The Engineer's View

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Bedding Sand Selection for Interlocking Concrete Pavements in Vehicular Applications

All sand-set segmental concrete paving systems in street or heavy-duty industrial, port or airport pavements require special attention to bedding sand selection. While ICPI provides guidance on gradation experience and research over the past several years has demonstrated that other characteristics should be assessed in order to ensure long-term pavement performance. This article examines these characteristics and provides guidance to specifiers and contractors.

This article gives specifiers and contractors some more tools for evaluating and selecting bedding sands exposed to vehicular traffic.

Background

Bedding sand provides four main functions that include:

- Bedding the pavers during installation;
- Initializing interlock among the pavers;
- Providing a structural component for the system (per *ICPI Tech Spec 4 Structural Design of Interlocking Concrete Pavement for Roads and Parking Lots*, 2004);
- Facilitating water drainage that infiltrates through the paver joint sand.

ICPI guide specifications require bedding sands to conform to ASTM C33 and CSA A23.1 (FA1) gradation. These are typically concrete sands meaning those used to manufacture ready-mix concrete. ICPI provides additional limits on material that passes the No. 200 (0.075 mm) sieve (See Tables 1 and 2). The importance of gradation is emphasized in other countries. For example, Knapton (1994) notes that since 1980 the amount of material passing the No. 200 (0.075 mm) sieve has been reduced in the British Standard BS 7533-1 (2001) *Guide for the Structural Design of Heavy Duty Pavements Constructed of Clay or Concrete Pavers*. The allowable material passing the No. 200 sieve has been reduced from 10% in 1980, to 3% in 1991 and to 1% for heavily trafficked pavements. For bus stations the reduction is 0.1% passing.

As noted in Tables 1 and 2, ICPI guidelines limit the amount of allowable material passing these sieves to 1%. In regularly trafficked vehicular applications, other factors besides gradation contribute to the successful function of the bedding layer. Studies by Lilley and Dowson (1988) and Beaty (1996) investigated failures of interlocking

Table 1
ASTM C 33 requirements

Sieve Size	Percent Passing
3/8 in. (9.5 mm)	100
No. 4 (4.75 mm)	95 to 100
No. 8 (2.36 mm)	85 to 100
No. 16 (1.18 mm)	50 to 85
No. 30 (0.600 mm)	25 to 60
No. 50 (0.300 mm)	10 to 30
No. 100 (0.150 mm)	2 to 10
No. 200 (0.075 mm)	0 to 1

Table 2
CSA A23.1 (FA1) requirements

Sieve Size	Percent Passing
10mm	100
5 mm	95 to 100
2.5 mm	80 to 100
1.25 mm	50 to 90
0.630 mm	25 to 65
0.315 mm	10 to 35
0.160 mm	2 to 10
0.080 mm*	0 to 1

*Although the ASTM equivalent for the No. 200 sieve size is 75 microns (0.075 mm), CSA standards use the German (DIN) and French (ANFOR) standard equivalent sieve size of 80 microns (0.080 mm).

concrete pavements subjected to channelized vehicular traffic. They concluded that more comprehensive specifications are required that address more than gradation. Lilley and Dowson (1988) suggested that bedding sands that carry more than 1.5 million equivalent 18-kip (80 kN) axle loads should be subjected to grading and degradation tests. For the purposes of this article, vehicular traffic is defined as a minimum of 1.5 million lifetime 18-kip (80 kN) equivalent single axle load (ESALs) with axle loads up to 24,250 lbs (11,000 kg) or with a maximum vehicle load of 50,000 lbs (22,680 kg).

Failure Mechanisms

Bedding sand layer failure can occur in channelized vehicular loads from two main actions: structural failure through degradation and saturation due to inadequate drainage. Since bedding sands are located high in the pavement structure, they are subjected to repeated applications of high stress from the passage of vehicles over the pavement (Beaty 1996). This repeated action, particularly from high bus and truck axle loads degrades the bedding sand and causes failure. For these applications sand should be selected based on their ability to withstand long-term degradation.

