Stormwater Best Management Practice

Permeable Pavements

Minimum Measure: Post Construction Stormwater Management in New Development and Redevelopment
Subcategory: Infiltration

Description

Permeable pavements are a stormwater control that allows stormwater to infiltrate through the surface of the pavement to the ground below—a green infrastructure alternative to traditional impervious surfaces. Types of permeable pavements include porous asphalt, pervious concrete and permeable interlocking concrete pavement (PICP).

Porous asphalt (sometimes called pervious, permeable, popcorn or open-graded asphalt) and pervious concrete (sometimes called porous, gap-graded or enhanced porosity concrete) are versions of traditional asphalt or concrete with reduced sand and fines to allow for greater porosity and infiltration. PICP consists of manufactured concrete units (pavers) with small openings between permeable joints that contain highly permeable, small-sized aggregates.

As with traditional pavement or concrete, construction staff install permeable pavements on a crushed stone aggregate bedding layer and base, which can also temporarily detain stormwater that has passed through the permeable surface layer. With proper installation, permeable pavements can serve as durable, low-maintenance and low-cost alternatives to traditional impermeable pavements.

Permeable pavement can reduce the impervious area in an urban landscape without losing the functionality of impervious surfaces.
Credit: Anthony D'Angelo for USEPA, 2015

Applicability

Permeable pavements can help achieve multiple benefits since they provide surfaces to move vehicular and pedestrian traffic and reduce stormwater discharges. They are suitable for municipal stormwater management programs and private development applications. For municipal applications, permeable pavements can reduce pavement ponding and local flooding by infiltrating stormwater on-site. Similarly, private development projects can use them to meet post-construction stormwater quantity and quality requirements. Permeable pavements can be especially helpful in developed areas with little open space that cannot accommodate post-construction stormwater controls requiring dedicated surface area. They can also reduce the need for additional expenditures and land use associated with conventional collection, conveyance and stormwater management infrastructure.

Permeable pavements can generally replace traditional impervious pavement in local roadway, pedestrian walkway, sidewalk, driveway, parking lot and bike path applications. They may not be appropriate for certain high-volume and high-speed roadways, although permeable friction course overlays can reduce road ponding, splash and noise on these types of roadways. Some permeable concrete can handle heavier loads; however, the increased surface abrasion can cause the pavement to deteriorate more quickly than conventional concrete, and the eroded material can create a clogging concern.

Individual permeable pavement types also have unique characteristics and offer additional benefits. Porous asphalt and pervious concrete have slightly rougher surfaces than their traditional counterparts, providing more traction to vehicles and pedestrians. Amending pervious concrete with photocatalytic compounds can help remove harmful air pollutants (Shen et al., 2012). Researchers have also found ways to increase the conductivity of permeable pavement, which not only improves infiltration capacity but also wicks moisture from the ground to improve evaporation. This process, along with the generally lighter colors of permeable pavement compared to asphalt, may help to reduce the urban heat island effect under certain conditions (Yong et al., 2018). The gridded surface texture of PICP also tends to slow traffic and can even provide an aesthetic amenity. Additionally, PICP reduces the risk of ponding on the roadway surface, which in turn reduces the chance of vehicles hydroplaning and reduces splashing of vehicle undercarriages that can release pollutants.

PICP differs from 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 pavement designs generally lack a crushed stone base, which limits water storage. Moreover, grids are more typical in areas with intermittent traffic, such as overflow parking areas and emergency fire lanes.

Siting and Design Considerations

The purpose of permeable pavements is to intercept, evaporate, detain, filter and infiltrate stormwater on-site. Site developers can install permeable pavements across an entire street width, across an entire parking area or within a portion of a larger impervious area. For example, designers can use permeable pavements in parking lot lanes or parking spaces to treat stormwater flow from adjacent upgradient impermeable pavements and roofs. Designers can also incorporate inlets to accommodate overflows from extreme storms. The area of a permeable pavement installation depends on the infiltration capacity of the particular type of pavement or paver system (with an appropriate allowance for clogging); its depth or storage capacity; and the stormwater volume that the permeable pavement will need to capture, store or infiltrate.

