing structural design standards for interlocking concrete pavements.

It is recognized that the trend in North America is towards the development and implementation of mechanistic-empirical design protocols. While efforts are underway by the interlocking concrete pavement industry to move towards adopting a mechanistic-empirical design procedure, the required data to implement such a procedure is not yet available and therefore this standard guideline was developed based on the 1993 AASHTO *Guide for Design of Pavement Structures* (AASHTO 1993).

The development of this standard guideline is a result of a partnership between the Transportation and Development Institute of ASCE and the Interlocking Concrete Pavement Institute. The organizations jointly encouraged expert volunteers to become a part of the standards committee that developed the standard guideline and supported the efforts of that committee. This committee comprises individuals from many backgrounds, including consulting engineering, research, design and manufacturing, education, government, and private practice.

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CONTENTS

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1
GENERAL

1.1 SCOPE

The provisions of this Standard Guideline establish the procedures for the structural design of interlocking concrete pavements. This Standard applies to paved areas subject to applicable permitted axle loads and trafficked up to 10 million 80-kN (18,000-lb)-equivalent single axle loads (ESALs). A minimum 80-mm (3 1⁄8–in.) thick paver is used in the standard guideline as this is the minimum thickness recommended for municipal roadways. This Standard Guideline applies to roadways with a design speed of up to 70 kph (45 mph). Many of the design considerations herein require a working knowledge of soil mechanics, traffic loading, and pavement materials. Such knowledge is necessary for the application of this Standard Guideline.

This Standard Guideline applies only to the design of new pavement structures surfaced with interlocking concrete pavers. The Standard Guideline includes structural design guidelines for untreated, asphalt-treated, and cement-treated bases. Asphalt concrete (hot mix asphalt) bases are considered on a limited basis for high traffic, low subgrade strength conditions as a means to reduce the overall thickness of the pavement.

The Standard Guideline does not include provisions for inclusion of interlocking concrete pavers on a portland cement concrete (PCC) base. This Standard Guideline does not address aspects such as project-specific details, specifications, construction, and maintenance practices that are critical to the successful performance of the pavement. Other references should be consulted for the design of these pavement systems.

1.2 REFERENCED STANDARDS

In addition to provincial, state, and local pavement design procedures and guidelines having jurisdiction, the provisions of this Standard Guideline's References should be considered where they apply and where noted.

1.3 DEVIATIONS FROM THIS STANDARD GUIDELINE

Use of proprietary, new, and/or improved interlocking concrete pavement, materials, evaluation techniques, and installation methods are not prohibited, as long as the design and installation of the pavement are shown to comply with or exceed these Standard Guidelines.

1.4 ENGINEER REQUIRED

Work covered by this Standard Guideline should be carried out under the guidance of a Professional Engineer with a background in the design of pavement systems. The Professional Engineer is hereinafter referred to as the Engineer.

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2
PREPARATION FOR PAVEMENT DESIGN

Interlocking concrete pavers can provide a durable and effective pavement system, but, as with any pavement, proper design, construction, and maintenance procedures are required. Information on site conditions, expected traffic loadings and repetitions, and desired design life is required as it is for any other pavement system.

The Engineer has a responsibility to apply scientific and engineering methods. The result of the application of those methods is only as good as the data used. Chapter 3, Design Elements, describes the various elements required to complete the structural design of the pavement.

It is important that the Engineer adequately investigate the physical conditions on the project site and the anticipated use of the pavement to adequately determine an appropriate value for each of those elements. Requirements for an adequate investigation will vary from location to location.

This document does not dictate the means and methods to be used by the Engineer. Means and methods must be appropriate to the project.

3
DESIGN ELEMENTS

3.1 GENERAL

This Standard Guideline relies on the flexible pavement design procedure described in the 1993 American Association of State Highway and Transportation Officials *Guide for Design of Pavement Structures* (AASHTO 1993). The 1993 AASHTO Guide procedure for flexible pavements has been used in the development of this Standard Guideline because research studies have shown that the load distribution and failure modes of an interlocking concrete pavement are similar to those of other flexible pavement systems (i.e., the main failure mode is increasing roughness due to repetitive shear deformations). The method has been condensed to a series of design tables that provide minimum thickness for bases and subbases given the design traffic and characterization of the subgrade soil strength and drainage.

The Engineer should determine pavement cross sections and base/subbase thicknesses considering the design elements as described in the subsequent sections and in the design process outlined in Fig. 3-1.

Figure 3-1 illustrates a flow chart for this design method. The design utilizes 80-mm ($3\frac{1}{8}$-in.)-thick pavers and 25-mm (1-in.; prior to compaction) bedding sand as well as assumptions about the strength of base and subbase materials as described in this section.

3.2 DESIGN PRINCIPLES

The basis of the design tables in Chapter 4 are developed from the AASHTO (1993) flexible pavement design method, which can be summarized using the following equation:

$$\log(W) = Z_R \times S_0 + 9.36 \times \log(SN+1) - 0.20 + \frac{\log\left[\frac{p_i - p_t}{p_i - 1.5}\right]}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \times \log(M_R) - 8.07 \qquad (3\text{-}1)$$

where:

W = design traffic load in equivalent single axle loads (ESALs)
Z_R = standard normal deviate for reliability R
S_0 = overall standard deviation
SN = structural number of the pavement, calculated as $\Sigma\, a_i \times d_i$, where
  a_i = structural layer coefficient per layer i
  d_i = layer thickness per layer i
p_i = initial serviceability
p_t = terminal serviceability
M_R = subgrade resilient modulus (units must be U.S. Customary)

3.3 DESIGN LIFE

The design life of a pavement is the intended years of service from the pavement structure prior to major rehabilitation. Major rehabilitation typically consists of removal of the pavers and bedding sand layer, repairs to the base material, and drainage improvements and replacement of the bedding sand and pavers. Rehabilitation is typically required to address shear failure of the bedding sand, base, subbase, or subgrade soils as typically indicated by surface deformation from wheel loads or settlements. Design life in this Standard Guideline is the pavement structure required to accommodate the designed number of ESALs.

3.4 DESIGN RELIABILITY

The reliability design concepts are generally incorporated into the way the pavement designer assembles pavement design inputs. For the AASHTO (1993) design procedure, the higher the selected reliability and standard deviation, the higher the design ESALs used in the design. The effect of the reliability and standard deviation are factored from the actual ESALs using the following equation:

$$\log(\text{design ESALs}) = \log(\text{actual ESALs}) + Z_R \times S_0 \qquad (3\text{-}2)$$

For this Standard Guideline, a constant reliability level of 75% ($Z_R = 0.67$) and standard deviation of 0.45 have been selected. This represents a low- to medium-reliability level, which is typical for low-speed municipal roadways. Using Eq. 3-2 and an actual ESAL value of 1,000,000, the reliability function of the AASHTO (1993) design equation would

