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Permeable Pavement for Stormwater Management

Carmen T. Agouridis, Jonathan A. Villines, and Joe D. Luck, Biosystems and Agricultural Engineering

Managing runoff in urban areas offers many challenges for engineers, landscape architects, and planners. As cities grow, the amount of impermeable surfaces—those that do not allow water to infiltrate into the ground—increases. Examples of impervious surfaces are asphalt roads, concrete sidewalks, parking lots, building roofs, and areas of highly compacted soils such as in subdivisions. If not properly managed, the stormwater runoff produced by these impermeable surfaces can have negative effects on nearby surface waters. When waters from storm events do not infiltrate the soil, the stormwater management system, consisting of stormwater structures and pipes, quickly directs them to streams, rivers, and lakes. Such increases in stormwater runoff can have detrimental effects on nearby lands and receiving streams resulting in flooding, increased peak flows, groundwater or stream baseflow reductions, increased stream velocities and streambank erosion, increased water temperatures, and reduced water quality.

Stormwater must be managed in such a way as to prevent or minimize these negative impacts from urban growth. One method of stormwater management is to reduce runoff by increasing infiltration through the use of permeable or pervious pavement (Figure 1). Permeable pavement allows stormwater to percolate through the pavement and infiltrate the underlying soils thereby reducing runoff from a site, unlike standard pavement which prohibits infiltration (Figure 2). Permeable pavement looks similar to standard asphalt or concrete except void spaces are created by omitting fine materials. Compacted gravel is not considered permeable pavement.

When properly designed, installed, and maintained, permeable pavement is an effective stormwater best management practice (BMP) that can last for decades. The purpose of this publication is to explain the benefits of permeable pavement, review the types of permeable pavement available, and discuss design considerations and maintenance requirements.

Figure 1. Used to construct the parking spaces (permeable pavers), sidewalks (pervious concrete), and roadways (porous asphalt) at the fire department in Georgetown, Ky., permeable pavement allows stormwater to infiltrate to the underlying soils.

Figure 2. Permeable pavement (upper portion of figure) has large void spaces to allow water to infiltrate, unlike traditional asphalt (lower portion of figure).

Types of Permeable Pavement

Numerous types of permeable pavement are available. Pervious concrete is most common today, but porous asphalt, interlocking concrete pavers, concrete grid pavers, and plastic reinforced grids filled with either gravel or grass are also available. Other types and variations exist, but these are the most popular and versatile designs. The pavement type itself typically refers only to the surface layer of a structure consisting of multiple layers.

Beneath the permeable pavement or surface layer, typically lies a filter course comprised of finer aggregate (0.5 inch diameter). This filter course overlays a stone reservoir (1.5 to 3.0 inch diameter), the thickness of which depends on the stormwater storage needs and load bearing requirements. Below the stone reservoir, a layer of filter fabric rests on the undisturbed soil. The filter fabric prevents soil particles from entering the stone reservoir due to fluctuations in the water table or any pumping action from repeated loadings. Filter fabric should also be used along the sides or perimeter of the permeable pavement system to prevent soil from entering at those locations. Figure 3 shows a typical cross-section of a permeable pavement installation.

To prevent clogging, only cleaned, washed stone that meets municipal roadway standards should be used. Depending on design needs, perforated pipes can be added near the top of the stone reservoir to discharge excess stormwater from large events. Also, instead of allowing stormwater to infiltrate into the underlying soil or where the permeability of the underlying soil is not optimal, perforated underdrain pipes can be installed to route water to an outflow facility structure. It is recommended that an observation well be installed at the down-gradient end of the permeable pavement to monitor performance.

