

Permeable Interlocking Pavers

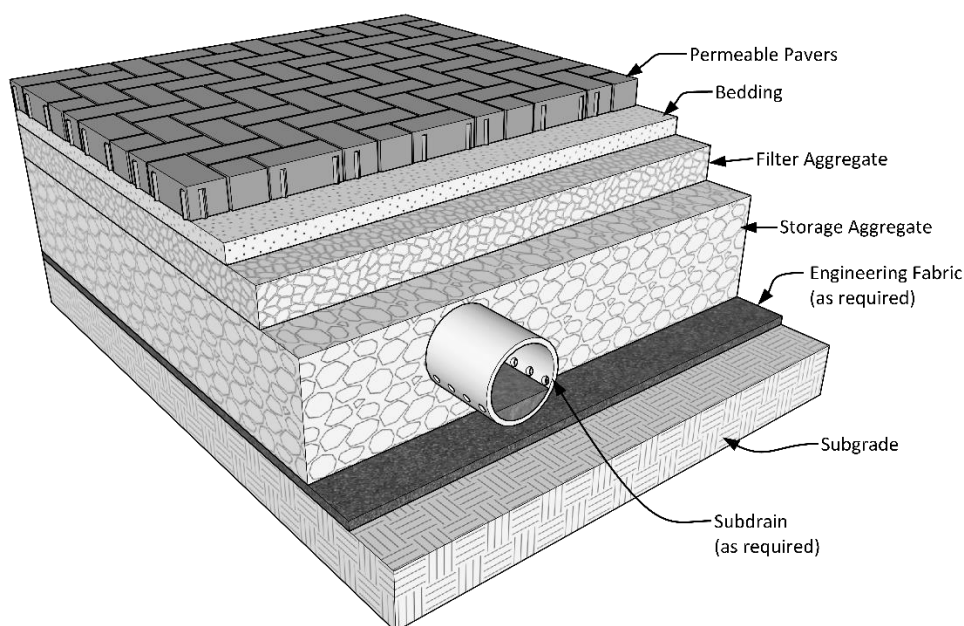
A. General

Permeable pavements are designed to infiltrate runoff, whereas runoff sheds off the surface of conventional pavements. In permeable pavements, runoff passes through the surface and is stored in the aggregate base. In pervious soils, the runoff infiltrates the soil; in less permeable soils, a subdrain system is placed to slowly discharge the runoff. Runoff volume reduction is achieved as the water is infiltrated into the underlying soils. The peak runoff rate is reduced due to the stormwater being stored in the aggregate subbase and slowly released to the downstream piping systems. Traditionally, at a minimum, the depth of the aggregate subbase is designed to meet the storage needs for the Water Quality Volume (WQv), which is 1.25 inches of rainfall in Iowa.

Permeable pavements can dramatically reduce the surface runoff from most rainfall events by disconnecting and distributing runoff through filtration and detention. The use of permeable pavements can result in stormwater runoff conditions that approximate the predevelopment site conditions for the immediate area covered by the pavers.

The design of permeable interlocking pavements (PIP) involves both structural and hydrological analyses. Figure 5K-1.01 illustrates a typical cross-section of a PIP. These two design elements are typically not interconnected and in reality are often in conflict. This is particularly the case with the subgrade treatment and volume of aggregate subbase. Structural design requires a compacted subgrade and the hydrologic design desires an uncompacted subgrade to allow as much infiltration as possible. In most instances, the hydrologic requirements for filter and storage aggregate exceed the structural needs for the unbound aggregate subbase.

Figure 5K-1.01: Permeable Interlocking Paver Cross-section



PIP are used for low speed/low volume streets, alleys, parking lots, and driveways. The design and

operating speed of the facility should be below 35 mph. Permeable paver projects should only be developed in areas dominated by impermeable surfaces or surfaces that are fully vegetated so that sediment runoff is minimized and life of the pavement is maximized. PIP are capable of handling truck traffic.

