Permeable Interlocking Concrete Pavement

Description

Permeable interlocking concrete pavement (PICP) consists of manufactured concrete units that reduce stormwater runoff volume, rate and pollutants. The impervious units are designed with small openings between permeable joints. The openings typically comprise 5% to 15% of the paver surface area and are filled with highly permeable, small-sized aggregates. The joints allow stormwater to flow enter a crushed stone aggregate bedding layer and base that supports the pavers while providing storage and runoff treatment. PICPs are highly attractive, durable, easily repaired, require low maintenance, and can withstand heavy vehicle loads. Figure 1 shows installed pavers in a Seattle, Washington residential neighborhood.

Figure 1. PICP in Seattle's High Point neighborhood significantly reduce the total amount of impervious surface and runoff. Photo courtesy of ICPI.

Applicability

PICP can be used for municipal stormwater management programs and private development applications. The runoff volume and rate control, plus pollutant reductions allow municipalities to meet regulatory water quality criteria. Municipal initiatives such as Chicago's Green Alley program, use PICP to reduce combined sewer overflows and minimize localized flooding by infiltrating and treating stormwater on site. Private development projects use PICP to meet post-construction stormwater quantity and quality requirements. Public and private investments in PICP can potentially reduce additional expenditures and land consumption for conventional collection, conveyance and detention stormwater infrastructure.

PICP can replace traditional impervious pavement for most pedestrian and vehicular applications except high volume/high speed roadways. PICP has performed successfully in pedestrian walkways, sidewalks, driveways, parking lots, and low-volume roadways. The environmental benefits from PICP allow it to be incorporated into municipal green infrastructure programs and low impact development guidelines. In addition to providing stormwater volume and quality management, light colored pavers are cooler than conventional asphalt and help to reduce urban temperatures and improve air quality. The textured surface of pavers also provides traffic calming while contributing neighborhood identity and character.

PICP should not be confused with concrete grid pavements, i.e., concrete units with cells that typically contain topsoil and grass. These paving units can infiltrate water but at rates lower than PICP. Unlike PICP, concrete grid pavements are generally not designed with an open-graded, crushed stone base for water storage. Moreover, grids are for intermittently trafficked areas such as overflow parking areas and emergency fire lanes.

Siting and Design Criteria

PICP should be designed and sited to intercept, contain, filter and infiltrate stormwater on site. Several design possibilities can achieve these design aspects. For example, PICP can be installed across an entire street width or along on-street parking by the curbs. The pavement can also be installed in combination with impermeable pavements to infiltrate runoff and initiate a treatment train. Inlets can be placed in the PICP to accommodate overflows from extreme storms. Several applications use PICP in parking lot lanes or parking stalls to treat runoff from adjacent impermeable pavements and roofs. This design economizes PICP installation costs while providing sufficient treatment area for the runoff generated from impervious surfaces. The stormwater volume to be captured, stored, infiltrated or harvested determines the PICP scale required. Figures 2 and 3 illustrate some PICP design variations.

Figure 2. PICP is combined with bioretention to treat runoff from this college campus parking lot in Elmhurst, Illinois. Photo courtesy of ICPI.

Figure 3. A residential street in Portland, Oregon uses PICP to reduce combined sewer overflows. Photo courtesy of ICPI.

The concrete pavers with permeable joint material comprise the surface layer of PICP. Pavers are typically 80 mm (3 1/8 in.) thick for vehicular areas. Pedestrian areas may use 60 mm (2 3/8 in.) thick units. Additional subsurface components of this treatment practice are illustrated in Figure 4 and include the following (NCSU, 2008):

- Open-graded bedding course—This permeable layer is typically 50 mm (2 in.) thick and provides a level bed for the pavers. It consists of small-sized, open-graded aggregate usually ASTM No. 8 stone.
- Open graded base reservoir –An aggregate layer immediately beneath the bedding layer. The base is 75 to 100 mm thick and consists of crushed stones generally 20 mm down to 5 mm (3/4 in. to 3/16 in.) such as ASTM No. 57 stone. Besides storing water, this high infiltration rate layer provides a transition between the bedding and subbase layers.
- Open-graded subbase reservoir—The stone sizes are larger than the base, generally 65 mm down to 20 mm (2½ in. to ¾ in.) typically ASTM No. 2, 3 or 4 stone. Like the base layer, water is stored in the spaces among the stones. The subbase layer thickness depends on water storage requirements and traffic loads. A subbase layer may not be required in pedestrian or residential

driveway applications. In such instances, the base layer is increased to provide water storage and support.