Permeable pavements consist of surface and subsurface layers that each have a specific material composition and thickness depending on the desired application (FHWA, 2016). As with traditional pavements, surface layers are generally less than 4 inches thick. Porous asphalt consists of open-graded coarse aggregate that bituminous asphalt bonds together. Adding polymers to

Close-up view of permeable concrete.

the mix can also increase its strength for heavier load applications. The thickness of porous asphalt ranges from 2 to 4 inches depending on the traffic loads that design engineers expect. Pervious concrete consists of cement, open-graded coarse aggregate and water. Adding admixtures to the concrete mixture can enhance strength, increase setting time or add other properties. The thickness of pervious concrete ranges from 4 to 8 inches depending on the traffic loads that design engineers expect. PICP pavers consist of precast modular units of various shapes and sizes. They are typically 80 millimeters (3⅛ inches) thick for vehicular areas and 60 millimeters (2⅜ inches) thick for pedestrian areas.

For any application, proper design of subsurface components is as important as the design of the permeable surface itself. Not every permeable pavement application needs each subsurface layer. In all cases, designers should follow any state or local codes and guidance. Typical subsurface components are described below, from top to bottom (MDE, 2009; NAPA, 2008; UNHSC, 2009). Note that the descriptions provide a typical thickness range for each layer, but actual thicknesses can vary substantially depending on project-specific requirements, such as desired storage capacity, pavement strength or subgrade composition.

- **Choker course.** Also called a bedding course for PICP, this permeable layer is usually 1 to 2 inches thick and provides a level and stabilized bed surface for the permeable surface layer. It consists of small, uniformly sized (also sometimes called poorly graded) aggregate.
- **Filter course or base reservoir.** This layer sits immediately beneath the choker or bedding course and serves as a high-infiltration-rate transition layer between the bedding and subbase layers. It also provides additional storage and can provide some filtration. Sometimes it is necessary to place filter fabric at the base of this layer to reduce the migration of fines. This base reservoir is typically 3 to 4 inches thick and, depending on local design requirements, can consist of uniformly sized crushed stone (e.g., No. 57 stone) or bank run gravel. It is typically of an intermediate size between bedding and subbase aggregate, often ¾ to 3⁄16 of an inch in diameter.
- **Subbase reservoir.** The subbase layer or reservoir serves as the main water storage and support layer. The stone is uniformly graded and sizes are larger than the base, typically ¾ of an inch to 2½ inches in diameter. The thickness of the subbase layer depends on project-specific factors such as water storage requirements, traffic loads, subgrade soils and the need for frost heave protection. This layer often has a specific minimum thickness of 4 inches, but the total thickness can be greater than 24 inches in some cases. A subbase layer may not be a requirement in pedestrian or residential driveway applications. In such instances, the base layer is larger to provide water storage and support.
- **Underdrain (optional).** In instances where design engineers install porous asphalt over soils with poor infiltration rates, an underdrain facilitates water removal from the base and subbase. The underdrain is a perforated pipe that ties into an outlet structure. The pipes also provide additional storage volume beyond the stone base.
- **Geotextile (optional).** Geotextile can separate the subbase from the subgrade and keep soil from migrating into the aggregate subbase or base.
- **Subgrade.** The subgrade layer of soil is 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. Construction staff should not compact the subgrade soil.
- **Liner.** Some permeable pavements and PICP installations may include liners and underdrain systems where infiltration is not feasible or desirable due to the presence of underground utilities, contaminated soils that could pollute groundwater if those contaminants mobilize, or surface contaminants (e.g., chlorides) that might negatively affect receiving waters.

