CONSTRUCTION DETAILS AND GUIDE SPECIFICATIONS FOR INTERLOCKING CONCRETE PAVEMENT

Robert J. Burak, P.Eng.
Director of Engineering
Interlocking Concrete Pavement Institute
November 27, 2002

INFRA 2002
November 25-27, 2002
Hilton Bonaventure
Montreal, Quebec

1. INTRODUCTION

The concept of interlocking concrete pavement dates back to the Roman Empire. Even then, segmental pavements consisted of tightly fitted paving units on compacted granular base. Concrete pavers were developed in the late 1940's in the Netherlands as a replacement for clay brick streets. By the mid 70's automated production was introduced to North America. Today's concrete pavers are manufactured with highly controlled production equipment in controlled environments resulting in paving units with close tolerances to help ensure pavement interlock.

The use of concrete pavers for municipal applications is well accepted throughout the world. In North America, the process of institutionalization of the concrete paver began in the mid to late 80's (Smith, 1992). While institutionalization among engineers is still in the development stages concrete pavers are considered an orthodox solution in many applications, particularly heavy load applications. In 1980, the total consumption of pavers in North America for all markets was estimated at 40 million ft^2 (4 million m^2). For 2001, total sales of pavers in North America is estimated at 430 million ft^2 (43 million m^2). Commercial and municipal applications account for approximately 32% of the market.

The growing acceptance of concrete pavers, is due in part to acceptance overseas as well as acceptance of design methods within the North American engineering community. Internationally, over 5 billion ft^2 (500 million m^2) are installed annually. This paper will discuss how interlocking pavements function structurally, and how to detail, specify, and construct these pavements for successful performance. Design software for structural calculations will also be discussed.

2. PRINCIPLES OF DESIGN AND CONSTRUCTION OF INTERLOCKING PAVEMENTS

2.1 Advantages

Interlocking concrete pavements offer the advantages of concrete materials, but with flexible performance similar to asphalt pavement. As high strength concrete, the units have high resistance to freeze-thaw cycles and de-icing salts, high abrasion and skid resistance, no damage from petroleum products or from concentrated point loads or high temperatures. Load transfer is achieved through shear transfer through the various joints in the pavement. As with flexible asphalt pavement, an aggregate base accommodates minor settlement, however the difference with the interlocking pavement is that it will not crack. Another advantage to these pavements is access to underground utilities and the ability to re-instate the paving units, thereby reducing waste materials. The results of the life-cycle cost analysis for Main Street, North Bay, (JEGEL, 2000) indicate that when a discount rate of 4% is applied, interlocking concrete pavements are more cost-effective than asphalt pavements for this type of application.

2.2 Interlock

Critical to the structural performance of segmental concrete pavements is the concept of interlock between the units. Figure 1 demonstrates the three types of interlock that must be achieved; vertical, rotational, and horizontal. Vertical interlock relies primarily on shear transfer of loads to adjacent units through the jointing sand, rotational interlock relies mainly on paver thickness, unit

spacing, and edge restraint, and horizontal interlock relies primarily on laying patterns that disperse braking, turning, and accelerating forces. Figure 2 shows a herringbone pattern that is universally recommended for areas subjected to vehicular traffic. Testing has shown that this laying pattern with the use of dentated (or non-rectangular) paver shapes offer the greatest structural capacity and resistance to horizontal creep (Shackel, 1979, 1980).

