NORTH AMERICAN DESIGN GUIDELINES FOR PERMEABLE INTERLOCKING CONCRETE PAVEMENTS PART 1 – PAVER TYPES, EXFILTRATION OPTIONS, SITE SELECTION CRITERIA, DESIGN DATA, AND MATERIALS

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ABSTRACT

The Interlocking Concrete Pavement Institute (ICPI) has introduced a manual for the selection, design, specification, construction, and maintenance of permeable interlocking concrete pavements, also known as permeable concrete block pavements. This paper provides highlights from the manual. The manual synthesizes literature on infiltration trenches, porous asphalt pavement, research on and practical experience with permeable interlocking concrete pavements. The manual is for design professionals and municipal authorities who regulate stormwater runoff. The design procedure utilizes well-established methods for calculating runoff by the United States Soil Conservation Service (SCS), now the Natural Resources Conservation Service (NRCS). This paper is presented in two parts. Part 1 describes benefits, paver types, exfiltration options, site selection criteria, required design data, assessment of soil permeability, and pavement materials. Part 2 discusses base sizing methods, cold climate design, construction and maintenance. References for Part 1 and Part 2 are listed at the end of Part 2.

1. PERMEABLE INTERLOCKING CONCRETE PAVEMENTS

Permeable interlocking concrete pavements are typically built on an open-graded, crushed stone base. The base offers infiltration and partial treatment of stormwater pollution. Infiltration of rainfall helps maintain the balance of water in the soil, groundwater, and streams, thus supporting the water cycle. Figure 1 illustrates a typical permeable interlocking concrete pavement.

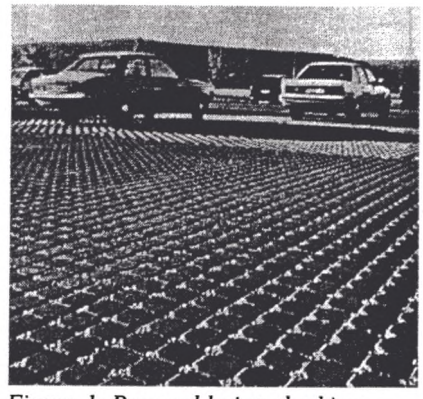


Figure 1. Permeable interlocking concrete pavement combines stormwater infiltration, retention and parking into one place, thereby conserving land.

If the infiltration capacity of the soil is exceeded, or there are particularly high levels of pollutants, the pavement base can be designed to filter, partially treat, and slowly release water into a storm sewer or water course. When conditions allow, returning rainfall to the soil through infiltration is preferred over retaining the water and slowly releasing it into a sewer or water course.

1.1 Benefits of Permeable Interlocking Concrete Pavements

These pavements essentially function as an infiltration and retention area that can accommodate pedestrians, vehicular parking and traffic. This combination of functions offers the following benefits:

- Conservation of space on the site by not using a single purpose retention/detention (dry/wet) pond.
- Reduction of runoff by as much as 100% from frequent, low-intensity and short duration storms.
- Reduction of retention requirements in other parts of the drainage system.
- Filtration through the base and soil for improvement of water quality.
- Reduction of runoff temperature.
- Slow the release of runoff.
- Increased recharge of groundwater.
- Reduction of downstream flows and bank erosion due to decreased peak flows and volumes.
- Reduced overall project development costs due to a reduction in storm sewers and drainage appurtenances.

1.2 Paver Types

Permeable interlocking concrete pavers can be grouped into three categories: interlocking shapes, permeable joints, and porous concrete units. Figure 2 lists the various types and rates their suitability in varous applications. The table also lists concrete grid pavers for comparison purposes.

	Interlocking shapes with openings	**Widened joints**	**Porous concrete units**	**Grid pavers**
Low-speed roads	Contact Manufacturer	Contact Manufacturer	Not recommended	Not recommended
Parking lots/bays driveways	Excellent	Excellent	Not recommended	Acceptable for low use
Overflow parking, Access and emergency lanes	Excellent	Excellent	Good	Good
Revetments, boat ramps	Good	Good	Not recommended	Good
Bike paths, Sidewalks Pedestrian areas	Good	Good (maintain narrow joints)	Excellent	Not recommended

Figure 2. Evaluation of Applications for Concrete Permeable Pavement (Adapted from Reference 1).

