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.

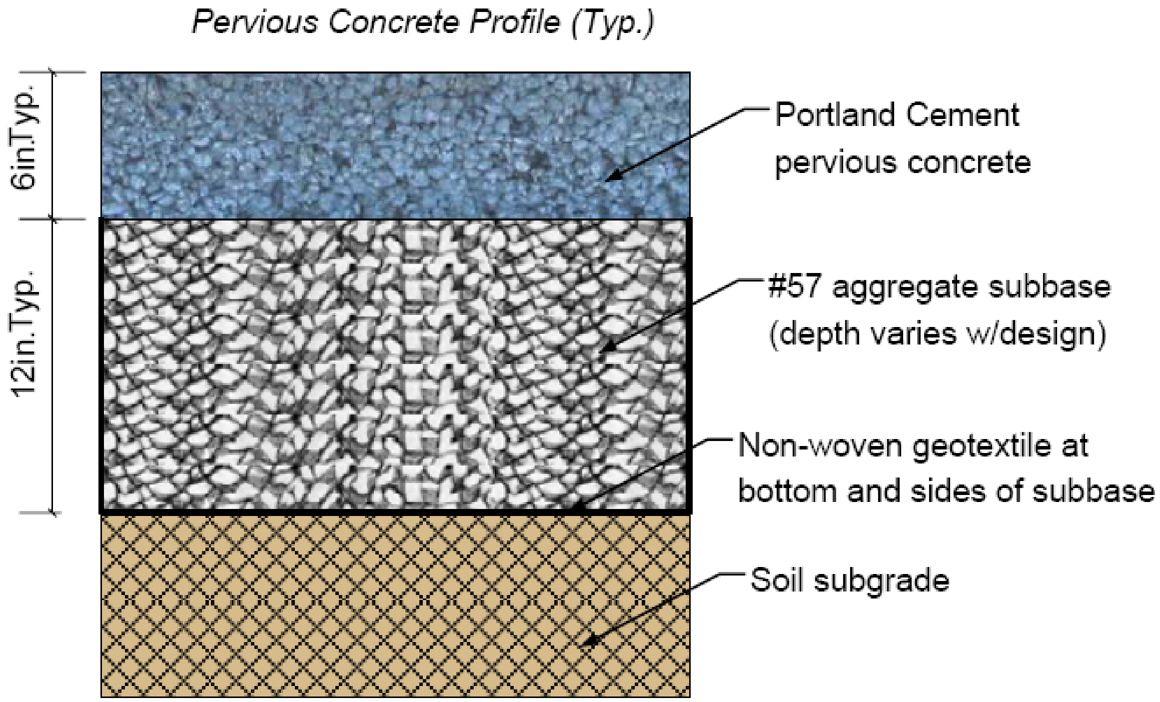
A drawback is the cost and complexity of pervious concrete systems compared to conventional pavements. Pervious concrete systems require a modified construction protocol for equipment and placement than is typical for regular PCC pavements. The level of construction workmanship is not necessarily more 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.

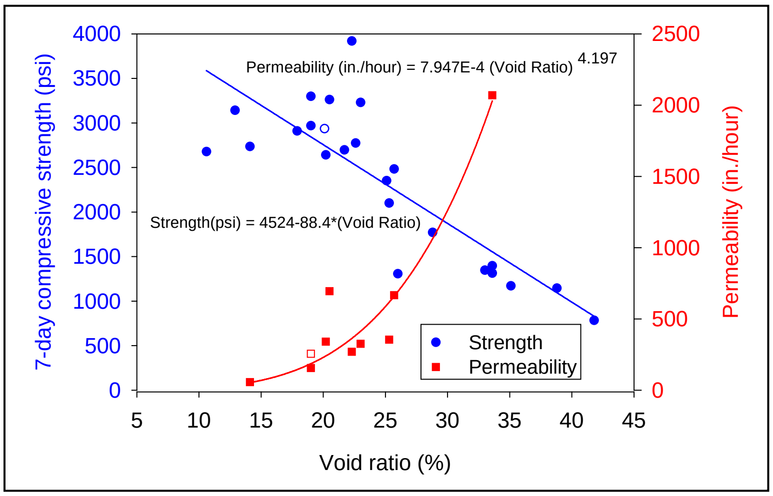
Figure 2: Jointing for pervious concrete pavement (a) Installation of joint during pervious placement
(b) Joint pattern and block-outs in pervious concrete
(Lot 122, Iowa State University, 2006)

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).

