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Tech Brief

Use of Permeable Pavements

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Background

The use of permeable pavements originated in Europe more than 70 years ago (Knapton 2009). They started as various forms of open aggregate or grass pavements to promote water infiltration instead of runoff. They were reinforced with a variety of cell structures using concrete or plastic materials to enhance their load carrying capacity.

In the 1970s, permeable pavements began to be used in the United States (NAPA 2008). If properly designed and constructed, permeable pavements can help stormwater infiltrate into subgrade soils, decrease urban heat island effects, replenish groundwater, reduce pollutants in stormwater and reduce peak water flow and flooding during storm events (ASCE 2015).

While open graded asphalt has been used as the surface layer of asphalt pavements, its primary function is to reduce tire/pavement noise and water spray during rain events. These are not considered to be permeable pavements.

Permeable Pavement Systems

Permeable pavement systems consist of a pavement surface that has a more open void structure than traditional pavements. The open surface allows rain and surface water to run onto the pavement and infiltrate into the system rather than traditional horizontal drainage off the pavement. This allows for rain and surface water to flow freely vertically through the surface into an open-graded base/subbase reservoir.

The reservoir collects and stores the water slowing its movement before it leaves the pavement through either infiltration into the subgrade or through underdrains. The storage reservoir typically has about 30 percent void space between the aggregates to temporarily store the water. For subgrade soil types with low infiltration rates such as clay, perforated drain pipes are typically needed to drain excess water.

For some project sites, infiltration into the subgrade may be prohibited such as near foundation walls, and underground utilities. For these situations, permeable pavements can be designed with an impermeable liner that prevents water from entering the soil subgrade. For this scenario, the water is temporarily detained and discharged through underdrains.

Considering the more open nature of the pavement surface, permeable pavements will collect sediment and debris. Over time, this can lead to decreased infiltration rates. The decreased infiltration rate will depend on site characteristics and sources of deposited sediment. Sources of debris could include, biomass loading from trees and other vegetation, vehicular/pedestrian dirt and debris, soil erosion from adjacent surfaces and, improper winter maintenance (sanding).

Permeable pavements can continue to perform under most storm events with reduced infiltration rates; however, reduced permeability and infiltration can be minimized or restored with timely inspections and maintenance.

There are three general permeable pavement system designs based on subgrade infiltration including full, partial and low infiltration designs.

For full infiltration, as shown in Figure 1, the design objective is to infiltrate all captured stormwater into the subgrade below the pavement. This design is typically only constructed in areas with highly permeable subgrade materials such as sand or sand and gravel. This system typically does not require any additional stormwater features such as catchbasins, underdrains, outlet pipes, and stormwater management ponds.

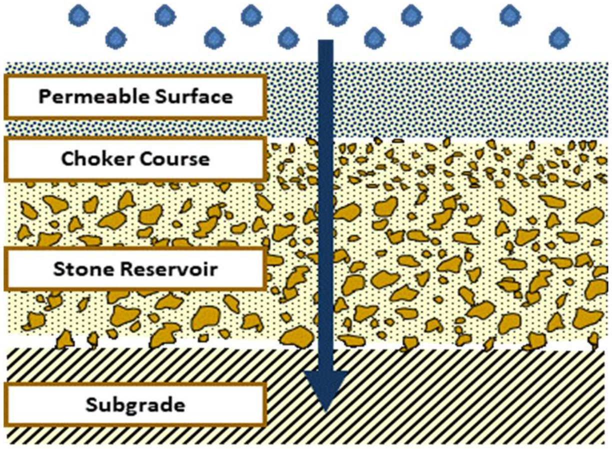

Figure 1. Illustration. Full Infiltration Design.

A partial infiltration design as shown in Figure 2, allows water to infiltrate into the subgrade; however, supplementary drainage features such as subdrains and outlet pipes are installed to ensure that water does not overflow the pavement in higher intensity storms. For this type of design, the designer can set the elevation based on site conditions of the downstream end of the pipe outlet to control the discharge versus infiltration.