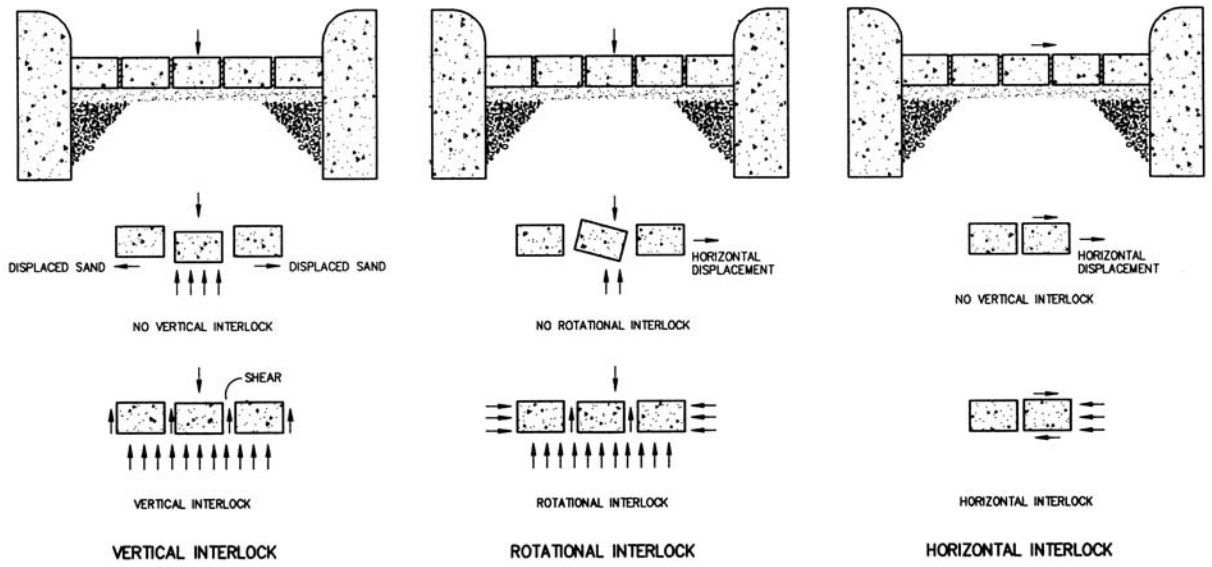

Figure 1: The three types of interlock – vertical, rotational, and horizontal
Source: Interlocking Concrete Pavement Institute

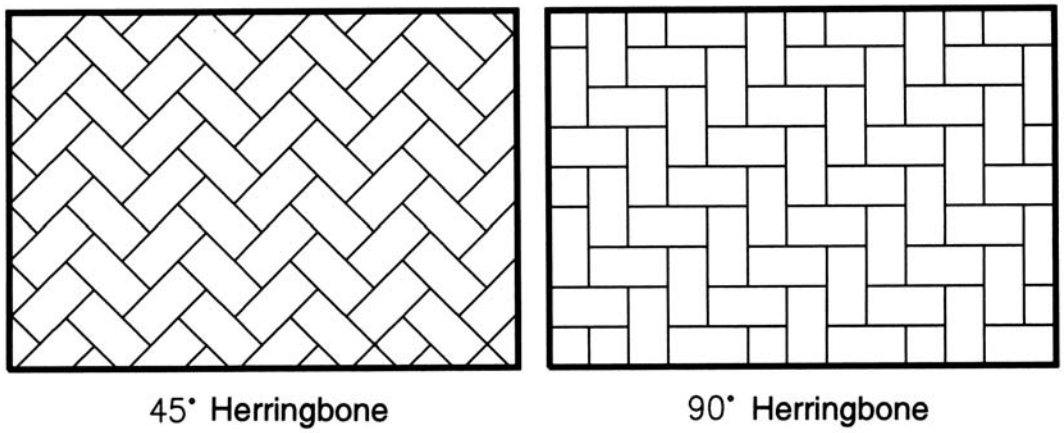

Figure 2: Recommended laying patterns for vehicular traffic
Source: Interlocking Concrete Pavement Institute

2.3 Typical Pavement Sections

Figure 3 shows typical pavement cross sections for interlocking concrete pavements. The pavers are laid on a one-inch (25 mm) thick sand bedding layer over a compacted bound or unbound base and a granular sub base as required. The base design and sub base requirement are determined by the severity of the applied loads and either the resulting vertical stresses and strains at the top of

the subgrade or the horizontal strains in the base. Many pavements for city uses do not require an aggregate sub base except for very heavy use, or over a weak soil subgrade. In these situations it may be more economical to use asphalt or cement stabilized base layers. Often, they are placed over a sub base layer of unbound compacted aggregate.

The Interlocking concrete paving system also relies on the design and installation of adequate restraint in the form of an edge restraint (ICPI, 1994). The requirement for geotextile application over the subgrade is dependent on the soil conditions. Geotextile may be required to facilitate encapsulation of bedding and joint sands in applications with stabilized bases.