Interlocking shapes with openings—These have patterns that create openings or drainage holes for rainfall to enter, while maintaining high side-to-side contact among the units for stability under vehicular loads. Figure 1 shows one of many designs.

Enlarged permeable joint—These are pavers with wide joints for rainfall to enter. Joints can be as wide as 35 mm. The joints are created with large spacers molded into the sides of each paver, or with wood or plastic spacers inserted between each unit. These maintain consistent joints and stable units (Figure 3). Some units have spacers on them for laying either with a narrow joint for drainage filled with open-graded crushed stone, or with a wider joint for accommodating grass and topsoil (see Figure 4).

Porous concrete units—The sponge-like appearance of the unit in Figure 5 allows rainfall to directly enter and pass through it because the concrete has no fines. Like solid pavers, the units

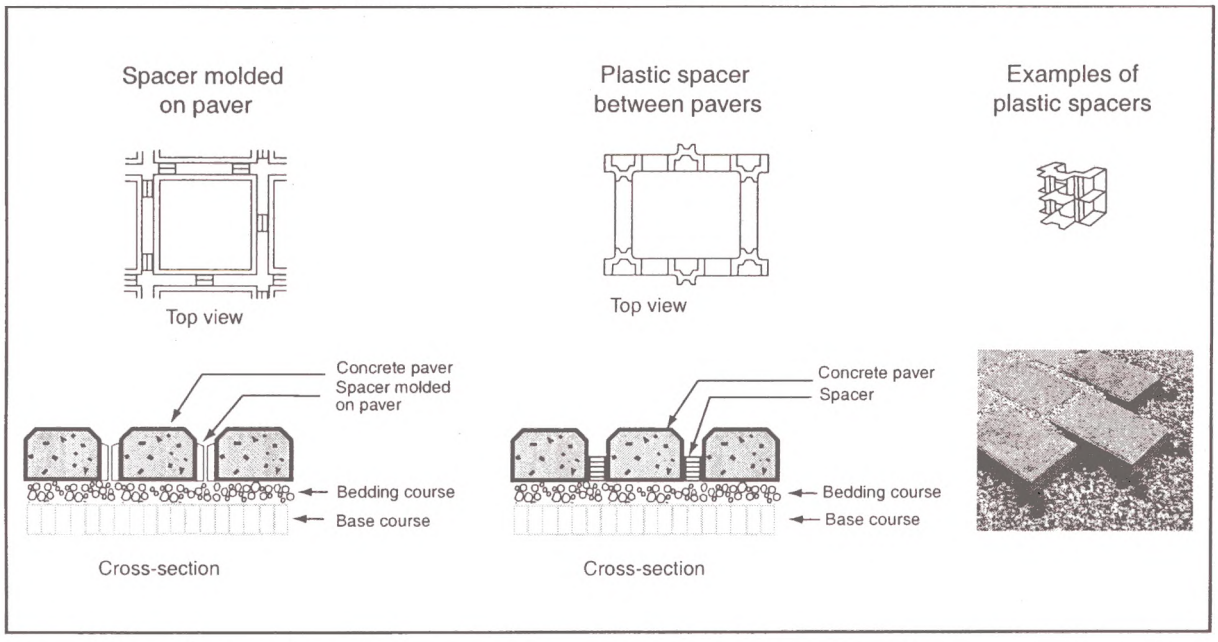


Figure 3. Methods of spacing units accommodate aggregate or grass in the joints (5).

are tightly fitted together over bedding sand, compacted, joints filled with coarse, washed sand, and compacted again. Care should be taken to not allow joint sand to clog the openings. While not commonly used, these types of units are appropriate in non-freeze-thaw areas. Compressive strengths should be at least 45 MPa to offer some degree of strength and durability in freezing climates. Their use is best for pedestrian areas, bicycle paths, and residential applications.

Permeable pavers and concrete grid pavers—Both concrete grid and solid permeable pavers can be placed on an open-graded base for enhanced runoff control, as well as on a dense-graded base. Grid pavers, however, have a different range of applications. They are intended for light-duty use such as overflow parking areas, occasionally used areas in parking lots, and access and emergency lanes. In contrast, permeable pavers are intended for more heavily trafficked pavements such as regularly used parking lots and low-traffic volume streets.