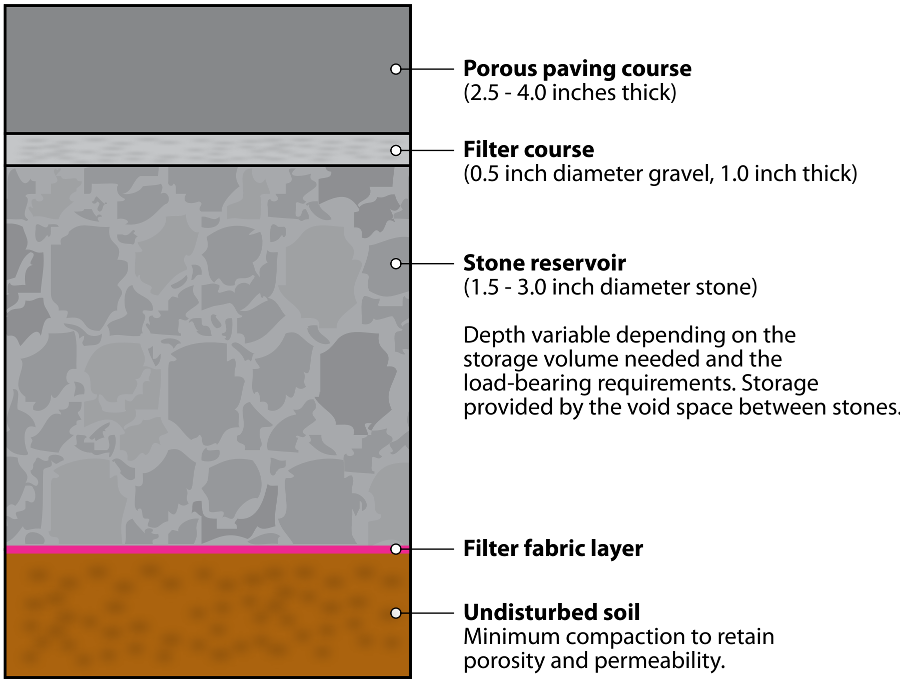

Figure 3. Typical cross-section of permeable pavement.
Adapted from City of Rockville, MD (1992).

Pervious Concrete

Pervious concrete is a mixture of Portland cement, coarse aggregate or gravel, and water (Figure 4). Unlike conventional concrete, pervious concrete contains a void content of 15 to 35 percent (average of 20 percent) that is achieved by eliminating the finer particles such as sand from the concrete mixture. This empty space allows water to infiltrate the underlying soil instead of either pooling on the surface or being discharged as runoff. Sidewalks and parking lots are ideal applications for pervious concrete. The structural strength of pervious concrete, although typically less than standard concrete mix designs, can easily withstand the relatively light loads generated by pedestrian and bicycle traffic. The loads placed on pervious concrete in parking lots can be much more substantial and require consideration when selecting the concrete mix and pavement thickness. While the structural strength of porous concrete can be increased by adding larger amounts of cement, the porosity will decrease, thus decreasing infiltration rates.

Porous Asphalt

Porous asphalt is a standard asphalt mixture of both fine and coarse aggregate bound together by a bituminous binder except it uses less fine aggregate than conventional asphalt. The void space in porous asphalt is similar to the 15 to 35 percent of pervious concrete. The surface appearance of porous asphalt is similar to conventional asphalt, though porous asphalt has a rougher texture. The surface layer of asphalt is usually thinner than a comparable installation of pervious concrete. While the compressive strength of pervious concrete is usually less than that of conventional concrete, the compressive strength of porous asphalt is comparable to that of conventional asphalt. Porous asphalt can be used for pedestrian applications such as greenways and low volume, low speed vehicular traffic applications such as parking lots, curbside parking lanes on roads, and residential or side streets (Figure 5).

Pavers

Permeable interlocking concrete pavers (PICP) and clay brick pavers (PICBP) as well as concrete grid pavers (CGP) are similar in installation and function but are made from different materials (Figure 6). PICPs are solid concrete blocks that fit together to form a pattern with small aggregate-filled spaces in between the pavers that allow stormwater to infiltrate. These spaces typically account for 5 to 15 percent of the surface area. PICBP as the same as PICPs except the material is brick instead of concrete. With CGPs,

Figure 4. Pervious concrete was used to construct a portion of the Legacy Trail in Coldstream Park in Lexington, Ky.