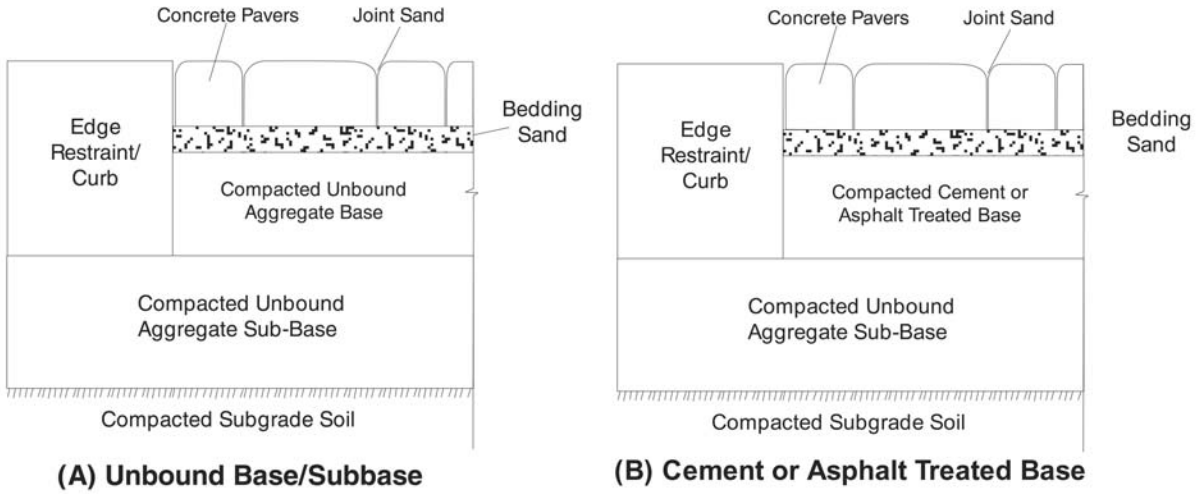

Figure 3: Typical Cross sections for interlocking concrete pavements
Source: Interlocking Concrete Pavement Institute

2.4 Concrete Paver Specifications

Concrete pavers are manufactured to CSA A231.2 specifications. In this specification, concrete pavers are defined by their aspect ratio (length over thickness) and by their total surface area. A concrete paver, by definition, must have an aspect ratio less than 4:1 and a surface area less than 100.25 in^2 (0.065 m^2). For areas subject to constant vehicular use the required aspect ratio is less than 2.5:1 and is assumed for the purposes of this paper. CSA specifies a minimum average compressive strength of 50 Mpa (7250 psi) and includes a durability requirement of a maximum loss of 200 g/m^2 of surface area after 25 cycles of freeze and thawing in a 3% saline solution or 500 g/m^2 loss after 50 cycles.

2.5 Pavement Materials

Compaction of the soil subgrade is critical to the performance of interlocking concrete pavements. Adequate compaction will minimize settlement. For vehicular areas, compaction should be a minimum of 95% modified proctor density according to ASTM D 1157. In extremely saturated or very fine soils stabilization of the soils may be required and geotextiles should be considered.

Crushed aggregate bases, or stabilized bases used in flexible asphalt construction are generally suitable for interlocking concrete pavement. Typically, provincial specifications fro gradation will

be sufficient. The minimum recommended strength requirements for unbound aggregate bases should be CBR=80% and for sub-bases, CBR=30%. Base material should have a plasticity index no greater than 6 and a liquid limit no greater than 25. Compaction of the granular base for vehicular areas should be at least 95% of modified proctor density as determined by ASTM D 1557, or AASHTO T-180 density. The final base tolerance should be checked with string lines, transit or straight edge and conform to a tolerance of +/- 10 mm over 3 m.

Bedding sand should be consistent throughout the pavement and not exceed 1.0 inches (25 mm) after compaction. The bedding layer acts as the resting spot for the pavers, but more importantly, facilitates initial interlock of the pavers and provides a drainage layer for water that penetrates through the joints. The sand should be as hard as practically available and should not be screening material or stone dust. Screening material will deteriorate after repetitive traffic loading, and both screenings and stone dust will not provide for adequate drainage. These materials will then lubricate, move, and result in deformation (rutting) under loading.

