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Pervious Concrete Parking Lot Project Report

Cloverdale Off-Leash Dog Park

Submitted to:

City of Surrey

Submitted by:

EXL Engineering Inc.

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1.0 INTRODUCTION

1.1 Project Description

In summer 2008, City of Surrey - Parks, Recreation & Culture Department began construction of the *Cloverdale Off-Lease Dog Park*, located at the northwest corner of 188 Street and 70 Avenue in Surrey, BC (Fig 1.1). The park design includes a separate small and large dog area, with separate entrances and green buffers and fencing dividing the two dog areas. The project also includes a parking lot of approximately 1570 m^2 (16,880 ft^2) in size. In an effort to provide "first flush" pollution control and storm water management, the decision was made to utilize **pervious concrete** as the pavement surface for the construction of the parking lot.

Fig. 1.1 – Signage posted near entrance of Clayton Off-Lease Dog Park during construction

1.2 Pervious Concrete

Pervious concrete is a special type of concrete with a high porosity used for concrete applications that allow water from precipitation and other sources to pass through it, thereby reducing the runoff from a site and recharging ground water levels. The high porosity is attained by a highly interconnected void content (Fig. 1.2). Typical pervious concrete, also known as "no-fines concrete," is a zero-slump, open-graded material consisting of Portland cement, coarse aggregate, little or no fine aggregate, admixtures, and water. Pervious concrete is traditionally used in parking areas, areas with light vehicular traffic, pedestrian walkways and greenhouses.

Fig. 1.2 - Pervious concrete pavement for parking lot and sample showing free draining of water

1.3 Advantages of Pervious Concrete

In storm water management applications the key advantage of pervious concrete is that of allowing surface water to easily flow through the pavement structure. Initial storm water runoff can carry a higher concentration of pollutants than runoff that occurs later, after the surface has been washed off by the rain. This part of the runoff with a higher pollutant load is termed the “first flush.” By capturing the first flush of rainfall and allowing it to percolate into the ground, soil chemistry and biology are allowed to “treat” polluted water naturally. Additionally, the filtering actions of the pervious concrete and base course provide some particulate and contaminate removal from storm water.

Impervious pavements—particularly parking lots—collect oil, anti-freeze, and other automobile fluids on the surface which can be washed into streams, lakes, and oceans when it rains. As early as the 1960s, engineers realized that runoff from developed real estate had the potential to pollute surface and groundwater supplies. Pervious concrete pavement reduces the impact of development by reducing runoff rates and protecting water supplies.

The relative high permeability (often in the 100s of inches per hour) provides for almost complete percolation of surface water into the pavement, with little to no resulting runoff from the pavement surfaces. This ability to reduce peak runoff from storm events reduces the need for separate storm water retention ponds and eliminates or at least allows for the use of smaller capacity storm sewers. The caveat in such applications is that the underlying base course and/or the subsurface soils must have sufficient permeability to handle the water flow through the pavement structure.

Pervious concrete paving systems also benefit the environment in other ways. The surface temperature of the pervious concrete is lower than, for example, an asphalt pavement, which reduces the “heat island” effect common in built-up areas. The initial runoff from conventional pavements can be much warmer than the receiving water temperature, raising the overall temperature of the receiving water and causing environmental distress. Pervious concrete can also reduce "black ice" formation, reducing potential slipping hazards, as melting snow drains into the pavement rather than ponding on the surface.

Pervious concrete is considered a Best Management Practice (BMP) by the United States Environmental Protection Agency (EPA), and federally mandated regulations have characterized it as a viable solution for storm water management. It has also been recognized as having the potential to provide a significant contribution to sustainable construction.

Pervious concrete has been used to achieve LEED Green Building certification credits. Leadership in Energy and Environmental Design (LEED) is a point rating system devised by the United States Green Building Council (USGBC) to evaluate the environmental performance of a construction project and encourage market transformation towards sustainable design. The system is credit-based, allowing projects to earn points for environmentally friendly building and design practices. LEED certification is based on the total point score achieved, following an independent review and an audit of selected Credits. There are four levels of certification: certified, silver, gold and platinum.

