DEVELOPMENT OF A NATIONAL STANDARD FOR THE STRUCTURAL DESIGN OF INTERLOCKING CONCRETE PAVEMENTS

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SUMMARY

The Transportation and Development Institute of the American Society of Civil Engineers (ASCE) and The Interlocking Concrete Paver Institute (ICPI) are jointly cooperating on the development of an ASCE/ANSI standard for the structural design of interlocking concrete pavers for North American design professionals. The pre-standard is expected for completion in the spring of 2007 and will represent the first of its kind for segmental pavements in North America. This paper reviews the design philosophy of the proposed standard, and the various sections, including; design elements, design life, analysis, criteria such as soil conditions, and trafficking used in the standard. Performance standards, a glossary, and best practices are also to be incorporated. The standard is targeted for municipal and commercial paving at typical urban street speeds. Techniques similar to those typically used for North American asphalt design procedures will be incorporated, to provide a familiar tool for designers.

1. INTRODUCTION

Concrete pavers have been manufactured in North America since 1973. Since then interlocking concrete pavements have been proven to be an appropriate, durable, cost effective pavement alternative for many applications. Concrete pavers have been successfully used in residential, commercial, public works, and heavy industrial environments such as ports and airports. For many years in North America, concrete pavers were selected and sold for their aesthetic appeal. However, when properly designed and installed, interlocking concrete pavements either equal or exceed other pavement types in regards to durability, toughness, structural load bearing capacity, and life cycle (JEGEL, 2000).

Despite these advantages, it has been difficult for concrete pavers in North America to make inroads against asphalt and poured in place concrete pavements in the municipal and commercial sectors. According to the most recent study by the Interlocking Concrete Pavement Institute (ICPI, 2006) the concrete paver market is approximately 77% residential, 16.5% commercial and 6% municipal. These percentages have remained fairly constant over the last several years. In contrast, in many parts of Europe the primary use is in the much larger commercial and municipal sectors.

Asphalt has been in use for over 100 years in North America and its use taught as part of every university engineering, architecture, or landscape curriculum. The design methods are standardized and readily available in text books and as computer programs. Hence, the performance of asphalt is well

understood by decision makers and pavement designers. There are also many references describing best practices for successful asphalt pavement design and how to avoid failure (ASTM, 2003). Engineers have clear precedents for the successful use of asphalt. A consensus standard developed specifically for the structural design of interlocking concrete pavements will help to provide the same level of comfort to design professionals.

In 2004 the Interlocking Concrete Paver Institute ICPI and the Transportation and Development Institute (T&DI) of the American Society of Civil Engineers (ASCE) engaged to produce a structural design standard fro interlocking concrete pavements. The ultimate goal of the standard is to provide municipal engineers and consultants with a standard design method that uses methodology consistent with accepted North American flexible pavement design methods. ASCE is an American National Standards Institute (ANSI) accredited standards development organization and works with associations to develop such standards. This paper summarizes the scope and development of the pre-standard, the general conditions, design methodology and design elements that will be incorporated.

2. SCOPE AND DEVELOPMENT OF THE PRE-STANDARD

The scope of the work includes the development of a pre-standard document by a six-person Project Team (PT). Guidance and feedback is given to the PT by the Project Advisory Committee (PAC) which is composed of six to eight engineers with extensive knowledge in design, installation and application of pavers both in the United States and abroad. The members of both the PT and PAC will eventually be a part of the proposed standards committee. Having the members of both the PT and PAC as voting members of the standards committee allows them to provide detailed explanations to the full standards committee on how they came to their conclusions during the development of the pre-standard.

It would be extremely difficult to prepare a standard that adequately addresses all the markets where unit paving is appropriate. This standard is being prepared for engineers and others involved in the selection and design of city streets and commercial facilities. While it might also be useful to for the residential and industrial uses it is not specifically intended for those sectors. This standard applies to all paved areas subject to axle loads up to 11,000 kg (24,250 lbs) or maximum vehicle load of 36,287 kg (80,000 lbs) trafficked up to 10 million 80 kN (18-kip) equivalent single axle loads (ESALs). Design lives of 20 or 40 years are included.

The standard guideline will not specifically address design requirements for the subgrade support of pavers. Instead, the standard will specify the performance requirements for the subgrade to be addressed by a geotechnical engineer. Use of proprietary, new and/or improved paver configurations, materials, evaluation techniques and installation methods are not prohibited by the standard, as long as the design and installation of the pavement are shown to comply with the guidelines set out in the document.

3. GENERAL CONDITIONS OF THE STANDARD

3.1 Engineer Required

Any work designed under the standard will be at the direction of a professional engineer having experience and qualifications in pavement design and construction, and having an understanding of the verification techniques and the project requirements.