Site slopes and soils are important considerations during the design phase. For slopes greater than 2 percent, the soil subgrade base may need terracing to prevent stormwater from flowing through the pavement structure. Alternatively, designers can dig lined trenches with underdrains across the slope to intercept flow through the subbase (ACPA, 2006). For soils that are weak or have poor infiltration capacity, designers should take certain measures to accommodate pervious pavements. For example, clay soils exhibit both of these problematic characteristics. To compensate for the lower structural support capacity of clay soils, permeable pavements often need greater subbase depth—which also adds storage volume to compensate for the lower infiltration rate of the clay subgrade. Underdrains can increase drainage over clay soils. Designers may install an impermeable liner between the subbase and the subgrade to limit water infiltration when clay soils have a high shrink-swell potential (Hunt & Collins, 2008).

For pervious concrete, consistent porosity through the concrete structure is critical to prevent freeze-thaw damage. Cement paste and smaller aggregate can settle to the bottom of the structure during consolidation and seal the pores. Trapped water can freeze, expand and break apart the pavement. In general, larger aggregate size helps improve permeability and reduce freeze-thaw damage (Thompson Materials Engineers, Inc., 2008).

Installation Considerations

For all surface types, proper installation is key to ensuring long-term effectiveness. While construction staff can generally use much of the same equipment to mix and lay permeable and conventional versions of asphalt and concrete, the mixtures are slightly different and have different handling and installation requirements.

During compaction of porous asphalt, contractors should use minimal pressure to avoid closing pore space. They should avoid vehicular traffic for 24 to 48 hours after pavement installation.

Pervious concrete has a lower water content than traditional concrete, greatly reducing its handling time. Contractors should pour pervious concrete within 1 hour of mixing unless they use admixtures to extend the handling time. A screed—which construction staff use to level concrete—is a manual or mechanical device typically set ½ inch above the finished height. Construction staff should not use floating and troweling because these may close the surface pores. Consolidation of the concrete, usually with a non-vibratory steel roller, typically happens within 15 minutes of placement. For all permeable pavements, designers should take measures to protect these surfaces from high sediment loads. When contributing areas are large, designers should consider pretreatment practices such as filter strips and swales. Preventing sediment from entering the base of permeable pavement during construction is critical for ensuring that permeable pavements retain a high infiltration rate. Construction staff should divert stormwater flow from disturbed areas away from the permeable pavement until stabilization is complete, which can take up to a week for concrete systems.

Limitations

Several factors may limit permeable pavement use. Permeable pavements are not as strong as conventional asphalt and are not appropriate for applications with high volumes and extreme loads. Permeable pavements are also not appropriate for stormwater hot spots where hazardous material loading, unloading or storage occurs, or in areas where spills and fuel leakage are possible.

PICP designs also have limitations. Most pavers comply with the Americans with Disabilities Act. However, designers may want to limit units with large openings containing aggregate for paths or parking areas that disabled persons, bicycles, pedestrians with high heels and the elderly use. Such areas can use solid interlocking concrete pavements (ICPI, 2019).

Maintenance

The most prevalent maintenance concern for permeable pavements is clogging, which can limit infiltration rates. Fine particles that may clog permeable pavements can come from vehicles, the atmosphere and stormwater discharge from adjacent land surfaces—the more frequent (e.g., vehicle use) or large (e.g., drainage area) these sources are, the faster that clogging will occur. Although clogging increases with age and use, it generally does not lead to complete impermeability. Long-term studies have found that permeable pavements have high initial infiltration rates that then decrease and eventually level off with time (Bean et al., 2007a). Compared to initial infiltration rates of hundreds of inches per hour, long-term infiltration rates decrease but usually remain well above 1 inch per hour, which may be sufficient in most circumstances to infiltrate stormwater from intense storm events (ICPI, 2000). A study of 11 pervious concrete sites found infiltration rates ranging from 5 inches per hour to 1,574 inches per hour, with the lowest rates coming from sites receiving discharge from areas with poor maintenance or earth disturbance activities. However, the infiltration rates were still high relative to rainfall intensities (Bean et al., 2007a).

