# 4.3  Permeable Pavement Systems

## Introduction

Permeable pavement systems represent alternative paving surfaces that capture and temporarily store the design volume by filtering runoff through voids in the pavement surface into an underlying stone reservoir. Filtered runoff may be collected and returned to the conveyance system, or allowed to partially infiltrate into the soil. This allows permeable pavement systems to provide measurable reductions in post-construction stormwater runoff rates, volumes, and pollutant loads.

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**KEY CONSIDERATIONS: PERMEABLE PAVEMENT SYSTEMS**

**DESIGN CRITERIA:**

- Permeable pavement systems should be designed to completely drain within 48 hours.
- If the infiltration rate of the native soils located beneath a permeable pavement system do not meet or exceed 0.3 in/hr, an underdrain should be included in the design.
- The distance from the bottom of the practice to the top of the seasonal high water table should not be less that 0.5 feet.

**BENEFITS:**

- Helps reduce post-construction stormwater runoff rates, volumes and pollutant loads without consuming valuable land.
- Particularly well suited for use on urban development sites and in low traffic areas, such as overflow parking lots.

**LIMITATIONS:**

- Relatively high construction costs, which are typically offset by savings on stormwater infrastructure (e.g., storm drain system).
- Permeable pavement systems should be installed only by experienced personnel.

**SITE APPLICABILITY:**

- Rural Use
- Suburban Use
- Urban Use

- Construction Cost: High
- Maintenance: High
- Area Required: Low

**STORMWATER MANAGEMENT PRACTICE PERFORMANCE:**

**Runoff Reduction Credit Approach**
(applies to Shellfish Bed, SMS4, and infiltration credit approaches)

- ▶ 100% credit for storage volume of infiltration design.
- ▶ 50% credit for storage volume of standard design.

**Coastal Zone Credit Approach**

- ▶ 100% credit for storage volume of practice

**Statewide Water Quality Requirement Credit Approach**

- ▶ Runoff Reduction credit applies to infiltration requirement.

**Pollutant Removal[1]**
80% - Total Suspended Solids
60-80% - Total Phosphorus
60-80% - Total Nitrogen
N/A - Metals
45-75% - Pathogens

[1] *expected annual pollutant load removal*

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*Figure 4.3-1. Permeable pavement parking spaces in North Myrtle Beach, SC (Photo: Travis DuPree)*
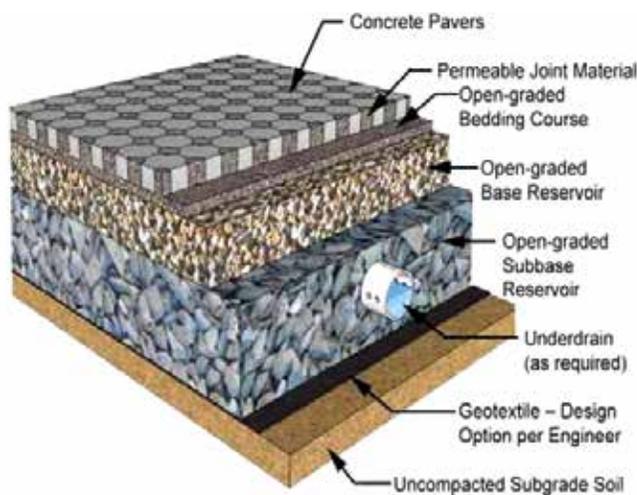


*Figure 4.3-2. Permeable pavement section detail (Source: David Smith, ICPI)*

There are a variety of permeable pavement surfaces available in the commercial marketplace, including pervious concrete, permeable pavers, concrete grid pavers, and plastic grid pavers with turf (Figure 4.3-3). Each of these permeable pavement surfaces is briefly described below:

**Pervious Concrete.** Pervious concrete (also known as porous concrete) is similar to conventional concrete in structure and form, but consists of a special open-graded surface course, typically 4 to 8 inches thick, that is bound together with portland cement. This open-graded surface course has a void ratio of 15% to 25% (conventional concrete pavement has a void ratio of between 3% and 5%), which gives it a high permeability that is often many times more than that of the underlying native soils, and allows rainwater and stormwater runoff to rapidly pass through it and into the underlying stone reservoir. Although this particular type of permeable pavement surface may not require an underlying base layer to support traffic loads, site planning and design teams may wish to provide it to increase the stormwater storage capacity provided by a pervious concrete system.

**Porous Asphalt.** Porous asphalt is similar to pervious concrete, and consists of a special open-graded surface course bound together by asphalt cement. The open-graded surface course in a typical porous asphalt installation is 3 to 7 inches thick and has a void ratio of between 15% and 20%. Porous asphalt is thought to have a limited ability to maintain its structure and permeability during hot summer months and, consequently, is currently not recommended for use in coastal South Carolina. If it is used on a development site in the coastal region, it should be carefully monitored and maintained over time.

*Figure 4.3-3. Various Permeable Pavement Surfaces. Clockwise from top left: (a) Pervious concrete parking lot, Reebok Crossfit Hilton Head Island  (Photo: K. Ellis); (b) Permeable pavers at Islanders Beach Park, on Hilton Head Island (Photo: K. Ellis); (c) Concrete grid pavers at Morse Park Landing, Murrells Inlet (Photo: K. Ellis); and (d) Grass pavers at Verizon store in North Myrtle Beach (Photo: Nicole Saladin).*

**Permeable Pavers.** Permeable pavers (PP) are solid structural units (e.g., blocks, bricks) that are installed in a way that provides regularly spaced openings through which stormwater runoff can rapidly pass through the pavement surface and into the underlying stone reservoir. The regularly spaced openings, which generally make up between 8% and 20% of the total pavement surface, are typically filled with pea gravel (i.e., ASTM D 448 Size No. 8, $^3/_8$ inch to $^1/_8$ inch). Typical PP systems consist of the pavers, a 1.5- to 3-inch thick fine gravel bedding layer and an underlying stone reservoir.

**Concrete Grid Pavers.** Concrete grid pavers (CGP) are precast concrete units that allow rainfall and stormwater runoff to pass through large openings that are filled with gravel, sand, or topsoil and turf (Figure 4.3-3c). CGP are typically 3.5 inches thick and have a void ratio between 20% and 50%, which means that the material used to fill the spaces between the grids has a large influence on the overall permeability (i.e., void space) of a CGP system. A typical CGP installation consists of the pavers, 1- to 1.5- inch sand or pea gravel bedding layer, and an underlying stone reservoir. Void Structured Concrete is a similar design type that utilizes molded cast in place concrete rather than pavers.

