Case Studies in Construction Materials 1 (2014) 1–9

Contents lists available at ScienceDirect

Case Studies in Construction Materials

journal homepage: www.elsevier.com/locate/cscm

Case Study

Monitoring in situ performance of pervious concrete in British Columbia—A pilot study[☆]

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ARTICLE INFO

Article history:
Received 25 September 2013
Accepted 3 October 2013
Available online 27 October 2013

Keywords:
Pervious concrete system
No-fines concrete
Raveling
Stormwater management
Sustainability
Asphalt replacement

ABSTRACT

Modern day infrastructure calls for use of impervious surfaces and curb and gutter systems on pavements to rapidly collect and transport rain runoff. Due to this stormwater reaches the receiving water bodies rapidly, in greater volume and carries more pollutants than natural conditions. Porous pavement on parking lots, sidewalks, and driveways provides a solution to this problem. One such material that can be used to produce porous surfaces is pervious concrete. Even though no-fines concrete mix has been used for many years, there are still many outstanding issues related to its structural performance and issues with reduced percolation capacity over time especially when exposed to real conditions. This paper presents a case study describing a project in British Columbia, Canada where 1000 ft^2 of asphalt was replaced with a pervious concrete system. The details of the unique construction technique including details of the material used are described in this paper. On-going tests to monitor the performance of this test slab are also described.

1. Introduction

Stormwater management has become a concern for cities and municipalities due to increased urbanization of residential and commercial neighborhoods. In a built environment with significant amount of impervious surfaces and integration of curb and gutter systems in our pavements, stormwater reaches the receiving water bodies much faster, in greater volume and carries more pollutants. Cities and municipalities along with engineers, researchers and developers are exploring different ways to reduce the impervious surfaces and to deal with stormwater management in a sustainable and environment friendly manner. Porous pavement is found to be an effective measure to mitigate the impact of urbanization on the environment. Without occupying any additional space, porous pavement on parking lots, sidewalks, and driveways provides multiple benefits, i.e. promotes infiltration, reduces peak flows and runoff volume, improves water quality, and reduces thermal pollution, thus helping to maintain our delicate ecological balance and the environment we live in. Using materials that allow water to permeate into the ground helps contribute to the ground water table. One such material that can be used to construct porous pavements and porous urban surfaces is “pervious concrete.” This type of concrete has high permeability and allows rain water to permeate.

According to Sustainable Concrete Canada (2012), the pervious concrete system can have the following impact on the environment: eliminating time consuming and costly storm water detention facilities and underground piping systems, allowing water, air and nutrients to tree roots promoting healthy tree growth without damaging your pavement surface, increasing the quantity of water which can be retained on your site and infiltrate into aquifers thus promoting healthy water

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http://dx.doi.org/10.1016/j.cscm.2013.10.001

levels which sustain our streams and drinking water, eliminating the expense of curbs and gutters, reclaiming valuable property otherwise consumed by stormwater tanks and ponds, preventing harmful hydrocarbons, and other pollutants from reaching our waterways which commonly occur with conventional storm water systems. Pervious concrete is being used for many applications including use as a paving material for parking lots, lightweight structural walls, tennis courts, and greenhouse floors (ACI Committee 522, 2006). Pervious concrete is also known as "no-fines" concrete. Pervious concrete reduces storm water pollution at the source, control storm water runoff, and eliminate or reduce the size of storm sewers (Schokker, 2010). However, there are many issues related to pervious concrete that still need to be further investigated to improve its life and performance during service. Some of the current issues for pervious concrete are as follows.

1.1. Clogging

When small material such as dirt and fine sand are carried by storm water through the pores of pervious concrete, the debris can eventually reduce the effectiveness of the drainage and permeability of the concrete. Such clogging could then lead to flooding and the concrete being susceptible to extensive freeze–thaw cycles (Deo et al., 2010). One issue associated with this is the requirement to maintain the slabs by frequent power washing to unclog the pores.

1.2. Abrasion resistance

As the bonding in pervious concrete is aggregate-to-aggregate rather than the aggregate embedded in a cementitious paste like in regular concrete, pervious concrete has poorer mechanical properties. Pervious concrete is susceptible to abrasion failure caused by the surface course being worn off or crushed under traffic loads (Wu et al., 2011). This phenomenon is sometimes referred to as "raveling."

1.3. Freeze and thaw

When pervious concrete is exposed to cold climates, there is a possibility the concrete would undergo extensive freeze–thaw cycles if the placement was fully saturated. This leads to pressure on the thin cement paste surrounding the aggregates and a loss of durability of the concrete (Kevern et al., 2010).

To study these issues, a project was recently initiated by the author at British Columbia Institute of Technology (BCIT) in Canada. This project involved replacing a section of the asphalt paved surface in a parking lot with pervious concrete. The aim of this project is to determine the feasibility of using pervious concrete on a larger scale, especially as an alternative to using asphalt for paving. The pilot slab is being exposed to real environmental conditions and traffic. The observations and test results from this study will help address above-mentioned issues and determine the feasibility of using larger placements in the future especially when using in regions that are prone to freeze–thaw cycles. In this paper, the procedure used to construct this non-traditional system of pervious concrete as a pavement is discussed and the on-going tests to monitor the performance of the pavements are described. Some of the initial test results are also presented.