The Canadian Green Building Council (CaGBC) has adapted the USBBC rating system by tailoring it specifically for Canadian climates, construction practices and regulations. Pervious concrete is eligible for the following LEED points as shown in Table 1.1 below.

LEED Category	Credit	Details	Possible Credit Points	Technology
Sustainable Sites (SS)	6.1	Storm Water Design: Quantity Control - 25% Reduction	1	Pervious Concrete
	6.2	Storm Water Design: Quality Control - Limit Disruption and Pollution of Natural Water Flows	1	Pervious Concrete
	7.1	Heat Island Effect: Non-roof	1	Pervious Concrete [1]
Materials and Resources (MR)	4.1	Recycled Content: 10% (Post-consumer + 1/2 Pre-consumer)	1	Pervious Concrete
	4.2	Recycled Content: 20% (Post-consumer + 1/2 Pre-consumer)	1	
	5.1	Regional Materials: 10% Extracted, Processed & Manufactured Regionally (within 500-mile radius)	1	Pervious Concrete [2]
	5.2	Regional Materials: 20% Extracted, Processed & Manufactured Regionally (within 500-mile radius)	1	
Innovation in Design (ID)	1.1 to 1.4	Innovation in Design: Exemplary Performance	1	Pervious Concrete

(1) All types of concrete can contribute to this credit as concrete is light in color and hence reflects more light and absorbs less heat.
(2) All types of concrete can contribute to these credits as concrete is generally produced from locally available materials.

Table 1.1 – LEED certification credit points eligible with the use of pervious concrete.

2.0 MATERIALS

2.1 General

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 combination of materials used can typically produce a hardened material with connected pores, ranging in size from 2 to 8 mm that allows water to pass through easily. The void content can range from 15 to 35%, with typical compressive strengths of 3 to 25 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 81 to 730 L/min/m^2 (2 to 18 gal. /min/ft^2).

Lafarge Canada Inc. in cooperation with EXL Engineering Inc. developed the pervious concrete mix design for use on the project. The materials selected and mix proportions were developed for the pervious pavement application with locally available materials based on trial batching and with experience on several small demonstration projects throughout 2008. Lafarge supplied the concrete mix, brand named “Ultra Green Pervious” to the project.

2.2 Aggregates

A rounded, single-sized coarse aggregate was used in the pervious concrete mix with a nominal maximum size of 10 mm. The material met the grading requirements as per the CSA Specification for a Group II – 10 to 5 mm coarse aggregate. Rounded aggregate (natural gravel) and angular aggregate (crushed stone) with gradations between 19 and 9.5 mm (¾ and 3/8 in.) can be used to produce pervious concrete.

2.3 Cementitious materials

Normal Portland cement (CSA Type GU) was used in the mix for the project. The use of Type GU cement is typical as the main binder. Fly ash and other supplementary cementitious materials (such as slag cement and silica fume) may also be used.

2.4 Water

The pervious concrete mix was proportioned with a relatively low water-cement ratio (w/c) (0.30 to 0.35) because an excess amount of water can lead to drainage of the paste and subsequent clogging of the pore system. The addition of water, therefore, was monitored closely in the field (Fig. 2.1).

Fig. 2.1 - 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.

2.5 Admixtures

Water-reducing admixtures (high-range or medium range) can be used depending on the water-cement ratio and retarding admixtures are used to stabilize and control cement hydration. Retarding admixtures can also act as lubricants to help discharge concrete from a mixer and can improve handling and in-place performance characteristics.

Viscosity modifying admixture can be used in combination with water reducing and retarding admixtures which may significantly reduced or eliminated most of the previous difficulties experienced placing pervious concrete pavements.

Air-entraining admixtures were specified for use in the pervious concrete to enhance freezing and thawing durability. This is a recommended practice in environments susceptible to freezing and thawing. Although no reliable method exists to quantify the entrained air volume in these materials; laboratory tests of hardened pervious concrete samples show improved freeze-thaw resistance with the addition of air-entraining admixture.