2. EXFILTRATION OPTIONS

Design options include full, partial, or no exfiltration of an open-graded base into the soil. For most applications, high surface infiltration will be required and open-graded aggregate is placed in the openings between the paving units. Where high surface infiltration is not required, grass and topsoil, rather than aggregate, can be used in the openings. In rare cases, the pavers will be placed on bedding material over dense-graded base.

2.1 Full or Partial Exfiltration

A design for full exfiltration uses an open-graded base with aggregate-filled joints for maximum infiltration and stor-



Figure 4. Joints can be filled with aggregate or with topsoil and grass.

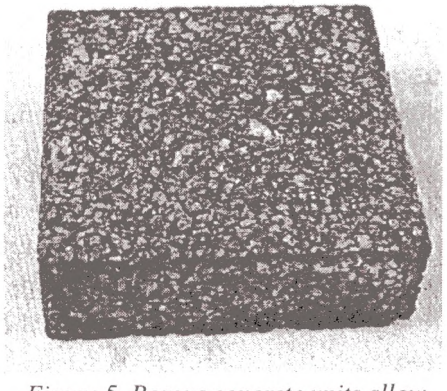


Figure 5. Porous concrete units allow water directly into open-graded concrete.

age of stormwater. The water infiltrates directly into the base and exfiltrates to the soil. Pipes provide drainage in overflow conditions. This is the most common application.

Partial exfiltration does not rely completely on exfiltration of the base into the soil to dispose all of the captured runoff. Some of the water may exfiltrate into the soil while the remainder is drained by pipes. Excess water is drained from the base by pipes to sewers or a stream. Figures 6 and 7 show schematic cross-sections of full and partial exfiltration designs.

2.2 No Exfiltration

No exfiltration is required when the soil has low permeability and low strength, or there are other site limitations. An impermeable liner may be used if the pollutant loads are expected to

Figure 6. ***Full exfiltration*** *through the soil. Pipes may be included in the design to handle excess water in heavy, flood-prone rainstorms.*

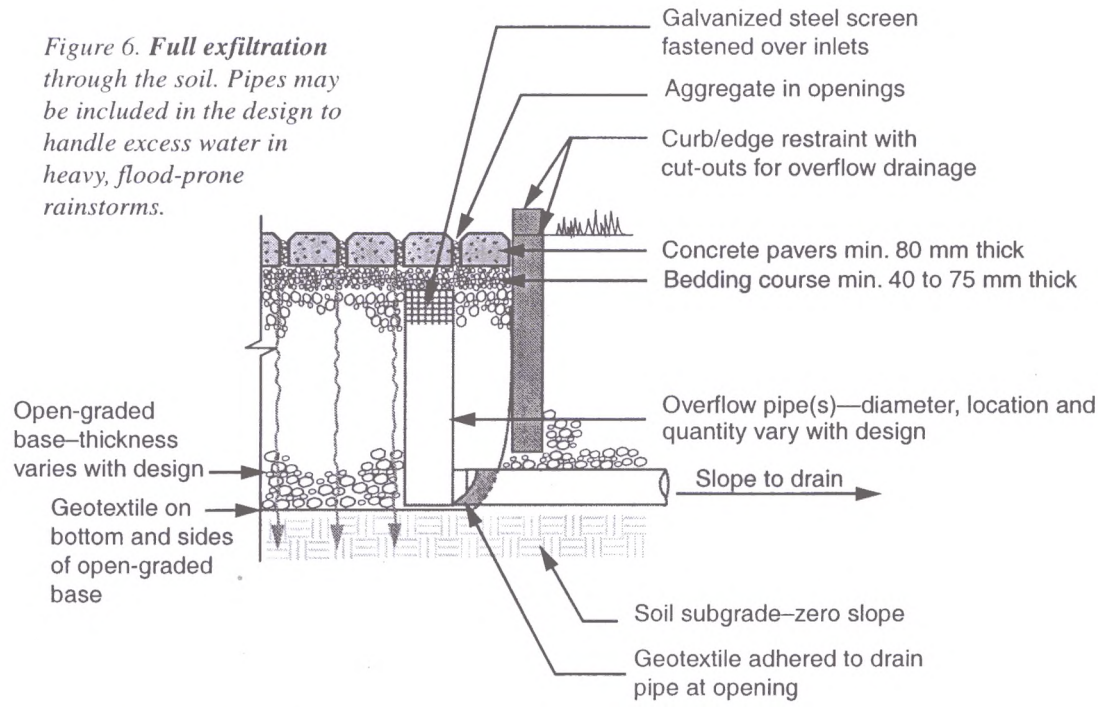
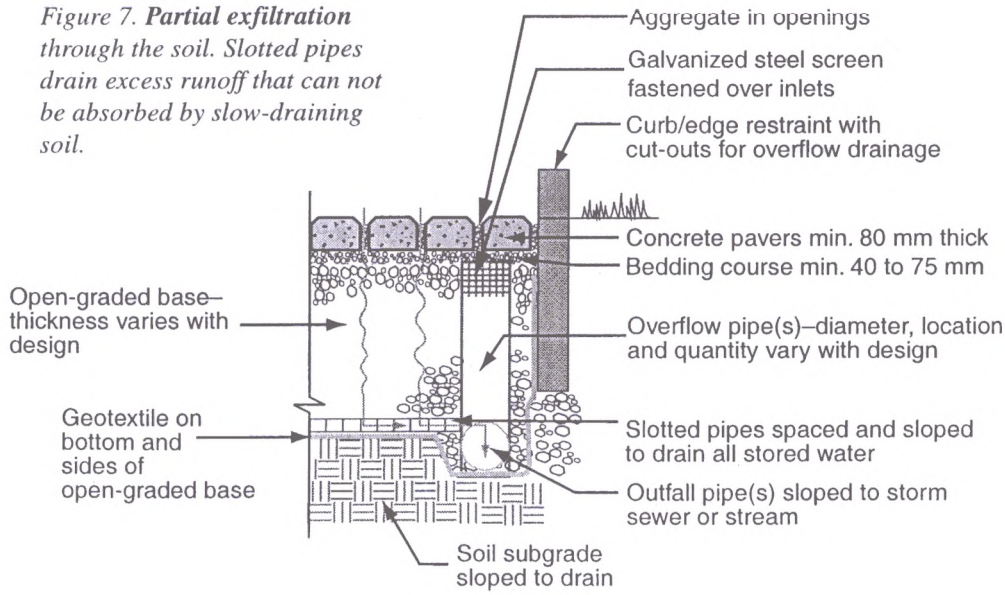


