



# Capturing the Rain

Permeable interlocking concrete and stormwater

by Julie Rapoport, PhD, PE, LEED AP

Photo courtesy Fred Adams Paving Co.

**AS SUSTAINABLE BUILDING PRACTICES BECOME MORE COMMON, THE PRINCIPLES OF LOW-IMPACT DEVELOPMENT AND STORMWATER MANAGEMENT ARE SEEN AS INCREASINGLY VITAL TO NEW AND RETROFIT COMMERCIAL AND RESIDENTIAL PROJECTS.** FEDERAL, STATE, AND LOCAL MANDATES, AS WELL AS GREEN BUILDING CERTIFICATION PROGRAMS, FURTHER DRIVE THE NEED TO UNDERSTAND VARIOUS RUNOFF-REDUCTION CONTROLS.

The options for controlling stormwater runoff are numerous and are often implemented in combination to create systems appropriate for the site and project budget. Permeable interlocking concrete pavements (PICPs) are widely recognized as an effective means of stormwater control. They consist of solid paving units with joints filled with highly permeable aggregates placed over an open-graded base and sub-base. These systems capture and temporarily store stormwater, and then allow it to infiltrate into the ground.

## Why stormwater management?

When it rains, water that falls on impervious surfaces—such as roads, parking lots, and alleyways—generally runs off into storm sewers. As more natural areas are developed, the amount of water rushing through municipal waterways grows. This can overburden streams and storm sewer systems and create budget problems. Overtaxed systems, particularly during periods of heavy or extended rainfall, can lead to overflowing storm sewers and flooding that can inflict economic damage.

In addition to the economic concern, environmental impact should be considered. Water that rushes off driveways and parking lots into storm sewers is not percolating back into the soil to recharge underground aquifers. Runoff can also lead to erosion problems at the site or downstream. Finally, sediment and chemicals on hardscape surfaces (e.g. oil drips or gasoline spills) can mingle with stormwater runoff and subsequently be introduced into the water supply.

Permeable systems—whether concrete, natural, or a combination thereof—reduce or eliminate rainwater flowing offsite and instead capture, filter, and direct

it back into the ground. This allows the water to recharge groundwater and be filtered into the native soil, rather than running off into the storm sewer. In places with combined storm and sanitary sewer systems, overwhelmed systems can flood, with severe environmental consequences. Infiltration systems, such as permeable pavements, help the load on these sewers and mitigate the impact of flooding.

Stormwater runoff is regulated under the *Clean Water Act* (CWA) and the National Pollutant Discharge Elimination System (NPDES) permit program. The U.S. Environmental Protection Agency (EPA) includes permeable surfacing as one of its best management practices (BMP) for meeting CWA requirements. Beyond federal regulations, many state and local jurisdictions are enacting even stricter requirements. At the same time, demonstration projects are helping drive the use of permeable pavements, including 'Green Alley' initiatives aiming to improve stormwater management of hardscaped alleyways in:

- Chicago, Illinois;
- Philadelphia, Pennsylvania;
- Baltimore, Maryland;

