Pervious Concrete Pavements

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Concrete Thinking for a sustainable world

NRMCA National Ready Mixed Concrete Association

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Abstract: Pervious concrete as a paving material has seen renewed interest due to its ability to allow water to flow through itself to recharge groundwater and minimize stormwater runoff. This introduction to pervious concrete pavements reviews its applications and engineering properties, including environmental benefits, structural properties, and durability. Both hydrologic and structural design of pervious concrete pavements are discussed, as well as construction techniques.

Keywords: Applications, construction techniques, hydrologic design, inspection, pervious concrete, properties, structural design

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WARNING: Contact with wet (unhardened) concrete, mortar, cement, or cement mixtures can cause SKIN IRRITATION, SEVERE CHEMICAL BURNS (THIRD DEGREE), or SERIOUS EYE DAMAGE. Frequent exposure may be associated with irritant and/or allergic contact dermatitis. Wear waterproof gloves, a long-sleeved shirt, full-length trousers, and proper eye protection when working with these materials. If you have to stand in wet concrete, use waterproof boots that are high enough to keep concrete from flowing into them. Wash wet concrete, mortar, cement, or cement mixtures from your skin immediately. Flush eyes with clean water immediately after contact. Indirect contact through clothing can be as serious as direct contact, so promptly rinse out wet concrete, mortar, cement, or cement mixtures from clothing. Seek immediate medical attention if you have persistent or severe discomfort.

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Introduction

Pervious concrete pavement is a unique and effective means to meet growing environmental demands. By capturing rainwater and allowing it to seep into the ground, pervious concrete is instrumental in recharging groundwater, reducing stormwater runoff, and meeting U.S. Environmental Protection Agency (EPA) stormwater regulations. In fact, the use of pervious concrete is among the Best Management Practices (BMP) recommended by the EPA—and by other agencies and geotechnical engineers across the country—for the management of stormwater runoff on a regional and local basis. This pavement technology creates more efficient land use by eliminating the need for retention ponds, swales, and other stormwater management devices. In doing so, pervious concrete has the ability to lower overall project costs on a first-cost basis.

In pervious concrete, carefully controlled amounts of water and cementitious materials are used to create a paste that forms a thick coating around aggregate particles. A pervious concrete mixture contains little or no sand, creating a substantial void content. Using sufficient paste to coat and bind the aggregate particles together creates a system of highly permeable, interconnected voids that drains quickly. Typically, between 15% and 25% voids are achieved in the hardened concrete, and flow rates for water through pervious concrete typically are around 480 in./hr (0.34 cm/s, which is 5 gal/ft^2/ min or 200 L/m^2/min), although they can be much higher. Both the low mortar content and high porosity also reduce strength compared to conventional concrete mixtures, but sufficient strength for many applications is readily achieved.

While pervious concrete can be used for a surprising number of applications, its primary use is in pavement. This report will focus on the pavement applications of the material, which also has been referred to as porous concrete, permeable concrete, no-fines concrete, gap-graded concrete, and enhanced-porosity concrete.

Figure 1. Pervious concrete's key characteristic is its open pore structure that allows high rates of water transmission. Trail in Athens Regional Park in Athens, TN, (A. Sparkman).

Applications

Although not a new technology (it was first used in 1852 (Ghafoori and Dutta 1995b), pervious concrete is receiving renewed interest, partly because of federal clean water legislation. The high flow rate of water through a pervious concrete pavement allows rainfall to be captured and to percolate into the ground, reducing stormwater runoff, recharging groundwater, supporting sustainable construction, providing a solution for construction that is sensitive to environmental concerns, and helping owners comply with EPA stormwater regulations. This unique ability of pervious concrete offers advantages to the environment, public agencies, and building owners by controlling rainwater on-site and addressing stormwater runoff issues. This can be of particular interest in urban areas or where land is very expensive. Depending on local regulations and environment, a pervious concrete pavement and its subbase may provide enough water storage capacity to eliminate the need for retention ponds, swales, and other precipitation runoff containment strategies. This provides for more efficient land use and is one factor that has led to a renewed interest in pervious concrete. Other applications that take advantage of the high flow rate through pervious concrete include drainage media for hydraulic structures, parking lots, tennis courts, greenhouses, and pervious base layers under heavy-duty pavements. Its high porosity also gives it other useful characteristics: it is thermally insulating (for example, in walls of buildings) and has good acoustical properties (for sound barrier walls).

Although pavements are the dominant application for pervious concrete in the U.S., it also has been used as a structural material for many years in Europe (Malhotra 1976). Applications include walls for two-story houses, load-bearing walls for high-rise buildings (up to 10 stories), infill panels for high-rise buildings, sea groins, roads, and parking lots. Table 1 lists examples of applications for which pervious concrete has been used successfully, and Figure 2 shows several examples.

All of these applications take advantage of the benefits of pervious concrete's characteristics. However, to achieve these results, mix design and construction details must be planned and executed with care.

Table 1. Applications for Pervious Concrete

Low-volume pavements
Residential roads, alleys, and driveways
Sidewalks and pathways
Parking lots
Low water crossings
Tennis courts
Subbase for conventional concrete pavements
Patios
Artificial reefs
Slope stabilization
Well linings
Tree grates in sidewalks
Foundations/floors for greenhouses, aquatic amusement centers, and zoos
Hydraulic structures
Swimming pool decks
Pavement edge drains
Groins and seawalls
Noise barriers
Walls (including load-bearing)

Figure 2 continued on next page.

Figure 2. Example applications of pervious concrete.
(a) Oregon zoo sidewalk, Portland, OR (P. Davis);
(b) Miller Park in Fair Oaks, CA, (A. Youngs);
(c) Finley Stadium parking lot, Chattanooga, TN (L. Tiefenthaler);
(d) Imperial Beach Sports Park, CA (D. Akers);
(e) Storage facility lot, Mt. Angel, OR (R. Banka);
(f) Colored pervious concrete walkway, Bainbridge Island, WA (G. McKinnon);
(g) Large concrete parking lot, Buford, GA (L. Tiefenthaler)

Performance

After placement, pervious concrete has a textured surface which many find aesthetically pleasing and which has been compared to a Rice Krispies® treat. Its low mortar content and little (or no) fine aggregate content yield a mixture with a very low slump, with a stiffer consistency than most conventional concrete mixtures. In spite of the high voids content, properly placed pervious concrete pavements can achieve strengths in excess of 3000 psi (20.5 MPa) and flexural strengths of more than 500 psi (3.5 MPa). This strength is more than adequate for most low-volume pavement applications, including high axle loads for garbage truck and emergency vehicles such as fire trucks. More demanding applications require special mix designs, structural designs, and placement techniques.

Pervious concrete is not difficult to place, but it is different from conventional concrete, and appropriate construction techniques are necessary to ensure its performance. It has a relatively stiff consistency, which dictates its handling and placement requirements. The use of a vibrating screed is important for optimum density and strength. After screeding, the material usually is compacted with a steel pipe roller. There are no bullfloats, darbies, trowels, etc. used in finishing pervious concrete, as those tools tend to seal the surface. Joints, if used, may be formed soon after consolidation, or installed using conventional sawing equipment. (However, sawing can induce raveling at the joints.) Some pervious concrete pavements are placed without joints. Curing with plastic sheeting must start immediately after placement and should continue for at least seven days. Careful engineering is required to ensure structural adequacy, hydrologic performance, and minimum clogging potential. More detail on these topics is provided in subsequent sections.

