Permeable Interlocking Concrete Pavements – Selection, Design, Construction and Maintenance

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Paper prepared for presentation

At the “Innovations in Managing Roadway Runoff to Protect Surface Water and Groundwater”
Session

Of the 2004 Annual Conference of the
Transportation Association of Canada
Québec City, Québec

Abstract

Urbanization brings an increasing concentration of pavements, buildings, and other impervious surfaces. They generate additional runoff and pollutants during rainstorms, causing stream-bank erosion as well as degenerating lakes and polluting sources of drinking water. Increased runoff also deprives groundwater from being recharged, decreasing the amount of available drinking water in many communities.

Many jurisdictions are now requiring best management practices (BMP's) to control non-point source water pollution, and they are divided into non-structural and structural BMP's. Structural BMP's capture runoff and rely on gravitational settling and/or the infiltration through a porous medium for pollutant reduction and peak discharge control. They include detention dry ponds, wet retention ponds, infiltration trenches, sand filtration systems, and permeable pavements.

This paper will discuss the use of permeable interlocking concrete pavements as a structural BMP under infiltration and partial treatment of stormwater pollution. It will cover the selection of the pavement cross-section based upon the municipal stormwater management objective, and the criteria for design, construction and maintenance.

Introduction

With a North American population that not only relies on water as a resource, but continues to live in close proximity to these sources, there is growing concern regarding the management of storm water in our watersheds. Table I summarizes some of the various impacts of impervious surfaces (United States EPA, 1997). In the United States, federal law mandates that states control non-point source water pollution through the National Pollution Discharge Elimination System (NPDES). Among other things, the law requires best management practices (or BMP's) to control non-point source pollution from new development.

The United States Environmental Protection Agency (USEPA) describes nonpoint source (NPS) pollution as follows: "Unlike pollution from industrial and sewage treatment plants, (it) comes from many diffuse sources. NPS pollution is caused by rainfall or snowmelt moving over and through the ground. As the runoff moves, it picks up and carries away natural and human-made pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters, and even our underground sources of drinking water. These pollutants include:

- Excess fertilizers, herbicides, and insecticides from agricultural lands and residential areas;
- Oil, grease, and toxic chemicals from urban runoff and energy production;
- Sediment from improperly managed construction sites, crop and forest lands, and eroding streambanks;
- Salt from irrigation practices and acid drainage from abandoned mines;
- Bacteria and nutrients from livestock, pet wastes, and faulty septicsystems"

In Canada, the challenges and concerns are similar.

Permeable interlocking concrete pavements utilize infiltration trench experience and design to address water quantity and quality concerns. From an engineering perspective, permeable interlocking concrete pavements are infiltration trenches with paving over them to support pedestrians and vehicles. Infiltration trenches have been in use for decades as a means to reduce stormwater runoff and pollution, and to recharge groundwater.

Permeable Interlocking Concrete Pavements as a Best Management Practice

Storm water management best practice objectives can be divided into three main criteria: water *quality* control, water *quantity* control, and preservation of the hydrologic cycle. Permeable interlocking concrete pavements provide design options to meet all three of these objectives through: "zero runoff", infiltration of post-development run-off, fixed volume infiltration, and control of peak rate of run-off discharge.

Permeable interlocking concrete pavements are typically built on an open graded, crushed stone base. It is the base that offers infiltration, storage, and partial treatment of storm-water pollution. Figure I shows a typical permeable interlocking concrete pavement.

Permeable pavements are considered a structural best management practice (BMP) under infiltration practices. Structural BMP's include storage practices, filtration practices, and infiltration practices. They capture runoff to various degrees and rely on infiltration through a porous medium for the reduction of pollutants. In terms of their engineering, permeable pavements are no different than infiltration trenches. The important difference, however, is that the surface supports pedestrian and vehicular traffic.

