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Pervious Concrete

This TechBrief presents an overview of pervious concrete and its use in pavement applications. General information on the composition of pervious concrete is provided, along with a summary of its benefits, limitations, and typical properties and characteristics. Important considerations in mix proportioning, hydrological design, structural design, construction, and maintenance are also described.

Introduction

Pervious concrete, sometimes referred to as no-fines, gap-graded, permeable, or enhanced porosity concrete, is an innovative approach to controlling, managing, and treating stormwater runoff. When used in pavement applications, pervious concrete can effectively capture and store stormwater runoff, thereby allowing the runoff to percolate into the ground and recharge groundwater supplies.

Pervious concrete contains little or no fine aggregate (sand) and carefully controlled amounts of water and cementitious materials. The paste coats and binds the aggregate particles together to create a system of highly permeable, interconnected voids that promote the rapid drainage of water (Tennis et al. 2004; ACI 2010). Typically, between 15 and 25 percent voids are achieved in the hardened concrete, and flow rates for water through the pervious concrete are generally in the range of 2 to 18 gal/min/ft^2 (81 to 730 L/min/m^2), or 192 to 1,724 inch/hr (488 to 4,379 cm/hr) (ACI 2010). Figure 1 shows a typical cross section of a pervious concrete pavement.

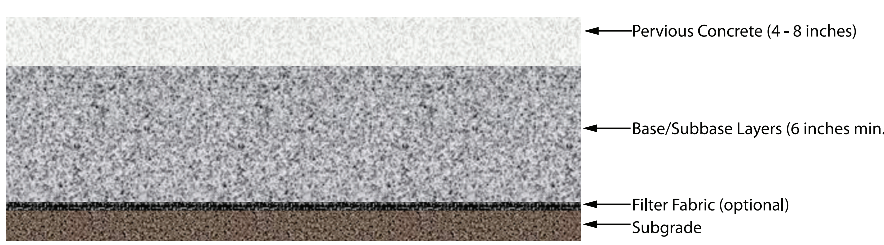

FIGURE 1. Typical pervious concrete pavement cross section (adapted from EPA 2010).

Benefits and Limitations

Table 1 summarizes some of the major benefits and limitations associated with pervious concrete. As described above, perhaps the most significant benefit provided by pervious concrete is in its use as a stormwater management tool. Stormwater runoff in developed areas (often the result of or exacerbated by the presence of conventional impervious pavement) has the potential to pollute surface and groundwater supplies, as well as contribute to flooding and erosion (Leming et al. 2007).

Pervious concrete can be used to reduce stormwater runoff, reduce contaminants in waterways, and renew groundwater supplies. With high levels of permeability, pervious concrete can effectively capture the "first flush" of rainfall (that part of the runoff with a higher contaminant concentration) and allow it to percolate into the ground where it is filtered and "treated" through soil chemistry and biology (Tennis et al. 2004; ACI 2010).

Other major benefits provided by pervious concrete include reduction in heat island effects (water percolating through the pavement can exert a cooling effect through evaporation, and convective airflow can also contribute to cooling (Cambridge 2005)), reductions in standing water on pavements (and associated hydroplaning and splash/spray potential), and reduced tire–pavement noise emissions (due to its open structure that helps absorb noise at the tire–pavement interface) (ACI 2010). In addition, pervious concrete can contribute toward credits in the LEED® (Leadership in Energy and Environmental Design) rating system for sustainable building construction (Ashley 2008).

Along with its many benefits, there are some limitations associated with the use of pervious concrete. First and foremost, pervious concrete has typically been used on lower trafficked roadways, although there are a number of installations on higher volume facilities, and research is being conducted on the structural behavior of pervious concrete slabs (see, for example, Suleiman et al. 2011; Vancura et al. 2011). In addition, pervious concrete exhibits material characteristics (primarily lower paste contents and higher void contents) and produces hardened properties (notably density and strength) that are significantly different from conventional concrete; as a result, the current established methods of quality control/quality assurance (e.g., slump, strength, air content) are in many

TABLE 1. Summary of Pervious Concrete Benefits and Limitations (Tennis et al. 2004; ACI 2010)

Benefits/Advantages	Limitations/Disadvantages
• Effective management of stormwater runoff, which may reduce the need for curbs and the number and sizes of storm sewers. • Reduced contamination in waterways. • Recharging of groundwater supplies. • More efficient land use by eliminating need for retention ponds and swales. • Reduced heat island effect (due to evaporative cooling effect of water and convective airflow). • Elimination of surface ponding of water and hydroplaning potential. • Reduced noise emissions caused by tire–pavement interaction. • Earned LEED® credits.	• Limited use in heavy vehicle traffic areas. • Specialized construction practices. • Extended curing time. • Sensitivity to water content and control in fresh concrete. • Lack of standardized test methods. • Special attention and care in design of some soil types such as expansive soils and frost-susceptible ones. • Special attention possibly required with high groundwater.

cases not applicable (ACI 2010). Moreover, a number of special practices, described later, are required for the construction of pervious concrete pavements. And, while there have been concerns about the use of pervious concrete in areas of the country subjected to severe freeze–thaw cycles, available field performance data from a number of projects indicate no signs of freeze–thaw damage (Delatte et al. 2007; ACI 2010).