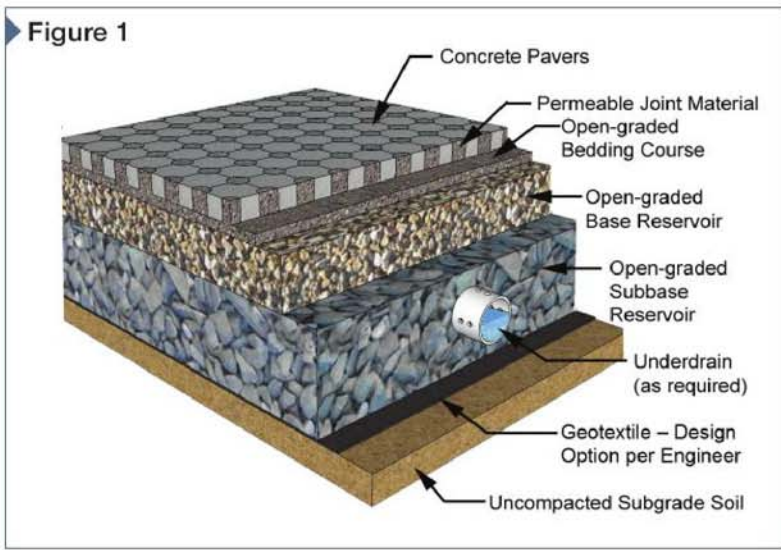


Figure 1  
A typical permeable interlocking concrete pavement (PICP) cross-section. Images courtesy ICPI

- Los Angeles, California; and
- Richmond, Virginia.

#### What are PICPs?

A common misconception is permeable pavers allow water to soak through the pavers themselves. In fact,

# We've Reached New Heights

IN MASONRY CONSTRUCTION



14" high

outside corner boot



14" high

inside corner boot

Made in the USA

Visit us at  
**WORLD OF CONCRETE**  
Booth #N1357  
Register to **WIN**  
a pair of custom-made  
**BOOTS!**

## New High-Performance Corner Boots

- One-piece injection molded
- Price competitive with standard height boots
- Full flashing height
- Faster installation
- Fewer chances for leaks

Visit [www.MortarNet.com](http://www.MortarNet.com) for more information

800-664-6638

MortarNet.com

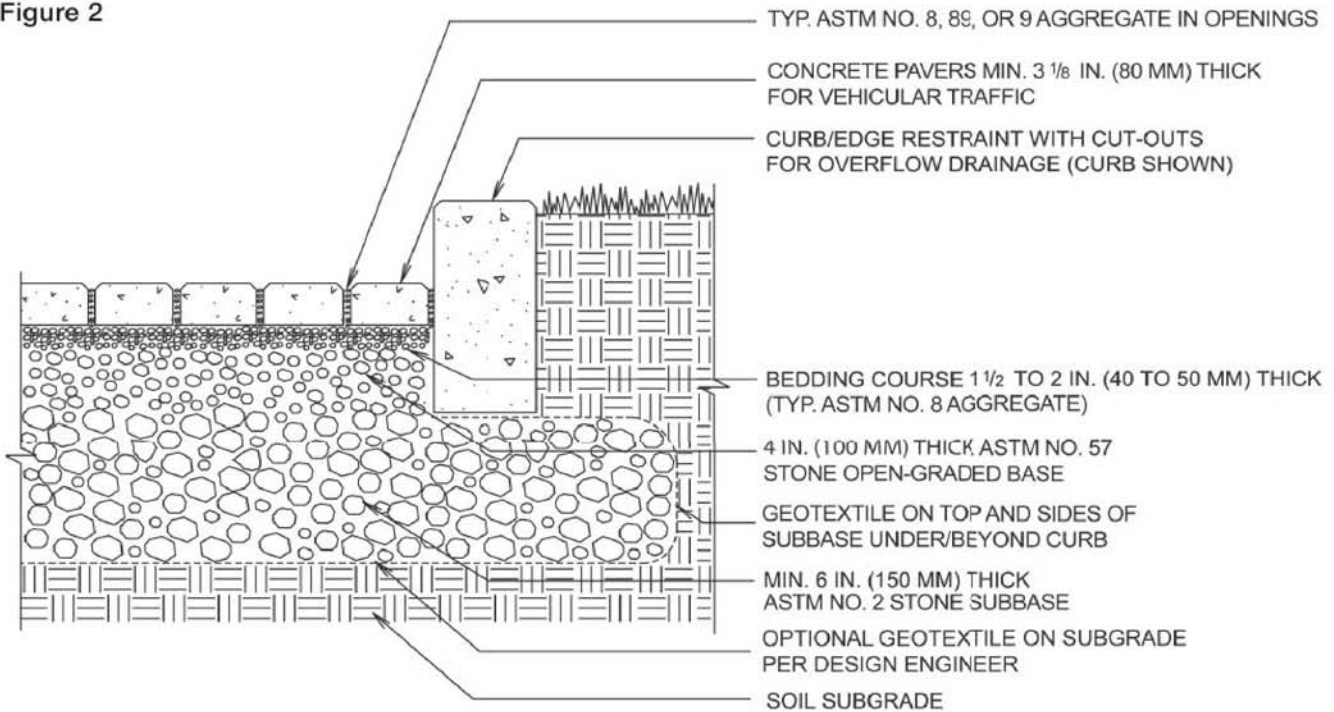
Makers of Mortar Net® with Insect Barrier™, TotalFlash®, Blok-Flash®, BlockNet®, HouseNet®, Stone & Stucco Drain™, & Mortar Net® Weep Vents™