Environmental Benefits

As mentioned earlier, pervious concrete pavement systems provide a valuable stormwater management tool under the requirements of the EPA Storm Water Phase II Final Rule (EPA 2000). Phase II regulations provide programs and practices to help control the amount of contaminants in our waterways. Impervious pavements—particularly parking lots—collect oil, anti-freeze, and other automobile fluids that can be washed into streams, lakes, and oceans when it rains.

EPA Storm Water regulations set limits on the levels of pollution in our streams and lakes. To meet these regulations, local officials have considered two basic approaches: 1) reduce the overall runoff from an area, and 2) reduce the level of pollution contained in runoff. Efforts to reduce runoff include zoning ordinances and regulations that reduce the amount of impervious surfaces in

Table 2. Effectiveness of Porous Pavement Pollutant Removal, % by mass*

Study location	Total suspended solids (TSS)	Total phosphorus (TP)	Total nitrogen (TN)	Chemical oxygen demand (COD)	Metals
Prince William, VA	82	65	80	—	—
Rockville, MD	95	65	85	82	98–99

*Schueler, 1987, as quoted in EPA, 2004. This data was not collected on pervious concrete systems, but on another porous pavement material.

new developments (including parking and roof areas), increased green space requirements, and implementation of "stormwater utility districts" that levy an impact fee on a property owner based on the amount of impervious area. Efforts to reduce the level of pollution from stormwater include requirements for developers to provide systems that collect the "first flush" of rainfall, usually about 1 in. (25 mm), and "treat" the pollution prior to release. Pervious concrete pavement reduces or eliminates runoff and permits "treatment" of pollution: two studies conducted on the long-term pollutant removal in porous pavements suggest high pollutant removal rates. The results of the studies are presented in Table 2.

By capturing the first flush of rainfall and allowing it to percolate into the ground, soil chemistry and biology are allowed to "treat" the polluted water naturally. Thus, stormwater retention areas may be reduced or eliminated, allowing increased land use. Furthermore, by collecting rainfall and allowing it to infiltrate, groundwater and aquifer recharge is increased, peak water flow through drainage channels is reduced and flooding is minimized. In fact, the EPA named pervious pavements as a BMP for stormwater pollution prevention (EPA 1999) because they allow fluids to percolate into the soil.

Another important factor leading to renewed interest in pervious concrete is an increasing emphasis on sustainable construction. Because of its benefits in controlling stormwater runoff and pollution prevention, pervious concrete has the potential to help earn a credit point in the U.S. Green Building Council's Leadership in Energy & Environmental Design (LEED) Green Building Rating System (Sustainable Sites Credit 6.1) (PCA 2003 and USGBC 2003), increasing the chance to obtain LEED project certification. This credit is in addition to other LEED credits that may be earned through the use of concrete for its other environmental benefits, such as reducing heat island effects (Sustainable Site Credit 7.1), recycled content (Materials and Resources Credit 4), and regional materials (Materials and Resources Credit 5).

The light color of concrete pavements absorbs less heat from solar radiation than darker pavements, and the relatively open pore structure of pervious concrete stores less heat, helping to lower heat island effects in urban areas.

Trees planted in parking lots and city sidewalks offer shade and produce a cooling effect in the area, further reducing heat island effects. Pervious concrete pavement is ideal for protecting trees in a paved environment. (Many plants have difficulty growing in areas covered by impervious pavements, sidewalks and landscaping, because air and water have difficulty getting to the roots.) Pervious concrete pavements or sidewalks allow adjacent trees to receive more air and water and still permit full use of the pavement (see Figure 2 (b)). Pervious concrete provides a solution for landscapers and architects who wish to use greenery in parking lots and paved urban areas.

Although high-traffic pavements are not a typical use for pervious concrete, concrete surfaces also can improve safety during rainstorms by eliminating ponding (and glare at night), spraying, and risk of hydroplaning.

Engineering Properties

Fresh Properties

The plastic pervious concrete mixture is stiff compared to traditional concrete. Slumps, when measured, are generally less than ¾ in. (20 mm), although slumps as high as 2 in. (50 mm) have been used. When placed and compacted, the aggregates are tightly adhered to one another and exhibit the characteristic open matrix.

For quality control or quality assurance, unit weight or bulk density is the preferred measurement because some fresh concrete properties, such as slump, are not meaningful for pervious concrete. Conventional cast cylinder strength tests also are of little value, because the field consolidation of pervious concrete is difficult to reproduce in cylindrical test specimens, and strengths are heavily dependent on the void content. Unit weights of pervious concrete mixtures are approximately 70% of traditional concrete mixtures.

Concrete working time typically is reduced for pervious concrete mixtures. Usually one hour between mixing and placing is all that is recommended. However, this can be controlled using retarders and hydration stabilizers that extend the working time by as much as 1.5 hours, depending on the dosage.

Hardened Properties

Density and porosity. The density of pervious concrete depends on the properties and proportions of the materials used, and on the compaction procedures used in placement. 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, which is in the upper range of lightweight concretes. A pavement 5 in. (125 mm) thick with 20% voids will be able to store 1 in. (25 mm) of a sustained rainstorm in its voids, which covers the vast majority of rainfall events in the U.S. When placed on a 6-in. (150-mm) thick layer of open-graded gravel or crushed rock subbase, the storage capacity increases to as much as 3 in. (75 mm) of precipitation (see Figure 3 and discussion on Hydrological Design Considerations).

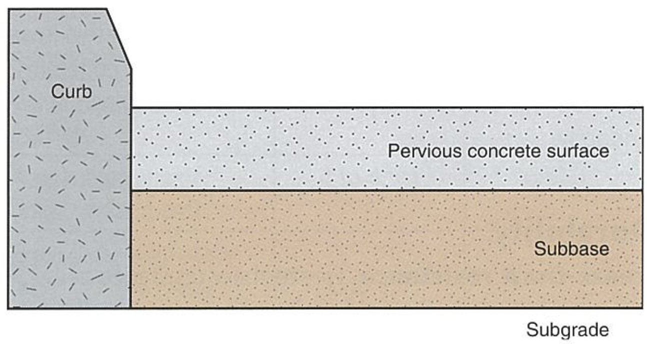

Figure 3. Typical cross section of pervious concrete pavement. On level subgrades, stormwater storage is provided in the pervious concrete surface layer (15% to 25% voids), the subbase (20% to 40% voids), and above the surface to the height of the curb (100% voids). Adapted from Paine 1990.

Permeability. The flow rate through pervious concrete depends on the materials and placing operations. Typical flow rates for water through pervious concrete are 3 gal/ft^2/min (288 in./hr, 120 L/m^2/min, or 0.2 cm/s) to 8 gal/ft^2/min (770 in./hr, 320 L/m^2/min, or 0.54 cm/s), with rates up to 17 gal/ft^2/min (1650 in./hr, 700 L/m^2/min, 1.2 cm/s) and higher having been measured in the laboratory (Crouch 2004).

Compressive strength. 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). As with any concrete, the properties and combinations of specific materials, as well as placement techniques and environmental conditions, will dictate the actual in-place strength. Drilled cores are the best measure of in-place strengths, as compaction differences make cast cylinders less representative of field concrete.

Flexural strength. Flexural strength in pervious concretes generally ranges between about 150 psi (1 MPa) and 550 psi (3.8 MPa). Many factors influence the flexural strength, particularly degree of compaction, porosity, and the aggregate:cement (A/C) ratio. However, the typical application constructed with pervious concrete does not require the measurement of flexural strength for design.