**Plastic Grid Pavers.** Plastic grid pavers (PGP) are similar to CGP. They consist of flexible, interlocking plastic units that allow rainfall and stormwater runoff to pass through large openings that are filled with gravel, sand, or topsoil and turf. Since the empty plastic grids have a void ratio of between 90% and 98%, the material used to fill the spaces between the grids has a large influence on the overall permeability (i.e., void space) a PGP system.

When designing a permeable pavement system, planning and design teams must not only consider the storage capacity of the system, but also the structural capacity of the underlying soils and the underlying stone reservoir. The infiltration rate and structural capacity of the native soils found on a development site directly influence the size of the stone reservoir that is needed to provide structural support for a permeable pavement system and measurable reductions in post-construction stormwater runoff rates, volumes, and pollutant loads. Site planning and design teams should strive to design permeable pavement systems that can accommodate the stormwater runoff volume generated by the target runoff reduction rainfall event (e.g., 85th percentile rainfall event). If this cannot be accomplished due to site characteristics or constraints, site planning and design teams should consider using permeable pavement systems in combination with other runoff reducing low impact development practices.

The particular design configuration to be implemented on a site is typically dependent on specific site conditions and the characteristics of the underlying soils. There are three different types of permeable pavement design configurations:

⬦ **Standard Designs**. Practices with a standard underdrain design and no infiltration sump or water quality filter (see Figure 4.3-4).

⬦ **Infiltration Designs**. Practices with no underdrains that can infiltrate the design storm volume in 48 hours (see Figure 4.3-5).

⬦ **Hybrid Designs**. Practices with underdrains that contain a water quality filter layer and an infiltration sump beneath the underdrain sized to drain a portion of the design storm in 48 hours (see Figure 4.3-6).

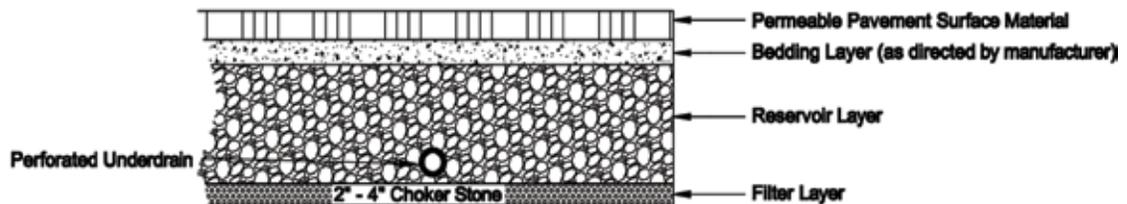*Figure 4.3-4. Cross section of a standard permeable pavement design*

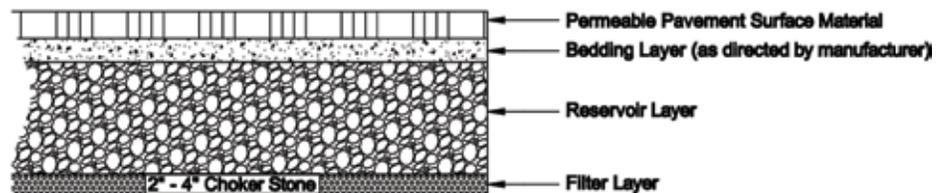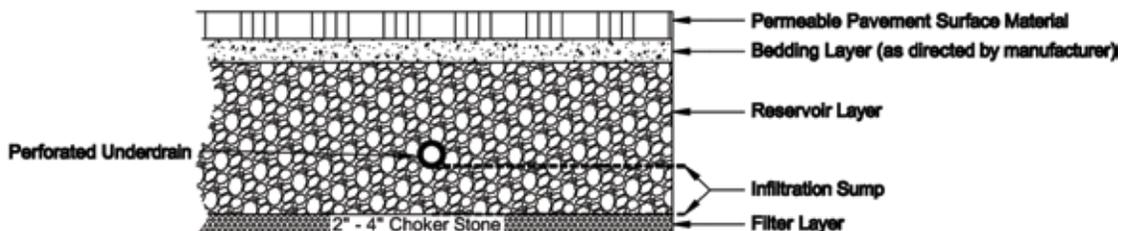*Figure 4.3-5. Cross section of an infiltration permeable pavement design without an underdrain*

*Figure 4.3-6. Cross section of enhanced hybrid permeable pavement design with an underdrain*

## Permeable Pavement Feasibility Criteria

Since permeable pavement has a very high retention capability, it should always be considered as an alternative to conventional pavement. Permeable pavement is subject to the same feasibility constraints as most infiltration practices, as described below.

**Required Space.** A prime advantage of permeable pavement is that it does not normally require additional space at a new development or redevelopment site, which can be important for space-constrained sites or areas where land prices are high.

**Soils.** Soil conditions do not typically constrain the use of permeable pavement, although they do determine whether an underdrain is needed. Underdrains are required if the measured permeability of the underlying soils is less than 0.3 in/hr. Infiltration may be promoted in these designs, however, by incorporating an infiltration sump (i.e., a layer of stone below the invert of the underdrain. See Figure 4.3-6). When designing a permeable pavement practice, designers must verify soil permeability by using the on-site soil investigation methods provided in *Appendix B*.

In fill soil locations, geotechnical investigations are required to determine if the use of an impermeable liner and underdrain are necessary or if the use of an infiltration sump is permissible (see *Permeable Pavement Design Criteria*).

**Contributing Drainage Area.** The portion of the contributing drainage area that does not include the permeable pavement should not exceed 5 times the surface area of the permeable pavement (2 times is recommended), and it should be as close to 100% impervious as possible to help prevent clogging of the pavement by sediment from pervious surfaces.

**Pavement Surface Slope.** Steep pavement surface slopes can reduce the stormwater storage capability of permeable pavement and may cause shifting of the pavement surface and base materials. The permeable pavement slope must be less than 5%. Designers may consider using a terraced design for permeable pavement in areas with steeper slopes. In all cases, designs must ensure that the slope of the pavement does not lead to flow occurring out of the stone reservoir layer onto lower portions of the pavement surface.

