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Pervious Concrete—Report

Reported by ACI Committee 522

ACI PRC-522-23



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Pervious Concrete—Report

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Pervious Concrete—Report

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This report provides technical information on pervious concrete's application, design methods, materials, properties, mixture proportioning, construction methods, testing, and inspection.

The term "pervious concrete" typically describes a near-zero-slump, open-graded material consisting of portland cement, coarse aggregate, little or no fine aggregate, admixtures, and water. The combination of these ingredients will produce a hardened material with connected pores, ranging in size from 0.08 to 0.32 in. (2 to 8 mm), that allow water to pass through easily. The void content can range from 15 to 35%, with typical compressive strengths of 400 to 4000 psi (2.8 to 28 MPa). The drainage rate of pervious concrete pavement will vary with aggregate size and density of the mixture but will generally fall into the range of 2 to 18 gal./min/ft² (81 to 730 L/min/m²). Pervious concrete is widely recognized as a sustainable building material, as it reduces stormwater runoff,

improves stormwater quality, may recharge groundwater supplies, and can reduce the impact of the urban heat island effect.

Keywords: construction; design; drainage; green building; LEED® credit; permeability; pervious concrete pavement; stormwater; sustainability; testing.

CONTENTS

CHAPTER 1—INTRODUCTION AND SCOPE, p. 2

1.1—Introduction, p. 2

1.2—Scope, p. 3

CHAPTER 2—NOTATION AND DEFINITIONS, p. 3

2.1—Notation, p. 3

2.2—Definitions, p. 3

CHAPTER 3—APPLICATIONS, p. 4

3.1—General, p. 4

3.2—Building applications: history, p. 4

3.3—Pavement applications, p. 5

3.4—Other applications, p. 7

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ACI PRC-522-23 supersedes ACI 522R-10(11) and was published in June 2023.
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CHAPTER 4—MATERIALS, p. 7

- 4.1—General, p. 7
- 4.2—Aggregates for use in pervious concrete, p. 7
- 4.3—Cementitious materials, p. 8
- 4.4—Water, p. 8
- 4.5—Admixtures, p. 8

CHAPTER 5—PROPERTIES, p. 8

- 5.1—General, p. 8
- 5.2—Permeability, p. 8
- 5.3—Compressive strength, p. 10
- 5.4—Flexural strength, p. 11
- 5.5—Durability under freezing-and-thawing conditions, p. 12
- 5.6—Surface abrasion and raveling resistance, p. 13
- 5.7—Fracture toughness, p. 14
- 5.8—Acoustic absorption, p. 14
- 5.9—Slip and fall prevention, p. 14
- 5.10—Urban heat island mitigation, p. 15
- 5.11—Pollutant removal capacity, p. 15

CHAPTER 6—PERVIOUS CONCRETE MIXTURE PROPORTIONING, p. 15

- 6.1—General discussion of proportioning, p. 15
- 6.2—Proportioning criteria, p. 15
- 6.3—Proportioning process, p. 16
- 6.4—Mixture proportioning process examples, p. 17

CHAPTER 7—PERVIOUS PAVEMENT DESIGN, p. 19

- 7.1—Introduction, p. 19
- 7.2—Site design, p. 19
- 7.3—Structural design, p. 19
- 7.4—Stormwater management design, p. 21
- 7.5—Other considerations, p. 29

CHAPTER 8—PERVIOUS PAVEMENT CONSTRUCTION, p. 30

- 8.1—General construction principles, p. 30
- 8.2—Subgrade/subbase preparation, p. 30
- 8.3—Placing, p. 31
- 8.4—Compaction and finishing, p. 33
- 8.5—Jointing, p. 33
- 8.6—Curing and protection, p. 33
- 8.7—Cold weather protection, p. 35
- 8.8—Hot weather protection, p. 35

CHAPTER 9—QUALITY CONTROL AND ASSURANCE INSPECTION AND TESTING, p. 35

- 9.1—General, p. 35
- 9.2—Preconstruction inspection and testing, p. 35
- 9.3—Inspection and testing during construction, p. 36
- 9.4—Postconstruction inspection and testing, p. 36

CHAPTER 10—PERFORMANCE, p. 37

- 10.1—General, p. 37
- 10.2—Changes in infiltration rates, p. 37
- 10.3—Structural distress, p. 38

- 10.4—Surface distress, p. 38
- 10.5—Resistance to freezing and thawing, p. 38
- 10.6—Resistance to deicers, p. 39
- 10.7—Repairing pervious concrete pavements, p. 39
- 10.8—Maintenance, p. 40
- 10.9—Pervious concrete overlay field durability and performance, p. 40

CHAPTER 11—LIMITATIONS, POTENTIAL APPLICATIONS, AND RESEARCH NEEDS, p. 41

- 11.1—Pervious concrete in cold climates, p. 41
- 11.2—Characterization of the material structure, p. 42
- 11.3—Strength and other testing needs and limitations, p. 42
- 11.4—Nondestructive determination of performance and properties, p. 43
- 11.5—Stormwater management, p. 43
- 11.6—Urban heat island effect, carbonation, and other thermal properties, p. 44
- 11.7—Construction, operation, and maintenance needs, p. 45
- 11.8—Other novel applications and uses, p. 45

CHAPTER 12—THE ENVIRONMENT AND PERVIOUS CONCRETE, p. 46**CHAPTER 13—REFERENCES, p. 46**

Authored documents, p. 47

CHAPTER 1—INTRODUCTION AND SCOPE**1.1—Introduction**

The term “pervious concrete” typically refers to a hydraulic-cement concrete proportioned with sufficient, distributed, interconnected macroscopic voids that allow water to flow through the material under the action of gravity alone. The mixture often is composed of open-graded coarse aggregate, cementitious binder, little or no fine aggregate, admixtures, and water (Fig. 1.1a). The combination of these

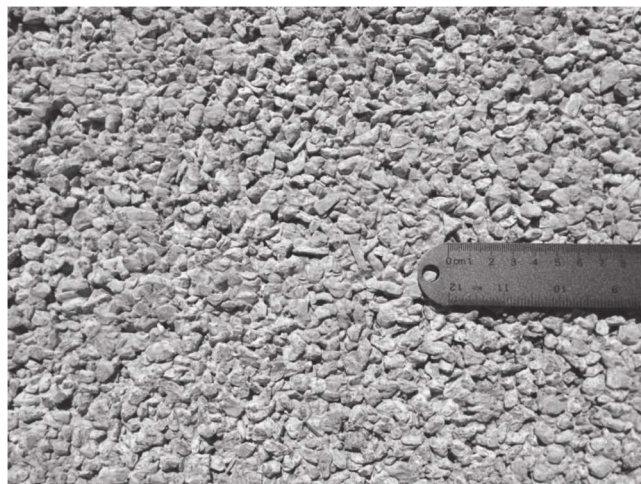


Fig 1.1a—Pervious concrete pavement (photo courtesy of M. Offenbergl).



Fig 1.1b—Uniform porosity observed from a core sample (photo courtesy of J. Montgomery).

ingredients will produce a hardened material with voids (Fig. 1.1b), ranging in size from 0.08 to 0.32 in. (2 to 8 mm), that allow water to flow through easily. The void content can range from 15 to 35%. The infiltration rate of pervious concrete pavement will vary with aggregate size and density of the mixture but will generally fall into the range of 250 to 1700 in./h (0.17 to 1.20 cm/s).

1.2—Scope

The Environmental Protection Agency (EPA) recognizes that stormwater runoff is the single largest contributor to surface water impairment in the United States. Stormwater runoff also has the potential to pollute surface and groundwater supplies. Furthermore, as land is developed, stormwater runoff leaves the site in higher rates and volumes than predevelopment, leading to downstream flooding and bank erosion. Pervious concrete pavement reduces the impact of development by reducing the rate of or eliminating stormwater runoff and protecting water supplies. This report provides technical information on pervious concrete applications, design methods, materials, properties, mixture proportioning, construction methods, testing, and inspection.