Acting as a combination of both infiltration and retention areas, permeable interlocking concrete pavements can offer the following additional benefits (Smith, 2000):

1. Filtration for water quality improvement
2. Conservation of space on the site
3. Reduction of run-off by as much as 100%
4. Recharge of groundwater
5. Reduction of run-off temperature
6. Reduction of downstream flows and bank erosion from a decrease in peak flows and volumes
7. Reduction in storm sewers and other drainage appurtenances

Design Options

Most storm water BMP objectives utilizing permeable interlocking concrete pavements can be met by designing a system for full, partial, or no exfiltration of an open-graded base into the soil. A design for full exfiltration means that surface water infiltrates directly into the base and exfiltrates into the soil (See figure II). The system also includes drainage in overflow conditions and secondary drainage should the base become clogged and lose some of its capacity over time.

Partial exfiltration (See figure III) relies on some of the water exfiltrating to the soil with the remainder drained by perforated pipes. This is usually the case with slow-draining soil. If the soil has extremely low permeability (less than 0.27 in/hr or 2 x 10^{-6} m/sec) and low strength, or if there are other site limitations, a design for no exfiltration is required (See figure IV). An impermeable liner may also be used if the pollutant loads are such that they exceed the capacity of the soil and base to treat them.

The liner for the no exfiltration design option can be a high density polyethylene (HDPE), ethylene propylene diene monomer (EPDM), rubber asphalt, or asphalt-based materials. A liner may also be required if the depth to bedrock or to the water table is less than 0.6 m. This design acts much like an underground detention pond by storing water in the base and then slowly releasing it through pipes. The design for no exfiltration should be considered under the following criteria:

1. When the depth of the bottom of the base is within 0.6 m of the high level of the water table.
2. When there is not sufficient depth of the soil to offer adequate filtering and treatment of water pollutants
3. When the pavement is directly over solid rock or over solid rock with no loose rock layer above it
4. Over aquifers where there isn’t sufficient depth of soil to filter the pollutants before entering the groundwater
5. Over fill soils whose behaviour will change when exposed to infiltrating water (example, expansive soils)

Types of Permeable Interlocking Concrete Pavement Surfaces

Permeable interlocking concrete pavers can be grouped into three categories: interlocking shapes, enlarged permeable joints, and porous concrete. Interlocking shapes with openings (See figure V) have patterns that create openings or drainage holes for rainfall to enter, while at the same time maintaining high side-to-side contact among adjacent units. This provides stability under vehicular loads. This alternative is excellent for parking lots, driveways, overflow parking and access and emergency lanes. In addition, it provides a good option for boat ramps, bike paths, sidewalks, and pedestrian areas.

Enlarged permeable joints (See figure VI) are pavers with wide joints that allow rainfall to enter. These joints can be as wide as 35 mm and can be created with large spacers moulded into the sides of each paver, or with plastic spacers inserted between each unit. Some joints may also include indented sides or chambers in the sides of each unit that can store additional runoff. Pavers with enlarged joints can be used in similar applications to pavers with interlocking shapes with openings.

Care should be exercised with either of these two approaches in disabled-accessible areas. Generally, the disabled-accessible areas should be isolated from the rest of the pavement by providing access paths with standard solid pavers.

Permeable concrete units (porous concrete, see figure VII) consist of pavers made with no-fines concrete, and are laid in a similar fashion to other pavers. Experience has shown, however, that they are more susceptible to clogging than other alternatives. Further, they do not typically meet the requirements of CSA A231.2 in terms of strength or durability. For that reason, they are not recommended in most parts of Canada.

Materials for the Open Graded Base, Bedding and Joint Openings

A common design error is to assume that the amount (or percent) of open surface is equal to the percentage of perviousness. It is incorrect to assume, for example, that an 18% open surface is 18% pervious or 82% impervious. The perviousness and amount of infiltration is dependent on the infiltration rate of the jointing material, bedding layer, and base materials – not the percentage of surface open area. In fact, most permeable interlocking concrete pavements can be designed to qualify for 100% infiltration of surface runoff.

