2J-1 General Information for Permeable Pavement Systems

A. Introduction

This section provides design guidelines for a group of stormwater management BMPs broadly referred to as permeable pavement systems. In urban watersheds, almost all of the impervious surface area is represented by building rooftops and paved surfaces. In residential areas most of the paved area is represented by the roadway system and residential driveways. Parking lots and paved industrial storage areas represent an even larger portion of the impervious surface in commercial and industrial areas. Impervious pavements can produce two-thirds of the excess runoff in an urban catchment. Runoff from impervious pavements contributes a substantial loading of hydrocarbons and heavy metal pollutants, and contributes greatly to the increased temperature of surface runoff. In most urban jurisdictions, a paved roadway system with a traditional curb and gutter configuration provides a key component of the overall urban drainage system. Surface flow from adjoining tributary watersheds is conveyed directly into catch basin inlets and connected piping systems. In these traditional impervious paved systems, the runoff coefficient (runoff volume) is increased and the time of concentration (T_c) is decreased resulting in increased peak rates of runoff.

Permeable pavement includes a variety of stabilized surfaces that can be used for the movement and parking of vehicles (automobiles, trucks, construction equipment, light aircraft, etc.) and storage of materials and equipment. Compared to conventional pavement, these pavements are designed to infiltrate stormwater runoff instead of shedding it off the surface. Permeable pavement systems reduce the amount of runoff by allowing water to pass through surfaces that would otherwise be impervious. The storm water passes through the load bearing surface and aggregate subbase that are selected based upon the intended application and required infiltration rate. Runoff is stored in the stone aggregate subbase course and storage layer, and allowed to infiltrate into the surrounding soil (functioning like an infiltration basin). For less permeable subsoils, a subdrain system can be placed in the aggregate subbase to collect and convey runoff from larger storm events to the storm sewer system or directly to receiving waters (functioning like a surface sand filter). Water can infiltrate into the ground if soil permeability rates allow, be conveyed to other downstream BMPs, or routed through a subdrain and piped to an adjacent storm water system. Since the pavement surface is permeable these pavement systems can effectively reduce the volume and peak rate of runoff compared to traditional impervious pavement surfaces. The value of permeable pavement systems includes:

- *Runoff volume reduction* is achieved when permeable pavements are placed over permeable soils and a defined volume of the water passing through the pavement is infiltrated into the soil subgrade below.
- *Peak runoff rate reduction* is achieved when the volume of water passing through the pavement surface is "detained" for a defined period of time within the pavement cross-section and the open-graded aggregate subbase beneath the pavement. The effective infiltration rate for the watershed is increased by trapping the water in the permeable surfaces and effectively increasing the time of concentration in the catchment area. The depth of the aggregate subbase can be designed to meet varying degrees of stormwater detention from the Water Quality Volume (WQv) up to the Channel Protection Volume (CPv). For sites using underground detention for peak discharge control (Qp), a permeable pavement system can provide an efficient method to move water into the underground storage.

- Water quality is improved by capturing pollutants in the open matrix of the pavement structure. Removal of soluble pollutants is achieved by moving a portion of the water into the subsoil though infiltration.

B. General description

Permeable pavements offer the advantage of decreasing the effective imperviousness (I_A) of a new urbanizing area or redevelopment site, thereby reducing runoff and pollutant loads leaving the site. Permeable pavements can be designed with and without underdrains. When underdrains are used, infiltrated water will behave similarly to interflow and will surface at a much reduced rate over extended periods of time. All types of permeable pavement help return stormwater runoff hydrology to more closely resemble pre-developed conditions. The designer needs to consider the development site and soil conditions to ensure the suitability of each type of permeable pavement for the loads and traffic it will support and carry, as well as the geologic conditions the pavement will rest upon. What follows is a description of five types of permeable pavement and defines their acronyms. These will be used throughout the remainder of this section of the manual:

Permeable pavements can be divided into the following general categories.

- **Pervious concrete:** Open graded portland cement concrete surface. (See Section 2J-2).
- **Porous asphalt:** Uniformly graded hot mix asphalt. (See Section 2J-3).
- **Permeable pavers:** Two types are included in this category. The first type is monolithic units that do not have void areas incorporated in the pavers. The second type includes manufactured paving units with incorporated void areas that are filled with pervious materials such as gravel or grass turf. (See Section 2J-4).

Permeable pavement systems can replace traditional pavement allowing rainfall and runoff from adjacent contributing areas to infiltrate directly through the pavement surface and receive water quality treatment. Unlike traditional concrete pavement, pervious concrete pavement contains little or no "fine" aggregate materials. Removing the fine aggregate from the concrete mix creates voids that encourage infiltration. Porous asphalt pavement consists of an open-graded coarse aggregate, bonded together by asphalt cement, with sufficient interconnected voids to make it highly permeable to water. Pervious concrete typically consists of specially formulated mixtures of cementitious materials, a uniform open-graded coarse aggregate, and water. Pervious concrete and porous asphalt have enough void space (approximately 15% to 18%) to allow rapid percolation of water through the pavement. Permeable pavers and modular pavements, including concrete and brick pavers, geowebs, and manufactured concrete and plastic units, have void areas that are filled with sand, gravel, or grass to allow infiltration. Other alternative paving surfaces can help reduce runoff from paved areas, but do not incorporate an aggregate subbase layer or trench for temporary storage below the pavement. While permeable pavement can be a highly effective treatment practice, maintenance and proper installation are necessary to ensure its long-term effectiveness.

1. **Advantages/disadvantages.** Aside from the potential for high particulate pollutant removal and the removal of other constituents similar to what a sand filter would provide, permeable pavements of all types can dramatically reduce the surface runoff from most rainstorms and snowmelt events and virtually eliminate surface runoff from smaller storms. These reductions in runoff volumes translate directly to proportional reductions in pollutant loads leaving the site. The use of permeable pavements can result in stormwater surface runoff conditions that approximate the predevelopment site conditions. These BMPs can be used in selecting surface retention and infiltration parameters that are close to pre-developed conditions when using stormwater runoff hydrologic models. Even when underdrains are used, the response time of runoff is significantly delayed and approaches the characteristics of what is sometimes called interflow. As a result, drainage and downstream flooding problems can be significantly reduced.

This can translate in savings since the downstream facilities needed to address site runoff rate and volume, such as detention volumes and conveyance facilities, can be smaller.

Another advantage is creative selection by land planners and landscape architects of materials, patterns and colors to provide aesthetic enhancements to what are often are very plain surfaces.

The primary disadvantage of permeable pavements is that they cost more to install and maintain than conventional concrete or asphalt pavement. These added costs can be somewhat offset by the cost savings in the downsizing of on-site and downstream drainage systems and facilities such as detention basins, numbers of inlets, storm sewers and channels. Other disadvantages can include a somewhat rougher surface texture for walking and other activities.

2. **Physical site suitability and need for underdrains.** All types of permeable pavements can be installed over low permeability subsoils by providing underdrain piping systems. An underdrain insures that the aggregate subbase is drained when the subsoils or site conditions do not allow infiltration. In the case where the installation is located on top of expansive soils, the installation of an impermeable liner along with underdrains is strongly recommended. The liner is needed to prevent wetting the underlying expansive clays. In addition, permeable pavements installed over expansive soils should not be located adjacent to structure foundations in order to reduce the potential for damages to structures.

   A continuous impermeable liner with underdrains should also be used whenever a commercial or industrial site may have activities, or processes, that could result in the storage and/or handling of toxic or caustic chemicals, fertilizers, petroleum products, fats, or greases. The impermeable liner is designed to prevent groundwater and soil contamination should such products or materials come into contact with stormwater and could infiltrate into the ground. If the site is expected to have contaminants mentioned above, the underdrains are directed or connected to runoff capture and treatment facilities.

3. **Pollutant removal.** Specific field data on the reductions of pollutant concentrations by various permeable pavements are limited. However, reductions in the concentrations of total suspended solids and associated constituents, such as metals, oils, and greases appear to be relatively high. The fact that all permeable pavements significantly reduce the average annual runoff volume makes them very effective in reducing pollutant loads reaching the receiving waters. Infiltration of stormwater runoff through the pavement surface will provide a degree of suspended solids removal followed by additional removal of colloidal solids and soluble pollutants in the aggregate subbase and subsoils. Sorption of metals to colloidal solids and within the pavement void matrix is another removal function. Soluble organic pollutants adsorbed within the pavement void matrix and the open graded aggregate subbase will be exposed to biodegradation over time. Adsorption and ion exchange occur as stormwater travels through the unsaturated (vadose) zone below the aggregate base and reduce the particulate and dissolved pollutant loading to the groundwater (saturated zone).

   Permeable pavement can be used to provide ground water recharge. Some data suggest that as much as 70% to 80% of annual rainfall will go toward ground water recharge (Gburek and Urban, 1980). This data will vary depending on design characteristics and underlying soils. Two studies have been conducted on the long-term pollutant removal of permeable pavement, both in the Washington, DC area. They suggest high pollutant removal, although it is difficult to extrapolate these results to all applications of the practice. The results of the studies are presented in Table 1.

Table 1: Effectiveness of permeable pavement pollutant removal

Study	Pollutant Removal (%)				
	TSS	TP	TN	COD	Metals
Prince William, VA	82	65	80	-	-
Rockville, MD	95	65	85	82	98-99
Source: Schueler, 1987					

A third study by Brattebo and Booth (2003) indicates that many trademarked permeable paver systems effectively reduced concentrations of motor oil, copper, and zinc. Furthermore, the study found that almost all precipitation that fell on the permeable pavers infiltrated even after 6 years of daily use as a parking area.

4. **Reduction in effective site imperviousness and stormwater runoff volume.** When using permeable pavements the site designer can take advantage of the fact that it reduces the effective surface runoff rates and volumes. All of the three main types of permeable pavement (pervious concrete, porous asphalt, permeable pavers) have very high initial surface infiltration rates and all can immediately infiltrate and store rainfall and runoff from high intensity rainstorms. In many cases, direct runoff is completely eliminated. The surface infiltration rates for these pavements will in most cases exceed 200-250 inches/hour. This is several orders of magnitude higher than all the rainfall intensities encountered in the upper Midwest. These high infiltration rates are also 2-3 orders of magnitude higher than most soil infiltration rates. Permeable pavements rely on the ability of the void space within the surface material and the subbase to receive, store, and infiltrate water into the underlying subsoils. The aggregate subbase provides a temporary "reservoir", receiving the inflow from the surface pavement layer and providing temporary storage while the water is discharged to the subgrade through infiltration or released to surface discharge through a subdrain system. The reduction in runoff volume is achieved by infiltrating all or a portion of the "collected" rainfall or runoff. The primary limitations to the reduction in volume will be the infiltration rate of the subgrade soils and the depth to the seasonal high water table. The infiltration rate and the area under the pavement will control the "drain-down" time for the accumulated water in the subbase. The goal is to "empty" the aggregate reservoir before the next rainfall event occurs. A maximum time of 72 hours is typical, while a 48 hour drain-down represents a more conservative approach. Sites with soil infiltration rates $\geq$ 0.5 inches/hour will, in most cases, be able to infiltrate the WQv from the site drainage area within a 24-48 hour time period. For larger storm events (i.e. Cpv for the 1 year, 24 hour storm or the 2 year storm) a perforated subdrain placed in the aggregate layer can be placed and configured to release the water from the aggregate "reservoir" at a controlled rate.

   Like all BMPs, permeable pavement can and should be combined with other practices to capitalize on each technology's benefits and to allow protection in case of BMP failure. However, construction using pervious materials may not require as much treatment as other BMP approaches. For instance, a small facility using permeable pavement may only need several bioretention basins or a grass swale, rather than a full dry detention basin. This combined approach might prove less land intensive and more cost effective. It may increase the amount of open space for public or tenant use. It may also lead to an increase in environmental benefits.

5. **Applications.** Medium traffic areas are the ideal application for permeable pavement. It may also have some application on highways, where it is currently used to reduce hydroplaning. In some areas, such as truck loading docks and areas of high commercial traffic, the permeable pavement design will need to include consideration of vehicle traffic loads (ESALs), soil classification (USCS), and strength (CBR) for determining required base thickness for structural

support. In these instances, the aggregate base material provides both strength and storage function for the pavement system.

6. **Regional applicability.** Permeable pavement is suitable for most regions of the country, but cold climates present special challenges. Road salt contains chlorides that may migrate through the permeable pavement into ground water. Plowing may present a challenge to block pavers, because snow plow blades can catch the block's edge and damage its surface. Infiltrating runoff may freeze below the pavement causing frost heave, though design modifications can reduce this risk. These potential problems do not mean that permeable pavement cannot be used in cold climates. For the cold wet-freeze conditions encountered in Iowa and the upper Midwest, the site design must consider a reliable drainage system for the aggregate and upper portion of the subgrade. A common site design includes a perimeter drain installed below the typical frost line as a conservative method to prevent possible frost action. Research at a full-scale pervious concrete parking facility at Iowa State University has shown temperatures in the pervious pavement, aggregate, and subsoil remain above freezing for all but the very coldest of winter conditions. The open void space in the pavement and aggregate allows for convection movement of warmer air from the underlying soils. Additionally, the open void space allows for expansion of any water that may freeze within the aggregate or the pavement surface during wet-freezing rain events. A pervious concrete mix design has been developed at Iowa State University that provides a durable and freeze-thaw resistant material (Section 2J-2).

7. **Stormwater hot spots.** Stormwater hot spots are areas where land use or activities generate highly contaminated runoff. Hot spot runoff frequently contains pollutant concentrations exceeding those typically found in stormwater. Hot spots include commercial nurseries, auto recycle facilities, fueling stations, storage areas, industrial rooftops, marinas, outdoor container storage of liquids, outdoor loading and unloading facilities, public works storage areas, hazardous materials generators (if containers are exposed to rainfall), vehicle service and maintenance areas, and vehicle and equipment washing and steam cleaning facilities. Since permeable pavement is an infiltration practice, it should not be applied at stormwater hot spots due to the potential for ground water contamination (see exception for no exfiltration systems with liners).

8. **Stormwater retrofit.** A stormwater retrofit is a stormwater management practice (usually structural) installed post development to improve water quality, protect downstream channels, reduce flooding, or to meet other specific objectives. The best retrofit application for permeable pavement is parking lot replacement on individual sites. If many impervious lots are replaced with pervious concrete, permeable interlocking concrete pavers, or porous asphalt, then overall stormwater peak flows can be reduced.

9. **Cold water streams.** Permeable pavement can help lower high stormwater runoff temperatures commonly associated with impervious surfaces. Stormwater pools on the surface of conventional pavement, where it is heated by the sun and the hot pavement surface. By rapidly infiltrating rainfall, permeable pavement reduces stormwater exposure to sun and heat.

10. **Siting and design considerations.** A preliminary assessment of the site should be conducted prior to detailed design and hydrologic evaluation. This initial assessment is similar to the procedures presented in Part 2E - Infiltration Practices and includes a review of the following:
    - Underlying geology and soil maps
    - Preliminary identification of the NRCS soil classifications for the site: texture classification and hydrologic soil grouping (HSG_A/B/C/D)
    - Preliminary assessment of engineering, physical, and chemical properties can be obtained from the NRCS/USDA soil survey data
    - Determining evidence of fill soil or previous disturbance or compaction

- Determination of local topography and drainage patterns for the site and contributing catchment area
- Determining absence of stormwater hotspots in the contributing catchment area
- Identification of existing and proposed land use in the contributing catchment area

11. Rainfall and traffic data.

The design of the pavement system will require the following data:

- The total contributing catchment area and percent of impervious surface draining to the permeable pavement system.
- The design storm used for the project. The typical and minimum design for permeable pavement systems is the Water Quality Volume (WQv). As discussed in Section 2B, the WQv design storm event for Iowa is a depth of 1.25 inches.
- Permeable pavement systems can be designed for larger and less frequent events such as the 1 year, 24 hour duration rainfall for Channel Protection Volume (CPv), or possibly 2 year up to 5 year recurrence interval storms.
- The design of permeable pavement systems is a volume-based design. While the Rational method can be used to determine the peak runoff rate (cfs), the recommended approach is to use the simplified methodology for WQv or the NRCS CN method for larger storms. The NRCS WINTR55 computational method will provide a runoff volume in inches for any desired storm up through the 100 year reoccurrence interval event. (See Part 2B and Sections 2C-5, 2C-6, and 2C-9).
- An estimate of the vehicle traffic loading expressed as 18,000 kip (80kN) equivalent single axle load (ESALs) over the design life of the pavement (typically 20 years).

Permeable pavement has the same site design considerations as other infiltration practices (see Part 2E). The site needs to meet the following criteria:

- Soils should have a permeability of at least 0.5 inches per hour. An acceptable alternative design for soils with low permeability would be the installation of a subdrain system within the aggregate subbase and a connection to the traditional storm sewer system (with approval from the local jurisdiction). This modified design allows the treatment of stormwater from small to medium stormwater events while allowing a bypass for large events, which will help prevent flooding.
- The configuration and condition of adjacent catchment area contributing direct runoff onto the permeable pavement. Uncontrolled sediment loading from these areas can cause premature failure of the pavement system.
- The bottom of the stone reservoir should be flat, so that runoff can infiltrate through the entire surface.
- If permeable pavement is used near an industrial site or similar area, the pavement should be sited at least 2 to 5 feet above the seasonally high ground water table and at least 100 feet away from drinking water wells.
- Permeable pavement should be sited on low to medium traffic areas such as recreational trails, walkways, parking lots, and possibly residential roads. The use of permeable pavements for roadways in the upper Midwest should consider the additional potential for increased sediment loading from the adjacent right-of-way area and the traditional use of sand and de-icing chemicals in the winter. A detailed plan for increased annual maintenance should be considered in this case.
- Slopes should be flat or gentle (0.5 to 1.0%) to facilitate infiltration versus runoff.

12. Exfiltration

a. **Full or partial exfiltration.** A design for *full exfiltration* means the water infiltrates directly into the base and exfiltrates to the subsoil. This is the most common application where the site soils have high to moderate permeability. Overflows from larger, infrequent storm events are managed with perimeter conveyance to swales, bioretention areas or storm sewer intakes. *Partial exfiltration* does not rely completely on exfiltration of the base reservoir for release of all the captured runoff. Some of the water may infiltrate into the subgrade soil profile while the remainder is conveyed out of the system through perforated underdrain piping. The underdrain piping can discharge to a surface outfall at a swale or bioretention area, or can be connected directly to an adjacent stormsewer structure. For some applications, the depth of the aggregate subbase can be increased to handle larger storms to manage the Channel Protection Volume (CPv), which is based on releasing the runoff from a 1 year, 24 hour storm. Figures 1 and 2 illustrate the configurations for full and partial exfiltration, respectively.

b. **No exfiltration.** When the site soils have very low permeability and low strength, or there are other site limitations, a system with no exfiltration can be used. For sites where pollutant loads may exceed the capacity of the soil base to provide treatment, an impermeable liner may be used. Examples of liner materials are polyethylene (HDPE), ethylene diene monomer (EPDM), rubber asphalt, or asphalt-based materials. While an infiltration based practice is not generally recommended where there is a stormwater hotspot, a permeable pavement system with a liner could be a feasible solution. The permeable surface reduces the direct runoff potential and the liner system provides a final capture system to allow the pollutants to be retained and removed for off-site disposal. Figure 3 illustrates a no exfiltration system. The permeable pavement surface in the following illustrated systems can be any of the three general types of permeable pavements.

Figure 1: Full exfiltration through the soil subgrade surface

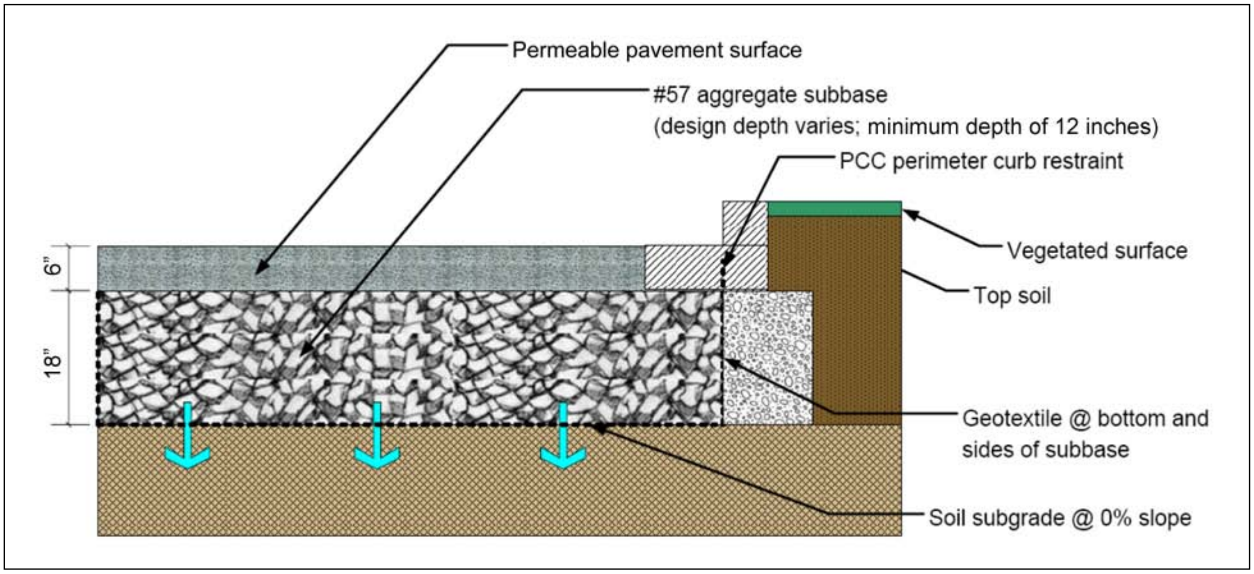


Figure 2: Partial exfiltration through the soil subgrade surface

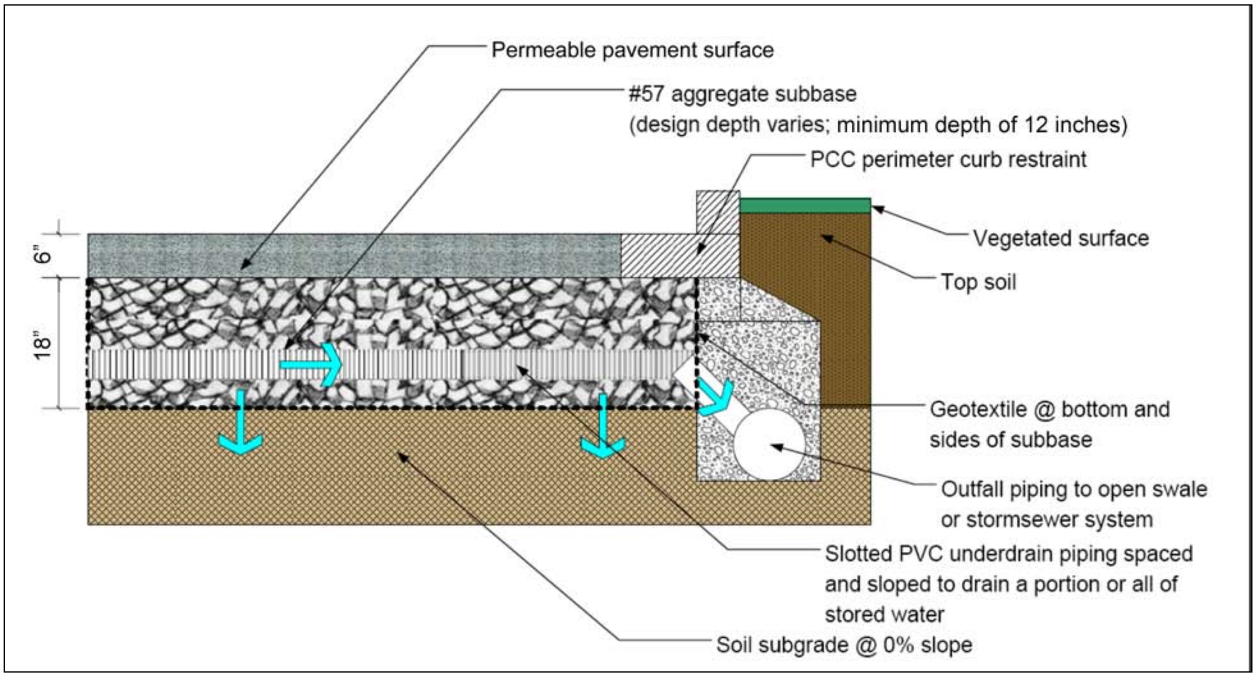
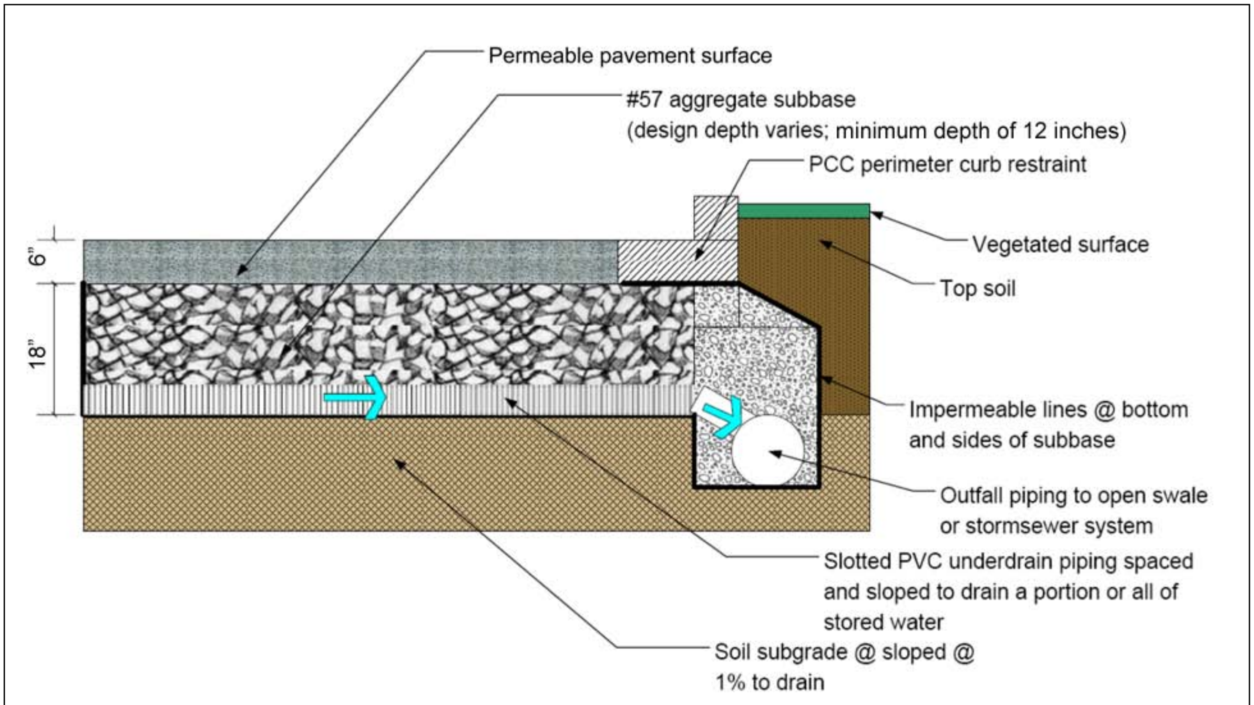


Figure 3: No exfiltration through the soil subgrade surface



13. **Soil subgrade sampling and analysis.** The site soils characterization should be supervised by a licensed professional engineer with experience in soil sampling procedures. The assessment should include soil borings and/or test pits and other testing as required to determine design strength, permeability, soil density, and depth to water table.