- Underdrain (optional) – In instances where PICP is installed over low-infiltration rate soils, an underdrain facilitates water removal from the base and subbase. The underdrain is perforated pipe that ties into an outlet structure. Supplemental storage can be achieved by using a system of pipes in the aggregate layers. The pipes are typically perforated and provide additional storage volume beyond the stone base.
- Geotextile (optional) – This can be used to separate the subbase from the subgrade, prevent the migration of soil into the aggregate subbase or base.
- Subgrade – The layer of soil immediately beneath the aggregate base or subbase. The infiltration capacity of the subgrade determines how much water can exfiltrate from the aggregate into the surrounding soils. The subgrade soil is generally not compacted.

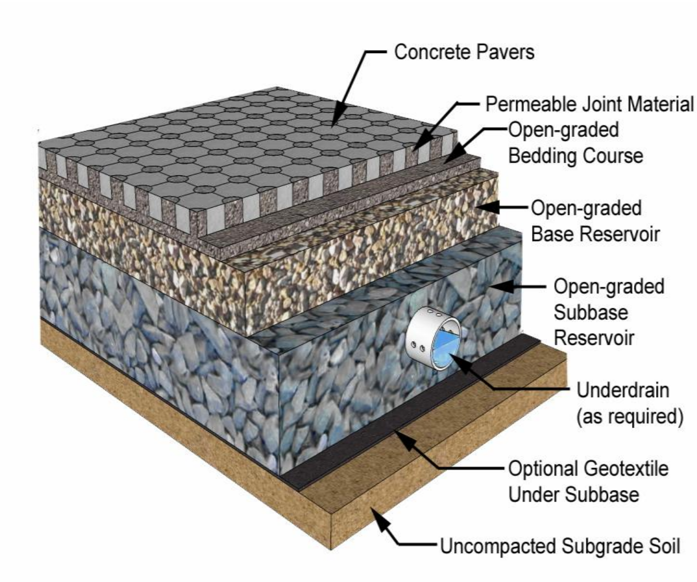

Figure 4. PICP cross-section

Specific Design Considerations and Limitations

The load-bearing and infiltration capacities of the subgrade soil, the infiltration capacity of the paver surface, and the storage capacity of the stone base/subbase are the key stormwater design parameters. To compensate for the lower structural support capacity of clay soils, additional subbase depth is often required. The increased depth also provides additional storage volume to compensate for the lower infiltration rate of the clay subgrade. Underdrains are often used when pavers are installed over clay. In addition, an impermeable liner may be installed between the subbase and the subgrade to limit water infiltration when clay soils have a high shrink-swell potential or there is a high depth to bedrock (NCSU, 2008).

Measures should be taken to protect PICP high sediment loads, particularly fine sediment. Appropriate pretreatment BMPs for run-on to pavers include filter strips and swales. Preventing sediment from entering the base or permeable pavement during construction is critical. Runoff from disturbed areas should be diverted away from the PICP until they are stabilized.

Several factors may limit PICP use. It is not appropriate for stormwater hotspots where hazardous materials are loaded, unloaded or stored, or where there is a potential for spills and fuel leakage. For slopes greater than 2%, terracing of the soil subgrade base may be likely needed to slow runoff from flowing through the pavement structure.

There are many PICP paver designs on the market. While most pavers are ADA compliant, units with large openings filled with aggregate may not be appropriate for some paths or parking areas used by disabled persons, bicycles, pedestrians with high-heels, and the elderly (SPU, 2009). Such areas can be paved with solid interlocking concrete pavements (see Figure 5).