The typical recommended base material is open graded base conforming to the gradation requirements of ASTM No. 57 crushed aggregate. Some contractors, however, experience better constructability with a larger size sub base material under the No. 57 base, using 2 to 3 inch (50-75 mm) top size aggregate. The larger aggregate offers better support for construction traffic. Nevertheless, the material should have a minimum of 90% crushed faces, a Los Angeles abrasion (LA) less than 40, and a minimum porosity of 32%. The infiltration rate of a No. 57 stone base is typically over 1000 in/hr (7×10^{-3} m/sec). For structural design purposes, the base material should have a design CBR (California Bearing Ratio) of at least 80%.

Because the No. 57 aggregate creates an uneven surface when compacted, a bedding course of ASTM No. 8 crushed aggregate is placed and compacted into the top of the No. 57 open graded base. This helps to stabilize and “choke” the surface of the open graded base, as well as provide a permeable layer with an infiltration rate similar to the No. 57 stone. The thickness of this layer should be no greater than 75 mm for stability reasons. This same aggregate is also recommended for filling the open joints between the pavers.

When using a sub base of larger 50 to 75 mm aggregate, it is typical to use a minimum thickness of 6 inches, followed by the No. 57 base material at a 50 to 75 mm thickness.

Geotextiles are required to prevent clogging through the build-up of fines that can eventually reduce the permeability of all of the materials. In a typical construction, they are required between the base (or sub base) and soil subgrade, and are wrapped up the sides of the excavation as well (See Figure VIII). Geotextile should be selected according to the guidelines of the U.S. Federal Highway Administration (FHWA) and the American Association of State and Highway and Transportation Officials (AASHTO) for clogging and permeability.

Infiltration Rates of the Permeable Interlocking System

Studies on permeable interlocking concrete pavers have attempted to estimate their long- term infiltration performance. Permeable concrete units (made with no fines aggregate) demonstrate the lowest average permeability, whereas interlocking shapes with openings or those with enlarged permeable joints offer substantially higher infiltration performance over the long run. New pavements, including the soil subgrade, have demonstrated very high total infiltration rates of almost 9 in./hr (6×10^{-5} m/sec). It is generally accepted, however, that there is a decrease in total infiltration rate as the pavement ages. This is due, over time, to the deposit of fine materials such as dirt, vegetation in the joints, and clogging of the base and geotextiles. This is similar to the experiences with infiltration trenches. Therefore, a conservative long-term design rate of 10% of the initial rate for the entire pavement should be used. This is typically around 1.1 in./hr (8×10^{-6} m/sec).

Site Selection Criteria

Permeable interlocking concrete pavements are recommended in areas with the following site characteristics:

1. The slope of the permeable pavement surface is at least 1%
2. The estimated depth from the bottom of the pavement to the highest 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
3. Drainage area < 2 ha
4. The owner has a maintenance plan
5. The site in not classified as a stormwater “hot spot” – an example of which is industrial facilities that generate or store hazardous materials
6. The pavement is down slope from building foundations, and the foundations have piped drainage at the footers

Sizing an Open-Graded Base for Infiltration and Storage

The Interlocking Concrete Pavement Institute (ICPI, 2000) describes methodology from the Maryland Stormwater manual published by the State of Maryland, Department of the Environment (State of Maryland, 1999). The Maryland method is described and recommended because it has been refined over many years and it illustrates important aspects of infiltration design. The method assumes familiarity with SCS (NCRS) TR 55 method (USCS, 1986). The Maryland method finds the maximum allowable depth of the pavement (d_{max}) for a maximum storage time of 3 days. It may be desirable, however, to run calculations on 1 and 2 days to compare the differences in base thickness, since the three-day criteria will facilitate continual saturation and a subsequently weakened soil subgrade that may not support the anticipated vehicular traffic.

There are two methods to design the base storage area. The first method computes the minimum depth of the base, given the area of the permeable pavement. This is called the minimum depth method, and it is the more frequently used. The other is to compute the minimum surface area of the permeable pavement given the required design depth of the base.

The minimum depth method is described as follows (See figure IX for parameters):

1. From the selected design rainfall (P) and the SCS runoff curve number, compute the increase runoff volume of the contributing area (ΔQ_c).