CHAPTER 2—NOTATION AND DEFINITIONS

2.1—Notation

A_b	=	area of the nonpervious area to be drained, ft ² (m ²)
A_p	=	area of the pervious pavement, ft ² (m ²)
C	=	runoff coefficient
c	=	cement content, lb (kg)

D_a	=	diameter between coarse aggregate particles
D_c	=	diameter between coarse aggregate particles coated with cement paste or mortar
d_1	=	thickness of the pavement, ft (m)
d_2	=	thickness of the subgrade, ft (m)
f'_c	=	specified compressive strength of concrete, psi (MPa)
f_r	=	modulus of rupture of concrete, psi (MPa)
t	=	time, s
h_1	=	initial head, in. (mm)
h_2	=	final head, in. (mm)
h_c	=	thickness of the pervious concrete layer, ft (m)
h_{curb}	=	height of curb to hold ponded water, ft (m)
h_s	=	thickness of the subbase or reservoir layer, ft (m)
I	=	rainfall intensity, ft (m)
k	=	permeability, in./s (mm/s)
p_1	=	percentage of void space in the pavement
p_2	=	percentage of void space in the subgrade
R	=	pressure reflection coefficient
r_c	=	porosity of the pervious concrete layer, %
r_s	=	porosity for the subbase or reservoir layer, %
V	=	total volume of water to be drained, ft ³ (m ³)
V_p	=	available storage in pavement, ft ³ (m ³)
V_r	=	required storage volume, ft ³ (m ³)
V_s	=	available storage in subgrade, ft ³ (m ³)
w	=	water content, lb (kg)

2.2—Definitions

ACI provides a comprehensive list of acceptable definitions through an online resource, ACI Concrete Terminology. Definitions provided herein complement that resource.

exfiltration rate—the design or measure rate at which water exits the pervious concrete system.

hydraulic conductivity—the ease of which fluids pass through concrete as a function of fluid density and viscosity and degree of saturation, also known as the coefficient of permeability when referring to water under saturated conditions.

impervious area—an area covered by a material that prevents precipitation from infiltrating soils and recharging groundwater supplies.

infiltration rate—the design or measured rate at which water enters the pervious concrete surface.

percolation rate—the rate, usually expressed as inches (millimeters) per hour or inches (millimeters) per day, at which water moves through pervious concrete.

permeability—the ability of pervious concrete to allow fluids (typically water) to pass through as a function of sample volume, fluid head, and fluid viscosity.

pervious concrete—hydraulic cement concrete proportioned with sufficient, distributed, interconnected macroscopic voids that allow water to flow through the material under the action of gravity alone.

pervious pavement—a pavement comprising material with sufficient continuous voids to allow water to pass from the surface to the underlying layers.

porosity—the volume of open and connected interstitial void space in pervious concrete expressed as a percentage of the total volume.

raveling—the wearing away of the concrete surface caused by the dislodging of individual aggregate particles.

runoff—water from rain or snow that is not absorbed into the ground but instead flows over less-pervious surfaces into streams and rivers.

surface course—the top layer of a concrete pavement structure.

void content—the ratio of the volume of voids, including both entrapped and entrained air, to the total volume expressed as a percentage.

CHAPTER 3—APPLICATIONS

3.1—General

Pervious concrete is most commonly applied in parking (Fig. 3.1) and low-volume road applications for the management of stormwater volume. However, pervious concrete, much like conventional concrete, has a wide variety of applications and benefits. Some of the wide range of applications include, but are not limited to: parking lots, drainage layers, greenhouse floors, thermal insulating structural walls, acoustic barriers, tennis courts, floors for animal barns and stalls, seawalls, and artificial reefs.

Typically, unreinforced pervious concrete is used in all these applications because of the perceived high risk of

reinforcing steel corrosion due to the open pore structure of the material. Noncorrosive reinforcement alternatives consisting of synthetic or natural microfibers and macro-fibers are routinely included in certain areas for additional toughness and durability.

3.2—Building applications: history

Pervious concrete has been used in building construction since at least the middle of the nineteenth century. Pervious concrete for building applications was first driven by lack of suitable fine aggregate and later for material conservation after World War II. Throughout this chapter, the term “pervious concrete” is used to describe the material, but in the references and historically, it may have been described as no-fines concrete or gap-graded concrete. European countries have used pervious concrete in different modes: cast-in-place load-bearing walls in single- and multi-story houses and, in some instances, in high-rise buildings, prefabricated panels, and steam-cured blocks. In 1852, pervious concrete was first used in the construction of two houses in the United Kingdom. This concrete consisted of only coarse gravel and cement. It is not mentioned in the published literature again until 1923, when a group of 50 two-story houses were built with clinker aggregate in Edinburgh, Scotland. In the late 1930s, the Scottish Special Housing Association Limited adopted the use of pervious concrete for residential construction (Francis 1965).

From 1939 to 1945, the havoc of World War II left almost all of Europe with vast housing needs, which encouraged the development of new or previously unused methods of building construction. Notably among them was pervious concrete (Malhotra 1969, 1976). Pervious concrete used less cement per unit volume of concrete as compared with conventional concrete, and the material was advantageous where labor force was scarce or expensive. By 1942, pervious concrete had been used to build over 900 houses in the United Kingdom. Elsewhere, the unprecedented demand for brick, and the subsequent inability of the brick-making industry to provide an adequate supply, led to the adoption of pervious concrete as a building material. Germany used this system because disposal of large quantities of brick rubble was a problem after the war, leading to research into the properties of pervious concrete. Similarly, in Scotland between 1945 and 1956, many homes were built with pervious concrete. This was mainly due to the presence of unlimited supplies of hard aggregates and the absence of good facing bricks. The first reported use of pervious concrete in Australia was as early as 1946. The pervious concrete system contributed substantially to the production of new houses in the United Kingdom, Germany, Holland, France, Belgium, Scotland, Spain, Hungary, Venezuela, West Africa, the Middle East, Australia, and Russia.

Before World War II, production of pervious concrete was confined to two-story homes. After 1946, however, pervious concrete was used for a much broader range of applications. It was specified as a material for load-bearing elements in buildings up to 10 stories tall (Francis 1965).



Fig. 3.1—Parking lot built with pervious concrete pavement.



Fig. 3.2—Reinforced pervious concrete walls constructed in the early 1900s (photo courtesy of G. Seegebrecht).

Although pervious concrete has been used in Europe and Australia for the past 60 years, its early use as a building material in North America has been extremely limited. One reason for this limited use is, after World War II, North America did not experience a materials shortage as much as Europe. The earliest example of pervious concrete in the United States are the reinforced pervious concrete walls surrounding Rosehill Cemetery in Chicago, IL, constructed in the early 1900s (Fig. 3.2).

In Canada, the first reported use of pervious concrete was in 1960. Pervious concrete was used in the construction of some houses in Toronto and on a nonstructural basis in a federal building in Ottawa.

3.3—Pavement applications

3.3.1 Pervious concrete pavements' advantages over conventional concrete pavements include:

- (a) Controlling stormwater pollution at the source
- (b) Controlling stormwater runoff
- (c) Increasing facilities for parking by eliminating the need for water-retention areas
- (d) Reducing the interaction noise between tire and pavement
- (e) Reducing glare on road surfaces to a great extent, particularly when wet at night
- (f) Eliminating or reducing the size of storm sewers
- (g) Allowing air and water to reach tree roots, even with pavement within the tree drip line (Fig. 3.3.1)
- (h) Reduction in slips and falls due to the reduction in surface icing
- (i) Urban heat island mitigation and permafrost protection from reduced heat storage

Pervious concrete pavements' potential disadvantages and challenges include:

- (a) Limited experience in heavy vehicle traffic areas
- (b) Specialized construction practices
- (c) Extended curing time
- (d) Sensitivity to water content and control in fresh concrete

- (e) Special attention and care in design of some soil types such as expansive soils and frost-susceptible soils
- (f) Lack of standardized test methods to measure compressive and flexural strength and raveling resistance
- (g) Lack of a standardized design procedure for minimum infiltration requirements
- (h) Special attention possibly required with high groundwater

Engineers have recommended pervious concrete in pavements as:

- (a) Surface course
- (b) Permeable base and edge drains
- (c) Shoulders

Historically, the success of pervious pavement systems has been mixed. In many areas, pervious concrete pavement systems have been applied successfully; however, in others they have clogged in a short time or experienced excessive surface raveling. Many failures can be attributed to contractor or concrete mixture producer inexperience, higher compaction of soil than specified, and improper site design. Proper mixture designs and installation techniques have proven effective at combating clogging and raveling issues. For a pervious concrete pavement to work successfully:

- (a) Permeability of soils should be verified. The permeability of the soil should, at a minimum, match that of the stormwater system design whether on a sandy subgrade or less permeable soil type. For example, in the red-clay Piedmont regions of the Carolinas and Georgia where the subgrade infiltration rate is much less than 0.5 in./h (13 mm/h), permeable pavements facilitate infiltration and filtering of runoff and recharging of the groundwater table (although they do not infiltrate the entirety of the rain water from large storms).
- (b) Site layout should reduce sediment exposure from adjacent soil or vegetated areas.
- (c) Construction traffic (primarily vehicular) should be directed away from the pervious pavement area during construction to prevent compaction of underlying soil layers and loss of infiltrative capacity.



Fig. 3.3.1—Pervious concrete pavement used within the drip line of trees (photo courtesy of M. Offenberger).