Bedding sand permeability is also a significant factor in the selection process. Wherever difficulties have been experienced with laying course materials in heavily trafficked pavements, water in that layer has been a major factor (Knapton 1994). As bedding sands approach higher moisture levels in service they may become unstable. Smaller particle sizes (fines) become suspended in water, forming a slurry that lubricates the entire bedding layer. Choosing bedding sand with gradations shown in Tables 1 and 2 will help reduce the risk of poor drainage and instability. However, these sands will be susceptible to drainage problems if they do not have the hardness to withstand long term degradation from vehicular wheel loads.

Selection and Performance Design Principles—Going Beyond Gradation

Selecting Durable Bedding Sands—Aggregate durability has long been understood as a major factor in pavement performance. ASTM C88 Soundness of Aggregate by use of Sodium Sulfate or Magnesium Sulfate (ASTM 2005) is a typical test method used by road agencies to assess aggregate durability. The test involves soaking an aggregate in a solution of magnesium or sulfate salts and oven drying. This is repeated for a number of cycles, with each cycle causing salt crystals to grow and degrade the aggregate. The test takes at least six days. The percent loss is then calculated on individual particle size. This test method, however, is considered highly variable. Jayawickrama, Hossain and Phillips (2006) note that when ASTM initially adopted this test method they recognized the lack of precision, saying, "it may not be suitable for outright rejection of aggregates without confirmation from other tests more closely related to the specific service intended." ICPI recommends using ASTM C88 to assess aggregate durability as long as other material properties described in this article are also tested.

The Micro-Deval test is evolving as a test method for evaluating durability of aggregates in North America. Defined by CSA A23.2-23A, *The Resistance of Fine Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus* (CSA 2000), the test method involves subjecting aggregates to abrasive action from steel balls in a laboratory rolling jar mill. In the CSA test method a 1.1 lb (500 g)

Figure 1. The Micro-Deval test apparatus shows steel jar mills which are rotated while containing sand samples mixed with water. Photo courtesy of Geneq, Inc.

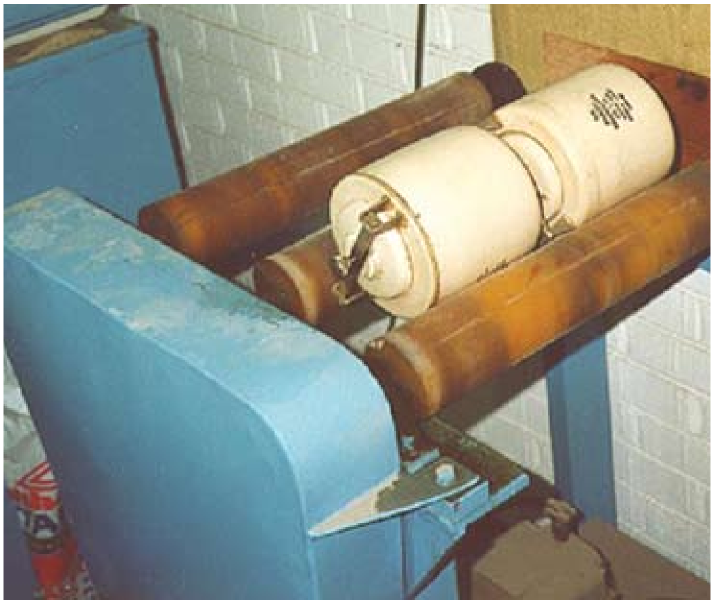

Figure 2. Developed in the UK in the late 1980's by two interlocking concrete pavement specialists, the Lilley-Dowson bottle rolling test evaluates the durability of dry sand samples rotated with two steel balls in porcelain jars.

