Pervious Concrete for Sustainable Development

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Pervious concrete is a special type of concrete with a high porosity used for concrete flatwork applications that allows water from precipitation and other sources to pass through it, thereby reducing the runoff from a site and recharging ground water levels. The void content can range from 18 to 35% with compressive strengths of 400 to 4000 psi. The infiltration rate of pervious concrete will fall into the range of 2 to 18 gallons per minute per square foot (80 to 720 liters per minute per square meter). Typically pervious concrete has little to no fine aggregate and has just enough cementitious paste to coat the coarse aggregate particles while preserving the interconnectivity of the voids. Pervious concrete is traditionally used in parking areas, areas with light traffic, pedestrian walkways, and greenhouses. Pervious Concrete is an important application for sustainable construction.

Applications

Although not a new technology (it was first used in 1852 (Ghafoori and Dutta 1995)), pervious concrete is receiving renewed interest, partly because of Federal Clean Water Legislation in the USA. The US Environmental Protection Agency's (EPA) Phase II Final Rule requires the operators of all municipalities in urban areas to develop, implement, and enforce a program to reduce pollutants in post-construction runoff from new development and redevelopment projects that result in the land disturbance of greater than or equal to 1 acre. The above is a requirement in order to attain a National Pollutant Discharge Elimination System (NPDES) permit. Among other things the municipalities are required to develop and implement strategies which include a combination of structural and/or non-structural best management practices (BMPs). Pervious concrete pavement is recognized as a Structural Infiltration BMP by the EPA for providing first flush pollution control and storm water management. In addition to federal regulations there has been a strong move in the USA towards sustainable development. Sustainable development is development that meets the needs of the present generation without compromising the needs of future generations. In the US the US Green Building Council (USGBC) through its Leadership in Energy and Environmental Design (LEED) Green Building Rating System fosters sustainable construction of buildings. Projects are awarded Certified, Silver, Gold, or Platinum certification depending on the number of credits they achieve. Pervious concrete pavement qualifies for LEED credits and is therefore sought by owners desiring a high LEED certification.

As regulations further limit storm water runoff, it is becoming more expensive for property owners to develop real estate, due to the size and expense of the necessary drainage systems. Pervious concrete paving reduces the runoff from paved areas, which reduces the need for separate storm water retention ponds and allows the use of smaller capacity storm sewers. This allows property owners to develop a larger area of available property at a lower cost. Pervious concrete also naturally filters storm water and can reduce pollutant loads entering into streams, ponds and rivers. It captures the first flush of rainfall (the first 30 to minutes of rainfall which will lead to a runoff with most pollutants) and allows that to percolate into the ground, so that soil chemistry and biology can treat the polluted water. Pervious concrete functions like a storm water retention basin and allows the storm water to infiltrate the soil over a large area, thus facilitating recharge of precious groundwater supplies locally. All of these benefits lead to more effective land use. Pervious concrete can also reduce the impact of development on trees. A pervious concrete pavement allows the transfer of both water and air to root systems allowing trees to flourish even in highly developed areas.

Common applications for pervious concrete are parking lots, sidewalks, pathways, tennis courts, patios, slope stabilization, swimming pool decks, green house floors, zoo areas, shoulders, drains, noise barriers, friction course for highway pavements, permeable based under a normal concrete pavement, and low volume roads. Pervious concrete is generally not used solely for concrete pavements for high traffic and heavy wheel loads.

Materials

Pervious concrete, also known as porous, gap-graded, permeable, or enhanced porosity concrete, mainly consists of normal portland cement, coarse aggregate, and water. In normal concrete the fine aggregates typically fills in the voids between the coarse aggregates. In pervious concrete fine aggregate is non existent or present in very small amounts. Also there is insufficient paste to fill the remaining voids with the result that pervious concrete has a porosity any where from 15 to 35% but most frequently about 20%. Aggregate gradings used in pervious concrete are typically either single-sized coarse aggregate or grading between ¾ and 3/8 in. (19 and 9.5 mm). All types of cementitious materials conforming to their ASTM specifications have been used. Pervious concrete can be made without chemical admixtures but it is not uncommon to find several types of chemical admixtures added to influence the performance in a favorable manner.