The following elements should be reviewed prior to undertaking a detailed design process:

- Underlying geology and soils
- NRCS hydrologic soils groups
- History of fill, disturbance, or compaction of underlying soils
- Current drainage patterns and volume of runoff
- Local and downstream drainage facilities
- Distances to potable water supply wells
- Elevation of the static water table
- Traffic volumes, including percent trucks

Because water is stored in the subbase rock, it may be necessary to protect structures that are adjacent to the permeable paver project by sealing the foundation walls. The PIP must be a minimum of 100 feet from a municipal water supply well.

There are two types of permeable interlocking pavers. One type is concrete pavers that are 3 1/8 inches thick; the other type is clay brick pavers that are at least 2 5/8 inches thick. The concrete pavers must comply with ASTM C 936. There are two ASTM standards for brick pavers, depending on the traffic loading. ASTM C 902 is for pedestrian and light vehicular traffic locations. ASTM C 1272 is for heavier vehicular traffic and will be the type listed in the SUDAS Specifications. The clay pavers should be 2 3/4 inches thick, Type F brick for PX applications according to ASTM C 1272.

B. Structural Design

The design procedure for permeable interlocking pavers is the same as for flexible pavements. Research has shown that the load distribution and failure modes of PIP are similar to other flexible pavements. Because the designs are the same as for flexible pavements, the AASHTO *Guide for Design of Pavement Structures* (AASHTO, 1993) can be used. The paver used in design for concrete pavers is a 3 1/8 inch thick paver with a minimum 1 inch bedding layer. The structural coefficient is 0.44 per inch. This provides a structural number of 1.82. The clay brick paver is 2 3/4 inches thick, which has a corresponding structural number of 1.21. The remaining structural support comes from the aggregate layers and the soil subgrade.

The American Society of Civil Engineers has developed a design standard called *Structural Design of Interlocking Concrete Pavement for Municipal Streets and Roadways* (ASCE/T&DI/ICPI 58-10). The structural design for clay brick pavers is the same as for concrete pavers. The engineer will need to determine or select the following:

- Design traffic loading (ESALS)
- Design life (40 years minimum)
- Design reliability (usually 75% to 80%)
- Overall standard deviation (0.45)
- Required structural number to meet traffic loading
- Initial serviceability (flexible pavements = 4.2)
- Terminal serviceability (local streets = 2.0)
- Subgrade resilient modulus based on saturated soil characteristics, including seasonal variability
- Drainage conditions

Once these elements are determined, the design thickness of the unbound aggregate subbase can be

determined. The ASCE design standard has tables showing thickness of the layers that were developed using the AASHTO 1993 Guide. Thickness is selected based on the ESALS, the soil category, and the drainage.

Three types of interlock are critical to achieve: vertical, rotational, and horizontal. Vertical interlock is achieved by the shear transfer of loads to surrounding pavers through the material in the joints. Rotational interlock is maintained by the pavers being of sufficient thickness and aspect ratio (3:1 minimum), being placed close together, and restrained by a curb from lateral forces of vehicle tires. Rotational interlock can be further enhanced if there is a slight crown to the pavement cross-section. Horizontal interlock is primarily achieved through the use of laying patterns that disperse forces from braking, turning, and accelerating vehicles. Herringbone patterns, either 45° or 90°, are the most effective patterns for maintaining interlock. A string or soldier course should be used at the interface between the pavers and the edge restraint.

A PCC edge restraint is typically used for street and alley projects. The edge restraint may be a standard curb and gutter section, a vertical curb section, or a narrow concrete slab, and should be placed on the subbase aggregates.

After placement, the pavers are compacted with a high frequency plate compactor, which forces the joint material into the joints and begins compaction of the paver into the bedding layer. The pavement is transformed from a loose collection of pavers into an interlocked system capable of spreading vertical loads horizontally through the shear forces in the joints.

One of the direct conflicts with the hydrologic design of PIP is the compaction of the subgrade soils. The structural design calls for subgrades compacted to 95% Modified Proctor Density according to AASHTO T 180. The effective compaction depth should be 12 inches minimum. This compaction requirement will prevent efficient infiltration of water through the subgrade and thus will likely necessitate a piping design to handle the stormwater that accumulates in the storage aggregate (unbound subbase).