**Minimum Hydraulic Head.** The elevation difference needed for permeable pavement to function properly is generally nominal, although 2 to 4 feet of head from the pavement surface to the underdrain outlet is typically necessary. This value may vary based on several design factors, such as required storage depth and underdrain location.

**Minimum Depth to Water Table.** A high groundwater table may cause runoff to pond at the bottom of the permeable pavement system. Therefore, a minimum vertical distance of 0.5 feet must be provided between the bottom of the permeable pavement installation (i.e., the bottom invert of the reservoir layer) and the seasonal high water table.

**Tidal Impacts.** For systems with an underdrain, the underdrain should be located above the tidal mean high water elevation. For entirely infiltration-based systems, the bottom of the stone reservoir should be located above the mean high water elevation. Where this is not possible, portions of the practice below the tidal mean high water elevation cannot be included in the volume calculations.

**Setbacks.** To avoid the risk of seepage and to prevent damage to building foundations and contamination of groundwater aquifers, permeable pavement areas should be located at least:

  ✧ 10 feet upgradient from building foundations*
  ✧ 10 feet from property lines
  ✧ 150 feet from water supply wells
  ✧ 50 feet from septic systems

*Where the 10-foot setback from building foundations is not possible, an impermeable liner may be used along the sides of the permeable pavement practice (extending from the surface to the bottom of the practice).

**Proximity to Utilities.** Interference with underground utilities should be avoided if possible. When large site development is undertaken the expectation of achieving avoidance will be high. Conflicts may be commonplace on smaller sites and in the public right-of-way. Where conflicts cannot be avoided, these guidelines shall be followed:

  ✧ Consult with each utility company on recommended offsets, which will allow utility maintenance work with minimal disturbance to the stormwater Best Management Practice (BMP).

  ✧ Whenever possible, coordinate with utility companies to allow them to replace or relocate their aging infrastructure while BMPs are being implemented.

  ✧ BMP and utility conflicts will be a common occurrence in public right-of-way projects. However, the standard solution to utility conflict should be the acceptance of conflict, provided sufficient soil coverage over the utility can be assured.

  ✧ Additionally, when accepting utility conflict into the BMP design, it is understood that the BMP will be temporarily impacted during utility maintenance but restored to its original condition.

**Pollutant Hotspot Land Uses.** Permeable pavement is not appropriate for certain pollutant-generating sites. In areas where higher pollutant loading is likely (i.e. oils and greases from fueling stations or vehicle storage areas, sediment from un-stabilized pervious areas, or other pollutants from industrial processes), appropriate pretreatment, such as an oil-water separator or filtering device must be provided, or the areas should be diverted from the permeable pavement.

On sites with existing contaminated soils, infiltration is not allowed. Permeable pavement areas must include an impermeable liner, and the Enhanced Design configuration cannot be used.

**High Loading Situations.** Permeable pavement is not intended to treat sites with high sediment or trash/debris loads, since such loads will cause the practice to clog and fail. Sites with a lot of pervious area (e.g., newly established turf and landscaping) can be considered high loading sites and the pervious areas should be diverted if possible from the permeable pavement area. If unavoidable, pretreatment measures, such as a gravel or sod filter strip should be employed (see *Permeable Pavement Pretreatment Criteria*).

**High Speed Roads.** Permeable pavement should not be used for high speed (>30 mph) roads, although it has been successfully applied for low speed residential streets, parking lanes, and roadway shoulders.

**Non-Stormwater Discharge.** Permeable pavement should not receive non-stormwater discharges such as irrigation runoff, air-conditioning condensation discharge, chlorinated wash-water, or other such non-stormwater flows.

**Economic Considerations.** Permeable pavement tends to be expensive relative to other LID practices, but when the cost of land and traditional paving are included in the calculations, permeable pavement becomes much more competitive. Permeable pavement is very space-efficient, since it combines a useful pavement surface with stormwater management for water quality and in some cases for 2-year and 10-year detention requirements.

## Permeable Pavement Conveyance Criteria

Permeable pavement designs must include methods to convey larger storms (e.g., 2-year, 10-year) to the storm drain system. The following is a list of methods that can be used to accomplish this.

  ◇ Place an overdrain, a perforated pipe horizontally near the top of the reservoir layer, to pass excess flows after water has filled the base.

  ◇ Increase the thickness of the top of the reservoir layer to increase storage (i.e., create freeboard). The design computations used to size the reservoir layer often assume that no freeboard is present.

  ◇ Create underground detention within the reservoir layer of the permeable pavement system. Reservoir storage may be augmented by corrugated metal pipes, plastic or concrete arch structures, etc.

  ◇ Route overflows to another detention or conveyance system.

  ◇ Set the storm drain inlets flush with the elevation of the permeable pavement surface to effectively convey excess stormwater runoff past the system. The design should also make allowances for relief of unacceptable ponding depths during larger rainfall events.

## Permeable Pavement Pretreatment Criteria

Pretreatment for most permeable pavement applications is not necessary. Pretreatment may be appropriate if the pavement receives runoff from adjacent pervious areas. For example, a gravel or sod filter strip can be placed adjacent to pervious (landscaped) areas to trap coarse sediment particles before they reach the pavement surface in order to prevent premature clogging.

## Permeable Pavement Design Criteria

**Type of Surface Pavement.** The type of pavement should be selected based on a review of the pavement specifications and properties and designed according to the product manufacturer's recommendations.

**Pavement Bottom Slope.** For unlined designs, the bottom slope of a permeable pavement installation should be as flat as possible (i.e., 0% longitudinal and lateral slopes is preferred and 5% is the maximum) to enable even distribution and infiltration of stormwater. On sloped sites, internal check dams or berms, as shown in Table 4.3-7, can be incorporated into the subsurface to encourage infiltration. In this type of design, the depth of the infiltration sump would be the depth behind the check dams.
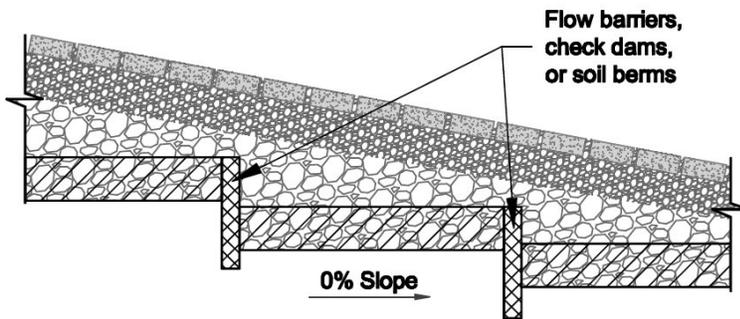
*Figure 4.3-7. Type Profile of Permeable Pavement on Sloped Sites*

**Internal Geometry and Drawdowns.**

◇ **Rapid Drawdown.** Permeable pavement should be designed so that the target storage volume is detained in the reservoir for as long as possible (36 to 48 hours) before completely discharging through an underdrain. A minimum orifice size of 1 inch is recommended regardless of the calculated drawdown time.