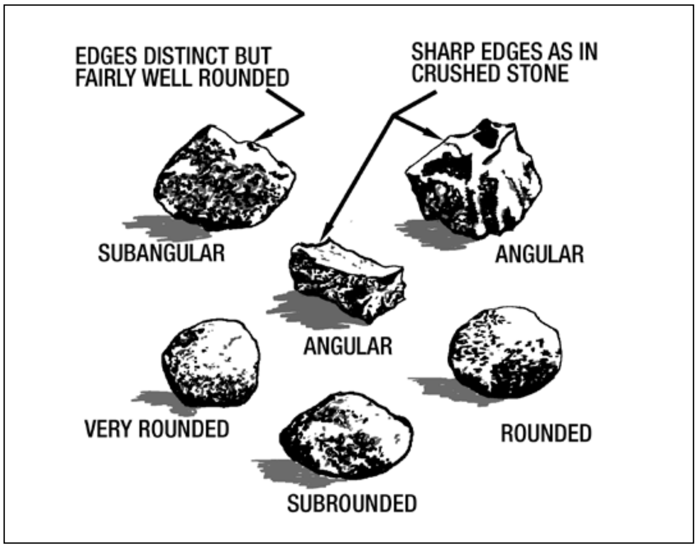

Figure 3. Description of coarse grains according to ASTM D2488 (Raymond)

representative sample is obtained after washing to remove the No. 200 (0.080 mm) material. The sample is saturated for 24 hours and placed in a stainless steel jar with 1250 g (2.75 lb) of steel balls and 750 mL of tap water (See Figure 1).

The jar is turned at 100 rotations per minute for 15 minutes. After rotation, the sand is separated from the steel balls over a sieve and the sample of sand is washed over an 80 micron (No. 200) sieve. The material retained on the 80 micron sieve is oven dried. The Micro-Deval loss is calculated as the total loss of original sample mass expressed as a percentage.

ASTM and the American Association of State Highway and Transportation Officials (AASHTO) have adopted a coarse aggregate version of the Micro-Deval test, ASTM D6928 (2006) and AASHTO TP 58. Both organizations are considering a version for fine aggregates. Since the test apparatus uses the same size drum and rotates at the same revolutions per minute, no modifications to the apparatus are required to perform the fine aggregate test in laboratories currently equipped to perform the coarse aggregate test procedure.

A study conducted by the Interlocking Concrete Pavement Institute (ICPI 2004) investigated nine sands from across the United States reported by contractors rated with "good to excellent" serviceability in vehicular applications. The results of this study indicated that eight of these sands had Micro-Deval degradation losses less than 8% when measured according to CSA A23.2-23A (CSA 2000). The same study subjected these sands to the ASTM C88 soundness loss and found that no sample had greater than 6% loss. ICPI recommends that the Micro-Deval test be used as the primary means to characterize bedding sand durability (See Table 4) and the magnesium or sulfate soundness tests should be considered when the Micro-Deval test is not locally available. As previously noted, the variability of the soundness test results should always be a consideration unless measured in relation to other material properties.

A test method similar in nature to Micro-Deval is the Lilley and Dowson test (Lilley Dowson 1998). This test method specifically developed for bedding sands is recognized internationally and is referenced in ICPI manuals *Port and Industrial Pavement Design with Concrete Pavers* (ICPI 1997) and *Airfield Design with Concrete Pavers* (ICPI 1995). This test method is performed on 1.4 kg (3 lbs) randomly selected, oven-dried sand samples with two 1 in. (25 mm) diameter steel balls together weighing 0.3 lb (135 g). Three sub-samples each weighing 0.2 kg (0.5 lbs.) are derived from the main sample. Each sub-sample is sieved according to ASTM C 136 then re-mixed and placed in a nominal liter capacity porcelain jar with the two steel balls. The three jars are rotated at 50 rpm for six hours and sieved again. For each sub-sample tested, the maximum increase in the percentages passing each sieve and the maximum individual percent passing should be as follows:

Sieve Size	Maximum Increase	Maximum Passing
No. 200 (0.075 mm)	2%	2%
No. 100 (0.150 mm)	5%	15%
No. 50 (0.300 mm)	5%	35%

Figure 2 shows the porcelain jars used in the Lilley-Dowson bottle rolling test. Developed in the UK, the test is not readily available at laboratories in North America. The CSA Micro-Deval test may be more available. Beaty demonstrated a correlation between the two tests with a correlation coefficient

Table 3
Modified Gradation or Reconstituted Aggregates According to Beaty (1996)