2.6 Material Cost

Approximately 200 m^3 of pervious concrete was supplied to the project at an approximate cost of \$27.00 / m^2 (\$2.50 / ft^2). Material cost included additional charges such as winter heat (hot water), environmental and delivery fuel surcharge. Goods and Services Tax (GST) and Provincial Sales Tax (PST) were extra.

Base material supply and installation of the as-designed gravel base material (see was 3.1 Hydrological Analysis) was completed separately by City of Surrey – Parks, Recreation and Culture and has not been taken into consideration as part of the material cost.

3.0 DESIGN

3.1 General

The material characteristics of the pervious concrete and other elements of the system significantly affect the final design. For instance, the porosity of pervious concrete affects both the hydrological properties (permeability and storage capacity) and the mechanical properties (strength and stiffness) of the pavement system. Pervious concrete used in pavement systems must be designed to support the intended traffic load (axle loads and repetitions) and contribute positively to local storm water management strategies.

The design must specify the appropriate material properties, the appropriate pavement thickness and base coarse thickness (Fig. 3.1). Other design characteristics may include the absence or presence of features such as filter fabric or geotextile reinforcement to meet the hydrological requirements and anticipated traffic loads simultaneously.

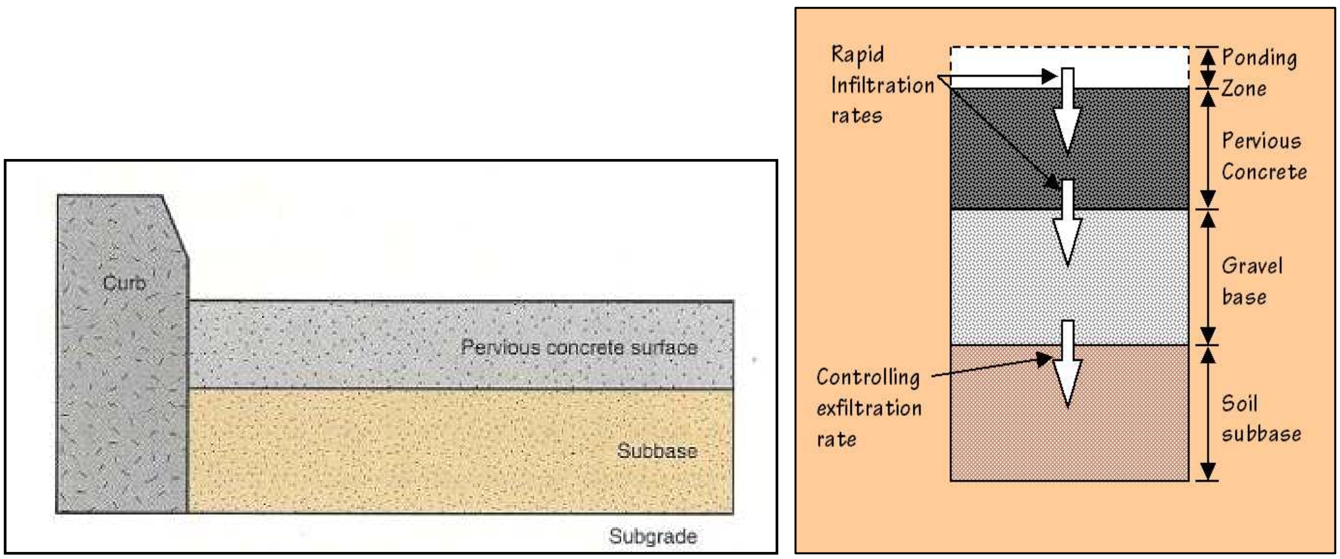

Fig. 3.1 - Example cross-section of a pervious concrete pavement system. Curbs (on both sides) will increase the storage capacity.

3.2 Geotechnical Analysis

Metro Testing Laboratories performed soil percolation (infiltration) tests at five locations over the project site, that is, the amount of precipitation which will soak into the soil for some given rainfall. Upon stripping topsoil layer, the percolation tests were performed at depths ranging from 0.60 to 0.62 m below the original grade in a silty sand layer. Percolation rates recorded in the various percolation test holes are presented in Table 1 below. With the exception of test location P5, the percolation rates are within the industry standard recommended level of less than 120 min / 25 mm (0.5 in. /hour).