Mortar Net®

USA LTD.

Figure 2



A cross-section of a full-exfiltration installation.

permeable interlocking concrete pavements consist of solid pavers with narrow openings or gaps between them that are filled with a permeable joint material. These openings allow water to seep through the paving surface and are generally five to 15 percent of the surface area.

Permeable pavements are distinct from pervious concrete, as the latter is designed to have many holes in the body of the concrete itself. Pervious concrete and pervious pavers tend to be weaker than interlocking pavers used in PICP. According to David Smith, technical director for the Interlocking Concrete Pavement Institute (ICPI), many pervious pavers do not meet ASTM standards for solid concrete paving units, such as ASTM C 936-09/C 936M-09, *Standard Specification for Solid Concrete Interlocking Paving Units*, which requires an average compressive strength of 55 MPa (8000 psi). PICPs also differ from concrete or plastic grid pavers, which have open cells typically filled with soil and grass. Smith notes these surfaces have lower infiltration rates and are limited to light-duty traffic areas.

PICP surfaces do not look much different than traditional interlocking concrete pavements. The paving units come in a range of styles, shapes, and colors. They can be installed in similar applications, including for vehicular traffic areas, provided the pavers themselves are of a sufficient thickness (typically 80 mm [3.2 in.]). For larger residential

developments or commercial projects, PICPs are often used in combination with other stormwater management strategies, including natural features such as bioswales and rain gardens.

According to EPA, PICP should be able to intercept, contain, filter, and infiltrate stormwater onsite. For example, PICP can be installed across a street width or parking area, or installed in combination with impermeable pavement to infiltrate runoff and start a treatment train. Various applications use PICP in parking lot lanes or parking stalls to treat runoff from adjacent impermeable pavements and roofs. This economizes installation costs and provides enough treatment area for the runoff made from impervious surfaces. Inlets can be placed in the PICP to accommodate overflows from extreme storms.

There are some places where no permeable pavement, including PICPs, should be used. These include 'stormwater hotspots' that may accumulate sediments or chemicals, such as vehicle salvage yards, outdoor unloading facilities in industrial areas, and outdoor liquid container storage areas.

Permeable pavers take about the same to install as traditional products. At present, permeable pavement systems can cost more to install than standard pavers, due to additional subsurface preparation. However, many jurisdictions are beginning to offer tax rebates or reduced stormwater fees, which can help offset the additional costs. Likewise, PICPs might save

Overtaxed systems, particularly during heavy or extended rainfall, can lead to overflowing storm sewers and flooding that can inflict economic damage.

developers money by reducing or eliminating the need for retention ponds and related drainage infrastructure, freeing up valuable land space on the developed properties.

### Installation overview

ICPI's handbook, *Permeable Interlocking Concrete Pavements*, offers extensive information on design, specifications, construction, and maintenance. Here is an overview of the basic makeup of PICP, from the top to the bottom layer (Figure 1, page 25).

**Solid pavers with molded joints or openings filled with permeable material**  
Pavers should comply with ASTM C 936-09, and should be at least 60 mm (2.4 in.) thick for pedestrian traffic and at least 80 mm thick for significant vehicular traffic.