    Test pits (dug with a backhoe) or soil borings (Shelby tubes) are recommended for every 7,000 square feet of pavement with a minimum of two holes per site. The depth of all pits or samples should be at least 5 feet deep with soil logs recorded to at least 4 feet below the proposed bottom of the pavement subbase material. Additional holes at varying depth may be required in areas where soil types are variable, near shallow bedrock, in low-lying areas or where the water table is likely to be within 8 to 10 feet of the surface. Confirmation of a high water table, impermeable soil layers, expansive clays, or fractured bedrock may require a pavement design with no exfiltration.

    The following tests are recommended to determine the suitability of the site soils in supporting traffic loads under saturated conditions:

    - Unified Soil Classification System (USCS) using ASTM D 2487 (17).
    - Sieve analysis and gradation of the subgrade soils.
    - Sampled moisture content in percent.
    - Onsite tests for the infiltration rate of the soils. Several test methods are described in Section 2E-7 for initial determination of soil permeability and for final confirmation of the design infiltration rate for the soils. All tests for infiltration should be done at the elevation corresponding to the bottom of pavement subbase (i.e. interface of the subbase and uncompacted soil subgrade). The recommended test method for determining the design infiltration rate is ASTM D 3385 (19) Test Method for Infiltration Rate of Soils in the Field Using a Double-Ring Infiltrometer. For soils with an expected infiltration rate of 1.4×10^{-2} inches/hour to 1.4×10^{-5} inches/hour, ASTM D 5093 (20) Test Method for Field Measurement of Infiltration Rate Using a Double-Ring Infiltrometer with a sealed Inner Ring

is used. The typical percolation tests for the design of wastewater soil adsorption fields are not recommended for design of stormwater infiltration systems.

- As discussed in Part 2E, Infiltration Practices, a factor of safety of 2.0 is recommended in the determination of the final design infiltration rate. Application of the safety factor will compensate for decreases in infiltration rate during construction and over the life of the permeable pavement system.

Soils with a tested permeability equal to or greater than 0.50 inches/hour will usually be gravel, sand, loamy sand, sandy loam, loam and silt loam (See Section 2E-1). These soils will usually have no more than 10-12% passing the No. 200 sieve. These soils would be characteristic of NRCS Hydrologic Soil Groups A and B. Silt and clay soils will likely have lower permeability and not be suitable for full exfiltration from the open-graded subbase. For the cold wet-freeze climate in Iowa and the Upper Midwest the lowest recommended design infiltration rate for the soil subgrade is 0.25 inches/hour.

For optimum infiltration the subgrade would have less than 5% passing the No. 200 sieve. Soils with up to 25% passing the No. 200 may provide adequate infiltration depending on site conditions, degree of compaction, and other characteristics. Soils with a permeability less than 0.50 inches/hour can be used for infiltration as long as the soil remains stable while saturated, particularly when loaded by vehicles. Under these conditions, a subdrain system will be required. Table 1 summarizes the permeability of soils using the USCS as well as typical ranges of the California Bearing Ratio (CBR) for the classifications. These are general guidelines and additional field and laboratory testing may be warranted for sites with variable soil conditions.

To qualify for use under vehicular traffic loads, a typical pavement design would call for a soil CBR (minimum 96 hours soaked per ASTM S 1883) of at least 5%. The compaction required to achieve this will likely reduce the infiltration rate of the soil. Therefore, the permeability or infiltration rate of the soil should be assessed at the density required to achieve 5% CBR. Soils with a lower soaked CBR or expansive soils can be treated to raise the CBR above 5%. Treatment can be accomplished with cement, lime or lime/flyash (expansive soils) to raise the CBR. For most applications, the subbase placed under the permeable pavement will raise the subgrade CBR to over 5%. The subbase layer should have a minimum soaked CBR of 20% and be a minimum of 8 inches in depth. A geotextile is also recommended as a separation layer between the subgrade and subbase.

14. **Soil compaction.** Soil compaction will decrease the soil infiltration rate. Compaction and decreased infiltration will shorten the design life of the permeable pavement system. Use and diligent site control of tracked construction equipment moving across the excavated subgrade will minimize additional compaction. Wheeled construction equipment should be kept off the excavated subgrade. Pedestrian applications such as recreational trails should not require soil subgrade compaction and it should be avoided if possible for vehicular applications. Most permeable pavement applications will be constructed on undisturbed native soils. A common exception would be redevelopment of an existing traditional paved parking structure with a new permeable pavement. Soil excavations will typically be 2-3 feet in depth and cut into consolidated soil horizons that provide some stability when wet. In most cases, the exposed soil layer will not require compaction except for static rolling after grading to provide a smooth subgrade surface for checking final grade, installation of the geotextile and subdrain piping, and placement of the open-graded subbase. Some heavier clays will require compaction to provide stability when wet. These will likely be soils with a low CBR (< 4%) and will already have low infiltration rates prior to compaction. In this case, the compaction will make little difference in the infiltration rate and the design will be based on partial exfiltration by using slotted underdrain piping to remove existing water at the bottom of the subbase reservoir.

Table 2: Suitability of soils (Unified Soils Classification System) for infiltration of stormwater and bearing capacity

USCS Soil Classification	Range of typical Permeability coefficient, k (inches/hr)	Relative permeability when compacted and saturated	Shear strength when compacted	Compressibility	Typical range of CBR values
GW-well graded gravels	1.3 to 137	Pervious	Excellent	Negligible	30 - 80
GP-poorly graded gravels	6.8 to 137	Very pervious	Good	Negligible	20 – 60
GM-silty gravels	1.3×10^{-4} to 13.5	Semi-pervious to impervious	Good	Negligible	20 – 60
GC-clayey gravels	1.3×10^{-4} to 1.3×10^{-2}	Impervious	Good to fair	Very low	20 – 40
SW-well graded sands	0.7 to 68	Pervious	Excellent	Negligible	10 – 40
SP-poorly graded sands	0.07 to 0.7	Pervious to semi-pervious	Good	Very low	10 – 40
SM-silty sands	1.3×10^{-4} to 0.7	Semi-pervious to impervious	Good	Low	10 – 40
SC-clayey sands	1.3×10^{-5} to 0.7	Impervious	Good to fair	Low	5 – 20
ML-inorganic silts of low plasticity	1.3×10^{-5} to 0.07	Impervious	Fair	Medium	2 – 15
CL-inorganic clays of low plasticity	1.3×10^{-5} to 1.3×10^{-3}	Impervious	Fair	Medium	2 – 5
OL-organic silts	1.3×10^{-5} to 1.3×10^{-2}	Impervious	Poor	Medium	2 – 5
MH-inorganic silts of high plasticity	1.3×10^{-6} to 1.3×10^{-5}	Very impervious	Fair to poor	High	2 -10
CH-inorganic clays of high plasticity	1.3×10^{-7} to 1.3×10^{-5}	Very impervious	Poor	High	2 – 5
OH-organic clays	Not appropriate under permeable pavements				
PT-peat, mulch, soils w/high organic content	Not appropriate under permeable pavements				

Source: (10), (11), (12)

C. Design considerations

Some basic features should be incorporated into all permeable pavement practices. These design features can be divided into four basic categories: pretreatment, treatment, conveyance, and landscaping.

- ***Pretreatment.*** Protect the permeable pavement surface from excessive sediment loading caused by poor erosion control in the contributing drainage area. The single largest contributing factor for premature failure of permeable pavements is clogging with sediment. The most critical time is during initial construction or re-development of a site when the permeable pavement is placed before the remainder of the site drainage area is stabilized for erosion and sediment control. The preferred option would be to complete the stabilization of the contributing drainage area with vegetation and/or “effective” erosion and sediment control prior to placing the new permeable pavement. In permeable pavement designs, the pavement itself acts as pretreatment to the stone reservoir below. Periodic maintenance of the surface, such as sweeping, is critical to prevent clogging. Permeable pavements will not need to be sanded in the winter for ice control. In fact, the application of sand can lead to premature clogging of the voids in the pavement. If ice control is needed, then a conservative application of de-icing chemical is recommended. Portland cement pervious concrete pavements should not receive any salt for the first winter of operation.

- ***Treatment.*** The stone reservoir is composed of layers of small stone or open-graded aggregate placed directly below the pavement surface. The aggregate subbase below the permeable surface should be sized to attenuate storm flows for the storm event to be treated. Typically, permeable pavement is sized to treat a small event, such as a water quality storm (i.e., the storms that will be treated for pollutant removal). The water quality design storm in Iowa is 1.25 inches (see Section 2B). As in infiltration trenches, water can be stored in the voids of the stone reservoir. During storage in the aggregate layer, pollutants can be removed through adsorption within the material, biological degradation, fine sediment removal, and filtration of pollutants in the upper layer of the soil vadose zone. Oils and greases will generally be trapped in the pavement profile and within the aggregate matrix.
- ***Conveyance.*** Water conveyed to the stone subbase though the pavement surface infiltrates into the ground below. A geotextile fabric liner and/or a sand layer are placed below the stone reservoir to prevent preferential flow paths and to maintain a flat bottom. The geotextile filter material can also prevent the movement of fine silts and clays into the aggregate layer from the surrounding soils and cause premature blinding of the aggregate/soil interface. If used, the geotextile material should meet the following general criteria: a non-woven fabric meeting ASTM D 4833 (puncture strength - 125 pounds); ASTM D-3786 (Mullen burst strength – 350 psi); ASTM D 4632 (Tensile strength – 200 LB); Fabric shall have 0.08 inch thick Apparent Opening Size (AOS) of #80 sieve, and maintain a minimum flow rate of 90 gpm/ft^2 flow rate. The design also requires a means to convey larger amounts of stormwater to the storm drain system. This can be accomplished with a subdrain system placed up in the aggregate subbase to convey the accumulated water directly to an adjacent open swale or to the stormsewer system. Storm drain inlets set slightly above the pavement surface is another option. This allows for some ponding above the surface, but bypasses flows too large to be treated by the system or when the surface clogs.
- ***Landscaping.*** For permeable pavement, the most important landscaping feature is a fully stabilized upland drainage area. Reducing sediment loads entering the pavement will reduce the rate of clogging and prolong the life of the pavement system.

1. **Geotextiles and filter layers.** Fine and colloidal particles suspended in stormwater runoff will be deposited in the pores of adjacent material surfaces. In the case of permeable pavements, particles will be deposited in and on the downstream soil matrix, the aggregate subbase, the bedding course under permeable pavers, the aggregate in permeable paver joint openings, in the pervious concrete and porous asphalt pore spaces, and in the geotextile. The build up of fines eventually clogs and reduces the permeability of these materials. To reduce the clogging, filter criteria must be met whenever there is change in materials. While aggregate materials can be used as filters, the use of geotextiles more common and often more cost effective. Figure 4 provides geotextile filter criteria from the FHWA (14) and AASHTO (15).

Figure 4: Geotextile Filter Criteria

U.S. Federal Highway Administration (FHWA)
For fine grained soils with more than 50% passing the No. 200 sieve:
Woven geotextiles: Apparent Opening Size (AOS) $\leq D_{85}$
Non-woven geotextiles: $AOS_{geotextile} \leq 1.8\ D_{85}$
AOS $\leq$ 0.3 mm or $\geq$ No. 50 sieve

For granular soils with 50% or less passing the No.200 sieve:
All geotextiles $AOS_{geotextile} \leq B \times D_{85soil}$
Where:
$B = 1$ for $2 \geq C_u \geq 8$
$B = 0.5$ for $2 \geq C_u \geq 4$
$B = 8/C_u$ for $4 < C_u < 8$
$Cu = D_{60}/D_{10}$ (Uniformity coefficient)

Permeability criteria: k (fabric) $\geq$ f (soil)

Clogging criteria
Woven: Percent of open area $\geq$ 4%
Non-woven Porosity $\geq$ 30%

American Association of State Highway and Transportation Officials (AASHTO)
For soils $\leq$ 50% passing the No. 200 sieve:
$O_{95} < 0.59$ mm ($AOS_{fabric} \geq$ No. 30 sieve)

For soils > 50% passing the No. 200 sieve:
$O_{95} < 0.30$ mm ($AOS_{fabric} \geq$ No. 50 sieve)

Notes:
1. D_x is particle size at which x percent of the particles are finer. Determined from the gradation curve. i.e. D_{10} is the size particle of soil or aggregate gradation for which 10% of the particles are smaller and 90% are larger.
2. O_x is geotextile size corresponding to x particle size based on dry glass bead sieving. i.e. O_{95} is the geotextile size opening for which 95% of the holes are smaller.
3. Apparent opening size (AOS) is essentially the same but normally defined as a sieve number rather than as a size (ASTM D 4751). POA is percent open area (for woven fabrics only).
4. Permeability, K, of the soil and geotextile (non-woven only) are designated k_s and k_G respectively.

Source: (14), (15)

2. **Subbase and bedding materials.** The following data are required for materials used for the subbase (pervious concrete, porous asphalt, permeable pavers) and for the bedding and aggregate in the openings between the permeable pavers.
   - Sieve analysis, including washed gradations IAW ASTM C 136.
   - Void space in percent for the open graded base IAW ASTM C 29.

a. Crushed stone, open-graded subbase. This material should be a hard durable rock with 90% fractured faces and a LA Abrasion of < 40. A minimum effective porosity of 0.32 and a design CBR of at least 80% are recommended (12, 13).The water storage capacity of the open-graded subbase will vary with depth and the percent of void space. The material supplier can provide the nominal porosity and gradation or independent testing can be called out in the materials specifications.

Crushed aggregate meeting ASTM No. 57 is commonly used for open-graded subbases along with ASTM No. 2 to No. 4. These materials are widely available and they are recommended for most permeable pavement applications. These materials will have a nominal porosity (volume of voids/total volume of base) over 0.32 and a storage capacity in the void space (volume of voids/volume of aggregate) approaching 40%. A 40% void space provides 0.4 cubic feet of storage capacity for each cubic foot of aggregate (the volume of the base will need to be 2.5 times the volume of water to be stored).

For permeable paver applications, the large size of the No. 57 aggregates creates an uneven surface when compacted. To provide a smooth and level surface for the placement of the pavers, a bedding course of ASTM No. 8 crushed aggregate is placed and compacted into the No. 57 open-graded base. The No. 8 bedding material is commonly called choke stone since it stabilizes and partially closes the surface of the open-graded base. The thickness of the No. 8 bedding layer should not exceed 2 inches prior to compaction. The No. 8 aggregate should be similar in hardness and shape to the No. 57. All of the materials need to be clean, washed material with less than 1 to 2% passing the No. 200 sieve. The No. 8 material stabilizes the surface of the No. 57 and provides some filtering of water.

If the bedding material cannot meet this filter criteria (i.e. the bedding aggregate is smaller or the subbase material is larger), a layer of geotextile can be used between the bedding and subbase course. This will add some stability to the structure. Standard aggregate gradations (ASTM D 448) are provided in Table 3 and Table 4. Supplemental information on using Iowa DOT standard aggregate gradations is also included. For permeable pavers, the No. 8 crushed stone aggregate is also recommended for fill material in the paver joint openings. Some additional filter criteria for aggregate layers are also provided by Ferguson (23).

b. Material descriptions for permeable pavement aggregate subbase

- Open graded; Uniformity coefficient (UC) ≤ 2.0
- Material: clean, bank-run river gravel or clean washed limestone or crushed granite – less than 0-1.5% passing a #200 sieve
  (*Note: Bank-run gravel will be more rounded and will be difficult to compact; this may cause problems with trucks backing onto the subbase. In this case, a choker layer of smaller, clean crushed aggregate can be placed and lightly compacted providing a smoother and firm surface*).
- Standard gradation - ASTM #5 and #57 (ASTM D 448) is widely available in Iowa and is the recommended subbase material for permeable pavement
- Flexible pavements like porous asphalt and permeable pavers may require a larger subbase material such as ASTM # 2 or Iowa DOT Macadam (Iowa DOT #13) to provide a stiffer base on fine-grained soils

Table 3: ASTM Gradations for Aggregate Materials
(ASTM D 448; Iowa DOT Section 4109)

Sieve	Size (inches)	Percent Passing					
		ASTM #2	**ASTM #4**	**ASTM #5**	**ASTM #57**	**Iowa DOT #3 (PCC CA)**	**Iowa DOT #29 (Permeable Backfill)**
3 inch	3.0	100	--------	--------	--------	--------	--------
2 1/2 inch	2.5	90 to 100	--------	--------	--------	--------	--------
2 inch	2.0	35 to 70	100	--------	--------	--------	--------
1 1/2 inch	1.5	0 to 15	90 to 100	100	100	100	--------
1 inch	1.0	--------	20 to 55	90 to 100	95 to 100	95 to 100	--------
3/4 inch	0.75	0 to 5	0 to 15	20 to 55	--------	--------	100
1/2 inch	0.5	--------		0 to 10	25 to 60	25 to 60	95 to 100
3/8 inch	0.375	--------	0 to 5	0 to 5	--------	--------	50 to 100
No. 4	0.187	--------	--------	--------	0 to 10	0 to 10	10 to 50
No. 8	0.0937	--------	--------	--------	0 to 5	0 to 5	0 to 8
No. 200		--------	--------	--------	--------	0 to 1.5	--------

- Iowa DOT Macadam Crushed Stone (Gradation #13) with a nominal maximum size of 3 inches, screened over a 3/4 or 1 inch screen can be used as larger subbase material for porous asphalt and permeable paver subbase material

- The filter ("choke") layer of smaller aggregate on top of the coarse aggregate subbase is used as a setting bed for permeable paver construction. This layer would be about 2 inches in depth. An ASTM # 8 gradation would meet the criteria listed above when placed over a #57 gradation.

Table 4: ASTM Gradations for Filter ("Choke") Layer (ASTM D 448)

Sieve	Size (inches)	Percent Passing	
		ASTM #8	**ASTM #78**
2 inch	2.0	--------	--------
1 1/2 inch	1.5	--------	--------
1 inch	1.0	--------	--------
3/4 inch	0.75	--------	100
1/2 inch	0.5	100	90 to 100
3/8 inch	0.375	85 to 100	40 to 75
No. 4	0.187	10 to 30	5 to 25
No. 8	0.0937	0 to 10	0 to 10
No. 16	0.0469	0 to 5	0 to 5
No. 50	0.0118	--------	--------
No. 100	0.0059	--------	--------

- Check local availability of what is called a "clean" 1/2 inch chip limestone; this would be close to the ASTM #78 or even a #8. Confirm that it is a washed material free of fines (i.e. #200 clay, silt and limestone dust).
- All aggregate used for the subbase should be washed clean to remove silt and fines.

3. **Sizing the open-graded base for stormwater infiltration and storage.** The design and sizing of the open-graded aggregate subbase for a permeable pavement system is similar to the sizing of an infiltration trench (Section 2E-2). Permeable pavement systems rely on an open-graded aggregate subbase into which water rapidly infiltrates for temporary storage. The pavement subbase essentially functions as an underground detention structure. The aggregate subbase storage can be designed with the same procedure used for conventional or extended detention basins. For a full exfiltration system, the rate of flow into the subgrade functions as the outflow function in performing the detention routing. For partial exfiltration systems, the subbase exfiltration flow functions as the first stage outlet, while the perforated underdrain piping performs the second stage outflow control for larger storm events. The design method presented below assumes full exfiltration of the stored water by infiltration into the subgrade soil.

   The catchment area for permeable pavement systems consists of the pavement surface area and the adjacent contributing surface area. The contributing area may be additional impervious area draining to the permeable pavement system (i.e. traditional pavement, roof drainage, etc) or runoff from adjacent vegetated pervious areas. If the contributing area has been disturbed by excavation and grading operations and is not fully stabilized with vegetation, installation of effective erosion and sediment control must be accomplished. The leading cause of permeable pavement failure is uncontrolled sediment loading during and just after construction. The runoff analysis for the contributing area can be completed using the NRCS CN method (Section 2C-5) using the manual methods or WINTR55. WINTR55 analysis will provide determination of the contributing runoff volume required for design of the pavement subbase volume.

   The main design constraint for the permeable pavement subbase storage is the textural class or USCS soil classification and nominal infiltration rate of the soils underlying the subbase. Soils with infiltration rates greater than 0.3 inches/hour are generally silt loam, loam, sandy loam, loamy sand, and sand. Soils with lower permeability ($\leq$0.25 inches/hour) will limit the exfiltration into the soil subgrade and will require a high ratio of bottom surface area to storage volume. For low permeability soils a partial exfiltration system will typically be used with perforated underdrain piping to convey the excess water. The following design method does not include guidance on design of the underdrain pipe system. Additional design guidance can be found in references (24) and (25).

   The following method finds the maximum allowable depth for the pavement subbase ($\mathbf{d_{max}}$) for a maximum storage time of 72 hours. Shorter storage times can be used to provide a conservative design and provide a factor of safety to minimize risk from continually saturates and potentially weakened subgrade in areas subject to heavier traffic loadings. Calculations for 24, 48 and 72 hours provide a comparison and range of base thicknesses. In some cases, the calculated depth of the subbase for storage may be too shallow to support vehicular traffic. In this case, the minimum subase thickness would be that required to accommodate traffic.

   The NRCS CN method uses a 24 hour duration storm (Section 2C-5) as the basis of design so this method is based on controlling the runoff for a specific 24 hour storm. When considering a permeable pavement application, the minimum design would be based on the WQv and the corresponding rainfall depth of 1.25 inches for Iowa (Section 2B). Based on site soil infiltration rates and other site constraints (i.e. depth to water table) a larger storm depth may be accommodated (i.e. extended detention for Cpv, and detention for peak flow attenuation from 5 year through 25 year recurrence interval storms.