- (d) Construction site runoff and heavy equipment should be kept away from entering the pervious pavement area. The pervious concrete pavement should not be placed into service until all disturbed land that drains to it has been stabilized by vegetation. Strict erosion and sediment controls during any construction or landscaping activity are essential to prevent the system from clogging and should be incorporated into the construction site stormwater management plan.
- (e) Proper specifications should be required that clearly state the desired performance and testing requirements of the fresh and hardened concrete. Many failures have been caused by a lack of clear guidance from the designer/engineer as to what is expected of the producer and contractor.

3.3.1.1 Parking lots—Pervious concrete was referred to as a parking lot paving material in central Florida as early as the 1970s (Medico 1975). The concept developed as a means of handling the enormous quantities of water running off a parking lot during a storm; pervious concrete allows the water to percolate into the ground under the pavement. The Environmental Protection Agency (EPA) adopted a policy that recommends the use of pervious pavements as a part of their best management practices (BMPs) as a way for communities to mitigate the problem of stormwater runoff (U.S. EPA 2021). Pervious concrete parking lots have also been selected as an integral solution to help mitigate urban heat island effects in the Cool Communities program. The air temperature over pervious concrete parking lots is generally cooler than dense-graded asphalt. Pervious concrete parking lots also reduce snow and ice buildup and are considered a non-pollutant to the environment. The practical range of design thicknesses for pervious concrete pavements is from 6 to 8 in. (150 to 200 mm) for most parking lots.

3.3.1.2 Sidewalks—In many locations, pervious concrete is first used in sidewalk applications for testing and training purposes before large-scale parking lot placement. Pervious concrete sidewalks, either cast-in-place or precast, offer the same stormwater and urban heat island benefits as pervious concrete parking lots, but with the specific benefit of reduced slipping potential (Kevern et al. 2012). The practical range of design thicknesses for pervious concrete sidewalks is from 4 to 6 in. (100 to 150 mm) for sections without routine vehicular traffic.

3.3.1.3 Roadways—Pervious concrete for roadways is usually considered for two applications as a roadway surface or friction course. The practical range of design thicknesses for pervious concrete is from 6 to 8 in. (150 to 200 mm) for roadway pavements. Bonded overlays (Maynard 1970; Schaefer et al. 2010), however, have been as thin as 2 in. (50 mm). Numerous highways in Europe have been constructed using an overlay of latex-modified pervious concrete that allows for pavement drainage and tire-noise reduction. The latex modification results in more desirable mechanical properties (Pindado et al. 1999). A bonded 4 in. (100 mm) pervious concrete overlay constructed in 2008 at the Minnesota DOT testing facility (MNROAD) performed well with truck traffic and was one of the quietest concrete

pavements in the United States, with on-board sound intensity (OBSI) testing at less than 95 dB (Schaefer et al. 2010; Kevern et al. 2011).

3.3.2 Permeable bases and edge drains—A pervious concrete base drains water that would normally accumulate beneath a pavement. This type of construction helps to reduce pumping of subgrade materials that could lead to the failure of the pavement. In some states, the departments of transportation have created standards for constructing drainable bases and edge drains using pervious concrete. North Dakota, California, Illinois, Oklahoma, and Wisconsin have such standard specifications (Mathis 1990). Pervious concrete in these applications is usually lower strength (1000 psi [7 MPa] or less) and is often used in conjunction with a nonwoven geotextile. A similar system can be used in slope stabilization. The runways beneath Lambert International Airport in St. Louis, MO, USA, are pervious concrete connected to a drainage system (Fig. 3.3.2).



Fig. 3.3.2—Pervious concrete base prior to conventional paving at Lambert International Airport.



Fig. 3.3.3—Pervious concrete shoulder for flood control

3.3.3 Shoulders—Pervious concrete shoulders have been used in France to reduce pumping beneath concrete pavements. In the United States, pervious concrete highway shoulders have been installed in several states, including Nevada, Utah, Missouri, and New York. In New York, pervious concrete shoulders have been used to mitigate areas with flooding problems (Fig. 3.3.3).

3.4—Other applications

3.4.1 Drains—Water and power resource services have used pervious concrete for the construction of permeable drain tiles as well as drains beneath hydraulic structures. The drains relieve uplift pressures and allow groundwater to be drained from beneath sewer pipes.

3.4.2 Greenhouses—The use of pervious concrete as a thermal storage system in greenhouse floors has been investigated by researchers (Monahan 1981; Herod 1981). The floor serves as a storage area as well as a heat exchanger for the solar-heated greenhouse. Pervious concrete has also been used as paving in greenhouse floors to keep water from ponding and to eliminate the growth of weeds while providing a durable, hard surface for moving equipment.

3.4.3 Tennis courts—Pervious concrete has been used extensively for the construction of tennis courts in Europe. Pervious concrete slabs allow water to permeate and then drain through an aggregate base to the edges of the slab.

3.4.4 Noise barriers and building walls—Noises from various traffic sources or occupants of a building can be problematic. Pervious concrete noise barriers and interior walls are sometimes constructed to reduce noise. The open-graded structure tends to absorb and dissipate the sound in the material rather than reflecting it to another location.

3.4.5 Retaining wall and abutment backfill—Pervious concrete is an effective backfill material behind vertical retaining walls, providing resistance to erosion and reducing hydraulic pressure. The Metropolitan Atlanta Rapid Transit Authority (MARTA) has used foamed, pumpable, pervious concrete to mitigate erosion behind rail abutments (Wright 2008).

CHAPTER 4—MATERIALS

4.1—General

Pervious concrete most simply consists of ordinary portland cement, open-graded coarse aggregate, and water. Pervious concrete typically has little or no fine aggregate in the mixture. This combination forms an aggregation of coarse aggregate particles cemented together by a thin layer of hardened cement paste. This configuration produces interconnected voids (typically of sizes in the range of 0.04 to 0.2 in. [1 to 5 mm]) between the coarse aggregate, which allows water to permeate at a much higher rate than conventional concrete. Pervious concrete is considered a special type of highly porous concrete. Another distinction between these two types of porous concrete is based mainly on the void structure. Lightweight aggregate concretes contain large percentages of relatively unconnected voids. Pervious concrete, however, contains high percentages (20 to 35%) of

interconnected voids, which allows for the rapid passage of water through the body of concrete.

4.2—Aggregates for use in pervious concrete

Coarse aggregate for conventional (impervious) concrete meeting gradations specified in ASTM C33/C33M may or may not possess sufficient void space to make a suitable pervious mixture. Bulk density and voids of aggregates should be determined in accordance with ASTM C29/C29M to ensure adequate voids exist to allow the specified cement content while maintaining specified void content. Aggregate gradations used in pervious concrete are open-graded coarse aggregate between the 3/8 in. (9.75 mm) and No. 4 (4.75 mm) sieves. Occasionally, larger 1/2 in. (12 mm) or 3/4 in. (19 mm) aggregates may be used in industrial applications, or finer 1/8 in. (3 mm) aggregates may be used for pedestrian applications. Rounded and crushed aggregates, either normalweight or lightweight, have been used to make pervious concrete. Research has shown the presence or addition of fine aggregate may increase compressive strengths and density but correspondingly reduce the flow rate of water through pervious concrete (Schaefer et al. 2006). Subsequent research and producer experience have shown that if there is sufficient void space in the coarse aggregate skeleton, the addition of 5% fine aggregates (sand) will decrease voids while providing other benefits such as improved resistance to freezing and thawing (Kevern et al. 2008a).

The quality of the aggregate used in pervious concrete is as important as it is in conventional concrete. Flat or elongated particles should be avoided. The narrow-graded coarse aggregate should be hard and clean, and free of coatings such as dust, clay, or other absorbed chemicals that might detrimentally affect the paste/aggregate bond or cement hydration. Aggregate sources with a service record of acceptable performance are preferable. In the absence of a source with an acceptable service record, a combination of tests could be conducted to provide a basis for assessing the suitability of a candidate aggregate for incorporation into a pervious concrete mixture (Kevern et al. 2010). Of primary importance in freezing-and-thawing conditions is to ensure the aggregate possesses soundness consistent with local acceptability. Likewise, comparative testing of similar mixtures with candidate aggregates by ASTM C1747/C1747M will provide an indication of suitability for use.

For unknown aggregate sources, results of tests conducted as per ASTM C33/C33M and ASTM D448 should be reviewed with the input of an experienced pervious mixture design consultant or materials engineer with experience in pervious concrete. Examining samples by an experienced petrographer can identify characteristics such as quality, hardness, absorption, degree of weathering, and the presence of deleterious coatings that could impair the performance of the material in service.

Aggregate moisture at time of mixing is important. The aggregate absorption should be satisfied by conditioning the stockpile as necessary to achieve saturated surface-dry (SSD) condition. Dry aggregates are not a good mixture that lacks adequate workability for placing and compaction.

Overly wet aggregates can contribute to draining of the paste, causing intermittent clogging of the intended void structure.