◇ **Infiltration Sump.** To promote greater retention for permeable pavement located on marginal soils, an infiltration sump can be installed to create a storage layer below the underdrain invert. This design configuration is discussed further below.

◇ **Conservative Infiltration Rates.** Designers must use ½ of the measured infiltration rate during design to approximate long-term infiltration rates (for example, if the measured infiltration rate is 0.7 inches per hour, the design infiltration rate will be 0.35 inches per hour). This requirement is included in Equation 4.3-1 through Equation 4.3-3.

**Reservoir Layer.** The reservoir layer consists of the stone underneath the pavement section and above the bottom filter layer or underlying soils, including the optional infiltration sump. The total thickness of the reservoir layer is determined by runoff storage needs, the infiltration rate of in situ soils, structural requirements of the pavement sub-base, depth to water table and bedrock, and frost depth conditions (see Permeable Pavement Feasibility Criteria above). A geotechnical engineer should be consulted regarding the suitability of the soil subgrade.

◇ The reservoir below the permeable pavement surface should be composed of clean, double-washed stone aggregate and sized for both the storm event to be treated and the structural requirements of the expected traffic loading (additional chamber structures may also be used to create larger storage volumes).

◇ The storage layer may consist of clean, double-washed No. 57 stone, although No. 2 stone is preferred because it provides additional structural stability.

◇ The bottom of the reservoir layer should be completely flat so that runoff will be able to infiltrate evenly through the entire surface. The use of terracing and check dams is permissible.

**Underdrains.** Most permeable pavement designs will require an underdrain (see Permeable Pavement Feasibility Criteria above). Underdrains can also be used to keep detained stormwater from flooding permeable pavement during extreme events. Multiple underdrains are recommended for

permeable pavement wider than 40 feet, and each underdrain should be located 20 feet or less from the next pipe. The underdrain should be perforated schedule 40 PVC pipe (corrugated HDPE may be used for smaller load-bearing applications), with $^3/_8$-inch perforations at 6 inches on center. The underdrain should be encased in a layer of clean, washed No. 57 stone, with a minimum 2-inch cover over the top of the underdrain. The underdrain system should include a flow control to ensure that the reservoir layer drains slowly (within 36-48 hours).

&#9671; The underdrain outlet can be fitted with a flow-reduction orifice within a weir or other easily inspected and maintained configuration in the downstream manhole as a means of regulating the stormwater detention time. The minimum diameter of any orifice is 1 inch. The designer should verify that the design volume will draw down completely within 36-48 hours.

&#9671; On infiltration designs, an underdrain(s) can be installed and capped at the downstream structure as an option for future use if maintenance observations indicate a reduction in the soil permeability.

All permeable pavement practices must include observation wells. The observation well is used to observe the rate of drawdown within the reservoir layer following a storm event and to facilitate periodic inspection and maintenance. The observation wells should consist of a well-anchored, perforated 4- to 6-inch (diameter) PVC pipe that is tied into any Ts or Ys in the underdrain system. The well should extend vertically to the bottom of the reservoir layer and extend upwards to be flush with the surface (or just under pavers) with a lockable cap.

**Infiltration Sump** (optional, required for Underdrain Enhanced Designs). For unlined permeable pavement systems, an optional upturned elbow or elevated underdrain configuration can be used to promote greater retention for permeable pavement located on marginal soils (see Figure 4.3-5). The infiltration sump must be installed to create a storage layer below the underdrain or upturned elbow invert. The depth of this layer must be sized so that the design storm can infiltrate into the subsoils in a 48-hour period. The bottom of the infiltration sump must be at least 0.5 feet above the seasonally high water table. The inclusion of an infiltration sump is not permitted for designs with an impermeable liner. In fill soil locations, geotechnical investigations are required to determine if the use of an infiltration sump is permissible.

**Filter Layer** (optional). To protect the bottom of the reservoir layer from intrusion by underlying soils, a filter layer can be used. The underlying native soils should be separated from the stone reservoir by a 2 to 4 inch layer of choker stone (e.g., No. 8).

**Geotextile** (optional). Geotextile fabric is another option to protect the bottom of the reservoir layer from intrusion by underlying soils, although some practitioners recommend avoiding the use of fabric beneath permeable pavements since it may become a future plane of clogging within the system. Geotextile fabric is still recommended to protect the excavated sides of the reservoir layer, in order to prevent soil piping. An appropriate geotextile fabric that complies with AASHTO M-288 Class 2, latest edition, requirements, and has a permeability of at least an order of magnitude higher (10x) than the soil subgrade permeability must be used.

**Impermeable Liner**. An impermeable liner is not typically required, although it may be utilized in fill applications where deemed necessary by a geotechnical investigation, on sites with contami-

nated soils, or on the sides of the practice to protect adjacent structures from seepage. Use a 30-mil (minimum) PVC geomembrane liner. (Follow manufacturer's instructions for installation.) Field seams must be sealed according to the liner manufacturer's specifications. A minimum 6-inch overlap of material is recommended at all seams.

