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DEVELOPMENT OF A NORTH AMERICAN STANDARD FOR THE STRUCTURAL DESIGN OF INTERLOCKING CONCRETE PAVEMENTS FOR MUNICIPAL STREETS AND ROADWAYS

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Note: The following is the notation used in this paper: (.) for decimals and ( ) for thousands.

Summary

Currently there exists no recognized standard for the structural design of interlocking concrete pavements in North America. In 2006, a pre-standard was developed under a joint project by the Transportation and Development Institute of the American Society of Civil Engineers (ASCE), the Interlocking Concrete Pavement Institute (ICPI), and the American National Standards Institute (ANSI). This paper provides an update to the development of a new standard for the structural design of interlocking concrete pavements for municipal streets and roadways in North America.

The paper describes the provisions of the proposed standard to establish guidelines for the structural design of interlocking concrete pavements. The standard relies on the flexible pavement design procedure described in the 1993 American Association of State and Highway Transportation Officials (AASHTO) *Guide for Design of Pavement Structures.* 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 standard was balloted for approval by the ASCE/ANSI Standards Committee in March 2009 and is expected to be available by summer 2009.

1. INTRODUCTION

In 2004 the ASCE Transportation and Development Institute and ICPI began a joint effort on the development of an ASCE/ANSI standard for the structural design of interlocking concrete pavements for North American design professionals. The draft pre-standard was introduced at the 2006 International Conference on Concrete Block Paving in San Francisco, California [Wilbanks, 2006]. The paper reviewed the design philosophy of the proposed standard and various sections including: design elements, design life, analysis, criteria such as soil conditions, and traffic loads used in the standard. The pre-standard was subsequently completed in 2008 and it served as the foundation for development of the standard described in this paper. In 2008, a Standards

Committee was established to develop a final draft standard for ballot. The draft standard was balloted in March 2009 and is expected to be available by summer 2009.

This paper describes the standard, *Structural Design of Interlocking Concrete Pavement for Municipal Streets and Roadways* [ASCE, 2009], which establishes the guidelines for the structural design of interlocking concrete pavements. The standard applies to paved areas subject to applicable permitted axle loads and trafficked up to 10 million 80 kN equivalent single axle loads (ESALs) with a design vehicle speed of up to 70 km/h. The standard provides preparatory information for design, key design elements, design tables for pavement equivalent structural design, construction considerations, applicable standards, definitions and best practices.

2. RATIONAL FOR DESIGN PROTOCOL

The pre-standard was originally developed to follow the empirical flexible pavement design procedures described in the 1993 AASHTO Guide for Design of Pavement Structures [AASHTO, 1993]. The Standards Committee reviewed other flexible pavement design methods, including the AASHTO mechanistic-empirical pavement design guide (ME PDG) procedure. However, the Standards Committee reaffirmed the pre-standard project team's consensus that the level of detailed information required to conform to the ME PDG procedure is unavailable in most non-highway applications. In addition, they determined that there is currently a paucity of North American mechanistic-empirical data for interlocking concrete pavement structural design. The forward to the standard acknowledges this with the following statement, "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 was developed based on the 1993 AASHTO Guide for the Design of Pavement Structures" [ASCE, 2009].

The AASHTO 1993 design methodology is well understood by municipal and consulting engineers in North America and provides a satisfactory level of reliability for the types of pavements covered by the standard. Nevertheless, the Standards Committee recognizes that the standard will be updated periodically and expects future versions to include the mechanistic-empirical design methodology.

3. TABLE OF CONTENTS

The standard consists of eight chapters with subsections. The following represents the Table of Contents of the standard [ASCE, 2009] is contained in Table 1.

Table 1. Table of Contents.

Abstract
Standards
Forward
1. General
1.1 Scope
1.2 Referenced Standards
1.3 Deviations from this Standard
1.4 Engineer Required
2. Preparation for Pavement Design
3. Design Elements
(Continues…)

(…Continuation from previous page)
3.1 General
3.2 Design Principles
3.3 Design Life
3.4 Design Reliability
3.5 Design Traffic
3.6 Subgrade Soil Strength Assessment
3.6.1 Characterize Subgrade Drainage
3.6.2 Frost, Swelling Soils and Other Considerations
3.7 Select Base Materials and Thicknesses
3.7.1 Unbound Dense Graded Base
3.7.2 Bound (or Treated) Bases
3.8 Determine Subbase Thicknesses
3.8.1 Unbound Dense Graded Subbase
3.9 Design Pavement Structure Drainage
3.10 Geotextile
3.11 Joint and Bedding Sand Requirements
3.11.1 Bedding Sand
3.11.2 Bedding Sand Drainage
3.11.3 Joint Sand
3.12 Concrete Pavers
3.13 Edge Restraints
3.14 Evaluate Solution for Life-Cycle Costs (Optional)
3.15 Construction Details and Specifications
4. Design Tables and Analysis
4.1 Design Tables
4.2 Example Case Studies
5. Other Design Considerations
6. References
7. Glossary of Terms
8. Index