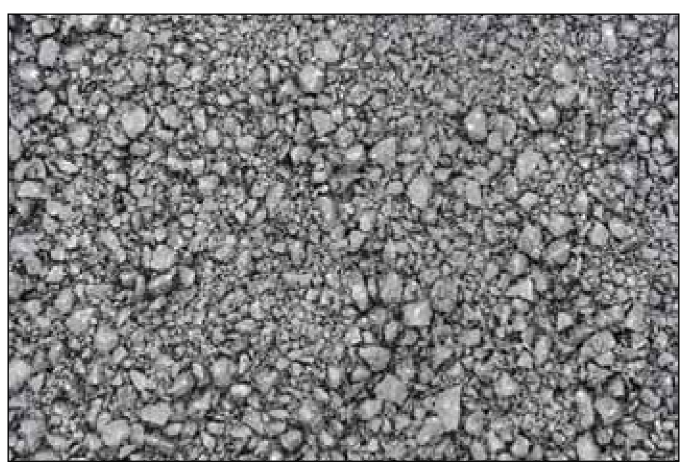

Figure 5. Porous asphalt is very similar in appearance to conventional asphalt except it has a rougher texture.

Figure 6. (a) Permeable interlocking concrete pavers (PICP), (b) permeable interlocking clay brick pavers (PICBP), and (c) concrete grid pavers (CGP).

large openings or apertures are created by the CGPs lattice-style configuration. These openings, which can account for 20 to 50 percent of the surface area, usually contain soil or grass, though small aggregates can be used. While CGPs have larger openings than PICPs and PICBPs, they are not designed for use with a stone reservoir but instead can be placed directly on the soil or an aggregate base. As such, the infiltration rate of PICPs and PICBPs is much higher than that of CGPs.

Plastic turf reinforcing grids (PTRG) are made of interlocking plastic units with large open spaces. PTRG are generally used to add structural strength to topsoil and reduce compaction. Typically grass fills the open spaces, although small aggregate can be used as well. Infiltration is improved when grass is used as the plant roots help increase the permeability of the underlying soil.

Benefits of Permeable Pavement

Permeable pavement offers a number of environmental benefits. Increasing the amount of stormwater infiltrated can result in lower stream flow levels after storm events, increased stream baseflow due to increased groundwater recharge, and increased stream stability through reduced stream velocities and peak flows. The benefits of providing stream stability range from erosion control to maintaining the habitat necessary for aquatic life. As permeable pavement eliminates standing water, other noticeable benefits include improved braking, reduced hydroplaning on roadways, and resistance to freeze/thaw conditions. Evaporation from beneath the permeable pavement can produce a cooler surface helping reduce the heat island effect often experienced in urban settings. Permeable pavement can also aid in the health and development of urban trees by providing root systems with greater access to water and air.

The materials used in permeable pavement and its foundation (described in more detail later in this publication) are capable of retaining soluble and fine particulate nutrients, sediments, heavy metals, and other pollutants from stormwater runoff thus improving the quality of water that enters surface waters and groundwaters. Coarse particulate removal is not advised due to issues with clogging, so some pretreatment may be required in addition to regular maintenance. Some stormwater pollutant loads may also be reduced as permeable pavements can act like a biofilter where microorganisms break down contaminants. Studies have reported reductions in sediment (60-100 percent), total nitrogen (40-80 percent), phosphorus (40-80 percent), BOD (60-80 percent), bacteria (60-80 percent), and metals (40-80 percent).

Additionally, using permeable pavement can lessen the need for treatment chemicals. For example, permeable pavement has been shown to reduce the need for road salt applications by up to 75 percent due to improved drainage conditions. Reducing road salt and chemical applications leads to a reduction in chloride levels in receiving waters thus benefiting aquatic habitats. Permeable pavement also reduces the temperature of waters entering surface and groundwater bodies thus reducing thermal pollution.