Properties

The plastic pervious concrete mixture is stiff compared to traditional concrete. Slumps, when measured, are generally less than 3⁄4 in. (20 mm), although slumps as high as 2 in. (50 mm) have been used. However, slump of pervious concrete has no correlation with its workability and hence should not be specified as an acceptance criteria. When placed and compacted, the aggregates are tightly adhered to one another and exhibit the characteristic open matrix that looks like pop corn. In-place densities on the order of 100 lb/ft^3 to 125 lb/ft^3 (1600 kg/m^3 to 2000 kg/m^3) are common. Pervious concrete mixtures can develop compressive strengths in the range of 500 psi to 4000 psi (3.5 MPa to 28 MPa), which is suitable for a wide range of applications. Typical values are about 2500 psi (17 MPa). The infiltration rate (permeability) of pervious concrete will vary with aggregate size and density of the mixture, but will fall into the range of 2 to 18 gallons per minute per square foot (80 to 720 liters per minute per square meter). A moderate porosity pervious concrete pavement system will typically have a permeability of 3.5 gallons per minute per square foot (143 liters per minute per square meter). Converting the units to in./hr (mm/hr) yields 336 in./hr (8534 mm/hr). Perhaps nowhere in the world would one see such a heavy rainfall. In contrast the steady state infiltration rate of soil ranges from 1 in./hr (25 mm/hr) and 0.01 in./hr (.25 mm/hr). This clearly suggests that unless the pervious concrete is severely clogged up due to possibly poor maintenance it is unlikely that the permeability of pervious concrete is the controlling factor in estimating runoff (if any) from a pervious concrete pavement. For a given rainfall intensity the amount of runoff from a pervious concrete pavement system is controlled by the soil infiltration rate and the amount of water storage available in the pervious concrete and aggregate base (if any) under the pervious concrete.

Generally for a given mixture proportion strength and permeability of pervious concrete are a function of the concrete density. Greater the amount of consolidation higher the strength, and lower the permeability. Since it is not possible to duplicate the in-place consolidation levels in a pervious concrete pavement one has to be cautious in interpreting the properties of pervious concrete specimens prepared in the laboratory. Such specimens may be adequate for quality assurance namely to ensure that the supplied concrete meets specifications. Core testing is recommended for knowing the in-place properties of the pervious concrete pavement. The relationship between the *w*/*cm* and compressive strength of conventional concrete is not significant. A high *w*/*cm* can result in the paste flowing from the aggregate and filling the void structure. A low *w*/*cm* can result in reduced adhesion between aggregate particles and placement problems. Flexural strength in pervious concretes generally ranges between about 150 psi (1 MPa) and 550 psi (3.8 MPa).

Limited testing in freezing-and-thawing conditions indicates poor durability if the entire void structure is filled with water (NRMCA 2004). Numerous successful projects have been successfully executed and have lasted several winters in harsh Northern climates such as IN, IL, PA etc. This is possibly because pervious concrete is unlikely to remain saturated in the field. The freeze thaw resistance of pervious concrete can be enhanced by the following measures – 1. Use of fine aggregates to increase strength and slightly reduce voids content to about 20%; 2. Use of air-entrainment of the paste; 3. Use of a 6 to 18 in. aggregate base particularly in areas of deep frost depths; 4. Use of a perforated PVC pipe in the aggregate base to capture all the water and let it drain away below the pavement. Abrasion and raveling could be a problem. Good curing practices and appropriate w/cm (not too low) is important to reduce raveling. Where as severe raveling is unacceptable some loose stones on a finished pavement is always expected. Use of snow ploughs could increase raveling. A plastic or rubber shield at the base of the plow blade may help to prevent damage to the pavement.

Design

There are two factors determine the design thickness of pervious pavements: the hydraulic properties, such as permeability and volume of voids, and the mechanical properties, such as strength and stiffness. ACI 522R-06 states that pervious concrete used in pavement systems must be designed to support the intended traffic load and contribute positively to the site specific storm water management strategy. The designer selects the appropriate material properties, the appropriate pavement thickness, and other characteristics needed to meet the hydrological requirements and anticipated traffic loads simultaneously. Separate analyses are required for both the hydraulic and the structural requirements, and the larger of the two values for pavement thickness will determine the final design thickness. Numerous applications have used a 5 to 6 in. thick pervious concrete over an aggregate base generally of the same dimension. Field performance of these projects have shown that they are adequate to handle the traffic loads expected in parking lot type applications (passenger cars) where the heaviest loads are generally from garbage trucks. If heavier loads and higher traffic are expected then a thicker pavement (8 to 12 in.) has been used. Another approach would be to try and use the structural design techniques outlined in the ACI 522R-06 which could help optimize the pavement thickness.