Key Siting and Maintenance Issues:

- Do not install in areas where hazardous material loading, unloading or storage occurs.
- Avoid high sediment loading areas.
- Divert stormwater from disturbed areas until the areas stabilize.
- Do not use sand for snow or ice treatment.
- Perform periodic maintenance to remove fine sediments from paver surface and optimize permeability.

Vacuum sweeping can increase permeability. Also, in cases of isolated clogging of porous asphalt and permeable concrete, construction staff can drill ½-inch holes through the pavement surface to allow stormwater to drain to the aggregate base. In cases of extreme clogging of PICP, construction staff can replace aggregate between the pavers (Clark et al., 2008; TRCA & CVCA, 2010). Placing a stone apron around the pavement and connecting it hydraulically to the aggregate base and subbase can provide a backup to surface clogging or pavement sealing.

Porous asphalt and concrete generally need less maintenance for cracks or potholes than traditional pavement surfaces, mostly due to effective draining of the stone bed, deep structural support and a better ability to withstand freeze-thaw stress. When cracking and potholes do occur, construction staff can use a conventional patching mix to repair them. The life span of porous alternatives can also be greater for similar reasons. The life span of a conventional pavement parking lot in a cold climate is typically 15 years, whereas porous asphalt parking lots can have life spans of more than 30 years due to the reduced freeze-thaw stress (Gunderson, 2008). Permeable concrete with proper construction can last 20 to 40 years because of its ability to handle temperature impacts (Gunderson, 2008).

Maintenance requirements for permeable pavements in cold climates are slightly different than those for traditional pavements. In cold climates, roadway managers should not use sand around permeable pavement. Snow plowing can occur similarly to plowing on conventional pavements, and deicing material use is acceptable in moderation. Plowed snow pile storage should not be above permeable surfaces, as melting snow can increase sediment loads and lead to clogging.

Compared to traditional pavements, permeable pavements generally need less road salt or deicing materials because the rapid surface drainage reduces the occurrence of freezing puddles and black ice (Gunderson, 2008). This benefit can be considerable, as deicing treatments are a significant expense, chlorides in stormwater have substantial environmental impacts, and no post-construction stormwater control can effectively reduce chloride concentrations. For example, a porous asphalt lot installed at the University of New Hampshire required 75 percent less deicing material than other impervious asphalt lots for equivalent deicing effects. In addition, the porous pavement required no deicing material application because it had a higher frictional resistance than conventional pavement (UNHSC, 2007).

Effectiveness

Permeable pavements can be effective at reducing stormwater discharges and pollutant concentrations, though their effectiveness can be variable and depends more on the design of underlying layers and surrounding environmental conditions than surface type. The choice of surface type is relevant to user needs, cost, material availability, constructability and maintenance, but it has minimal impact on the overall stormwater retention, detention and treatment of pollutants by the system.

Reduction in stormwater volume is generally a function of subsoil infiltration rate and base storage capacity. However, depending on site constraints, some designers may include liners and underdrain systems that would not infiltrate runoff. Both infiltrating and noninfiltrating systems provide ecological benefits—through detention, retention, evaporation and pollutant removal, all to varying degrees—so many entities treat them both as pervious surfaces. Permeable pavements with deeper subsurface layers can detain greater volumes of stormwater, while the high infiltration rates of surrounding soils allow subsurface layers to drain more rapidly—also improving detention capacity. Although pavement infiltration rate is important, it is rarely the limiting factor, as the infiltration rates of surface and base layers with proper construction tend to exceed peak rainfall and stormwater rates. Overall, permeable pavements have demonstrated stormwater reduction effectiveness from 25 to 100 percent, reflecting the range of design approaches and site conditions (Bean et al., 2007a, 2007b; Booth & Leavitt, 1999; Brattebo & Booth, 2003; Cahill et al., 2003; Collins et al., 2008; Fassman & Blackbourn, 2007; Legret & Colandini, 1999; Roseen & Ballestero, 2008; Pratt et al., 1999).