ICPI recommends the Liley-Dowson test to determine bedding sand hardness. One (1) 1.4 kg sample of bedding sand is randomly sampled from the sand source. The sample is dried for 24 hours at 115C to 121 C. Three (3) sub samples, each weighing 0.2 kg are obtained by passing the main sample several times through a riffle box. A sieve analysis is carried out on each sub sample according to ASTM C 136. Each sample is remixed and placed in a nominal liter capacity porcelain jar with two 25 mm steel ball bearings weighing 75 grams each. Each jar is rotated at 50 rpm for six hours. The sieve analysis is repeated and the individual and average sieve analysis is recorded. For each sample tested, the maximum increase in the percentages passing each sieve and the maximum individual percent passing shall be as indicated in Table 1 below.

Table 1
Bedding Sand Degradation Test – Maximum Percent Passing

Sieve Size	Maximum Increase	Maximum Passing
No. 200 (80µm)	2%	2%
No. 100 (160µm)	5%	15%
No. 50	5%	35%

The CSA A23.1 (FA 1) gradation for concrete sand should be used for the bedding layer (See Table 2). The only exception is that there should be no allowance for fines passing the 80 µm sieve (ie. 0% passing). To facilitate bedding of the pavers, the sand should be at optimum moisture content.

Table 2
CSA A23.1 (FA 1)
Gradation for Bedding Sand

Sieve Size:	% Passing
10 mm	100
5 mm	95-100
2.5 mm	80-100
1.25 mm	50-90
630 µm	25-65
315 µm	10-35
160 µm	2-10

Joint sand provides vertical interlock and shear transfer of loads. It can be slightly finer than the bedding sand. Gradation for this material can have a maximum 100% passing the 1.25 mm sieve and more than 10% passing the 80µm sieve. Commonly the bedding sand is used for the joint sand for easier control of job site materials. This will require additional effort in filling the joints during compaction due to the coarser gradation. Joint sand should be dry when swept in to the joints to ensure that there is no bridging of sand in the joints, which would decrease interlock. Consideration should also be given to joint sand stabilizers, which have been shown to reduce the long-term loss of joint sand.

2.6 Construction of Interlocking Pavements

Due to the similarities in flexible pavement performance, the soil subgrade and base materials are prepared and installed in a similar manner to asphalt pavements. Following the installation of the base, bedding sand is placed to a uniform thickness, typically 1 to 1-1/2 inches (25-50mm) by a process of hand or mechanical screeding (See Figure 4). The paver units are then placed either by hand or mechanically. Depending on the type of edge restraint used, it is installed either before the installation of the bedding sand or after. The pavers are then placed and vibrated into place with a high frequency plate vibrator with a minimum force of 22 kilo-newtons to facilitate compaction of the bedding sand and migration into the bottom of the joints of the pavers (See figure 5). Joint sand is then swept into the joints by hand or mechanically. The units are compacted again to ensure complete filling of the joints and the necessary interlock for performance of the pavement (See figure 6).

2.7 Detailing and Construction Tips

Well designed and constructed details increase the quality of any interlocking concrete pavement. Figure 7 shows pavers cut and placed directly against a restraint and Figure 8 shows the same detail with a row of full pavers against the restraint. Pavers will not only look better with the latter detail, but perform better as well. For vehicular traffic, cut pavers should be at least 1/3 of the whole paver. In Figure 9, the cracked units on one side of the curb were cut to less than a third in size and suffered from repetitive tire loads, whereas the ones on the right did not since they were larger.

Figure 4: Mechanical screeding of bedding sand
Source: Interlocking Concrete Pavement Institute