Shrinkage. Drying shrinkage of pervious concrete develops sooner, but is much less than conventional concrete. Specific values will depend on the mixtures and materials used, but values on the order of 200×10^{-6} have been reported (Malhotra 1976), roughly half that of conventional concrete mixtures. The material's low paste and mortar content is a possible explanation. Roughly 50% to 80% of shrinkage occurs in the first 10 days, compared to 20% to 30% in the same period for conventional concrete. Because of this lower shrinkage and the surface texture, many pervious concretes are made without control joints and allowed to crack randomly.

Durability

Freeze-thaw resistance. Freeze-thaw resistance of pervious concrete in the field appears to depend on the saturation level of the voids in the concrete at the time of freezing. In the field, it appears that the rapid draining characteristics of pervious concrete prevent saturation from occurring. Anecdotal evidence also suggests that snow-covered pervious concrete clears quicker, possibly because its voids allow the snow to thaw more quickly than it would on conventional pavements. In fact, several pervious concrete placements in North Carolina and Tennessee have been in service for more than 10 years.

Note that the porosity of pervious concrete from the large voids is distinctly different from the microscopic air voids that provide protection to the paste in conventional concrete in a freeze-thaw environment. When the large open voids are saturated, complete freezing can cause severe damage in only a few cycles. Standardized testing by ASTM C666 may not represent field conditions fairly, as the large open voids are kept saturated in the test, and because the rate of freezing and thawing is rapid. Neithalath (2003) found that even after 80 cycles of slow freezing and thawing (one cycle/day), pervious concrete mixtures maintained more than 95% of their relative dynamic modulus, while the same mixtures showed less than 50% when tested at a more rapid rate (five to six cycles/day). It was noted that better performance also could be expected in the field because of the rapid draining characteristics of pervious concrete.

Research indicates that entrained air in the paste dramatically improves freeze-thaw protection for pervious concrete (Neithalath 2003; Malhotra 1976). In addition to the use of air-entraining agents in the cement paste, placing the pervious concrete on a minimum of 6 in. (150 mm) (often up to 12 in. (300 mm) or even 18 in. (450 mm)) of a drainable rock base, such as 1-in. (25-mm) crushed stone, is normally recommended in freeze-thaw environments where any substantial moisture will be encountered during freezing conditions (NRMCA 2004a).

Sulfate resistance. Aggressive chemicals in soils or water, such as acids and sulfates, are a concern to conventional concrete and pervious concrete alike, and the mechanisms for attack are similar. However, the open structure of pervious concrete may make it more susceptible to attack over a larger area. Pervious concretes can be used in areas of high-sulfate soils and groundwaters if isolated from them. Placing the pervious concrete over a 6-in. (150-mm) layer of 1-in. (25-mm) maximum top size aggregate provides a pavement base, stormwater storage, and isolation for the pervious concrete. Unless these precautions are taken, in aggressive environments, recommendations of ACI 201 on water:cement ratio, and material types and proportions should be followed strictly.

Abrasion resistance. Because of the rougher surface texture and open structure of pervious concrete, abrasion and raveling of aggregate particles can be a problem, particularly where snowplows are used to clear pavements. This is one reason why applications such as highways generally are not suitable for pervious concretes. However, anecdotal evidence indicates that pervious concrete pavements allow snow to melt faster, requiring less plowing.

Most pervious concrete pavements will have a few loose aggregates on the surface in the early weeks after opening to traffic. These rocks were loosely bound to the surface initially, and popped out because of traffic loading. After the first few weeks, the rate of surface raveling is reduced considerably and the pavement surface becomes much more stable. Proper compaction and curing techniques will reduce the occurrence of surface raveling.

Mixture Proportioning

Materials

Pervious concrete uses the same materials as conventional concrete, with the exceptions that the fine aggregate typically is eliminated entirely, and the size distribution (grading) of the coarse aggregate is kept narrow, allowing for relatively little particle packing. This provides the useful hardened properties, but also results in a mix that requires different considerations in mixing, placing, compaction, and curing. The mixture proportions are somewhat less forgiving than conventional concrete mixtures—tight controls on batching of all of the ingredients are necessary to provide the desired results. Often, local concrete producers will be able to best determine the mix proportions for locally available materials based on trial batching and experience. Table 3 provides typical ranges of materials proportions in pervious concrete, and ACI 211.3 provides a procedure for producing pervious concrete mixture proportions.

Cementitious materials. As in traditional concreting, portland cements (ASTM C150, C1157) and blended cements (ASTM C595, C1157) may be used in pervious concrete. In addition, supplementary cementitious materials (SCMs), such as fly ash and pozzolans (ASTM C618) and ground-granulated blast furnace slag (ASTM C989), may be used. Testing materials beforehand through trial batching is strongly recommended so that properties that can be important to performance (setting time, rate of strength development, porosity, and permeability, among others) can be determined.

Aggregate. Fine aggregate content is limited in pervious concrete and coarse aggregate is kept to a narrow gradation. Commonly used gradations of coarse aggregate include ASTM C33 No. 67 (¾ in. to No. 4), No. 8 (⅜ in. to No. 16), or No. 89 (⅜ in. to No. 50) sieves [in metric units: No. 67 (19.0 to 4.75 mm), No. 8 (9.5 to 2.36 mm), or No. 89 (9.5 to 1.18 mm), respectively]. Single-sized aggregate up to 1 in. (25 mm) also has been used. ASTM D448 also may be used for defining gradings. A narrow grading is the important characteristic. Larger aggregates provide a rougher surface. Recent uses for pervious concrete have focused on parking lots, low-traffic pavements, and pedestrian walkways. For these applications, the smallest sized aggregate feasible is used for aesthetic reasons. Coarse aggregate size 89 (⅜-in. or 9.5-mm top size) has been used extensively for parking lot

Table 3. Typical Ranges of Materials Proportions in Pervious Concrete***

	Proportions, lb/yd^3	Proportions, kg/m^3
Cementitious materials	450 to 700	270 to 415
Aggregate	2000 to 2500	1190 to 1480
Water:cement ratio*** (by mass)	0.27 to 0.34	
Aggregate:cement ratio*** (by mass)	4 to 4.5:1	
Fine:coarse aggregate ratio**** (by mass)	0 to 1:1	

* These proportions are given for information only. Successful mixture design will depend on properties of the particular materials used and must be tested in trial batches to establish proper proportions and determine expected behavior. Concrete producers may have mixture proportions for pervious concrete optimized for performance with local materials. In such instances those proportions are preferable.

** Chemical admixtures, particularly retarders and hydration stabilizers, are also used commonly, at dosages recommended by the manufacturer. Use of supplementary cementitious materials, such as fly ash and slag, is common as well.

*** Higher ratios have been used, but significant reductions in strength and durability may result.

**** Addition of fine aggregate will decrease the void content and increase strength.

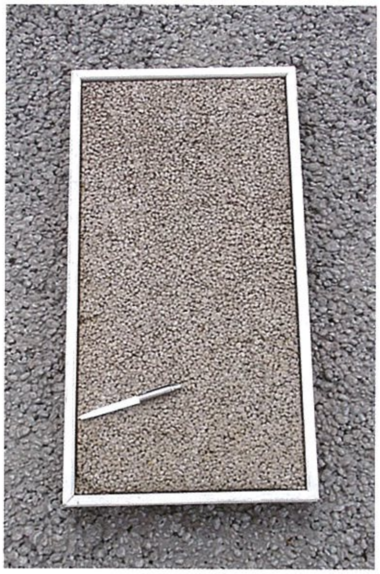

Figure 4. Pervious concrete is made with a narrow aggregate gradation, but different surface textures can be obtained through the use of different maximum sizes. The concrete in the box contained a 1/4-in. (6.5-mm) top size, while that below used a larger top size, 3/4 in. (20 mm) (J. Arroyo).

and pedestrian applications, dating back 20 years or more in Florida. Figure 4 shows two different aggregate sizes used in pervious concretes to create different surface textures.