Uses of Permeable Pavement

Permeable pavement can be installed in most places that conventional concrete or asphalt pavement is presently used. However, some properties of most permeable pavements limit their applicability. Permeable pavements are not generally used in applications where high traffic loads, in terms of volume and weight, and/or high rates of speed are encountered. Their use should be limited to pedestrian and light to medium vehicle traffic. Greenways, sidewalks, driveways, and overflow parking lots are ideal locations. Permeable pavement has also been used in agricultural facilities such as horse washing pads.

To reduce the potential for groundwater contamination, consideration should be given to the pollutant loads carried in the stormwater runoff because permeable pavement promotes infiltration. Permeable pavement should not be used near "hotspots" or areas generating significant concentrations of pollutants. Examples of such hotspots include vehicle service areas, industrial chemical storage facilities, and gas stations.

Permeable pavement is typically designed to absorb only the stormwater that falls directly on it, although stormwater from rooftops or adjacent parking lots can sometimes be directed to permeable paved areas. Typically, drainage from adjacent areas should be managed separately. If permeable pavement is to receive stormwater runoff from off-site areas, pre-treatment (e.g. grass filter strip, sand filter) may be needed to remove coarse particulates, even if the contributing area is 100 percent impervious. A variety of BMPs are available to manage stormwater runoff from adjacent lands. Refer to the Resources section to locate additional information.

Evaluating Site Conditions

Consideration of site conditions is also important. Permeable pavement is most applicable on sites with slopes of 0.5 percent or less so that stormwater runoff is evenly distributed and has a chance to infiltrate. Permeable pavement has been used on sites with slopes up to 5 percent.

The underlying soils should be carefully evaluated. Soils should have a minimum field-verified permeability rate of 0.5 inches per hour, although the U.S. Environmental Protection Agency lists 0.27 in/hr as the minimum acceptable infiltration rate. If underlying soils do not meet the permeability requirement, then modification using gravel and/or sand and/or the use of an underdrain is required. For these low permeability soils, a high ratio of bottom surface area to storage volume is needed. Installing permeable pavement at sites with soils not meeting the minimum infiltration rate of 0.27 in/hr should be approached with caution. If the combined silt/clay content exceeds 40 percent and/or the clay content exceeds 30 percent, frost-heave is likely and percolation is poor. Permeable pavement should not be used over uncompacted fill soils as this material can be unstable. The depth to bedrock or the seasonally high water table from the bottom of the system should be at least 2 feet, although 4 feet is more desirable.

Permeable pavement should not be installed within 100 feet of drinking water wells to avoid groundwater contamination. If possible, permeable pavement should be located away from building foundations to prevent damage from seepage. A minimum distance of 100 feet up-gradient and 10 feet down-gradient is recommended. Cost considerations generally limit the application of permeable pavement to sites less than 10 acres.

Design Considerations

To design permeable pavement, consideration must be given to both structural and hydraulic components. The manufacturer should be consulted to determine the appropriate structural design process for the type of permeable pavement selected. The intended use of the permeable paved surface will impact the needed thickness of the pavement and the underlying layers. Both must be sized to support anticipated traffic loads, storm volume storage, drain times, and water quality needs.

Permeable pavement has been successfully used in karst environments. The large surface area over which infiltration occurs helps reduce the potential for sinkhole development. However, a detailed geotechnical investigation may be needed to address concerns about sinkhole formation and/or groundwater contamination. It is recommended that the stone reservoir be carbonate to aid in buffering capacity.

Table 1. Estimated soil infiltration rates.