4. DESIGN PROCESS

4.1 Design Process Flowchart

The design process is characterized by a flowchart illustrated in Figure 1. Relevant clauses from the standard are referenced from the Table of Contents.

4.2 Design Traffic

The standard uses a design reliability of 75%, although the designer can adjust to higher reliabilities by consulting the AASHTO 1993 *Guide* and adjust the design traffic loads according to the reliability desired. The design life, typically 20 to 40 years, is chosen by the designer, but regardless of the design life chosen the maximum allowable lifetime 80 kN equivalent single axle load (ESAL) for the structural design is 10 million. The design traffic is determined by the following formula [AASHTO, 1993]:

$$ESAL/Year = 182.5 \times AADT \times TP \times TF \times [1.57 - 0.083 \times \log_e(AADT/2)] \quad \textbf{(1)}$$

where:

ESAL = Equivalent single axle design loads per year.

AADT = Average annual daily traffic.

TP = Percent of commercial vehicles (expressed as a decimal).

TF = Truck factor (0.76 for a typical municipal flexible pavement).

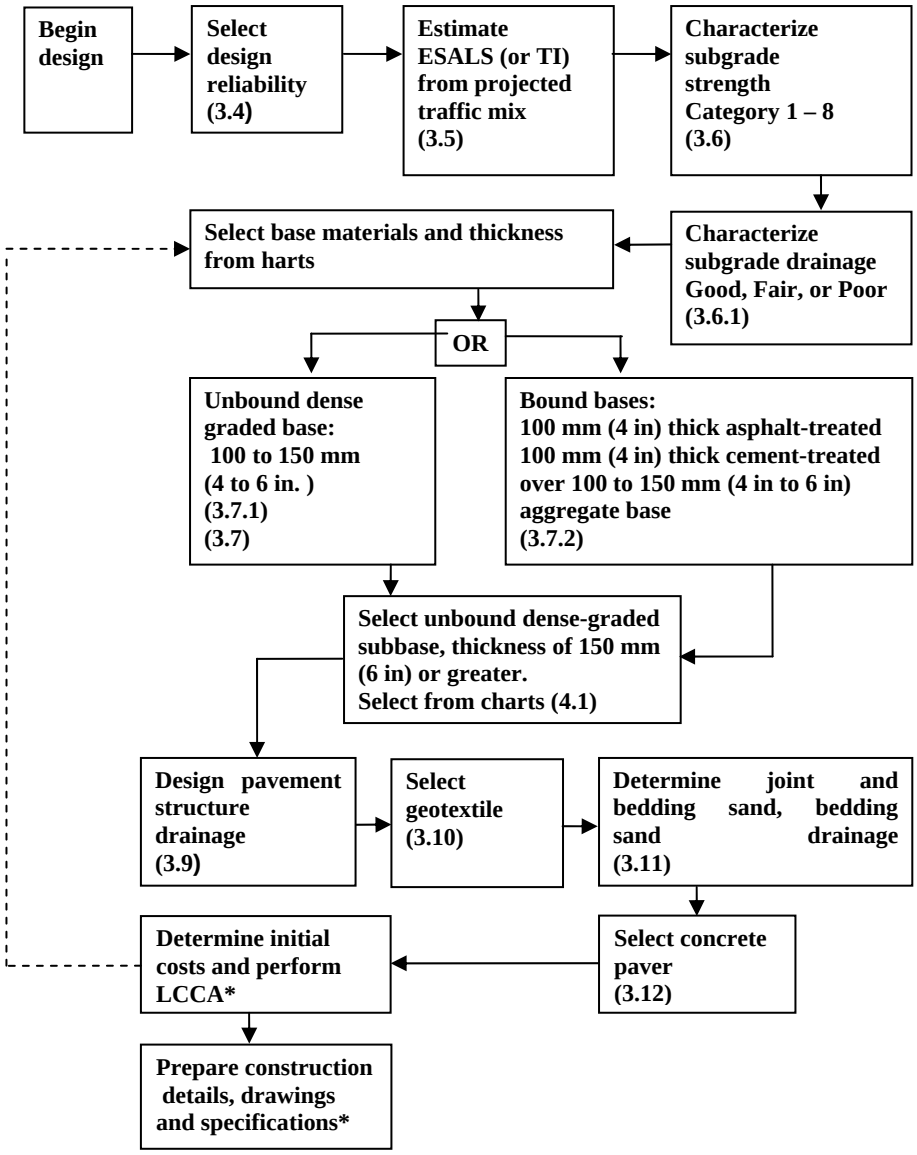


Figure 1. Design Process Flow Chart - * Indicates outside scope of the standard [ASCE, 2009].

4.3 Subgrade Characterization

The next step is for the designer to characterize the subgrade soil strength and drainage. Typically the resilient modulus (AASHTO T-274) is used to describe the strength of the subgrade soil. This can be determined directly from laboratory testing or California Bearing Ratio (CBR; ASTM D1883) and R-value (ASTM D2844) tests. The standard 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). Values in Table 2 form a part of the standard and are provided to the user of the standard for guidance only. Actual laboratory characterization of subgrade properties for each project is recommended. Designers are cautioned against making generalizations.

Table 2. General Soil Categories and Properties [ASCE, 2009].

CATEGORY NO.	CLASSIFICATION	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

Once the general subgrade type has been selected, it is necessary to identify the drainage quality of the subgrade and pavement structure (See Table 3). Depending on the type of subgrade, the strength of the pavement can be reduced if there is excess water in the subgrade. The standard includes an adjustment to the resilient modulus of the subgrade based on the overall quality of the pavement drainage, as shown in Table 4.

Table 3. Pavement Drainage According to Soil Category (ASCE, 2009).

QUALITY OF DRAINAGE	TIME TO DRAIN	SOIL CATEGORY NO. FROM TABLE 3.1
Good	1 day	1,2,3
Fair	7 days	3,4
Poor	1 month	4,5,6,7,8

Table 4. Resilient Modulus Values for Typical Subgrade Drainage Conditions [ASCE, 2009].

	RESILIENT MODULUS (MPa)								
	GOOD			FAIR			POOR		
Category	MPa	R	CBR	MPa	R	CBR	MPa	R	CBR