Initial recommendations had been that pervious concrete should be used only in sandy soils with infiltration rate greater than 0.5 in./hr. However, a detailed hydrologic analysis for a specific example with soils with infiltration rate of 1, 0.5, 0.1, and 0.01 in./hr has shown that the post construction run-off was lower in all 4 soils when compared to the pre-construction runoff. The draw down time in all cases was acceptable except for the soil with the lowest infiltration rate and that too only when an aggregate base was used. The authors concluded that pervious concrete can be used in silty soils with a soil infiltration of only 0.1 in//hr and that there is no need to arbitrarily limit its use only to sands. In soils with infiltration rates considerably less than 0.1 in./hr one way to reduce the draw down time could be to use buried perforated pipes that can transfer the collected water elsewhere. If that is not feasible the pervious concrete system could be placed without an aggregate base and the resulting excess run off (over prec construction but still lower than if an impervious system had been used) could be handled using additional detention devices.

Construction

An experienced installer is vital to the success of pervious concrete pavements. As with any concrete pavement, proper subgrade preparation is important. The subgrade should be properly compacted to provide a uniform and stable surface. When pervious pavement is placed directly on sandy or gravelly soils it is recommended to compact the subgrade to 92 to 95% of the maximum density (ASTM D 1557). With silty or clayey soils, the level of compaction will depend on the specifics of the pavement design and a layer of open graded stone may have to be placed over the soil. Engineering fabrics are often used to separate fine grained soils from the stone layer. Care must be taken not to over compact soil with swelling potential. The subgrade should be moistened prior to concrete placement to prevent the pervious concrete from setting and drying too quickly. Also wheel ruts from construction traffic should be raked and re-compacted.

This material is sensitive to changes in water content, so field adjustment of the fresh mixture is usually necessary. The correct quantity of water in the concrete is critical. Too much water will cause segregation, and too little water will lead to balling in the mixer and very slow mixer unloading. Too low a water content can also hinder adequate curing of the concrete and lead to a premature raveling surface failure. A properly proportioned mixture gives the mixture a wet-metallic appearance or sheen. Pervious concrete has little excess water in the mixture. Any time the fresh material is allowed to sit exposed to the elements is time that it is losing water needed for curing. Drying of the cement paste can lead to a raveling failure of the pavement surface. All placement operations and equipment should be designed and selected with this in mind and scheduled for rapid placement and immediate curing of the pavement. A pervious concrete pavement may be placed with either fixed forms or slip-form paver. The most common approach to placing pervious concrete is in forms on grade that have a riser strip on the top of each form such that the strike off device is actually 3/8-1/2 in. (9 to 12 mm) above final pavement elevation. Strike off may be by vibratory or manual screeds. After striking off the concrete, the riser strips are removed and the concrete compacted by a manually operated roller that bridges the forms. Rolling consolidates the fresh concrete to provide strong bond between the paste and aggregate, and creates a smoother riding surface. Excessive pressure when rolling should be avoided as it may cause the voids to collapse. Rolling should be performed immediately after strike off. Since floating and trowelling tend to close up the top surface of the voids they are not carried out.

Jointing pervious concrete pavement follows the same rules as for concrete slabs on grade, with a few exceptions. With significantly less water in the fresh concrete, shrinkage of the hardened material is reduced significantly, thus, joint spacings may be wider. The rules of jointing geometry, however, remain the same. Joints in pervious concrete are tooled with a rolling jointing tool. This allows joints to be cut in a short time, and allows curing to continue uninterrupted. Saw cutting joints also is possible, but is not preferred because slurry from sawing operations may block some of the voids, and excessive raveling of the joints often results. Removing covers to allow sawing also slows curing, and it is recommended that the surfaces be re-wet before the covering is replaced. Some pervious concrete pavements are not jointed, as random cracking is not viewed as a significant deficit in the aesthetic of the pavement (considering its texture), and has no significant affect on the structural integrity of the pavement.