Applications

Pervious concrete has been used in pavement applications ranging from driveways and parking lots to residential streets, alleys, and other low-volume roads (Tennis et al. 2004). Within these applications, pervious concrete has been used as the surface course, as a drainable base course (often in conjunction with edge drains to provide subsurface drainage), or as a drainable shoulder (to help provide lateral drainage to a pavement and prevent pumping). The focus in recent years has been on its use as a surface course as a means of providing stormwater management.

Typical Properties and Characteristics

As noted previously, many of the properties of pervious concrete are different from those of conventional concrete. These properties are primarily a function of the porosity (air void content) of the pervious concrete, which in turn depends on the cementitious content, the water-to-cementitious materials (w/cm) content, the compaction level, and the aggregate gradation and quality (ACI 2010). Table 2 summarizes some of the typical material properties associated with pervious concrete. These properties and characteristics must be considered during the structural design and pavement construction.

The cost of pervious concrete may be 15 to 25 percent higher than conventional concrete, but cost can vary significantly depending on the region, the type of application, the size of the project, and the inclusion of admixtures.

TABLE 2. Typical Pervious Concrete Properties (Tennis et al. 2004; Obla 2007)

Property	Common Value / Range
Plastic Concrete	
Slump	N/A
Unit weight	70% of conventional concrete
Working time	1 hour
Hardened Concrete	
In-place density	100 to 125 lb/ft^3
Compressive strength	500 to 4,000 lbf/in^2 (typ. 2,500 lbf/in^2)
Flexural strength	150 to 550 lbf/in^2
Permeability	2 to 18 gal/ft^2/min (384 to 3,456 ft/day)

1 in = 25.4 mm; 1 lb/ft^3 = 16 kg/m^3; 1 lbf/in^2 = 6.89 kPa; 1 gal/ft^2/min = 40.8 L/m^2/min

Mixture Proportioning

Like conventional concrete, pervious concrete is a mixture of cementitious materials, water, coarse aggregate, and possibly admixtures, but it contains little or no fines; however, note that a small amount of fine aggregate, typically 5 to 7 percent, is required for freeze–thaw durability (Schaefer et al. 2006; Kevern et al. 2008). Table 3 shows the typical range of materials proportions that have been used in pervious concrete. Commentary on the components of a pervious concrete is provided below (Tennis et al. 2004; Delatte et al. 2007; ACI 2010):

Cementitious materials. As with conventional concrete mixtures, conventional portland cements or blended cements are used as the primary binder in pervious concrete, although supplementary cementitious materials may also be used.

Coarse aggregate. Coarse aggregate is kept to a narrow gradation, with the most common gradings of coarse aggregate used in pervious concrete meeting the requirements of ASTM C33/C33M—aggregate sizes of 7, 8, 67, and 89. Coarse aggregate size 89 (top size 0.375 inch (9.5 mm)) has been used extensively for parking lot and pedestrian applications. Rounded and crushed aggregates, both normal and lightweight, have been used to make pervious concrete.

Water. The control of water is important in the development of pervious concrete mixtures, and the selection of an appropriate w/cm value is important for obtaining desired strength and void structure in the concrete. A high w/cm can result in the cement paste flowing off of aggregate and filling the void structure, whereas a low w/cm can result in mixing and placement difficulties and reduced durability. Commonly, w/cm values between 0.27 and 0.34 are used.

Admixtures. As with conventional concrete, chemical admixtures can be used in pervious concrete to obtain or enhance specific properties of the mixture. In particular, set retarders and hydration stabilizers are commonly used to help control the rapid setting associated with many pervious concrete mixtures. Air-entraining admixtures are required in freeze–thaw environments although no current method exists to quantify the amount of entrained air in the fresh paste. Air entrainment can be determined on hardened samples according to ASTM C457.

Mix proportioning for pervious concrete is based on striking a balance between voids, strength, paste content, and workability (ACI 2010). As such, the development of trial batches is essential to determining effective mix proportions using locally available materials. Detailed information on mix proportioning is available from ACI (2010).