3.2 Definitions

Definitions are provided in a glossary and references the terms consistent with the proposed standard. The glossary will be the largest and most complete for unit paving published in a North American segmental pavement design standard.

3.3 Design Principles

The Standard follows the flexible pavement design procedure described in the 1986 and 1993 AASHTO (American Association of State and Highway Transportation Officials) *Guide for Design of Pavement Structures* (AASHTO, 1993). Although other international design methods were considered by the PT, they were determined to be less well known and AASHTO was considered to provide a common and well known method used in North America. In addition, although AASHTO 2002 design procedures include mechanistic-empirical procedures aimed at offering higher reliabilities, the 1993 AASHTO method was selected in part because of its history of success and familiarity to the engineering community. It is felt that the level of detailed information required to conform to the 2002 design procedure will not be the type of information that a typical municipal engineer, or their consultant, will easily have available in non-highway applications.

The standard includes design charts that are developed by using an adaptation of the 1993 AASHTO Guide for the Design of Pavement Structures. Through an analysis of AASHTO 1993 and mechanistic design principles, typical interlocking concrete paver designs suitable for municipal type traffic have been developed (Leong, 2005) The resulting design charts represent a range of roadway functional classes along with three drainage categories, six traffic categories, three base types, and various combinations of subbase thicknesses – for typical municipal applications.

3.4 Design Elements

The following design elements are proposed to be included in the final standard and are defined by their own individual clauses; Design Life, Design Reliability, Traffic Loads, Characterization of Subgrade Strength, Characterization of Subgrade Drainage, Unbound Dense Graded Base, Bound (or Treated) Bases, Unbound Dense Graded Subbase, Design Subgrade Drainage, Geotextiles, Bedding Sand, Bedding Sand Drainage, Joint Sand, Concrete Paver Type and Thickness, and assumptions about the strength of base and subbase materials. The design assumes 80 mm (3 1/8 in.) thick pavers and 25 mm (1 in.) bedding sand.

4. DESIGN METHODOLOGY

Methodology for the Engineer is called out via a clear a flow chart (See Figure 1) that includes the aforementioned design elements. The standard walks the Engineer through the following steps:

First, the designer selects the design life of either 20 or 40 years (Tables are presented that include designs for both 20 and 40 year design lives). Next the designer identifies the subgrade conditions that are supplied by the geotechnical engineer and uses Tables 1 and 2 to describe the subgrade conditions and select a subgrade resilient modulus. Drainage, degree of saturation and frost susceptibility determine the ultimate bearing strength which is expressed in terms of resilient modulus (M_r), California Bearing Ratio (CBR) or R-value. Drainage conditions are selected as good, fair or poor and are defined by drainage in one day, seven days and one month respectively.

Table 1. Proposed Table 6.1 of the pre-standard showing the various resilient modulus values for typical subgrade conditions. Source: American Society of Civil Engineers

Category	Resilient Modulus for Typical Subgrade Conditions (MPa)								
	Good			Fair			Poor		
	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

Table 2. Subgrade types are classified according to the Unified Soils Classification method, ASTM D2487 (2000)

Category No.	Classification	Drainage Characteristics	Susceptibility to Frost Action
1	Boulders/cobbles	Excellent	None
2	GW, SW	Excellent	Negligible
3	GP, SP	Excellent to fair	Negligible to slight
4	GM, SM	Fair to semi-impervious	Slight to moderate
5	GC, SC	Practically impervious	Negligible to slight
6	ML, MI	Typically poor	Severe
7	CL, MH	Practically impervious	Slight to severe
8	CI, CH	Semi-impervious to impervious	Negligible to severe

The traffic is then selected from the proposed table 6.2 of the pre-standard. Traffic is described either in terms of equivalent single axle loadings (ESALs) or California Transportation Department (Caltrans) traffic index (TI) (See Table 3). The conversion to TI is defined by the following equation:

(1) $TI = 9.0 \times (ESAL/10^6)^{0.119}$.