**Open-graded bedding course**  
This layer, which is typically 50 mm (2 in.) thick, provides bedding for the pavers, consisting of small-sized, open-graded aggregate, ASTM No. 8 stone or similar.

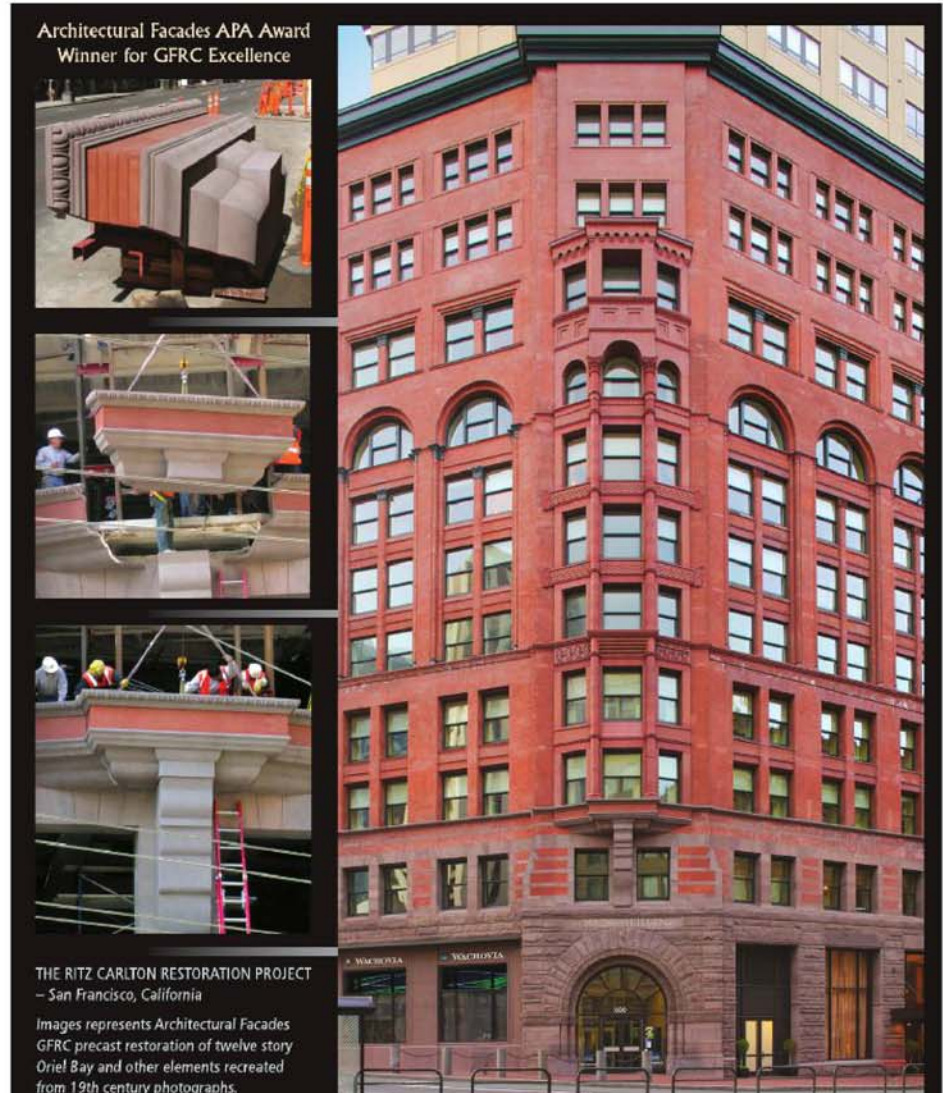
**Open-graded base reservoir**  
This is a 100-mm (4-in.) thick layer of 9.5- to 25-mm (0.4- to 1-in.) crushed stones (typically ASTM No. 57), which stores water while providing a gradational transition between the bedding above and the sub-base below.