Table 5: Recommended minimum open-graded base and subbase thicknesses for permeable pavements (inches)

Climate	No Frost	No Frost	No Frost	No Frost	Frost	Frost	Frost	Frost
	Soaked CBR	>15	10 - 14	5 - 9	Gravelly Soils	Clayey Gravels, Plastic Sandy Clays	Silty Gravel, Sand, Sandy Clays	Silts, Silty Gravel, Silty Clays
ESALs *	Layers of subbase	inches	inches	inches	inches	inches	inches	inches
Pedestrian	No. 57 No. 2	4 6	4 6	4 6	4 6	4 6	4 6	4 6
50,000	No. 57 No. 2	4 8	4 8	4 8	4 8	4 8	4 8	4 8
150,000	No. 57 No. 2	4 8	4 8	4 8	4 8	4 8	4 10	****
600,000	No. 57 No. 2	4 8	4 8	4 10	4 8	4 14	4 18	****

* ESALs = 18kip (80kN) Equivalent Single Axle Loads
**** Strengthen subgrade with aggregate subbase to full frost depth

1. All thicknesses are after compaction and apply to full, partial, and no exfiltration systems.
2. Pedestrian applications should use a minimum base thickness of 10 inches.
3. Thicknesses do not include the No. 8 bedding course (2 inches) plus the paver unit thickness (typical 3.125 inches) for permeable paver systems; a standard pervious concrete thickness of 6-inches and 5 to 6 inches of porous asphalt surface would be similar in thickness to the permeable paver bedding course and pavers.
4. Geotextile over the subgrade is recommended.
5. Silty soils or others with more than 3% of particles smaller than 0.02 mm are considered susceptible to frost action.
6. All soils have a minimum CBR of 5%.

Source: (26), (27)

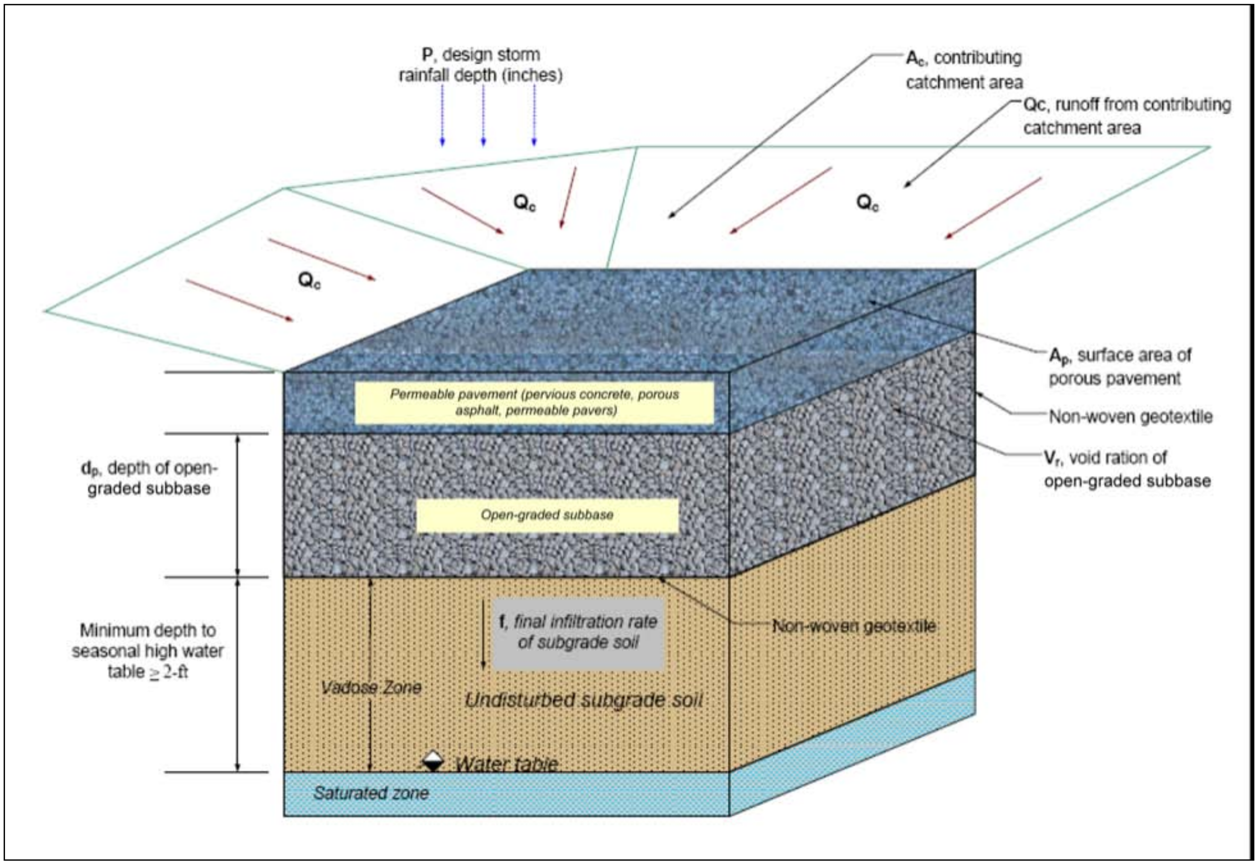
Table 6: Maximum allowable depths, inches of storage for selected maximum storage times (T_s, hrs), and minimum infiltration rates, inches/hr. (Ref: Sections 2E-1, 2E-2)

		Soil Subgrade Texture/Infiltration Rate (inches/hr)										
		Sand	**Loamy Sand**	**Sandy Loam**	**Loam**	**Silt Loam**	**Sandy Clay Loam**	**Clay Loam**	**Silty Clay Loam**	**Sandy Clay**	**Silty Clay**	**Clay**
Criterion	T_s (hrs)	8.27	2.41	1.02	0.52	0.27	0.17	0.09	0.06	0.05	0.04	0.02
fT_s / V_r *for* $V_r = 0.4$	24	496	145	61	31	16	10	5	4	3	2	1
	48	992	290	122	62	32	20	11	7	6	2	2
	72	1489	434	183	93	49	31	16	11	9	7	4

f = infiltration rate (in/hr) Ts = maximum allowable storage time Vr = voids ratio

Supplement subbase exfiltration with underdrain piping

Figure 5: Schematic of permeable pavement system with design parameters



Parameter definitions:

f = the final design infiltration rate in inches per hour of the soil under the pavement subbase aggregate layer

T_s = the maximum allowable storage time (hrs) (≤ 72 hours)

V_r = void ratio of the aggregate subbase (minimum ≥ 0.32, typical ≈ 0.4)

A_c = contributing runoff catchment area (ft^2)

Q_c = runoff volume from contributing catchment area (NRCS CN method/WINTR55) (ft^3)

A_p = area of pavement surface (ft^2)

P = design rainfall depth (1.25 inch for WQv; 1 year 24 hour event for CPv (in) (in/12 = ft)

d_p = depth of open-graded aggregate layer subbase (ft)

T = effective filling time of the aggregate subbase (hrs) (2 hours is typical)

As in the procedure for infiltration trenches (Section 2E-2), the design of the pavement subbase is also based on the maximum allowable depth of the subbase layer (d_{max} - inches). A schematic of a permeable pavement system with contributing catchment area and parameter definitions is provided in Figure 5.

The maximum allowable depth should meet the following criteria:

$d_{max} = (fT_s / n) = (fT_s / V_r)$ (inches) **Equation 1**

- Where *f* is the final infiltration rate of the soil subgrade area in inches per hour, T_s is the maximum allowable storage time in hours, and *n* is the porosity, volume voids/total volume (*Vv/Vt*) of the aggregate reservoir. *Also termed the void ratio, V_r.* A nominal value for *n* of 0.32-0.35 is typical. This can be adjusted based on specific measurement for the aggregate specified. The maximum allowable storage time should be no greater than 72 hours. The maximum allowable depth for a site may also be limited by the depth to the water table.
- The subbase aggregate layer is sized to accept the design volume that enters the pavement system from the contributing catchment area (V_C) plus the volume of rain that falls on the surface of the permeable pavement (PA_p) minus the exfiltration volume (fTA_p) out of the bottom of the subbase into the soil subgrade. Based on NRCS hydrograph analysis, the effective filling time for the aggregate subbase (T) will generally be less than two hours. The volume of water that must be stored in the permeable pavement subbase (V_W) is defined as:

  $V_W = V_C + (P/12)(A_p) – (f/12)TA_p$ **Equation 2**

  Where:
  - V_W = Water Quality Volume (WQv) or total runoff volume to be infiltrated (ft^3)
  - V_C = Volume of runoff from contributing catchment area (ft^3)
  - P = design rainfall event (in)
  - A_p = pavement surface area (ft^2)
  - f = infiltration rate (in/hr)
  - T = fill time (hr)

For a site configuration where an adjacent area contributes runoff to the pavement system, V_C is equal to the runoff in inches (Q_c) times the contributing catchment area (A_c) in ft^2. Equation 2 in Section 2E-2 then becomes:

$V_W = (Q_c)(A_c)/12 + (P/12)(A_p) – fTA_p$ **Equation 3**

Where:
- Q_c = Runoff from contributing catchment area (in) (from NRCS CN method)
- A_c = Contributing catchment area (ft^2)
- P = design rainfall event (in)
- A_p = pavement surface area (ft^2)
- f = infiltration rate (in/hr)
- T = fill time (hr)

For sites where there is no contributing runoff, the volume of water due to rainfall on the surface area of the pavement (PA_p) will define the design volume (V_W) of the aggregate subbase layer. The volume of rainfall entering the pavement system can be defined in terms of pavement and subbase geometry. The gross volume of the subbase layer (V_P) is equal to the ratio of the volume of water that must be stored (V_W) to the porosity (*n*) of the aggregate in the subbase layer; V_P is also equal to the product of the aggregate depth, d_p, (ft) and the surface area, A_p, (ft^2):

$$V_P = V_W/V_r = d_p \times A_p \times V_r \qquad \textbf{Equation 4}$$

Combining Equations 3 and 4 provides the following expression:

$$d_p \times A_p \times Vr = (Q_c)(A_c)/12 + (P/12)(A_p) - (f/12)TA_p \qquad \textbf{Equation 5}$$

The surface area of the pavement, A_p (ft^2) and the depth of the subbase, d_p (inches), can be defined from Equation 5 as follows:

$$A_p\ (ft^2) = \frac{(Q_C/12)(A_C)}{(V_r)(d_p/12) - P/12 + (f/12)T} \qquad \textbf{Equation 6}$$

and

$$d_p\ (\text{inches}) = \frac{(Q_C)(A_C/A_P) + P - fT}{V_r} \qquad \textbf{Equation 7}$$

Where:

- d_p = depth of subbase layer (in)
- Q_c = Runoff from contributing catchment area (in) (from NRCS CN method)
- A_c = Contributing catchment area (ft^2)
- P = design rainfall event (in)
- A_p = pavement surface area (ft^2)
- f = infiltration rate (in/hr)
- T = fill time (hr)
- V_r = void ration of aggregate base (typical value of 0.32 – 0.4)

Equation 7 will be used most often since the surface area of the pavement is normally defined by the project configuration (i.e. parking area) and depth of base is to be determined.

The NRCS CN method can be used to determine the value of Q_C (runoff volume) from either a graphical solution using CN and rainfall depth (See Figure 2, Section 2C-5) or using the WINTR55 computer model.

4. Design procedures. The design of the subbase storage area is completed through one of two methods:

- ***Minimum depth method.*** Compute the minimum depth of the subbase given the area of the permeable structure.
- ***Minimum area method.*** Compute the minimum surface area of the permeable pavement given the required design depth of the subbase.

a. Minimum depth method

1) Select the design rainfall event, P, and determine the CN for the contributing catchment area. Compute the runoff volume, Q_C from the contributing area. The Water Quality volume (WQv) can be used as a minimum design volume.
2) Compute the depth of the aggregate subbase (d_p) using Equation 7.
3) Compute the maximum allowable depth (d_{max}) of the aggregate base using Equation 1.
4) Check the feasibility of the computed depth, d_p.
   a) The depth d_p must be less than or equal to d_{max}.
   b) Based on the computed depth for d_p, the bottom of the aggregate must be a minimum of 2 feet above the seasonal high water table at the site.
   c) If d_p does not meet the above criteria, the surface area of the permeable pavement must be increased or the design storm depth must be reduced.

b. Minimum area method

1) Select the design rainfall event, P, and determine the CN for the contributing catchment area. Compute the runoff volume, Q_C from the contributing area. The Water Quality volume (WQv) can be used as a minimum design volume.
2) Compute the maximum allowable depth (d_{max}) of the aggregate subbase using Equation 1.
3) Select a design depth for the aggregate subbase, d_p less than or equal to the computed d_{max} or a depth that places the bottom of the aggregate subbase at least 2 feet above the seasonal high water table.
4) Compute the minimum required surface area for the permeable pavement (A_p) using Equation 6.

5. Additional considerations

a. Performance. In addition to the siting requirements of permeable pavement, keys to the success of a permeable pavement system include selection of appropriate materials, construction specifications, and installation by a qualified contractor. A limitation to the practice is the poor success rate it has experienced in the field; however, recent installations have shown improved performance and service life due to innovations in knowledge, materials, equipment, and contractor experience. Several studies indicate that with proper maintenance permeable pavement can retain its permeability (e.g., Goforth et al., 1983; Gburek and Urban, 1980; Hossain and Scofield, 1991). Dated studies indicate that when permeable pavement was implemented in communities, the failure rate was as high as 75% over 2 years (Galli, 1992). However, newer studies, particularly with permeable pavers and pervious concrete, indicate that success rates can be substantially higher when the paving medium is properly installed (Brattebo and Booth, 2003).

b. Maintenance. Owners should be aware of a site's permeable pavement because failure to perform maintenance is a primary reason for failure of this practice. One nonstructural component that can help ensure proper maintenance of permeable pavement is a carefully worded maintenance plan providing specific guidance, including how to conduct routine maintenance and how the surface should be maintained. Ideally, signs should be posted on the site identifying permeable pavement areas. Typical requirements are shown in Table 7.

One design option incorporates an "overflow edge," which is a trench surrounding the edge of the pavement. The trench connects to the stone reservoir below the pavement surface. Although this feature does not in itself reduce maintenance requirements, it acts as a backup in case the surface clogs. If the surface clogs, stormwater will flow over the surface and into the trench where some infiltration and treatment will occur.

Table 7: Typical maintenance activities for permeable pavement

Activity	Schedule
• Do not seal or repave with non-permeable materials.	N/A
• Ensure that paving area is clean of debris. • Ensure that paving dewaters between storms. • Ensure that the area is clean of sediments.	Semi-annually
• Mow upland and adjacent areas, and seed bare areas. • Vacuum sweep frequently to keep the surface free of sediment.	As needed (typically three to four times per year).
• Inspect the surface for deterioration.	Annual
Source: WMI, 1997	

c. Cost. Permeable pavement systems will be more expensive than traditional PCC or AC pavement. While traditional asphalt and concrete costs between $1.50 to $3.00 per square foot, permeable pavement can range from $2.00 to $8.00 per square foot, depending on the design and type of surface materials (pervious concrete, porous asphalt, permeable pavers). There will be additional costs for the aggregate subbase not traditionally used for parking lot design and construction. When compared to most traditional parking lot construction (pavement placed directly on a compacted subgrade) an increased durability and life span of a properly constructed permeable pavement with an open-graded subbase layer will be attained. Permeable pavement, when used in combination with other techniques such as bioretention cells, vegetated swales, or vegetated filter strips, may eliminate or reduce the need for land intensive BMPs, such as dry extended detention or wet retention ponds. The use of permeable pavement systems will reduce the impervious area of the project site, increase the time of concentration for runoff, and decrease the peak runoff rate from the site. Permeable pavement systems can be an effective BMP for Low Impact Development designs and provide a design option for projects seeking LEED accreditation for sustainable design. In areas where land prices are high, the savings associated with decreased land consumption should be considered. The cost of vacuum sweeping may be substantial if a community does not already perform vacuum sweeping operations. Finally, if not designed and maintained properly, the effective lifespan of permeable pavement may be short because of the potential high risks of clogging.

D. Permeable pavement design example

Figure 6: Site plan
Widget Manufacturing Company, Bucketsville, IA (Marshall County)

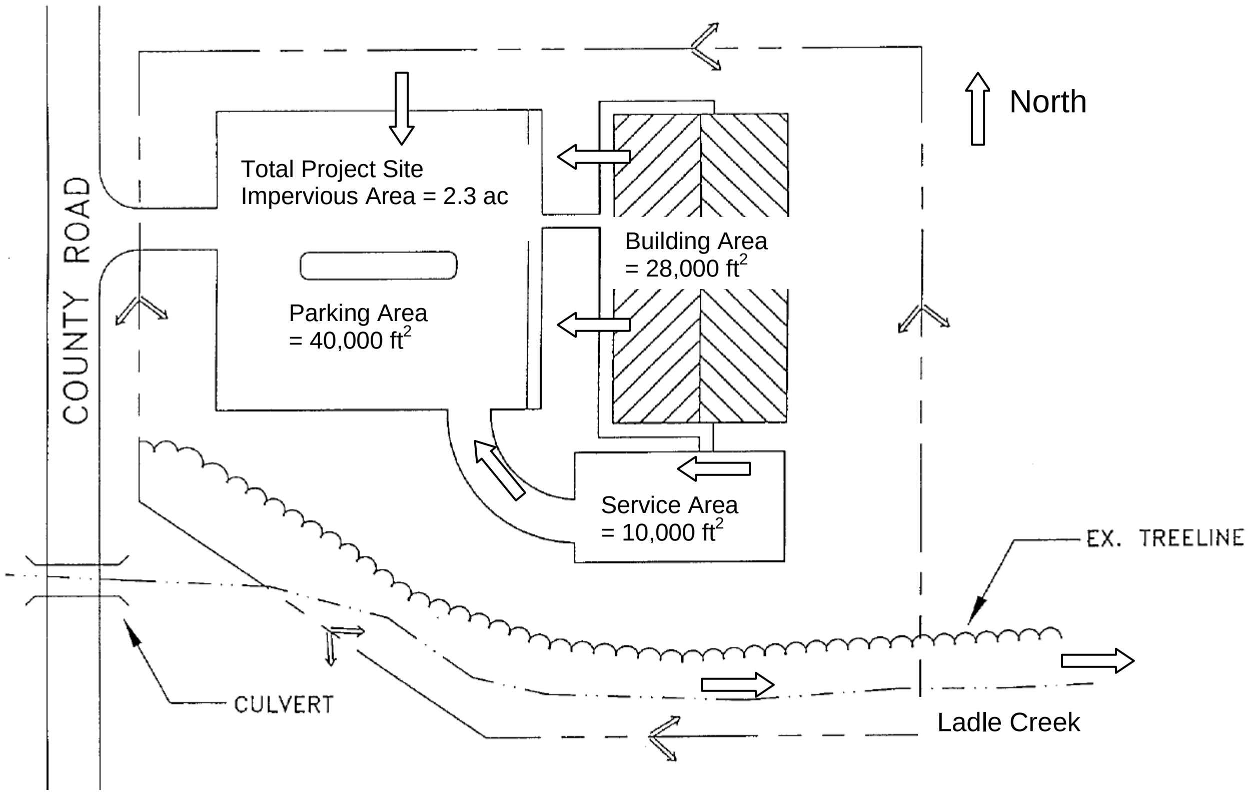


Table 8: Hydrologic site data for existing and proposed conditions

Base Site Data	Hydrologic Data			
Total Site Drainage Area (A) = 4.0 ac		Pre Development	Post Development w/traditional intakes and piping	Post Development w/impervious disconnected
Impervious Area = 2.3ac; I = 2.3/4.0 = 57.5%	CN	68	85	74
Soils: HSG B (Loam) ~50%; HSG C (Silt loam) ~ 50%	t_c	.29	.10	0.10

Existing conditions:

- Undeveloped - pasture/grassland in fair condition
- Land slope is ± 2% to 3% to the south to Ladle Creek
- Soil textures in north half of site are loam and silt loam (south half).
- Soil borings at the site indicate soils in the north half of site are SP and transition to SM and SC in the direction of the creek.
- Borings indicate depth to seasonal high water table at approximately 8 feet.
- Two tests with double-ring infiltrometer at the proposed location of parking area indicated infiltration rates at 0.88 in/hr (north) and 0.48 in/hr (south). A nominal rate of 0.32 in/hr will be used for design (0.68 in/hr / 2 = 0.32in/hr). Design safety factor = 2.

Proposed site structures and development:

- Commercial building: 38,000 ft^2
- Main parking lot: 50,000 ft^2
- Service road and service dock/loading area: 11,000 ft^2
- Additional entrance drive and sidewalks: 1,000 ft^2

Total impervious area ± 100,000 ft^2

This example is focused on the design of a permeable pavement system to meet the water quality treatment requirements (WQv) for the site. Analysis for CPv and Qp will be completed to determine preliminary storage volume and peak discharge requirements. The feasibility of providing CPv storage and Qp requirements will be examined. This example demonstrates the procedural steps and calculations for sizing the permeable pavement subbase and the minimum and maximum depth of aggregate.

Step 1: Compute runoff control volumes from Unified Sizing Criteria

a. Compute WQv
- Rv = 0.05 + (57.5)(0.009) = 0.57
- WQv = (1.25-in)(Rv)(A)/12
  = (1.25)(0.57)(4.0)(1-ft/12-in)(43,560-ft^2/ac) = 10,345 ft^3 = 0.237 ac-ft

b. Compute Stream Channel Protection Volume, (CPv):
- Use WINTR-55 to compute the pre and post development peak runoff rates for the 1-yr, 24-hr duration storm. (See Table 9)
- Use modified CN of 89 for 1-yr storm event. See Section 2C-6; P = 2.38-in and Q = 1.36 in.
- Use WINTR-55 to compute channel protection storage volume: (See Section 2C-6)
  q_u = 994 csm/in   qo/qi = 0.02   Qa = 1.34-in

  $Vs/Vr = 0.683-1.43(qo/qi)+1.64(qo/qi)^2 -0.804(qo/qi)^3$

  Vs/Vr = 0.64

  Vs = CPv and Vr = Qa = 1.34 volume of runoff in inches

  Vs = CPv = 0.64(1.34-in)(1/12)(4.0-ac) = 0.29 ac-ft = 12,726 ft^3

CPv of 12,726 ft^3 to be released over 24 hours or stored in aggregate subbase and infiltrated over design storage time (i.e. 48 to 72 hours):

12,726 ft^3 / (24-hrs x 3600 sec/hr) = 0.15 cfs (average release rate for CPv)

c. Determine Overbank Protection Flood Protection Volume (Q_p)
- Use WINTR-55 for analysis of Q5 to Q100 runoff volume in inches and respective peak rates. (See Section 2C-9).
- Using data in Table 10 for pre and post development runoff rates for the 5 year, 10 year, and 25 year storm events. The criterion is control of the post-development peak runoff rate to no more than the predevelopment peak rate.
- For a q_{in} of 21.29 cfs and an allowable q_{out} of 9.19 cfs, the volume of storage (V_{st}) necessary for 25-yr control is 0.36 ac-ft or 15,529 ft^3 under a developed CN of 85.
- For control of post-development rates to no more than the similar *pre-development rate*, the storage requirements (V_{st}) are summarized in Table 11.

Table 9: Storage requirements for attenuation of post-development peak rates to pre-development rates

Recurrence Interval	q_{pb} (cfs)	q_{pa} (cfs)	a	R_v	Q_a (inches)	Vs (inches)	Am (ac)	V_{st} (ac-ft)	V_{st} (ft^3)
5	4.28	13.16	0.33	0.36	2.13	0.77	4.00	0.26	11,217
10	6.23	16.54	0.38	0.33	2.69	0.90	4.00	0.30	13,008
25	9.19	21.29	0.43	0.31	3.50	1.07	4.00	0.36	15,529
100	14.56	29.20	0.50	0.28	4.87	1.35	4.00	0.45	19,581

- For control of post-development rates to no more than the 5 year pre-development rate, the storage requirements (V_{st}) are summarized in Table 9.
- For a q_{in} of 21.29 cfs and an allowable q_{out} of 4.28 cfs, the volume of storage (V_{st}) necessary for 25 year control is 0.53 ac-ft or 23,086 ft^3 under a developed CN of 85.

Table 10: Storage requirements for attenuation of post-development peak rates to pre-development 5 year rate

Recurrence Interval	q_{pb} (cfs)	q_{pa} (cfs)	a	R_v	Q_a (inches)	Vs (inches)	Am (ac)	V_{st} (ac-ft)	V_{st} (ft^3)
5	4.28	13.16	0.33	0.36	2.13	0.77	4.00	0.26	11,217
10	6.23	16.54	0.26	0.41	2.69	1.10	4.00	0.37	15,929
25	9.19	21.29	0.20	0.45	3.50	1.59	4.00	0.53	23,086
100	14.56	29.20	0.15	0.51	4.87	2.46	4.00	0.82	35,717

d. Compute WQv Peak discharge (Q_{wq}): From Section 2C-6 and Modified NRCS WINTR55 procedure.