Figure 7. ***Partial exfiltration*** *through the soil. Slotted pipes drain excess runoff that can not be absorbed by slow-draining soil.*



exceed the capacity of the soil and base to treat them. A liner may also be used if the depth to bedrock or to the water table is 0.6 to 0.8 m. By storing water in the base for a time and then slowly releasing it through pipes, the design behaves like an underground detention pond. Figure 8 illustrates a cross-section design for no base exfiltration into the soil. In some cases, the soil may be stabilized to render improved support for vehicular loads. This practice almost reduces infiltration into the soil to practically zero.

Grass and topsoil may be used in the joints with any of the three design options. However, surface infiltration rates will be substantially lower. Grass and topsoil require geotextile and bedding between the pavers and the open-graded base. Figure 9 illustrates a schematic cross-section with grass and topsoil filling the paver openings.

*Figure 8 . **No exfiltration** of water from the base into the soil due to the use of an impermeable liner at the bottom and sides of the base. Drain pipes are sized to slowly release the water into a sewer or stream.*

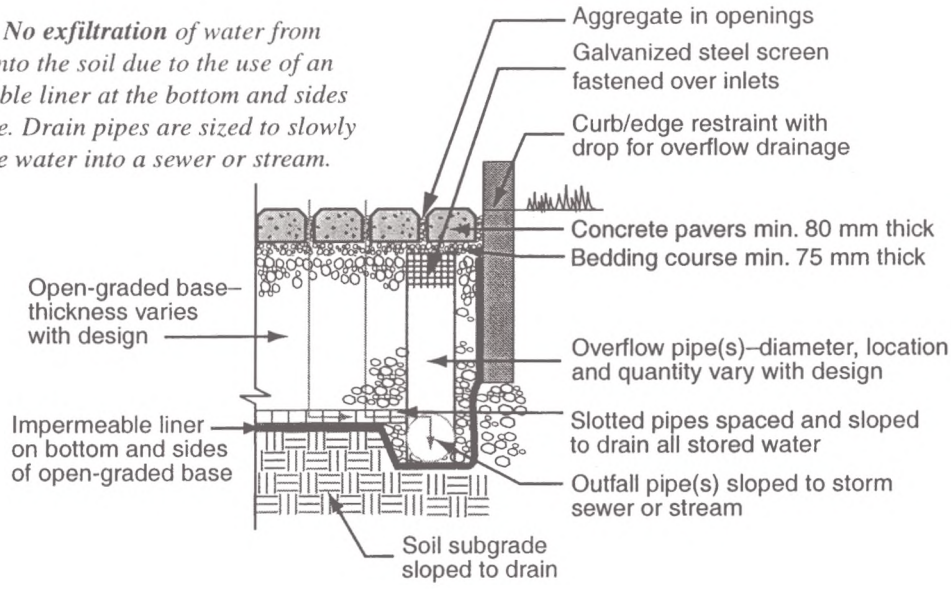
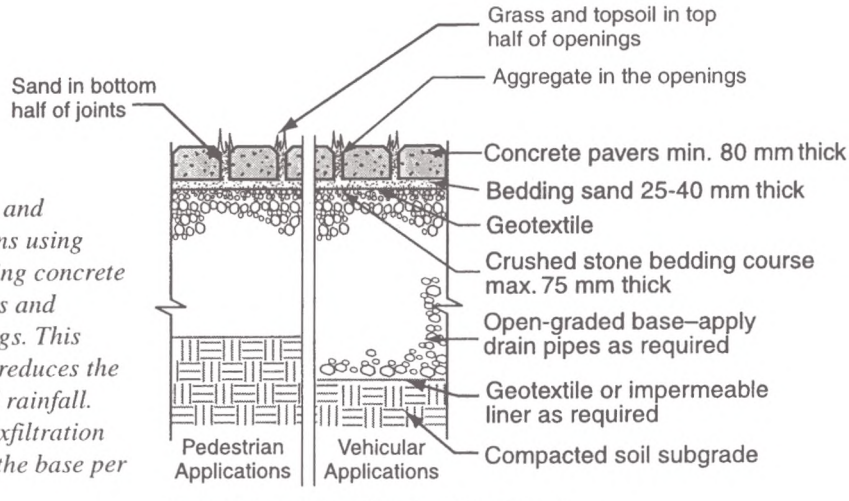


Figure 9. Pedestrian and vehicular applications using permeable interlocking concrete pavements with grass and topsoil in the openings. This option substantially reduces the amount of infiltrated rainfall. Full, partial, or no exfiltration can be designed for the base per Figures 6, 7 and 8.



Note: Minimum joint widths should be minimum 13mm when filled with topsoil and grass.

2.3 Site Selection Criteria

Permeable interlocking concrete pavements are recommended in areas with the following site characteristics (2)(3):

1. Residential, commercial, and institutional land uses.
2. The total catchment draining into the permeable pavement is not greater than 2 ha.
3. The estimated depth from the bottom of the pavement base to the high level of the water table is greater than 0.6 m. Greater depths may be required to obtain additional filtering of pollutants through the soil.
4. The pavement is downslope from building foundations, and the foundations have piped drainage at the footers.
5. The slope of the permeable pavement surface is at least 1%.
6. Land surrounding and draining into the pavement does not exceed 20% slope.
7. At least 30 m should be maintained between permeable pavements and water supply wells.
8. Sites where the owner can meet maintenance requirements.
9. Sites where there will not be an increase in impervious cover draining into the pavement (unless the pavement is designed to infiltrate and store runoff from future increase in impervious cover).
10. Sites where space constraints, high land prices, and/or runoff from additional development make permeable interlocking concrete pavements a cost-effective solution.

There are four situations where permeable interlocking concrete pavements should not exfiltrate. An impermeable liner is used to capture, store and release runoff from the base.

1. When the depth from the bottom of the base to the high level of the water table is less than 0.6 m, or when there is not sufficient depth of soil to offer adequate filtering and treatment of water pollutants.
2. Directly over solid rock, or over solid rock with no loose rock layer or above it.
3. Over aquifers where there isn't sufficient depth of soil to filter the pollutants before entering the ground water. These can include karst, fissured or cleft aquifers.
4. Over soils which can become unstable or swell when saturated.