The engineer should provide a geotextile between the subgrade and the storage aggregate (subbase) as a means of preventing mixing of the materials. The geotextile should comply with [Iowa DOT Section 4196](#) for subsurface drainage.

C. Hydrologic Design

The design process follows traditional storm sewer procedures for pavements. The initial step in the hydrologic design is the determination of the design storm event. Some agencies may establish the storm return period and the rainfall intensity. Information on intensity-duration-frequency for various return periods can be found in Chapter 2. In addition, the contributing area must be determined. The runoff volume should be determined according to the methods described in Chapter 2 using a design rainfall depth of 1.25 inches as a minimum, unless the jurisdiction has a different policy.

The next step involves establishing the drainage area. The storm event is then applied to the drainage area and the volume of runoff is determined.

The permeability of the subgrade soil is a critical design element. If the subgrade soil permeability is less than 1/2 inch per hour, a subdrain piping network will be needed. Soil compaction to support vehicular traffic will decrease permeability. Good design practice for vehicular traffic loads is to provide a minimum CBR of 5. Thus as the soil permeability is determined it should be assessed at the density required to realize a CBR of 5 under soaked conditions.

To maximize the effectiveness of the PIP, the pavement grade should be as flat as possible, although

steeper grades can be used. The general guideline is that the longitudinal grade should be greater than 1% and less than 12%. Three design alternatives exist for the PIP. They are:

- Full infiltration: All of the stormwater runoff from the design storm is infiltrated into the subgrade soils. See Figure 5K-1.02.A.
- Partial exfiltration: Some of the design storm runoff is infiltrated and the remainder is collected in the subdrain system and slowly discharged into the downstream systems. This is accomplished by setting the subdrain pipe above the top of the subgrade. See Figure 5K-1.02.B.
- Full Exfiltration: Soil permeability is limited and thus all of the runoff volume is carried away through the subdrain piping. See Figure 5K-1.02.C.

Designers must also evaluate and provide for larger storm events. One way to provide for the larger storms but still provide for infiltration of the water quality storms is to raise the elevation of the intakes above the pavers so the small storms are infiltrated and the large storms are handled by the intakes and pipe network.

Once the volume of runoff and the soil permeability are known, the thickness of the storage aggregate layer (Iowa DOT Gradation No. 13/ASTM Gradation No. 2) can be determined. The void space (volume of voids/volume of aggregate) for Iowa DOT Gradation No. 13 is 40%. A 40% void space provides 0.4 cubic feet of stormwater storage for each cubic foot of aggregate. Thus, the volume of the storage aggregate will need to be 2.5 times the volume of water to be stored.

Due to the need to compact the subgrade soil to handle vehicles, it is very likely that subdrains will be needed to discharge at least a portion of the runoff. The elevation and sizing of the subdrains should be set to provide for full discharge of the design storm within 72 hours either through infiltration into the subgrade soil or through subdrain pipe discharge.

In order to prevent absorption of the bedding stone into the storage aggregate layer, a layer of filter aggregate (Iowa DOT Gradation No. 3/ ASTM Gradation No. 57) is needed. This layer is typically 4 inches thick. The bedding aggregate (Iowa DOT Gradation No. 29/ASTM Gradation No. 8) is then placed 2 inches thick, compacted, and leveled. Fine graded sand should not be used as the bedding and for filling of voids due to the increased clogging potential.

The pavers are placed, additional bedding stone is added to fill the voids in between the pavers, the area is swept, and finally the pavers are compacted. Sweeping prior to compaction is important to prevent stones on the surface from marring or cracking the pavers. That process may need to be repeated to entirely fill the voids. The final step is to sweep and remove any excess void filler stone.