**Open-graded sub-base reservoir**  
This layer stores water among stone sizes of 50 to 75 mm (2 to 3 in.)—typically ASTM No. 2, 3, or 4. The thickness of the layers depends on water storage requirements and traffic loads. This layer might not be required for pedestrian and residential driveway applications; instead, the base layer thickness can be increased. One should always consult a local engineer with knowledge of regional conditions.

**Underdrain**  
Perforated pipes can help facilitate water removal, if required, when a permeable system is installed over low-infiltration soils. These can drain to a swale, stream, or lake; they can also

connect to an underground cistern for water collection.

**Geotextile (optional)**  
This separates the sub-base from the subgrade to prevent soil migration.



THE RITZ CARLTON RESTORATION PROJECT  
— San Francisco, California  
Images represent Architectural Facades  
GFRc precast restoration of twelve story  
Oriel Bay and other elements recreated  
from 19th century photographs.

## ARCHITECTURAL FACADES PRECAST ▲ STONE COMPANY

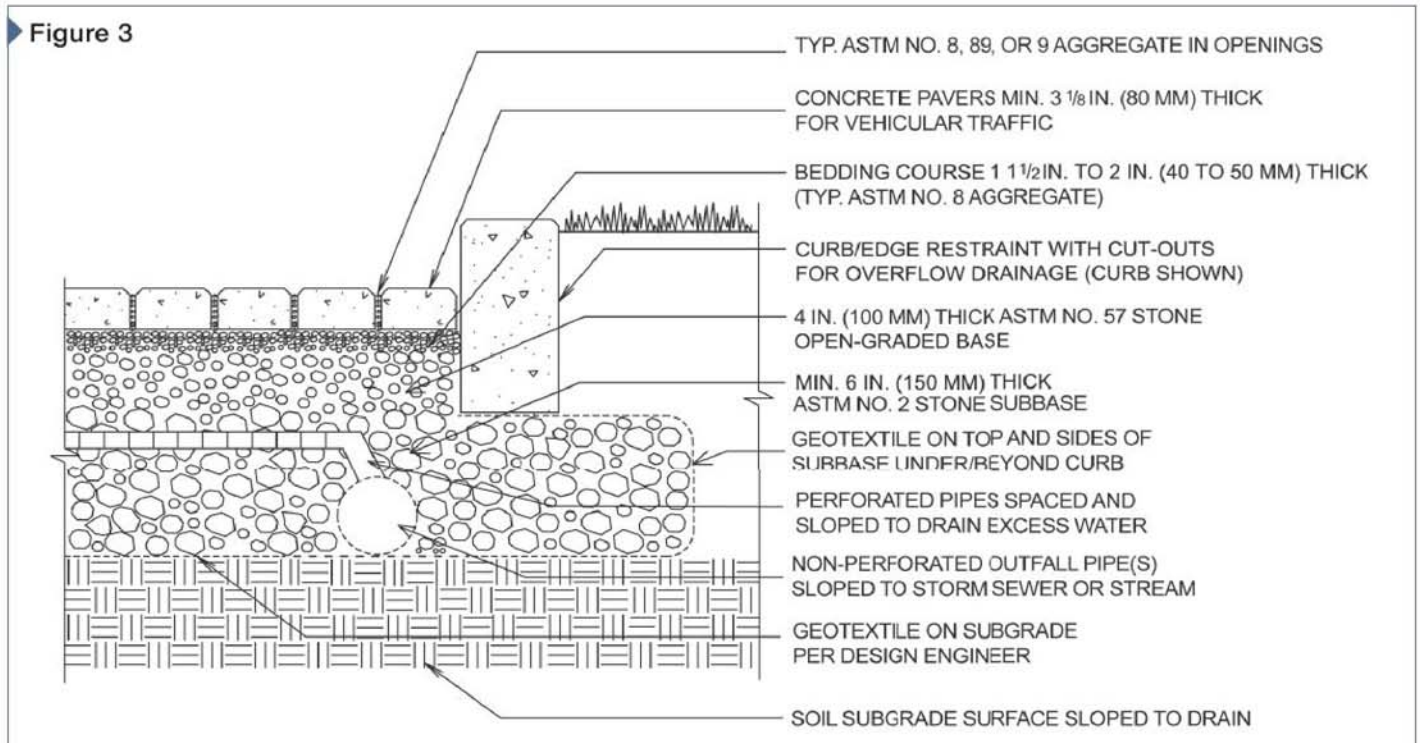
*Residential, Commercial and Restoration*