WQv = 10,345 ft^3 = 0.237 ac-ft

$CN = 1000/[10+5P+10Q_a-10(Q_a^2 + 1.25Q_aP)^{0.5}]$

- P = rainfall depth for Water Quality storm – 1.25 inches
- Q_a = runoff volume, inches (equal to P x Rv) = (1.25)(0.57) = 0.712-in

$CN = 1000 / [10 + 5(1.25”) + 10(.71”) – 10[(.71”)^2 + 1.25(0.71”)(1.25”)]^{0.5}$

CN = 93.8 Use CN = 94 Use t_c = 0.10 hour

Compute Q_{WQ} using WINTR55 using modified CN and t_c :
WINTR55 results for *modified* CN = 94 and t_c = 0.10-hr:

For 1.25-inch rainfall q_u = 622.89 csm/in

Q_{WQ} = 3.89 ft^3/sec

Step 2: Compute runoff volume and peak runoff rate for existing and proposed development conditions.

a. Hydrologic assessment conditions (See Table 7)
- Predevelopment (existing) condition
- Post development – runoff from impervious area conveyed via standard surface intakes and piping directly to Ladle Creek
- Post development – impervious area runoff disconnected and conveyed to Ladle Creek across vegetated pervious area

b. Compute 1 year, 2 year, 5 year, 10 year, 25 year, and 100 year peak discharge using *conventional* WINTR55 procedure:
At 57.5% impervious, HSG B and C soils, CN=98 for Imp and CN=64 for open space, composite CN = 85
Use t_c = 0.1-hr
WINTR55 results:

c. Summary of runoff volume and peak runoff rate listed in Table 10.

Table 11: Runoff volume and peak discharge summary for existing and post development conditions

Condition	**CN**	**Q_1**		**Q_2**		**Q_5**		**Q_{10}**		**Q_{25}**	**Q_{100}**
		in	**cfs**	**in**	**cfs**	**in**	**cfs**	**in**	**cfs**	**cfs**	**cfs**
Pre-developed	68	0.54	2.25	.85	3.78	1.33	6.15	1.79	8.38	11.68	17.42
Post-Dev (57.5% impervious) w/standard direct connected intakes and piping	85	1.08	6.66	1.5	9.33	2.13	13.16	2.69	16.54	21.29	29.20
Post-Dev (57.5% impervious) w/disconnected impervious area	74	.54	2.97	.85	4.96	1.33	8.07	1.79	10.98	15.30	22.84

Step 3: Determine if the development site and conditions are appropriate for using an infiltration trench

Site Specific Data	
Criteria	**Value**
Soil (NRCS texture)	Loam and Silt Loam
Soils (USCS)	SP; SM; SC
Infiltration Rate (onsite testing)	0.32 in/hr
Ground Elevation at BMP	1020
Seasonally high water table	1012
Stream Invert	1006
Soil Slopes	2.0 – 4.0 %

Step 4: Confirm design criteria and applicability

Infiltration Feasibility	
Criteria	**Status**
Infiltration rate (f) greater than or equal to 0.5 inches/hour.	Nominal infiltration rate 0.88 to 0.48 in/hr; nominal design rate of used will be 0.32. Soil type indicates moderate permeability; use underdrain piping for partial exfiltration from pavement base. OK.
Soils have a clay content of less than 20% and a silt/clay content of less than 40%.	Loam and silt loam soils at this site meets both criteria. SP/SM/SC soils. Soil gradation indicated 58% sand, 12% clay, and 18% silt. Soaked CBR of 15
Infiltration cannot be located on slopes greater than 6% or in fill soils.	Slope is 2-4%; not fill soils. OK.
Hotspot runoff should not be infiltrated.	Not a hotspot land use. OK.
Infiltration is prohibited in karst topography.	Not in karst. OK.
The bottom of the aggregate base must be separated by at least 2 feet vertically from the seasonally high water table.	Elevation of seasonally high water table: 1008 feet Elevation of BMP location: 1020 feet The difference is 12 feet The aggregate base can be up to 4 feet in depth and meet these criteria. OK.
Infiltration facilities must be located 100 feet horizontally from any water supply well.	No water supply wells nearby. OK.
Maximum contributing area generally less than 5 acres. (Optional)	4-acres. OK.
Setback 25 feet down-gradient from structures.	240 feet straight-line distance between the parking lot and the tree line. OK

Step 5: Size the aggregate base

a. Use the minimum depth method. Equation 7.

b. Design goal is to capture runoff from building roof, service area pavement, and access road and convey to permeable pavement system at main parking facility.

c. Contributing catchment area, A_C = 38,000 ft^2 (CN=98).

d. Permeable pavement area, A_P = 50,000 ft^2.

e. Design vehicle load on parking load is estimated at 250,000 ESALs over the 20 year life-cycle.

f. The minimum design will be for WQv; storage feasibility for the Cpv, as well as the 2 year and 5 year requirements to be checked.

g. Select the design rainfall event, P, and determine the CN for the contributing catchment area. Compute the runoff volume, Q_C from the contributing area.

h. The Water Quality volume (WQv) can be used as a minimum design volume. The WQV for the contributing area plus the parking area will based on P=1.25 inches.

- Solve for minimum depth of base, d_p using Equation 7:

  d_p (inches) = [(Q_C) (A_C/A_P) + P – fT] / V_r

  A_c = 38,000 ft^2
  A_p = 50,000 ft^2
  For P= 1.25 inch and CN =98 Qc = 0.674 inch (WINTR55 analysis)
  f = 0.32 in/hr (design infiltration rate
  T = 2 hours (nominal fill time for pavement)
  V_r = 0.4 (tested void ratio in #57/#4 subbase was 40%)

  d_p = [(0.647 inch) (38,000 ft^2/50,000 ft^2) + 1.25 inch – (0.32 in/hr)(2 hours)] / 0.4

  d_p = 2.75 inches (required depth for WQv)

  Other depth and storage options:

  CPv: Capture and release the 1 year, 24 hour runoff. P = 2.38 inches Qc = 1.70 inches
  d_p = [(1.70 inches) (38,000 ft^2/50,000 ft^2) + 2.38 inches – (0.32 in/hr)(2 hours)] / 0.4
  d_p = 7.58 inches (required depth for Cpv)

  2 year, 24 hour rainfall: P = 2.91 inches Qc = 2.23 inches
  d_p = [(2.23 inches) (38,000 ft^2/50,000 ft^2) + 2.91 inches – (0.32 in/hr)(2 hours)] / 0.4
  d_p = 9.91 inches (required depth for 2 year, 24 hour storm)

  5 year, 24 hour rainfall: P = 3.64 inches Qc = 3.02 inches
  d_p = [(3.02 inches) (38,000 ft^2/50,000 ft^2) + 3.64 inches – (0.32 in/hr)(2 hours)] / 0.4
  d_p = 13.24 inches (required depth for 5 year, 24 hour storm)

  10 year, 24 hour rainfall: P = 4.27 inches Qc = 3.69 inches
  d_p = [(3.69 inches) (38,000 ft^2/50,000 ft^2) + 4.27 inches – (0.32 in/hr)(2 hours)] / 0.4
  d_p = 16.1 inches (required depth for 10 year, 24 hour storm)

- Determine the maximum depth (d_{max}) using Equation 1:
  (Criterion is drain-down time of 48 hours).

  d_{max} = (fT_s / n) = (fT_s / V_r) (inches)

  Ts = 48 hours
  f = 0.32 in/hr
  Vr = 0.4

  d_{max} = (0.32 in/hr)(48 hours) / 0.4 (inches)
  d_{max} = 38-in

Step 6: Determine the minimum required subbase thickness for structural support

a. Must meet minimum depth for storage requirement plus also provide support for the expected vehicle loading (250,000 ESALs)

b. Table 5 provides guidance on aggregate subbase depth as a function of traffic load (ESALs), soil type, and presence of frost (cold climate conditions)

c. For the expected traffic load and the sandy/silty soil, a subbase depth of 16 to 18 inches is indicated for structural support

d. This depth is equal to the subbase depth for storing the 10 year, 24 hour storm

Step 7: Check for minimum separation of bottom of subbase aggregate from seasonal high water table

a. Existing ground elevation at site is 1,020 feet

b. Proposed finished floor elevation of building is 1,020 feet

c. Top of pavement for parking lot will be 1,018.7 feet

d. Thickness of permeable pavement surface is 6 inches

e. Top of aggregate subbase will ± 1,018 feet

f. For an aggregate subbase depth of 18 inches, the bottom of subbase will be at 1,016.5 feet

g. Measured water table elevation from soils investigation was ± 1,012 feet (8 feet)

h. At 18-in aggregate depth, the separation from water table will be ≈ 4.5 feet

Step 8: Check criteria for geotextile separation layer at base and sides of aggregate subbase

a. The sieve analysis of the subgrade soils showed a 6% passing the No. 200 sieve.

b. The gradation analysis results showed the following:

D_{10}	D_{15}	D_{50}	D_{60}	D_{85}
0.10	0.12	0.25	0.32	0.63

c. Use FHWA geotextile filter criteria from Figure 4.

d. For granular soils (i.e. SP/SM/SC) with less than 50% passing the No. 200 sieve the following criteria would apply (Figure 4):

All geotextiles: $AOS_{geotextile} \leq B \times D_{85soil}$

$C_u = D_{60} / D_{10} = 0.32 / 0.10 = 3.2$

Where :
$B = 1$ for $2 \geq C_u \geq 8$ 3.2 OK

B = 0.5 for $2 < C_u < 4$ 3.2 OK
B = 8/Cu for 4 < Cu < 8 8/3.2 = 2.5 does not meet criteria for 4 < Cu < 8 (Do not use for B).

e. Select a geotextile with AOS between 0.5 x 0.63 = 0.32-mm and 1.0 x 0.63 = 0.63-mm

f. Permeability criteria: k (fabric) ≥ k (soil) ≥ 0.32 in/hr

g. Use non-woven fabric with porosity ≥ 30%

Step 9: Design of underdrain piping

a. For this design, a 4 inch diameter perforated PVC underdrain will be installed with a flow line depth of 16 inches above the bottom of aggregate.

b. The final design depth for the subbase aggregate will be 24 inches.

c. This places the flow-line of the underdrain piping at the top of the storage depth for the 10-yr, 24-hr storm. This also allows a 4 inch aggregate cover over the top of the piping.

d. A 24 inch base depth still provides the minimum 2 feet separation from the water table.

e. The total storage capacity of the base below the underdrain piping is 26,600 ft^3. This storage volume would meet the detention requirements for reducing the 25 year runoff to the pre-development 5 year runoff rate.

f. The storage provided in the permeable pavement system will also provide complete capture and infiltration for up the 5 year storm and will more than meet the WQv and CPv requirements.

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2J-2 Pervious Concrete Pavement

(Iowa State University Parking Lot, 2006)

Pollutant Removal Low = <30% Medium = 30-65% High = 65-100%	Low	Med	High
Suspended Solids		■	
Nitrogen		■	■
Phosphorous		■	
Metals			■
Bacteriological		■	
Hydrocarbons		■	■

Description: Pervious concrete is the term for a mixture of coarse aggregate, cementitious materials, admixtures, and water that allow for rapid infiltration of stormwater and overlays a stone aggregate reservoir. A small amount of fine aggregate is added to increase strength and freeze-thaw durability in colder climates. The aggregate reservoir provides temporary storage as runoff infiltrates into underlying permeable soils and/or out through an underdrain system. The pavement system provides water quality capture volume (WQv) and some stormwater quantity management for smaller storms (Channel Protection volume, CPv).

Typical Uses: Intended for low traffic areas, recreational trails, pedestrian paths, or for residential or overflow parking applications in higher density residential areas, high-density ultra urban areas, and commercial areas. Good general application for parking areas to reduce impervious area. Aggregate layer can accept roof runoff from adjoining buildings.

Advantages:

- High level of pollutant removal
- Provides reduction in runoff volume and some peak rate control (CPv)
- Suitable for cold climates with modified pervious mix
- Fewer problems with icing in the winter

Limitations:

- Soil infiltration rate of 0.5 inches per hour or greater desired
- Underdrain system needed for low-permeability soils (f < 0.5 inches/hour)
- Higher cost compared to conventional pavements
- Increased maintenance requirements over standard PCC
- Potential for high failure rate if not adequately maintained or used in unstabilized areas
- Potential for groundwater contamination

Maintenance Requirements:

- Prevent run-on of sediment in runoff from adjoining areas
- Sweep/vacuum one to two times per year
- Avoid ("prevent") application of sand in winter

A. General description

Pervious concrete (also referred to as portland cement pervious concrete, enhanced porosity concrete, porous concrete, and pervious pavement) is a subset of a broader family of pervious pavements including porous asphalt, and various kinds of grids and paver systems. The number of pervious concrete installations in Iowa is increasing at a steady pace since the initial full scale applications began in 2006.

The pervious concrete mixes recommended for use in Iowa consist of a specially formulated mixture of portland cement, uniform, open-graded course aggregate, 5% to 7% by weight fine aggregate (concrete sand) and water. The sand in the "Iowa" mix provides additional compressive strength and durability and improved performance under repeated freeze-thaw testing (CPTech Center/ISU, 2006). The addition of a small amount of fine aggregate (sand) in the Iowa pervious mix is a departure from the standard pervious mix designs used in the warmer climates. The final concrete layer has a high permeability (~300 inches/hour), many times that of the underlying permeable soil layer, and allows rapid movement of rainwater through the surface and into the underlying aggregate subbase.. The void space in pervious concrete is in the 15% to 22% range compared to three to five percent for conventional pavements. This would be considered a moderate porosity pervious concrete. The pervious concrete pavement is placed over a layer of open-graded gravel or a clean durable crushed limestone aggregate. The void spaces in the stone act as a storage reservoir for runoff.

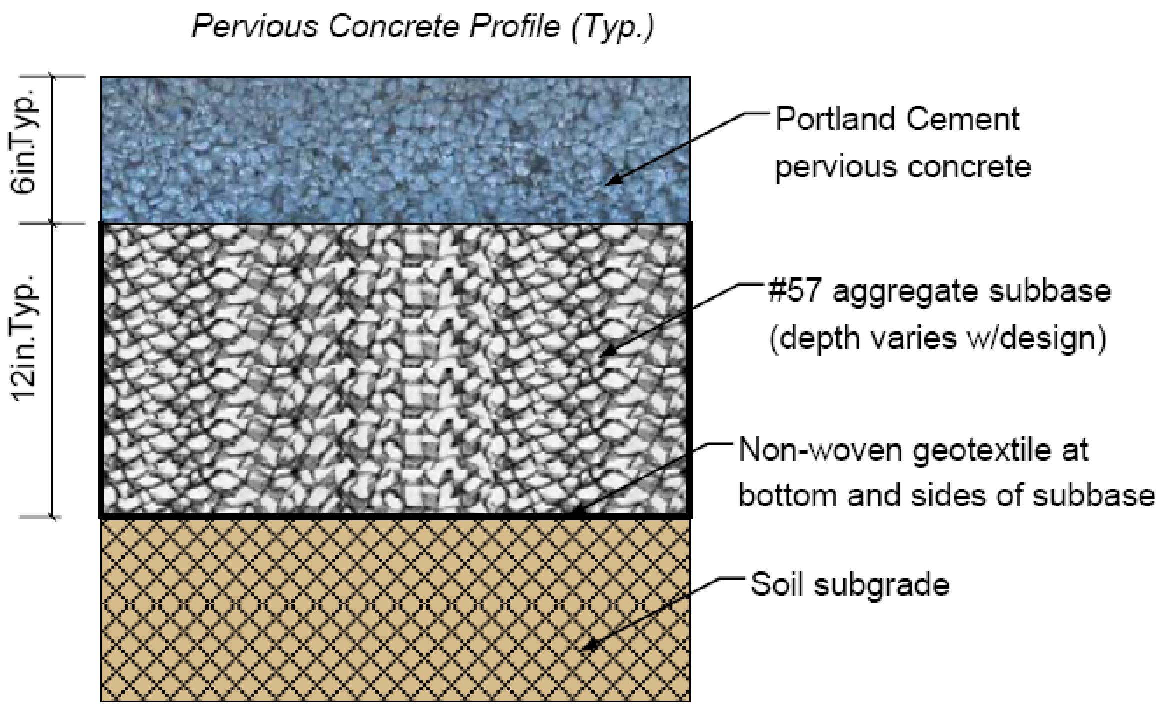
A drawback is the cost and complexity of pervious concrete systems compared to conventional pavements. Pervious concrete systems require a modified construction protocol for equipment and placement than is typical for regular PCC pavements. The level of construction workmanship is not necessarily more difficult, just different. The pervious concrete material is a "no-slump" mix so coordination between the material supplier and the contractor is extremely important to ensure delivery and placement of the pervious mix at the site is successful. As with other pavement systems, pervious pavements can experience an increased failure rate if they are not designed, constructed, and maintained properly. Construction of pervious concrete is exacting, and requires special handling, timing, and placement to perform adequately.

B. Design criteria and specifications

For the purpose of sizing downstream conveyance and structural control system, pervious concrete surface areas can be assumed to 20% impervious. An approximate CN for pervious pavement area would be in the range of 30-35 (i.e. meadow/pasture/grassland on HSG A soils). In addition, credit can be taken for the runoff volume infiltrated from other impervious areas conveyed onto the pervious pavement system. The cross-section typically consists of four layers, as shown in Figure 1. Descriptions of each of the layers is presented below:

- ***Pervious concrete layer.*** The pervious concrete layer consists of an open-graded concrete mixture usually ranging from depths of 4 to 6 inches depending on the required bearing strength and pavement design requirements (6 inches is the recommended minimum for mostly all parking applications). Pervious concrete can be assumed to contain 18% voids (porosity = 0.18) for design purposes. For example, a 6 inch thick pervious concrete layer would hold 1.08 inches of rainfall. The reduction in the quantity of fine aggregate provides the porosity of the porous pavement. To provide a smooth riding surface and to enhance handling and placement a coarse aggregate of #4 to 3/8 inch maximum size is normally used. Recommended mix designs for the cold wet-freeze climate in Iowa are provided in Table 2 and Table 3.

Figure 1: Typical profile for pervious concrete pavement



- ***Aggregate reservoir layer.*** The aggregate base course consists of a clean and durable crushed aggregate with a void space of 35-40% (0.32 minimum). Aggregate gradations and quality are presented in Section 2J-1. Depending on local availability, a #57 clean washed limestone aggregate can be used for the full thickness depth of the subbase course. The porosity will be close to 40%. The designer may wish to verify the porosity and condition of the aggregate prior to placement. The aggregate subbase layer should have a minimum depth of 10 inches. A 12 inch aggregate layer is recommended for parking lot applications. The layer should be designed to drain completely in 48 hours. The aggregate layer should be designed to store at a minimum the water quality volume (WQv). Aggregate contaminated with soil shall not be used. A porosity value (void space/total volume) of 0.36 should be used in calculations unless aggregate specific data have been acquired. An observation well for monitoring infiltration performance and water accumulation in the aggregate base is recommended. The observation well consists of perforated PVC pipe 4 to 6 inches in diameter and placed at the downstream end of the facility and provided with an access lid for measurement and inspection purposes.
- ***Geotextile filter fabric.*** The bottom and sides of the subbase aggregate layer are separated from the subgrade soils with a geotextile fabric. The filter fabric provides a separation and filter to prevent migration of fine soil particles (silt/clay fines) into the reservoir layer and reducing storage capacity. A geotextile design and selection criteria are provided in Section 2J-1.

Pervious pavement design. Pervious concrete pavements can be designed using either a standard pavement procedure, such as AASHTO, PCAPAV, ACI 325.9R, or ACI 330R. Pervious pavement is a rigid pavement surface as opposed to a flexible pavement design like porous asphalt or permeable pavers. Regardless of the procedure used, guidelines for roadbed (subgrade) soil properties, pervious concrete materials characteristics, and traffic loads should be considered.

Subbase aggregate and subgrade soils. The design of a pervious pavement should normally provide a 10 to 12 inch layer of open-graded subbase. The subbase material will typically be an ASTM #57 open-graded aggregate or equivalent. The subbase material provides for temporary storage of water as well as additional load-bearing capacity for fine grained soils. The modulus of subgrade reaction (k) is used as a primary input for rigid pavement design. It estimates the support of the layers below the rigid pavement surface course (the pervious concrete slab). The *k* value can be determined by field tests or by correlation with other tests. The value of k is in terms of pounds per square inch per inch of deflection, or pounds per cubic inch (lb/in^3) and ranges from 50 lb/in^3 for weak support, to over 1,000 lb/in^3 for strong support. Typically, the modulus of subgrade reaction is estimated from other strength/stiffness tests, however, in situ values can be measured using the plate bearing test. It is suggested that *k* not exceed 200 lb/in^3, and values of 150 to 175 lb/in^3 are generally suitable for design purposes (1). The composite modulus of subgrade reaction is defined using a theoretical relationship between *k* values from plate-bearing tests (ASTM D 1196 and AASHTO T 222), or estimated from the elastic modulus of subgrade soil (MR, AASHTO T292), as:

$$k\ (pci) = MR/19.4,\ (MR \text{ in units of psi}), \text{ or}$$

where *MR* is the roadbed soil resilient modulus (psi). The California Bearing Ratio (CBR), R-Value and other tests may also be used to determine the support provided by the subgrade. Empirical correlations between *k* and other tests, CBR (ASTM D 1883 and AASHTO T 193), or R-Value test (ASTM D 2844 and AASHTO T 190) are also available. A summary of CBR values by soil type is provided in Section 2J-1, Table 2. Determining the in-situ modulus of the subgrade in its intended saturated service condition can increase the design reliability. If the subgrade is not saturated when the in-situ test is performed, laboratory tests can develop a saturation correction factor.

Traffic loads. The anticipated traffic carried by the pervious pavement must be considered in the design and can be characterized as equivalent 18,000 pound single-axle loads (ESALs), average daily traffic (ADT), or average daily truck traffic (ADTT). Standard design procedures for design of PCC rigid pavements can be used as a design guide. The subbase aggregate layer depth provided for storage of water will provide additional stiffness to the pavement system and can be accounted for in the thickness design. A 6 inch thick pervious pavement will provide adequate support for almost all expected traffic loads except in high use heavy truck loading areas. Depending on the pavement design program used, design factors other than traffic and concrete strength may be incorporated. For example, if the AASHTO design procedure is used, items such as terminal serviceability, load transfer at joints, and edge support are important considerations. The terminal serviceability factor for pervious concrete is consistent with conventional paving. At joints, designers should take credit for load transfer by aggregate interlock. If curbs, sidewalks, and concrete aprons are used at the pavement edges, using the factors for pavement having edge support is recommended. Pervious concrete should be jointed unless cracking is acceptable. Since the pervious concrete has a minimal amount of water, the cracking potential is decreased and owners generally do not object to the surface cracks.

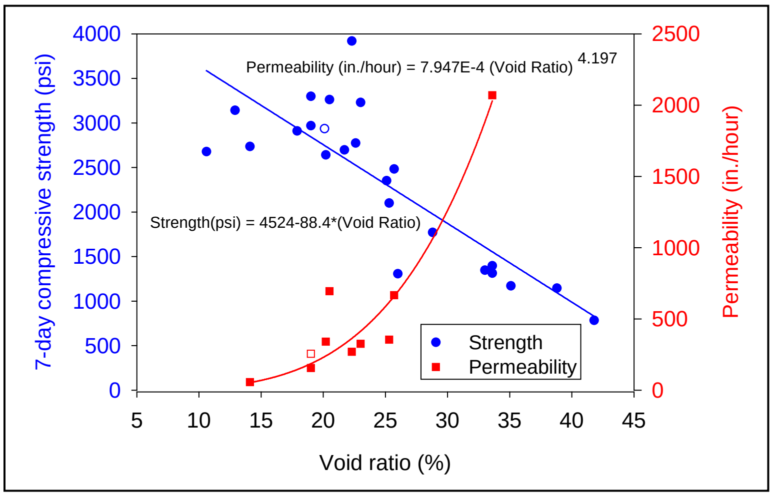
Figure 2: Jointing for pervious concrete pavement (a) Installation of joint during pervious placement
(b) Joint pattern and block-outs in pervious concrete
(Lot 122, Iowa State University, 2006)

Portland cement pervious concrete mix design. The goal of the mix design for a pervious concrete is to provide a material with high to moderate porosity and sufficient material strength to meet the durability requirements for the project. The conventional ingredients for the previous mix include portland cement, coarse aggregate, and water.