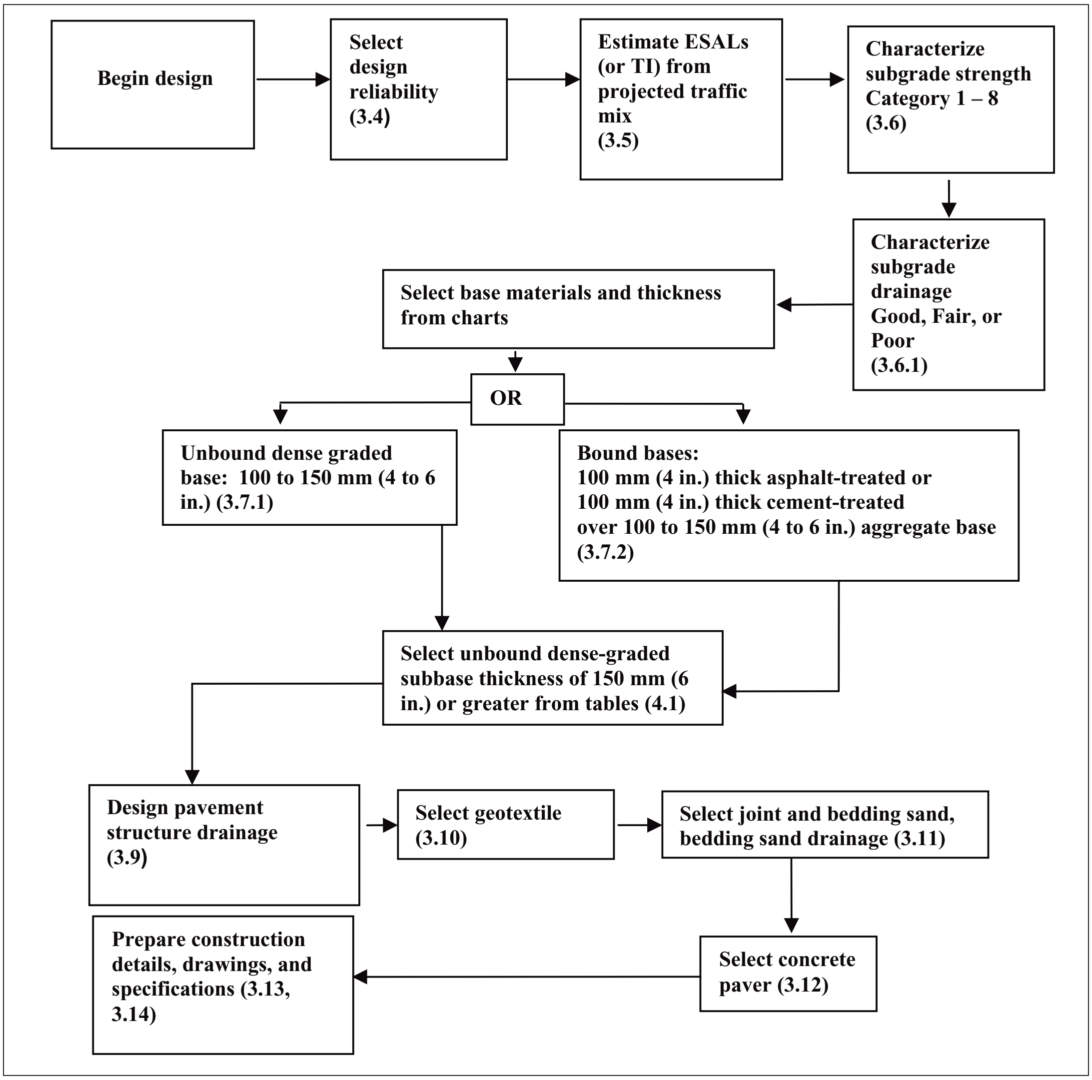

FIGURE 3-1. Design Process Flow Chart.
Note: Numbers in parentheses refer to sections of this Standard Guideline.

result in a factored ESAL value of 2,000,000. If a higher reliability value, say 90% ($Z_R = 1.28$), were input into Eq. 3-2, a factored ESAL value of about 3,750,000 would result.

3.5 DESIGN TRAFFIC

The amount of damage caused by traffic loading will depend on the number and type of vehicles that pass over the pavement section. Traffic design loading for the AASHTO (1993) design procedure is represented using the ESAL concept. One ESAL is represented as the impact from a single 80-kN (18,000-lb) axle load.

Conversion of the traffic ESALs to the Traffic Index (TI) used in California is accomplished as follows:

$$\mathrm{TI} = 9.0 \times \left(\frac{\mathrm{ESAL}}{10^6}\right)^{0.119} \qquad (3\text{-}3)$$

For this Standard Guideline, ESAL levels are provided for 10 typical levels of municipal traffic up to a maximum of 10 million ESALs (see Table 4-1). The designer needs to select the appropriate traffic level and design life. The typical initial design life for municipal pavements is on the order of 20 to 40 years.

Table 3-1. General Soil Categories and Properties

Category No.	Unified Soil Classification[a]	Brief Description	Drainage Characteristics	Susceptibility to Frost Action
1	Boulders/cobbles	Rock, rock fill, shattered rock, boulders/cobbles	Excellent	None
2	GW, SW	Well graded gravels and sands suitable as granular borrow	Excellent	Negligible
3	GP, SP	Poorly graded gravels and sands	Excellent to fair	Negligible to slight
4	GM, SM	Silty gravels and sands	Fair to semi-impervious	Slight to moderate
5	GC, SC	Clayey gravels and sands	Practically impervious	Negligible to slight
6	ML, MI	Silts and sandy silts	Typically poor	Severe
7	CL, MH	Low plasticity clays and compressible silts	Practically impervious	Slight to severe
8	CI, CH	Medium to high plasticity clays	Semi-impervious to impervious	Negligible to severe

[a] (ASTM 2006a).

3.6 SUBGRADE SOIL STRENGTH ASSESSMENT

Subgrade conditions should be assessed for all pavement designs. The soil strength is evaluated specifically for each project, and should be tested in accordance with the appropriate ASTM or AASHTO method or other local standard. Typically, the resilient modulus (AASHTO T-274, 1982) is used to describe the strength of the subgrade soil. This can be determined directly from laboratory testing or through surrogates such as California Bearing Ratio (CBR; ASTM D1883, 2007) tests. The soil should be tested in the moisture condition expected during the lifetime of the pavement. In most cases, except for arid regions, this is in a saturated (or soaked) condition. If it is not possible to perform laboratory tests, typical resilient modulus values are available based on soil classification system.

This Standard Guideline utilizes eight categories of subgrade quality ranging from good quality gravels and rock with excellent drainage to poor quality clay materials that are semi-impervious to water. Subgrade types are classified according to the Unified Soils Classification method (ASTM D2487, 2006a). Values in Table 3-1 are provided for guidance only. Where laboratory tests are unavailable, Table 3-1 should be used to select the appropriate category.

3.6.1 Characterize Subgrade Drainage

Once the general subgrade type has been selected, it is necessary to identify the drainage quality of the subgrade and pavement structure. The drainage will depend on the type and gradation of the subgrade, granular base and subbase materials, and on the general geometry of the pavement (elevation, proximity to a water source, presence of subdrains and ditches, etc.). Depending on the type of subgrade, the strength of the pavement can be reduced if there is excess water in the subgrade. This Standard Guideline includes an adjustment to the resilient modulus of the subgrade based on the overall quality of the pavement drainage as shown in Table 3-2.

Table 3-2. Pavement Drainage

Quality of Drainage	Time to Drain	Soil Category Number[a]
Good	1 day	1, 2, 3
Fair	7 days	3, 4
Poor	1 month	4, 5, 6, 7, 8

[a] From Table 3-1.

3.6.2 Frost, Swelling Soils, and Other Considerations

Subgrade swelling and frost heave can affect the performance of a municipal pavement and should be considered as appropriate for local conditions. Frost and swelling may be reduced or eliminated by removal and replacement of subgrade soil materials. Frost heave may also be mitigated by improving drainage conditions and/or by providing a non-frost-susceptible layer. Swelling may also be mitigated by stabilizing the subgrade with additives such as lime or cement.

This Standard Guideline assumes that issues with frost heave and swelling soils are addressed by the Engineer as needed and are reflected in the design subgrade strength value.

3.7 SELECT BASE MATERIALS AND THICKNESSES

The next step in the design process is to select the type of base material that will be used for the pavement. This Standard Guideline supports the use of both bound and unbound bases. High quality durable materials should always be selected in any pavement design. All aggregates should be crushed, angular materials. Recycled aggregates may be used but they must meet the same conditions as specified for non-recycled aggregates. Untreated aggregate base and subbase should be compacted to at least 98% of maximum dry density based on AASHTO T180 Method D (AASHTO 2009), or the equivalent.

3.7.1 Unbound Dense Graded Base

Aggregates should be crushed, angular materials. Crushed aggregate bases used in highway construction are generally suitable for interlocking concrete pavement. Unbound base materials should meet the local state, provincial, or municipal standards governing base materials. Where local specifications are unavailable, the base material should meet the gradation requirements of ASTM D2940 (ASTM 2009b). The minimum strength of the unbound base should be a CBR of 80% or equivalent bearing strength as described by the test methods in Section 3.6. Unbound base materials should have a maximum loss of 60% when tested in accordance with CSA A23.2-29A and a maximum loss of 40% when tested in accordance with ASTM C131 or CSA A23.2-17A (CSA 2004b; ASTM 2006d). The plasticity index should be a maximum of 6 and the liquid limit should be a maximum of 25 when tested in accordance with ASTM D4318 (ASTM 2005a) and AASHTO T-89 and 90 (AASHTO 2002, 2004). For constructability purposes, the minimum design unbound base thickness should be 100 mm (4 in.) for less than 500,000 ESALs and 150 mm (6 in.) for 500,000 or more ESALs.

3.7.2 Bound (or Treated) Bases

Asphalt treated base (ATB) and cement treated base (CTB) materials and installation should conform to provincial, state, or local specifications for a dense graded, compacted asphalt concrete. ATB material should have a minimum Marshall stability of 8000 N (1,800 lbs) per ASTM D5 (ASTM 2006b) or AASHTO T-49 (AASHTO 2007). Use of the appropriate asphalt cement binder for local climate conditions is recommended. Cement-treated base material should have a minimum 7-day unconfined compressive strength of 4.5 MPa (650 psi), per ASTM D4320 (ASTM 2009a) and D4219 (ASTM 2008c). For constructability purposes, the minimum bound base thickness for design purposes will be 100 mm (4 in.).