2. Compute the depth of the aggregate base d_p from the following equation:

[1] $d_p = (\Delta Q_c R + P - fT) / V_r$

3. Compute the maximum allowable depth (dmax) of the aggregate base by the feasibility formula:

[2] $d_{max} = f \times T_s / V_r$

d_p must be less than or equal to d_{max} and at least 2 feet (0.6m) above the seasonal high ground water table.

4. Check the structural base thickness to be sure that it has sufficient thickness to meet the storage requirements plus function as a base for the anticipated traffic and frost conditions. (Smith, 2000) provides tables for these calculations.

5. Check the geotextile filter criteria utilizing FHWA or AASHTO geotextile filter criteria (AASHTO, 1990) for permeability and clogging criteria.

d_p= depth of open graded base (m)
d_{max} = maximum depth of base (m)
ΔQ_c = increased runoff from contributing area (m)
P = Design storm rainfall depth (m)
f = final infiltration rate of soil determined by permeability tests (m/hr)
Ts = the maximum allowable storage time of 72 hours
T = effective filling time of the base, hours (2 hours is typical)
Vr = Void ratio of the crushed stone base (typically 0.4)
$R = A_c/A_p$
A_c = contributing area (m^2)
A_p = surface area of the permeable interlocking concrete pavement (m^2)

Construction

Reduction of Clogging

The highest priority during construction of these pavements is the prevention and diverting of sediment from entering the base. Practices such as keeping muddy construction equipment from the area, installing silt fences, staged excavation, and temporary drainage swales will make the difference between a good and poor performing pavement.

Soil Compaction

Soil should be compacted to 95% standard proctor density for pedestrian areas and to a minimum of 95% modified proctor density for vehicular applications. It should be noted that the initial infiltration design should use the infiltration rate of the compacted soil to ensure that the base will drain as designed.

Geotextiles

Geotextiles should be used in all permeable pavement applications. They are necessary to separate the base (or sub base) from the subgrade to ensure that there is no contamination, and to separate the base from contamination that might occur laterally along the sides of the excavation. (See figure VIII) The bases should therefore have their sides and bottoms wrapped and any overlap should be a minimum of 0.6 m.

Handling Excess Water

Designs for full exfiltration should incorporate overflow pipes and partial or no exfiltration designs should have properly sized pipes to handle storage and outflow. A civil engineer experienced with hydrological design should determine the size and spacing of these pipes. It should also be noted that care should be taken to ensure that pipes subjected to traffic should be selected to withstand repeated vehicular loads. Perforations in the pipes should be 10 mm in diameter and terminate within 0.3 m of the edge of the base. A 150 mm vertical perforated pipe is recommended in the downslope position of the pavement (1 m from the outside edge of the base) to act as an observation well. It should be capped at the bottom.

Open Graded Bases and Bedding Layer

The No. 57 aggregate should be spread in 100 to 150 mm lifts and compacted with a 9 T steel drum static roller. The initial passes can be made with vibration on and the final passes should be made with no vibration. The bedding layer should be 75 mm of no. 8 stone that will “choke” into the no. 57 with the same static roller. This will typically result in a 50 mm layer of no. 8 stone as the bedding layer for the pavers.

Edge Restraints

Plastic edge restraints that utilize spikes are not recommended on open graded bases. The recommended edge restraints for permeable interlocking concrete pavements on open graded bases are cast-in-place and precast concrete curbs. They should be 150 mm wide and 300 mm deep. A stable footing may be required depending upon the design.

Paver Installation

The pavers are laid similarly to a standard interlocking pavement and can be laid either by hand or mechanically (See figure XI).

Cold Climate Considerations

The design for cold climates needs to consider the possibility of large, rapid volumes of snow melt in the late winter and early spring. Designers should follow the following guidelines (Caraco et al. 1997):

1. Permeable interlocking concrete pavements should not be used in permafrost regions

2. Chlorides and sand can be concentrated in snowmelt. Removal of chlorides is nearly impossible for any best management practice, so it is recommended to use isolation methods. It is recommended to stockpile snow with chlorides and/or sand away from the permeable interlocking concrete pavement. Possible locations include parking lot islands or bioretention areas.