Permeable interlocking concrete pavements are not recommended on any site where there are risks that stormwater can infiltrate and contaminate groundwater. These land uses and activities may include the following:

- vehicle salvage yards, recycling facilities, fueling stations, service and maintenance facilities, equipment and cleaning facilities
- fleet storage areas (bus, truck, etc.)
- industrial sites
- marina service and maintenance areas
- outdoor liquid container storage areas
- outdoor loading/unloading facilities
- public works materials/equipment storage areas
- facilities that generate or store hazardous materials
- storage areas for various kinds of commercial shipping containers
- land uses that drain pesticides and/or fertilizers into permeable pavements (e.g., agricultural land, golf courses, etc.)
- other land uses and activities as designated by an appropriate review authority

3. DESIGN DATA

3.1 Infiltration Rate of Permeable Pavements

Limited research on permeable pavements made with solid, nonporous units provides some guidance on long-term infiltration rates. German studies (2)(5) reviewed parking lots with open-graded materials in the paver openings over an open-graded base. They showed a high initial infiltration when new, and a decrease and leveling off as they aged. The decrease in infilitration is natural and is due to the deposit of fine materials such a dirt, vegetation in the joints, and clogging of the base and geotextiles.

When tested, new pavements demonstrated very high infiltration rates of almost 6×10^{-5} m/sec and two four-year old parking lots indicated rates of about 2×10^{-5} m/sec. Lower rates were exhibited on pavements where openings were filled with sand or aggregate and itinerant vegetation. In another study of two and five-year old parking lots, the infiltration rates were about 4 and 3.5×10^{-5} m/sec respectively. Infiltration was measured over approximately one hour for these two studies.

The results of these studies confirm that the long-term infiltration depends on the intensity of use and the degree to which the surface and base receive sediment. This is also confirmed in the literature on the performance of infiltration trenches. Since there are differences between field tests and long-term performance, construction, plus inevitable clogging, a conservative design rate of 8×10^{-6} m/sec or 80 l/sec/hectare can be used as the basis for the design infiltration rate for a 20-year life. In other words, the German studies of new and existing pavements, as well experience with infiltration trenches, indicate that the life-time average infiltration rate is roughly 10% of the initial rate.

3.2 Rainfall and Traffic Data

The following data will be necessary to design the pavement:

1. The total area and percent of impervious surface draining into the permeable pavement.
2. The design storm with the return period and intensity in inches or millimeters per hour (usually supplied by municipality or other regulatory agency). Rainfall intensity-duration-frequency maps can be referenced to establish the design storm (6) (7).
3. The volume of runoff or peak flow to be captured, exfiltrated, or released using the design storm.
4. An estimate of the vehicular traffic loads expressed as 18,000 kip (80 kN) equivalent single axle loads (ESALs) over the design life of the pavement, typically 20 years.

3.3 Soil Subgrade Sampling and Analysis

Soil samples extracted with a core auger are recommended to be obtained every 15 m through the center of the proposed area to be paved with a minimum of two borings per site. All borings should be taken at least 1.5 m deep with soil logs recorded to at least 1 m below the bottom of the base. More frequent sampling may be required by the design engineer in areas where soil types may change, near rock outcroppings, in low lying areas, or where the water table is likely to be within 2.5 m of the surface. Evidence of a high water table, impermeable soil layers, rock, or dissimilar layers may require a base design with no exfiltration.

The following tests are recommended on the soil samples, especially if the soil has clay content. These assist in evaluating the soil's suitability for supporting traffic in a saturated condition while exfiltrating. Other tests may be required by the design engineer.

1. Unified (USCS) soil classification using the test method in ASTM D 2487 (8).
2. Sampled moisture content in percent.
3. Soaked CBR using the test method ASTM D 1883 (9) or AASHTO T 193 (10).
4. Onsite tests of infiltrate rate of the soil using local, state or provincial recommendations for test methods and frequency. All tests for infiltration should be done at the elevation corresponding to the bottom of the base. If there are no requirements for infiltration test methods, the ASTM D 3385 (11), Test Method for Infiltration Rate of Soils in Field Using a Double-Ring Infiltrometer is recommended. ASTM D 5093 (12), Test Method for Field Measurement of Infiltration Rate Using a Double-Ring Infiltrometer with a Sealed-Inner Ring for very pervious soils with an expected infiltration rate over 10^{-4} m/sec or greater, or impervious soils with rates lower than 10^{-8} m/sec. Percolation test results for the design of septic drain fields are not suitable for the design of stormwater infiltration systems.