3.8 DETERMINE SUBBASE THICKNESS

The required subbase thickness is determined based on the design reliability, design life, estimated traffic, subgrade soil type, pavement structure drainage, and base type selected.

3.8.1 Unbound Dense Graded Subbase

Aggregates should be crushed, angular materials. Crushed aggregate bases used in highway construction are generally suitable for interlocking concrete pavement. Unbound subbase materials should meet the local state, provincial, or municipal standards governing subbase materials. Where local specifications are unavailable, the subbase should meet the gradation requirements according to ASTM D2940 (ASTM 2009b). The minimum strength of the unbound subbase should be a CBR of 40% or equivalent bearing strength as described by the test methods in Section 3.6. The plasticity index should be a maximum of 10 and the liquid limit should be a maximum of 25, according to ASTM D4318 (ASTM 2005a) and AASHTO T-90 (AASHTO 2004). Subbase thicknesses should be chosen from Tables 4-3 through 4-6. For constructability purposes, a minimum unbound subbase design thickness of 150 mm (6 in.) is used.

3.9 DESIGN PAVEMENT STRUCTURE DRAINAGE

The design should consider drainage of the bedding sand layer and the soil subgrade. The typical drainage detail for untreated bases is shown in Fig. 3-2. For treated bases, bedding sand layer drainage is typically accomplished by providing vertical drainage at the lowest elevations, as shown in Fig. 3-3. A typical drainage detail for catch basins or utility structures with treated bases is shown in Fig. 3-4.

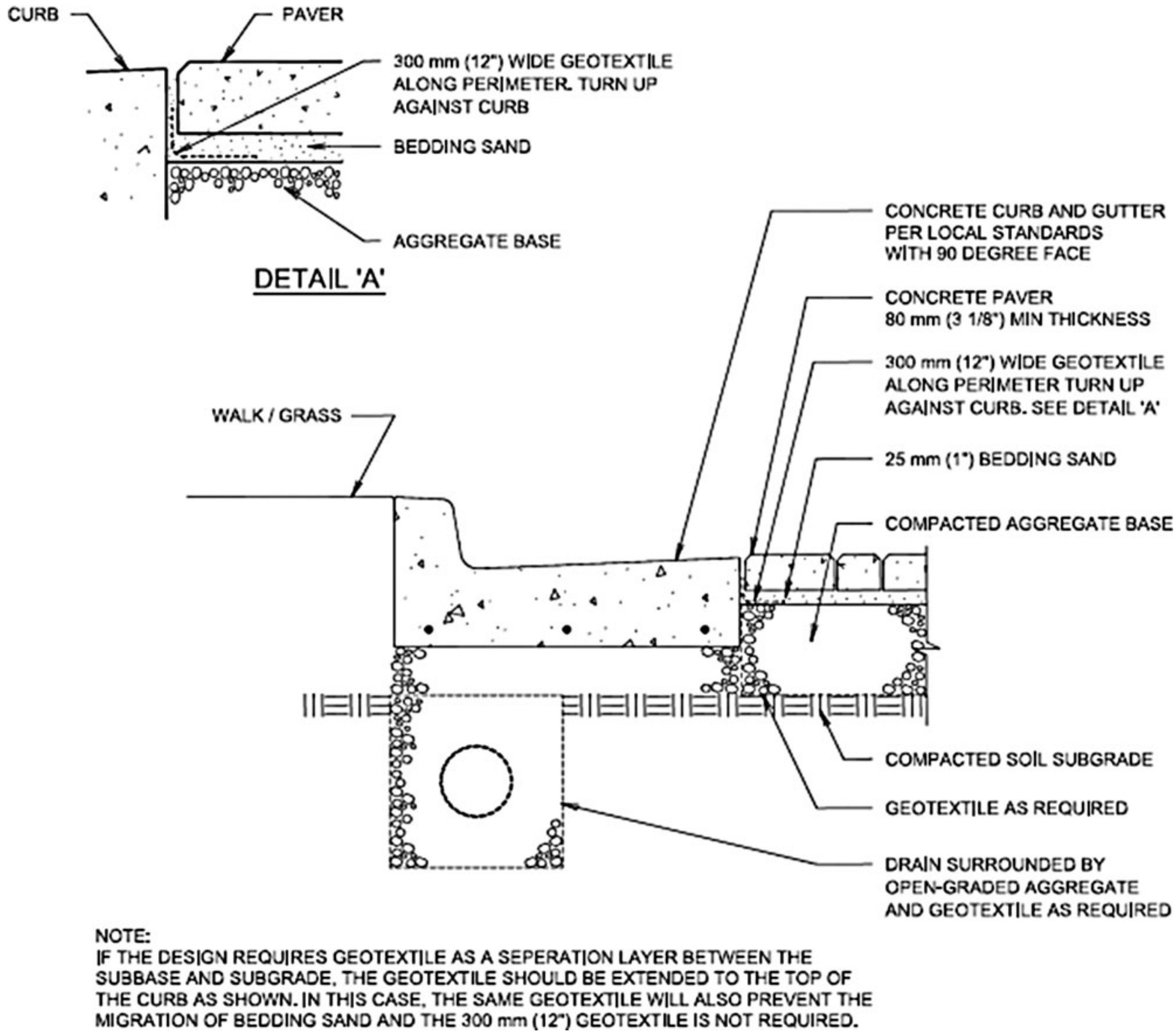

FIGURE 3-2. Drain Detail with Aggregate Base/Subbase.

All drainage outlets should be covered with geotextile to ensure that the design prevents migration of bedding sand into the drainage system. For unbound bases, the geotextile should extend 300 mm (12 in.) from the pavement edge as shown in Fig. 3-2. For treated bases, geotextile should be used full-width, on top of treated base, to prevent migration of the bedding sand through cracks and joints. In all cases, the geotextile should extend vertically upwards to the top of the pavement at all curbs or collars.

The design should consider drainage of the base and soil subgrade as this benefits pavement life and performance. Placement of perforated drain pipe and/or edge drains should conform to local practices.

3.10 GEOTEXTILE

The Engineer should review the need for a geotextile to separate the subgrade soil from the pavement structure or to prevent bedding sand migration into lower layers or laterally through discontinuities such as control joints and saw cuts.

Separation geotextiles should be used to prevent mixing of subgrade soil and base/subbase material.

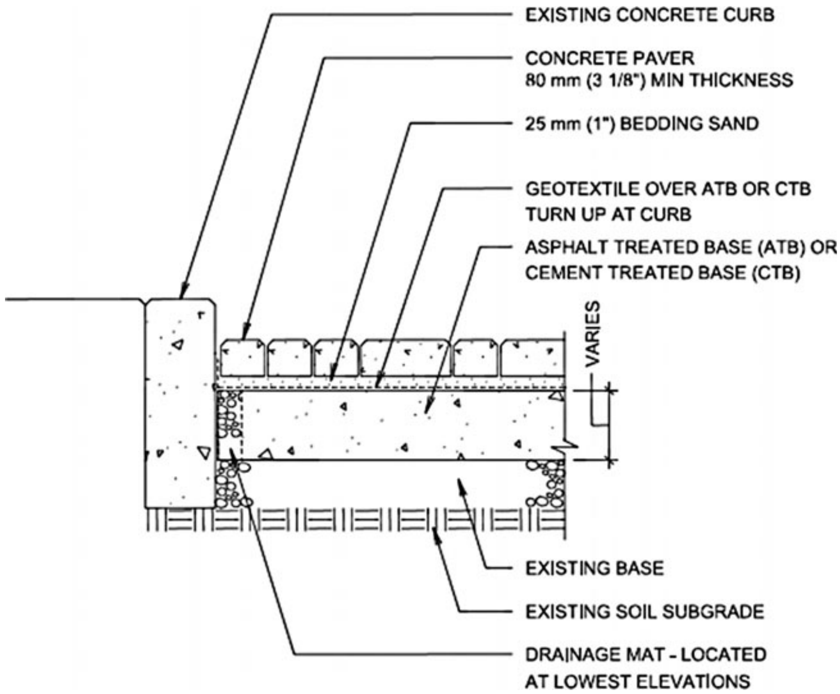

FIGURE 3-3. Drain Detail for Pavers over Treated Base.