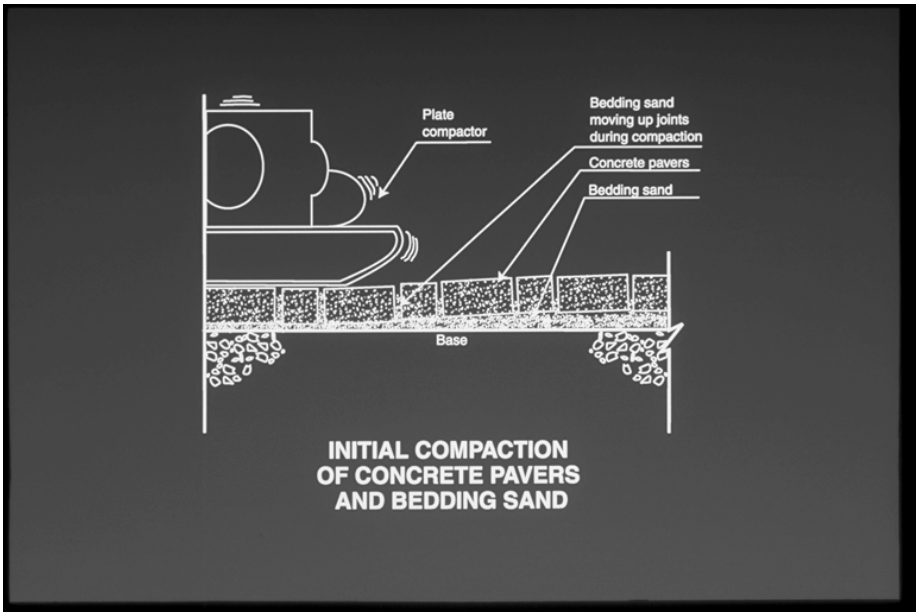

Figure 5: Initial compaction of concrete pavers begins the process of interlock by forcing the bedding sand to move up into the joints
Source: Interlocking Concrete Pavement Institute

Figure 6: Joint sand is applied and the pavers go through a final compaction
Source: Interlocking Concrete Pavement Institute

Figure 7: Pavers cut and placed directly against a restraint
Source: Interlocking Concrete Pavement Institute

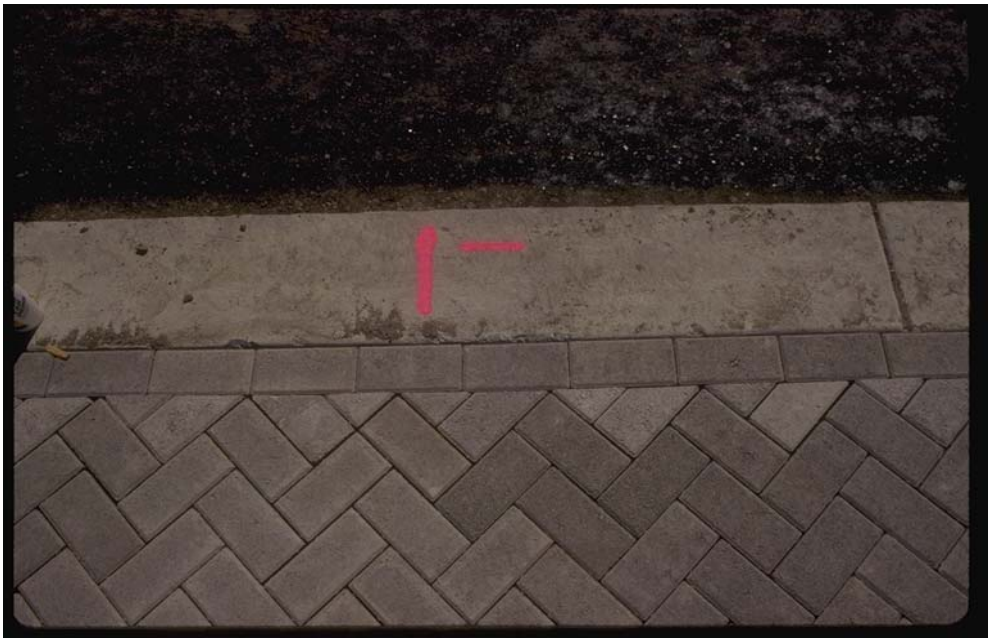

Figure 8: A row of full pavers against the restraint gives a better visual appearance and increases the performance of the pavement
Source: Interlocking Concrete Pavement

Institute
Figure 9: In this vehicular application, the pavers on the left were cut and placed at less than 1/3 of the original paver size, whereas the ones on the right were not.
Source: Interlocking Concrete Pavement Institute

Settlement of pavers against curbs is caused by two sources. One is insufficient compaction of the soil and the base next to the curb. After curbs are constructed, they are generally backfilled and the compaction of the material should be monitored with a density guage. Figure 10 shows failure

at a curb interface as the result of inadequate compaction. The other source of settlement at the curb is the loss of bedding sand through joints in the curb (See Figure 11). This can be mitigated by the detail and construction shown in Figures 12 and 13.