Soil Texture*	Hydrologic Soil Group	Minimum Infiltration Rate (in/hr)
Sand	A	8.27
Loamy sand	A	2.41
Sandy loam	B	1.02
Loam	B	0.52
Silt loam	C	0.27
Sand clay loam	C	0.17
Clay loam	D	0.09
Silty clay loam	D	0.06
Sandy clay	D	0.05
Silty clay	D	0.04
Clay	D	0.02

*Silt loam, sand clay loam, clay loam, silty clay loam, sandy clay, silty clay, and clay soils have infiltration rates below the recommended minimum of 0.5 in/hr. Silt loam at 0.27 in/hr is listed by the U.S. EPA as acceptable but not recommended.

Hydraulic Design

The stone reservoir is sized to hold the desired stormwater volume generated from the design storm. Specifications of duration and return period for the design storm should be obtained from the locality. Stormwater stored in the stone reservoir should ideally exfiltrate within 24 to 48 hours following rainfall, but no less than 12 hours and no more than 72 hours, to provide sufficient storage for subsequent storm events. The ability of the soil to infiltrate stormwater depends on its permeability. Infiltration rates should be tested in the field.

Table 1 shows ranges of infiltration rates for hydrologic soil groups (HSG). It is recommended that infiltration rates are tested in the field and that a design factor of safety of 2 is used. The design factor of safety accounts for any soil compaction that may occur during construction as well as clogging over time. The thickness of the stone reservoir depends largely on structural requirements. The thickness can be increased to accommodate water storage needs, but it should not be decreased from what is structurally required. Decreasing the thickness would compromise structural stability.

Design of the stone reservoir storage area is generally completed through one of two methods: minimum depth method or minimum area method. The minimum depth method determines the depth of the stone reservoir given a specific area for the permeable pavement. The minimum area method computes the needed surface area of the permeable pavement given a design depth for the stone reservoir. The method described in this publication does not provide guidance on underdrain design.

Minimum Depth Method

1. Compute the depth of the stone reservoir (d_p).

$$d_p = \frac{(Q_c)\left(\frac{A_c}{A_p}\right) + P - (f)(T)}{V_r}$$

- d_p = depth of stone reservoir (in)
- Q_c = runoff from contributing area (in)
- A_c = contributing area (ft^2)
- A_p = permeable pavement surface area (ft^2)
- P = design rainfall (in)
- f = infiltration rate (in/hr)
- T = fill time (hr)
- V_r = void ratio of stone reservoir

Not that void spaces typically range between 30 and 40 percent, although it is recommended that the exact value be obtained from the supplier.

2. Compute the maximum allowable depth of the stone reservoir (d_{max}).

$$d_{max} = \left(\frac{(f)(T_s)}{V_r}\right)$$

- d_{max} = Maximum allowable depth of stone reservoir (in)
- T_s = Maximum allowable storage time (hr)

Check the design feasibility:

- Is $d_p \leq d_{max}$?
- Is the bottom of the aggregate at least 2 ft above the seasonal high water table?
- If no to either, reduce design storm depth or increase permeable pavement surface area.

Minimum Area Method

1. Compute the maximum allowable depth of the stone reservoir (d_{max}).
2. Select dp so that it is less than or equal to dmax and bottom of aggregate is at least 2 ft above seasonal high water table.
3. Compute the minimum required surface area (A_p).

$$A_p = \frac{\left(\frac{Q_c}{12}\right)(A_c)}{(V_r)\left(\frac{d_p}{12}\right) - \left(\frac{P}{12}\right) + \left(\frac{f}{12}\right)(T)}$$

Following either method, complete the following:

1. Determine the minimal structural base thickness.
2. Check for minimum separation between bottom of structural base and seasonal high water table.
3. Select the geotextile filter fabric for soil separation.