The designer will typically require a woven fabric with a minimum equivalent opening size of 300 μm to a maximum of 600 μm (0.012 to 0.024 in.). The Engineer should reference AASHTO M288, *Standard Specification for Geotextile Specification for Highway Applications* (AASHTO 2006), to specify the appropriate geotextile. If weak (CBR < 3) or wet/saturated subgrade conditions exist, geotextile with stabilization and filtration capabilities may also be required.

3.11 BEDDING AND JOINT SAND REQUIREMENTS

Proper care and selection of bedding and joint sand is of paramount importance to the function of an interlocking concrete pavement. The bedding layer should be nominally 25 mm (1 in.) in thickness prior to compaction for all designs.

3.11.1 Bedding Sand

Bedding sand should be well graded, conforming to the particle size distribution requirements of ASTM C33 (ASTM 2008a) or CSA A23.1 (CSA 2004a), except that the amount passing the 75 μm (No. 200) sieve should preferably be limited to a maximum of 1%. Sands with predominant silica geologies and sub-angular to sub-rounded particle shape have shown excellent performance. For vehicular applications exceeding 1.5 million lifetime ESAL repetitions or a TI greater than 9.4, the bedding sand should also be tested for permeability, degradation, and durability prior to selection.

The following test methods, among others, have shown to be good indicators of bedding sands for vehicular applications: ASTM C88, *Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate* (ASTM 2005b); CSA A23.2-23A, *The Resistance of Fine Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus* (CSA 2004b); and ASTM D2434, *Standard Test Method for Permeability of Granular Soils (Constant Head)* (ASTM 2006c). See ICPI Tech Spec 17, *Selection of Bedding Sands for Interlocking Concrete Pavements in Vehicular Applications* (ICPI 2007), for guidance.

3.11.2 Bedding Sand Drainage

Additional drainage of the bedding sand layer should be provided where required. Examples are shown in Figs. 3-2 through 3-4.

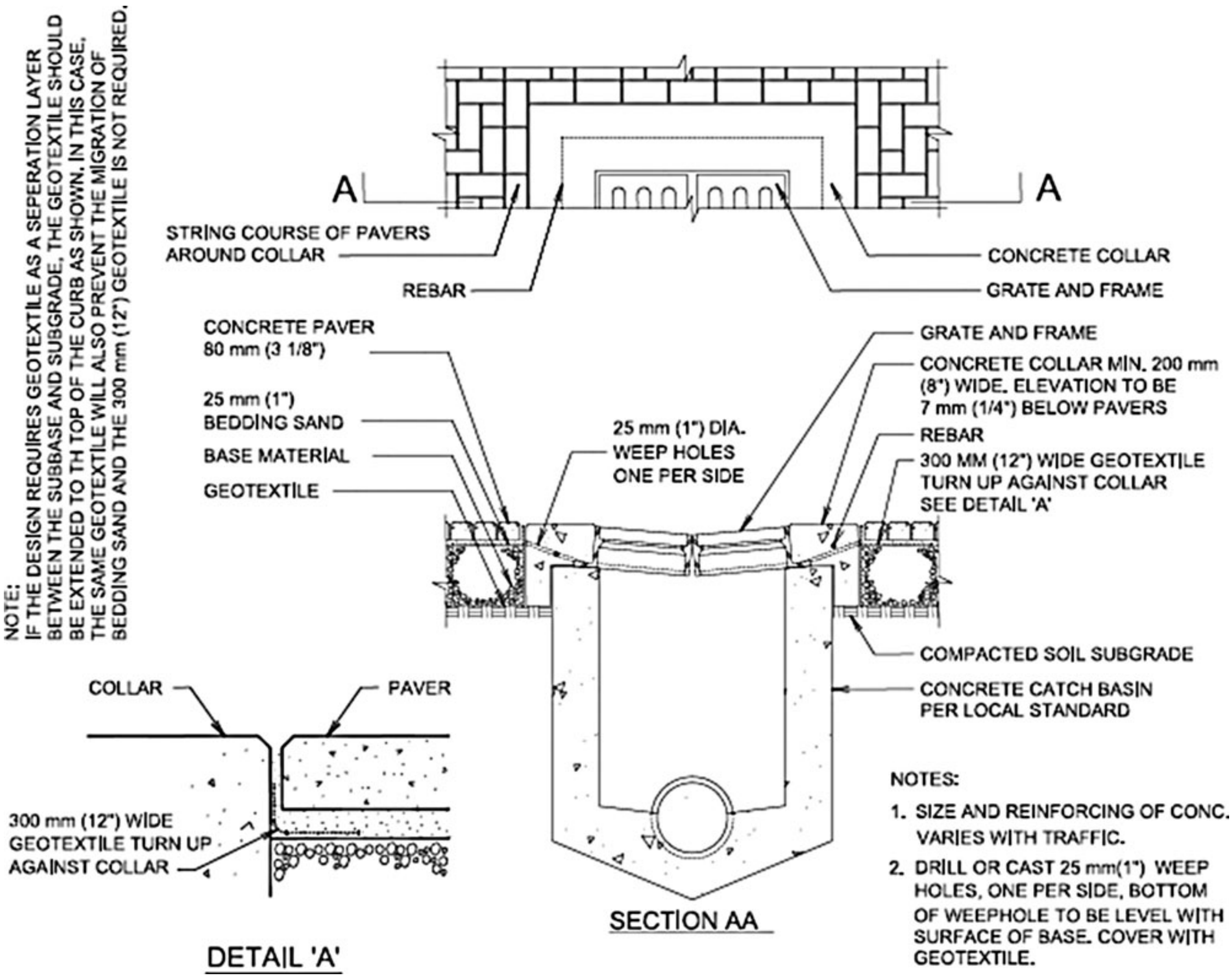

FIGURE 3-4. Drain Detail at a Catch Basin for Treated Base.

3.11.3 Joint Sand

It is recommended that the joint sand have the same properties as the bedding sand, but this may be modified based on local practices and conditions. For example, the gradation requirements may be adjusted to meet the requirements of ASTM C144 (ASTM 2004) or CSA A179 (CSA 2009), which allow a finer gradation.

3.12 CONCRETE PAVERS

Concrete pavers should conform to the product requirements of ASTM C936, *Standard Specification for Solid Concrete Interlocking Paving Units* (ASTM 2008b), in the United States and CSA A231.2, *Precast Concrete Pavers* (CSA 2006), in Canada (Fig. 3-5).

For vehicular traffic, pavers must have an aspect ratio less than or equal to 3 : 1 and a minimum thickness of 80 mm ($3\frac{1}{8}$ in.).

A 45- or 90-degree herringbone pattern as shown in Fig. 3-6 should be used for all vehicular pavements. Alternative laying patterns may be considered as long as they are functionally and structurally equivalent. A sailor or soldier course should be used at all pavement edge interfaces as shown in Fig. 3-6 to increase edge stability. This includes utility structures and other protrusions in the pavement surface as shown in Fig. 3-7.

If other shapes are considered, care has to be taken by the Engineer that the structural capacity is at least equal to the *SN* of 0.44 used in this guide. (The manufacturer may provide confirming data).

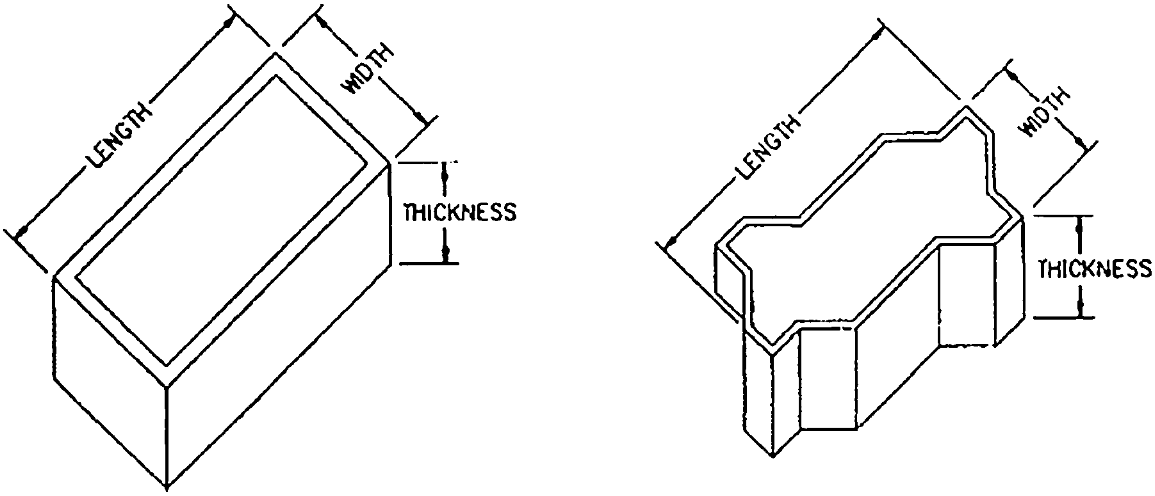

FIGURE 3-5. Length, Width, and Thickness of Concrete Paving Units.