**Material Specifications**. Permeable pavement material specifications vary according to the specific pavement product selected. A general comparison of different permeable pavements is provided in Table 4.3-1 below, but designers should consult manufacturer's technical specifications for specific criteria and guidance. Table 4.3-2 describes general material specifications for the component structures installed beneath the permeable pavement. Note that the size of stone materials used in the reservoir and filter layers may differ depending on the type of surface material.

| Table 4.3-1. Permeable Pavement Specifications | | |
|---|---|---|
| **Material** | **Specification** | **Notes** |
| Permeable Pavers (PP) | ♦ Surface open area: 5% to 15% <br> ♦ Thickness: 3.125 inches for vehicles <br> ♦ Compressive strength: 55 MPa <br> ♦ Open void fill media: aggregate | Must conform to ASTM C936 specifications. Reservoir layer required to support the structural load. |
| Concrete Grid Pavers (CGP) | ♦ Open void content: 20% to 50% <br> ♦ Thickness: 3.5 inches <br> ♦ Compressive strength: 35 MPa <br> ♦ Open void fill media: aggregate, topsoil and grass, coarse sand | Must conform to ASTM C1319 specifications. Reservoir layer required to support the structural load. |
| Plastic Reinforced Grid Pavers | ♦ Void content: depends on fill material <br> ♦ Compressive strength: varies, depending on fill material <br> ♦ Open void fill media: aggregate, topsoil and grass, coarse sand | Reservoir layer required to support the structural load. |
| Pervious Concrete (PC) | ♦ Void content: 15% to 25% <br> ♦ Thickness: typically 4 to 8 inches <br> ♦ Compressive strength: 2.8 to 28 MPa <br> ♦ Open void fill media: None | May not require a reservoir layer to support the structural load, but a layer may be included to increase the storage or infiltration. |
| Porous Asphalt (PA) | ♦ Void content: 15% to 20% <br> ♦ Thickness: typically 3 to 7 in. (depending on traffic load) <br> ♦ Open void fill media: None | Reservoir layer required to support the structural load. |

| Table 4.3-2. Material Specifications for Elements Underneath the Pavement Surface | | |
|---|---|---|
| **Material** | **Specification** | **Notes** |
| Bedding Layer | ♦ PP: 2 in. depth of No. 8 stone over 3 to 4 inches of No. 57 stone<br>♦ PC: 3 to 4 inches of No. 57 stone if No. 2 stone is used for Reservoir Layer<br>♦ PA: 3 to 4 inches of No. 57 stone | ASTM D448 size No. 8 stone (e.g., 3/8 to 3/16 inch in size). Must be double-washed and clean and free of all fines. |
| Reservoir Layer | ♦ PP: No. 57 stone or No. 2 stone<br>♦ PC: No. 57 stone or No. 2 stone<br>♦ PA: No. 2 stone | ASTM D448 size No. 57 stone (e.g., 1 1/2- to 1/2-inch in size); No. 2 Stone (e.g., 3 inch to 3/4 inch in size). Depth is based on the pavement structural and hydraulic requirements. Must be double-washed and clean and free of all fines. |
| Underdrain | Use 4- to 6-inch diameter perforated PVC pipe (or equivalent corrugated HDPE may be used for smaller load-bearing applications), with 3/8-inch perforations at 6 inches on center. Perforated pipe installed for the full length of the permeable pavement cell, and non-perforated pipe, as needed, is used to connect with the storm drain system. T's and Y's should be installed as needed, depending on the underdrain configuration. Extend cleanout pipes to the surface. | |
| Infiltration Sump (optional) | An aggregate storage layer below the underdrain invert. The material specifications are the same as Reservoir Layer. | |
| Filter Layer (optional) | The underlying native soils should be separated from the stone reservoir by a 2 to 4 inch layer of choker stone (e.g., No. 8). | |
| Geotextile (optional) | Use an appropriate geotextile fabric that complies with AASHTO M-288 Class 2, latest edition, requirements, and has a permeability of at least an order of magnitude higher (10x) than the soil subgrade permeability. | |
| Impermeable Liner (optional) | Where appropriate use a thirty mil (minimum) PVC Geomembrane liner (follow manufacturer's instructions for installation) . | |
| Observation Well | Use a perforated 4- to 6-inch vertical PVC pipe (AASHTO M 252) with a lockable cap, installed flush with the surface or just beneath PP. | |

**Permeable Pavement Sizing.** The thickness of the reservoir layer is determined by both a structural and hydraulic design analysis. The reservoir layer serves to retain stormwater and also supports the design traffic loads for the pavement. Permeable pavement structural and hydraulic sizing criteria are discussed below.

**Structural Design.** If permeable pavement will be used in a parking lot or other setting that involves vehicles, the pavement surface must be able to support the maximum anticipated traffic load. The structural design process will vary according to the type of pavement selected, and the manufacturer's specific recommendations should be consulted. The thickness of the permeable pavement and reservoir layer must be sized to support structural loads and to temporarily store the design storm volume (e.g., the water quality, channel protection, and/or flood control volumes). On most new development and redevelopment sites, the structural support requirements will dictate the depth of the underlying stone reservoir.

The structural design of permeable pavements involves consideration of four main site elements:

- ✧ Total traffic
- ✧ In-situ soil strength
- ✧ Environmental elements
- ✧ Bedding and Reservoir layer design

The resulting structural requirements may include, but are not limited to, the thickness of the pavement, filter, and reservoir layer. Designers should note that if the underlying soils have a low California Bearing Ratio (CBR) (less than 4 percent), they may need to be compacted to at least 95 percent of the Standard Proctor Density, which may limit their use for infiltration.

Designers should determine structural design requirements by consulting transportation design guidance sources, such as the following:

- ✧ AASHTO Guide for Design of Pavement Structures (1993)
- ✧ AASHTO Supplement to the Guide for Design of Pavement Structures (1998)

**Hydraulic Design.** Permeable pavement is typically sized to store the design storm or larger design storm volumes in the reservoir layer. The storage volume in the pavements must account for the underlying infiltration rate and outflow through any underdrains. The design storm should be routed through the pavement to accurately determine the required reservoir depth. The depth of the reservoir layer or infiltration sump needed to store the design storm can be determined by using Equation 4.3-1.