3. If salts are used for de-icing, then the groundwater should be monitored for chlorides to check on conformance with local or national criteria applicable to the use of the water in the receiving lake, stream, or river. This can be done through the sampling of water in observation wells that are located in the pavement base and soil (see figure XII).

4. When the frost exceeds 1 meter in depth, all permeable interlocking parking lots should be set back from the subgrade of adjacent roads by at least 6m. This is to reduce the potential of frost lenses and heaving of soils under the adjacent roadway.

5. If winter sanding is extreme, maintenance should include annual inspection in the spring and vacuum removal of the surface sediment. This will ensure continued infiltration performance of the pavement.

6. The designer may wish to incorporate a 1-2% slope as a safety factor for overflow should the system not be able to infiltrate all runoff under winter conditions. (UNI-GROUP, 2002)

Conclusion

Infiltration trenches have been in use for decades as a means to reduce stormwater runoff and pollution, and to recharge groundwater. From an engineering perspective, permeable interlocking concrete pavements are infiltration trenches with paving over them to support pedestrians and vehicles. With the utilization of proper design and material selection permeable interlocking concrete pavements are an excellent addition to alternatives for storm water best management practices.

References

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Tables

Table I: The effects of increased imperviousness and resulting impacts (Source: U.S. EPA, 1997)

RESULTING IMPACTS

Effects of increased imperviousness ↓	Flooding	Habitat loss	Erosion	Streambed alteration	Channel widening
• Increased runoff volume	X	X	X	X	X
• Increased peak flow	X	X	X	X	X
• Increased Peak flow duration	X	X	X	X	X
• Increased stream temperature		X			
• Decreased base flow		X			
• Changes in sediment loading	X	X	X	X	X

Figures

Figure I: A permeable interlocking concrete parking lot (Source: Interlocking Concrete Pavement Institute, 2000)

Figure II: Permeable Interlocking Concrete Pavement – Full Exfiltration (Source: ICPI, 2000)

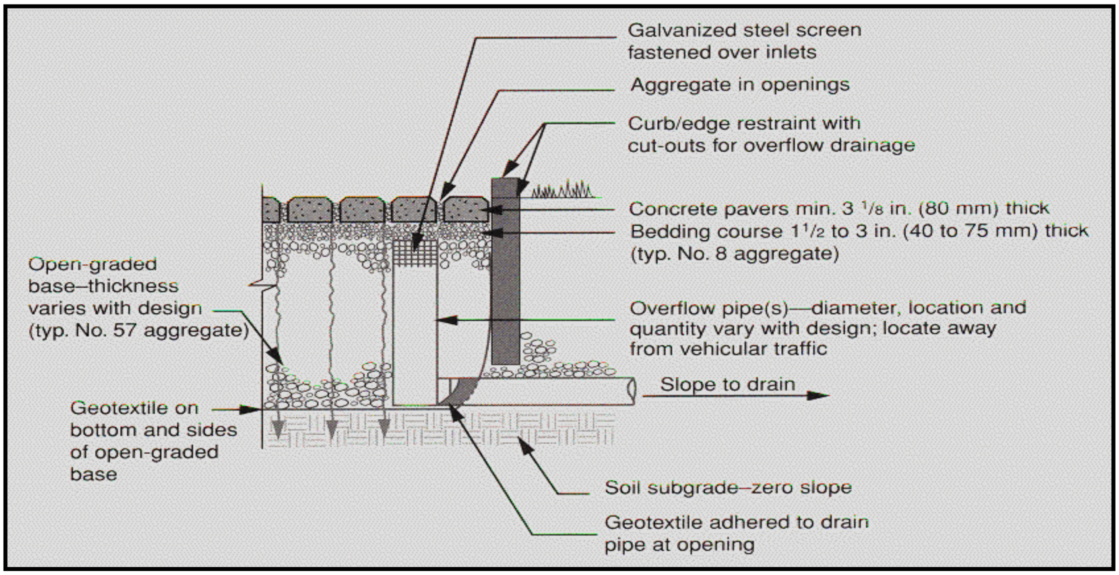

Figure III: Permeable Interlocking Concrete Pavement – Partial Exfiltration (Source: ICPI, 2000)