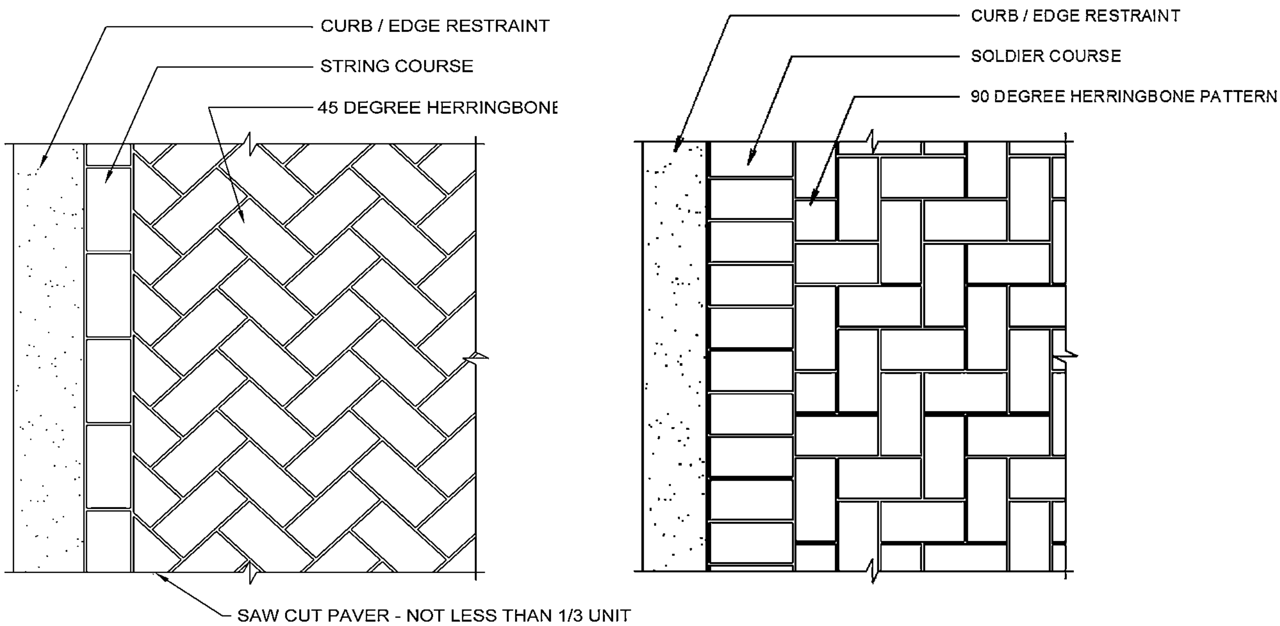

FIGURE 3-6. 45-Degree Herringbone Pattern with Single Sailor (or String) Course. 90-Degree Herringbone Pattern with Single Soldier Course.

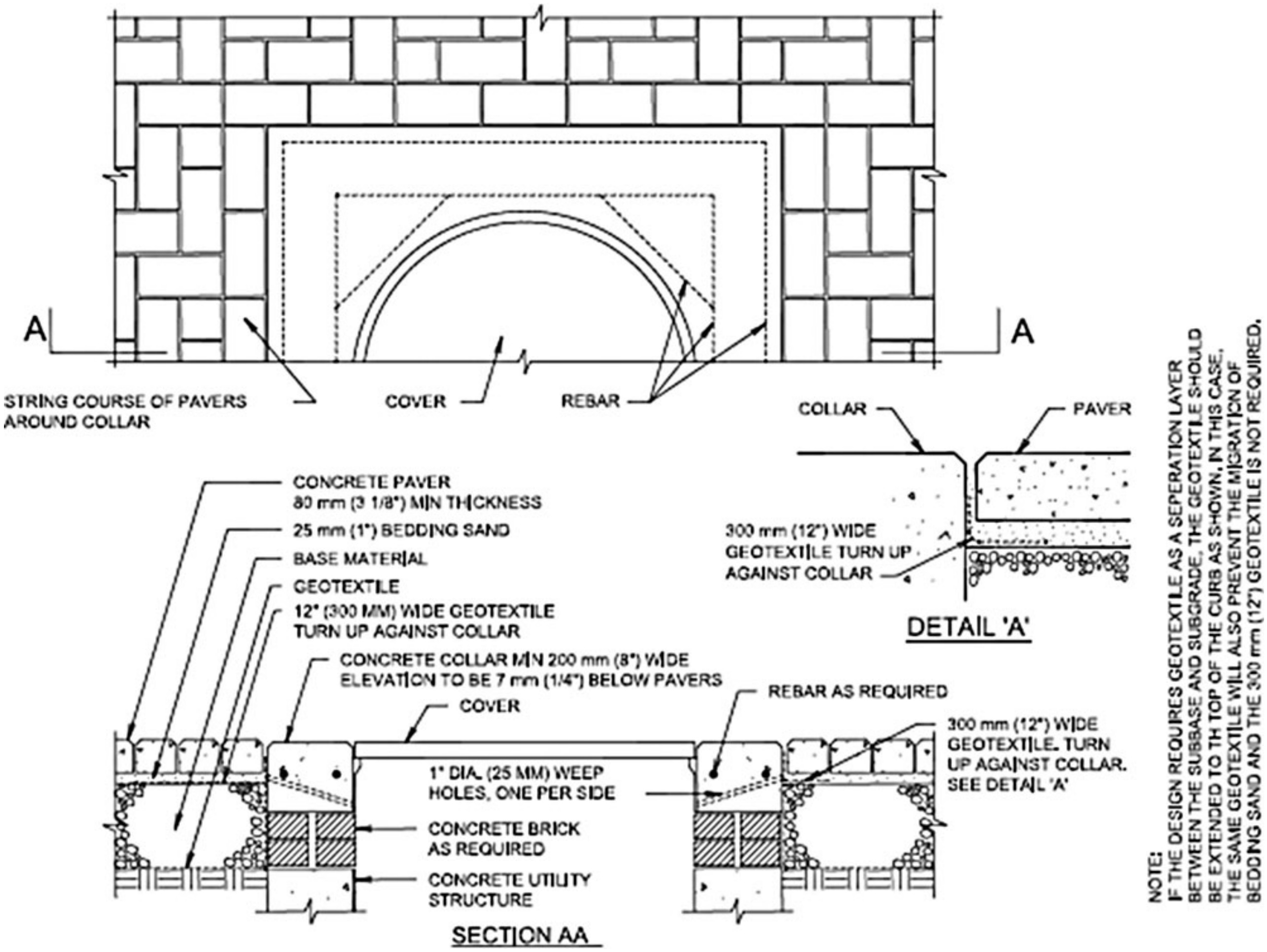

FIGURE 3-7. Sailor (or String) Course around a Utility Structure.

The joint width tolerance for purposes of the structural layer coefficients used in the design procedure should be 2 to 5 mm ($\frac{1}{16}$ to $\frac{3}{16}$ in.). Joints should be completely filled with joint sand to the bottom of the paver chamfer.

3.13 EDGE RESTRAINTS

All vehicular pavements should be designed with edge restraints (typically concrete curbs) at the perimeter (Fig. 3-2). Edge restraints help maintain rotational and horizontal interlock in the pavement surface resulting from dynamic vehicular wheel loads such as turning, braking, and accelerating.

3.14 CONSTRUCTION DETAILS AND SPECIFICATIONS

The appropriate use of construction details and specifications are of paramount importance to the success of a pavement system. Guidance on construction details and specifications are provided in Chapter 5.

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4
DESIGN TABLES AND WORKED EXAMPLES

4.1 DESIGN TABLES

The primary purpose of the design tables is to provide design thicknesses for unbound bases (granular base), asphalt treated bases (ATB), and cement treated bases (CTB). The values in the tables have been developed using the *Guide for Design of Pavement Structures* (AASHTO 1993). As outlined in Chapter 3, the designer must first select the design traffic in terms of ESALs as the initial input. For inputs other than those covered by the tables, the designer should use the AASHTO (1993) procedures to determine the appropriate pavement layer thicknesses.