4.3—Cementitious materials

Portland cement conforming to [ASTM C150/C150M](#), blended cement conforming to [ASTM C595/C595M](#), or hydraulic cement conforming to [ASTM C1157/C1157M](#) is used as the main binder. Supplementary cementitious materials such as fly ash, slag cement, and silica fume can also be used in addition to portland cement and should meet the requirements of [ASTM C618](#), [ASTM C989/C989M](#), and [ASTM C1240](#), respectively. Testing materials in trial batching is strongly recommended to verify that cement-admixture compatibility is not a problem with respect to false setting tendencies and that the setting time, rate of strength development, porosity, and permeability can be achieved to provide the characteristics needed for the anticipated placement and service conditions.

4.4—Water

Water quality for pervious concrete is governed by the same requirements as those for conventional concrete. Pervious concretes should be proportioned with a relatively low water-cementitious materials ratio (w/cm) (typically 0.34 to 0.41) because too much water will lead to drainage of the paste and subsequent clogging of the pore system. Too little water can result in inadequate hydration of the cement and lead to reduced strength, finishing difficulty, and raveling. The addition of water, therefore, must be monitored closely in the field. Further discussion of water quality is found in [ACI 301](#). Recycled water from concrete operations may be usable but only if it meets provisions of [ASTM C94/C94M](#) or [AASHTO M 157](#). In the case where hot water is used, the mixture placement should be observed to verify a lack of rapid or flash setting. Discontinue the use of hot water or halt the placement before workability of the mixture is lost.

4.5—Admixtures

Medium- or high-range water-reducers, meeting the requirements of [ASTM C494/C494M](#), are used to improve dispersion of the cementitious material particles and improve the rheology of pervious concretes at lower w/cm . In those cases where water-reducing admixtures are used, they should meet the requirements of [ASTM C494/C494M](#). Hydration stabilizing and retarding admixtures are used to stabilize and control cement hydration and are frequently preferred when dealing with low- w/cm mixtures, such as pervious concrete. Studies report the use of cement hydration stabilizers as an aid in extending the working time of the mixture. They are especially useful in hot weather applications ([NRMCA 2009](#)). Stabilizing/retarding admixtures can act as lubricants to help discharge concrete from a mixer and can improve handling and in-place performance characteristics. Accelerators should not be used when pervious concretes are placed in cold weather. Viscosity-modifying admixtures (VMAs) are also sometimes added to prevent drain-down. When multiple admixtures are used in a concrete mixture, it is recommended that a trial mixture

placement be conducted to identify any admixture incompatibility and to verify that desired fresh and hardened properties are consistently achievable.

Air-entraining admixtures, meeting the requirements of [ASTM C260/C260M](#), are not commonly used in pervious concretes but can be used in environments susceptible to freezing and thawing. There is no reliable method to quantify the amount of entrained air in a pervious concrete mixture ([Kevern et al. 2009e](#)). Research performed on the resistance to freezing and thawing of pervious concrete mixtures has considered the use of an air-entraining agent ([Neithalath et al. 2005b](#); [Schaefer et al. 2006](#); [Baas 2006](#); [Kevern 2006](#); [Kevern et al. 2008b, 2009e](#)). Although air entrainment cannot be easily measured, it is prudent to include an air-entraining admixture where a placement will be exposed to freezing and thawing. Incorporation of fibers for mixtures exposed to freezing and thawing has shown success in some studies to improve durability in cold climates ([Kevern et al. 2008a](#)). When used, fibers should be proportioned into the mixture from the start, not simply added to an existing mixture, as fibers can significantly change the fresh and hardened properties of the concrete.

The open void structure in pervious concrete allows moisture to rapidly evaporate from the mixture, especially in low humidity or windy conditions. The use of construction specialty chemicals is also reported to be beneficial when windy, drying ambient conditions create high evaporation rates that reduce the window of time when a mixture is most efficiently placed. The use of evaporation retarders may also be useful in this regard. It has been reported that superabsorbent polymer-based internal curing agents (ICAs) can maintain moisture in pervious concrete and provide additional water for a more complete hydration of the cement ([Kevern and Farney 2012](#)). Refer to [ACI 212.3R](#) for more information on ICAs.

CHAPTER 5—PROPERTIES

5.1—General

The various properties of pervious concrete are primarily dependent on its porosity, cementitious material content, water content, compaction level, and aggregate voids. Investigations have been based primarily on laboratory tests, with some data from actual field installations obtained. [ASTM C1688/C1688M](#), [ASTM C1701/C1701M](#), [ASTM C1747/C1747M](#), and [ASTM C1754/C1754M](#) are specifically intended for use on pervious concrete. The specifier should use caution when referencing test methods for pervious concrete that are intended for conventional concrete, aggregate, masonry, asphalt, or other materials. Throughout this section, the [Meininger \(1988\)](#) reference is used because it is the earliest significant reference that showed pervious concrete material properties that are validated consistently across the breadth of later research.

5.2—Permeability

One of the most important features of pervious concrete is its ability to percolate water through the matrix. The

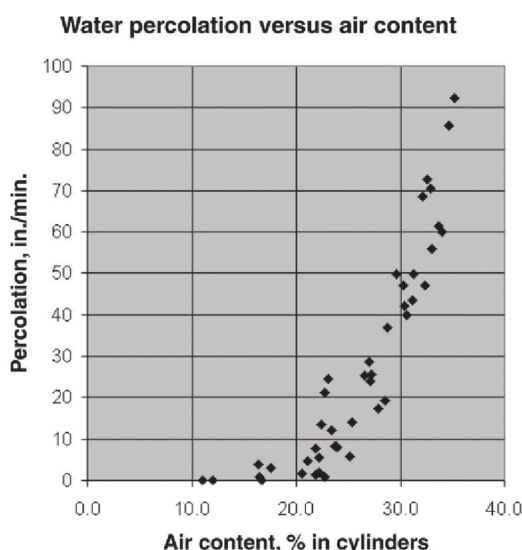


Fig. 5.2a—Relationship between percolation rate and porosity for pervious concrete (Meininger 1988). (Note: 1 psi = 0.069 MPa; 1 in. = 25.4 mm.)

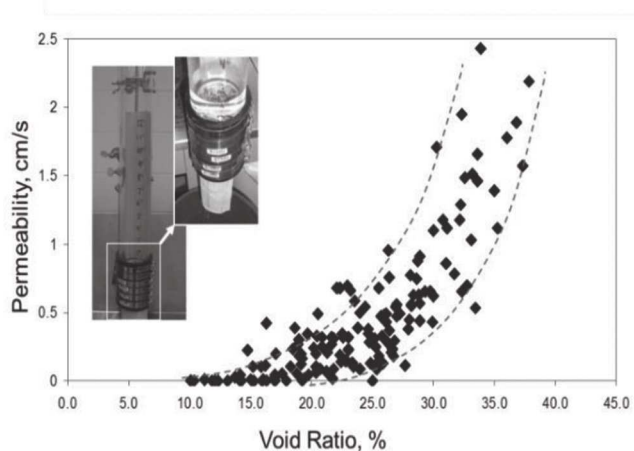


Fig. 5.2b—Influence of voids on permeability of pervious concrete (Kevorn 2006). (Note: 1 cm/s = 0.394 in./s.)

permeability rate of pervious concrete is directly related to the porosity and the pore sizes. Tests have shown (Meininger 1988) that a minimum porosity of approximately 15% is required to achieve significant percolation. For a porosity of 20 to 25%, the coefficient of permeability is reported to be approximately 0.03 ft/s (Brite/Euram Report 1994). Figure 5.2a (Meininger 1988) shows the relationship between the air void content and permeability rate for pervious concrete mixture. Because the permeability increases as air void content increases and, consequently, compressive strength decreases, the challenge in pervious concrete mixture proportioning is achieving a balance between an acceptable permeability and an acceptable compressive strength. Because permeability is not only a function of overall porosity, but pore size as well, permeability can have a great deal of variability at a particular void content controlled by the mixture constituents. Figure 5.2b (Kevorn 2006) shows the relationship between porosity and

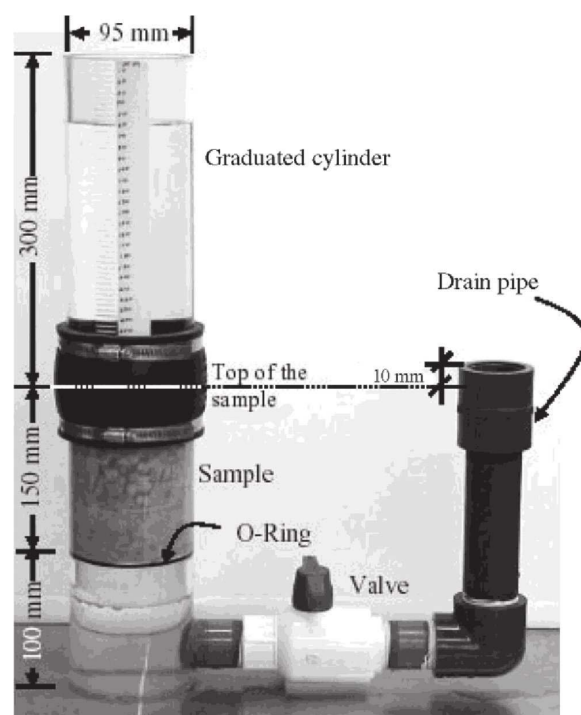


Fig. 5.2c—Apparatus for measuring permeability of pervious concrete by a simple falling-head permeameter (Neithalath et al. 2003). (Note: 1 mm = 0.0394 in.)

permeability for numerous mixtures containing different mixture proportions and mixture components.