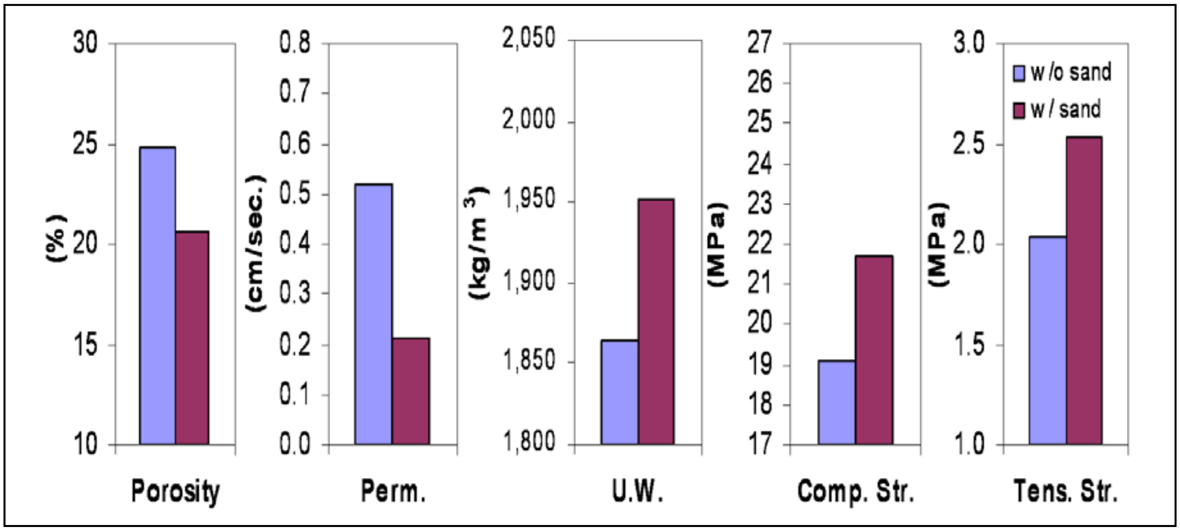
The National Concrete Pavement Technology (CP Tech) Center at Iowa State University developed several pervious concrete mix designs for use in Iowa. The ISU mix designs provide a pervious concrete of moderate porosity and increased strength and durability over other conventional pervious concrete. The 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)

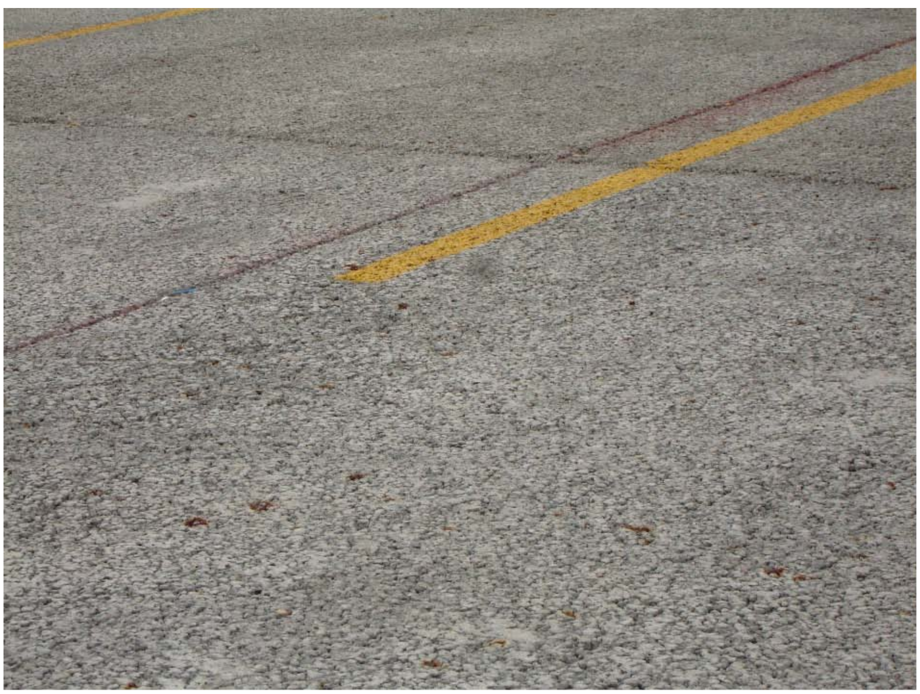


Figure 6: Pervious concrete profile, surface texture, #57 aggregate base, geotextile
(Iowa State University Lot 122)

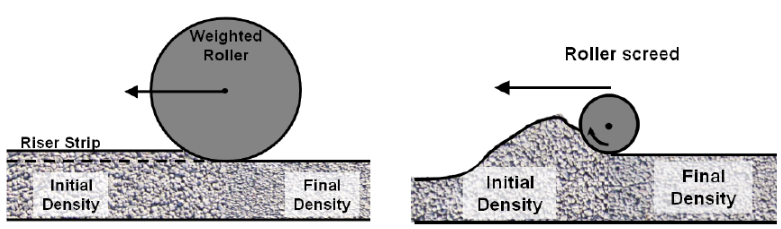
Figure 7: Pervious concrete surface and conventional PCC
(Iowa State University Lot 122)

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.