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

4.4 Selection of Base Material

The next step in the design process is selecting the type of base material for the pavement. The standard supports the use of bound and unbound bases.

For unbound dense graded bases, the aggregates are required to be crushed, angular materials. It is noted that crushed aggregate bases used in highway construction are generally suitable for interlocking concrete pavement, and that unbound base materials shall meet the local state, provincial or municipal standards governing subbase materials. Where local specifications are unavailable, the base material is required to meet the gradation requirements according to ASTM D 2940. The minimum required strength of the unbound base is a CBR of 80% or equivalent bearing strength as described by the test methods in Section 3.6 of the standard.

Unbound base materials are required to have a maximum loss of 60% when tested in accordance with CSA A23.2-29A (Micro-Deval abrasion) and a maximum loss of 40% when tested in accordance with ASTM C 131 or CSA A23.2-17A (Los Angeles abrasion). The required plasticity index is a maximum of 6 and the maximum liquid limit of 25 when tested in accordance with ASTM D4318 and AASHTO T-89 and T-90. For constructability purposes, the minimum design unbound base thickness is set at 100 mm for traffic less than 500,000 ESALs and 150 mm for 500,000 or more ESALs.

For bound or treated bases, asphalt-treated base (ATB) and cement-treated base (CTB) materials and installation are required to conform to provincial, state or local specifications for a dense graded, compacted, asphalt concrete. ATB material is required to have a minimum Marshall stability of 8000 N per ASTM D5 or AASHTO T-49. Use of the appropriate asphalt cement binder for local climate conditions is also recommended. Cement-treated base material is required to have a minimum 7 d unconfined compressive strength of 4.5 MPa per ASTM D4320 and D4219. For constructability purposes, the minimum bound base thickness for design purposes is set at 100 mm.

4.5 Subbase Material

Aggregates for subbase are required to be crushed, angular materials, and it is noted that crushed aggregate bases used in highway construction are generally suitable for interlocking concrete pavement. Unbound subbase materials are required to meet the local state, provincial or municipal standards governing subbase materials. Where local specifications are unavailable, the subbase is required to meet the gradation requirements according to ASTM D2940. The required minimum strength of the unbound subbase is a CBR of 40% or equivalent bearing strength as described by the test methods in Section 3.6 of the standard. The required plasticity index is a maximum of 10 and the maximum liquid limit of 25 according to ASTM D4318 and AASHTO T-90.