Some limited work has been done investigating the freeze–thaw characteristics of pervious concrete and mix design for cold weather climates (NRMCA 2004; Schaefer et al. 2006). The freeze–thaw resistance of pervious concrete appears to be dependent on the saturation level of the voids; consequently a drainable base layer with a minimum thickness of 6 inches (150 mm) is recommended to help keep the pervious concrete layer from becoming saturated. Furthermore, as previously noted, the freeze–thaw resistance of pervious concrete has been shown to improve when sand is included in the pervious concrete mixture (Schaefer et al. 2006; Kevern et al. 2008).

Design of Pervious Pavements

Two primary considerations enter into the determination of the thickness of pervious concrete pavements: 1) hydrologic design to meet environmental requirements and 2) structural design to withstand the anticipated traffic loading applications (Leming et al. 2007; ACI 2010). These design considerations are briefly described below.

TABLE 3. Typical Pervious Concrete Materials Proportions (ACI 2010)

Mix Constituent or Design Parameter	Range
Coarse aggregate	2,000 to 2,500 lb/yd^3
Cementitious materials	450 to 700 lb/yd^3
Water-to-cementitious ratio	0.27 to 0.34
Aggregate-to-cementitious ratio (by mass)	4 to 4.5:1

1 lb/yd^3 = 0.59 kg/m^3

Hydrologic Design

In evaluating the hydrologic design capabilities of a pervious pavement, the approach is to determine whether the characteristics of the pervious concrete pavement system are sufficient to infiltrate, store, and release the expected inflow of water (which includes direct rainfall and may also include excess runoff from adjacent impervious surfaces). As such, information required in a hydrologic analysis includes the precipitation intensity levels, the thickness and permeability characteristics of the pervious concrete pavement, cross slopes and geometrics, and permeability properties and characteristics of the underlying base, subbase, and subgrade materials.

Many hydrological design methods exist that can be used when designing pervious concrete pavement systems, including the Natural Resources Conservation Service Curve Number Method and the Rational Method (Leming et al. 2007). In essence, the hydrologic design of pervious concrete pavements should consider two possible conditions to ensure that excess surface runoff does not occur (Leming et al. 2007):

1. Low permeability of the pervious concrete material that is inadequate to capture the "first flush" of a rainfall event.
2. Inadequate retention provided in the pervious concrete structure (slab and subbase).

Often, the thickness of a pervious concrete pavement is first determined based on structural requirements and then analyzed to determine its suitability to meet the hydrologic needs of the project site. If the thickness is found to be insufficient, adjustments can be made to the thickness of the pervious pavement or the underlying base course. Details on hydrologic design are beyond the scope of this document but are available in the literature (Leming et al. 2007; Wanielista et al. 2007; Rodden et al. 2011).

Structural Pavement Design

Pervious concrete pavements can be designed using virtually any standard concrete pavement procedure (e.g., American Association of State Highway and Transportation Officials, Portland Cement Association, StreetPave) (Delatte 2007). The American Concrete Pavement Association has recently developed a comprehensive program, PerviousPave, that can be used to develop both structural and hydrological designs for pervious pavements (Rodden et al. 2011). Regardless of the procedure used, there are critical factors to consider in the design of pervious concrete pavements (ACI 2010):

Subgrade and subbase. In the design of pervious pavements, foundation support is typically characterized by a composite modulus of subgrade reaction, which should account for the effects of both the subgrade and the subbase. An open-graded subbase is commonly used beneath pervious concrete pavements not only to provide an avenue for vertical drainage of water to the subgrade, but also to provide storage capabilities. Special subgrade conditions (such as frost susceptibility or expansive soils) may require direct treatment.

Concrete flexural strength. The flexural strength of concrete is an important input in concrete pavement structural design. However, testing to determine the flexural strength of pervious concrete may be subject to high variability; therefore, it is common to measure compressive strengths and to use empirical relationships to estimate flexural strengths for use in design (Tennis et al. 2004).

Traffic loading applications. The anticipated traffic to be carried by a pervious pavement is commonly characterized in terms of equivalent 18,000-lb (80 kN) single-axle load repetitions, which many procedures compute directly based on assumed truck-traffic distributions. Most pervious concrete pavements are used in low-truck-traffic applications.

Currently there are no thickness standards for pervious concrete pavements, but many pervious pavements for parking lots are constructed 6 inches (150 mm) thick, whereas pervious pavements for low-volume streets have been constructed between 6 and 12 inches (150 and 300 mm) thick (ACI 2010).