Figure 10: To eliminate settlement at the edge of curbs, backfilled materials must be adequately compacted and the density monitored with density gauges
Source: Interlocking Concrete Pavement Institute

Figure 11: To prevent loss of bedding sand at the edge of curb, geotextile is recommended
Source: Interlocking Concrete Pavement Institute

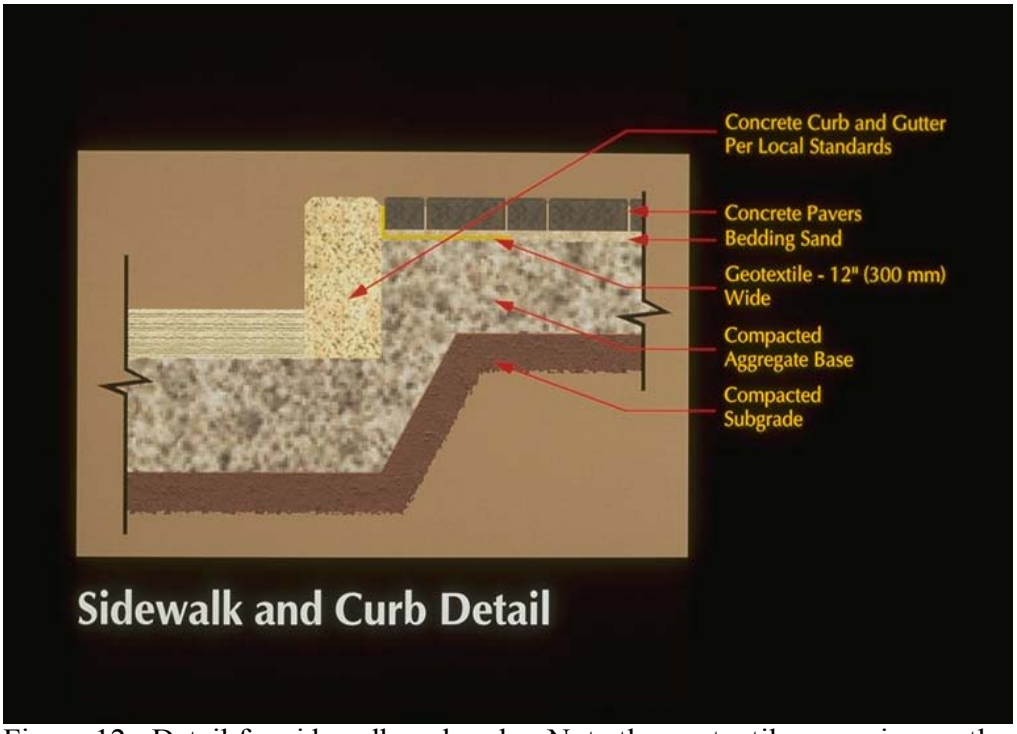

Figure 12: Detail for sidewalk and curb – Note the geotextile wrapping up the full height of the curb and extending 300mm into the pavement section
Source: Interlocking Concrete Pavement Institute

Figure 13: Geotextile shown at the interface of the curb to prevent loss of the bedding sand
Source: Interlocking Concrete Pavement Institute

Settlement and cracking of pavers against a utility access cover can be prevented by using a concrete collar (See Figure 14). The paver pattern is brought to and cut against the square collar instead of attempting to fit the pavers against the round cover.

Figure 14: A concrete collar around a utility cover creates a better visual as well as eliminating settlement and cracking
Source: Interlocking Concrete Pavement Institute

Cross walks are subject to as much as twice the normal wheel loads from turning, accelerating, and braking tires. The result is additional stress on the pavers and base. For new crosswalks, it is important to maintain the continuity of the base and its thickness under the concrete pavers and the adjacent asphalt pavement. Disturbing or changing the base material may weaken it, especially next to different pavements. One way to ensure continuity is to pave either side of the crosswalk with at least 1 meter of asphalt resting inside the crosswalk area. After rolling the asphalt, saw cut and remove it, creating smooth sides perpendicular to the base. Asphalt on both sides of the crosswalk should be thicker than the pavers and bedding sand. In most cases, the minimum asphalt thickness restraining the pavers should be at least 115 mm. Drainage can be either through the base to the subgrade through weepholes, or through small drains into the side of catch basins. Drains are recommended at the lowest elevations of the cross walk. These are usually along the curb or gutter. The drain openings should be covered with geotextile to prevent loss of bedding sand.