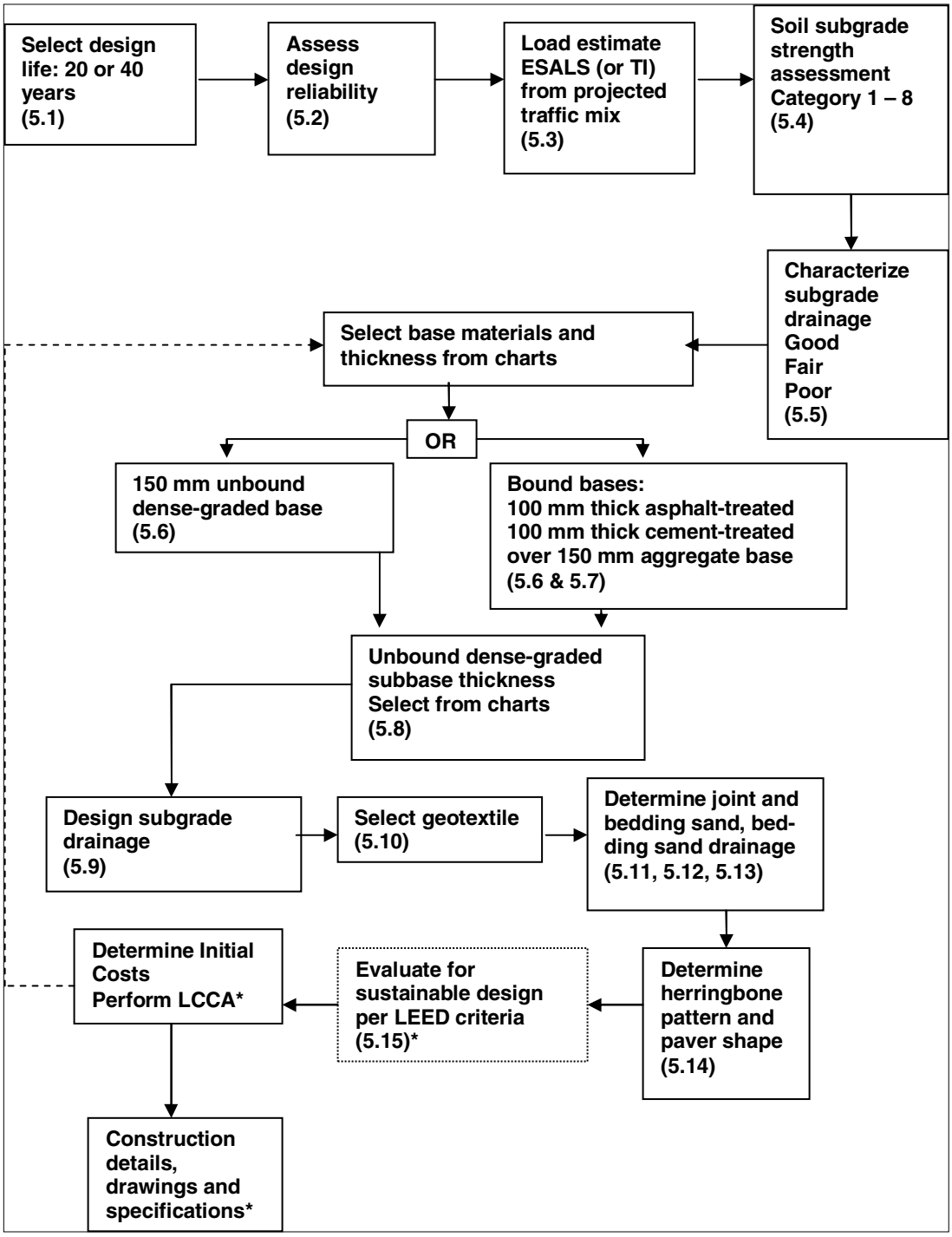


Figure 1. Proposed design flow chart for the pre-standard. Clauses in brackets relate to the pre-standard clauses. Source: American Society of Civil Engineers

Table 3. Proposed Table 6.2 of the pre-standard. Design ESALs and Traffic Index for 20 and 40 years related to AADT and annual ESAL's. Source: American Society of Civil Engineers

AADT	ESALs	Design ESALs		Traffic Index (TI)	
		20 Years	40 Years	20 Years	40 Years
500	800	16,000	32,000	5.5	6.0
1,000	3,000	60,000	120,000	6.4	7.0
5,000	15,000	300,000	600,000	7.8	8.5
10,000	80,000	1,600,000	3,200,000	9.5	10.3
15,000	200,000	4,000,000	8,000,000	10.6	11.5
20,000	250,000	5,000,000	10,000,000	10.9	11.8

The last decision that must be made is the type of base. Thus, once the engineer has determined the design life, subgrade category, drainage condition and traffic, the *subbase* thickness is chosen from the tables. Tables 6.3, 6.4 and 6.5 of the proposed standard are used to select the resulting subbase thickness for the 20 year design charts for unbound base, ATB (Asphalt Treated Base) or CTB (Cement Treated Base). Tables 6.6, 6.7 and 6.8 of the proposed standard are 40 year design charts used to select the resulting sub base, again for the unbound base condition, ATB condition or CTB. Typically resultant subbase thicknesses of less than 100 mm would be converted to granular base and added to the standard 150 mm of granular base.