- Supplementary cementitious materials (SCMs) such as fly ash, pozzolans, and slag can be added to the cement. These influence concrete performance-- setting time, rate of strength development, porosity, permeability, etc.
- Coarse aggregates are kept to a narrow gradation in order to minimize surface roughness, as well as for aesthetic reasons. Aggregates can be either rounded or angular (i.e., bank run river gravel or crushed stone). Typically, higher strengths are achieved with the river gravel.
- Fine aggregates (sand) are used in minimal amounts (5% to 7%) because they decrease the porosity of the concrete.
- The aggregate in pervious mixes must be free of excessive fines and debris and be an air (surface) dry condition. The water content in pervious concrete is much lower than traditional PCC so the aggregates must be close to a saturated, surface-dry condition so as not to give-up or remove too much water to the mix.
- Too little water in a mixture leads to aggregates that are dry and do not place or compact well.
- Too much water makes the concrete mixture soupy (paste flows off the aggregates) and eliminates air voids (fills in the spaces between the aggregates).
- Admixtures are chemicals which are added to the mixture to provide the concrete with special properties.
- Retarders / hydration-stabilizing admixtures lengthen cement's rapid setting time. Since the water content of the pervious mix is much lower, the working time from material preparation to placement will be much shorter. A maximum working time of 60 to 90 minutes is recommended.
- Air-entraining admixtures reduce freeze-thaw damage, and are therefore used in the cold wet-freeze conditions found in Iowa and the Upper Midwest.
- Other proprietary admixture products which facilitate the placement and protection of pervious pavements can also be used. The addition of polyethylene fibers can increase both workability and provide some increase in overall strength. The fibers also provide a small increase in the permeability of the pervious concrete (CP Tech Center, Iowa State University).

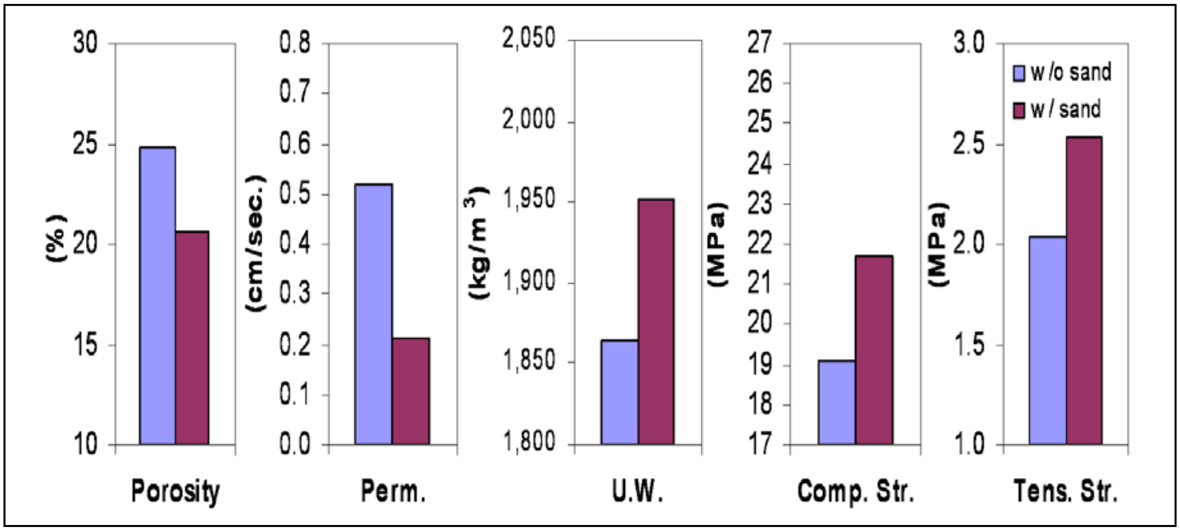
The National Concrete Pavement Technology (CP Tech) Center at Iowa State University developed several pervious concrete mix designs for use in Iowa. The ISU mix designs provide a pervious concrete of moderate porosity and increased strength and durability over other conventional pervious concrete. The goal of the pervious mix development was to provide a pervious concrete of high durability (resistant to freeze-thaw damage), increased compressive strength, and a moderate porosity in the range of 16-20%. Figure 3 illustrates the relationship between strength and porosity (permeability). For the Iowa pervious mix designs, a small amount of fine aggregate (sand) is added to the mix ingredients (~ 5% to 7% by weight). The addition of the sand decreases the porosity, but increases the overall strength (28 day f''_c) and durability (freeze-thaw resistance). A 28 day strength of about 3,500 psi can be attained with a final porosity in the range of 16% to 20%. At this porosity, the nominal permeability will be in the range of 250 to 300 inches/hour.

Figure 3: Relationship between pervious concrete strength and porosity (2)



The increase in durability and freeze thaw resistance with the addition of sand to the pervious mix is illustrated in Figure 4. More details on the mix development and freeze thaw testing are available from the CP Tech Center at Iowa State University (http://www.intrans.iastate.edu/reports/mix_design_pervious.pdf)

Figure 4: Pervious concrete characteristics with and without fine aggregate (sand) (2)



The Iowa pervious mix designs provide two selections for coarse aggregate sizes. The aggregate gradations (coarse and fine limits) are provided in Table 1. The coarse limit represents the largest gradation which is placeable and aesthetically pleasing. Fine limit represents the tightest gradation that can consistently produce successful pervious pavement. The maximum amount of additional sand, material passing the #4 sieve not represented in the coarse aggregate gradation, is 7% by weight of coarse aggregate.

Table 1: Coarse aggregate gradation for Iowa pervious concrete mix (2)

Coarse Limit				Fine Limit			
Sieve				Sieve			
in.	in.	mm	% passing	in.	in.	mm	% passing
1 1/2"	1.5	38.1	100.0	1 1/2"	1.500	38.1	100.0
3/4"	0.75	19.1	99.8	3/4"	0.752	19.1	100.0
1/2"	0.5	12.7	95.6	1/2"	0.500	12.7	100.0
3/8"	0.375	9.5	34.8	3/8"	0.374	9.5	99.3
#4	0.19	4.75	0.6	#4	0.187	4.75	43.3
#8	0.09	2.36	0.0	#8	0.093	2.36	13.1
#16	0.05	1.18	0.0	#16	0.046	1.18	10.6
#30	0.02	0.6	0.0	#30	0.024	0.6	7.3
#50	0.01	0.3	0.0	#50	0.012	0.3	4.0
#100	0.006	0.15	0.0	#100	0.006	0.15	1.8
Pan	-	-	0.0	Pan	-	-	0.0

The Iowa pervious mix designs are presented in Tables 2 and Table 3. The Iowa pervious mix #12 uses a smaller aggregate, which will provide a more consistent and smoother surface texture. Both mixes will provide a very durable pavement of high strength (28-d) in the range of 3,400 to 3,600 psi. Unit weight will be about 125 pcf and porosity in the range of 16-20%. These mixes have been in use since summer of 2006. Both of these pervious mixes were used in the construction of the pervious concrete demonstration parking lot at Iowa State University (Lot 122) in 2006.

Table 2: Iowa pervious concrete mix #12 (smaller aggregate size)

Clean No. 4 river gravel	2525	lb/cy
Sand (ASTM C 33 concrete sand)	175	lb/cy
Portland Cement	503	lb/cy
Fly ash	75	lb/cy
Fibers	1 to 1.5	lb/cy
Water (w/c = 0.29)	20	gal/cy
Mid-range water reducer	6	oz/cwt
Hydration stabilizer*	6	oz/cwt
Air Entraining Agent	2.15	oz/cwt

* Delvo ® or Recover ®

Table 3: Iowa pervious concrete mix #19 (larger aggregate size)

Clean 3/8" river gravel	2525	lb/cy
Sand (ASTM C33 concrete sand)	175	lb/cy
Portland Cement	503	lb/cy
Fly ash	75	lb/cy
Fibers	1 to 1.5	lb/cy
Water (w/c = 0.29)	20	gal/cy
Mid-range water reducer	6	oz/cwt
Hydration stabilizer*	6	oz/cwt
Air Entraining Agent	2.15	oz/cwt

* Delvo ® or Recover ®

Figure 5: Pervious concrete surface texture (Iowa State University Lot 122)

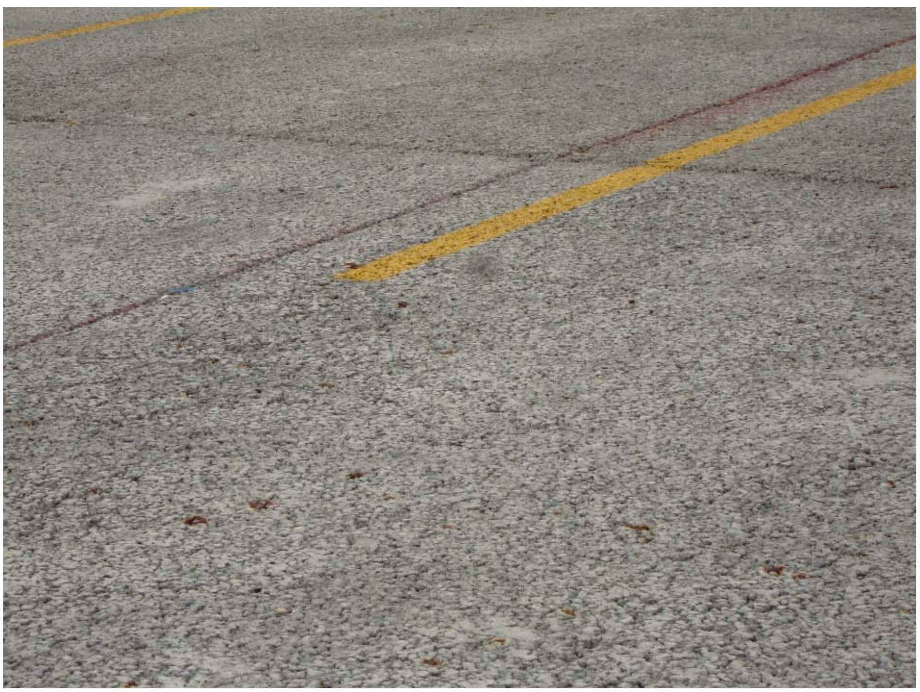


Figure 6: Pervious concrete profile, surface texture, #57 aggregate base, geotextile (Iowa State University Lot 122)

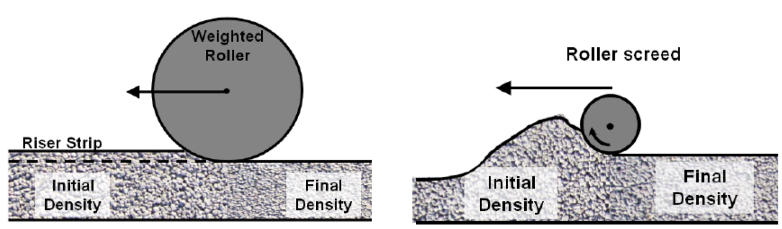
Figure 7: Pervious concrete surface and conventional PCC (Iowa State University Lot 122)

Pervious concrete construction. The construction of a pervious concrete parking structure consists of the following procedures:

1. Complete site soils testing as outlined above and in Section 2J-1.
2. The use of a contractor who is certified in pervious concrete placement is highly recommended. The Iowa Ready Mix Association can provide assistance in training and certification through the Pervious Concrete Technician program of the National Ready Mix Association (NRMCA).
3. A test slab placement is recommended to ensure the material supplier is familiar with the pervious mix preparation and can make needed adjustments in mix proportions prior to the main placement.
4. Prepare the subgrade to design elevation and place geotextile material. Keep wheeled vehicles off of the pervious subgrade,
5. Place aggregate subbase layer to the design thickness and lightly compact. A 5 ton vibratory roller or plate compactor can be used. This operation is to provide light to moderate compaction of the subbase aggregate and will provide a more stable surface for the pervious placement operations. (DO NOT COMPACT THE SUBGRADE).
6. If subdrain piping is used in the system, place and make the piping connections prior to placing the aggregate. Place the subdrain piping in the aggregate layer to the design elevations.
7. Complete the construction of the perimeter PCC curb if used. The PCC curb section provides a stable edge surface for the pervious concrete and a visual and definitive stop for parking of vehicles.
8. Place forms to support the desired construction width of the placement. Standard width of pervious placement “panels” will be in range of 12 feet up to 20 feet. The placement width is somewhat controlled by the length of the screed used in the placement. Screeds can be leased in various lengths to support the project dimensions.
9. A “roller” type screed is recommended as it provides a uniform degree of compaction for the pervious concrete material as its placed. An optional method is to level the concrete with a vibratory screed a small height above the formwork and then compress the material with a weighted roller. A roller type screed performs both functions together and avoids excessive smearing and separation of the cement paste at the surface and sealing the surface voids. The roller screed provides the following functions:
   - Levels and smoothes final surface of the pervious mix to the design elevation (top of formwork)
   - Provides compaction energy to achieve the desired unit weight of the pervious pavement

   A schematic of the roller compaction procedure is provided in Figure 8.

Figure 8: Compaction of pervious concrete material during placement



In either method the degree of compaction is low, only about one inch of material, which produces a 25% compaction factor for a 4 inch section, 17% for a 6 inch section, and 13% for an 8 inch section.

Figure 9: Placement of pervious concrete material onto subbase and formwork (ISU Lot 122, 2006)

Figure 10: Roller screed finish operation on pervious concrete material (ISU Lot 122, 2006)

10. Add weight to roller screed as necessary to achieve a unit weight of approximately 29 pounds/linear foot of roller length to achieve sufficient compaction energy.
11. Place joints at a nominal spacing of 20 feet or match joint pattern of adjacent concrete.
12. Cover rolled pervious concrete surface within 10 to 15 minutes after final placement to prevent loss of moisture from evaporation. Mist surface with water immediately prior to covering pervious surface with polyethylene plastic (6-mil). Secure plastic firmly around edges to prevent air movement under the plastic cover.
13. Leave plastic in place to provide a 7 day moist cure for the pervious pavement.

Figure 11: Covering fresh pervious concrete with plastic for 7 day moist curing period (ISU Lot 122, 2006)

Maintenance

1. Stabilize surrounding disturbed and graded areas to prevent run-on of eroded sediment to the new pervious surface. Provide effective sediment control on contributing catchment areas.
2. Do not allow salt application on the new pervious surface for the first year. Subsequently only use salt if absolutely necessary.
3. Sand should not be needed for ice control nor should sand be applied at any time as it will increase plugging.
4. Remove loose debris (leaves, grass clippings, etc.) from the surface as needed during the year.
5. Depending on usage and traffic load, vacuum sweep the surface once to twice per year to remove heavier silt and sediment.
6. Paint markings may be applied after one month.

References

1. Tennis, Paul D., Lemming, L.L., Akers, David J., Pervious Concrete Pavements, Portland Cement Association, Skokie, IL, 2004.
2. Schaefer, V.R., Wang, K., Suleiman M.T., Kevern, J.T., Mix Design Development for Pervious Concrete In Cold Weather Climates, CP Tech Center, Center for Transportation Research and Education, Iowa State University, Ames, IA, 2006.

2J-3 Porous Asphalt Pavement


Porous Asphalt Parking (Lot 121 – Iowa State University)

Pollutant Removal **Low = <30% Medium = 30-65% High = 65-100%**			
	Low	Med	High
Suspended Solids		■	
Nitrogen		■	■
Phosphorous		■	
Metals			■
Bacteriological		■	
Hydrocarbons		■	■

Description: Porous asphalt concrete is the term for a mixture of coarse aggregate and asphalt binder materials. An aggregate subbase reservoir provides temporary storage as runoff infiltrates into underlying permeable soils and/or out through an underdrain system. Provide water quality capture volume (WQv) and some stormwater quantity management for smaller storms (channel protection volume, CPv).

Typical Uses: Intended for low traffic areas, recreational trails, pedestrian paths, or for residential or overflow parking applications in higher density residential areas, high-density ultra urban areas, and commercial areas. Good general application for parking areas to reduce impervious area. Aggregate layer can accept roof runoff from adjoining buildings.

Advantages:
- High level of pollutant removal.
- Provides reduction in runoff volume and some peak rate control (CPv).
- Suitable for cold climates with modified pervious mix.
- Fewer problems with icing in the winter.

Limitations:
- Soil infiltration rate of 0.5 inches per hour or greater required
- Higher cost compared to conventional pavements
- Increased maintenance requirements over standard PCC.
- Potential for high failure rate if not adequately maintained or used in unstabilized areas
- Potential for groundwater contamination

Maintenance Requirements:
- Prevent run-on of sediment in runoff from adjoining areas.
- Sweep/vacuum one to two times per year.
- Avoid ("prevent") application of sand in winter.

A. General description

Porous asphalt consists of standard bituminous asphalt in which the fines have been screened and reduced, creating void space to make it highly permeable to water. The void space of porous asphalt is approximately 16%, as opposed to two to three percent for conventional asphalt. Porous asphalt pavement consists of a porous asphalt surface layer, a top filter base course of 1/2 inch open graded aggregate, an aggregate subbase layer to provide temporary water storage and structural support, a geotextile filter fabric, and the existing subgrade soil. Porous asphalt surface course is also called Open Graded Friction Course (OGFC). The number of porous asphalt installations in Iowa is increasing at a steady pace since the initial full scale applications began in 2006.

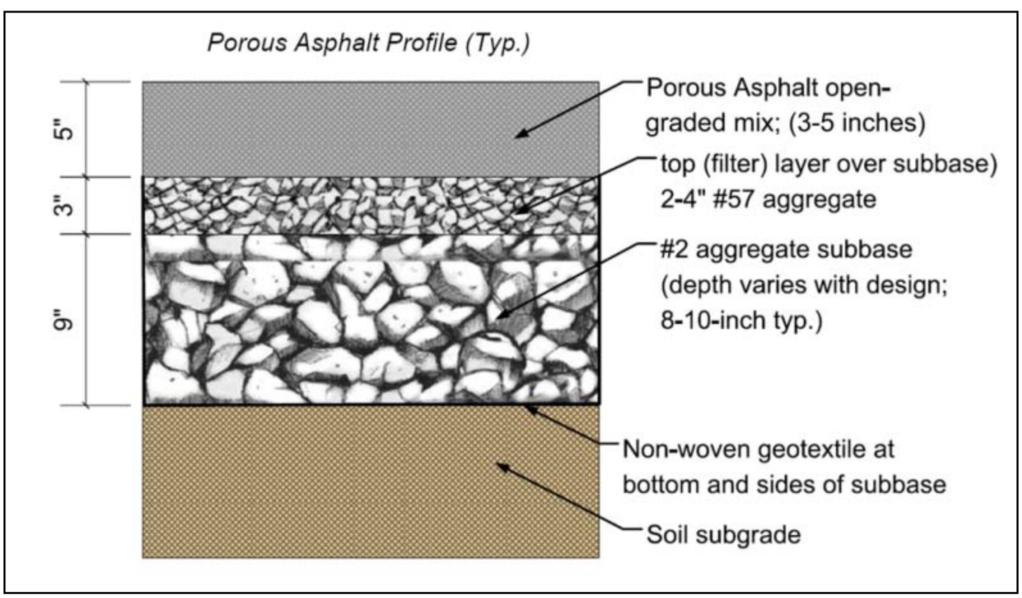
Porous asphalt has the positive characteristics of an ability to blend into the normal urban landscape relatively unnoticed. It will typically allow a reduction in the cost of other stormwater detention infrastructure by increasing the time of concentration and reducing the peak discharge rates for the larger storms. This can offset the somewhat greater placement cost over traditional impervious pavements.

A drawback is the cost and complexity of porous asphalt systems compared to conventional pavements. Porous asphalt systems require a modified construction protocol for equipment and placement than is typical for regular asphalt pavements. The level of construction workmanship is not necessarily more difficult, just different. As with other pavement systems, pervious pavements can experience an increased failure rate if they are not designed, constructed, and maintained properly.

B. Design criteria and specifications

For the purpose of sizing downstream conveyance and structural control system, porous asphalt surface areas can be assumed to 20% impervious. An approximate curve number for pervious pavement area would be in the range of 30 to 35 (i.e. meadow/pasture/grassland on hydrologic soils group A soils). In addition, credit can be taken for the runoff volume infiltrated from other impervious areas conveyed onto the pervious pavement system. The cross-section typically consists of four layers, as shown in Figure 1. A description of each of the layers is presented below:

Figure 1: Typical cross-section for porous asphalt pavement



- ***Porous asphalt layer.*** The porous asphalt layer consists of an open-graded asphalt mixture usually ranging from depths of 3 to 5 inches depending on the required bearing strength and pavement design requirements (3 inches is the recommended minimum for mostly all parking applications). Porous asphalt can be assumed to contain 16% voids (porosity = 0.16) for design purposes. For example, a 6 inch thick pervious concrete layer would hold 0.96 inches of rainfall. The reduction in the quantity of fine aggregate provides the porosity of the porous pavement. To provide a smooth riding surface and to enhance handling and placement a coarse aggregate of #4 to 3/8 inch maximum size is normally used.
- ***Top filter layer.*** For an aggregate subbase layer size of AASHTO #2, a 0.5 inch diameter crushed stone to a depth of 2 inches (minimum) is placed to provide a more uniform compacted surface for placement of the porous asphalt mix. When a #57 aggregate is used, the porous asphalt surface course should be placed directly on top of the aggregate. The filter course layer can be lightly compacted with a vibratory roller or plate compactor to provide a level and firm paving surface. A typical thickness for this upper filter layer is 2 to 4 inches.
- ***Subbase reservoir layer.*** This subbase layer provides the bulk of the aggregate storage capacity for water. The typical base aggregate will be an AASHTO #2 that provides a nominal size of 2.5 to 1.5 inches. The minimum thickness of this layer will depend on the type of subgrade soils, the design subgrade infiltration rate, and the minimum depth required for the storage of the design storm event (i.e. WQv, CPv, 2 year, etc.). A nominal thickness of at least 8 to 10 inches is used. Porous asphalt is a flexible pavement and the #2 base layers provide additional structural support for the pavement system. Guidance on minimum aggregate thickness for structural support based on traffic load (ESALs) and soil conditions is presented in Section 2J-1, Table 2. The gradation for the #2 aggregate will provide a nominal porosity of 0.4. A subbase layer of #2 aggregate 12 inches in depth will provide 0.4 cubic feet of storage for each cubic foot of material. Aggregate gradations based on ASTM D 448 are presented in Section 2J-1, Table 3 and Table 4. Standard sizes of coarse aggregate can also be obtained in Table 4, AASHTO Specifications, Part I, 13th Ed., 1982 or later.
- ***Filter fabric layer.*** A non-woven geotextile fabric provided a separation layer between the subgrade soil and the base course. Selection criteria for the geotextile are provided in Section 2J-1, Figure 4. The geotextile prevents the migration of soil fines into the base course and some additional structural support for weaker soils.

Porous asphalt materials. General design criteria for conventional HMA pavement mix selection design is provided in SUDAS Design Manual, Chapter 5D-1, including guidance on determination of traffic load (ESALs) and material properties for asphalt binder and aggregate. For porous asphalt design, the National Asphalt Paving Association (NAPA) provides a design procedure for Open-graded Friction Courses (1). A summary of the mix design procedure for the porous asphalt surface layer follows:

Coarse aggregates:
- L.A. Abrasion $\leq$ 30 %
- Fractured faces $\geq$ 90% two fractured faces; 100% one of more fractured faces
- Flat and Elongated $\leq$ 5% 5:1 ratio; $\leq$ 20% 2:1 ratio

Fine aggregate:
- Fine Aggregate Angularity (FAA) $\geq$ 45

Asphalt binder:
- High stiffness binder generally two grades stiffer (high temperature designation) than normally used for the local climate.
- Asphalt grade - AASHTO Designation M 20-70 (1996) for 65-80 penetration graded asphalt cement as binder. A performance or PG 64-22 PG 70-22 is acceptable.

- The asphalt binder is the same as used for conventional HMA pavement in Iowa. Since the porous asphalt pavement is more susceptible to scuffing, a stiffer binder should be considered (1). The use of fibers may prevent drain down.
- When using the PG grading system, the high temperature designation is increased one to two grades (1).
- Polymer modifies binder, asphalt rubber binder, or fiber may be used.
- The asphalt content will normally be in the range of 6.0 to 6.5% based on the total weight of the mix. The lower limit assures an adequate coating around the aggregate for durability and the upper limit to prevent an over asphalted mix. The optimum binder content is for the mix design will be based on the local aggregate gradation and determined previously described.