For cross walks in existing pavements, again the thickness of the existing asphalt must be thicker than the pavers and bedding sand to provide for a strong edge restraint. If the existing pavement is showing rutting, this may indicate that the base is not sufficient to handle the anticipated traffic. In these cases stabilizing the base may be necessary. It is critical when cutting into the existing asphalt pavement that particular attention is paid to the adjacent base materials. It may be necessary to support the asphalt at the cut edge with concrete or unshrinkable fill.

Figure 15: The stress on asphalt beside paver crosswalks can cause it to deform or move away resulting in reduced interlock and potential deformation of the pavement. The designer should consider reinforcing the asphalt edge with concrete and should ensure an adequate thickness for the asphalt restraint
Source: Interlocking Concrete Pavement Institute

For very heavily trafficked crosswalks, in new or existing pavement, concrete bases may be required under the pavers and bedding sand. These include walks subject to constant truck or bus traffic. Although a compacted aggregate base may be desirable to take advantage of interlock among the pavers, plus allow for easier access to underground utilities, the optimum compaction of the soil and base next to the concrete header beams is often difficult to achieve. The result can be unwanted rutting and settlement due to constant wheel loads. Figure 16 shows a concrete header at the leading and trailing edges of the cross walk. Figure 17 shows a typical cross section for a paver cross walk on a concrete base.

3. STRUCTURAL DESIGN PROCEDURES

Generally, interlocking concrete pavements are designed by semi-empirical or layered elastic (mechanistic) design procedures. A summary of some of the design methodologies for interlocking pavement follows.

Due to the similarities with asphalt pavements in terms of the nature of load distribution and failure modes, the AASHTO method can be used for the structural design of interlocking concrete pavements. This is based in part on full scale traffic testing. Environmental conditions such as drainage and frost susceptibility, traffic, subgrade and base modulus are necessary inputs in the design. "Progressive stiffening" or interlock occurs within the paver and sand layer early in the life of the interlocking pavement. This typically occurs before 10,000 equivalent single axle loads. Once this condition occurs, the elastic modulus (M_r) is considered approximately 450,000 psi (3100 Mpa) for a 3.125 inch (80 mm) paver and a 1 inch (25 mm) bedding layer. This results in a

structural layer coefficient similar to asphalt (0.44). However, unlike asphalt, concrete pavers are not susceptible to a decrease in modulus and surface distress from warm temperatures.

Figure 16: Concrete headers may be required at the edges of the cross walk depending on the amount of truck and bus traffic that is anticipated
Source: Interlocking Concrete Pavement Institute