**Equation 4.3-1. Reservoir Layer or Infiltration Sump Depth**

$$d_p = \frac{\left( \dfrac{P \times Rv_I \times DA}{A_p} \right) - \left( \dfrac{i}{2} \times t_f \right)}{\eta_r}$$

where:

| | | |
|---|---|---|
| $d_p$ | = | depth of the reservoir layer (or depth of the infiltration sump for enhanced designs with underdrains) (ft) |
| $P$ | = | rainfall depth for the design storm (ft) |
| $Rv_I$ | = | runoff coefficient for impervious cover (0.95) |
| $DA$ | = | total contributing drainage area, including permeable pavement surface (ft²) |
| $A_p$ | = | permeable pavement surface area (ft²) |
| $i$ | = | field-verified infiltration rate for the subgrade soils (ft/day). If an impermeable liner is used in the design then i = 0. |
| $t_f$ | = | time to fill the reservoir layer (day) (assume 2 hours or 0.083 day) |
| $\eta_r$ | = | effective porosity for the reservoir layer (0.35) |

This equation makes the following design assumptions:

◇ The contributing drainage area (CDA) does not contain pervious areas.

◇ For design purposes, the field-tested subgrade soil infiltration rate ($i$) is divided by 2 as a factor of safety to account for potential compaction during construction. If the subgrade will be compacted to meet structural design requirements of the pavement section, the design infiltration rate of the subgrade soil shall be based on measurement of the infiltration rate of the subgrade soil subjected to the compaction requirements.

◇ The porosity ($\eta_r$) for No. 57 stone is 0.35.

The depth of the reservoir layer cannot be less than the depth required to meet the pavement structural requirement. The depth of the reservoir layer may need to be increased to meet structural or larger storage requirements.

Designers must ensure that the captured volume will drain from the pavement in 36 to 48 hours. For infiltration designs (no underdrains) or designs with infiltration sumps, Equation 4.3-2 can be used to determine the drawdown time in the reservoir layer or infiltration sump.

**Equation 4.3-2. Drawdown Time**

$$t_d = \frac{d_p \times \eta_r}{0.5 \times i}$$

where:

$t_d$     =     drawdown time (day)

$d_p$     =     depth of the reservoir layer (or the depth of the infiltration sump, for hybrid designs) (ft)

$\eta_r$     =     effective porosity for the reservoir layer (0.35)

$i$     =     field-verified infiltration rate for the subgrad

For design with underdrains, the drawdown time should be determined using the hydrological routing or modeling procedures used for detention systems with the depth and head adjusted for the porosity of the aggregate.

The total storage volume provided by the practice, *Sv*, should be determined using Equation 4.3-3, Equation 4.3-4, or both. For infiltration designs, *Sv* is calculated using Equation 4.3-3. For standard designs, *Sv* is calculated using Equation 4.3-4. For hybrid designs, both equations are used. Equation 4.3-3 provides *Sv* for the infiltration sump and Equation 4.3-4 provides *Sv* for the stone reservoir above the underdrain,

### Equation 4.3-3. Permeable Pavement Storage Volume for Infiltration Design

$$Sv = A_p \times \left[ (d_p \times \eta_r) + \left( \frac{i \times t_f}{2} \right) \right]$$

where:

| | | |
|---|---|---|
| $Sv$ | = | storage volume (ft³) |
| $d_p$ | = | depth of the reservoir layer (or depth of the infiltration sump for enhanced designs with underdrains) (ft) |
| $\eta_r$ | = | effective porosity for the reservoir layer (0.35) |
| $A_p$ | = | permeable pavement surface area (ft²) |
| $i$ | = | field-verified infiltration rate for the subgrade soils (ft/day). If an impermable liner is used in the design then $i = 0$. |
| $t_f$ | = | time to fill the reservoir layer (day) (assume 2 hours or 0.083 day) |

*Note: For enhanced designs that use an infiltration sump, $dp$ is only the depth of the infiltration sump.

### Equation 4.3-4. Permeable Pavement Storage Volume for Standard Design

$$Sv = (d_p \times \eta_r \times A_p)$$

where:

| | | |
|---|---|---|
| $Sv$ | = | storage volume (ft³) |
| $d_p$ | = | depth of the reservoir layer (ft) |
| $\eta_r$ | = | effective porosity for the reservoir layer (0.35) |
| $A_p$ | = | permeable pavement surface area (ft²) |

*In the LID Compliance Calculator spreadsheet, the Sv for infiltration designs is given a 100% runoff reduction credit; the Sv for standard designs is given a 50% runoff reduction credit, since much of the water stored quickly exits the underdrain. For projects in the Coastal Zone, the Sv for all design types is given a 100% credit toward the storage requirement.*

*Note: The hybrid design is not included as a separate practice in the spreadsheet. Instead, it is treated as two separate practices in series. The designer should first enter the Sv in the Infiltration Sump and drainage area for the Porous Pavement – Infiltration Design. Next, select Permeable Pavement-Standard as the downstream BMP, and on this line do not enter any value for the drainage area, and enter the Sv for the stone reservoir above the underdrain.*

**Detention Storage Design:** Permeable pavement can also be designed to address, in whole or in part, the detention storage needed to comply with channel protection and/or flood control requirements. The designer can model various approaches by factoring in storage within the stone aggregate layer (including chamber structures that increase the available storage volume), expected infiltration, and any outlet structures used as part of the design. Routing calculations can also be used to provide a more accurate solution of the peak discharge and required storage volume.

Once runoff passes through the surface of the permeable pavement system, designers should calculate outflow pathways to handle subsurface flows. Subsurface flows can be regulated using underdrains, the volume of storage in the reservoir layer, the bed slope of the reservoir layer, and/or a control structure at the outlet (see Permeable Pavement Conveyance Criteria Section above).

### Permeable Pavement Landscaping Criteria

Permeable pavement does not have any landscaping needs associated with it. However, large-scale permeable pavement applications should be carefully planned to integrate the typical landscaping features of a parking lot, such as trees and islands, in a manner that maximizes runoff treatment and minimizes the risk that sediment, mulch, grass clippings, leaves, nuts, and fruits will inadvertently clog the paving surface. Bioretention areas may be a good design option to meet these needs.

### Permeable Pavement Construction Sequence

Experience has shown that proper installation is absolutely critical to the effective operation of a permeable pavement system.

**Erosion and Sediment Controls.** The following erosion and sediment control guidelines must be followed during construction:

⬦ All permeable pavement areas should be fully protected from sediment intrusion by silt fence or construction fencing, particularly if they are intended to infiltrate runoff.