Construction Considerations

Because of its unique material characteristics, pervious concrete has a number of special construction requirements. Key aspects of pervious concrete construction include the following (Tennis et al. 2004; ACI 2010):

Placement and consolidation. Most pervious concrete is placed using fixed-form construction. For smaller projects, a hand-held straightedge or vibrating screed may be acceptable for placement, whereas for larger projects an A-frame, low-frequency, vibrating screed may be used. A few projects have used laser screeds and concrete slipform equipment. Consolidation is generally accomplished by rolling the concrete with a steel roller. Overall, the low water content and porous nature of pervious concrete require that delivery and placement be completed as quickly as possible.

Finishing. Pervious concrete pavements are not finished in the same manner as conventional pavements. In essence, the final surface finish is achieved as part of the consolidation process, which leaves an open surface. Normal concrete finishing procedures, such as with bull floats and trowels, should not be performed.

Jointing. Jointing is commonly done on pervious concrete to control random crack development. These joints are commonly formed (using a specially designed compacting roller-jointer) to a depth between one-fourth and one-third of the slab thickness.

Curing and protection. After the concrete has been jointed, it is important that the concrete be effectively cured; this is commonly achieved through the placement of thick (typically 6 mil (0.15mm)) plastic sheeting over all exposed surfaces. The plastic sheeting should be applied no later than 20 minutes following discharge of the concrete, and should remain in place for at least 7 days (longer times may be required under cold weather placement conditions or if supplementary cementitious materials are used in the mix). Liquid membrane curing compounds are not commonly used because they prevent surface moisture loss and do nothing to prevent evaporation from within the pervious concrete (Kevern et al. 2009).

Inspection and testing. The American Concrete Institute has prepared a summary of recommended inspection and testing activities that should be performed during construction of pervious concrete pavements (ACI 2010), as well as a specification for pervious concrete construction (ACI 2008). Acceptance testing for pervious concrete is typically limited to density (ASTM C1688) and thickness (ASTM C42). Test methods specific to pervious concrete are listed below:

- ASTM C1688, *Standard Test Method for Density and Void Content of Freshly Mixed Pervious Concrete.*
- ASTM C1701, *Standard Test Method for Infiltration Rate of In Place Pervious Concrete.*
- ASTM C1747, *Standard Test Method for Determining Potential Resistance to Degradation of Pervious Concrete by Impact and Abrasion.*
- ASTM C1754, *Standard Test Method for Density and Void Content of Hardened Pervious Concrete.*

In recognition of the special construction requirements of pervious concrete, the National Ready Mixed Concrete Association has developed a program designed to educate, train, and certify contractors in pervious concrete placement (see http://nrmca.org/Education/Certifications/Pervious_Contractor.htm).

Maintenance

Over time, sand, dirt, vegetation, and other debris can collect in pervious concrete's voids and reduce its porosity, which can negatively affect the functionality of the system. Thus, periodic maintenance may be needed to remove surface debris and restore infiltration capacity. Two common maintenance methods are pressure washing and power vacuuming (ACI 2010).

Performance

The performance of pervious concrete pavements may be assessed in a number of ways, including monitoring changes in the permeability/porosity of the system (which would indicate clogging of the void structure), the presence of distress (both structural and surficial), and resistance to freeze–thaw damage. Unfortunately, there are limited long-term performance data on pervious concrete, but generally performance is considered satisfactory. For example, a study in Florida indicated that pervious concrete pavements that were 10 to 15 years old were operating in a satisfactory manner without significant amounts of clogging (Wanielista et al. 2007). In another study, field inspections of 22 projects located in freeze areas were conducted, with reported good performance and no visual signs of freeze–thaw damage (although all projects were less than 4 years old at the time of inspection) (Delatte et al. 2007).

Where the performance of pervious concrete pavements has not been satisfactory, poor performance is often attributed to contractor inexperience, higher compaction of soil than specified, and improper site design (ACI 2010).

Summary and Future Needs

The use of pervious concrete has increased significantly in the last several years, perhaps largely because it is considered an environmentally friendly, sustainable product. The use of pervious concrete provides a number of benefits, most notably in the effective management of stormwater runoff. Other significant benefits include reducing contaminants in waterways, recharging groundwater supplies, reducing heat island effects, and reducing pavement–tire noise emissions.

Still, there are a number of areas that need additional developmental work to improve or enhance the capabilities of pervious concrete pavements. One area is the continued monitoring of the performance of pervious concrete so that long-term performance trends can be documented; this will also help in evaluating the suitability of pervious concrete for other applications, such as overlays. Tied in with this is the assessment of the suitability of current structural design approaches to provide competent designs, particularly regarding the fatigue behavior of pervious concrete. Finally, a third area is in the testing and evaluation of pervious concrete, as current test methods for conventional concrete are not generally applicable to pervious concrete.

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