Example: Minimum Depth Method

Local regulations require capture of the 2-year 24-hour storm, which is 3.1 inches for Lexington, Kentucky. The goal is to capture runoff from building roofs and access roads and convey stormwater runoff to a permeable pavement system in the parking lot. Since the contributing area has a CN = 98, all of the flow from the design storm will flow to the permeable pavement. Contributing area (A_c) is 30,000 ft^2, and permeable pavement area (A_p) is 40,000 ft^2. The field tested infiltration rate (f) is 0.64 in/hr. With a design factor of safety of 2, f=0.32 in/hr. The voids ratio (V_r) supplied by the quarry is 0.4. T is assumed to be 2 hours (typical value). A maximum allowable storage time of 24 hour is the design criteria.

$$d_p = \frac{(3.1\text{ in})\left(\frac{30{,}000\text{ ft}^2}{40{,}000\text{ ft}^2}\right) + 3.1\text{ in} - (0.32\text{ in/hr})(2\text{ hr})}{0.4} = 12.0\text{ in}$$

$$d_{max} = \left(\frac{(0.32\text{ in/hr})(24\text{ hr})}{0.4}\right) = 19.2\text{ in}$$

Check:

- d_p is less than d_{max}.
- The structural base thickness. In this example, assume a structural base thickness of 16 in. is required for expected loadings and frost conditions. This is thicker than the 12.0 in. required.
- The bottom of the structural base is at least 2 ft from the seasonal water table. The total thickness of the permeable pavement system will consist of the thickness of the permeable pavement surface, filtering layers, and the structural base. If a leveling course is used with permeable pavers, include this in the total thickness.

Based on a sieve analysis of the soil subgrade, use the U.S. Highway Administration (FHWA) geotextile filter criteria to select the appropriate geotextile.

Maintenance

Openings in the surface of permeable pavements are susceptible to clogging by sediment from passing vehicles, wear of the pavement surface, and runoff from nearby disturbed soils. It is therefore essential to ensure that nearby soils are adequately secured prior to, during, and after installation of permeable pavement. Pretreatment systems may be required to help prevent clogging. Legally binding easements or covenants may be needed to ensure proper maintenance techniques are followed.

Maintenance should be performed on a regular basis. To prevent clogging, the permeable pavement surface should be vacuum swept followed by high-pressure jet hosing at least four times per year. Do not apply sand or ash to permeable pavement for snow removal purposes. Signage should be posted at locations where permeable pavement is installed to advise maintenance crews of this requirement.

The permeable pavement should undergo regular inspection. Inspection should occur several times within the first few months after construction to check that pretreatment systems, such as vegetative filter strips, are functioning properly in addition to the permeable pavement. Afterwards, inspection can occur on a quarterly to annual basis depending on performance. It is also recommended that following large storms permeable pavement be inspected for evidence of clogging. If spot clogging is identified on pervious concrete or porous asphalt, drilling half-inch holes into the pavement every few feet may help. For permeable pavers, select pavers can be replaced. Another option is to design a perimeter stone filter inlet as a backup. Extending the stone base several feet outside the perimeter of the permeable pavement offers a means of infiltrating stormwater should the system clog.

If the subsoil or subsoil-filter cloth becomes clogged, complete replacement will be required. One possibility is to include additional capped underdrains in the design as a backup system. This way, the system can still provide a level of stormwater storage and treatment.

Costs

A number of factors affect the cost of permeable pavement, such as the availability of materials, transport, site conditions, stormwater management requirements, project size, contractor experience, and, in the case of pavers, method of installation (mechanical vs. hand). Consideration should also be given to long-term maintenance costs. However, using permeable pavement as part of a larger stormwater management effort can yield substantial long-term savings.

The most obvious savings come in the form of land that would otherwise have to be used for retention ponds and other traditional stormwater infrastructure. Since permeable pavement and other low-impact development (LID) stormwater management methods can reduce or eliminate the need for surface ponds, the space saved can be used for income-generating property development. In addition, curb and gutter systems now being used in conventional parking lots can be reduced in size or eliminated entirely. The EPA conducted a series of case studies across the U.S. which revealed that total capital costs of comprehensive LID stormwater management installations (consisting of permeable pavements) were actually 15 to 80 percent less than conventional retention and drainage facilities.

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