Sieve Size	Percent Passing
4.75 mm	100
2.36 mm	90
1.18 mm	70
0.600 mm	47
0.300 mm	20
0.150 mm	7
0.075 mm	0

greater than 0.99. The relationship between the two tests is:

$$L = 1.97 + 1.21\ M$$

Where:
M = CSA Micro-Deval Degradation Loss (%)
L = Lilley and Dowson Degradation Loss (%)

Beaty's correlation involved reconstituting the test aggregates into a standard gradation shown in Table 3 and performing the Micro Deval and Lilley Dowson tests on the re-graded aggregate. In this modified version of the Lilley Dowson test procedure the loss (L) is measured as the total increase in percentage of fines passing the No. 200 (0.075 mm) sieve at the completion of the test.

Assessing Drainage

Drainage of the bedding layer is important for early and long-term pavement performance. One failure documented by Knapton (1993) describes a segmental pavement in a northwestern U.S. city that opened to bus traffic and within hours of construction subjected to continuous heavy rain. The bedding sand had a high percentage of fines. The rainfall transported the finer sieve sizes into the drain holes of the underlying concrete slab. With compromised drainage the bedding sand liquefied and pumped through the joints of the pavement from repeated bus traffic, resulting in immediate rutting and failure. The pavement was subsequently reconstructed with harder bedding sand with 0% material passing the No. 200 (0.075 mm) sieve and the results yielded excellent performance.

It was clear from this failure and reconstruction that hardness and gradation are important factors since both affect drainage. Another material property that affects drainage is permeability. Even specifications that allow up to 3% of fines can result in a five-fold decrease in permeability from the lowest to highest percentage passing (Bullen 1998).

ICPI (2004) conducted research on the permeability of sands rated by contractors rated as "very good to excellent." Using ASTM D2434-68 *Standard Test Method for Permeability of Granular Soils (Constant Head)* (ASTM 2006), permeability ranged from 2.8 in./hr (2.1 x 10^{-3} cm/second) to 15.6 in./hr (1.1 x 10^{-2} cm/second). These values correspond to fines that range from 0 to 2.5% passing the No. 200 (0.075 mm) sieve. More importantly the research showed that they are also associated with Micro-Deval maximum degradation values of 8%. Table 4 indicates a minimum permeability of 2.1 x 10^{-3} cm/second (2.8 in/hr) that should also be considered in concert with the other properties listed.

Table 4
Recommended Laboratory Material Properties for Bedding and Joint Sands in Vehicular Applications

Material Properties	Test Method	Recommended Maximum or Minimum
Primary Properties		
Micro-Deval Degradation	CSA A23.2-23A	Maximum 8%
Constant Head Permeability	ASTM D2434	Minimum 2 x 10-3 cm/second (2.83 in/hr)
Gradation	ASTM C33 CSA A23.1 (FA1)	Maximum 1 % passing No. 200 (0.075 or 0.080 mm) sieve
Secondary Properties		
Soundness – Sodium Sulfate or Magnesium Sulfate	ASTM C88	Maximum 7%
Silica (Quartz and Quartzite)/ Carbonate Ratio	MTO LS-616 ASTM C295	Minimum 80/20 ratio
Angularity and Particle Shape	ASTM D 2488	Minimum 60% combined sub- angular and sub- rounded

Note: Bedding sand may also be selected based on field performance. Field performance is selected when the specifier or contractor assumes responsibility for the selection and performance of bedding sand not conforming to the properties in Table 4. Field performance as a selection criteria is suggested when the available local materials do not meet the primary material properties suggested in Table 4, but the specifier or contractor can demonstrate to the satisfaction of the owner (or owner's representative), successful historical field performance. In this case the owner should specify the class of vehicular traffic, and the contractor should verify past field performance of the bedding sand under similar vehicular traffic.

However, eliminating all material passing the No. 200 (0.075 mm) sieve by washing can sometimes be impractical. For that reason, ICPI recommends up to 1% passing the No. 200 (0.075 mm) sieve.