The permeability of pervious concrete can be measured by a simple falling-head permeameter as shown in Fig. 5.2c (Neithalath et al. 2003). In this approach, the sample is enclosed in a latex membrane to avoid water flowing along the sides of the specimen. Water is added to the graduated cylinder to fill the specimen cell and the draining pipe. The specimen is preconditioned by allowing water to drain out through the pipe until the level in the graduated cylinder is the same as the top of the drainpipe. This minimizes any air pockets in the specimen and ensures that the specimen is completely saturated. With the valve closed, the graduated cylinder is filled with water. The valve is then opened, and the time in seconds t required for water to fall from an initial head h_1 to a final head h_2 is measured. An initial head h_1 of 10 in. (250 mm) and a final head h_2 of 1 in. (25 mm) have shown to work well in practice. The permeability k (in./s [mm/s]) can be expressed as

$$k = A/t$$

where A is a constant equal to 7.7 in. (192 mm).

A simple triaxial flexible-wall constant-head permeameter has been used to determine the permeability of pervious portland-cement concrete (PCC) in the range of 1 to 14,000 in./h (0.001 to 10 cm/s) (Crouch et al. 2006). Constant-head permeability appears to be a function of paste drain-down, effective air void content, and void size. The results of the falling-head and constant-head methods agree reasonably for laboratory samples.

Apart from the porosity and pore size, a crucial factor that influences the permeability of pervious concrete is the pore tortuosity or the degree of connectivity of the pore network. There is no straightforward methodology to measure the pore connectivity of pervious concrete. Neithalath et al. (2006) investigated the use of electrical impedance-based methods to determine the pore connectivity factor of pervious concretes to link it to the hydraulic characteristics of the material. Additionally, X-ray-computed tomography has been used to accurately determine of pore connectivity in pervious concretes (Kevern 2006).

The environmental benefits of pervious concrete have been well documented. Deo et al. (2008) investigated the efficiency of pervious concrete in retaining vehicular oil spills in its material structure using carefully designed experiments and modeling. Pervious concrete mixtures with porosities ranging from 13 to 25% were proportioned using two different size aggregates. The oil retention and recovery were experimentally determined on 2 in. (50 mm) slices of pervious concrete specimens using a partition gravimetric method. It was observed that a porosity of 20% is ideal for optimal oil retention in the pore structure of the material. An idealized pore-aperture model was used to develop a modeling framework for the oil retention in pervious concrete. The material parameters as well as the input features that are most likely to influence the retention and recovery of oil were identified. A genetic programming-based model was used to predict the oil retention in pervious concrete specimens. This modeling methodology provides good estimates of oil retention. The performance of the genetic programming-based model was judged in terms of its error statistics. Results obtained from this model were more reliable than those obtained using a linear regression method with the same input parameters. The study is expected to lead to further tests on optimization of pore structure of pervious concrete for applications including oil retention and water transport.

5.3—Compressive strength

The compressive strength of pervious concrete is strongly affected by the mixture proportion and compaction effort during placement. Meininger (1988) investigated the relationship between pervious concrete compressive strength and void content. Results are shown in Fig. 5.3a. In this study, the series of laboratory tests was performed on two sizes of coarse aggregate. The compaction effort and aggregate gradation were varied for each size of aggregate. Kevern (2006) investigated the same relationship of pervious concrete compressive strength and void content but used more varied mixture proportions, including various aggregate types, aggregate sizes, aggregate gradations, paste contents, paste compositions, and w/cm (Fig. 5.3b). Fundamentally, both studies show that there is a strong relationship between void content and compressive strength; however, mixtures can be modified to improve compressive strength for a particular void content. Mulligan (2005) also indicates that there is a relationship between pervious concrete compressive strength and unit weight (Fig. 5.3c). Although his study only used one size of coarse aggregate,

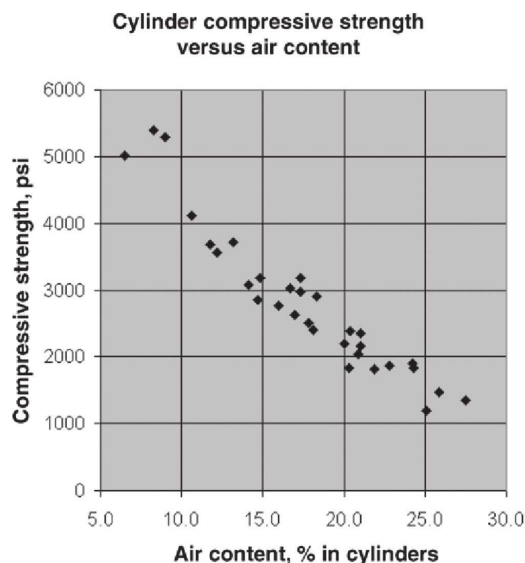


Fig. 5.3a—Relationship between compressive strength and porosity for pervious concrete (Meininger 1988). (Note: 1 psi = 0.0069 MPa.)

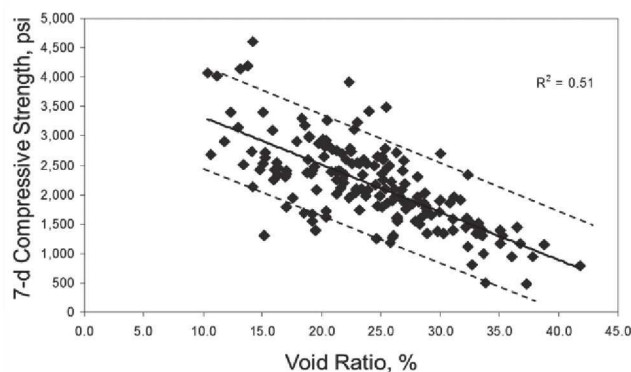


Fig. 5.3b—Relationship between compressive strength and porosity for pervious concrete (Kevern 2006). (Note: 1 psi = 0.0069 MPa.)

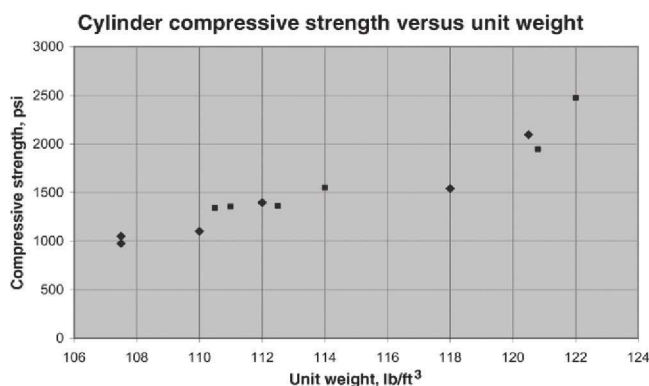


Fig. 5.3c—Relationship between unit weight and compressive strength for pervious concrete (Mulligan 2005). (Note: 1 psi = 0.0069 MPa; 1 lb/ft³ = 16.02 kg/m³.)

the compaction effort and the aggregate-cement ratio were varied. The data of Meininger (1988) indicate that relatively high compressive strength of pervious concrete mixtures

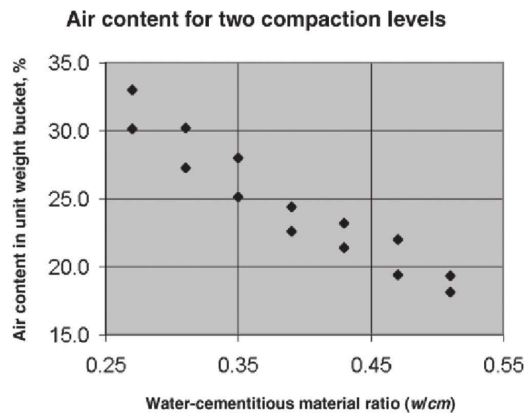


Fig. 5.3d—Relationship between air content (porosity) and w/cm for pervious concrete at two compaction levels (Meininger 1988).