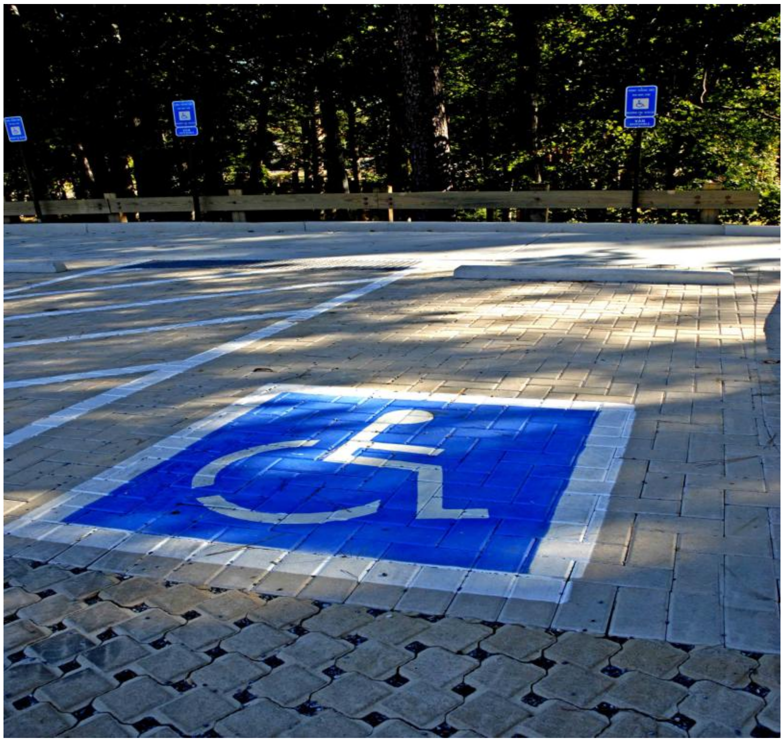

Figure 5. Solid concrete pavers used with permeable ones at Stone Mountain Park near Atlanta, Georgia. Courtesy of ICPI.

Maintenance

The most prevalent maintenance concern is the potential clogging of the openings and joints between the pavers. Fine particles that can clog the openings are deposited on the surface from vehicles, the atmosphere, and runoff from adjacent land surfaces. Clogging will increase with age and use; but while more particles become entrained in the pavement surface, it does not become impermeable. Studies of the long term surface permeability of PICP and other permeable pavements have found high infiltration rates initially, a decrease, and then a leveling off with time. With initial infiltration rates of hundreds of centimeters or inches per hour, the long term infiltration capacity remains high even with clogging. When clogged, surface infiltration rates usually well exceed 25 mm or 1 inch per hour, sufficient in most circumstances to effectively manage stormwater. Permeability can be increased with vacuum sweeping or in extreme circumstances, replacing the aggregate between pavers.

Key Siting and Maintenance Issues:

- Do not install in areas where hazardous materials are loaded, unloaded or stored.
- Avoid high sediment loading areas.
- Divert runoff from disturbed areas until stabilized.
- Do not use sand for snow or ice treatment.
- Periodic maintenance to remove fine sediments from paver surface will optimize permeability.

In cold climates, sand should not be applied for snow or ice conditions and snow plowing can proceed as with other pavements. PICP has been found to work well in cold climates as the rapid drainage of the surface reduces the occurrence of freezing puddles and black ice. However, plowed snow piles should not be left to melt over the paver joints and openings as they can receive high sediment concentrations that can clog them more quickly. In addition, all permeable pavements do not treat chlorides from road salts (SPU, 2009).

Effectiveness

PICP is an on-site stormwater management practice that reduces the volume and rate of stormwater runoff as well as pollutant concentrations. PICP transforms areas that were a source of stormwater to a treatment system and can effectively reduce or eliminate runoff that would have been generated from an impervious paved area. Because it reduces the effective impervious area of a site, PICP should receive credit for pervious cover in drainage system design. The infiltration rate of the pavers and base generally exceed the design storm peak rainfall rate, the subsoil infiltration rate and base storage capacity are the factors determining stormwater detention potential. Table 1 provides monitored reductions in stormwater volumes via storage and infiltration.