BALUSTRADES • COLUMNS • MANTELS • MOLDINGS • WINDOW & WALL TRIMS  
POOL & EDGE COPINGS • PAVERS • WALL CAPS • ENTRY PIERS • PLANTERS

Celebrating 25 years of Manufacturing Standard, GFRc and LCS Stone™ Precast Products

1-800-346-0826 [ArchitecturalFacades.com](http://ArchitecturalFacades.com)

Figure 3



A cross-section of a partial-exfiltration installation.

#### *Subgrade*

This is the layer of soil beneath the aggregate base or sub-base, generally not compacted so as to allow optimal water infiltration through the soil. If the subgrade is compacted, then the hydrologic design must account for decreased infiltration.

According to the ICPI handbook, PICP can be designed with three types of exfiltration (Figures 2, 3, and 4, pages 26, 28, and 30).

#### *Fill exfiltration*

Water is directed through the base/sub-base and exfiltrates into the soil subgrade—a common application over high-infiltration soils such as gravels and sands. Overflow is directed to swales, bio-retention areas, or storm sewer inlets via surface-level perimeter drains.

#### *Partial exfiltration*

This is a design common to lower infiltration rate soils, such as silts and clays. Perforated pipes above the soil subgrade drain excess water, usually to the storm sewer.

#### *No exfiltration*

This approach is used with:

- soil with low permeability and low strength;
- sites with insufficient soil depth to filter pollutants before entering groundwater; and

- fill soils in which water may cause settling and movement.

This method functions as a detention pond, with the bottom and sides of the PICP sub-base enclosed with an impermeable liner and geotextile. Water is captured and drains through the sub-base via an underdrain.

#### **Maintenance**

Maintaining infiltration rates begins during the construction phase. Fred Adams, owner of Fred Adams Paving (Morrisville, North Carolina) says a clean jobsite—one in which sediment is not flowing or blowing onto the paver surface—is essential for ensuring the system functions well from the start. Over time, all permeable pavements are subject to some degree of surface clogging from sediment from blown dust, debris from vehicles, runoff, and other sources.

However, EPA's "Porous Pavement Fact Sheet" shows various studies have covered PICP and other permeable pavements' long-term surface permeability and found high infiltration rates at the beginning, which then decreases and levels off. With initial rates being hundreds of inches per hour, the long-term infiltration capacity remains high, even with clogging. When significantly clogged, surface infiltration rates usually exceed 1 inch per hour, which is usually sufficient to effectively manage stormwater.

Regular maintenance can help manage sediment buildup in the pavement openings, says Smith. For streets, this is accomplished through municipalities' regular street cleaning programs. For private property, ICPI recommends cleaning once or twice a year with vacuuming sweeping equipment. Surface infiltration rates can be monitored using an inexpensive test conforming with ASTM C1701, *Standard Test Method for Infiltration Rate of In Place PerVIOUS Concrete*, or by observing drainage immediately following a heavy rainstorm.

According to EPA, PICPs are suitable for cold climates because surface drainage of melting snow reduces the opportunity for freezing puddles and black ice. However, some precautions should be taken. If sand is applied for traction in snow and ice conditions, it should be removed with vacuuming in the spring. Snow plowing is safe for PICP, but the plowed piles should not be left to melt over the paver joints and openings because they can be clogged quicker due to high sediment concentrations. Permeable pavements do not heave during winter and spring freezing and thawing, says Smith, and



Permeable pavers, such as these units made with 40 percent recycled content, offer the same aesthetic and performance properties as traditional interlocking units.

Image courtesy CalStar Products

PICP has the advantage of being made with concrete resistant to degradation from de-icing materials.