Generally, A/C ratios are in the range of 4.0 to 4.5 by mass. These A/C ratios lead to aggregate contents of between about 2200 lb/yd³ and 3000 lb/yd³ (1300 kg/m³ to 1800 kg/m³). Higher A/C ratios have been used in laboratory studies (Malhotra 1976), but significant reductions in strength result.

Both rounded aggregate (gravel) and angular aggregate (crushed stone) have been used to produce pervious concrete. Typically, higher strengths are achieved with rounded aggregates, although angular aggregates generally are suitable. Aggregates for pavements should conform to ASTM D448, while ASTM C33 covers aggregates for use in general concrete construction. As in conventional concrete, pervious concrete requires aggregates to be close to a saturated, surface-dry condition or close monitoring of the moisture condition of aggregates should allow for accounting for the free moisture on aggregates. It should be noted that control of water is important in pervious concrete mixtures. Water absorbed from the mixture by aggregates that are too dry can lead to dry mixtures that do not place or compact well. However, extra water in aggregates contributes to the mixing water and increases the water to cement ratio of the concrete.

Water. Water to cementitious materials ratios between 0.27 to 0.30 are used routinely with proper inclusion of chemical admixtures, and those as high as 0.34 and 0.40 have been used successfully. The relation between strength and water to cementitious materials ratio is not clear for pervious concrete because unlike conventional concrete, the total paste content is less than the voids content between the aggregates. Therefore, making the paste stronger may not always lead to increased overall strength. Water content should be tightly controlled. The correct water content has been described as giving the mixture a sheen, without flowing off of the aggregate. A handful of pervious concrete formed into a ball will not crumble or lose its void structure as the paste flows into the spaces between the aggregates. See Figure 5.

Figure 5. Samples of pervious concrete with different water contents, formed into a ball: (a) too little water, (b) proper amount of water, and (c) too much water.

Water quality is discussed in ACI 301. As a general rule, water that is drinkable is suitable for use in concrete. Recycled water from concrete production operations may be used as well, if it meets provisions of ASTM C94 or AASHTO M 157. If there is a question as to the suitability of a water source, trial batching with job materials is recommended.

Admixtures. Chemical admixtures are used in pervious concrete to obtain special properties, as in conventional concrete. Because of the rapid setting time associated with pervious concrete, retarders or hydration-stabilizing admixtures are used commonly. Use of chemical admixtures should closely follow manufacturer's recommendations. Air-entraining admixtures can reduce freeze-thaw damage in pervious concrete and are used where freeze-thaw is a concern. ASTM C494 governs chemical admixtures, and ASTM C260 governs air-entraining admixtures. Proprietary admixture products that facilitate placement and protection of pervious pavements are also used.

Design

Basis for Design

Two factors determine the design thickness of pervious pavements: the hydrologic properties, such as permeability and volume of voids, and the mechanical properties, such as strength and stiffness. Pervious concrete used in pavement systems must be designed to support the intended traffic load and contribute positively to the site-specific stormwater 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 hydrologic and the structural requirements, and the larger of the two values for pavement thickness will determine the final design thickness.

This section presents an overview of considerations for both hydraulic and structural aspects of designing pervious concrete pavements.

Hydrological Design Considerations

The design of a pervious concrete pavement must consider many factors. The three primary considerations are the amount of rainfall expected, pavement characteristics, and underlying soil properties. However, the controlling hydrological factor in designing a pervious concrete system is the intensity of surface runoff that can be tolerated. The amount of runoff is less than the total rainfall because a portion of the rain is captured in small depressions in the ground (depression storage), some infiltrates into the soil, and some is intercepted by the ground cover. Runoff also is a function of the soil properties, particularly the rate of infiltration: sandy, dry soils will take in water rapidly, while tight clays may absorb virtually no water during the time of interest for mitigating storm runoff. Runoff also is affected by the nature of the storm itself; different sizes of storms will result in different amounts of runoff, so the selection of an appropriate design storm is important. This section will briefly discuss these topics. For more detail, see Leming (in press).

In many situations, pervious concrete simply replaces an impervious surface. In other cases, the pervious concrete pavement system must be designed to handle much more rainfall than will fall on the pavement itself. These two applications may be termed "passive" and "active" runoff mitigation, respectively. A passive mitigation system can capture much, if not all, of the "first flush," but is not intended to offset excess runoff from adjacent impervious surfaces. An active mitigation system is designed to maintain runoff at a site at specific levels. Pervious concrete used in an active mitigation system must treat runoff from other features on-site as well, including buildings, areas paved with conventional impervious concrete, and buffer zones, which may or may not be planted. When using an active mitigation system, curb, gutter, site drainage, and ground cover should ensure that flow of water into a pervious pavement system does not bring in sediment and soil that might result in clogging the system. One feasibility study found that by using pervious concrete for a parking lot roughly the size of a football field, approximately 9 acres (3.6 hectares) of an urbanized area would act hydrologically as if it were grass (Malcolm, 2002).

Rainfall

An appropriate rainfall event must be used to design pervious concrete elements. Two important considerations are the rainfall amount for a given duration and the distribution of that rainfall over the time period specified. Estimates for these values may be found in TR-55 (USDA 1986) and NOAA Atlas 2 or Atlas 14 maps (NOAA 1973; Bonnin et al. 2004). (See Figure 6.) For example, in one location in the mid-Atlantic region, 3.6 in. (9 cm) of rain is expected to fall in a 24-hour period, once every two years, on average. At

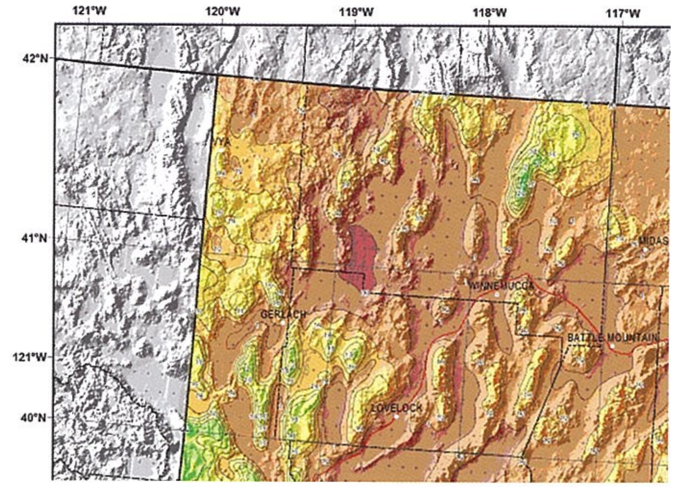

Figure 6. Isopluvials of 2-year, 24-hour precipitation in tenths of an inch, for a portion of Nevada. Maps such as these are useful in determining hydrological design requirements for pervious concrete based on the amount of precipitation expected. Map available at: http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_data.html.

that same location, the maximum rainfall anticipated in a two-hour duration every two years is under 2 in. (5 cm).

Selection of the appropriate return period is important because that establishes the quantity of rainfall which must be considered in the design. The term "two-year" storm means that a storm of that size is anticipated to occur only once in two years. The two-year storm is sometimes used for design of pervious concrete paving structures, although local design requirements may differ.

Pavement Hydrological Design

When designing pervious concrete stormwater management systems, two conditions must be considered: permeability and storage capacity. Excess surface runoff—caused by either excessively low permeability or inadequate storage capacity—must be prevented.