Selection of design gradation:

Table 1: Recommended Gradation for Porous Asphalt (OGFC) (1)

Sieve	Percent Passing
3/4 inch	100
1/2 inch	85 to 100
3/8 inch	55 to 75
No. 4	10 to 25
No. 8	5 to 10
No. 200	2 to 4

- Blend selected aggregate stockpiles to produce three trial blends.
  - One near the coarse side of the gradation band
  - One near the fine side of the gradation band
  - One near the middle of the gradation band
- Determine the dry-rodded voids in the coarse aggregate fraction (VCA_{DRC}) where coarse aggregate fraction is that retained on the No. 4 sieve.
  - Compact the coarse aggregate IAW AASHTO T 19.
  - Calculate the VCA_{DRC}.

  $$VCA_{DRC} = [VCA_{DRC} (\gamma_w - \gamma_s)] \times 100 / G_{CA}\, \gamma_w$$

  Where:

  G_{CA} = bulk specific gravity of the coarse aggregate (AASHTO T 85)

  γ_s = unit weight of the coarse aggregate fraction in the dry condition (kg/m^3)

  γ_w = unit weight of water (998 kg/m^3)

- For each trial gradation prepare three batches at between 6.0 and 6.5 % asphalt binder. Include polymer modifier if used.
- Compact two specimens from each trial gradation using 50 gyrations of the Superpave gyratory compactor.
  - Determine the bulk specific gravity (G) of each specimen.
  - Determine the VCA_{MIX} of each compacted specimen.

  $$VCA_{MIX} = 100 - [\, G_{MB}/G_{CA} \times P_{CA}]$$

  Where:

  G_{MB} = bulk specific gravity of compacted OGFC specimens

  G_{CA} = bulk specific gravity of compacted coarse aggregate

P_{CA} = percent coarse aggregate in the total mixture

- Use the remaining sample from each trial gradation to determine the theoretical maximum specific gravity (G_{mm}) of each trial.
- Compare VCA_{MIX} to VCA_{DRC} for each trial gradation.
- The design gradation is the trial gradation with the highest air voids $VCA_{MIX} < VCA_{DRC}$.

Optimum asphalt content:
- Using the selected design gradation, prepare porous asphalt (OGFC) mixes at three binder contents in increments of 0.5%.
- Conduct draindown test (ASTM D 63900 on loose mix at a temperature 15° higher than anticipated production temperature.
- Compact mix using 50 gyrations of a Superpave gyratory compactor and determine air void contents.
- Conduct the Cantabro abrasion test on un-aged and aged (7-d @ 140° F) samples.
- The asphalt content that meets the following criteria is selected as optimum asphalt content.
    - Air voids ≥ 18%
    - Cantabro Abrasion Test (un-aged) ≤ 20%
    - Cantabro Abrasion Test (aged) ≤ 30%
    - Draindown ≤ 0.3%

Evaluate mix for moisture susceptibility:
- Test final mix for moisture susceptibility using the modified Lottman method (AASHTO T 2830).
    - Compact using 50 gyrations of Superpave gyratory compactor.
    - Apply partial vacuum of 26 inches Hg for 10 minutes to whatever saturation is achieved.
    - Use five freeze-thaw cycles in lieu of one cycle.
    - Keep specimens submerged in water during freeze cycles.
- Retained tensile strength (TSR) ≥ 80%.

Porous asphalt pavement construction. The construction of a porous asphalt pavement system consists of the following procedures:
1. Complete site soils testing as outlined above and in Section 2J-1.
2. Conduct a pre-construction meeting with the contractor to review the design elements and emphasize the importance of avoiding soil compaction on the subgrade and installation of erosion and sediment control BMPs. Review the installation process with the contractor.
3. Prepare the subgrade to design elevation and place geotextile material. Keep wheeled vehicles off of the pervious subgrade.
4. Install the geotextile filter fabric; as an option, several inches of #57 aggregate can be placed as a bottom lower filter course.
5. Place a clean AASHTO #2 (2.5 to 1.5 inch) aggregate base layer in lifts to the *design* thickness and lightly compact. A 5 ton vibratory roller or plate compactor can be used. This operation is to provide light to moderate compaction of the subbase aggregate and will provide a more stable surface for the porous asphalt placement operations. (DO NOT COMPACT THE SUBGRADE).
6. The AASHTO #2 gradation calls for a 0% to 5% passing the 3/4 inch sieve. Most of the material passing the 3/4 inch sieve could be fines that could lead to clogging of the filter fabric. An additional gradation requirement of no more than 0% to 2% passing the No. 100 sieve can be added to the specification to prevent future problems.
7. If subdrain piping is used in the system, place and make the piping connections prior to placing the aggregate. Place the subdrain piping in the aggregate layer to the design elevations.
8. Place a 2 to 4 inch top filter layer of #57 aggregate on top of the subbase layer. When compacted, this layer provides a level and solid base layer to support the installation of the porous asphalt surface layer.

9. Complete the construction of the perimeter PCC curb if used. The PCC curb section provides a stable edge surface for the pervious concrete and a visual and definitive stop for parking of vehicles. (See Figure 4).
10. The porous asphalt layer is placed to a depth of 4 to 6 inches following guidelines for construction of open-graded asphalt mixes (1). (See Figure 4).
11. The asphalt is rolled with two to three passes with a 10 ton roller. (See Figure 5). More frequent rolling may lead to over compaction and reduced infiltration rate of the open-graded mix.

Maintenance

- Protect pavement from vehicular traffic for at least two days after installation.
- Post signs to prevent vehicles with muddy tires from entering area.
- Potholes and cracks may be patched with traditional patching mix, unless more than 10% of porous surface area needs to be repaired.
- Inspect one to two times per month after construction and then a minimum of once annually.
- Check for surface ponding after large storms (> 3.5 inches).
- The porous asphalt surface can be flushed or pressure washed to maintain surface porosity.
- Maintain effective erosion and sediment control on contributing catchment areas.
- Do not allow the use of sand or salt/sand mixtures in the winter for ice control. Liquid de-icer can be used in small amounts in severe conditions, but generally will not be needed.
- Conventional removal of snow with plowing and/or power brushes should not damage the pavement since porous asphalt pavements will accumulate less compacted snow and ice than traditional pavements because of the porous structure and infiltration of melting snow/ice prior to re-freezing.

Figure 2: Placement of geotextile and aggregate subbase on subgrade
(Lot 121, Iowa State University, 2007)

Figure 3: Placement of porous asphalt material over aggregate top layer
(Lot 121, Iowa State University, 2007)

Figure 4: Placement of porous asphalt material
(Lot 121, Iowa State University, 2007)

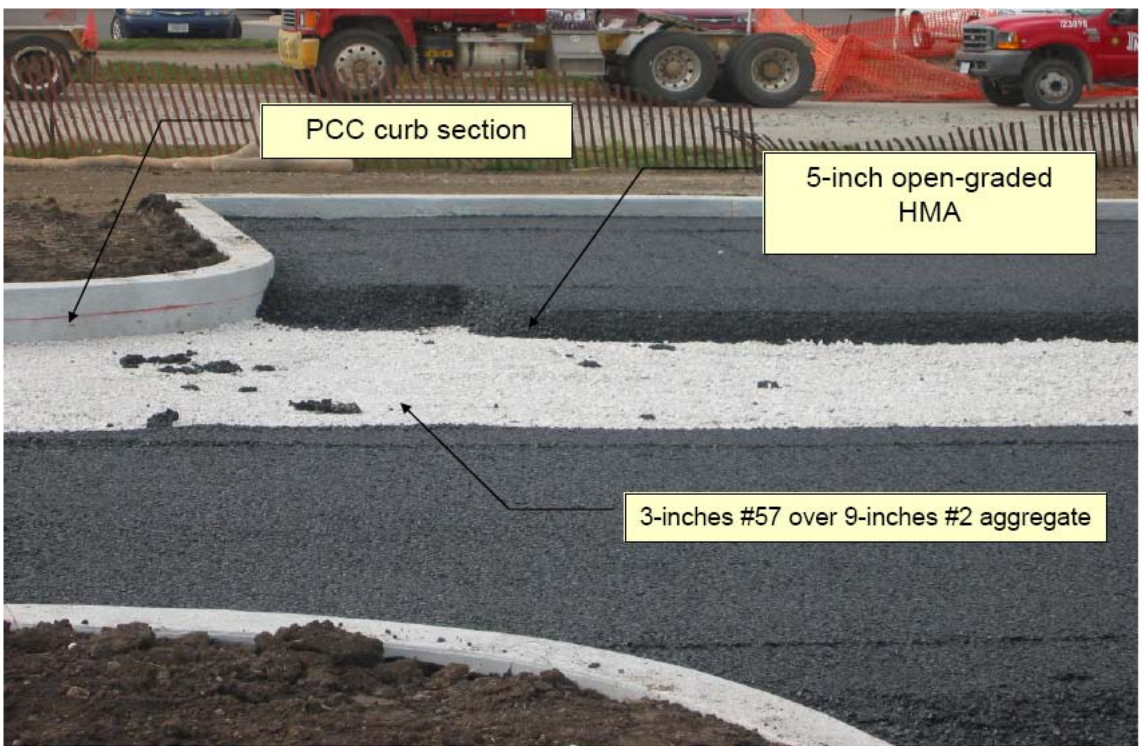


Figure 5: Finish rolling of porous asphalt surface
(Lot 121, Iowa State University, 2007)

Figure 6: Finished porous asphalt surface (18% porosity, PG 82-22)
(Lot 121, Iowa State University, 2007)

Figure 7: Lot 121, Iowa State University - Second winter of operation (2009)

References

1. National Asphalt Pavement Association, "*Design, Construction, and Maintenance of Open-Graded Asphalt Friction Courses,*" NAPA IS-115, Latham, MD, 2003.
2. Center for Transportation Research and Education, "*SUDAS Design Manual,*" Iowa State University, Ames, IA, 2008.
3. U.S. Environmental Protection Agency, Office of Water, Washington D.C., "*Storm Water Technology Fact Sheets Porous Pavement,*" EPA 832-F-99-023, 1999.

2J-4 Permeable Pavers

Pollutant Removal **Low = <30% Medium = 30-65% High = 65-100%**			
	Low	Med	High
Suspended Solids			■
Nitrogen		■	■
Phosphorous		■	
Metals			■
Bacteriological			■
Hydrocarbons		■	

Description: Two types of permeable pavers are included in this section. The first type is monolithic units that do not have void areas incorporated in the pavers. The second type includes manufactured modular paving units with incorporated void areas that are filled with pervious materials such as gravel or grass turf. Permeable pavers are installed over a gravel base course that provides storage as runoff infiltrates through the permeable paver system into underlying permeable soils.

Typical Uses: Intended for low traffic areas, or for residential or overflow parking applications in higher density residential areas, high-density ultra urban areas, commercial areas.

Advantages:
- High level of pollutant removal
- Provides reduction in runoff volume
- Suitable for cold climates
- Available from commercial vendors

Limitations:
- Soil infiltration rate of 0.5 inches per hour or greater required
- High cost compared to conventional pavements
- High maintenance requirements
- Potential for high failure rate if not adequately maintained or used in unstabilized areas
- Potential for groundwater contamination

Maintenance Requirements:
- Prevent run-on of sediment in runoff from adjoining areas
- Sweep/vacuum one to two times per year
- Avoid ("prevent") application of sand in winter

A. General description

Modular permeable pavers are structural units, such as concrete blocks, bricks, or reinforced plastic mats, with regularly inter-dispersed void areas used to create a load-bearing pavement surface. The void areas are filled with permeable materials (gravel, sand, or grass turf) to create a system that allows for the infiltration of stormwater runoff. Permeable pavers provide water quality benefits in addition to groundwater recharge and a reduction in stormwater volume. The use of permeable pavers results in a reduction of the effective impermeable area on a site.

There are many different types of modular permeable pavers available from different manufacturers, including both precast and mold in-place concrete blocks, concrete grids, interlocking bricks, and plastic mats with hollow rings or hexagonal cells (Figure 1).

Figure 1: Examples of modular permeable pavers

Figure 2: Examples of monolithic permeable pavers

Monolithic permeable pavers are solid units that when placed provide area between the units for stormwater infiltration. The monolithic permeable pavers are manufactured in many different shapes that provide for easier placement and increased permeable areas.

Permeable pavers are typically placed on a gravel (stone aggregate) base course. Runoff infiltrates through the permeable paver surface into the gravel base course, which acts as a storage reservoir as it exfiltrates to the underlying soil. The infiltration rate of the soils in the subgrade must be adequate to support drawdown of the entire runoff capture volume within 24 to 48 hours. Special care must be taken during construction to avoid undue compaction of the underlying soils, which could affect the infiltration capability of the soils.

Permeable paver systems are typically used in low-traffic areas such as the following types of applications:
- Parking pads in parking lots
- Overflow parking areas
- Residential driveways
- Residential street parking lanes
- Recreational trails
- Golf cart and pedestrian paths
- Emergency vehicle and fire access lanes

A major drawback is the cost and complexity of permeable paver systems compared to conventional pavements. Permeable pavers require a moderate level of construction workmanship to ensure that they function as designed. In addition, there is the difficulty and cost of rehabilitating the surfaces should they become clogged. Therefore, consideration of permeable pavers should include the construction and maintenance requirements and costs.

B. Pollutant removal capabilities

As they provide for the infiltration of stormwater runoff, permeable pavers have a high removal of both soluble and particulate pollutants, where they become trapped, absorbed, or broken down in the underlying soil layers. Due to the potential for clogging, permeable paver surfaces should not be used for the removal of sediment or other coarse particulate pollutants. The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes:
- Total suspended solids - not applicable
- Total phosphorus - 80%
- Total nitrogen - 80%
- Fecal coliform - insufficient data
- Heavy metals - 90%

C. Design criteria and specifications

1. Permeable pavers can be used where the underlying in-situ subsoils have an infiltration rate between 0.5 and 3.0 inches per hour. Therefore, unless underdrains and pipe discharge are provided, permeable pavers are not suitable on sites with hydrologic group D or most group C soils, or soils with a high (>30%) clay content. During construction and preparation of the subgrade, special care must be taken to avoid compaction of the soils.

2. Permeable pavers should typically be used in applications where the pavement receives tributary runoff only from impermeable areas. The ratio of the contributing impermeable area to the permeable paver surface area should be no greater than 3:1.

3. If runoff is coming from adjacent permeable areas, it is important that those areas be fully stabilized to reduce sediment loads and prevent clogging of the permeable paver surface.

4. Permeable pavers are not recommended on sites with a slope greater than 2%.

5. A minimum of 2 feet of clearance is required between the bottom of the gravel base course and underlying bedrock or the seasonally high groundwater table.

6. Permeable pavers should be sited at least 10 feet down gradient from buildings and 100 feet away from drinking water wells.

7. An appropriate permeable paver should be selected for the intended application. A minimum of 40% of the surface area should consist of open void space. If it is a load-bearing surface, then the pavers should be able to support the maximum load.

8. The permeable paver infill is selected based upon the intended application and required infiltration rate. Masonry sand (such as ASTM C 33 concrete sand or Iowa DOT Fine Aggregate Size No. 10) has a high infiltration rate (8 inches per hour) and should be used in applications where no vegetation is desired. A sandy loam soil has a substantially lower infiltration rate (1 inch per hour), but will provide for growth of a grass ground cover.

9. The gravel base course should be designed to store at a minimum the water quality volume (WQv). The stone aggregate used should be washed, bank-run gravel, 0.75 to 1.0 inches in diameter with a void space of about 40% (Iowa DOT No. 5 or 57 Stone). Aggregate contaminated with soil should not be used. A porosity value (void space/total volume) of 0.32 should be used in calculations.

10. The gravel base course must have a minimum depth of 9 inches. The following equation can be used to determine if the depth of the storage layer (gravel base course) needs to be greater than the minimum depth:

    $$d = V / A * n$$

    Where:
    - d = Gravel Layer Depth (feet)
    - V = Water Quality Volume –or– Total Volume to be Infiltrated
    - A = Surface Area (square feet)
    - n = Porosity (use n = 0.32)

11. The surface of the subgrade should be lined with a non-woven geotextile filter fabric and be completely flat to promote infiltration across the entire surface.

12. Designs of permeable pavers must use some method to convey larger storm event flows to the conveyance system. One option is to use storm drain inlets set slightly above the elevation of the pavement. This would allow for some ponding above the surface, but would accept bypass flows that are too large to be infiltrated by the permeable paver system, or if the surface clogs.

13. For the purpose of sizing downstream conveyance and structural control system, permeable paver surface areas can be assumed to be 35% impermeable.

D. Inspection and maintenance requirements

Table 1: Typical maintenance activities for permeable pavers

Activity	Schedule
Ensure that the permeable surface is free of sediment.	Monthly
Check to make sure that the system dewaters between storms.	
Ensure that the contributing area and permeable surface are clear of debris.	As needed, based on inspection
Ensure that the contributing and adjacent area is stabilized and mowed with clippings removed.	
Vacuum sweep permeable surface to keep free of sediment.	Semi-annually
Inspect the surface for deterioration or spalling.	Annually

PERVIOUS PORTLAND CEMENT CONCRETE (PCC) PAVEMENT

These specifications compliment the pervious PCC pavement design portion of the Iowa Stormwater Management Manual in Chapter 2, Section 2J-2.

Sections of the following documents, as referenced within these specifications, are hereby made a part of these specifications:

- SUDAS Standard Specifications: The standard specifications issued by the Iowa Statewide Urban Design and Specifications Program effective at the date of publication of the Notice to Bidders, unless a different effective date is identified in the contract documents.

- Iowa DOT Standard Specifications for Highway and Bridge Construction: The Iowa Department of Transportation Standard Specifications for Highway and Bridge Construction and the General Supplemental Specifications effective at the date of publication of the Notice to Bidders unless a different effective date is identified in the contract documents.

- Iowa DOT Materials Instructional Memorandum: The Iowa Department of Transportation's Materials Instructional Memorandum effective at the date of publication of the Notice to Bidders, unless a different effective date is identified in the contract documents.

- American Concrete Institute, Specification for Pervious Concrete Pavement, ACI 522.1-08.

- American Society for Testing and Materials (ASTM) standards.

- American Association of State Highway and Transportation Officials (AASHTO) Standard Specifications for Transportation Materials and Methods of Sampling and Testing.

PART 1 - GENERAL

1.01 SECTION INCLUDES

A. Subgrade Preparation for Pervious Portland Cement Concrete (PCC) Pavement

B. Placement of Filter Aggregate

C. Placement of Pervious PCC Pavement

D. Testing of Pervious PCC Pavement

1.02 DESCRIPTION OF WORK

Construct pervious PCC pavement for treatment of stormwater runoff.

1.03 SUBMITTALS

A. Concrete Materials:

1. Proposed concrete mixture proportions including all material weights, volumes, fresh design unit weight per 3.09, B, water-to-cement ratio, in-place design density, and in-place design void content.

1.03 SUBMITTALS (Continued)

2. Aggregate types, sources, and gradations from a qualified testing agency.

3. Material certifications signed by manufacturers certifying that each of the following materials complies with the specified requirements:
   a. Cement.
   b. Supplementary cementitious materials.
   c. Chemical admixtures.
   d. Fiber reinforcement.

B. Filter Aggregate: Including aggregate type, source, gradation, and compacted void content.

C. Project Details: Including jointing plan, schedule, construction procedures, and quality control plan.

D. Qualifications: Comply with 1.07 below for contractor and concrete producer.

E. Involved Parties: Submit a list of all subcontractors, material suppliers, and testing laboratories.

1.04 SUBSTITUTIONS

Comply with the requirements of the contract documents.

1.05 DELIVERY, STORAGE, AND HANDLING

Comply with the requirements of the contract documents.

1.06 SCHEDULING AND CONFLICTS

Comply with the requirements of the contract documents.

1.07 SPECIAL REQUIREMENTS

A. Quality Control:

1. **General:** Test and inspect concrete materials and operations as work progresses. Failure to detect defective work or material early could result in rejection if a defect is discovered later.

2. **Contractor Qualifications:**
   a. Provide employees who have a minimum of one of the following National Ready Mixed Concrete Association (NRMCA) certifications:
      1) One certified Pervious Concrete Craftsman, or
      2) Two certified Pervious Concrete Installers, or
      3) Three certified Pervious Concrete Technicians.
   b. Certified employees must be overseeing placement or working as part of the placement crew during all pervious PCC placement.

1.07 SPECIAL REQUIREMENTS (Continued)

c. Alternative qualifications or previous project experience, in lieu of required certification, may be submitted to Engineer for approval prior to submitting the bid.

3. Ready Mixed Supplier Qualifications:

a. Manufacturer of ready mixed concrete products who complies with ASTM C 94 for production facilities and equipment.
b. Manufacturer certified according to NRMCA's "Certification of Ready Mixed Concrete Production Facilities."
c. Ready mixed plant must have current Iowa DOT plant calibration.
d. Provide at least one employee overseeing production of pervious PCC mix who is a NRMCA certified Pervious Concrete Technician.

4. Test Panel:

a. Prior to installation of pervious PCC at the site, construction of a test panel is required.
   1) Construct a minimum 10 foot by 15 foot pervious PCC panel equal to the proposed thickness.
   2) Install, consolidate, joint, and cure the test panel using the materials, mixture proportions, equipment, and personnel proposed for the project.
   3) During test panel installation, provide density and workability testing complying with 3.09.
   4) Test panel may be constructed on-site and demolished after test approval or may be constructed at an off-site location.
   5) Upon approval of the Engineer, the test panel may be constructed on-site and incorporated as part of the project. When the test panel is used as part of the project, it must be placed at least 7 days prior to placement of the main pervious PCC sections to allow for approval of the hardened section.
   6) Acceptance of the test panel will be based on the following:
      a) Organized construction team with proper equipment and installation practices.
      b) Unit weight of mixture within 5 pounds per cubic foot of the design weight, tested according to 3.09, B.
      c) Acceptable surface finish, joint details, thickness, and curing procedures.
   7) If the Engineer determines the test panel is unacceptable, the test panel will be removed and redone until accepted.
b. Experienced pervious PCC contractors and suppliers may submit written documentation of previous successful pervious PCC installations. Based on experience, the Engineer may waive the requirement for test panel construction.

5. Pre-placement Conference:

a. Schedule a pre-placement conference with the Engineer and Concrete Supplier within one week prior to beginning placement. Preferably, the meeting will take place after the test section has been placed. The pervious PCC supplier and the placement crew supervisor, who will be on-site during pervious PCC placement, must be in attendance.
b. During the pre-placement conference, explain knowledge and understanding of how pervious PCC placement differs from traditional concrete. Explain how unexpected conditions (weather, equipment breakdowns, etc.) will be handled.

1.07 SPECIAL REQUIREMENTS (Continued)

B. Weather Restrictions:

1. Do not place pervious PCC when the forecasted ambient air temperature is 40 ˚F or lower during the 7 days following the placement, unless a cold weather protection plan has been submitted and approved by the Engineer.

2. Do not place pervious PCC when the ready mixed supplier has switched to heated mixing water for winter production.

3. Do not place pervious PCC when the ambient air temperature is 90 ˚F or higher, unless a written hot weather plan has been submitted and approved by the Engineer.

4. Additional hydration stabilizing admixture is required in hot weather.

1.08 MEASUREMENT AND PAYMENT

A. Class 10, Class 12, or Class 13 Excavation: Refer to SUDAS Section 2010, 1.08, E for measurement and payment information for Class 10, Class 12, or Class 13 Excavation.

B. Engineering Fabric:

1. **Measurement:** Measurement will be in square yards for the surface area covered with engineering fabric. Both horizontal and vertical areas covered with engineering fabric will be measured.

2. **Payment:** Payment will be made at the unit price per square yard of engineering fabric.

3. **Includes:** Unit price includes, but is not limited to, placing and securing filter fabric and any overlapped areas.

C. Underdrain:

1. **Measurement:** Measurement will be in linear feet for each type and size of pipe installed. Pipe will be measured from end of pipe to end of pipe along the centerline of pipe, exclusive of outlets. The vertical height of cleanouts and observation wells will be included in the length of pipe measured. Lengths of elbows, tees, wyes and other fittings will be included in length of pipe measured.

2. **Payment:** Payment will be made at the unit price per linear foot for each type and size of pipe.

3. **Includes:** Unit price includes, but is not limited to, furnishing and placing pipe and pipe fittings.

1.08 MEASUREMENT AND PAYMENT (Continued)

D. Filter Aggregate:

1. **Measurement:** Measurement will be in tons based upon scale tickets for the material delivered and incorporated into the project.

2. **Payment:** Payment will be made at the unit price per ton of filter aggregate.

3. **Includes:** Unit price includes, but is not limited to, engineering fabric and furnishing, hauling, and placing filter aggregate.

E. Pervious Portland Cement Concrete:

1. **Measurement:** Measurement will be in square yards for each thickness of pervious PCC pavement. The area of manholes, intakes, or other fixtures in the pavement will not be deducted from the measured pavement area.

2. **Payment:** Payment will be made at the unit price per square yard for each thickness of pervious PCC pavement.

3. **Includes:** Unit price includes, but is not limited to, construction of test panel(s), mixture testing, final trimming of subbase, surface curing, pavement protection, safety fencing, and boxouts for fixtures.

PART 2 - PRODUCTS

2.01 ENGINEERING FABRIC

Comply with Iowa DOT Section 4196, requirements for subsurface drainage.