4.6 Concrete Paver Selection

Concrete pavers are required to conform to the product requirements of ASTM C936 *Standard Specification for Solid Interlocking Paving Units* in the United States and CSA A231.2 *Concrete Pavers* in Canada. For this ASCE/ANSI standard, pavers must have an aspect ratio (overall length/thickness) less than or equal to 3:1 and a minimum thickness of 80 mm. A 45 or 90-degree herringbone pattern is recommended for use and the designer is advised that alternative laying patterns may be considered as long as they are functionally and structurally equivalent. Other shapes than rectangular pavers can be considered in the design with the responsibility of the design engineer to confirm that the structural capacity is at least equal to the AASHTO structural number layer coefficient (SN) of the 0.44 used in the standard, either by testing or confirmation from the manufacturer.

4.7 Subbase Thickness and Final Pavement Structural Design

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. Subbase thicknesses are determined from one of the four design tables in the standard. The design tables provide structural design thicknesses primarily for unbound bases (granular base), ATB, and CTB. However, a thickness design table is also provided for asphalt concrete (AC) bases to reduce thick pavement structures associated with high traffic/low subgrade strength conditions. In the development of the AC table, an AASHTO structural layer coefficient of 0.44 has been assumed for AC. For AC layer SNs other than 0.44, the designer is advised to consult the 1993 AASHTO Guide. Table 5 shows the design tables for unbound granular base.

5. DESIGN EXAMPLE

The standard provides three design examples with soil conditions ranging from poor (subgrade category 8) to good (subgrade category 3), varying drainage conditions, and with lifetime traffic ranging from 500,000 ESALs to 10,000,000 ESALs. Below is one of the design examples [ASCE, 2009]. Using Tables 4.3 through 4.6 from the standard, designs were developed for the sample conditions and the comparative designs are shown in Table 6 [SCE, 2009].

Given:

ESALs: 2 000 000.
Drainage: Good.
Subgrade Category: 3 (GP, SP).

Required:

Interlocking Concrete Pavement Structural Thickness Design.

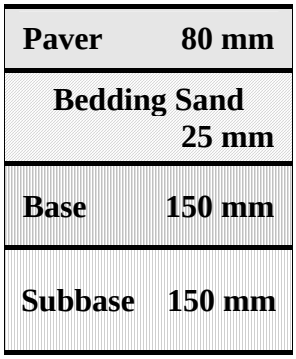
Table 5. Design Tables for Granular Base [ASCE, 2009].

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	11.5
1	Drainage	Layer Type										
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	150	200	150	150
		Unbound Dense Graded Subbase									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								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								150	300	400
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	175	150	150	150
		Unbound Dense Graded Subbase								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								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							150	275	425	550
Category 4	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								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							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						175	300	400	575	725
Category 8	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							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						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					175	225	350	475	650	800

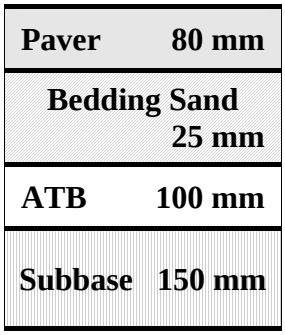
GRANULAR BASE STRUCTURE THICKNESSES (mm)											
		ESALs	10,000	20,000	50,000	100,000	200,000	500,000	1,000,000	2,000,000	5,000,000	10,000,000
		TI	5.2	5.7	6.3	6.8	7.4	8.3	9.0	9.8	10.9	11.8
	Drainage	Layer Type										
Category 5	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense Graded Base	100	100	100	100	175	150	150	150	150	150
		Unbound Dense Graded Subbase						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					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
Category 6		Unbound Dense Graded Subbase					250	300	425	550	750	875
	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					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					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
Category 7		Unbound Dense Graded Subbase				250	350	450	575	700	900	1050
	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					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				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
Category 8		Unbound Dense Graded Subbase			200	325	425	525	650	800	1000	1150
	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					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				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			200	325	425	525	650	800	1000	1150

Table 6. Results for Design Example [ASCE, 2009].