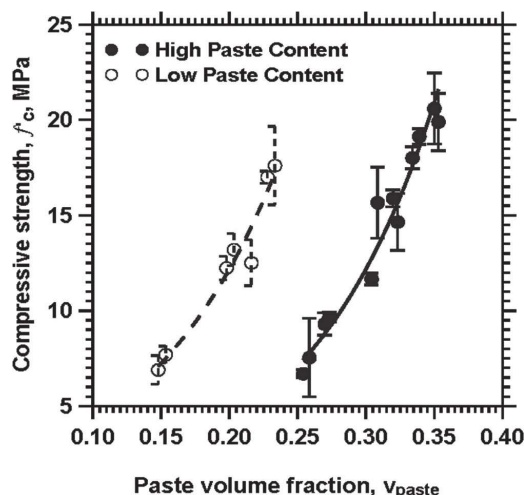


Fig. 5.3e—Relationship between paste volume and compressive strength (Deo and Neithalath 2011). (Note: 1 MPa = 145 psi.)

are possible, but that high strength is achieved only with the reduction of void content (Fig. 5.3a). However, the reduction in air voids results in a loss in percolating efficiency of pervious concrete. Suleiman et al. (2006) reported that an 11% decrease in compressive strength was observed when the vibration amplitude of the compactor is reduced to 0.0034 in. (0.086 mm) from 0.005 in. (0.127 mm). Crouch et al. (2006) reported that an increase in fineness modulus of the aggregates reduces the compressive strength. Mahboub et al. (2008) cautions that field cored strengths can be significantly different than cast test cylinders.

Although the w/cm of a pervious concrete mixture is important for the development of compressive strength and void structure, the relationship between the w/cm and compressive strength of conventional concrete does not apply to pervious concrete. A high w/cm can result in the paste flowing from the aggregate, filling the void structure. A low w/cm can result in reduced adhesion between aggregate particles, resulting in low density and raveling. The relationship between the w/cm and void content of a pervious concrete mixture (with cement and aggregate content held

constant) at two different compaction levels is given in Fig. 5.3d (Meininger 1988). Experience has shown that a w/cm of 0.34 to 0.41 provides good aggregate coating and paste stability. When fine aggregates are used in pervious concrete proportioning, the grain size of the fine aggregate in relation to the coarse aggregate is believed to influence the porosity and, consequently, the compressive strength of the material (Onstenk et al. 1993).

The total cementitious material content and resultant paste content of a pervious concrete mixture are important for the development of compressive strength and void structure. An excessive paste content may result in a filled void structure and, consequently, reduced porosity. An insufficient cementitious material content can result in reduced paste coating of the aggregate and reduced compressive strength. The optimum cementitious material content is strongly dependent on aggregate size and gradation. For the aggregate selected, binder drainage tests are recommended to ascertain the optimum cementitious material content (Nelson and Phillips 1994). In some cases, reduction of the total cementitious material content of the mixture allows the use of increased water content with a resulting increase in workability, without affecting the overall paste content.

Another factor that can have a significant impact on the strength of pervious concrete is the thickness of the paste layer surrounding the aggregate. Paste thickness is related to the aggregate size, cementitious material content, and the w/cm . The paste thickness and aggregate size influence the pore features of pervious concrete and influence strength separately from just porosity. The mean free spacing between the pores was also shown to influence ultimate strengths of pervious concretes (Deo and Neithalath 2010). In a companion study, Deo and Neithalath (2011) found a statistically significant strength-to-porosity relationship irrespective of the total paste contents in the mixtures. Distinct trends relating the paste content to the compressive strength were observed for both the low and high paste contents, as shown in Fig. 5.3e. The effects of relative volumes of aggregates and the compaction effort would need to be considered when paste contents are related to compressive strength of pervious concretes.

5.4—Flexural strength

The relationship between pervious concrete flexural strength and void content based on beam specimens is shown in Fig. 5.4a (Meininger 1988). Although these results are based on a limited number of specimens, comparing the data in Fig. 5.3a and 5.4a indicates that a relationship between the compressive and flexural strengths of pervious concrete exists. This relationship, like compressive strength, depends on several variables. The relationship between compressive and flexural strengths of pervious concrete for one laboratory test series is shown in Fig. 5.4b (Meininger 1988). The addition of a small amount of sand (approximately 5% by volume) increases the flexural strength of pervious concrete (Neithalath 2004). An increase in flexural strength of pervious concrete has been reported when a polymer additive is used (Onstenk et al. 1993). Flexural strength

of approximately 535 psi (3 MPa) has been observed for a pervious concrete proportioned using 1/4 to 3/8 in. (6 to 10 mm) aggregates and having 25% porosity (Nissoux et al. 1993; Brite/Euram Report 1994). The ability to achieve high flexural strengths for pervious concrete was demonstrated by a wearing course overlay, which achieved 900 psi (6.2 MPa) (Schaefer et al. 2011).

Crouch et al. (2006) investigated the relationship between flexural strength f_r and compressive strength f_c' for pervious pavement. They determined that the relationship most closely matches the equation established by Shah and Ahmad (1985) for precast concrete.

$$\begin{aligned} f_r &= 2.3f_c'^{2/3} \quad (\text{in.-lb}) \\ f_r &= 0.083f_c'^{2/3} \quad (\text{SI}) \end{aligned} \quad (5.4)$$

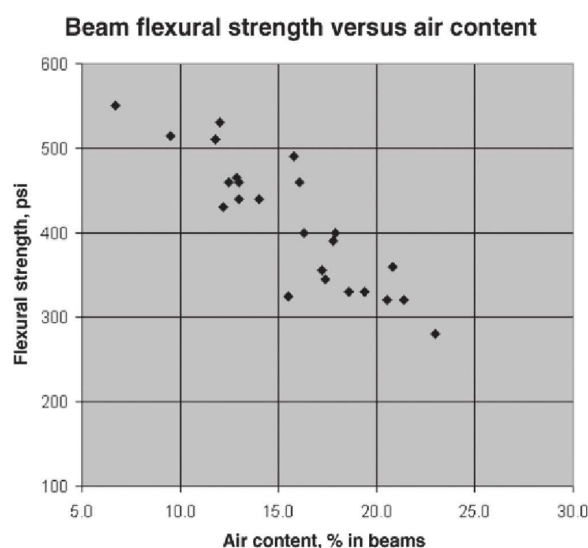


Fig. 5.4a—Relationship between flexural strength and porosity for pervious concrete (Meininger 1988). (Note: 1 psi = 0.0069 MPa.)

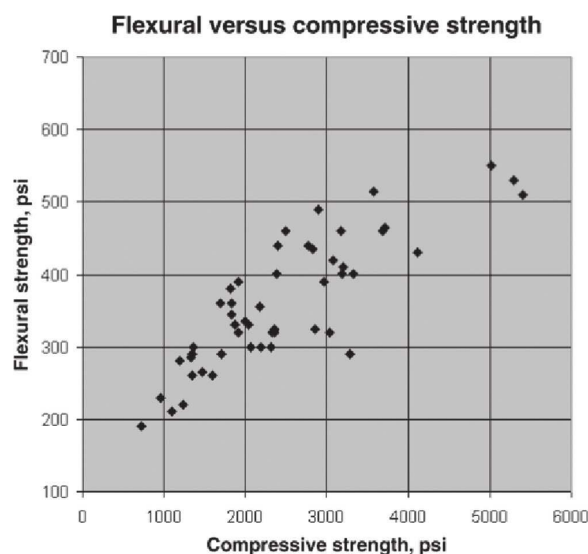


Fig. 5.4b—Relationship between flexural strength and compressive strength for pervious concrete (Meininger 1988). (Note: 1 psi = 0.0069 MPa.)

5.5—Durability under freezing-and-thawing conditions

ACI Concrete Terminology (CT-21) defines durability as “the ability of a material to resist weathering action, chemical attack, abrasion, and other conditions of service.” When possible, it is important to design the system so that the pervious concrete is not saturated when it freezes. Many factors influence this, including strength, porosity, the ratio of impervious to pervious areas, and frequency of maintenance (cleaning). Apart from the porosity and pore size, a crucial factor that influences the flow of water through pervious concrete is the pore tortuosity or the degree of connectivity of the pore network. The mixture factors that have the greatest influence on pervious concrete freezing-and-thawing resistance are air entrainment, including fine aggregate; w/cm ; and aggregate durability (Kevern et al. 2008c, 2010).