The following design parameters according to Eq. 3-1 are used in the development of the structural design tables used in this chapter:

W = variable
Z_R = −0.674 for R = 75%
S_0 = 0.45
a_i = structural layer coefficients used in this Standard Guideline are as follows:
concrete paver and bedding sand = 0.44
untreated dense graded base = 0.14
untreated dense graded subbase = 0.09
asphalt treated base (ATB) = 0.28
cement treated base (CTB) = 0.20
p_i = 4.2
p_t = 2.5
M_R = variable

Thickness design tables are also provided for asphalt concrete (AC) bases solely as a means to reduce thick pavement structures associated with high traffic, low subgrade strength conditions. In the development of these tables, a structural layer coefficient of 0.44 has been assumed for AC. For AC layer coefficients other than 0.44, the designer should consult AASHTO (1993). The determination of AC material properties and specific design details is beyond the scope of this Standard Guideline. The Interlocking Concrete Pavement Institute (ICPI) provides some design detail guidance (ICPI 1995b).

The traffic input is presented in Table 4-1 in terms of both the equivalent single axle loadings (ESALs) and traffic index (TI). Each design table also categorizes the subgrade strength (Category 1 through 8) and the drainage condition as good, fair, or poor, as outlined in Table 4-2. Thus, once the Engineer has determined the design life, subgrade category, drainage condition, and traffic, the design thicknesses can be found in Tables 4-3 through 4-6 for unbound base, ATB, CTB, and AC, respectively.

Alternative designs can be considered based on local conditions, but the Structural Number (*SN*) of the pavement should be equal to or greater than the design section obtained from Tables 4-3 through 4-6. The design tables and worked examples are provided in metric units only. To convert millimeters to inches, divide by 25.4.

Table 4-1. Design Equivalent Single Axle Loadings and Traffic Index

ESALs	Traffic Index
10,000	5.2
20,000	5.7
50,000	6.3
100,000	6.8
200,000	7.4
500,000	8.3
1,000,000	9.0
2,000,000	9.8
5,000,000	10.9
10,000,000	11.8

Table 4-2. Various Resilient Modulus Values for Typical Subgrade Drainage Conditions

	Resilient Modulus for Typical Subgrade Drainage Conditions								
	Good			Fair			Poor		
Category	MPa	R[a]	CBR[b]	MPa	R[a]	CBR[b]	MPa	R[a]	CBR[b]
1	90	216	13	80	190	11	70	164	9
2	80	190	11	70	164	9	50	111	5
3	70	164	9	50	111	5	35	71	3
4	50	111	5	35	71	3	30	58	2
5	40	84	4	30	58	2	25	45	2
6	30	58	2	25	45	2	18	26	1
7	27	50	2	20	32	1	15	19	1
8	25	45	2	20	32	1	15	19	1

[a] R-value, determined by California Test 301.

[b] California Bearing Ratio, from ASTM D1883 (2007).

Table 4-3. Design Table for Granular Base

GRANULAR BASE
STRUCTURE THICKNESSES (mm)

		ESALs	10,000	20,000	50,000	100,000	200,000	500,000	1,000,000	2,000,000	5,000,000	10,000,000
		TI	5.2	5.7	6.3	6.8	7.4	8.3	9.0	9.8	10.9	11.8
	Drainage	Layer Type										
Category 1	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense Graded Base	100	100	100	100	100	150	150	200	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	0	200	300
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense Graded Base	100	100	100	100	100	150	175	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	150	250	350
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense Graded Base	100	100	100	100	100	150	200	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	150	300	400
Category 2	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense Graded Base	100	100	100	100	100	150	175	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	150	250	350
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense Graded Base	100	100	100	100	100	150	200	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	150	300	400
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense Graded Base	100	100	100	100	125	200	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	150	275	425	550
Category 3	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense Graded Base	100	100	100	100	100	150	200	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	150	300	400
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense Graded Base	100	100	100	100	125	200	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	150	275	425	550
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense Graded Base	100	100	100	125	200	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	175	300	400	575	725
Category 4	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense Graded Base	100	100	100	100	125	200	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	150	275	425	550
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense Graded Base	100	100	100	125	200	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	175	300	400	575	725
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense Graded Base	100	100	100	150	100	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	175	225	350	475	650	800

Table 4-3. *Continued*

GRANULAR BASE
STRUCTURE THICKNESSES (mm)

		ESALs	10,000	20,000	50,000	100,000	200,000	500,000	1,000,000	2,000,000	5,000,000	10,000,000
		TI	5.2	5.7	6.3	6.8	7.4	8.3	9.0	9.8	10.9	11.8
	Drainage	Layer Type										
Category 5	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense Graded Base	100	100	100	100	175	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	150	250	350	525	650
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense Graded Base	100	100	100	150	100	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	175	225	350	475	650	800
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense Graded Base	100	100	150	200	100	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	250	300	425	550	750	875
Category 6	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense Graded Base	100	100	100	150	100	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	175	225	350	475	650	800
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense Graded Base	100	100	150	200	100	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	250	300	425	550	750	875
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense Graded Base	100	125	200	100	100	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	250	350	450	575	700	900	1050
Category 7	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense Graded Base	100	100	125	175	100	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	225	275	400	525	700	850
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense Graded Base	100	100	175	100	100	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	225	325	400	525	650	850	1000
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense Graded Base	100	150	100	100	100	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	200	325	425	525	650	800	1000	1150
Category 8	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense Graded Base	100	100	150	200	100	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	250	300	425	550	750	875
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense Graded Base	100	100	175	100	100	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	225	325	400	525	650	850	1000
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense Graded Base	100	150	100	100	100	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	200	325	425	525	650	800	1000	1150

Table 4-4. Design Table for Asphalt Treated Base

		ASPHALT TREATED BASE STRUCTURE THICKNESSES (mm)										
		ESALs	10,000	20,000	50,000	100,000	200,000	500,000	1,000,000	2,000,000	5,000,000	10,000,000
		TI	5.2	5.7	6.3	6.8	7.4	8.3	9.0	9.8	10.9	11.8
	Drainage	Layer Type										
Category 1	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	0	0	0
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	175
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	0	0	0
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	0	0	150
Category 2	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	175
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	0	0	0
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	0	0	150
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	0	150	250
Category 3	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	0	0	150
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	0	150	250
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	150	275	400

Table 4-4. *Continued*

		ASPHALT TREATED BASE STRUCTURE THICKNESSES (mm)										
		ESALs	10,000	20,000	50,000	100,000	200,000	500,000	1,000,000	2,000,000	5,000,000	10,000,000
		TI	5.2	5.7	6.3	6.8	7.4	8.3	9.0	9.8	10.9	11.8
	Drainage	Layer Type										
Category 4	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	0	150	250
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	150	275	400
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	175	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	175	350	475
Category 5	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	150	175	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	0	200	350
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	175	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	175	350	475
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	150	250	425	575

Category 6	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	175	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	175	350	475
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	150	250	425	575
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	125	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	150	250	400	600	750
Category 7	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	200	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	200	400	525
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	200	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	200	350	525	700
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	175	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	200	350	475	675	850
Category 8	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	150	250	425	575
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	200	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	200	350	525	700
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	175	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	200	350	475	675	850

Table 4-5. Design Table for Cement Treated Base

CEMENT TREATED BASE
STRUCTURE THICKNESSES (mm)

		ESALs	10,000	20,000	50,000	100,000	200,000	500,000	1,000,000	2,000,000	5,000,000	10,000,000
		TI	5.2	5.7	6.3	6.8	7.4	8.3	9.0	9.8	10.9	11.8
	Drainage	Layer Type										
Category 1	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	200
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	0	0	0
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	175	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	0	0	150
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	200	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	0	0	200
Category 2	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	175	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	0	0	150
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	200	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	0	0	200
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	150	175	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	0	200	325

Category 3	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	200	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	0	0	200
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	150	175	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	0	200	325
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	200	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	200	350	500
Category 4	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	150	175	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	0	200	325
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	200	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	200	350	500
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	175	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	150	250	425	575
Category 5	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	150	175	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	0	150	300	425
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	175	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	150	250	425	575
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	125	200	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	200	325	525	675

Table 4-5. *Continued*

CEMENT TREATED BASE
STRUCTURE THICKNESSES (mm)

		ESALs	10,000	20,000	50,000	100,000	200,000	500,000	1,000,000	2,000,000	5,000,000	10,000,000
		TI	5.2	5.7	6.3	6.8	7.4	8.3	9.0	9.8	10.9	11.8
	Drainage	Layer Type										
Category 6	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	175	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	150	250	425	575
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	125	200	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	200	325	525	675
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	125	200	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	225	350	475	675	825
Category 7	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	100	200	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	175	300	475	625
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	175	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	175	300	425	625	775
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	175	100	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	200	300	425	575	775	925
Category 8	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	125	200	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	0	200	325	525	675
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	100	175	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	0	175	300	425	625	775
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense Graded Base	100	100	100	175	100	150	150	150	150	150
		Unbound Dense Graded Subbase	0	0	0	0	200	300	425	575	775	925