Other Important Material Properties

Other studies show that bedding sand particle shape plays a role in performance. Knapton (1993) notes that rounded or cubical grains lead to stable

Figure 4. Example of sand from the ICPI bedding sand test program with a total combined percentage of sub-angular and sub-rounded particles equal to 65% according to ASTM D 2488

sands, whereas more angular grains are frequently associated with sands that fail. Sands tested by ICPI (2004) showed that eight of the nine "good to excellent" performing sands had a predominance of sub-angular to sub-rounded particle shapes when tested according to ASTM D 2488 *Description and Identification of Soils (Visual-Manual Procedure*) (ASTM 2000). Specifiers and contractors should consider bedding sand angularity using Figure 3 as a guide. Figure 4 shows a photograph of one of these sands at high magnification. Table 4 suggests that a combined percentage of sub-angular to sub-rounded particles should be a minimum of 60%.

Petrography

Several studies have noted petrography (mineral content) playing an important role in bedding sand performance. Quartz mineralogy is preferred over crushed sandstones (Knapton 1993). In the study by the Interlocking Concrete Pavement Institute (ICPI 2004), eight of the nine "good to excellent" performing sands were noted to be consist predominately of silica minerals with over 80% of the material either quartz or quartzite. Table 4 recommends a minimum 80/20 ratio of silica/carbonate mineralogy. A tenth sample, included in the study (and noted as poor performing in the field) was characterized as having up to 50% carbonate content. Petrographic analysis was conducted according to the Ministry of Transportation of Ontario laboratory method MTO LS-616 Procedure for the Petrographic Analysis of Fine Aggregate (MTO 1996). ASTM C 295 Standard Guide for *Petrographic Examination of Aggregates for Concrete* (2003) offers an alternative test method.

Specifier Guidelines

Table 4 lists the primary and secondary material properties that should be considered when selecting bedding sands for vehicular applications. Eliminating all material passing the No. 200 (0.075 mm) sieve by washing is desirable but can be impractical and expensive. For that reason, ICPI recommends up to 1% passing the No. 200 (0.075 mm). Bedding sands may exceed the gradation requirement for the maximum amount passing the No. 200 (0.075 mm) sieve as long as the sand meets degradation and permeability recommendations in Table 4.

Micro-Deval degradation testing can be replaced with sodium sulfate or magnesium soundness testing as long as this test is accompanied by the other primary material property tests listed in Table 4. Other material properties listed, such as petrography and angularity testing are at the discretion of

Table 5.
Recommended Installation Properties for Bedding Sands in Vehicular Applications

Primary Properties	Test	Recommended Maximum or Minimum	Construction Tolerance	Frequency of Field Test
Gradation	ASTM C33 and CSA A23.1 (FA1)	See Tables 1 and 2	Not Applicable	Provided by aggregate supplier every 25,000 sf (2,500 m^2)
Bedding Layer Thickness	Check with ruler	Nominal 1 in. (25 mm)	± 3/8 in. (10 mm)	By contract or every 5,000 to 10,000 sf (500 to 1000 m^2)
Hardness	Test with Swiss army pocket knife blade	No broken particles	Not Applicable	By contractor every 25,000 sf (2,500 m^2)
Secondary Properties	**Test**	**Recommended Maximum or Minimum**	**Construction Tolerance**	**Frequency of Field Test**
Moisture content at time of installation	Hand test	Holds together without shedding water	Not applicable	While screeding

Figure 5. A two-man, hand pulled screed can level large areas of bedding sand. This is a port paving project in Florida.

the specifier and may offer additional insight into bedding sand performance.

Limestone screenings (i.e. waste material from the quarry screening process) and stone dust are not recommended for bedding sand. In addition to being unevenly graded and having excessive material passing the No. 200 (0.075 mm) sieve, some screenings and stone dust will break down over time from wetting and abrasion due to vehicular loads. Unlike soft limestone screenings and stone dust, hard, durable concrete sand meeting the requirements in Table 4 will not break down easily. Limestone screenings also tend to break down during pavement construction under initial paver compaction. Depressions will eventually appear in the pavement surface with limestone screenings or stone dust.