Test Location (near test pit locations)	Percolation Rate (min / 25 mm)
P1	23
P2	19
P3	11
P4	65
P5	>120

Table 3.1 – Percolation test results at five locations over the project site

3.3 Hydrological Analysis and Base Design

R.F. Binnie Associates performed hydrological analysis calculations to determine the depth of gravel base which will provide the required storage volume of stormwater for the pervious pavement system during a theoretical 5-year 24 hour rainfall event.

By incorporating a base course (open-graded crushed rock) layer of 250 mm beneath the pervious concrete, the total storage capacity provided by the pavement system is calculated to be 137 m^3 of stormwater. This exceeds the required storage volume of 128 m^3 based on the 5-year 24 hour rainfall event. The design calculations incorporate numerous criteria such as the total surface area of the parking lot, soil and gravel base percolation rates, runoff coefficient, etc. Design calculations including storage volume and infiltration are shown in Appendix A of this report.

4.0 CONSTRUCTION

4.1 General

Construction of the pervious concrete parking lot was accomplished in compliance with project plans and pervious concrete specifications to provide a finished product to meet the expectations of the City of Surrey. Materials design, supply, placement and curing of pervious concrete for the project were based on a project specific pervious concrete specification prepared by EXL Engineering as shown in Appendix B of this report.

As construction of a pervious concrete pavement is quite different from ordinary concrete, it was essential that thorough planning take place. Therefore, several preconstruction meetings were arranged to review plans and specifications. Representatives from City of Surrey, EXL Engineering, Lafarge and Gastaldo Concrete reviewed construction of previously placed test sections and addressed key elements for the project such as:

1. Subgrade and base course preparation
   - Subgrade should be uniform and properly compacted
   - Base course material should be uniform and compacted

2. Concrete mixing water and concrete supply
   - Determining the construction sequence

- Arranging for a realistic delivery rate of concrete
- Arranging for adequate access to the project site for the concrete trucks
- Ensuring the concrete has the correct amount of water

3. Concrete placement
   - Concrete should be compacted and finished without excessive effort
   - Coordinating testing and inspection
   - Demonstrating that the proposed mixture proportions perform as expected

4. Sufficient curing
   - Verifying adequate curing materials and methods
   - Performed in a timely manner and of sufficient duration

4.2 Subgrade and Base Course Preparation

Just like any other pavement system, uniform subgrade compaction is critical for a successful pervious concrete pavement. Further, it is important not to overcompact the subgrade soils. A key design feature of a pervious concrete pavement system is its permeability. The permeability of subgrade soils decreases nonlinearly with increases in density. Thus, if subgrade soils are compacted beyond their design limits, then the infiltration rate of the soil will decrease and the pavement will not drain the desired amount of runoff. Subgrade density was performed over the project site prior to the installation of base course material and was measured between 90 to 95% by modified procotor hammer.

Base coarse thicknesses vary based on the pavement design storm and infiltration rate of the natural soil, although typically six to twelve inches of a highly drainable material is used. The base course consisted of open-graded crushed rock with thickness of approximately 250 mm (10 in.) due to anticipated drainage from surrounding impervious area. As in other types of pavements, truck ruts and other irregularities in the base course material are removed prior to placing (Fig. 4.1).

Fig. 4.1 – Preparation of the base course material. Truck ruts are raked out prior to pervious concrete placement.

4.3 Concrete Mixing Water

The most complicated skill for a pervious concrete inspector or contractor to acquire is judging the proper quantity of mixing water in the fresh pervious concrete. The material is sensitive to minor changes in water content and field adjustment of the fresh mixture is almost always necessary (Fig. 3). Having the proper quantity of water in the concrete is critical because too much water causes the pores to collapse, and too little water prevents proper curing of the concrete, which will lead to a premature surface raveling failure.

Experienced project inspectors and contractors learn to judge the proper water content in the fresh pervious concrete by visual inspection. Key characteristics to note include the presence of open pore space in the compacted concrete and a light sheen from the free water in the concrete. The concrete supplier should take some responsibility in this as well. Drivers should be trained to understand the basics of pervious concrete.