⬦ Intended permeable pavement areas must remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment (unless the area has been determined to have a low CBR and will require compaction during the permeable pavement construction phase). Where this is unavoidable, the impacted area should not be excavated below 2 feet above the final design elevation of the bottom of the aggregate reservoir course until further compaction by heavy equipment can be avoided. Once the area is excavated to grade, the impacted area should be tilled to a depth of 12 inches below the bottom of the reservoir layer. Permeable pavement areas must be clearly marked on all construction documents and grading plans.

⬦ During construction, care should be taken to avoid tracking sediments onto any permeable pavement surface to avoid clogging.

⬦ Any area of the site intended ultimately to be a permeable pavement area should generally not be used as the site of a temporary sediment basin. Where locating a sediment basin on an area intended for permeable pavement is unavoidable, the invert of the sediment basin must be a minimum of 2 feet above the final design elevation of the bottom of the aggregate reservoir course. All sediment deposits in the excavated area should be carefully removed prior to installing the sub-base, base, and surface materials.

**Permeable Pavement Installation.** The following is a typical construction sequence to properly install permeable pavement, which may need to be modified depending on the specific variant of permeable pavement that is being installed.

**Step 1:** Construction of the permeable pavement should only begin after the entire contributing drainage area has been stabilized. The proposed site should be checked for existing utilities prior to any excavation. Do not install the system in rain or snow and do not install frozen bedding materials.

**Step 2:** As noted above, temporary erosion and sediment controls are needed during installation to divert stormwater away from the permeable pavement area until it is completed. Special protection measures, such as erosion control fabrics, may be needed to protect vulnerable side slopes from erosion during the excavation process. The proposed permeable pavement area must be kept free from sediment during the entire construction process. Construction materials contaminated by sediments must be removed and replaced with clean materials.

**Step 3:** Where possible, excavators or backhoes should work from the sides to excavate the reservoir layer to its appropriate design depth and dimensions. For small pavement applications, excavating equipment should have arms with adequate extension so they do not have to work inside the footprint of the permeable pavement area (to avoid compaction). Contractors can utilize a cell construction approach, whereby the proposed permeable pavement area is split into 500-to 1,000-square foot temporary cells with a 10- to 10-foot earth bridge in between, so cells can be excavated from the side. Excavated material should be placed away from the open excavation so as to not jeopardize the stability of the side walls.

**Step 4:** The native soils along the bottom of the permeable pavement system should be scarified or tilled to a depth of 3 to 4 inches prior to the placement of the filter layer or geotextile fabric. In large scale paving applications with weak soils, the soil subgrade may need to be compacted to 95 percent of the Standard Proctor Density to achieve the desired load-bearing capacity. Note: This may reduce or eliminate the infiltration function of the installation, and it must be addressed during hydrologic design.

**Step 5:** Geotextile fabric should be installed on the sides of the reservoir layer (and the bottom if the design calls for it). Geotextile fabric strips should overlap down-slope by a minimum of 2 feet and be secured a minimum of 4 feet beyond the edge of the excavation. Where the filter layer extends beyond the edge of the pavement (to convey runoff to the reservoir layer), install an additional layer of geotextile fabric 1 foot below the surface to prevent sediments from entering into the reservoir layer. Excess geotextile fabric should not be trimmed until the site is fully stabilized.

**Step 6:** Provide a minimum of 2 inches of aggregate above and below the underdrains. The up-gradient end of underdrains in the reservoir layer should be capped. Where an underdrain pipe is connected to a structure, there shall be no perforations within 1 foot of the structure. Ensure there are no perforations in clean-outs and observation wells within 1 foot of the surface.

**Step 7:** Spread 6-inch lifts of the appropriate clean, washed stone aggregate (usually No. 2 or No. 57 stone). Place at least 4 inches of additional aggregate above the underdrain, and then compact it using a vibratory roller in static mode until there is no visible movement of the aggregate. Do not crush the aggregate with the roller.

**Step 8:** Install the desired depth of the bedding layer, depending on the type of pavement, as indicated in Table 4.3-2.

**Step 9:** Paving materials shall be installed in accordance with manufacturer or industry specifications for the particular type of pavement.

**Installation of Porous Asphalt.** The following has been excerpted from various documents, most notably Jackson (2007):

♦ Install porous asphalt pavement similarly to regular asphalt pavement. The pavement should be laid in a single lift over the filter course. The laying temperature should be between 230°F and 260°F, with a minimum air temperature of 50°F, to ensure the surface does not stiffen before compaction.

♦ Complete compaction of the surface course when the surface is cool enough to resist a 10-ton roller. One or two passes of the roller are required for proper compaction. More rolling could cause a reduction in the porosity of the pavement.

♦ The mixing plant must provide certification of the aggregate mix, abrasion loss factor, and asphalt content in the mix. Test the asphalt mix for its resistance to stripping by water using ASTM 1664. If the estimated coating area is not above 95%, additional anti-stripping agents must be added to the mix.

♦ Transport the mix to the site in a clean vehicle with smooth dump beds sprayed with a non-petroleum release agent. The mix shall be covered during transportation to control cooling.

♦ Test the full permeability of the pavement surface by application of clean water at a rate of at least five gallons per minute over the entire surface. All water must infiltrate directly, without puddle formation or surface runoff.

♦ Inspect the facility 18 to 30 hours after a significant rainfall (greater than ½ inch) or artificial flooding to determine the facility is draining properly.

**Installation of Pervious Concrete.** The basic installation sequence for pervious concrete is outlined by the National Ready Mixed Concrete Association (NRMCA, 2004). It is strongly recommended that concrete installers successfully complete a recognized pervious concrete installers training program, such as the Pervious Concrete Contractor Certification Program offered by the NRMCA. The basic installation procedure is as follows:

♦ Drive the concrete truck as close to the project site as possible.

♦ Water the underlying aggregate (reservoir layer) before the concrete is placed, so the aggregate does not draw moisture from the freshly laid pervious concrete.

♦ After the concrete is placed, approximately ⅜ to ½ inch is struck off, using a vibratory screed. This is to allow for compaction of the concrete pavement.

♦ Compact the pavement with a steel pipe roller. Care should be taken to ensure over-compaction does not occur.

♦ Cut joints for the concrete to a depth of ¼ inch.

◇ The curing process is very important for pervious concrete. Concrete installers should follow manufacturer specifications to the extent allowed by on-site conditions when curing pervious concrete.