When bedding sand doesn't conform to the properties in Table 4, it may be selected based on field performance. This basis for acceptance can be adequate if the sand is supplied from a consistent quarry source and the specifier or contractor can demonstrate successful historical field performance in similar traffic conditions. The owner should specify the class of vehicular traffic and the contractor should verify past field performance of the bedding sand under similar vehicular traffic.

Bedding Sand in Construction

It almost goes without saying that all bedding sands must be on a base installed according to recommended construction practices and tolerances in *ICPI Tech Spec 2 Construction of Interlocking Concrete Pavements*. Among other things, the base surface ensures that bedding sand has a uniform slope and meets surface tolerances without surface undulations or "waviness." Sand should be screeded (without compaction) to a uniform nominal 1 in. (25 mm) thickness. Screeds can either be pulled by hand or by machine (i.e. mechanical screed) as shown in Figures 5 and 6. Mechanical screeding provides the most efficient method with a three to four-fold increase in productivity over hand screeding.

Pavers are placed on loose, uncompacted sand. Pre-compaction is a waste of time and can interfere with interlock. The sand should allow the pavers to be uniformly seated during their initial compaction with a minimum 4,000 lbf (18kN) force plate compactor. Uniform seating is helped by sufficient and uniform moisture in the bedding sand. At no time should the bedding sand be "bone dry" or saturated. A 6% to 8% moisture content has been shown to be optimal for most sands (Beaty 1992).

Contractors can assess moisture content by squeezing a handful of sand in their hand. Sand at the suggested optimal moisture content will hold together when the hand is reopened without shedding excess water. Although it can be difficult to control the exact moisture content on the job site,

Figure 6. Mechanical screeding is the most efficient method of bedding sand installation. In the largest projects, a laser guided asphalt spreader (right) can be used to accurately screed bedding sand.

uniformity of moisture content can be maintained by covering stock piles with tarps if rain is forecast. Digging into sand piles at mid-height is recommended to avoid saturated material that may be at the bottom of the pile.

While on the job site, a contractor should check the hardness of the bedding sand particles. Particles of sufficient hardness will not break under the pressure of a Swiss Army pocket knife blade. Although not recommended for pre-selection of bedding sands, this quick field test helps assess acceptable material at the time of delivery. Table 5 summarizes recommended bedding sand properties for consideration by a contractor during installation.

Pavement design and construction should not allow bedding sand migration into the base or laterally through the edge restraints. Dense-graded base aggregates with 5% to 12% passing the No.200 (0.075 mm) sieve will help ensure bedding sand doesn't migrate into the base surface. For interlocking concrete pavements built over asphalt or concrete bases, 2 in. (50 mm) diameter drain holes should be placed at the lowest points in the pavement to drain excess water from the bedding layer. Drain holes should be filled with washed pea gravel and covered with geotextile to prevent the loss of bedding sand. Figure 7 shows a typical detail.

Figure 8 shows geotextile installed against concrete curb to help prevent sand migration into joints in the curb and between the base and curb. Woven geotextile is placed on top of the aggregated base, extending approximately 1 ft. (300 mm) onto the pavement and on the sides of the curb to contain the bedding sand. Specifiers can visit www.icpi.org to download similar detail drawings.

Jointing Sand Functions

Jointing sand provides two primary functions in an interlocking concrete pavement. First it creates interlock and second it helps seal the pavement. ICPI recommends that the same material properties listed in Table 4 also apply to jointing sand. ICPI recommends either finer mortar sand conforming to ASTM C144 or CSA A179 in the joints or coarser bedding sand.

Panda and Ghosh (2002) describe laboratory research on pavements using fine and coarse joint sands. Simulated loading consisted of 11,000 lbs (49 kN) over 80 mm thick pavers with varying joint widths and joint sand gradations. Deflection of the pavement was then measured with coarser sand exhibiting lower deflections. The study concluded that "the coarser the sand, the better the performance." The coarser sands used in the study correspond to the gradations in Tables 1 and 2 and the study recommended joint widths up to 3/16 in. (5mm). ICPI recommends joint widths of 2 mm to 5 mm.