5. OTHER DESIGN ELEMENTS

5.1 Design Pavement Structure Drainage

The Engineer considers drainage of the bedding sand layer and the soil subgrade. Drain holes and other methods are discussed, depending on the application. Figures illustrating typical drain conditions for unbound and bound bases are also included.

5.2 Geotextile

The standard will assist the designer in the selection and need for a geotextile to separate the subgrade soil from the pavement structure, or to prevent bedding sand migration into lower layers. Guidance on the installation of a geotextile is also provided

5.3 Determine Joint and Bedding Sand Requirements

In this step, the joint and bedding sand are selected. Importance of joint and bedding sand is discussed and details on joint and bedding sand are provided.

5.4 Determine Paver Shape and Herringbone Pattern

Type, shapes, and aspect ratio of pavers is discussed. Guidance on laying pattern is also given**.**

5.5 Evaluate Solution for Sustainable Design – LEED (Optional)

Interlocking concrete pavement can contribute to sustainability through applying the Leadership in Energy and Environmental Design or LEED® credit system (USGBC, 2005). Reference to LEED organizations and standards are provided and LEED credits are discussed.

5.6 Evaluate Solution for Life-Cycle Costs (Optional)

Life-cycle cost input and analysis methods will be provided and referenced at the option of the designer.

5.7 Construction Details and Specifications

The pre-standard recognizes that the appropriate use of construction details and specifications are of paramount importance to the success of a pavement system. Hence, guidance on segmental concrete construction details and specifications are also provided. Some of the related subjects in this section will include; paver selection, pattern direction, cutting, edge restraints, joint widths, freeze thaw requirements, drainage of the bedding layer, and slope considerations.

5.8 Materials

In this section material properties and minimum requirements for sand, pavers, geotextile, and base materials are discussed. Where appropriate, ASTM and AASHTO material standards are referenced.

6. DESIGN EXAMPLES

To give additional guidance to the designer, sample completed designs will also form part of the standard. The methodology included in the standard is followed. An example case study from the pre-standard follows.

Given criteria:
Design Life: 40 Years
Drainage: Good
TI: 10.3
Subgrade Category: 3 (GP, SP)
ESAL's: 3,200,000

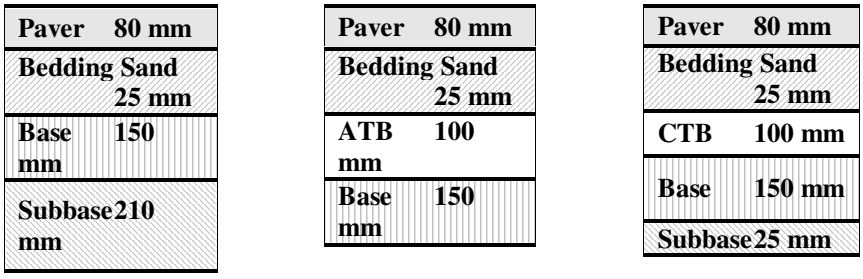
Required:
Interlocking Concrete Pavement Structure

Analysis:
Using tables 6.6, 6.7 and 6.8 from the proposed pre-standard, the following designs are developed.

Table 4. Design thicknesses resulting from the pre-standard design example. Design 1 is the solution for an unbound base design, Design 2 is for ATB and Design 3 is for CTB. Source: American Society of Civil Engineers

	Layer Thicknesses (mm)		
	Design 1	**Design 2**	**Design 3**
Pavers	80	80	80
Bedding Sand	25	25	25
ATB	0	100	0
CTB	0	0	100
Unbound Base	150	150	150
Subbase	210	0	25

The three resulting sections are shown below as Figure 2. It should be noted that the 25 mm subbase in Design 3, since it is less than 100 mm, would be converted to base material by applying an equivalence factor. In this case the dense graded subbase would be converted to dense graded base by multiplying by the conversion: (45mm/25mm).



Design 1 Design 2 Design 3

Figure 2. The resultant cross-sections from case study 1 from the proposed pre-standard

7. CONCLUSION

The pre-standard is expected to be completed in the spring of 2007. The pre-standard will be submitted to an ASCE Standards Committee for review and approval using a consensus balloting process in accordance with ASCE's Rules for Standards Committees. Once the standards committee has approved the pre-standard, interested parties and the general public will have an opportunity to review and comment on the document during a public review period. Once the public comment period is closed and the standards committee has addressed any comments the document will be published. The following Table of Contents has been developed as part of the pre-standard.

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Determine Subbase Thickness
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Need for a Geotextile
Determine Joint and Bedding Sand Requirements
Determine pave Shape and Herringbone Pattern
Evaluate Solution for Sustainable Design – LEED (Optional)
Evaluate Solution for Life-Cycle Costs (Optional)
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8. REFERENCES

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