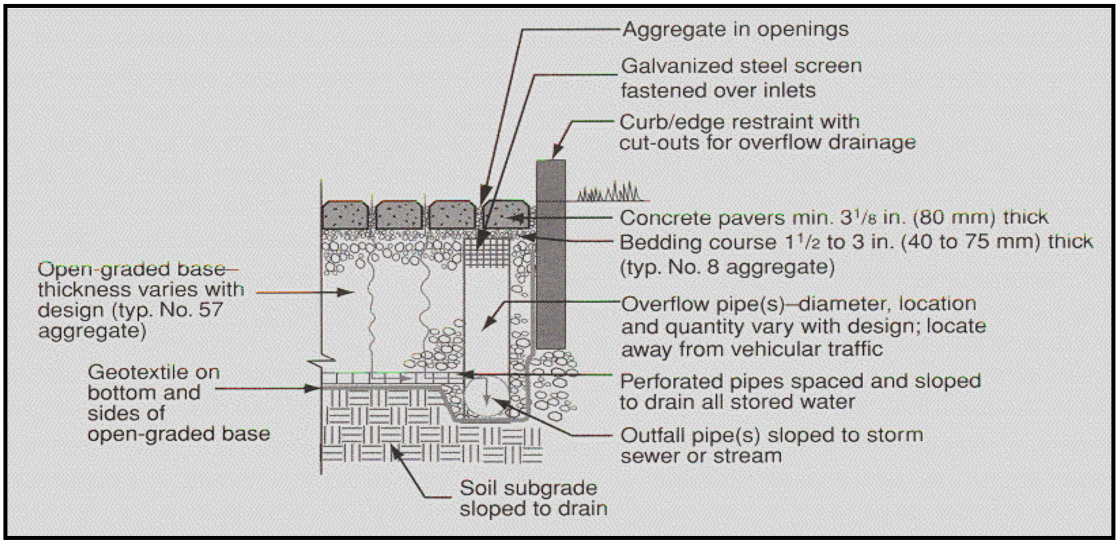

Figure IV: Permeable Interlocking Concrete Pavement – No Exfiltration (Source: ICPI, 2000)

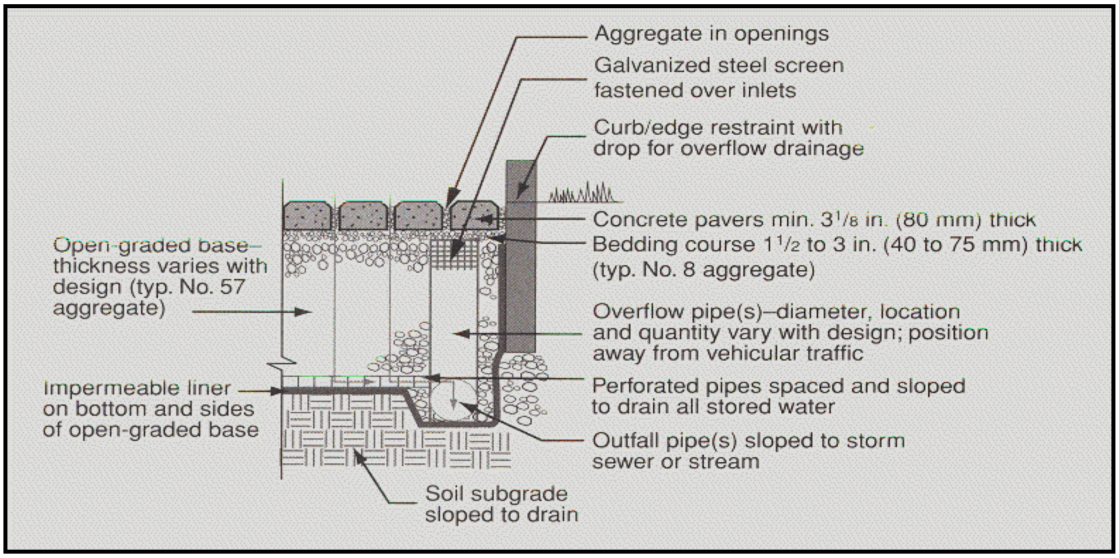

Figure V: An example of interlocking shapes with openings on corners. These types of pavers have excellent side-to-side contact and provide load transfer to adjacent units, making them acceptable for parking lots. (Source: ICPI, 2000)