Contractors also realize a benefit from using one sand source. There are advantages to using the bedding material for the jointing sand during construction. Using one material allows the contractor to monitor and control one sand product on the job site. Over time the joints become filled with detritus, providing some degree of sealing. Regardless of the sand used, segmental concrete pavements will always allow some water penetration through the joints. The same coarse graded sand in the bedding layer facilitates the drainage of this water. Bedding sand may require additional effort in sweeping by the contractor. In some cases, smaller joint widths may require the use of finer graded sand. In this case, the use of mortar sand is permitted. Mortar sand should conform to the gradations of either ASTM C144 or CSA A179 but should also meet the requirements of Table 4.

Although joint sand selection is an important factor, design and construction play a more important role. Considerations such as joint width, ensuring that sand is swept in dry, degree of compaction and ensuring the joints are fully filled are critical to the long term success of interlocking concrete pavement performance. Additional information on joint sand installation can be found in *ICPI Tech Spec 2 Construction of Interlocking Concrete Pavements* (ICPI 2004).

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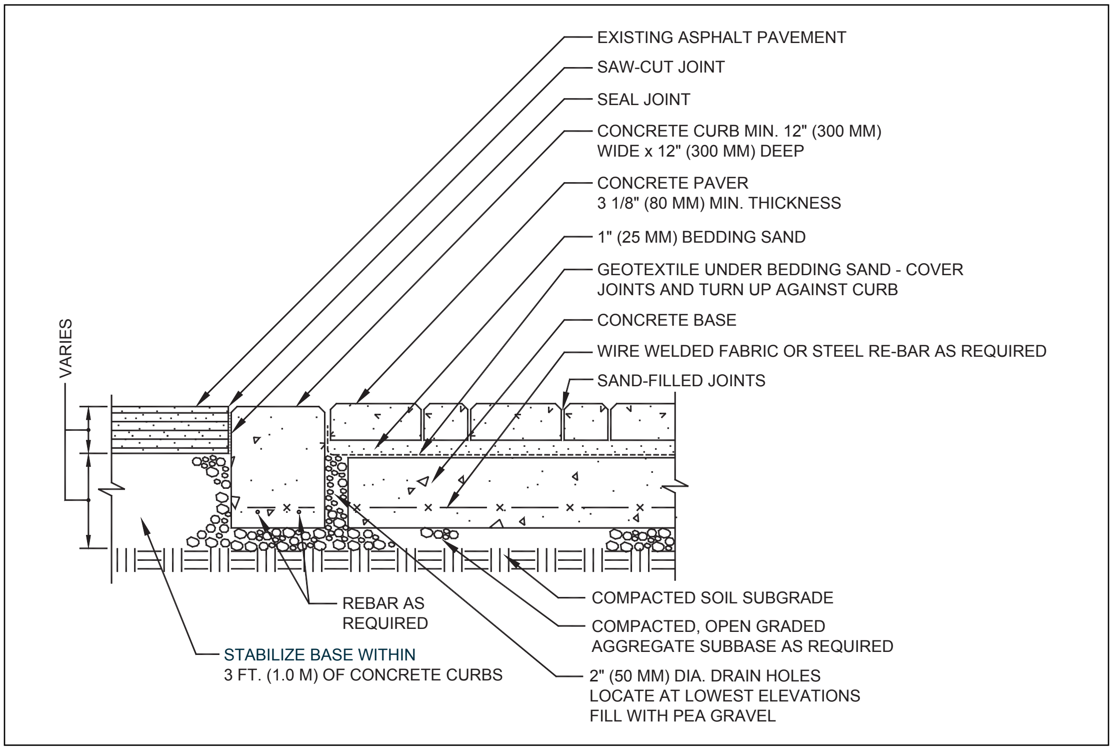

Figure 7. Detail for sand set pavers over a concrete base crosswalk. Holes provide drainage for water that enters the bedding layer. The same detail applies for paver overlays on asphalt.

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Figure 8. Woven geotextile contain bedding sand from migrating into curb joints or between the curb and base.

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