Table 1. Volume Retention of PICP

Application	Location	Soil Type	Underdrain	Volume Retention
Residential street	Auckland, New Zealand	Clay	Yes	60%
Driveway	Cary, NC	Clay	Yes	66%
Field and laboratory tests	Guelph, Ontario, Canada	---	---	90%
Parking lot	Swansboro, NC	Sandy soil	No	100%
Parking lot	United Kingdom	Impermeable liner installed	Yes	34%-45%
Parking lot	Renton, WA	---	No	100%
Parking lot	Kingston, NC	Clay	No	99%

(Fassman and Blackbourn, 2006)(Bean, et al., 2005)(Pratt, 1999)(Booth and Leavitt, 1999)(Brattebo and Booth, 2003)(Collins, et al., 2008)

PICP reduce pollutant concentrations through several processes. The aggregate filters the stormwater and slows it sufficiently to allow sedimentation to occur. The subgrade soils are also a major factor in treatment. Sandy soils will infiltrate more stormwater but have less treatment capability. Clay soils have a high cation exchange capacity and will capture more pollutants but will infiltrate less. Also, studies have found that in addition to beneficial treatment bacteria in the soils, beneficial bacteria growth has been found on established aggregate bases. In addition, PICP can process oil drippings from vehicles. Table 2 provides measured pollutant removals from PICP compared to impervious surfaces.

Table 2. Monitored Pollutant Removals of PICP

Application	Location	TSS	Metals	Nutrients
Driveways	Jordan Cove, CT	67%	Cu: 67% Pb: 67% Zn: 71%	TP: 34% NO_3-N: 67% NH_3-N: 72%
Parking lot	Goldsboro, NC	71%	Zn: 88%	TP: 65% TN: 35%
Parking lot	Renton, WA	--	Cu: 79% Zn: 83%	--

Parking lot	King College, ON	81%	Cu: 13% Zn: 72%	TP: 53% TKN:53%

(Bean, et al., 2004)(Clausen and Gilbert, 2006)(Van Seters/TRCA 2007)

PICP water quantity and pollutant reduction characteristics such as 80% TSS reduction can qualify it to earn credits under green or sustainable building evaluations systems such as Leadership in Energy and Environmental Design (LEED®) and Green Globes. Credits also can be earned for water conservation, urban heat island reduction, and conservation of materials by utilizing some recycled materials and regional manufacturing and resource use.

Cost

Several factors influence the overall cost of PICP:

- Material availability and transport – The ease of obtaining construction materials and the time and distance for delivery
- Site conditions – Accessibility by construction equipment, slope and existing buildings and uses
- Subgrade – Subgrade soils such as clay may result in additional base material needed for structural support or added stormwater storage volume.
- Stormwater management requirements – The level of control required for the volume, rate or quality of stormwater discharges will impact the volume of treatment needed.
- Project size – Larger PICP areas tend to have lower per square meter or per square foot due to construction efficiencies. Mechanized installation of the paving units shown in Figure 6 is often used for larger projects thereby reducing construction time.

Costs vary with site activities and access, PICP depth, drainage, curbing and underdrains (if used), labor rates, contractor expertise and competition. For vehicular applications over 1,500 square meters (15,000 square feet), cost generally range from $43 to $86 per square meter or $4 to $8 per square foot for the pavers, jointing and bedding materials. Base and subbase can vary in thickness and price depending on the design. For guidance and planning purposes experienced PICP contractors should be contacted for more precise budget numbers or for specific project proposals.

Figure 6. PICP units can be installed any time of year using mechanized methods. Photo courtesy of ICPI.

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Additional Resources

Interlocking Concrete Pavement Institute (ICPI) PICP resource for design, construction and maintenance http://www.permeablepavement.org/
Low Impact Development Center http://www.lowimpactdevelopment.org/
North Carolina State University http://www.bae.ncsu.edu/info/permeable-pavement/