Table 4-6. Design Table for Asphalt Concrete Base

ASPHALT CONCRETE BASE
STRUCTURE THICKNESSES (mm)

		ESALs	10,000	20,000	50,000	100,000	200,000	500,000	1,000,000	2,000,000	5,000,000	10,000,000
		TI	5.2	5.7	6.3	6.8	7.4	8.3	9.0	9.8	10.9	11.8
	Drainage	Layer Type										
Category 1	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	50	50	50	50
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	50	50	50	50
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	50	50	50	70
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
Category 2	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	50	50	50	50
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	50	50	50	70
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	50	50	70	100
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
Category 3	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	50	50	50	70
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	50	50	70	100
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	50	70	100	130
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
Category 4	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	50	50	70	100
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	50	70	100	130
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	50	80	120	140
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150

Table 4-6. *Continued*

ASPHALT CONCRETE BASE
STRUCTURE THICKNESSES (mm)

		ESALs	10,000	20,000	50,000	100,000	200,000	500,000	1,000,000	2,000,000	5,000,000	10,000,000
		TI	5.2	5.7	6.3	6.8	7.4	8.3	9.0	9.8	10.9	11.8
	Drainage	Layer Type										
Category 5	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	50	50	90	120
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	50	80	120	140
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	70	100	130	160
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
Category 6	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	50	80	120	140
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	70	100	130	160
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	60	70	100	130	170	200
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
Category 7	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	60	90	130	160
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	60	90	120	160	190
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	80	90	120	140	190	220
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
Category 8	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	70	100	130	160
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	60	90	120	160	190
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	80	90	120	140	190	220
		Unbound Dense Graded Base	100	100	100	100	100	150	150	150	150	150

4.2 EXAMPLE CASE STUDIES

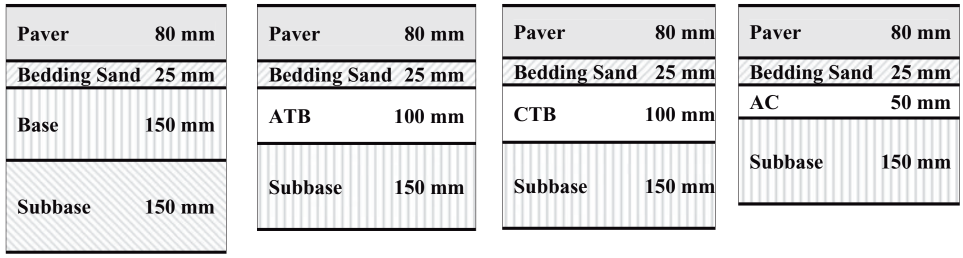
This section provides example designs based on the design charts.

CASE STUDY 1

Given: ESALs 2,000,000 (TI 9.8)
Drainage Good
Subgrade Category 3 (GP, SP)
Required: Interlocking Concrete Pavement Structure
Analysis: Using Tables 4-3 through 4-6, the following designs were developed.

	Design 1	Design 2	Design 3	Design 4
Pavers	80	80	80	80
Bedding Sand	25	25	25	25
ATB	0	100	0	0
CTB	0	0	100	0
AC	0	0	0	50
Unbound Base	150	0	0	0
Unbound Subbase	150	150	150	150

Therefore, the four design candidates given the site conditions are as follows.



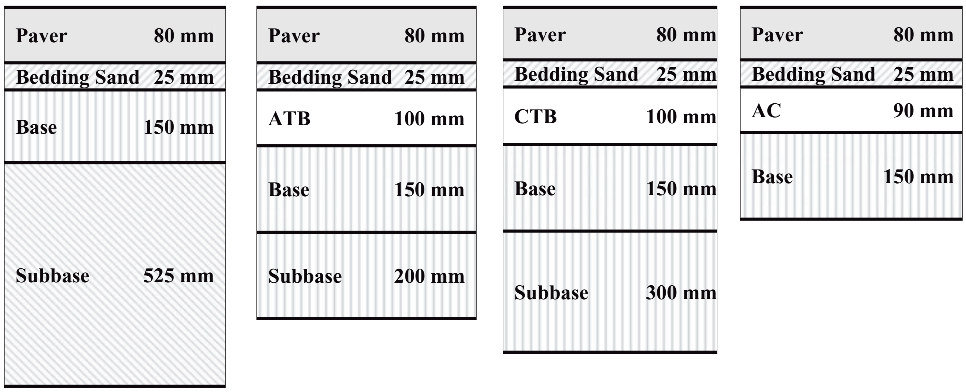
Design 1 **Design 2** **Design 3** **Design 4**

CASE STUDY 2

Given: ESALs 500,000 (TI 8.3)
Drainage Poor
Subgrade Category 7 (CL, MH)
Required: Interlocking Concrete Pavement Structure
Analysis: Using Tables 4-3 through 4-6, the following designs were developed.

	Design 1	Design 2	Design 3	Design 4
Pavers	80	80	80	80
Bedding Sand	25	25	25	25
ATB	0	100	0	0
CTB	0	0	100	0
AC	0	0	0	90
Unbound Base	150	150	150	150
Subbase	525	200	300	0

Therefore, the four design candidates given the site conditions are as follows.



Design 1 **Design 2** **Design 3** **Design 4**

CASE STUDY 3

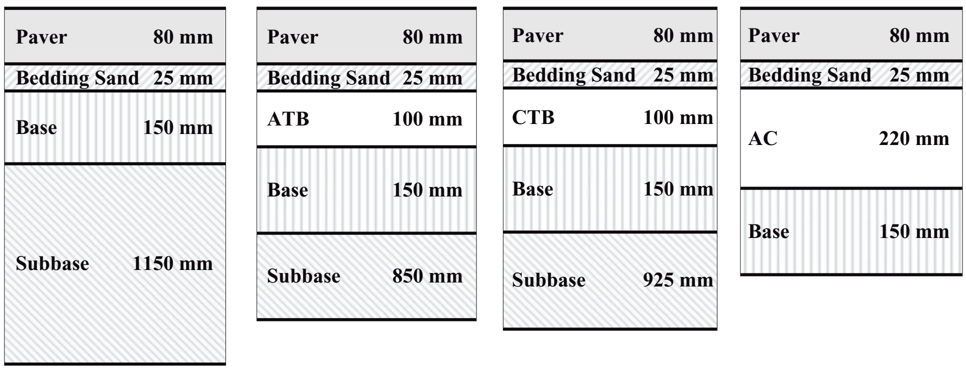
Given:	ESALs	10,000,000 (TI 11.8)
	Drainage	Poor
	Subgrade Category	8 (CI, CH)

Required: Interlocking Concrete Pavement Structure

Analysis: Using Tables 4-3 through 4-6, the following designs were developed.

	Design 1	Design 2	Design 3	Design 4
Pavers	80	80	80	80
Bedding Sand	25	25	25	25
ATB	0	100	0	0
CTB	0	0	100	0
AC	0	0	0	220
Unbound Base	150	150	150	150
Subbase	1150	850	925	0

Therefore, the four design candidates given the site conditions are as follows.



Design 1 **Design 2** **Design 3** **Design 4**

5
OTHER DESIGN CONSIDERATIONS

Detailing of any project is important. Detailing is perhaps more important on the municipal and commercial projects this Standard Guideline intends to address. The public has direct access to municipal and commercial projects. Developments of trip hazards, unnecessary maintenance, visual deterioration of a pavement, and other issues have a real effect on the livability and safety of a community.

The designer should be certain that details provided address all of the issues of a pavement including, but not limited to, user safety and Americans with Disabilities Act (ADA) standards in the public right-of-way. The designer should also address how interlocking concrete pavement can contribute to sustainability through applying the Leadership in Energy and Environmental Design (LEED) rating system (U.S. Green Building Council 2009).

Further details, design considerations, best practices, and maintenance procedures are available in the Interlocking Concrete Pavement Institute's Tech Spec series, available at http://www.icpi.org/view/tech_specs.

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GLOSSARY OF TERMS

This Appendix contains definitions of terms common to interlocking concrete pavements that are used in this document. Other terms are used in the interlocking concrete paving industry. ICPI Tech Spec 1, *Glossary of Terms Used in the Production, Design, Construction, and Testing of Interlocking Concrete Pavement* (ICPI 2006), is a collection of additional terms as defined by that trade organization.