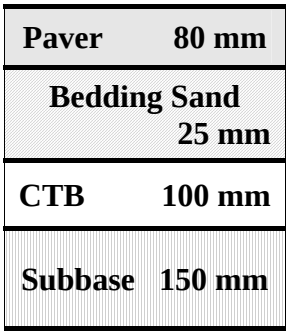
	DESIGN 1 (mm)	DESIGN 2 (mm)	DESIGN 3 (mm)	DESIGN 4 (mm)
Pavers	80	80	80	80
Bedding Sand	25	25	25	25
ATB	0	100	0	0
CTB	0	0	100	0
AC	0	0	0	50
Unbound Base	150	150	150	150
Subbase	150	0	0	0



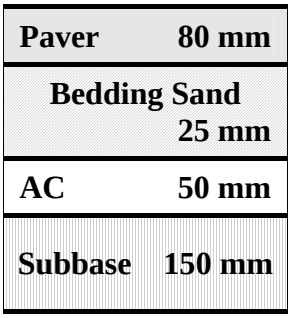
Design 1 – Unbound Base



Design 2 – ATB



Design 3 – CTB



Design 4 – AC

6. OTHER DESIGN CONSIDERATIONS AND CONSTRUCTION DETAILS

Guidance is also provided in the standard to the practitioner on proper detailing around utility structures, including edge detailing with sailor and soldier courses as shown in Figure 2. Particular emphasis is given to drainage details for unbound aggregate and treated bases since this benefits pavement life and performance for all structural designs and the details are unique to interlocking concrete pavements; see Figure 3. For further details, design considerations, best practices, and maintenance procedures designers are directed to the ICPI Tech Spec series at www.icpi.org. The designer is also encouraged to address how interlocking concrete pavement can contribute to sustainability through applying the Leadership in Energy and Environmental Design (LEED®) credit system [USGBC, 2003]. In addition, a glossary of terms in included in the standard.

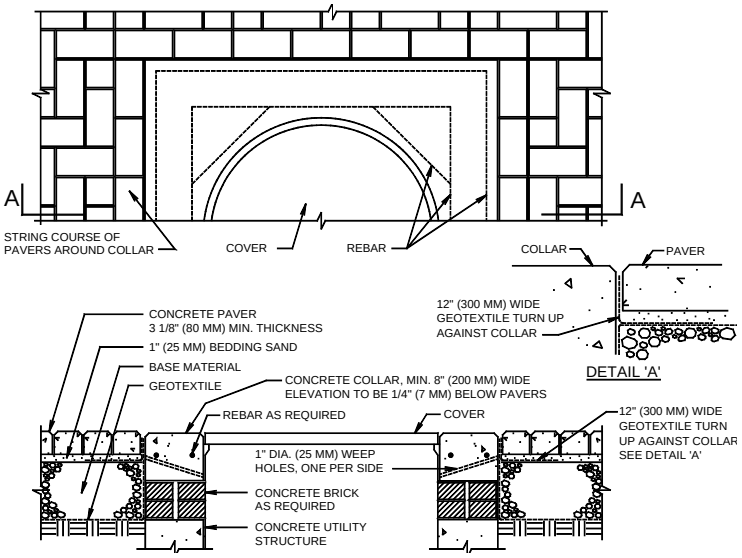


Figure 2. Sailor Course Around Utility Structure.

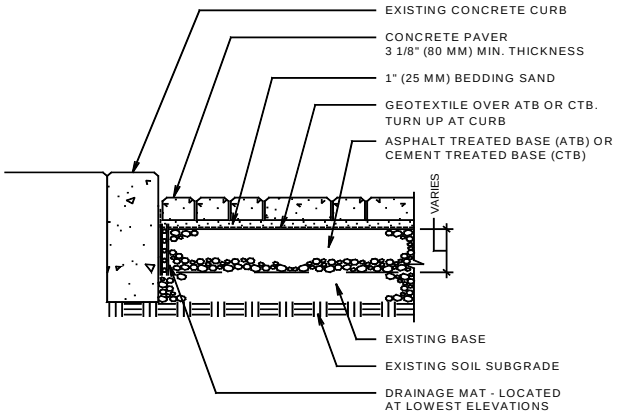


Figure 3. Drain Detail for Pavers over Treated Base.

7. CONCLUSION

The standard is the first consensus document on the structural design of interlocking concrete pavements in North America. Philosophically, this represents a validation of the ICP system among

practitioners as a viable alternative to asphalt and concrete pavements in municipal applications. Practically, the standard will ensure structurally adequate designs that will improve the long term performance of these pavements. The standard, *Structural Design of Interlocking Concrete Pavement for Municipal Streets and Roadways*, is expected to be available by summer 2009.

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