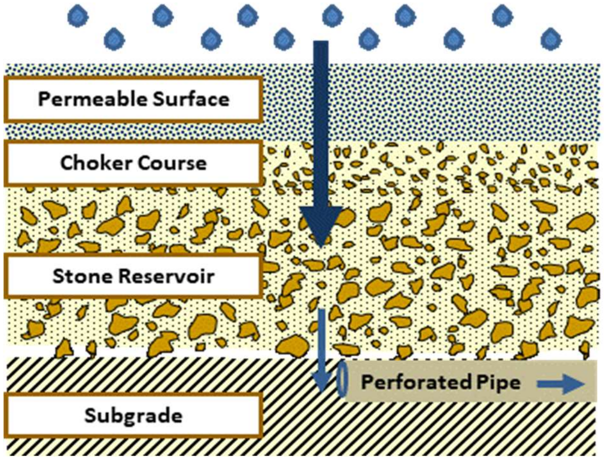

Figure 2. Illustration. Partial Infiltration Design.

A low infiltration design, as shown in Figure 3, is used for sites with lower permeability subgrades such as clay or silty clay. This design may also be used where infiltration would be undesirable or detrimental, such as: where subgrade saturation could reduce the structural strength of the pavement, areas susceptible to frost heave, adjacent to foundation walls, water harvesting, and contaminated subgrades.

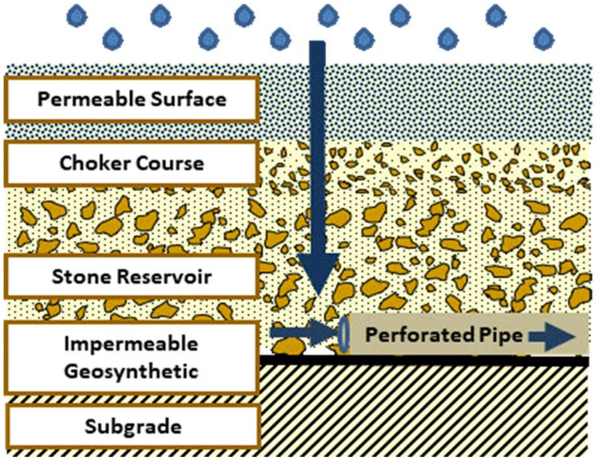

Figure 3. Illustration. Low Infiltration Design.

Depending on the site characteristics and the objectives of the project, each infiltration type design typically includes further design details to achieve the desired goals for the project. These design details may include but are not limited to items such as:

- Pavement surface type (porous asphalt, pervious concrete or permeable interlocking concrete pavers).
- Edge restraints and support features such as curbs.
- Outlet pipes and monitoring wells.
- Geosynthetics for separation or water filtration.

Effectiveness and Limitations

Permeable pavements can be an effective and more sustainable means of managing storm water and enhance resilience. Some of the potential benefits of permeable pavements include:

- Decrease peak runoff flow rates.
- Decrease the volume of storm water runoff.
- Reduce storm water pollutant loading to surface waters.
- Increase groundwater recharge.
- Reduce thermal impacts.

However, there also are potential concerns that may need to be addressed, including structural capacity, clogging, saturated roadway conditions, rutting, freeze-thaw effects, constructability, maintenance requirements, and durability.

For highway applications, permeable pavements are generally not suitable for the main driving surfaces due to challenges related to pavement strength and durability. Also, depending on the type of subgrade, fully permeable pavements may not be feasible or practical. However, the highway rights-of-way may provide opportunity to achieve some permeable pavement benefits as they have the potential to be used as shoulders, median cross overs, carpool lots, rest stops, and snowplow turnarounds (NCHRP 2013).

For pavements, compaction is a key component to achieving adequate strength. For permeable pavements, strength and permeability need to be balanced. If the permeable bases and subbases are too dense, then permeability and storage capacity will be reduced. Conversely, without adequate compaction, permeable pavements may not have sufficient structural capacity, which could lead to load-related distresses and premature deterioration of the pavements.

Permeable shoulders can have sufficient hydraulic capacity to be used as an alternative, best-management practice (BMP) method to capture highway surface runoff. The thickness of the aggregate reservoir layer needed to capture the rain falling onto the pavement over the course of a rain-season can range from as little as 5 inches to 10 feet, depending on site conditions. The permeability of subgrade soil is a key factor determining whether a full infiltration design can be used (Chai 2012). For soil permeability less than 10^{-2} inches/hour, the typical thickness of the reservoir (aggregate) layer becomes excessive and impractical. The permeability of silty soils ranges from 1.42 to 0.0142 inches/hour with clay soils typically 10^{-3} inches/hour or less.