Permeability. In general, the concrete permeability limitation is not a critical design criteria. Consider a passive pervious concrete pavement system overlying a well-draining soil. Designers should ensure that permeability is sufficient to accommodate all rain falling on the surface of the pervious concrete. For example, with a permeability of 3.5 gal/ft^2/min (140 L/m^2/min), a rainfall in excess of 340 in./hr (0.24 cm/s) would be required before permeability becomes a limiting factor. The permeability of pervious concretes is not a practical controlling factor in design. However, the flow rate through the subgrade may be more restrictive (see discussion under "Subbase and Subgrade Soils").

Storage capacity. Storage capacity of a pervious concrete system typically is designed for specific rainfall events, which are dictated by local requirements. The total volume of rain is important, but the infiltration rate of the soil also must be considered. Details may be found in Leming (in press).

The total storage capacity of the pervious concrete system includes the capacity of the pervious concrete pavement, the capacity of any subbase used, and the amount of water which leaves the system by infiltration into the underlying soil. The theoretical storage capacity of the pervious concrete is its effective porosity: that portion of the pervious concrete which can be filled with rain in service. If the pervious concrete has 15% effective porosity, then every 1 in. (25 mm) of pavement depth can hold 0.15 in. (4 mm) of rain. For example, a 4-in. (100-mm) thick pavement with 15% effective porosity on top of an impervious clay could hold up to 0.6 in. (15 mm) of rain before contributing to excess rainfall runoff.

Another important source of storage is the subbase. Compacted clean stone (#67 stone, for example) used as a subbase has a design porosity of 40%; a conventional aggregate subbase, with a higher fines content, will have a lower porosity (about 20%). From the example above, if 4 in. (100 mm) of pervious concrete with 15% porosity was placed on 6 in. (150 mm) of clean stone, the nominal storage capacity would be 3.0 in. (75 mm) of rain:

$$(15\%)\ 4\ \text{in.} + (40\%)\ 6\ \text{in.} = 3.0\ \text{in.}$$

The effect of the subbase on the storage capacity of the pervious concrete pavement system can be significant.

A critical assumption in this calculation is that the entire system is level. If the top of the slab is not level, and the infiltration rate of the subgrade has been exceeded, higher portions of the slab will not fill and additional rainfall may run to the lowest part of the slab. Once it is filled, the rain will run out of the pavement, limiting the beneficial effects of the pervious concrete. For example, if a 6-in. (150-mm) thick pavement has a 1% slope and is 100 ft (30 m) long, there is a 1-ft (300-mm) difference in elevation from the front to the back and only 25% of the volume can be used to capture rainfall once the infiltration rate of the subgrade is exceeded. (See Figure 7.)

These losses in useable volume because of slopes can be significant, and indicate the sensitivity of the design to slope. When the surface is not level, the depth of the pavement and subbase must be designed to meet the desired runoff goals, or more complex options for handling water flow may

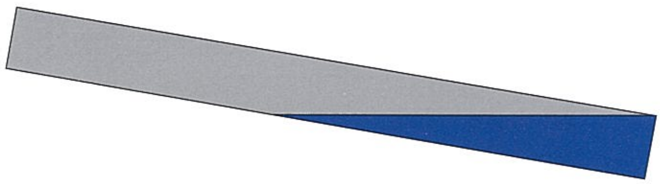

Figure 7. For sloped pavements, storage capacity calculations must consider the angle of the slope, if the infiltration rate of the subgrade is exceeded.

be used. Pervious concrete pavements have been placed successfully on slopes up to 16%. In these cases, trenches have been dug across the slope, lined with 6-mil visqueen, and filled with rock (CCPC 2003). (See Figures 8 and 9.) Pipes extending from the trenches carry water traveling down the paved slope out to the adjacent hillside.

The high flow rates that can result from water flowing downslope also may wash out subgrade materials, weakening the pavement. Use of soil filter fabric is recommended in these cases.

Figure 8. Preparation for a sloped installation. Crushed rock drains at intervals down the slope direct water away from the pavement and prevent water from flowing out of the pervious concrete (See also Figures 9 and 10). (S. Gallego)

Subbase and Subgrade Soils

Infiltration into subgrade is important for both passive and active systems. Estimating the infiltration rate for design purposes is imprecise, and the actual process of soil infiltration is complex. A simple model is generally acceptable for these applications and initial estimates for preliminary designs can be made with satisfactory accuracy using conservative estimates for infiltration rates. Guidance on the selection of an appropriate infiltration rate to use in design can be found in texts and Soil Surveys published by the Natural Resources Conservation Service (http://soils.usda.gov). TR-55 (USDA 1986) gives approximate values.

As a general rule, soils with a percolation rate of ½ in./hr (12 mm/hr) are suitable for subgrade under pervious pavements. A double-ring infiltrometer (ASTM D 3385) provides one means of determining the percolation rate. Clay soils and other impervious layers can hinder the performance of pervious pavements and may need to be modified to allow proper retention and percolation of precipitation. In some cases, the impermeable layers may need to be excavated and replaced. If the soils are impermeable, a greater thickness of porous subbase must be placed above them. The actual depth must provide the additional retention volume required for each particular project site. Open-graded stone or gravel, open-graded portland cement subbase (ACPA 1994), and sand have provided suitable subgrades to retain and store surface water runoff, reduce the effects of rapid storm runoffs, and reduce compressibility. For existing soils that are predominantly sandy and permeable, an open-graded subbase generally is not required, unless it facilitates placing equipment. A sand and gravel subgrade is suitable for pervious concrete placement.

In very tight, poorly draining soils, lower infiltration rates can be used for design. But designs in soils with a substantial silt and clay content—or a high water table—should be approached with some caution. It is important to recall that natural runoff is relatively high in areas with silty or clayey soils, even with natural ground cover, and properly designed and constructed pervious concrete can provide a positive benefit in almost all situations. For design purposes, the total drawdown time (the time until 100% of the storage capacity has been recovered) should be as short as possible, and generally should not exceed five days (Malcolm 2003).

Another option in areas with poorly draining soils is to install wells or drainage channels through the subgrade to more permeable layers or to traditional retention areas. These are filled with narrowly graded rock to create channels to allow stormwater to recharge groundwater. (See Figure 9.) In this case, more consideration needs to be given to water quality issues, such as water-borne contaminants.