Other than infiltration maintenance, PICP surfaces offer the same durability and low maintenance levels as properly designed and installed traditional pavers. In a 2004 study that was published by the University

## When Floor Failure is NOT an Option!

See us at the 2012 World of Concrete at booth S 10807 in the South Hall on Jan 24 – 27th



## Moisture Problem?

**KOSTER**  
Waterproofing Systems

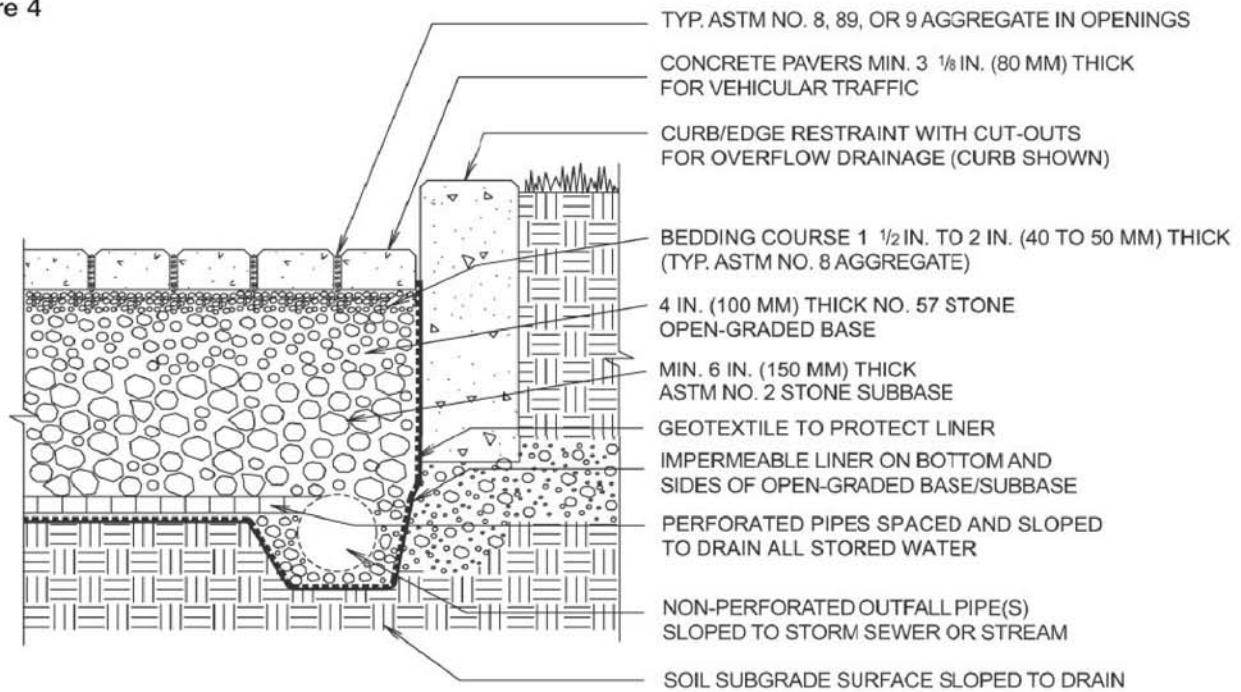
## Problem Solved!

- 10 Year Warranty
- Unaffected by pH14
- Reduces Moisture Levels from 25 lbs to Below 3 lbs



**KOSTER American Corporation** | 2585 Aviator Drive, Virginia Beach, VA 23453  
Phone: 877-425-1206 | Fax: 757-425-9951 | [www.kosterusa.com](http://www.kosterusa.com)

Figure 4



A cross-section of a no-exfiltration installation.

Images courtesy ICPI

of Washington, researchers compared several types of permeable paving systems in parking lot applications over six years.<sup>1</sup> The PICPs in the test showed no signs of rutting, settling, or shifting.