2.02 UNDERDRAIN

A. Provide slotted pipe(s) complying with the requirements for Type 1 Subdrain in SUDAS Section 4040.

B. Provide 6 inch diameter collector pipes unless otherwise specified in the contract documents.

C. Provide 4 inch diameter lateral pipes unless otherwise specified in the contract documents.

2.03 TYPE 1 FILTER AGGREGATE

Provide aggregate complying with Iowa DOT Section 4115, Gradation No. 3, Class 2 durability gravel or crushed stone (AASHTO M 43/ASTM D 448, Size 57).

2.04 PERVIOUS PORTLAND CEMENT CONCRETE

A. Portland Cement: Type I or Type II complying with Iowa DOT Section 4101 and Materials I.M. 401.

B. Supplementary Cementitious Materials:

1. Fly ash complying with Iowa DOT Section 4108.

2. Ground Granulated Blast Furnace Slag (GGBFS) complying with Iowa DOT Section 4108.

C. Aggregate:

1. Coarse Aggregate:
   a. With at least 36% voids calculated on a compacted dry bulk density basis complying with ASTM C 29.
   b. Washed, clean, and free of dirt and excess fines.
   c. Specific gravity greater than 2.5.
   d. Absorption of less than 2.5%.
   e. Aggregate should be in a saturated surfaced dry condition.

2. Fine Aggregate: Concrete sand complying with Iowa DOT Section 4110, Gradation No. 1 (ASTM C 33).

3. Combined Aggregate:
   a. Combine coarse and fine aggregate to comply with gradation limits in the table below.
   b. Provide at least 5% of combined aggregate weight from fine aggregate.

2.04 PERVIOUS PORTLAND CEMENT CONCRETE (Continued)

Sieve Size	Percent Passing	
	Max.	Min.
1 1/2”	100	---
3/4”	100	---
1/2”	94	100
3/8”	38	99
No. 4	5.5	44
No. 8	4.5	13
No. 16	3.5	11
No. 30	2	7
No. 50	0.5	4
No. 100	0	2

D. Admixtures:

1. Air Entraining Admixture:
- a. Comply with ASTM C 260.
- b. Dosed at 2 oz/cwt.

2. Chemical Admixtures:
- a. Mid-Range Water Reducing Admixtures:
  - 1) Polycarboxylate type water reducer complying with ASTM C 494, Type A.
  - 2) Provide one of the following, or approved equal:
    - a) Catexol Hydrosense, Axim Concrete Technologies
    - b) Duralflux 77, Axim Concrete Technologies
    - c) Polyheed 1725, BASF Admixtures, Inc.
    - d) Sikaplast 500, Sika Corporation
- b. Extended Control Admixtures (hydration stabilizers):
  - 1) Comply with ASTM C 494, Type B (Retarding) or Type D (Water Reducing / Retarding).
  - 2) Provide one of the following:
    - a) Delvo Stabilizer, BASF Admixtures, Inc.
    - b) Recover, W.R. Grace & Company
- c. Make water reducer and hydration stabilizer available at the project site for re-dosing if required.

E. Fiber Reinforcement:

1. Comply with ASTM C 1116.

2. Provide fibers with a maximum length of 1 1/2 inches.

F. Water:

1. Comply with Iowa DOT Section 4102.

2. Do not use heated water.

2.04 PERVIOUS PORTLAND CEMENT CONCRETE (Continued)

G. **Mixture Proportions:** Develop and furnish a proposed concrete mixture complying with the requirements below. Trial mixtures should be placed to establish proper proportions and determine expected behavior.

1. Concrete mixture density between 115 pcf to 130 pcf determined by ASTM C 1688.

2. Volumetric void content from 15% to 25%.

3. Cementitious content from 500 pcy to 600 pcy.

4. Supplementary Cementitious Material (SCM):
   a. Up to 50% replacement for cement.
   b. Maximum of 25% for fly ash and 50% for GGBFS.
   c. SCMs are recommended at 35% slag and 15% fly ash by weight of total cementitious materials.

5. Water-to-cementitious materials (w/c) ratio from 0.29 to 0.34.

6. Admixture Dosing (for all mixes):
   a. Air Entraining Agent: Air content of pervious PCC cannot be measured. Dose according to admixture company recommendations for concrete exposed to severe freeze/thaw conditions.
   b. Mid-range Water Reducer: Dose at 6 ounces per 100 pounds of cementitious material.
   c. Hydration Stabilizer:
      1) Delvo: 6 to 12 ounces per 100 pounds of cementitious material.
      2) Recover: 7.5 to 15 ounces per 100 pounds of cementitious material.
      3) Use higher dosage rates for placement in hot weather.

2.05 ISOLATION JOINT MATERIAL

Comply with SUDAS Section 7010, 2.02, L.

2.06 CURING

A. Polyethylene sheeting complying with ASTM C 171.

B. Minimum 6 mil thickness.

C. Provide sheeting with a width at least 2 feet wider than pavement being placed. Roll sheeting onto a tube prior to concrete placement.

D. Provide 2 by 4 lumber and sand bags to anchor polyethylene sheeting.

E. Provide soybean oil based concrete curing compound or equivalent.

PART 3 - EXECUTION

3.01 EQUIPMENT

A. **Forms:** Comply with SUDAS, Section 7010, 2.07.

B. **Roller Screed:** Powered (hydraulic or electric) roller screed weighted with sand or water to achieve a weight of approximately 20 pounds per linear foot.

C. **Cross Rollers:** Maximum weight of 100 pounds.

D. **Rolled Joint Former:** Cross roller with a flange welded around its circumference at the midsection. Depth of the flange is between 1.5 and 2.0 inches.

E. **Hand Tamper:** 8 inch by 8 inch cast iron.

3.02 PRE-INSTALLATION PROTECTION

A. Complete grading, utility installation, and other earth disturbing operations prior to excavating for the permeable paver system.

B. Prior to placing permeable interlocking concrete pavers, install sediment control practices upstream to protect the area from sediment in stormwater runoff from disturbed soil.

3.03 SUBGRADE PREPARATION FOR PERVIOUS PCC

A. Do not compact or subject the subgrade area under the pervious PCC pavement to excessive construction equipment prior to placement of the engineering fabric.

B. Excavate area to the elevations and grades specified in the contract documents.

C. In areas where cuts are required, do not compact surface. After final elevation is achieved, scarify surface to a minimum depth of 3 inches to reduce compaction caused by construction equipment.

D. Where fill materials are required, compact material to 92% of maximum Standard Proctor Density. Do not over-compact.

E. Fill and lightly re-grade any areas damaged by erosion, ponding, or traffic compaction prior to placing the engineering fabric.

3.04 ENGINEERING FABRIC

A. Install engineering fabric over completed subgrade, including trench for underdrain when specified in the contract documents.

B. Overlap adjacent strips of fabric a minimum of 6 inches.

C. Extend fabric up the sides of the subbase trench to the bottom of the proposed pavement.

3.05 UNDERDRAIN

A. Underdrain Collector Pipes:

1. Place 2 inches of filter aggregate in the bottom of the underdrain trench over engineering fabric.

2. Begin underdrain collector installation at the outlet and continue upgrade.

3. Lay underdrain collector pipe to the proper line and grade. Place pipe with perforations down.

4. Place filter aggregate over installed pipe in layers not more than 6 inches thick. Thoroughly tamp each layer with mechanical tampers.

5. Provide cleanouts where specified in the contract documents. Comply with SUDAS Figure 4040.232.

6. Connect underdrain collector to outlet. Comply with SUDAS Figure 4040.233. Install rodent guard on all underdrain pipe 6 inches or smaller.

7. Install underdrain cleanout pipes and observation wells as specified in the contract documents.

B. Underdrain Lateral Pipes:

1. Place 2 inches of filter aggregate over the bottom of the prepared subgrade at lateral pipe locations specified in the contract documents.

2. Lay underdrain lateral over filter aggregate to the proper line and grade. Place pipe with perforations down.

3. Connect underdrain laterals to underdrain collector with wye or tee fitting.

4. Install plug or cap on upstream end of lateral pipe.

3.06 FILTER AGGREGATE

A. Place filter aggregate in 6 inch maximum lifts. If underdrain system is specified, take care not to damage or displace pipe during placement of filter aggregate.

B. Compact each lift with a maximum of two passes from a vibratory plate compactor or vibratory drum roller. Do not operate compaction equipment directly over underdrain, until a minimum of 12 inches of filter aggregate is placed over the underdrain.

C. Install filter aggregate to the elevation specified in the contract documents.

D. Proof roll completed filter aggregate subbase with a maximum 5 ton static roller.

3.07 PERVIOUS PCC PLACEMENT

A. Forms:

1. The vertical face of previously placed adjacent concrete may be used.
   a. Protect previously placed concrete from damage.
   b. Do not apply form release agent to previously placed concrete.

2. Where adjacent pavement does not create a perimeter for the pervious PCC area, provide paving forms as follows:
   a. Set, brace, and secure forms to the lines, grades, and elevations specified in the contract documents.
   b. Extend forms to the full depth of the pavement.
   c. Install forms to allow continuous progress of work and so forms can remain in place at least 24 hours after concrete placement.
   d. Immediately before placing concrete, apply form release agent to form faces that will be in contact with concrete.

B. Mixing and Hauling: Batch, mix, and deliver in compliance with ASTM C 94, with the following exceptions.

1. Deliver and discharge mixture completely within 60 minutes of the addition of mix water to the cement.

2. Delivery time may be extended to 90 minutes when dosages of hydration stabilizer are increased.

3. After 30 minutes of mixing time, re-dosing of admixtures at project site may be required to achieve workability.

C. Initial Inspection and Adjustments:

1. Visually inspect each load for consistency and workability.

2. Perform inverted slump-cone test on each load as described in 3.09 until uniform consistency is achieved for all loads.
   a. If mixture flows from cone, workability is acceptable and mix may be placed.
   b. If mixture flow is unacceptable, adjust as follows:
      1) Add 1/2 gallon of water per cubic yard.
      2) Mix for 3 minutes.
      3) Retest mix for workability.
      4) If mixture is still unworkable, add 50% of the original dosage of hydration stabilizer and 1/2 gallon of water per cubic yard.
      5) Mix for 3 minutes.
      6) Retest mix for workability. If mixture is still unworkable, the load will be rejected.
      7) Adjust subsequent loads at the plant.

3. Perform at least one fresh density test according to 3.09 at the mid-point of the load for the first concrete truck and for every five loads thereafter.

3.07 PERVIOUS PCC PLACEMENT (Continued)

4. Perform at least one estimated in-situ unit weight test each day pervious PCC is placed and after each mix adjustment.

D. Placing and Finishing:

1. Moisten subbase thoroughly prior to placement.
2. Deposit concrete into the forms by mixer truck chute, conveyor, or buggy. Do not pump pervious PCC.
3. Do not place concrete on frozen subgrade or subbase.
4. Do not push or drag concrete into place or use vibrators to move concrete into place. Spread concrete with a square-ended shovel or rake.
5. Do not allow foot traffic on fresh concrete.
6. Strike off the surface and compact the concrete with a roller screed.
7. Maintain a 1 to 2 inch pile of concrete across the width of the front of the roller screed during the initial pass.
8. After the initial pass with the roller screed, hand place an additional 6 inch wide by 1/2 inch thick strip of loose mix around the perimeter of the pervious PCC surface. Fill the mix into the surface with a hand tamper until level with the adjacent surface. Additional passes of the roller will be allowed to smooth surface if necessary.
9. Roll the surface perpendicular to the direction of the roller screed with overlapping passes of the cross roller. Operate the cross roller on top of the polyethylene sheeting installed for curing.
10. Do not finish pervious PCC with floats or trowels.
11. Finish all edges of pervious PCC with a 1/2 inch radius edging tool.

E. Jointing:

1. Pre-mark joint locations prior to beginning paving.
2. Joints may be sawed into the hardened concrete 24 hours after placement or constructed immediately after finishing with roller screed. For sawed joints, limit the time polyethylene sheeting is removed in order to prevent excessive evaporation.
3. Soybean oil cure may be placed prior to forming joints.
4. Place formed joints with approved pizza-cutter type jointing roller. Only one pass of the roller is allowed for each joint.

3.07 PERVIOUS PCC PLACEMENT (Continued)

5. Install isolation (expansion) joints where the pavement abuts the fixed vertical structures such as buildings, manholes, and light poles.

F. Curing:

1. Begin curing procedures within 10 minutes of the concrete being discharged or within 10 feet behind the compaction roller, whichever comes first.

2. Apply soybean oil cure at rate recommended by manufacturer. Apply cure from two different directions to ensure complete coverage of porous surface.

3. Cover surface with polyethylene sheeting. Concrete must be covered within 10 minutes of discharging.

4. Additional rolling with cross roller, if necessary, may be completed after covering concrete with polyethylene sheeting.

5. Anchor sheeting by placing 2 by 4 lumber along the edge of the sheeting and weighting the lumber with sand bags. Do not place lumber or anchors directly on newly finished concrete.

6. Do not use mud clods, concrete chunks, or other debris to anchor the sheeting.

7. Additional anchoring will be required if the wind causes billowing of the sheeting during the curing period.

8. Keep the sheeting in place and maintain during the minimum 7 day curing period.

9. Do not allow vehicular traffic on the pavement until curing is completed.

3.08 POST PLACEMENT PAVEMENT PROTECTION

A. Erosion and Sediment Control: Maintain erosion and sediment control practices until vegetation is established to prevent sediment in stormwater runoff from clogging the concrete pores.

B. Pavement:

1. Keep polyethylene sheeting in place, properly secured, for at least 7 days after placement.

2. Protect the pavement from heavy construction traffic, including trucks, skid steers, loaders, and all tracked vehicles until project completion.

3. Do not stockpile soil, mulch, compost, sand, gravel, crushed stone, or other loose materials on pervious PCC, or in areas where uncontrolled stormwater runoff could carry these materials to the pervious PCC and contaminate the pervious surface.

3.09 TESTING

A. **Inverted Slump Cone Test:** The purpose of the inverted slump cone is to determine if the delivered pervious PCC has sufficient workability for rapid discharge and to achieve the desired compaction using methods outlined in 3.07, D.

1. Fill inverted slump cone with plastic pervious PCC. Do not rod or compact.
2. Lift the cone to knee height with a smooth motion. If necessary, give the cone a jostle or mild shake to initiate flow.
3. If material flows from the cone, its workability is acceptable.
4. If material remains lodged in the cone, it does not have adequate workability. Remediation or rejection of the mix is required.
5. Comply with 3.07, C for remediation of mixtures determined to be unworkable.

B. **Verification of Fresh Design Unit Weight:** After verifying correct workability using the inverted slump cone test in 3.09, A, determine the fresh concrete density and compare with the design density submitted by the concrete producer.

1. Fill a unit weight container (commonly the bottom 1/4 cubic foot of an air pressure meter) of known weight and volume with fresh pervious PCC in two lifts.
2. Compact each layer with 20 drops of a standard proctor hammer.
3. Strike off the surface flush with the top of the unit weight bucket.
4. Calculate the fresh density.
5. Compare fresh density to the ASTM C 1688 design density specified for the mixture proportions. The allowable variation is plus or minus 5 pounds per cubic foot from the design unit weight.

C. **Estimated In-situ Unit Weight:** Determine the estimated in-place, in-situ unit weight from the loose, uncompacted concrete state.

1. Fill a unit weight container (commonly the bottom 1/4 cubic foot of an air pressure meter) of known weight and volume with fresh pervious PCC concrete in two lifts.
2. Evenly distribute the concrete in the container but do not compact or consolidate.
3. Strike off the surface even with the top of the container.
4. Weigh the filled container and determine the unit weight of the uncompacted mix.

3.09 TESTING (Continued)

5. Calculate the estimated in-situ density by multiplying the uncompacted unit weight by the appropriate compaction factor provided in the table below:

Pavement Thickness (inches)	Compaction Factor
4	1.25
6	1.17
8	1.13

6. Compare estimated in-situ density to the design unit weight specified for the mix design. The allowable variation is plus or minus 5 pounds per cubic foot from the design unit weight.

POROUS HOT MIX ASPHALT (HMA) PAVEMENT

These specifications compliment the porous HMA pavement design portion of the Iowa Stormwater Management Manual in Chapter 2, Section 2J-3.

Sections of the following documents, as referenced within these specifications, are hereby made a part of these specifications:

- SUDAS Standard Specifications: The standard specifications issued by the Iowa Statewide Urban Design and Specifications Program effective at the date of publication of the Notice to Bidders, unless a different effective date is identified in the contract documents.

- Iowa DOT Standard Specifications for Highway and Bridge Construction: The Iowa Department of Transportation Standard Specifications for Highway and Bridge Construction and the General Supplemental Specifications effective at the date of publication of the Notice to Bidders unless a different effective date is identified in the contract documents.

- American Society for Testing and Materials (ASTM) standards.

- National Asphalt Pavement Association's Information Series 131.

- American Association of State Highway and Transportation Officials (AASHTO) Standard Specifications for Transportation Materials and Methods of Sampling and Testing.

PART 1 - GENERAL

1.01 SECTION INCLUDES

A. Subgrade Preparation

B. Placement of Storage Aggregate

C. Placement of Filter Aggregate

D. Placement of Porous HMA Pavement

E. Testing of Porous HMA Pavement

1.02 DESCRIPTION OF WORK

Construct porous HMA pavement for treatment of stormwater runoff.

1.03 SUBMITTALS

A. Porous HMA Materials:

1. A statement from the polymer-modified asphalt supplier certifying that the polymer-modified asphalt complies with these specifications and indicating the following:
   a. Type of elastomer polymer used to modify the asphalt.
   b. Quality control sampling and testing procedures used to certify the polymer modified asphalt prior to shipping to the contractor's asphalt plant.

1.03 SUBMITTALS (Continued)

c. Information on storage and stability of the polymer modified asphalt.
d. Recommended mixing and compaction temperatures.

2. Aggregate types, sources, and gradations from a qualified testing agency.

3. Results of proposed asphalt mix testing for resistance to stripping and draindown.

4. Depending on the type of aggregates used, submit binder content determination results.

B. Filter and Storage Aggregates: Including aggregate type, source, gradation, and void content.

1.04 SUBSTITUTIONS

Comply with the requirements of the contract documents.

1.05 DELIVERY, STORAGE, AND HANDLING

Comply with the requirements of the contract documents.

1.06 SCHEDULING AND CONFLICTS

Comply with the requirements of the contract documents.

1.07 SPECIAL REQUIREMENTS

None.

1.08 MEASUREMENT AND PAYMENT

A. Class 10, Class 12, or Class 13 Excavation: Refer to SUDAS Section 2010, 1.08, E for measurement and payment information for Class 10, Class 12, or Class 13 Excavation.

B. Engineering Fabric:

1. **Measurement:** Measurement will be in square yards for the surface area covered with engineering fabric. Both horizontal and vertical areas covered with engineering fabric will be measured.

2. **Payment:** Payment will be made at the unit price per square yard of engineering fabric.

3. **Includes:** Unit price includes, but is not limited to, placing and securing filter fabric and any overlapped areas.

1.08 MEASUREMENT AND PAYMENT (Continued)

C. Underdrain:

1. **Measurement:** Measurement will be in linear feet for each type and size of pipe installed. Pipe will be measured from end of pipe to end of pipe along the centerline of pipe, exclusive of outlets. The vertical height of cleanouts and observation wells will be included in the length of pipe measured. Lengths of elbows, tees, wyes and other fittings will be included in length of pipe measured.

2. **Payment:** Payment will be made at the unit price per linear foot for each type and size of pipe.

3. **Includes:** Unit price includes, but is not limited to, furnishing and placing pipe, cleanouts, observation wells, and pipe fittings.

D. Storage Aggregate:

1. **Measurement:** Measurement will be in tons based upon scale tickets for the material delivered and incorporated into the project.

2. **Payment:** Payment will be made at the unit price per ton of storage aggregate.

3. **Includes:** Unit price includes, but is not limited to, furnishing, hauling, and placing storage aggregate.

E. Filter Aggregate:

1. **Measurement:** Measurement will be in tons based upon scale tickets for the material delivered and incorporated into the project.

2. **Payment:** Payment will be made at the unit price per ton of filter aggregate.

3. **Includes:** Unit price includes, but is not limited to, furnishing, hauling, and placing filter aggregate.

F. Porous HMA Pavement:

1. **Measurement:** Measurement will be in square yards for each thickness of porous HMA pavement. The area of manholes, intakes, or other fixtures in the pavement will not be deducted from the measured pavement area.

2. **Payment:** Payment will be made at the unit price per square yard for each thickness of porous HMA pavement.

3. **Includes:** Unit price includes, but is not limited to, testing, asphalt binder, final trimming of subbase, pavement protection, and safety fencing.

PART 2 - PRODUCTS

2.01 ENGINEERING FABRIC

Comply with Iowa DOT Section 4196, requirements for subsurface drainage.

2.02 UNDERDRAIN

A. Provide slotted pipe(s) complying with the requirements for Type 1 Subdrain in SUDAS Section 4040.

B. Provide 6 inch diameter collector pipes unless otherwise specified in the contract documents.

C. Provide 4 inch diameter lateral pipes unless otherwise specified in the contract documents.

2.03 STORAGE AGGREGATE

Aggregate complying with Iowa DOT Section 4122, Gradation No. 13, Class 2 durability gravel or crushed stone (AASHTO M 43/ASTM D 448, Size 2).

2.04 TYPE 1 FILTER AGGREGATE

Aggregate complying with Iowa DOT Section 4115, Gradation No. 3, Class 2 durability gravel or crushed stone (AASHTO M 43/ASTM D 448, Size 57).

2.05 POROUS HOT MIX ASPHALT

A. Asphalt Binder:

1. Provide polymer-modified asphalt binder complying with PG 76-22 or 82-22.

2. Modify asphalt binder with a styrene-butadiene-styrene (SBS) elastomeric polymer.
    a. Ensure polymer-modified asphalt binder is heat and storage stable.
    b. Apply elastomeric polymer at a rate of 3% by total weight of binder.
    c. Thoroughly blend binder materials at asphalt refinery or terminal prior to being loaded into transport vehicle.

B. Aggregate:

1. Provide aggregate with a minimum of 90% crushed particles.

2.05 POROUS HOT MIX ASPHALT (Continued)

2. Provide an aggregate gradation as required to develop a mixture with a 13 to 18% void ratio. The following gradation is recommended but must be verified:

Sieve Size	Percent Passing	
	Min.	**Max.**
3/4”	100	---
1/2”	85	100
3/8”	55	75
No. 4	10	25
No. 8	5	10
No. 200	2	4

C. Porous HMA Mixture:

1. Provide a binder content between 5 to 6.5% by weight of dry aggregate.

2. If more absorptive aggregates, such as crushed limestone, are used, determine the required binder content according to the testing procedures in the National Asphalt Pavement Association’s Information Series 131.

3. Perform testing of proposed mixture as follows:
   a. Test draindown of mixture according to ASTM D 6390. Ensure draindown of binder is no greater than 0.3%.
   b. Test mixture for resistance to stripping by water according to ASTM D 3625. If estimated coating area is not above 95%, add anti-stripping agents to the asphalt.
   c. Test mixture for air void content by dimension according to ASTM D 3203 or ASTM D 6857. Do not determine the density using saturated surface dry procedures.

PART 3 - EXECUTION

3.01 PRE-INSTALLATION PROTECTION

A. Complete grading, utility installation, and other earth disturbing operations prior to excavating for the porous asphalt system.

B. Prior to placing porous asphalt pavement, install sediment control practices upstream to protect the area from sediment in stormwater runoff from disturbed soil.

3.02 SUBGRADE PREPARATION FOR POROUS HMA

A. Do not compact or subject subgrade area under porous HMA pavement to excessive construction equipment prior to placement of the storage aggregate.

B. Excavate area to the elevations and grades specified in the contract documents.

C. When underdrain is specified, excavate a minimum 12 inch wide by 8 inch deep trench at locations specified in the contract documents.

D. In areas where cuts are required, do not compact surface. After final elevation is achieved, scarify surface to a minimum depth of 3 inches to reduce compaction caused by construction equipment.

E. Where fill materials are required, compact materials to 92% of maximum Standard Proctor Density. Do not over-compact.

F. Fill and lightly re-grade any areas damaged by erosion, ponding, or traffic compaction prior to placing the engineering fabric.

3.03 ENGINEERING FABRIC

A. Install engineering fabric over completed subgrade, including trench for underdrain when specified in the contract documents.