Figure 5K-1.02: Permeable Interlocking Paver Design Alternatives

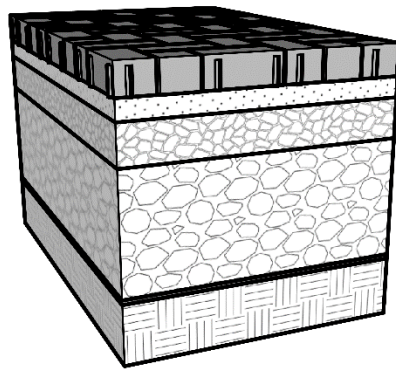


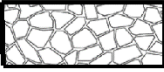
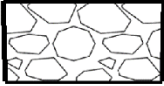




Figure 2.A
Full Infiltration
(Requires soils with infiltration rates greater than 0.5" / hour)

Key

-  Permeable Paver
-  Bedding
-  Filter Aggregate
-  Storage Aggregate
-  Engineering Fabric
-  Subgrade

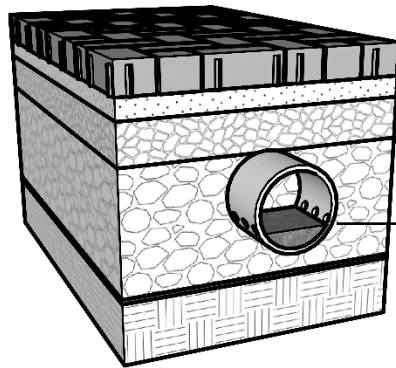


Figure 2.B
Partial Infiltration

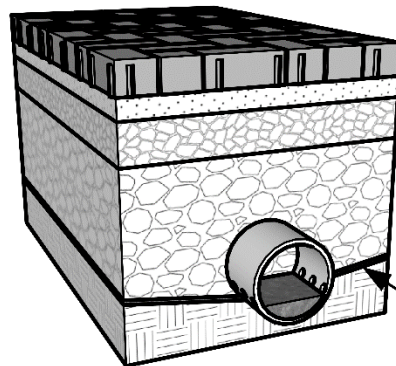


Figure 2.C
Full Exfiltration

D. Construction Elements

Monitoring and controlling the construction activities of a permeable interlocking paver project are critical to the long-term performance of the permeable pavement. Preventing and diverting sediment from entering the aggregates and pavement during construction must be of the highest priority. Aggregate stockpiles must be isolated to prevent contamination by sediment. Erosion and sediment control devices must be placed and maintained throughout the project until vegetation is fully established. All unnecessary vehicle and pedestrian traffic should be restricted once the aggregate placement has initiated. It may be necessary to wash vehicle and equipment tires to prevent tracking dirt and mud onto the aggregate layers.

A test section (approximately 5 feet by 5 feet) should be constructed to provide a basis for construction monitoring. The test section should be placed on the prepared subgrade to illustrate the processes used to place the pavers and illustrate the paver pattern and the edge details.

Restrict all equipment and workers from the paver placement area once the bedding stone has been placed, leveled, and compacted. Pavers may be placed by hand or mechanically. Placement should proceed from one end or side and continue work from the completed placement areas. An important consideration with mechanically placed pavers for large projects is to ensure the wear on the paver molds does not change the size of the pavers and thus impact the ability to correctly place the pavers.

E. Maintenance

As with any pavement, particularly permeable pavements, specific maintenance activities are necessary to achieve the design life of the pavement. PIP can become clogged with sediment that affects its infiltration rate. The rate of sedimentation can depend on the number and type of vehicles using the pavement, as well as the control of erosive soils adjacent to the pavement. The most important element of maintenance is keeping the sediment out of the pavement by vacuum sweeping. Regular vacuum street sweeping will maintain a high infiltration rate and keep out vegetation. Calibration of the vacuum force may be necessary to remove the sediment but minimize removal of the filler material from the joints. Over time, it may be necessary to add additional joint filler material to prevent intrusion by sediment.

Winter maintenance involves plowing snow and applications of de-icing chemicals. Although not required, snowplows can be equipped with rubber edged blades to minimize chipping of the pavers. Use of de-icing chemicals is often not necessary because the PIP remains warmer throughout the winter. Sand should not be used as an abrasive for traction. The sand will clog the filler material in the pavement joints.