According to the ICPI handbook, cracked or damaged pavers, bedding, or base material can be removed and replaced. Unlike site-formed materials (such as asphalt or cast-in-place concrete), this repair can be conducted

in below-freezing temperature provided the aggregate material is not frozen. PICPs can also be removed to access underground utilities.

#### Green building program requirements

Permeable pavers can contribute to several Leadership in Energy and Environmental Design (LEED) credits under LEED 2009.

## ADDITIONAL INFORMATION

#### Author

Julie Rapoport, PhD, PE, LEED AP, is vice president of product development at CalStar Products. She has more than a decade of experience in the concrete products and cementitious materials industries. Before joining CalStar, Rapoport worked for Exponent Failure Analysis Associates as a forensic engineer. She earned her PhD and MS at Northwestern University in Evanston, Illinois, and her BA in physics and english from Williams College in Williamstown, Massachusetts. Rapoport can be contacted via e-mail at [info@calstarproducts.com](mailto:info@calstarproducts.com).

#### Abstract

Low-impact development and stormwater management are becoming increasingly vital to commercial and residential projects in the United States. Federal, state, and local mandates, as well as green building certification programs, are further driving the need to understand runoff-reduction

controls. Permeable interlocking concrete pavements (PICPs) are becoming more common. These systems consist of solid paving units with joints filled with highly permeable aggregates placed over an open-graded base and sub-base. They capture and temporarily store stormwater, and then allow it to infiltrate into the ground.

#### MasterFormat No.

32 14 43—Porous Unit Paving

#### UniFormat No.

G20—Site ImprovementsI

#### Key Words

Division 32  
LEED  
Permeable interlocking concrete pavement  
Stormwater runoff



Aesthetic options abound for PICP installations, with little limitation in style, color, or shape.

*Sustainable Sites (S S) 6.1, Stormwater Design—Quantity Control (1 point)*

For sites with existing imperviousness of 50 percent or less, post-development peak discharge must not exceed predevelopment discharge rates and quantity for one- and two-year 24-hour design storms. Alternatively, the team must incorporate a stormwater management plan that protects receiving stream channels from excessive erosion and includes quantity control strategies. For sites with existing imperviousness greater than 50 percent, the project must have a stormwater management plan resulting in a 25 percent decrease in the volume of stormwater runoff from the two-year 24-hour design storm.

*SS 6.2, Stormwater Design—Quality Control (1 point)*

Projects must have a plan to reduce impervious cover, promote infiltration, and capture and treat stormwater runoff from 90 percent of the average annual rainfall. This is done using best management practices capable of removing 80 percent of the average annual post-development total suspended solids (TSS) load based on existing monitoring reports.

In addition to these points, PICPs can contribute to other credits depending on the paver type chosen and the system implemented. For example, additional credits can be earned for regional materials, reducing the urban heat island (UHI) effect (provided the SRI of the pavers is > 29), and for incorporating recycled content.

The November 2010 version of the *International Green Construction Code (IgCC)* requires a project to improve,

maintain, or restore a site’s pre-development runoff hydrology or retain the volume of a single storm equivalent to the 95<sup>th</sup> percentile rainfall event. Under *IgCC*, permeable pavements must have a percolation rate of no less than 100 L/min/m<sup>2</sup> (2 gal/min/sf) and have no less than 152 mm (6 in.) of open-graded base below.

**Conclusion**

The reduction of the strain on storm sewers is becoming a priority for a growing number of municipalities, as evidenced by a host of new incentives, requirements, and demonstration projects related to reducing runoff on new and retrofit construction projects. Permeable interlocking concrete pavements provide an appropriate, aesthetically appealing solution. **CS**

**Notes**

<sup>1</sup> See “Long-term Stormwater Quantity and Quality Performance of Permeable Pavement Systems,” by Benjamin O. Brattebo and Derek B. Booth, University of Washington (2004).

**Stepstone, Inc.**

**LONG SPAN STEPTREAD**

STEPSTONEINC.COM | NATIONAL  
800.572.9029 | DISTRIBUTION