B. Overlap adjacent strips of fabric a minimum of 6 inches.

C. Extend fabric up the sides of the subbase trench to the bottom of the proposed pavement.

3.04 UNDERDRAIN

A. Underdrain Collector Pipes:

1. Place 2 inches of filter aggregate in the bottom of the underdrain trench over engineering fabric.

2. Begin underdrain collector installation at the outlet and continue upgrade.

3. Lay underdrain collector pipe to the proper line and grade. Place pipe with perforations down.

3.04 UNDERDRAIN (Continued)

4. Place filter aggregate over installed pipe in layers not more than 6 inches thick. Thoroughly tamp each layer with mechanical tampers.

5. Provide cleanouts where specified in the contract documents. Comply with SUDAS Figure 4040.232.

6. Connect underdrain collector to outlet. Comply with SUDAS Figure 4040.233. Install rodent guard on all underdrain pipe 6 inches or smaller.

7. Install underdrain cleanout pipes and observation wells as specified in the contract documents.

B. Underdrain Lateral Pipes:

1. Place 2 inches of filter aggregate over the bottom of the prepared subgrade at lateral pipe locations specified in the contract documents.

2. Lay underdrain lateral over filter aggregate to the proper line and grade. Place pipe with perforations down.

3. Connect underdrain laterals to underdrain collector with wye or tee fitting.

4. Install plug or cap on upstream end of lateral pipe.

5. Place additional filter aggregate along each side of the lateral pipe to the springline of the pipe.

3.05 STORAGE AGGREGATE

A. Place storage aggregate in 6 inch maximum lifts. If underdrain system is specified, take care not to damage or displace pipe during placement of storage aggregate.

B. Compact each lift with a vibratory drum roller. Do not operate compaction equipment directly over underdrain, until a minimum of 12 inches of storage aggregate is placed over the underdrain.

C. Install storage aggregate to the elevation specified in the contract documents.

3.06 FILTER AGGREGATE

A. Place filter aggregate directly over storage aggregate.

B. Install material in a single lift with a thickness of 4 inches.

C. Lightly compact filter aggregate with one or two passes from a vibratory plate compactor or vibratory roller.

3.07 POROUS HMA PAVEMENT

A. Transporting Porous HMA:

1. Transport the mixture to the site in vehicles with smooth, clean dump beds that have been sprayed with a non-petroleum release agent.

2. Cover mixture during transport to control cooling.

B. Placing Porous HMA:

1. The use of a polymer-modified binder requires higher placement temperatures than normal HMA. Ensure mix temperature is between 300°F and 350°F during placement.

2. The use of a remixing material transfer device between trucks and the paver to eliminate cold lumps in the mix is highly recommended but not required.

3. The polymer-modified asphalt is difficult to rake. Ensure a well heated screed is utilized to minimize the need for raking.

4. Place porous HMA pavement in a single lift directly over the granular subbase.

5. Begin compaction when the pavement surface is cool enough to resist a 10 ton roller. One or two passes are all that is normally required to achieve proper compaction.

3.08 PROTECTION OF PAVEMENT

A. After final rolling, protect pavement from all vehicular traffic for at least 48 hours.

B. Protect pavement from heavy construction traffic, including trucks, skid steers, loaders, and all tracked vehicles.

C. Provide barriers and protection as necessary.

D. Do not place soil, mulch, sand, or aggregate, or stockpile other materials that may contaminate the pavement and plug the porous surface, on or near the pavement surface.

PERMEABLE INTERLOCKING CONCRETE PAVERS

These specifications compliment the permeable pavers design portion of the Iowa Stormwater Management Manual in Chapter 2, Section 2J-4.

Sections of the following documents, as referenced within these specifications, are hereby made a part of these specifications:

- SUDAS Standard Specifications: The standard specifications issued by the Iowa Statewide Urban Design and Specifications Program effective at the date of publication of the Notice to Bidders, unless a different effective date is identified in the contract documents.

- Iowa DOT Standard Specifications for Highway and Bridge Construction: The Iowa Department of Transportation Standard Specifications for Highway and Bridge Construction and the General Supplemental Specifications effective at the date of publication of the Notice to Bidders unless a different effective date is identified in the contract documents.

- American Society for Testing and Materials (ASTM) standards.

- American Association of State Highway and Transportation Officials (AASHTO) Standard Specifications for Transportation Materials and Methods of Sampling and Testing.

PART 1 - GENERAL

1.01 SECTION INCLUDES

A. Subgrade Preparation

B. Placement of Storage Aggregate

C. Placement of Filter Aggregate

D. Placement of Bedding Course

E. Placement of Permeable Interlocking Concrete Pavers

1.02 DESCRIPTION OF WORK

Construct permeable interlocking concrete pavers for treatment of stormwater runoff.

1.03 SUBMITTALS

A. Sample pavers: Representative of the type and color proposed for the project.

B. Installation instructions: Manufacturer’s published installation instructions.

C. Material Certification: Submit certification letter from paver manufacturer indicating compliance with the ASTM specifications and the contract documents.

D. Bedding, Filter, and Storage Aggregates: Include aggregate type, source, gradation, and compacted void content.

1.03 SUBMITTALS (Continued)

E. Project Details: Include schedule, construction procedures, and quality control plan.

F. Involved Parties: Submit a list of all subcontractors, material suppliers, and testing laboratories.

1.04 SUBSTITUTIONS

Comply with the requirements of the contract documents.

1.05 DELIVERY, STORAGE, AND HANDLING

Comply with the requirements of the contract documents.

1.06 SCHEDULING AND CONFLICTS

Comply with the requirements of the contract documents.

1.07 SPECIAL REQUIREMENTS

None.

1.08 MEASUREMENT AND PAYMENT

A. Class 10, Class 12, or Class 13 Excavation: Refer to SUDAS Section 2010, 1.08, E for measurement and payment information for Class 10, Class 12, or Class 13 Excavation.

B. Engineering Fabric:

1. **Measurement:** Measurement will be in square yards for the surface area covered with engineering fabric. Both horizontal and vertical areas covered with engineering fabric will be measured.

2. **Payment:** Payment will be made at the unit price per square yard of engineering fabric.

3. **Includes:** Unit price includes, but is not limited to, placing and securing filter fabric and any overlapped areas.

C. Underdrain:

1. **Measurement:** Measurement will be in linear feet for each type and size of pipe installed. Pipe will be measured from end of pipe to end of pipe along the centerline of pipe, exclusive of outlets. The vertical height of cleanouts and observation wells will be included in the length of pipe measured. Lengths of elbows, tees, wyes and other fittings will be included in length of pipe measured.

2. **Payment:** Payment will be made at the unit price per linear foot for each type and size of pipe.

1.08 MEASUREMENT AND PAYMENT (Continued)

3. **Includes:** Unit price includes, but is not limited to, furnishing and placing pipe, cleanouts, observation wells, and pipe fittings.

D. Storage Aggregate:

1. **Measurement:** Measurement will be in tons based upon scale tickets for the material delivered and incorporated into the project.

2. **Payment:** Payment will be made at the unit price per ton of storage aggregate.

3. **Includes:** Unit price includes, but is not limited to, furnishing, hauling, and placing storage aggregate.

E. Filter Aggregate:

1. **Measurement:** Measurement will be in tons based upon scale tickets for the material delivered and incorporated into the project.

2. **Payment:** Payment will be made at the unit price per ton of filter aggregate.

3. **Includes:** Unit price includes, but is not limited to, furnishing, hauling, and placing filter aggregate.

F. Permeable Interlocking Concrete Pavers with Bedding Course:

1. **Measurement:** Measurement will be in square yards for the area of permeable interlocking concrete pavers. The area of manholes, intakes, or other fixtures in the pavement will not be deducted from the measured pavement area.

2. **Payment:** Payment will be made at the unit price per square yard of permeable interlocking concrete pavers.

3. **Includes:** Unit price includes, but is not limited to, testing, placement of bedding course, installing permeable interlocking concrete pavers, and pavement protection.

PART 2 - PRODUCTS

2.01 ENGINEERING FABRIC

Comply with Iowa DOT Section 4196, requirements for subsurface drainage.

2.02 UNDERDRAIN

A. Provide slotted pipe(s) complying with the requirements for Type 1 Subdrain in SUDAS Section 4040.

B. Provide 6 inch diameter collector pipes unless otherwise specified in the contract documents.

C. Provide 4 inch diameter lateral pipes unless otherwise specified in the contract documents.

2.03 STORAGE AGGREGATE

Aggregate complying with Iowa DOT Section 4122, Gradation No. 13, Class 2 durability gravel or crushed stone (AASHTO M 43/ASTM D 448, Size 2).

2.04 FILTER AGGREGATE

Provide aggregate complying with Iowa DOT Section 4115, Gradation No. 3, Class 2 durability gravel or crushed stone (AASHTO M 43/ASTM D 448, Size 57).

2.05 BEDDING AGGREGATE

Provide crushed stone complying with Iowa DOT Section 4125, Gradation No. 21 (AASHTO M 43/ASTM D 448, Size 8).

2.06 PERMEABLE INTERLOCKING CONCRETE PAVERS (PICP)

A. Comply with ASTM C 936.

B. Provide PICP system from list of approved products specified in the contract documents.

2.07 PAVER EDGE RESTRAINTS

Provide paver manufacturer's recommended edge restraint system.

2.08 PERMEABLE PAVER VOID FILLER

If required by the contract documents or the PICP system manufacturer, provide void filler complying with Iowa DOT Section 4125, Gradation No. 21 (AASHTO M 43/ASTM D 448, Size 8) or other aggregate, as recommended by the paver manufacturer. Do not add cement to void filler.

PART 3 - EXECUTION

3.01 PRE-INSTALLATION PROTECTION

A. Complete grading, utility installation, and other earth disturbing operations prior to excavating for the permeable paver system.

B. Prior to placing permeable interlocking concrete pavers, install sediment control practices upstream to protect the area from sediment in stormwater runoff from disturbed soil.

3.02 SUBGRADE PREPARATION FOR PERMEABLE INTERLOCKING CONCRETE PAVERS

A. Do not compact or subject subgrade area under proposed permeable paving area to excessive construction equipment prior to placement of the storage aggregate.

B. Excavate area to the elevations and grades specified in the contract documents.

C. When underdrain is specified, excavate a minimum 12 inch wide by 8 inch deep trench at locations specified in the contract documents.

D. In areas where cuts are required, do not compact surface. After final elevation is achieved, scarify surface to a minimum depth of 3 inches to reduce compaction caused by construction equipment.

E. Where fill materials are required, compact materials to 92% of maximum Standard Proctor Density. Do not over-compact.

F. Fill and lightly re-grade any areas damaged by erosion, ponding, or traffic compaction prior to placing the engineering fabric.

3.03 ENGINEERING FABRIC

A. Install engineering fabric over completed subgrade, including trench for underdrain when specified.

B. Overlap adjacent strips of fabric a minimum of 6 inches.

C. Extend fabric up the sides of the subbase trench to the bottom of the proposed pavement.

3.04 UNDERDRAIN

A. Underdrain Collector Pipes:

1. Place 2 inches of filter aggregate in the bottom of the underdrain trench over engineering fabric.

2. Begin underdrain collector installation at the outlet and continue upgrade.

3. Lay underdrain collector pipe to the proper line and grade. Place pipe with perforations down.

3.04 UNDERDRAIN (Continued)

4. Place filter aggregate over installed pipe in layers not more than 6 inches thick. Thoroughly tamp each layer with mechanical tampers.

5. Provide cleanouts where specified in the contract documents. Comply with SUDAS Figure 4040.232.

6. Connect underdrain collector to outlet. Comply with SUDAS Figure 4040.233. Install rodent guard on all underdrain pipe 6 inches or smaller.

7. Install underdrain cleanout pipes and observation wells as specified in the contract documents.

B. Underdrain Lateral Pipes:

1. Place 2 inches of filter aggregate over the bottom of the prepared subgrade at lateral pipe locations specified in the contract documents.

2. Lay underdrain lateral over filter aggregate to the proper line and grade. Place pipe with perforations down.

3. Connect underdrain laterals to underdrain collector with wye or tee fitting.

4. Install plug or cap on upstream end of lateral pipe.

5. Place additional filter aggregate along each side of the lateral pipe to the springline of the pipe.

3.05 STORAGE AGGREGATE

A. Place storage aggregate in 6 inch maximum lifts. If underdrain system is specified, take care not to damage or displace pipe during placement of storage aggregate.

B. Compact each lift with a vibratory drum roller. Do not operate compaction equipment directly over underdrain, until a minimum of 12 inches of storage aggregate is placed over the underdrain.

C. Install storage aggregate to the elevation specified in the contract documents.

3.06 FILTER AGGREGATE

A. Place filter aggregate directly over storage aggregate.

B. Install aggregate in a single lift with a thickness of 4 inches.

C. Lightly compact filter aggregate with one or two passes from a vibratory plate compactor or vibratory roller.

3.07 BEDDING AGGREGATE

A. Place bedding aggregate directly over filter aggregate.

B. Install aggregate in a single lift with a thickness of 1 1/2 inches to 2 inches.

C. Lightly compact bedding aggregate with one or two passes from a vibratory plate compactor or vibratory roller. Ensure surface is even, smooth, and at the proper elevation to accommodate permeable pavers.

3.08 INSTALLING INTERLOCKING PERMEABLE CONCRETE PAVER SYSTEM

Place and install pavers according to paver manufacturer's published installation specifications and the following:

A. Where pavers are placed against a curb and gutter or other pavement, installation of an edge course or soldier course is required if the pavement edge is not straight. Trim pavers as required to compensate for deviations in the adjacent pavement edge.

B. Where pavers are placed against an unrestrained edge, install edge restraint system.

C. Place chalk lines on the bedding course to maintain straight joint lines.

D. After pavers have been installed on the bedding course, and all cut pavers have been inserted to provide a full and complete surface, inspect pavers for damaged units and irregular joint lines. Remove and replace pavers as required.

E. After inspection and replacement of damaged pavers, install void filler if required by paver manufacturer or contract documents. Place filter aggregate to the bottom of the chamfer on the paver and sweep the surface clean.

F. Compact pavement surface with two passes of a vibratory plate compactor. Do not operate plate compactor within 3 feet of an unrestrained pavement edge.

G. Re-inspect pavers, and remove and replace all damaged units.

3.09 PROTECTION OF PAVEMENT

A. Protect pavement from heavy construction traffic, including trucks, skid steers, loaders, and all tracked vehicles.

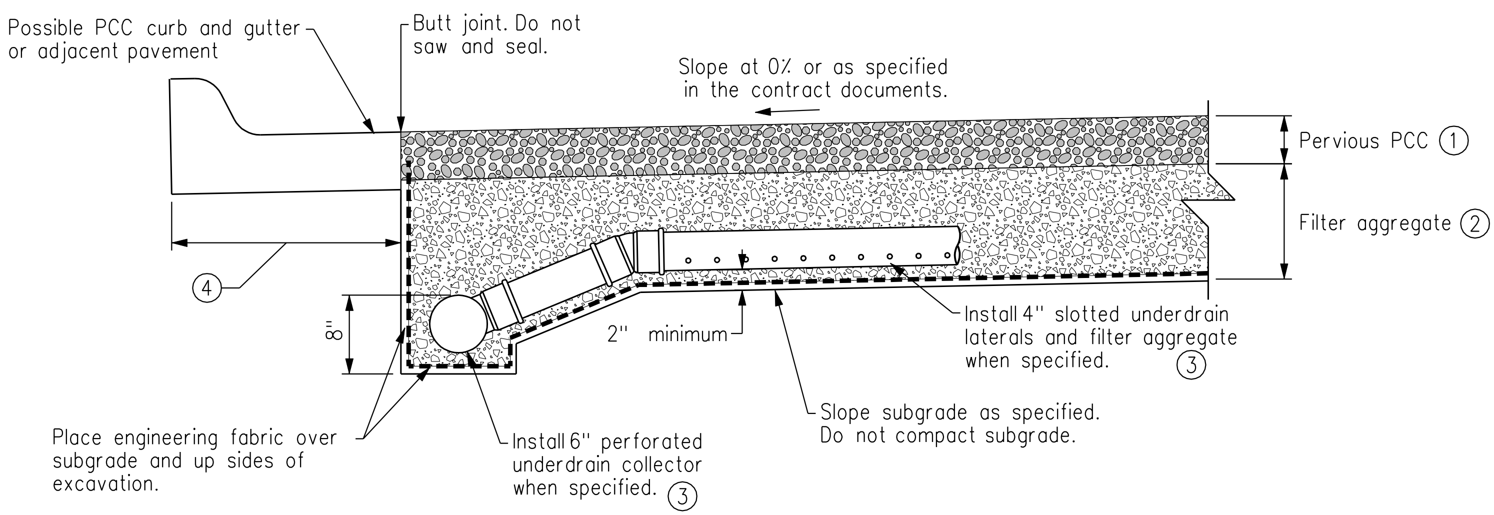
B. Provide barriers and protection as necessary.

C. Do not place soil, mulch, sand, aggregate, or stockpile other materials on the pavement surface that may contaminate the pavement and plug the porous surface.

GENERAL NOTES:

Refer to the contract documents for dimensions, grades, and additional requirements for pervious PCC pavement and associated improvements.

1. Pervious PCC pavement thickness as specified in the contract documents.
2. Permeable pavement filter aggregate thickness as specified in the contract documents.
3. When underdrain collectors and/or laterals are required, install to the line and grade specified in the contract documents.
4. Subgrade and/or subbase under curb and gutter as specified in the contract documents.



ISMM
Iowa Stormwater Management Manual

REVISION	
NEW	04/01/2010

FIGURE 1J-2.1

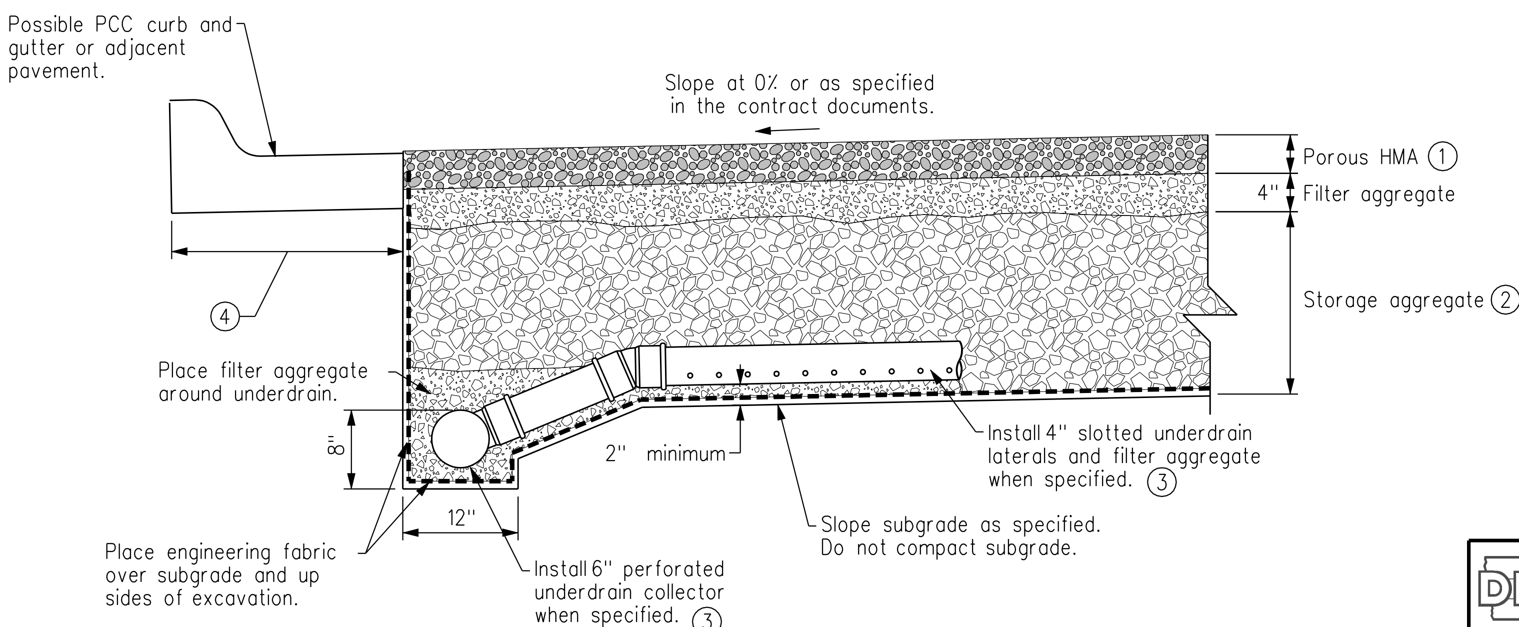
SHEET 1 OF 1

PERVIOUS PCC PAVEMENT

GENERAL NOTES:

Refer to the contract documents for dimensions, grades, and additional requirements for porous HMA pavement and associated improvements.

1. Porous HMA thickness as specified in the contract documents.
2. Permeable pavement storage aggregate thickness as specified in the contract documents.
3. When underdrain collectors and/or laterals are specified, install to the line and grade specified in the contract documents. Place permeable pavement filter aggregate to springline of pipe.
4. Subgrade and/or subbase under curb and gutter as specified in the contract documents.



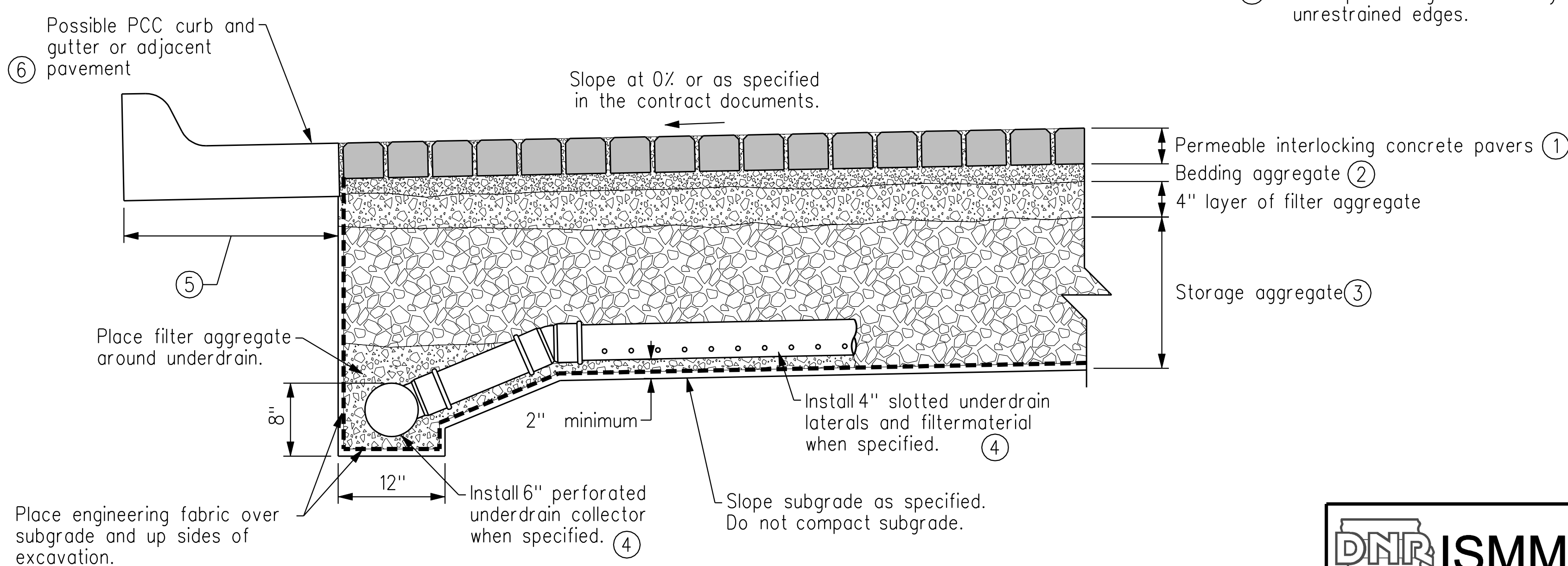
DNR ISMM Iowa Stormwater Management Manual	REVISION	
	NEW	04/01/2010
	FIGURE 1J-3.1	
	SHEET 1 OF 1	

POROUS HMA PAVEMENT

GENERAL NOTES:

Refer to the contract documents for dimensions, grades, and additional requirements for permeable interlocking concrete pavers and associated improvements.

1. Permeable interlocking concrete pavers as specified in the contract documents.
2. 1 1/2" to 2" permeable pavement bedding aggregate to accomodate imperfections in the permeable pavement filter aggregate layer.
3. Permeable pavement storage aggregate thickness as specified in the contract documents.
4. When underdrain collectors and/or laterals are specified, install to the line and grade specified in the contract documents. Place permeable pavement filter aggregate to springline of pipe.
5. Subgrade and/or subbase under curb and gutter as specified in the contract documents.
6. Install paver edge restraint system along unrestrained edges.



REVISION	
NEW	04/01/2010
FIGURE 1J-4.1	
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PERMEABLE INTERLOCKING CONCRETE PAVERS