The following terms are defined with reference to the work covered in this Standard. Terms in the Standard that are not defined should have their ordinarily accepted meaning within the context with which they are used. The most recent edition of *Webster's New International Dictionary of the English Language, Unabridged* should be considered as providing ordinarily accepted meanings.

Abrasion: The mechanical wearing, grinding, scraping, or rubbing away (or down) of paver surface by friction or impact, or both.

Aggregate: Sand, gravel, shell, slag, or crushed stone used in base/subbase materials, mixed with cement to make concrete, or with asphalt.

Angularity: The sharpness of edges and corners of particles. Used to describe sand and aggregates.

Aspect Ratio: The longest overall length of a paver divided by its thickness. Example: a 100-mm (4-in.) wide by 200-mm (8-in.) long by 80-mm (3⅛-in.) thick paver has an aspect ratio of 2.5.

Base or Base Course: A material of a designed thickness placed under the surface wearing course of paving units and bedding course. It is placed over a subbase or a subgrade to support the surface course and bedding materials. A base course can be compacted aggregate, cement- or asphalt-stabilized aggregate, asphalt, or concrete.

Bedding Sand or Bedding Course: A layer of coarse, washed sand screeded smooth for bedding the pavers. The sand can be natural or manufactured (crushed from larger rocks) and should conform to the grading requirements of ASTM C33 (ASTM 2008a) or CSA A23.1 (CSA 2004a) with limits on the percent passing the 0.075 µm (No. 200) sieve. A screeded sand layer is generally 25 mm (1 in.) thick. See Concrete Sand.

California Bearing Ratio (CBR): A standardized soils test defined as the ratio of: (1) the force per unit area required to penetrate a soil mass with a 19 cm^2 (3 $in.^2$) circular piston (approximately 51 mm (2 in.) diameter) at the rate of 1.3 mm/min (0.05 in./min), to (2) that required for corresponding penetration of a standard material. The ratio is usually determined at 2.5 mm (0.1 in.) penetration, although other penetrations are sometimes used. See ASTM D1883 (ASTM 2007) or AASHTO T-193 (AASHTO 1999).

Chamfer: A 45° beveled edge around the top of a paver unit, usually 2 to 6 mm (1⁄16 to ¼ in.) wide. It allows water to drain from the surface, facilitates snow removal, helps prevent edge chipping, and delineates the individual paving units.

Coarse Aggregate: Aggregate predominantly retained on the 4.75 mm (No. 4) sieve; or, that portion of an aggregate retained on the 4.75 mm (No. 4) sieve.

Compaction: The process of inducing close packing of solid particles such as soil, sand, or aggregate.

Compressive Strength: The measured maximum resistance of a concrete paver to loading expressed as force per unit cross-sectional area such as $lb/in.^2$ or N/mm^2 (MPa).

Concrete Pavers: Precast concrete units meeting the requirements of ASTM C936 (ASTM 2008b) or CSA A231.2 (CSA 2006), but for the purpose of this Standard, having an aspect ratio of 3 or less.

Concrete Sand: Washed sand used in the manufacture of ready-mix concrete which conforms to the grading requirements of ASTM C33 (ASTM 2008a) or CSA A23.1 (CSA 2004a). See Bedding Sand.

Course: A row of pavers.

Crushed Stone: A product used for pavement bases made from mechanical crushing of rocks, boulders, or large cobblestones at a quarry. All faces of each aggregate have well-defined edges resulting from the crushing operation.

Degradation Testing: Testing of sands or aggregate to determine resistance to change in particle size or gradation under loading.

Dense-Graded Aggregate Base: A compacted crushed stone base whose gradation yields very small voids between the particles with no visible spaces between them. Most dense-graded bases have particles ranging in size from 38 mm (1½ in.) or 19 mm (¾ in.) down to fines passing the 0.075 µm (No. 200) sieve.

Density: The mass per unit volume.

Edge Restraint: A curb, edging, building, or other stationary object that contains the sand and pavers so they do not spread and lose interlock. It can be exposed or hidden from view.

Elastic Modulus: See Modulus of Elasticity.

Equivalent Single Axle Loads (ESALs): Summation of equivalent 80-kN (18,000-pound-force) single axle loads used to combine mixed traffic to a design traffic load for the design period; also expressed as Equivalent Axle Loads (EALs).

Flexible Pavement: A pavement structure that maintains intimate contact with and distributes loads to the subgrade. The base course materials rely on aggregate interlock, particle friction, and cohesion for stability.

Frost Action: Freezing and thawing of moisture in pavement materials and the resultant effects on them.

Geotextiles: Woven or non-woven fabrics made from plastic fibers used for separation, reinforcement, or drainage between pavement layers.

Gradation: Soil, sand, or aggregate base distributed by mass in specified particle-size ranges. Gradation is typically expressed in percent of mass of sample passing a range of sieve sizes. See ASTM C136 (ASTM 2006e).

Grade: (noun) The slope of finished surface of an excavated area, base, or pavement, usually expressed in percent; (verb) To finish the surface of same by hand or with mechanized equipment.

Gravel: Rounded or semi-rounded particles of rock that will pass a 75 mm (3 in.) and be retained on a 4.75 mm (No. 4) sieve. Naturally occurs in streambeds or riverbanks that have been smoothed by the action of water. A type of soil as defined by the Unified Soil Classification System (ASTM 2006a) having particle sizes ranging from the 4.75 mm (No. 4) sieve size and larger.

Herringbone Pattern: A pattern where joints are no longer than the length of 1½ pavers. Herringbone patterns can be 45 or 90 degrees, depending on the orientation of the joints with respect to the direction of the traffic.

Interlocking Concrete Pavement: A paving system consisting of discrete, hand-sized paving units with either rectangular or dentated shapes manufactured from concrete. Either type of shape is placed in an interlocking pattern, compacted into coarse bedding sand, the joints filled with sand, and compacted again to start interlock. The paving units and bedding sand are placed over an unbound or bound aggregate layer.

Joint: The space between concrete paving units, typically filled with sand.

Joint Sand: Sand swept into the openings between the pavers.

Layer Coefficient: From the 1993 AASHTO pavement design procedure; a dimensionless number that expresses the material strength per 25 mm (1 in.) of thickness of a pavement layer (surface, base, or subbase). Example: the layer coefficient of 80–mm-(3⅛-in.)-thick pavers and 25-mm (1-in.) bedding sand is 0.44 per 25 mm (1 in.), therefore the Structural Number (SN) = $(3\frac{1}{8} + 1) \times 0.44 = 1.82$.

Laying Pattern: The sequence of placing pavers where the installed units create a repetitive geometry. Laying patterns may be selected for their visual or structural benefits.

Life-cycle Cost Analysis: A method of calculating all costs anticipated over the life of the pavement, including construction costs. Discounted cash-flow methods are generally used, typically with calculation of present worth and annualized cost. Factors that influence the results include the initial costs, assumptions about maintenance and periodic rehabilitation, pavement user and delay costs, salvage value, inflation, discount rate, and the analysis period. A sensitivity analysis is often performed to determine which variables have the most influence on costs.

Mechanical Installation: The use of machines to lift and place layers of pavers on screeded sand in their final laying pattern. It is used to increase the rate of paving.

Mechanistic Design: Analysis of structural response of applied loads through modeling of stresses and strains in a pavement structure.

Modified Proctor Test: A variation of the Standard Proctor Test used in compaction testing that measures the density–moisture relationship under a higher compaction effort.

Modulus of Elasticity or Elastic Modulus: The ratio of stress to strain for a material under given loading conditions.

Pavement Structure: A combination of subbase, base course, and surface course placed on a subgrade to support traffic loads and distribute it to the roadbed.

Performance Period: The period of time that an initial pavement structure will last before requiring rehabilitation. The performance period is equivalent to the time elapsed as a new, reconstructed, or rehabilitated pavement structure deteriorates from its initial serviceability to its terminal serviceability.

Sailor Course: A paver course where lengths of rectangular pavers are laid parallel (lengthwise) to the edge restraint. See Soldier Course.

Serviceability: The ability of the pavement to serve the types of traffic that use the facility. The primary measure of serviceability is the Present Serviceability Index (PSI), ranging from 0 (very poor road) to 5 (perfect road).

Soldier Course: A paver course where widths abut against the edge restraint. See Sailor Course.

Subbase: The layer or layers of specified or selected material of designed thickness placed on a subgrade to support a base course. Aggregate subbases are typically made of stone pieces larger than that in bases.

Subgrade: The soil upon which the pavement structure and shoulders are constructed.

Treated Base: An aggregate base with cement, asphalt, or other material added to increase its structural capacity.

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INDEX