Permeable pavements reduce pollutant concentrations through several processes. The media layers filter stormwater and promote pollutant removal through physical filtration and biological processes. The subgrade soils are also a major factor in treatment. Sandy soils infiltrate more stormwater but have less treatment capability. Clay soils can hold and capture more pollutants, but they infiltrate less. Table 1 provides measured pollutant removals from pervious pavement systems.

Table 1. Permeable pavement pollutant removals.

Surface Type	Total Suspended Solids	Metals	Nutrients
Porous asphalt	94–99%	76–97%	42–43%
Pervious concrete	91%	75–92%	N/A
PICP	67–81%	13–88%	34–72%

Sources: Barrett et al., 2006; Bean et al., 2007b; Clausen & Gilbert, 2006; Rushton, 2001; UNHSC, 2007; Van Seters, 2007

Permeable pavement and paver systems are considered green infrastructure as defined under the Clean Water Act. Permeable pavements may provide stormwater volume reductions, detention and pollutant removal depending on the design of the systems.

Permeable pavements with water quantity and pollutant reduction characteristics (e.g., 80 percent total suspended solids reductions) can earn credits under voluntary standards, i.e., green or sustainable building evaluation systems such as Leadership in Energy and Environmental Design (LEED) and Green Globes. They can also earn credits for water conservation, conservation of materials through the use of recycled materials, and regional manufacturing and resource use.

Cost Considerations[1]

Permeable pavement can be a cost-effective alternative to traditional pavement. Although it typically costs more than traditional pavement to construct initially, savings in maintenance and stormwater management costs can make it more economical in the long term (U.S. EPA, 2013).

As with other green infrastructure practices, permeable pavement costs depend on site conditions and the level of stormwater management necessary. Subgrade soils such as clay may need more base material for structural support or more stormwater storage volume. Areas that have low infiltration capacity or that need a high level of stormwater treatment may need deeper base layers for greater detention capacity or require components like underdrains. Each of these factors may increase overall costs.

Construction costs range from $1 to $1.50 per square foot for porous asphalt, $3 to $9 per square foot for pervious concrete and $7 to $14 per square foot for PICP (VDEQ, 2013). In comparison, asphalt alone costs around $1 to $2 per square foot depending on the thickness and type (RSMeans, 2019), while typical road construction can cost more than $15 per square foot when considering full construction costs, including stormwater management (ARTBA, 2019; FDOT, 2019). Still, it is difficult to compare costs if not looking at a single site. A study from Olympia, Washington, evaluated the life cycle cost of traditional versus permeable concrete sidewalks and found the total cost to be $8 per square foot for the permeable alternative and $15 per square foot for the traditional, impermeable alternative. Greater costs for the traditional alternative were due to the cost of a stormwater pond that would have been needed to treat discharge from the impervious surface (U.S. EPA, 2008). Similarly, in a life cycle cost analysis of permeable versus traditional pavement, the city of West Union, Iowa, found that despite greater upfront costs, installation of permeable pavement would result in savings over the life span of the project owing to lower maintenance and repair costs for deicing (U.S. EPA, 2013). EPA's Green Infrastructure Cost-Benefit Resources page offers more examples of successful, economically viable permeable pavement and other green infrastructure projects.

[1] Prices updated to 2019 dollars. Inflation data obtained from the Bureau of Labor Statistics CPI Inflation Calculator Web site: https://data.bls.gov/cgi-bin/cpicalc.pl.

Additional Information

Additional information on related practices and the Phase II MS4 program can be found at EPA's National Menu of Best Management Practices (BMPs) for Stormwater website

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