Results from field tests are approximations because the structure and porosity of soils are easily changed. On-site tests do not account for loss of the soil's conductivity from construction, compaction, and clogging from sediment. Nor do they account for lateral drainage of water from the soil into the sides of the base. Individual test reults should not be considered absolute values directly representative of expected drawdown of water in the open-graded base. Instead, the test results should be interpreted with permeability estimates based on soil texture, structure, pore geometry, and consistence.

The minimum tested infiltration for considering full exfiltration of water through soils subject to vehicular traffic is 10^{-6} m/sec. Some localities may require higher minimum infiltration rates. Soils with a tested permeability equal to or greater than 4×10^{-6} m/sec usually will be gravel, sand, loamy sand, sandy loam, loam, and silt loam. These are usually soils with no more than 10-12% passing the 0.075 mm sieve. Silt and clay soils will likely have lower permeability, and be not suitable for full exfiltration from an open-graded base. For cold climates in the northern U.S. and Canada, the lowest recommended infiltration rate for the soil subgrade is 4×10^{-6} m/sec.

To help maximize infiltration, the subgrade should have less than 5% passing the 0.075 mm sieve, although soils with up to 25% passing may drain adequately depending on site conditions and specific characteristics. Soils with a permeability lower than 4×10^{-6} m/sec can be used to infiltrate water as long as the soil remains stable while saturated, especially when loaded by vehicles. However, drain pipes will be required. Soil stability under traffic should be carefully reviewed for each application by a qualified geotechnical or civil engineer. Pedestrian applications not subject to vehicular traffic can be built over soils with a lower permeability.

This design procedure assumes a soil CBR (minimum 96-hour soaked) strength of at least 5% or an R-value of 24 to qualify for use under vehicular traffic. The compaction required to achieve this will greatly reduce the infiltration rate of the soil. Therefore, the permeability or infiltration rate of soil should be assessed at the density required to achieve at least 5% CBR. If soils have a lower soaked CBR or are highly expansive, they should be treated to raise the CBR above 5%. Treatment can be with cement, lime or lime/flyash (to control expansive soils) while raising the CBR. Guidelines on the amount and depth of cement required for soil stabilization can be found in reference 13 by the Portland Cement Association.

An alternative approach to raising the CBR of non-expansive soils to over 5% is by placing a capping layer of crushed stone on the subgrade. The layer should have a minimum soaked CBR of 20% and be a minimum of 200 mm thick. Geotextile is recommended between this layer and the soil subgrade.

The CBR treatments described above reduce the infiltration of soil to practically zero. In these

cases there is no exfiltration of water into the soil, so all water is stored and slowly released from the open-graded base. Obviously, this rate of drainage is taken into account when sizing pipes draining the base. The guidance of an experienced civil or geotechnical engineer familiar with local site conditions and stormwater management should be sought to confirm the suitability of the soil characteristics and possible treatments for use under all permeable interlocking concrete pavements.

3.4 Filters and Geotextiles

Fines particles suspended in slowly moving water will be deposited in the pores of the adjacent material. In the case of permeable interlocking pavements, particles will be deposited in another soil, the aggregate base, bedding course, the aggregate in the pavement openings or geotextile. The build-up of fines eventually clogs and reduces permeability of these materials. To reduce this action, filter criteria must be met whenever there is a change in materials. Therefore, criteria must be met for joint and bedding materials (if different materials are used), the bedding course, the bedding course and the base, base and sub-base (as applicable), and the soil subgrade. While aggregate materials can be used for filters, the use of geotextiles is more common and is recommended. The U.S. Federal Highway Administration (FHWA) and The American Association of State Highway and Transportation Officials (AASHTO) (14)(15) provide filter criteria.

3.5 Materials for the Base, Bedding and Openings

The following data is required on materials for the base, bedding course, and aggregate in the pavement openings:

1. Sieve analysis.
2. Void space in percent for the open-graded base.

Crushed stone, open-graded base—This material should be a hard, durable rock with 90% fractured faces and a Los Angeles (LA) Abrasion of < 40. A minimum effective porosity of 0.32 and a design CBR of at least 80% are recommended. A water storage capacity of open-graded base will vary with its depth and the percent of void spaces in it. The void space of open-graded aggregate can be supplied by the quarry or from independently conducted tests.