◇ Remove the plastic sheeting only after the proper curing time. Inspect the facility 18 to 30 hours after a significant rainfall (greater than ½ inch) or artificial flooding, to determine the facility is draining properly.

**Installation of Permeable Pavers.** The basic installation process is described in greater detail by Smith (2006):

◇ Place edge restraints for open-jointed pavement blocks before the bedding layer and pavement blocks are installed. Permeable pavement systems may require edge restraints to prevent vehicle loads from moving the paver blocks. Edge restraints may be standard curbs or gutter pans, or precast or cast-in-place reinforced concrete borders a minimum of 6 inches wide and 18 inches deep, constructed with Class A3 concrete. Edge restraints along the traffic side of a permeable pavement block system are recommended.

◇ Place the No. 57 stone in a single lift. Level the filter course and compact it into the reservoir course beneath with at least four passes of a 10-ton steel drum static roller until there is no visible movement. The first two passes are in vibratory mode, with the final two passes in static mode. The filter aggregate should be moist to facilitate movement into the reservoir course.

◇ Place and screed the bedding course material (typically No. 8 stone).

◇ Fill gaps at the edge of the paved areas with cut pavers or edge units. When cut pavers are needed, cut the pavers with a paver splitter or masonry saw. Cut pavers no smaller than $1/3$ of the full unit size.

◇ Pavers may be placed by hand or with mechanical installers. Fill the joints and openings with stone. Joint openings must be filled with ASTM D 448 No. 8 stone; although, No. 8P or No. 9 stone may be used where needed to fill narrower joints. Remove excess stones from the paver surface.

◇ Compact and seat the pavers into the bedding course with a minimum low-amplitude 5,000-lbf, 75- to 95-Hz plate compactor.

◇ Do not compact within 6 feet of the unrestrained edges of the pavers.

◇ The system must be thoroughly swept by a mechanical sweeper or vacuumed immediately after construction to remove any sediment or excess aggregate.

◇ Inspect the area for settlement. Any blocks that settle must be reset and re-inspected.

◇ Inspect the facility 18 to 30 hours after a significant rainfall (½ inch or greater) or artificial flooding to determine whether the facility is draining properly.

**Construction Supervision.** Supervision before, during, and after construction by a qualified professional is recommended to ensure permeable pavement is built in accordance with these specifications. Inspection checklists that require sign-offs by qualified individuals should be used at critical stages of construction, to ensure the contractor's interpretation of the plan is consistent with the designer's intent.

Some common pitfalls can be avoided by careful construction supervision that focuses on the following key aspects of permeable pavement installation:

◇ Store materials in a protected area to keep them free from mud, dirt, and other foreign materials.

◇ The contributing drainage area should be stabilized prior to directing water to the permeable pavement area.

◇ Check the aggregate material to confirm it is clean and washed, meets specifications and is installed to the correct depth. Aggregate loads that do not meet the specifications or do not appear to be sufficiently washed may be rejected.

◇ Check elevations (e.g., the invert of the underdrain, inverts for the inflow and outflow points, etc.) and the surface slope.

◇ Make sure the permeable pavement surface is even, runoff evenly spreads across it, and the storage bed drains within 48 hours.

◇ Ensure caps are placed on the upstream (but not the downstream) ends of the underdrains.

◇ Inspect the pretreatment structures (if applicable) to make sure they are properly installed and working effectively.

◇ Once the final construction inspection has been completed, log the GPS coordinates for each facility and submit them for entry into the BMP maintenance tracking database.

It may be advisable to divert the runoff from the first few runoff-producing storms away from larger permeable pavement applications, particularly when up-gradient conventional asphalt areas drain to the permeable pavement. This can help reduce the input of fine particles often produced shortly after conventional asphalt is laid down.

### *Permeable Pavement Maintenance Criteria*

Maintenance is a required and crucial element to ensure the long-term performance of permeable pavement. The most frequently cited maintenance problem is surface clogging caused by organic matter and sediment. Periodic street sweeping will remove accumulated sediment and help prevent clogging; however, it is also critical to ensure that surrounding land areas remain stabilized.

The following tasks must be avoided on ALL permeable pavements:

◇ Sanding

◇ Re-sealing

◇ Re-surfacing

◇ Power washing

◇ Storage of mulch or soil materials

◇ Construction staging on unprotected pavement

It is difficult to prescribe the specific types or frequency of maintenance tasks that are needed to maintain the hydrologic function of permeable pavement systems over time. The frequency of maintenance will depend largely on the pavement use, traffic loads, and the surrounding land use.

One preventative maintenance task for large-scale applications involves vacuum sweeping on a frequency consistent with the use and loadings encountered in the parking lot. Many consider an annual, dry-weather sweeping in the spring months to be important. The contract for sweeping should specify that a vacuum sweeper be used that does not use water spray, since spraying may lead to subsurface clogging. Typical maintenance tasks are outlined in Table 4.3-3.

| Table 4.3-3. Typical Maintenance Tasks for Permeable Pavement Practices | |
|---|---|
| **Frequency** | **Maintenance Tasks** |
| After installation | ♦ For the first 6 months following construction, the practice and CDA should be inspected at least twice after storm events that exceed 1/2 inch of rainfall. Conduct any needed repairs or stabilization. |
| Once every 1–2 months during the growing season | ♦ Mow grass in grid paver applications. |
| As needed | ♦ Stabilize the contributing drainage area to prevent erosion<br>♦ Remove any soil or sediment deposited on pavement.<br>♦ Replace or repair any necessary pavement surface areas that are degenerating or spalling |
| 2–4 times per year (depending on use) | ♦ Vacuum pavement with a standard street sweeper to prevent clogging. |
| Annually | ♦ Conduct a maintenance inspection.<br>♦ Spot weeding of grass applications. |
| Once every 2–3 years | ♦ Remove any accumulated sediment in pretreatment cells and inflow points. |
| If clogged | ♦ Conduct maintenance using a regenerative street sweeper.<br>♦ Replace any necessary joint material. |

When permeable pavements are installed on private residential lots, homeowners will need to (1) be educated about their routine maintenance needs and (2) understand the long-term maintenance plan.

It is recommended that a qualified professional conduct a spring maintenance inspection and cleanup at each permeable pavement site, particularly at large-scale applications. An example maintenance checklist for permeable pavement areas is included in *Appendix F*.

## *Permeable Pavement References and Additional Resources*

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