5.5.1 Air entrainment—While the pervious concrete system should not be designed to store water in the concrete pore space in climates that are subject to freezing-and-thawing conditions, situations may exist when the pavement is wet and the paste is saturated without having the voids filled. Clogged specimens also have an increased degree of saturation compared to unclogged samples in wet-freeze environments, which increases freezing-and-thawing damage (Guthrie et al. 2010). Consequently, mixtures subject to freezing should be designed for durability to freezing-and-thawing conditions, although testing of fully saturated pervious concretes may be overly severe and may indicate a worst-case scenario. However, the standard laboratory test for evaluating the durability of pervious concretes when subjected to cycles of freezing and thawing is ASTM C666/C666M, Procedure A, where samples are frozen and thawed rapidly in the saturated condition. A slower freezing condition—one cycle per day as compared with five or six per day as stated in ASTM C666/C666M, Procedure A—may allow the water to drain from the pervious concrete, improving results as compared to Procedure B, where the samples are thawed in water (Neithalath et al. 2005b).

Laboratory tests indicate that entraining air in the cement paste improves resistance to cycles of freezing and thawing for pervious concrete (Kevern et al. 2008b, 2009e). In the laboratory under ASTM C666/C666M test conditions, non-air-entrained pervious concrete samples failed (relative dynamic modulus drops to less than 60%) in 100 cycles or less of freezing and thawing in the chamber (ASTM C666/C666M requires a standard 300 cycles for the test). Also, pervious concrete specimens subjected to slow freezing and thawing (one cycle per day) suffered less damage than those subjected to the ASTM C666/C666M Procedure A test, where samples were subjected to five to seven cycles a day (Neithalath et al. 2005b). Another study shows that partially saturated pervious concrete subjected to freezing and thawing in air demonstrated substantially higher durability than those subjected to freezing and thawing while submerged under water (Yang et al. 2006). This suggests the need for routine surface cleaning of pervious concrete to prevent clogging and surface ponding.

5.5.2 Inclusion of fine aggregate or fibers—The addition of small dosages of fine aggregate or synthetic fiber has been reported to increase the freezing-and-thawing resistance (Wang et al. 2006; Kevern 2006; Kevern et al. 2008a, 2015). The fine aggregate increases the cementitious material paste viscosity, allowing a thicker film of paste to surround each aggregate particle. When those aggregate particles come in contact during placement, the contact area between the particles is increased from the thicker paste film, resulting in greater load transfer and higher strength. The angle of incidence between the particles is also reduced, which helps protect against freezing-and-thawing stresses. Fibers help hold the aggregate particles together, retaining more mass and increasing freezing-and-thawing performance.

Macro-synthetic fibers in higher dosages contribute more to pervious durability than micro-synthetic fibers in low dosages. Macro-fibers have shown considerable enhancements to the Mass Durability Factor and Relative Durability Factor in freezing-and-thawing testing of pervious concrete (Kevern et al. 2015). Per ASTM C666/C666M-A research, macrofiber (5.0 lb/yd³ [3 kg/m³], 2.25 in. [57 mm] long) specimens easily survived 300 freezing-and-thawing cycles essentially intact, as compared to plain control specimens that failed completely at 187 cycles (Kevern et al. 2015).

5.5.3 Water-cementitious materials ratio—One additional study (Kevern et al. 2008c) investigated the performance of a single mixture produced at w/cm from 0.25 to 0.32 with admixture dosages held constant to simulate unanticipated water changes that could occur at a construction site. Results indicated that at very low w/cm (0.25, 0.26), the paste was dry, voids were high (28 and 24%), and, consequently, freezing-and-thawing resistance was poor (74 and 95 cycles to failure, respectively). As water was added, the mixture became more workable and the voids were reduced to approximately 16%. The increased workability and water content improved freezing-and-thawing resistance to 300 cycles for w/cm of 0.31 and 0.32. For this set of mixture proportions, paste drain-down occurred above a w/cm of 0.32. As first mentioned in Section 5.2, w/cm trends are different for pervious concrete, and this study showed that a properly wetted paste is more important than a low w/cm for resistance to freezing and thawing.

5.5.4 Aggregate durability—A study performed for the Portland Cement Association (PCA) evaluated the resistance to freezing and thawing of pervious concrete that was produced using coarse aggregate types from different locations in the United States and Canada. Mixtures were produced using the same proportions to evaluate effects of the aggregate. Results indicate that statistically significant factors include specific gravity and absorption. Aggregates with higher specific gravity (an average of 2.64) and lower absorption (an average of 0.82%) had good freezing-and-thawing resistance whereas samples with unacceptable freezing-and-thawing resistance had lower specific gravity (2.57) and higher absorption (2.27%). For a single mixture design, porosity, unit weight, compressive strength, and tensile strength did not correlate to freezing-and-thawing

performance for any of the different aggregates (Kevern et al. 2010).

5.5.5 Application of deicing chemicals—In locations where freezing-and-thawing resistance is a concern, resistance to deicing salts is also a significant deterioration mechanism. Research performed by Cutler et al. (2010) showed that for pervious concrete produced with 50% replacement for cement with Class C fly ash and blast-furnace slag, samples containing a latex-based admixture had much poorer resistance to deicing salts than the mixture without. Calcium chloride produced the greatest deterioration followed by sodium chloride, then calcium-magnesium acetate, and little deterioration was caused by distilled water. Recommendations from the study include avoiding latex-based admixtures and calcium chloride for deicing applications (Cutler et al. 2010). Other studies have demonstrated that magnesium chloride deicer damages concrete materials. This is due to chemical attack on the cement that reduces its binding capacity through the formation of brucite. This reaction occurs at above-freezing temperatures. (Sutter et al. 2008; Sumsion and Guthrie 2013).

Furthermore, field experience and experimental results indicate severe deterioration when deicing chemicals are applied at early ages after installation, and with prolonged heavy use of deicing products. Therefore, deicing products should be avoided as much as possible, particularly in the first year after placement.

5.6—Surface abrasion and raveling resistance

Raveling is a primary deterioration mechanism of pervious concrete, not only affecting the surface appearance and smoothness, but also reducing permeability. ASTM C1747/C1747M measures the mass loss of samples abraded in the Los Angeles (LA) abrasion device for 500 revolutions. ASTM C944/C944M determines surface abrasion through mass loss and depth of wear from weighted dressing wheels abrading the concrete surface at 200 rpm for 2 minutes. ASTM C1747/C1747M is more applicable for evaluating different mixtures (Offenberg 2011), whereas ASTM C944/C944M can determine improvements from curing compounds or surface treatments.

Surface abrasion testing has allowed verification of the most appropriate curing and repair methods. Curing under plastic has been shown more effective than surface-applied curing compounds alone (Kevern et al. 2009b). However, as with other admixtures, samples internally cured using a super-absorbent polymer had better abrasion resistance than a conventional pervious concrete mixture, even under hot and dry conditions (100°F [32°C] and 32% relative humidity). One additional activity investigated techniques to reduce raveling when samples were cured under the same hot and dry conditions. Surface-applied sodium silicate densifier, traditionally used to harden polished concrete floors, was able to reduce raveling by 50% without affecting porosity or permeability (Kevern and Sparks 2013). Both micro-synthetic and macrosynthetic fibers have also shown the ability to significantly reduce raveling when tested using the ASTM C944/C944M method (Kevern et al. 2009b, 2015).

5.7—Fracture toughness

Synthetic fibers can be employed to increase toughness. Toughness can be quantified in one of several test methods, such as [ASTM C1399/C1399M](#). This test produces a post-crack strength value in psi that relates to the flexural strength of the concrete matrix. Product testing of synthetic fibers in beam specimens of pervious concrete in accordance with [ASTM C1399/C1399M](#) demonstrated that fibers 1.5 to 2.0 in. (40 to 50 mm) in length were the most effective in imparting toughness to the concrete ([SI Concrete Systems 2002](#)).

The fracture toughness of pervious concretes, in addition to the use of fiber reinforcement, also depends on the pore structure features. The material fracture parameters—the critical stress intensity factor (K_{IC}) and the critical crack tip opening displacement ($CTOD_c$)—were determined using three-point bend tests on notched beams in a study ([Rehder et al. 2014](#)). Two different porosities (ϕ_d) designed using a particle-packing-based methodology with two different aggregate sizes (and, hence, pore sizes) were used to demonstrate the influence of the pore structure features on fracture toughness ([Rehder et al. 2014](#)). Contrary to conventional concretes, the larger pore size in pervious concretes somewhat inhibits the influence of fibers in enhancing the fracture toughness. This relationship was computationally determined from three-dimensional reconstruction ([Sumanasooriya et al. 2010](#)).

5.8—Acoustic absorption

Due to the presence of a large volume of interconnected pores of considerable sizes in the material, pervious concrete is highly effective in acoustic absorption. The material can be employed to reduce noise generated by tire-pavement interaction on concrete pavements. Noise reduction occurs from a combination of reduced noise generation and increased sound absorption. Pervious pavements alter the generation of noise by minimizing the air pumping between tire and road surface. In addition, pores absorb sound through internal friction between the moving air molecules and the pore walls.