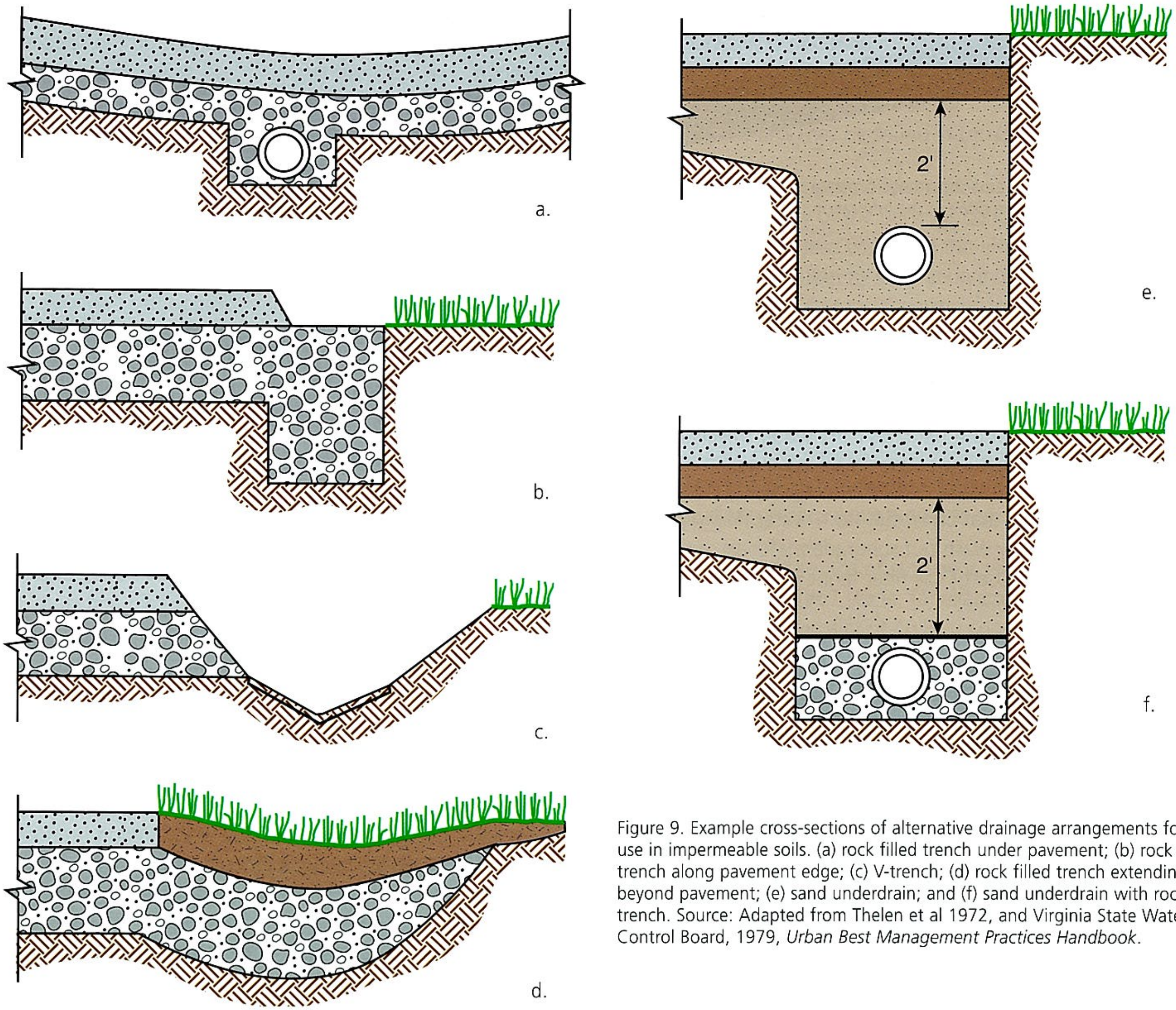

Figure 9. Example cross-sections of alternative drainage arrangements for use in impermeable soils. (a) rock filled trench under pavement; (b) rock trench along pavement edge; (c) V-trench; (d) rock filled trench extending beyond pavement; (e) sand underdrain; and (f) sand underdrain with rock trench. Source: Adapted from Thelen et al 1972, and Virginia State Water Control Board, 1979, *Urban Best Management Practices Handbook*.

Example

As an example, Leming (in press) shows sample calculations for a 3.6 in. (9 cm) (24-hr, two-year) design storm for a site with an active mitigation system composed of an automobile parking area 200 ft by 200 ft (61 m by 61 m) of 6-in. (150-mm) thick pervious concrete with 12% effective porosity and 6 in. (150 mm) of clean stone (40% porosity) overlying a silty soil with an infiltration rate estimated to be 0.1 in./hr (2.5 mm/hr). The pervious concrete system is intended to capture the runoff from an adjacent building (24,000 ft^2 (2300 m^2), impervious) and contiguous park-like, grassed areas (50,000 ft^2 (4600 m^2)), caused by slope, sidewalks, and areas worn from use. In this example, the total runoff was estimated to be about ¾ in. (20 mm) over the entire site for a two-year, 24-hr storm. Without a pervious concrete stormwater management system in place the pre-development runoff would be expected to be 1.2 in. (30 mm) for this storm—about 50% more.

Structural Design Considerations

This section provides guidelines for the structural design of pervious concrete pavements. Procedures described provide a rational basis for analysis of known data and offer methods to determine the structural thickness of pervious concrete pavements.

Pervious concrete is a unique material that has a matrix and behavior characteristics unlike conventional portland cement concrete or other pavement materials. Although these characteristics differ from conventional concretes, they are predictable and measurable. Projects with good to excellent performance over service lives of 20 to 30 years provide a great deal of empirical evidence related to material properties, acceptable subgrades, and construction procedures. Laboratory research in these areas has only recently begun.

Pavement Structural Design

Pervious concrete pavements can be designed using either a standard pavement procedure (AASHTO, WinPAS, StreetPave, or ACI 330R) or using structural numbers derived from a flexible pavement design procedure. Regardless of the procedure used, guidelines for roadbed (subgrade) soil properties, pervious concrete materials characteristics, and traffic loads should be considered.

Subbase and Subgrade Soils

The design of a pervious pavement base should normally provide a 6- to 12-in. (150- to 300-mm) layer of permeable subbase. The permeable subbase can either be 1 in. (25 mm) maximum size aggregate or a natural subgrade soil that is predominantly sandy with moderate amounts of silts, clays, and poorly graded soil, unless precautions are taken as described in "Clays and Highly Expansive Soils" (later in this section). Either type of material offers good support values as defined in terms of the Westergaard modulus of subgrade reaction (*k*). It is suggested that k not exceed 200 lb/in.^{3} (54 MPa/m), and values of 150 to 175 lb/in.^{3} (40 to 48 MPa/m) generally are suitable for design purposes (FCPA, 2002). Table 4 lists soil characteristics and their approximate *k* values.

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 (M_R, AASHTO T 292), as:

(Eq. 1) $k\ (pci) = M_R/19.4$, (M_R in units of psi), or

(Eq. 1a) $k\ (MPa/m) = 2.03\ M_R$, (M_R in units of MPa).

where M_R is the roadbed soil resilient modulus (psi). Depending on local practices, the California Bearing Ratio (CBR), R-Value and other tests may be used to determine the support provided by the subgrade. Empirical correlations between *k* and other tests, CBR (ASTM D1883 and AASHTO T 193), or R-Value test (ASTM D2844 and AASHTO T 190), are shown in Table 4.

Determining the subgrade's in-situ modulus 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. Two samples (one in the "as field test moisture condition" and another in a saturated condition) are subjected to a short-term 10 psi consolidation test. The saturated modulus of subgrade reaction is the ratio of the "field test moisture" to the saturated sample multiplied by the original in-situ modulus.

Table 4. Subgrade Soil Types and Range of Approximate k Values

Type of Soil	Support	*k* Values psi/in^l (MPa/m)	CBR	R-Value
Fine-grained soils in which silt and clay-size particles predominate	Low	75 to 120 (20 to 34)	2.5 to 3.5	10 to 22
Sands and sand-gravel mixtures with moderate amounts of sand and clay	Medium	130 to 170 (35 to 49)	4.5 to 7.5	29 to 41
Sands and sand-gravel mixtures relatively free of plastic fines	High	180 to 220 (50 to 60)	8.5 to 12	45 to 52

Clays and Highly Expansive Soils

Special design provisions should be considered in the design of pervious concrete pavement for areas with roadbed soils containing significant amounts of clay and silts of high compressibility, muck, and expansive soils. It is recommended that highly organic materials be excavated and replaced with soils containing high amounts of coarser fill material. Also, the design may include filter reservoirs of sand, open-graded stone, and gravel to provide adequate containment and increase the support values. Another design alternative is a sand subbase material placed over a pavement drainage fabric to contain fine particles. In lieu of the sandy soil, a pervious pavement of larger open-graded coarse aggregate (1½ in. or 38 mm) may provide a subbase for a surface course of a pervious mixture containing ⅜-in. (9.5-mm) aggregate. Figure 9 shows several options as examples.