4.4 Placement

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. Strikeoff may be performed mechanically (truss screed or roller screed) or manually (wood straightedge) for small areas.

The equipment used in this project to strike-off and compact the concrete was a hydraulically-driven, roller-screed (Bunyan Screed). During initial demonstration placements, the roller-screed was only somewhat successful due to the lack of weight in the tube and mixes that had been supplied with excessive water content and fines. For use on the project, the improved mix designs and the use of a weighted (sand-filled) roller screed alleviated those problems and produced very flat, tight surface with acceptable void content and virtually no surface raveling.

Upon discharge, the concrete was spread with conventional comealong rakes. Edges near forms were compacted using a 300 mm by 300 mm (1 ft by 1 ft) rubber tamp (like those used in decorative stamped concrete). Roller-screeding compacted the fresh concrete to provide strong bond between the paste and aggregate and creates a smooth riding surface (Fig. 4.2).

Fig. 4.2 – Spreading, strike-off and compaction of the pervious concrete.

To smooth out any flatness deviations and improve ride quality, the fresh concrete was cross-rolled (Fig. 4.3a). Additionally, a hand float and an edging tool were used to further consolidate and prevent ravelling of the edges of the concrete. It is common to see the rollers not compacting sufficiently out at the edges, so the concrete is hand floated to ensure quality all the way up to the form (Fig. 4.3b). Each of these steps was done after the initial rolling, but before jointing.

Jointing pervious concrete pavement follows the same rules as for an unreinforced concrete pavement. Rather than saw cutting, joints in the pervious concrete were tooled with a rolling/jointing tool (Fig. 4.3c). This allows joints to be cut in short time, and allows curing to continue uninterrupted.

Fig. 4.3 – (a) Cross roller to improve surface finish (b) Hand float and an edging tool used to prevent ravelling of the edges

Fig. 4.3 – (c) Jointing tool and finished joint

4.5 Curing

Proper curing is essential to the structural integrity of a pervious concrete pavement. Curing ensures sufficient hydration of the cement paste to provide the necessary strength in the pavement section. Further, insufficient curing will cause the surface to ravel, in extreme cases, to the full depth of the pavement. Therefore, it was specified that curing begin within 20 minutes of concrete placement.

Heavy plastic sheeting (6-mil polyethylene) was used to retain moisture in the pavement mass for curing (Fig. 4.4). The plastic sheeting was cut to a minimum of a full placement width and was secured with reinforcement for the full 7-day curing period.

Fig. 4.4 – Curing with heavy plastic sheeting began immediately and continued for a period of 7-days.

4.6 Construction Cost

Gastaldo Concrete Ltd. supplied labour, equipment and materials to place, finish and cure the pervious concrete pavement for the project. Curing materials included enough 6-mil poly and reinforcement for complete coverage of the parking lot surface area. Construction cost to provide these services was approximately \$15.50 / m^2 (\$1.40 / ft^2) and included post construction clean-up and disposal of waste materials. Goods and Services Tax (GST) was extra.

5.0 INSPECTION AND TESTING

5.1 General

Normal construction inspection practices for conventional concrete that base acceptance on slump, air content and cylinder strengths are not meaningful for pervious concrete. Strength, for instance, is a function of the degree of compaction, and compaction of pervious concrete is difficult to reproduce in cylinders. Further, standard test methods do not yet exist for measuring physical properties of pervious concrete.

Draft test methods are currently being developed by American Society of Testing and Materials (ASTM) and the draft unit weight (density) test method is usually used for quality assurance. As recommended, acceptance would be based on the unit weight of the in-place pavement being within 80 kg/m^3 (5 lb/ft^3) of the design unit weight.

5.2 Engineering Properties

EXL Engineering Inc. provided design support, on-site supervision and inspection, as well as, some quality control and quality assurance testing during the construction of the pervious concrete parking lot. As new testing methods are still being developed, inspection was based on specific mixture proportions known for pervious concrete.