Even when full or partial infiltration is not possible, by temporarily storing the water in the reservoir subbase, a permeable pavement can function as a detention facility to reduce peak flow, while providing treatment of stormwater.

Several components should be evaluated to determine if a particular site is suitable for a permeable pavement. The key components in completing a site suitability evaluation are summarized below (NCHRP 2013). There is no Federal requirement that these components be considered.

Evaluate acceptability. Determine if they are permitted by national, state and local regulations for the project location. Elements that may impact the applicability of a permeable pavement for a particular site may include:

- Regulatory hydrologic control requirements or restrictions.
- Proximity to stormwater hotspots such as fueling facilities, landfills and wastewater treatment plants.
- Presence of existing underground contamination.
- Proximity to water wells.
- Proximity to septic systems or cesspools.

Evaluate opportunities and drivers. Evaluate whether the project provides the opportunity for any of the following general considerations:

- Desire or regulatory requirements to reduce the volume of stormwater runoff, reduce peak runoff flowrates, improve the quality of stormwater runoff, and/or address other related run-off issues such as effluent temperature.
- Increase safety via reducing splash and/or surface ponding when vehicles are using the pavement.
- Potential for reduction in future stormwater management costs by modifying pavement design for stormwater management and eliminating end of pipe structures.
- Incentives (financial, environmental benefits and sustainability achievement).

Evaluate benefits, risks, and technical design factors. If the suitability evaluation indicates that the use of a permeable pavement may be suitable for a particular project, additional considerations should be analyzed to evaluate the anticipated benefits and risks associated with its use.

The design and technical factors can be divided into three different categories of considerations. Primary considerations are fatal flaws or major design challenges that would have a major influence on or preclude the project from moving forward. Some examples include:

- Environmental approval.
- Regulatory requirement to consider use of permeable pavements.
- Safety.
- Significant longitudinal grades (>5 percent).
- Depth of water table. (<2 feet from the bottom of the subbase).
- Geotechnical risks.
- Groundwater contamination risk.

Secondary considerations are issues or concerns that do not necessarily preclude a project site; however, they need to be addressed as part of the design. Secondary considerations may require additional design items and increased costs that need to be considered. Examples may include:

- Stringent receiving water quality standards.
- Sand use for winter maintenance.
- Run-on from adjacent areas with exposed soils.
- Low soil infiltration rates.
- Target design volumes and runoff rates.
- Complexity of geometric conditions.
- Risk of flooding.
- Mandates for stormwater quality control.
- Mandates for drainage and peak flow control.
- Maintenance protocols.

Other considerations may affect the decision to install permeable pavements, but are considered to have less of an influence than the primary and secondary considerations, such as:

- Presence of utilities.
- Impact of unknown site conditions.
- Risk of accidental chemical spill.
- Owner experience and resources.

The Federal Highway Administration (FHWA) as well as the American Society of Civil Engineers (ASCE) and each of the respective trade associations provide information related to the design, construction and maintenance of permeable pavements:

- FHWA Tech Briefs:
  - Porous Asphalt Pavements with Stone Reservoirs (FHWA-HIF-15-009).
  - Permeable Concrete Pavements (FHWA-HIF-16-004).
  - Permeable Interlocking Concrete Pavement (FHWA-HIF-15-007).
- American Society of Civil Engineers , Environmental and Water Resources Institute, Permeable Pavements (ASCE 2015).
- American Society of Civil Engineers , Transportation and Development Institute, Permeable Interlocking Concrete Pavements, ASCE 68-18 (ASCE 2018).
- National Asphalt Pavement Association, Porous Asphalt Pavements for Stormwater Management and Structural Design Guidelines for Porous Asphalt Pavement (NAPA 2008).
- National Ready Mixed Concrete Association, Pervious Concrete Pavements (NRMCA 2010).
- Concrete Masonry & Hardscapes Association (*formerly the Permeable Interlocking Concrete Pavement Institute),* Permeable Interlocking Concrete Pavements (CMHA 2000).

Permeable Pavement Components

Porous Asphalt

Conventional asphalt mixes are designed to have an in-situ air void space of between 6 and 8 percent once compacted. This makes the asphalt mix relatively impermeable. During rainstorms, surface water is shed off the surface by gravity. Open graded asphalt mixes consist of primarily coarse aggregate with a small amount of fine aggregate creating a material with an in-situ air voids content of between 15 and 30 percent. Porous asphalt can provide a stable wearing surface for the pavement while allowing stormwater to infiltrate through the surface into the underlying permeable stone reservoir (Figure 4).