Traffic Loads

The anticipated traffic carried by the pervious pavement can be characterized as equivalent 18,000-lb single axle loads (ESALs), average daily traffic (ADT), or average daily truck traffic (ADTT). Since truck traffic impacts pavements to a greater extent than cars, the estimate of trucks using the pervious pavement is critical to designing a long-life pavement.

Other Design Factors

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.

Materials Properties Related to Pavement Design

The flexural strength of concrete in a rigid pavement is very important to its design. Rigid pavement design is based on the strength of the pavement, which distributes loads uniformly to the subgrade. 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 an empirical relationship to estimate flexural strengths for use in design. Since the strength determines the performance level of the pavement and its service life, the properties of the pervious concrete should be evaluated carefully.

A mix design for a pervious pavement application will yield a wide range of strengths and permeability values, depending on the degree of compaction. Pre-construction testing should determine the relationship between compressive or splitting tensile and flexural strength, as well as the unit weight and/or voids content for the materials proposed for use. The strength so determined can be used in standard pavement design programs such as AASHTO, WinPAS, StreetPave or ACI 330R, to name a few.

Specification Guidance

Recommendations and specifications for pervious concrete have been prepared by the National Ready Mixed Concrete Association (NRMCA 2004b), the Florida Concrete and Products Association (FCPA 2001), the Georgia Concrete and Products Association (GCPA 1997), and the Pacific Southwest Concrete Alliance (PSCA 2004). ACI Committee 522 is actively preparing a comprehensive document on the use of pervious concrete.

Construction

Subgrade and Subbase Preparation

Uniformity of subgrade support is a key criterion for placing pervious pavement. As in other types of pavements, truck ruts and other irregularities must be smoothed and compacted prior to placement. Since subgrade and subbase preparation are critical components of pervious concrete pavement performance, refer to "Hydrological Design Considerations" and "Structural Design Considerations" elsewhere in this document for more information. Compaction to a minimum density of 90% to 95% of theoretical density per AASHTO T 180 often is recommended for consistent subgrade support; however, increasing the subgrade density decreases its permeability. Local geotechnical engineers may be the best source of knowledge regarding the properties of subgrade soils.

Since pervious pavements contain minimal water and high porosity, care must be taken to ensure that the pavement does not dry out prematurely. The subgrade must be moist (without free-standing water) prior to placement to prevent water from being removed from the lower portion of the pavement too soon. This is recommended practice for conventional concrete pavement placement if conditions for high evaporation rates are present, but is even more important in pervious concrete placement because the high voids can allow more rapid drying, with subsequent decrease in strength and durability, under less extreme conditions.

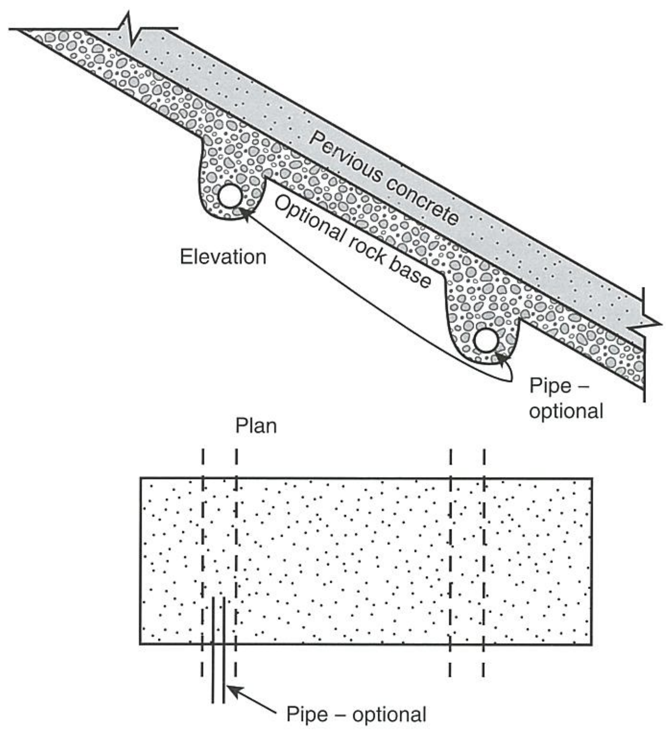

Figure 10. Elevation and plan view drawings of sloped installation.

Batching and Mixing

The special properties of pervious concrete require tighter control of mixture proportioning. In particular, the water content of pervious concrete is limited to a narrow range to provide adequate strength and permeability, and prevent the paste from flowing off the aggregates and closing of the open structure. A limited paste content means that added water will have more drastic impact than that experienced in conventional concrete applications. Aggregate moisture level should be monitored carefully and accounted for, as both water absorbed by the aggregate and excess moisture supplied with the aggregate can be detrimental. Contractors and producers must work together to ensure a proper mixture prior to delivery at the job site. On some occasions, slight adjustments to the water content may be necessary at the job site to achieve proper consistency; however, this should be done with care because jobsite additions of water can be difficult to control. The correct water content will provide a mix with a sheen. A unit weight test is necessary to provide assurance of consistent mixture proportions. Unit weights between 100 lb/ft^3 and 125 lb/ft^3 (1600 kg/m^3 and 2000 kg/m^3) are typical, and on-site measured values typically are required to be within 5% of the design unit weight.

Aggregate and cement proportions will be established by testing and experience with locally available materials, as variations in materials characteristics (for example, cement setting times, strength development rates, aggregate shape, gradation, and density) will limit the usefulness of "cook book" or prescriptive mix designs.

Almost certainly, the mixtures will be stiff. Conventional concrete mixing equipment is used, although mixing times may be extended compared to conventional concrete.

Transportation

Because pervious concrete has a low water content, special attention is required during transportation and placement. Its very low slumps may make discharge from transit mixers slower than for conventional concrete; transit mixers with large discharge openings or paving mixers tend to provide a faster unloading time. A pervious pavement mixture should be discharged completely within one hour after initial mixing. The use of retarding chemical admixtures or hydration-stabilizing admixtures may extend discharge times to 1½ hours or more. High ambient temperatures and windy conditions will have more pronounced effects relative to conventional pavements and should be taken into account.

Placement and Consolidation

A variety of placement techniques can be used for constructing pervious concrete pavements; as with conventional concrete, placement techniques are developed to fit the specific jobsite conditions. It should be noted that pervious concrete mixtures cannot be pumped, making site access an important planning consideration. Prior to placement, the subbase preparation and forms should be double-checked. Any irregularities, rutting, or misalignment should be corrected.

Each load of concrete should be inspected visually for consistency and aggregate coating. The stiff consistency of pervious concrete means that slump testing is not a useful method of quality control. Unit weight tests provide the best routine test for monitoring quality and are recommended for each load of pervious concrete.

Placement should be continuous, and spreading and strikeoff should be rapid. (See Figure 11.) Conventional formwork is used. Mechanical (vibrating) and manual screeds are used commonly, although manual screeds can cause tears in the surface if the mixture is too stiff. Other devices, such as laser screeds, could also be used. For pavements, it is recommended to strike off about ½ to ¾ in. (15 to 20 mm) above the forms to allow for compaction. One technique for accomplishing this (Paine 1992) is to attach a temporary wood strip above the top form to bring it to the desired height. After strikeoff, the strips are removed and the concrete is consolidated to the height of the form. Special height-adjusting vibrating screeds also have been used to provide the extra height. With vibrating screeds, care should be taken that the frequency of vibration is reduced to avoid over-compaction or closing off the surface, resulting in blocked voids. Edges near forms are compacted using a 1 ft by 1 ft (300 mm by 300 mm) steel tamp (like those used in decorative stamped concrete), a float, or other similar device to prevent raveling of the edges.