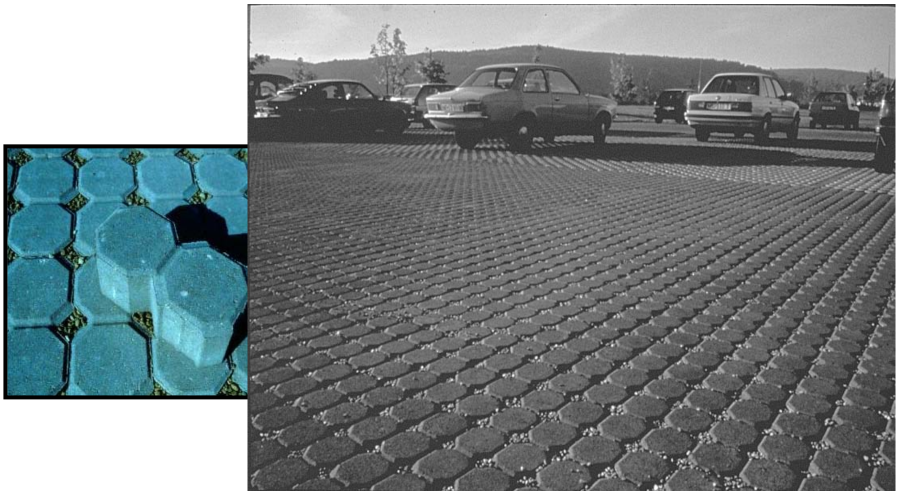

Figure VI: Plastic spacers are used to create enlarged permeable joints (Source: ICPI, 2000)

Figure VII: Porous concrete paver – these pavers are not recommended for extreme freeze/thaw climate conditions (Source: ICPI, 2000)

Figure VIII: Permeable pavement with geotextile to prevent contamination of the base layer at bottom and sides

Figure IX: Design parameters for calculating the base depth of interlocking concrete pavements (Source: ICPI, 2000)

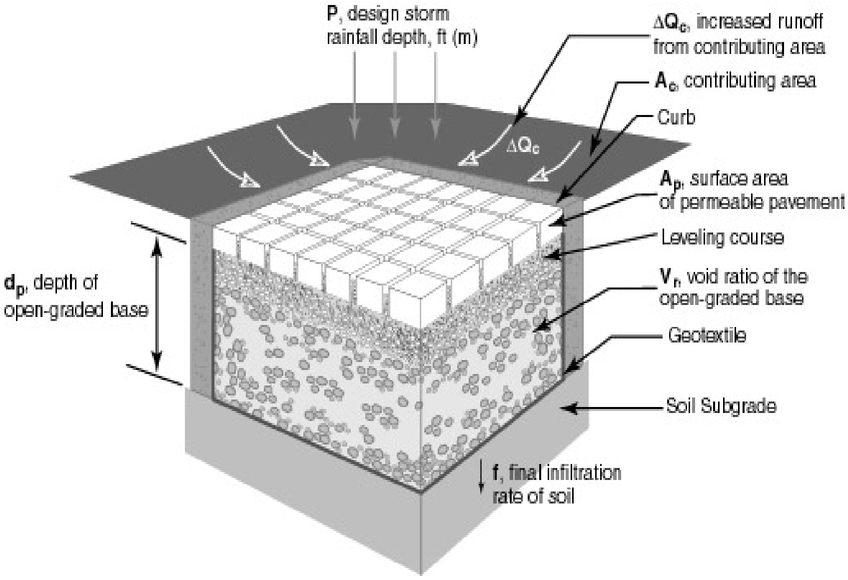

Figure X: Mechanical screeding of the No. 8 bedding layer (Source: ICPI, 2000)

Figure XI: Mechanical installation of pavers for a permeable pavement

Figure XII: A typical observation well (Source: ICPI, 2000)