Proper curing is essential to the structural integrity of a pervious concrete pavement. The open structure and relatively rough surface of pervious concrete exposes more surface area of the cement paste to evaporation, making curing even more essential than in conventional concreting. Curing ensures sufficient hydration of the cement paste to provide the necessary strength in the pavement section to prevent raveling. Curing should begin within 20 minutes after final consolidation and continue through 7 days. Plastic sheeting is typically used to cure pervious concrete pavements

Testing and Maintenance

Currently no ASTM test methods exist for testing pervious concrete. An ASTM subcommittee on pervious concrete, ASTM C09.49 was recently formed. Until testing is specifically developed for pervious concrete the following testing is recommended. Job site acceptance must be based on the density (unit weight) of fresh concrete. A standard value is 120 lb/ft^3 (1920 kg/m^3). An acceptable tolerance is plus or minus 5 lb/ft^3 (80 kg/m^3) of the design density. This should be verified through field testing. The fresh density (unit weight) of pervious concrete is measured using the jigging method described in ASTM C 29. Slump and air content tests are not applicable to pervious concrete. If the pervious concrete pavement is an element of the storm water management plan, the designer should ensure that it is functioning properly through visual observation of its drainage characteristics prior to opening of the facility. Once the pavement has been constructed cores are taken and tested for the following: 1. Thickness; 2. Void Content; 3. Unit weight. Void content and unit weight can be determined according to ASTM C 140. ACI Committee 522 on pervious concrete is working on a specification for pervious concrete that will have these test methods as requirements.

Maintenance of pervious concrete pavement consists primarily of prevention of clogging of the void structure. In preparing the site prior to construction, drainage of surrounding landscaping should be designed to prevent flow of materials onto pavement surfaces. The two commonly accepted maintenance methods are pressure washing and power vacuuming. Pressure washing forces the contaminants down through the pavement surface. This is effective, but care should be taken not to use too much pressure, as this will damage the pervious concrete. Power vacuuming removes contaminants by extracting them from the pavement voids. The most effective scheme, however, is to combine the two techniques and power vacuum after pressure washing.

References

1. Pervious Pavement Manual, Florida Concrete and Products Association Inc., Orlando, FL. http://www.fcpa.org.

2. Meininger, R.C., "No-Fines Pervious Concrete for Paving," Concrete International, Vol. 10, No. 8, August 1988, pp. 20-27.

3. Storm Water Technology Fact Sheet Porous Pavement, United States Environmental Protection Agency, EPA 832-F-99-023, September 1999. www.epa.gov/npdes

4. ACI Committee 522, Pervious Concrete, 522R-06, American Concrete Institute, Farmington Hills, MI, http://www.concrete.org

5. Ghafoori, N., and Dutta, S., "Building and Nonpavement Applications of No-Fines Concrete," Journal of Materials in Civil Engineering, Volume 7, Number 4, November 1995, pgs. 286-289.

6. National Ready Mixed Concrete Association (NRMCA), Freeze Thaw Resistance of Pervious Concrete, Silver Spring, MD, May 2004, 17 pp.

7. NRMCA, "What, Why, and How? Pervious Concrete," Concrete in Practice series, CIP 38, Silver Spring, Maryland, May 2004b, 2 pages.

8. Tennis, P., Leming. M.L., and Akers, D.J., "Pervious Concrete Pavements," EB 302, Portland Cement Association (PCA), Skokie, Illinois, 2004, 25 pp.

9. Leming, M.L., Rooney, M.H., and Tennis, P.D., "Hydrologic Design of Pervious Concrete," PCA R&D Serial No. 2829 (in press), Skokie, Illinois, 2007.

10. Pervious Concrete: Hydrological Design and Resources, CD063, CD-ROM, PCA, Skokie, IL, 2007.

11. Storm water Phase II Final Rule Fact Sheet Series, United States Environmental Protection Agency, http://cfpub.epa.gov/npdes/stormwater/swfinal.cfm

12. Leadership in Energy and Environmental Design (LEED) Green Building Rating System, US Green Building Council, http://www.usgbc.org/DisplayPage.aspx?CategoryID=19