To increase the strength and durability of a porous asphalt pavement under moderate to high traffic applications, polymer modified asphalt and/or fibers are used. The design of porous asphalt must consider a balance between providing infiltration through the surface while being stable enough to resist rutting and/or deformation under traffic loading.

Figure 4. Photo. Porous Asphalt.

Pervious Concrete

Traditional concrete pavement is dense and relatively impermeable. It is designed with an in-situ air voids content typically between 6 and 8 percent to allow for the expansion of water on freezing without causing any damage to the concrete. Similar to porous asphalt, pervious concrete is designed with an in-situ air void content of between 15 and 30 percent to permit water infiltration through the surface to the underlying permeable stone reservoir (Figure 5).

Figure 5. Photo. Pervious Concrete.

To increase the strength and durability of a pervious concrete pavement under moderate to high traffic applications, fibers are typically used. The design of pervious concrete needs to consider the reduction in strength when determining the design thickness of permeable pavements for the intended traffic.

Permeable Interlocking Concrete Pavements

For permeable interlocking concrete pavement (PICP), the pavers themselves are not permeable, rather infiltration occurs through the joints between the pavers (Figure 6). The area of the joint openings is typically between 8 and 10 percent of the overall surface area of the pavement.

For vehicular traffic a minimum paver thickness of 3 1/8 inches is suggested.

Figure 6. Photo. Permeable Interlocking Concrete Pavement.

Bedding Layer and Joint Filler

Traditional interlocking concrete pavers are laid over a thin layer of bedding sand and rely on sand-filled joints to provide the interlock between the pavers. For PICP, the permeable pavers are seated on a 2 inch thick open graded “stone chip” bedding layer to ensure a level surface for the placement of the pavers and to allow infiltration of water into the underlying permeable base/subbase. The joints between the pavers are filled with stone chip similar to the bedding layer to provide interlock between the pavers.

Base/Subbase

The permeable pavement surface layer is underlain by one or more layers of permeable aggregate. These layers provide structural strength to accommodate the design traffic and to detain/retain stormwater infiltrating through the pavement surface. The void content of the aggregates in the reservoir layer is typically 25 to 35 percent (Hein 2014).

Filter Course

While not common, a filter course can be included within the reservoir layer to provide additional water quality treatment. A filter course is designed similarly to filter beds used to treat wastewater. The purpose of a filter course is to remove materials such as oils or solids from the water infiltrating the permeable pavements. A filter course typically consists of a sand layer sandwiched between two aggregate choker courses that are used to prevent the migration of the sand to/from the other aggregate layers in the permeable pavements.

Underdrains

Partial infiltration and low infiltration permeable pavement designs typically include an underdrain at the bottom of the pavement layer. Underdrains are used to convey water from the pavement structure that cannot be infiltrated into the subgrade in a timely fashion. Permeable pavement design guidance generally specifies that stormwater entering a permeable pavement be drained within a period of 24 to 72 hours of the end of the storm (Hein 2011). Underdrains are typically 4 to 6 inches in diameter perforated polyvinylchloride (PVC) pipes.

Outlet Structure

For partial infiltration designs with an underdrain, an outlet structure may be utilized. The outlet pipe at the bottom of the permeable pavement is connected to an underground structure with a V-notch weir that controls the depth of water in the permeable pavement. Water flowing over the weir is then discharged to a storm sewer, ditch or stormwater pond.

Geosynthetics

Geosynthetics such as geotextiles, geogrids and impermeable liners may be used in permeable pavements. Geotextiles may be used as a separation layer between the bottom of the subbase to prevent the migration of soft soils into the base/subbase layers or to protect impermeable liners from puncture during subbase installation. Geogrids may be used within the aggregate layers to enhance the structural capacity of the pavement. Impermeable liners are typically used for low infiltration designs to recover stormwater for reuse or to protect building foundations from water infiltration. Impermeable liners may also be used to prevent water from the permeable pavement infiltrating adjacent non-permeable pavements (Figure 7).