Initially, the pervious concrete as delivered was visually inspected to determine any change in appearance of the fresh mixture and was then tested for unit weight. For each day's placement at least one test was conducted to verify the density of the material. Additional acceptance criterion was based on the completed pavement.

These quality assurance and acceptance tests were based on test cylinders and core samples. Cylinders were cast from fresh pervious concrete (Fig. 5.1) and cores were drilled from the hardened pervious concrete pavement (Fig. 5.2). These samples were measured for thickness and approximate unit weight. They were also used to approximate void content and compressive strength (Table 5.1). Preliminary testing using test cylinders have indicated that porosity of the pervious concrete is between 20 to 22%. Compared to the as-designed void content of 19% this may explain the lower unit weight as measured in the plastic and hardened samples of pervious concrete.

Sample No.	Design Unit Weight (kg/m^3)	Plastic Unit Weight (kg/m^3)	Hardened Unit Weight (kg/m^3)	7-Day Compressive Strength (Mpa)	28-Day Compressive Strength (Mpa)
9880	2124	1931	1856	7.2	8.1
10103	2124	1931	1905	7.3	9.5
9889	2124	1950	1931	10.0	11.0
10104	2124	1950	1964	11.9	12.4

Table 5.1 –Estimated physical properties of pervious concrete based on cylinders cast

Fig. 5.1 – Cylinders were cast for measurement of unit weight, compressive strength and void content.

Fig. 5.2 – Cores were extracted to inspect compaction through pavement depth.

5.3 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.

6.0 CONCLUSIONS

As more and more agencies see this material as a way to meet stormwater management requirements, expectations are to see the use of pervious concrete continue to grow exponentially. Innovations in mix design, placement techniques and design/promotion have fueled this growth, and will be essential for maintaining it.

One of the most important lessons learned during the demonstration placements and the construction of the Clayton Heights Off-Lease Dog Park pervious concrete parking lot is that creating pervious pavements is not as simple as it looks. Concrete, which for centuries has been prized for its impervious qualities, needs understanding and assistance to reverse its natural tendency. Creating a concrete surface with uniformly distributed voids that can pass and store water requires more than just omitting the fine aggregates. A small change in the free water content of a pervious concrete mixture has a large impact on the behavior of the mixture. Without the use of chemical admixtures, a low water-to-cement ratio creates stiff and unworkable mixtures that are difficult to place and compress, which is an essential requirement for load carrying strength. Too high a w/c compromises strength and porosity, which is a desired property for durable pervious concrete. Other variables affecting the results are aggregate type, compactive effort, thickness of slab, both type and thickness of base material, and the use of chemical admixtures.

The use of water reducing admixtures in combination with viscosity modifying admixtures significantly reduced or eliminated most of the previous difficulties experienced placing pervious concrete pavements. Much of the hard physical labour was eliminated and the quality of the finished product was improved. This is a major milestone in facilitating successful placement of quality pervious concrete pavements.

The collaborators are looking forward to building on these important lessons. Future projects will include the use of similar concrete materials, construction techniques and involve more careful observation, testing, and measurements.

7.0 REFERENCES

American Concrete Institute, ACI (2002). ACI 211.3R Guide for Selecting Proportions for No-Slump Concrete

American Concrete Institute, ACI (2006). ACI 522R-06 Pervious Concrete

Canadian Standards Association, CSA (2004). CSA A23.1 / A23.2-04 Concrete materials and Methods of Concrete Construction

National Ready Mixed Concrete Association (NRMCA). (2004). Freeze-Thaw Resistance of Pervious Concrete.

National Ready Mixed Concrete Association, NRMCA. NRMCA #2PPCRT (February 2007). Text reference for Pervious Concrete Contractor Certification

Tennis, P.D., Leming, M.L., and Akers, D.J. (2004). Pervious Concrete Pavements, Special Publication by the Portland Cement Association and the National Ready Mixed Concrete Association.

Tennis, P.D., Leming, M.L., and Akers, D.J. (2007). Hydrologic Design of Pervious Concrete by the Portland Cement Association.

Wang, K., Schaefer, V. R., Kevern, J. T., and Suleiman, M.T. (2006). Development of Mix Proportion for Functional and Durable Pervious Concrete.