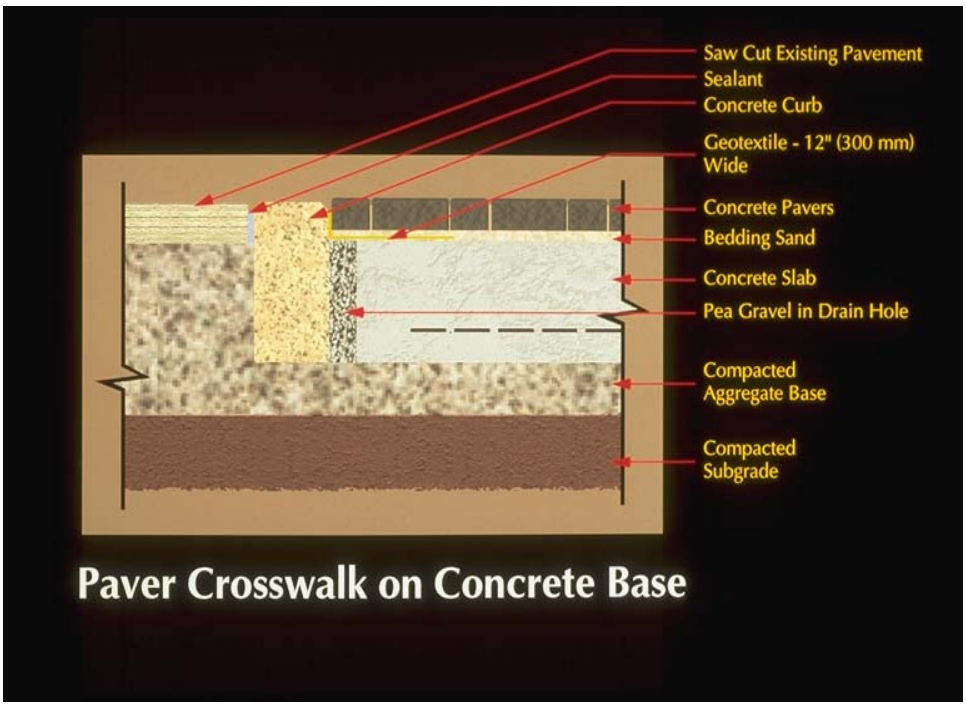

Figure 17: A typical section for a concrete base. Note the drainage provision.
Source: Interlocking Concrete Pavement Institute

Mechanistic design theory and procedures have been described in detail elsewhere. Shackel (2000) details the development and application of mechanistic design procedures for "concrete

block paving" or interlocking concrete pavements. Mechanistic design uses elastic analysis to calculate the stresses and strains in the pavement caused by wheel loads. Computerized design procedures tailored specifically to interlocking pavements have been developed. Some of these programs can allow the designer to input additional criteria beyond those noted above for the AASHTO method. For example, the designer can input shape, thickness and laying pattern into the design and assign a modulus. Others (ICPI Lockpave, 2000) allow designers to combine the effects of load repetitions and the resultant strains with environmental factors. Users can adjust material strengths for varying moisture and freeze-thaw conditions.

4. CONCLUSION

Interlocking concrete pavers are proving to be a viable design option for municipal applications. Proven design tools are available to designers and new methods of construction offer fast and efficient installation for immediate serviceability of the pavement. In North America the use of concrete pavers for these applications is increasing dramatically. International research and development continues to improve the analytical tools. The summation of global work takes place every three years at the international conferences on concrete block paving. Each conference produces proceedings that have provided much of the technical basis for design, specification, construction and maintenance in North America. The next international conference will be in Sun City, South Africa, October 12-15, 2003 sponsored by the Concrete Manufacturers Association of South Africa, confplan@iafrica.com. In 2006 the Interlocking Concrete Pavement Institute will host the conference in North America.

5. REFERENCES

John Emery Geotechnical Engineering Limited (JEGEL) Consulting Engineers (2000) *Life Cycle Cost Analysis Interlocking Concrete Pavements*

Shackel, B. (1979) *A Pilot Study of the Performance of Block Paving Under Traffic Using a Heavy Vehicle Simulator*, Proceedings of a Symposium on Precast Concrete Block, Johannesburg, South Africa

Shackel, B. (1980) *An Experimental Investigation of the Roles of the Bedding and Joint Sand in the Performance of Interlocking Concrete Block Pavements*, Concrete/Beton, No. 19: pp 5-15

Shackel, B. (2000) *The Development and Application of Mechanistic Design Procedures for Concrete Block Paving*, Proceedings of the 6th International Conference on Concrete Block Paving, Tokyo September 2000: pp13-22

Smith, D.R. (1992) *The Institutionalization of Concrete Block Pavements in North America*, Fourth International Conference on Concrete Block Paving, Pave New Zealand '92, Porirua, New Zealand, Volume II: 355-359

Interlocking Concrete Pavement Institute (1994) *Tech Spec 3 Edge restraints For Interlocking Concrete Pavements*, ICPI, Washington D.C., USA

Guide for Design of Pavement Structures, American Association of State Highway and Transportation Officials, Washington, D.C., 1993

Precast Concrete Pavers, CSA A231.2-95, Canadian Standards Association, Rexdale, Ontario, 1995

Annual Book of ASTM Standards, Vols. 4.02, Concrete and Aggregates, 4.03, Road and Paving Materials, and 4.08, soil and rock, American Society for Testing and Materials, Philadelphia, Pennsylvania, 1995

ICPI Lockpave Version 11.4, Interlocking concrete Pavement Institute, Washington, D.C., 2000