Edge Restraints

Edge restraints are needed around the perimeter of porous asphalt and PICP and are suggested for pervious concrete pavements and at all joints with conventional pavements. Edge restraints should be concrete curb for vehicular use pavements and can be flexible plastic or metal “L” shaped channels fastened with long spikes for areas subjected to only pedestrian use. The concrete curb can be flush with the pavement surface for pavement type transitions. The edge restraints ensure tight and consistent joint widths for PICP and protection for the edges of porous asphalt and pervious concrete pavements.

Figure 7. Photo. Geotextile/Impermeable Liner Installation.

Monitoring Well

Stormwater runoff frequently carries pollutants such as litter, animal waste, fertilizers (nitrogen and phosphorous), heavy metals from rusting vehicles, brake linings and hydrocarbons downstream to rivers, lakes and streams. Permeable pavement systems are able to remove some or all of these pollutants through suspended solids removal, volatilization and biological degradation. For larger permeable pavement applications, a monitoring well may be installed to observe the depth of water in the reservoir layer and to take samples for water quality assessment. The well should be installed at or near the lowest elevation of the permeable pavement.

Design

Permeable pavement design involves consideration of both structural and hydrologic aspects for the pavements. The desire to use a permeable pavement may be influenced by different objectives such as reducing flooding and erosion, improvement of stormwater quality, water harvesting and aquifer recharge. The key to success related to the design of permeable pavements is ensuring that designers have a complete understanding of permeable pavement design practices and then optimizing the design to achieve both the pavement structural and hydrologic performance goals. Some structural and hydrologic technology gaps include:

- Criteria development for the use of mechanistic-empirical design approaches for permeable pavement design.
- Validation of pervious concrete flexural strength for various mixes through laboratory and/or field testing.

- Design for heavier traffic volume and weights.
- Characterization of load/deflection response to develop long-term structural performance characteristics/models.
- Potential impact of moisture conditions and possible reduced structural support of any adjacent pavement/building subgrade.
- Volume reduction and water quality performance studies.
- Water quantity and quality benefits assurances.
- Quantifying pollutant reduction and removal effectiveness.
- Long-term durability and performance of surface and infiltration capacity.

Specifications

Specifications for permeable pavements typically are similar to those used for conventional asphalt, concrete and interlocking concrete pavements. This includes pavement materials sourcing, production, transportation and installation. Quality control/ quality assurance testing requirements are similar to that for conventional pavements. Some gaps in current permeable pavement specifications include:

- Characterization and specification of stabilized bases/subbases.
- Compaction procedures for open graded aggregate bases.
- Codifying methods to measure base/subbase in-situ density.

Construction

The construction of permeable pavements is generally similar to conventional pavement; however, there are some unique characteristics to consider such as construction timing, pre-construction meeting, subgrade compaction, underdrains, base/subbase placement, and construction protection.

Good quality construction is a key component to the long-term success of permeable pavements. Some gaps related to permeable pavement construction include:

- Surface placement, compaction, curing times.
- Base/subbase placement and compaction.
- Methods for measuring surface infiltration.
- Field and laboratory quality control/quality assurance standards for permeable pavement materials.

Maintenance

Maintenance is a key factor for the long-term durability and effectiveness of permeable pavements. Maintenance treatments reduce the risk of premature deterioration, slow the progression of defects, and cost-effectively extend the life of the pavement (Smith 2018).

Maintenance activities and schedules should reflect the objectives and goals for the pavement. For example, if improving water quality of the surrounding watershed is a main objective, then the use of de-icing chemicals may need to be limited. Other keys for success are ensuring that operations and maintenance staff are fully aware of the unique requirements of the permeable pavements and that the monitoring and maintenance is being performed as recommended. Some gaps related to the maintenance of permeable pavements include:

- Maintenance manuals and training.
- Clogging prevention and restoration.
- Deicing and safety.
- Winter maintenance guidance, manuals and training guidelines.
- Comparative analysis of maintenance costs permeable pavements versus traditional pavement.

Summary

The primary drivers for the use of permeable pavements stem from an environmental perspective and less from a specific pavement durability or performance perspective.

Allowing water to flow through (or be temporarily retained in) a pavement, contradicts historical design practices where rapid drainage away from the pavement is considered a fundamental design principle.

While permeable pavements have a long history of use, an owner and the pavement designer assume the performance risk. A thorough understanding of key aspects such as structural strength, long-term performance, and life cycle cost will need to be evaluated and demonstrated in order to reduce these risks.

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