To evaluate the sound absorption characteristics of pervious concrete, an impedance tube can be used as shown in [Fig. 5.8](#) ([Neithalath 2004](#); [Marolf et al. 2004](#)). Cylindrical specimens with a diameter of 3.75 in. (95 mm) can be accommodated in the impedance tube. The sample is placed inside a thin cylindrical polytetrafluoroethylene (PTFE) sleeve, into which it fits snugly. The sample assembly is placed against a rigid backing at one end of the impedance tube, which is equipped with a sound source. A plane acoustic wave is generated by the sound source and propagates along the tube axis. Microphones placed along the tube's length are used to detect the sound wave pressure transmitted to the sample and portion of the wave that is reflected ([ASTM E1050](#)). The pressure reflection coefficient R is the ratio of the pressure of reflected wave to that of incoming wave, at a particular frequency.

The absorption coefficient is a measure of a material's ability to absorb sound. A material with an absorption coefficient of 1.0 indicates a purely absorbing material, whereas

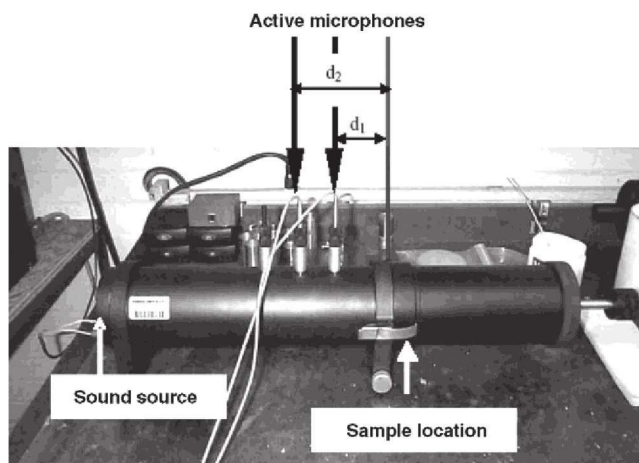


Fig. 5.8—Impedance tube for measuring the sound absorption characteristics of pervious concrete ([Neithalath 2004](#); [Marolf et al. 2004](#)).

a material with an absorption coefficient of 0 indicates the material is purely reflective. Normal concrete, for example, typically has an absorption coefficient of 0.03 to 0.05 ([Neithalath 2004](#)). Pervious concrete typically has an absorption range from 0.1 (for poorly performing mixtures) to nearly 1 (for mixtures with optimal pore volume and sizes). Because the absorption coefficient depends on the frequency of impinging sound waves, it is important to determine the minimum pervious concrete thickness that will minimize sounds of the desired frequency. Values between 800 and 1200 Hz are the most objectionable to the human ear.

In 2008, a pervious concrete overlay was constructed as part of the Federal Highway Administration (FHWA) surface characteristics program to evaluate the potential for pervious concrete to mitigate noise in urban areas. [AASHTO T 360](#) averages leading and trailing edge microphones near a standard tire on a standard vehicle traveling at 60 mph (97 km/h). Using this testing method, pavements with results less than 100 dB are considered quiet pavements ([Schaefer et al. 2011](#)). On-board sound intensity (OBSI) results from the pervious concrete overlay show values between 90 and 96 dB ([Schaefer et al. 2010](#)). Those results show that pervious concrete pavements can be 50 to 100% quieter than current quiet conventional pavements. Complete details are provided in [Schaefer et al. \(2010\)](#).

5.9—Slip and fall prevention

Although intuitively and anecdotally observed to be a more slip-resistant walking surface, prior to a recent study, no empirical evidence existed to characterize pervious concrete as a walking surface with superior slipping properties in comparison to traditional concrete. A unique testing program was developed at the Human Motion Laboratory at the University of Missouri-Kansas City using biomechanical evaluation to investigate pervious concrete's impact on slipping characteristics during gait. The pervious concrete samples tested had 30% voids, high permeability with infiltration rates greater than 100 in./h (10 cm/s). Pervious samples were found to have 45% of the surface

area compared to traditional concrete within a zone for potential shoe contact. Shoe-to-pavement contact pressure for pervious concrete was found to be more than twice that for traditional concrete pavement. The dry pervious concrete pavement also had coefficient of friction two to three times greater than the traditional concrete. When icy, the greatest difference in coefficient of friction between the two surface types occurred between 25 and 30°F (−4 and −1°C), with less slipping occurring on the pervious concrete. The additional contact pressure, coefficient of friction, and reduced potential for ponding water and surface freezing indicated pervious concrete may be a more slip-resistant walking surface in winter conditions (Kevern et al. 2012).

5.10—Urban heat island mitigation

Pavements contribute to the urban heat island (UHI) effect due to their bulk mass and heat absorption capacities. Granular ground surfaces composed of soils or sands do not contribute to the UHI effect in a similar manner. Their porous nature may lessen the effect both with an increased insulating capacity and with an enhanced mechanism for evaporative cooling from absorbed water. Pervious concrete has a network of interconnected voids that allow water exfiltration to the subbase below. Limited studies on pervious concrete indicate that the pervious concrete surface can have elevated temperatures as compared with similar traditional impervious pavements, but that temperatures are lower under the pavements.

Studies have been performed in Iowa, South Carolina, and Washington where both a pervious concrete and a traditional concrete paving system have been installed and temperatures recorded within the systems for extended time periods (Kevern et al. 2009a,c; Haselbach and Gaither 2008). The analyses covered days with negligible antecedent precipitation and high air temperatures—extreme conditions for UHI impacts. Results showed that less energy is stored during heating in pervious concrete systems than the traditional concrete systems. This was using similar cementitious material mixtures for both pavements (similar cement colors) and where, based on previous research, the pervious concrete surface would have a lower solar reflectance and, hence, a higher surface temperature under similar solar radiation conditions.

A strategy for mitigating the UHI effect may be to employ lower energy storage pavement systems. Using pervious concrete systems with their layers of materials with higher porosity than traditional pavement systems may be an effective tool in reducing the UHI effect. Considerations of material characteristics below grade such as porosity are important in determining a permeable pavement's capacity for heat island mitigation. Solar reflectance should not be used independent of these other variables, and pervious concrete pavement is considered a cool pavement solution in the International Green Construction Code (IgCC) regardless of color (Kevern et al. 2009a; ICC IgCC 2021).

5.11—Pollutant removal capacity

Pervious concrete pavement systems have been shown to have high capacity for stormwater pollutant removal. Some

of the removal process is by physical filtration of the particulates in the stormwater, with the pollutants either remaining on the surface or within the system. Examples of pollutants with high removal efficiencies are solids, hydrocarbons, and metals. In addition, there are opportunities within the systems for chemical removal by sorption or ion exchange or, in the case of oils or other hydrocarbons, microbial degradation. This may occur in pervious concrete but has been observed within the underlying system, including the aggregate subbase and soil (Pratt et al. 1999). The pervious concrete layer itself has been shown to have substantial capacity for long-term zinc and copper removal due to the chemistry of the concrete (Ahiablame et al. 2012; Haselbach et al. 2014a; Rushton 2001).

CHAPTER 6—PERVIOUS CONCRETE MIXTURE PROPORTIONING

6.1—General discussion of proportioning

For pervious concrete, the cement factor (coarse aggregate to cementitious materials ratio) and w/cm are the major variables affecting the mechanical characteristics. A wide range of cement factors has been found to be acceptable, depending on the specific application and desired performance. Chemical admixtures, in addition to affecting the w/cm , are used to influence paste content, workability and setting times, enhance various mechanical characteristics of pervious concrete, and improve long-term durability. Currently, there is not a standardized test for strength and strength testing is not appropriate as an acceptance criteria. Durability in terms of resistance to raveling is determined using ASTM C1747/C1747M.

The process of developing mixture proportions for pervious concrete is often repeated through successive iterations. For example, a series of trial batches may be developed in the laboratory and then tested in the field to ensure expected behavior and performance. In general, pervious concrete mixtures are proportioned to achieve a balance among voids, paste content, workability, and durability.

6.2—Proportioning criteria

The optimum water content produces a fully wetted cementitious paste with sufficient viscosity to cover the coarse aggregate particles without the paste draining from coarse aggregate and clogging the pores of the pervious concrete. A fully wetted cementitious paste is often described as having a wet metallic appearance or sheen. For a given set of mixture proportions containing a particular aggregate size, type, and admixture dosages, there is a smaller range of acceptable w/cm than typical for conventional concrete. The cementitious paste creates sufficient bond between the aggregate particles while providing sufficient void volume for the infiltration of water. The w/cm is an important consideration for obtaining the desired durability and void structure in pervious concrete. A high w/cm reduces the adhesion of the paste to the aggregate and causes the paste to flow and fill the voids even when fully mixed. A low w/cm will prevent thorough mixing and tend to cause balling