Figure 11. Pervious concrete is usually placed and then struck off with a vibratory screed. (R. Banka)

Consolidation generally is accomplished by rolling over the concrete with a steel roller (see Figures 12 and 13), compacting the concrete to the height of the forms. Because of rapid hardening and high evaporation rates, delays in consolidation can cause problems; generally, it is recommended that consolidation be completed within 15 minutes of placement.

Figure 12. Pervious concrete after screeding (left) and after compaction (right). Note the joint aligned with previously placed slab to avoid reflective cracking. Roller used for compaction is visible on the far right. (R. Banka)

Figure 13. Compaction of pervious concrete with a steel roller. (R. Banka)

Finishing

Typically, pervious concrete pavements are not finished in the same way as conventional concrete pavements. Normal floating and troweling operations tend to close up the top surface of the voids, which defeats the purpose (for most applications) of pervious concrete. For the majority of pervious pavements, the "finishing" step is the compaction. This leaves a rougher surface, but can improve traction.

Joint Placement

Control joints should be placed if prevention of random cracking of the pavement is desired, although the joint spacing is usually larger than for conventional concrete pavements because pervious concretes tend to shrink much less. Recommended joint spacings of 20 ft (6 m) (GCPA 1997) have been suggested, although some installations have had joint spacings of 45 ft (13.5 m) or more without uncontrolled cracking (Paine 1992). Prevention of uncontrolled reflective cracking is accomplished by installing joints at the same location as in the adjoining pavements. (See Figure 12.) As for conventional pavements, joints one-fourth of the slab thickness provide good control of cracking.

Because setting time and shrinkage are accelerated in pervious concrete construction, joint installation should be soon after consolidation, with a rolling joint tool (see Figure 14). Another technique, suitable for small sections, is to drive a steel straightedge to the required depth with a hammer.

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.

As noted previously, 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.

Figure 14. Joint roller, commonly referred to as a "pizza cutter." (R. Banka)

Curing and Protection

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. Water is needed for the chemical reactions of the cement and it is critical for pervious concrete to be cured promptly. In some regions, it is common to apply an evaporation retarder *before* compaction to minimize any potential for surface water loss.

Because pervious concrete pavements do not bleed, they can have a high propensity for plastic shrinkage cracking. In fact, "curing" for pervious slabs and pavements begins before the concrete is placed: the subgrade must be moistened to prevent it from absorbing moisture from the concrete. After placement, fog misting followed by plastic sheeting is the recommended curing procedure, and sheeting should remain in place for at least seven days. Using sand or dirt to hold plastic sheeting in place is not recommended because clogging of the voids could result from spillage on removal. Instead, securing plastic sheeting with lumber, rebar, stakes, or other methods is recommended.

Curing should be started as soon as practical after placing, compacting, and jointing. Best practice calls for curing to begin within a maximum of 20 minutes after these procedures. High ambient temperatures and windy conditions will have more pronounced effects relative to conventional pavements and should be taken into account.

Figure 15. Plastic sheeting should be used to cover the pervious concrete and be installed within a few minutes of consolidation to prevent moisture loss. (R. Banka)

Opening to Traffic

For pavement applications that will see traffic in service, it is generally recommended that the pavements not be opened to construction or public traffic for seven days. Continuous curing is recommended until the pavement is opened.

Inspection and Maintenance

Construction Inspection and Testing

As noted previously, normal construction inspection practices that base acceptance on slump and cylinder strengths are not meaningful for pervious concrete. Strength is a function of the degree of compaction, and compaction of pervious concrete is difficult to reproduce in cylinders. Instead, a unit weight test usually is used for quality assurance, with acceptable values dependent on the mix design, but generally between 100 lb/ft^3 and 125 lb/ft^3 (1600 kg/m^3 and 2000 kg/m^3). ASTM C29 generally is preferred over ASTM C138 because of the consistency of pervious concrete, although ASTM C138 is used in some areas. Testing frequencies of once per day, or when visual inspection indicates a change in the concrete, are common. Acceptance criteria typically are plus or minus 5 lb/ft^3 (80 kg/m^3) of the target value for the mix design.

Post-Construction Inspection and Testing

After seven days, core samples can be taken (per ASTM C42) and measured for thickness and unit weight as quality assurance and acceptance tests. A typical testing rate is three cores for each 100 yd^3 (75 m^3). Compression testing for strength is not recommended, because of the dependence of compressive strength on compaction. Unit weights, in accordance with ASTM C140, provide an acceptance measurement; typical requirements dictate that average unit weights be within 5 lb/ft^3 (80 kg/m^3) of the design unit weight. The common criterion for acceptance of thickness is that no core shall be under the design thickness by more than ½ in. (13 mm). It should be noted that pervious concrete pavements may have a higher variability in pavement thicknesses when placed on an open-graded subgrade, compared with conventional concrete pavements.

Maintenance

The majority of pervious concrete pavements function well with little or no maintenance. 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. Soil, rock, leaves, and other debris may infiltrate the voids and hinder the flow of water, decreasing the utility of the pavement. Landscaping materials such as mulch, sand, and topsoil should not be loaded on pervious concrete, even temporarily.

Vacuuming annually or more often may be necessary to remove debris from the surface of the pavements. Other cleaning options may include power blowing and pressure washing. Pressure washing of a clogged pervious concrete pavement has restored 80% to 90% of the permeability in some cases (MCIA 2002). It also should be noted that maintenance practices for pervious concrete pavements are still being developed.

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ACI 330, Guide for Design & Construction of Concrete Parking Lots

ACI 552R, Pervious Concrete

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ASTM C33, Specification for Concrete Aggregates

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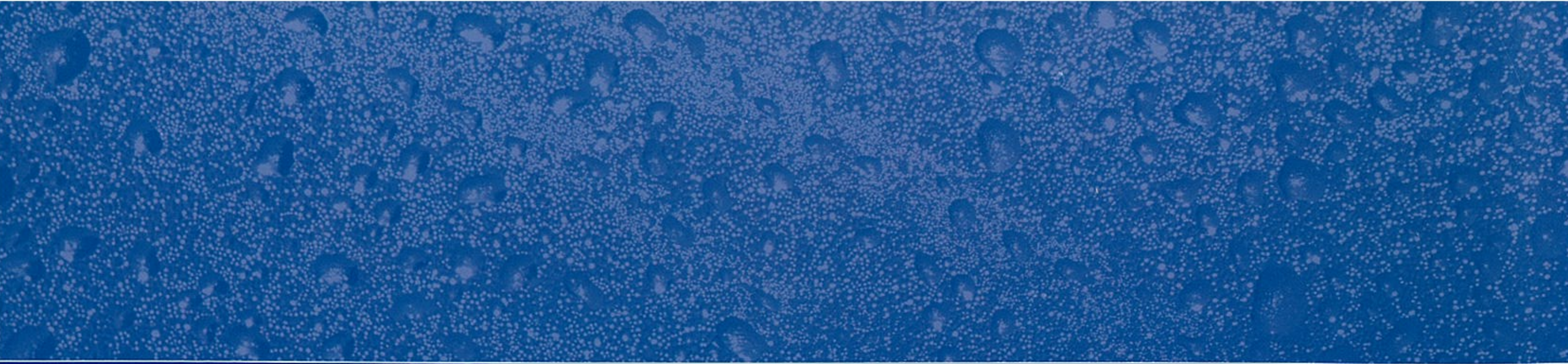

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