ASTM No. 57 crushed aggregate is commonly used for open-graded bases and is recommended for most permeable pavement applications. It has ample storage capacity in its void spaces, typically 20% to 40%. A 40% void space means that the volume of the base will need to be 2.5 times the volume of the water to be stored. The infiltration rate of No. 57 stone base is over over 7×10^{-3} m/sec.

The large size of the aggregates in No. 57 crushed stone creates an uneven surface when compacted. To smooth the surface, a bedding course of ASTM No. 8 crushed aggregate is placed and compacted into the top of the No. 57 open-graded base. The No. 8 material is often called choke stone since it stabilizes and partially chokes or closes the surface of the open-graded base. The thickness of the No. 8 layer should not exceed 75 mm prior to compaction. Like No. 57, it should be hard material, having 90% fractured faces and an LA Abrasion < 40. The CBR should be at least 80% and have an infiltration rate of at least 7×10^{-3} m/sec. The No. 8 material stabilizes the surface of the No. 57 and provides some filtering of water. Therefore the No. 8 stone should meet the following criteria:

$$D_{15\ \text{open-graded base}} / D_{50\ \text{choke stone}} < 5 \text{ and } D_{50\ \text{open-graded}} / D_{50\ \text{choke stone}} > 2$$

D_x is the particle size at which x percent of the particles are finer. For example, D_{15} is the particle size of a soil or aggregate gradation for which 15% of the particles are smaller and 85% are coarser.

Besides use as a bedding material, No. 8 crushed stone aggregate is also recommended for fill material in the paver openings. The void space in the bedding and joints is not considered in water storage calculations. They provide an additional factor of safety since they have capacity for storing water.

ASTM C 33 or CSA A23.1 bedding sand—Bedding sand, when used, should conform to the grading requirements of ASTM C 33 (16) or CSA A23.1 (17). (These are recommended by ICPI for use under solid interlocking concrete pavers as well.) The sand should be washed and there should be no more than 3% passing the 0.075 mm sieve. Limestone screenings and stone dust must never be used. The infiltration rate of C 33 bedding sand is approximately 10^{-5} m/sec.

Topsoil, if used in the joints, should conform to ASTM D 5268, *Specification for Topsoil Used for Landscaping Purposes* (18). If grass is used, heat and drought-tolerant species are recommended. Consult with a turfgrass specialist for specific recommendations. The permeability of grass and topsoil is low, in the order of 7×10^{-6} m/sec. They do not allow adequate infiltration for managing stormwater.

3.6 Permeable Paving Materials

Concrete units for permeable pavement—The following data is needed on the pavers:

1. Minimum thickness = 80 mm.
2. Percent of open area of the surface.
3. Test results indicating conformance to ASTM C 936, *Standard Specification for Solid Interlocking Concrete Paving Units* (19), or CSA A231.2, *Precast Concrete Pavers* (20) as appropriate. If the dimensions of the units are larger than those in these standards, then CSA A231.1, *Precast Concrete Paving Slabs* (21) is recommended as a product standard.

4. CONCLUSION

As with solid interlocking concrete pavements, permeable interlocking pavements are made in various shapes that offer a structural wearing course and allow infiltration of stormwater. Additional studies are needed to establish the structural contribution of the wearing course to the entire pavement system. This would include studies on the role of jointing material and shapes.

The open-graded base materials discussed here are common in North America. Grading specifications are provided in the ICPI design manual. There are many kinds of open-graded bases and there may be ones that provide better structural and drainage characteristics. Studies on structural and drainage performance would further advance the art and science of thickness design.

Like all pavements, establishing a reliable design value for the bearing and/or shear capacity of the soil subgrade is the most important design factor influencing the base thickness. A reasoned assessment of soil strength can be a difficult exercise since the soil subgrade is designed to be saturated for a brief time, rather than be drained as with ordinary pavements. Laboratory and experienced-based assessment of the geology, soil permeability, and expected compaction are critical to determining the design infiltration rate of permeable interlocking concrete pavements. There is a paucity of infiltration studies on permeable interlocking concrete pavements. However, years of experience with the performance of infiltration trenches in North America provides an empirical basis for using a 10-fold safety factor for establishing a conservative and reliable long-term (design) infiltration rate for permeable interlocking concrete pavement systems.

(Continued in Part 2)