2. Construction details

The site is located at the northern area of Parking Lot F at the Burnaby campus of BCIT, Canada (Fig. 1a). The placement size is 24 ft × 40 ft, and covers three parking stalls (794, 795, and 796) and the roadway adjacent to it. The site location was specifically chosen to study the effect of standing traffic, moving traffic, and turning vehicles.

The construction of the concrete slab was completed in three major stages: excavation and asphalt removal, subbase fill, and the concrete placement and curing. The details of each are described below.

2.1. Excavation

The existing asphalt was saw cut to form straight edges and 12 in. deep excavation was done. The soil below the asphalt pavement consisted of sandy soil for the top 6 in., and sandy clay in the lower 6 in. Sets of perforated pipes were placed below lanes 795 and 796 located at west end of the test slab (Fig. 1b). One set was placed at the bottom of the clear crush and one at the bottom of the 6 in. thick pervious concrete slab (Photos 1 and 2). Separate pipes were used at each level under lot 795 and 796 to study the reduction in percolation capacity (if any) by not maintaining (power washing) one section of the pavement. In this study, lot 795 will be maintained and lot 796 will be left unmaintained. A small portion of the ditch north of the placement (outside the test slab) was also excavated to accommodate a water collection system for testing purposes (Photo 3). The perforated pipes were 3 in. in diameter, 7 ft in length, and made from PVC.

2.2. Subbase fill

Once the excavation was complete, 6 in. of fractured clear crush with a maximum aggregate size of ¾ in. was deposited above the subgrade. The fill was then compacted using a vibratory roller and measured to gain a uniform depth of 6 in.

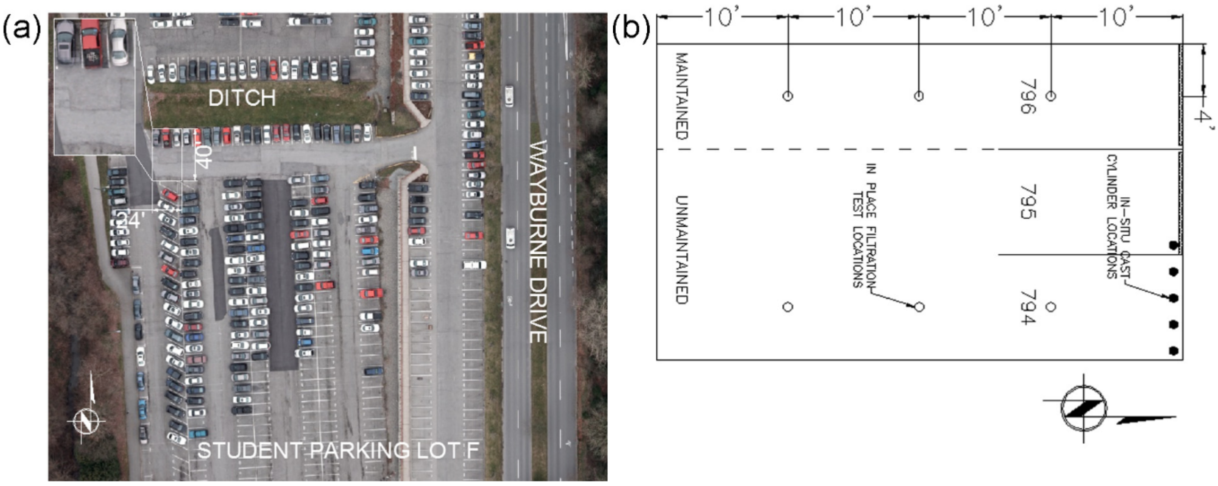

Fig. 1. (a) Site location at BCIT's Burnaby campus (inset – zoomed in view of the test slab). (b) Dimensions of the test slab.

Photo 1. Perforated pipes above the subgrade.

Photo 2. Perforated pipes on top of crush connecting to ABS pipes.

throughout the placement. Photo 4 shows the clear crush being compacted by the vibratory compactor. The background of Photo 4 also shows the simultaneous excavation of soil and the transportation of clear crush from a nearby deposited pile. The clear crush is necessary for pervious concrete as it acts as a storage medium and a filtration system for water passing through the pervious concrete. The crush also acts as a subbase for receiving the pervious concrete layer.

2.3. Concrete placement and curing

The concrete placement was divided into two equal bays as the width of the placement was limited by the length of the roller screed that was approximately 12 ft. Bay 2 was placed after a seven day cure for the first bay. Fig. 1b illustrates the division of the pavement into two bays. A proprietary concrete mix was supplied by the ready-mix supplier. The target properties of the concrete mix reported by the supplier are given in Table 1. In addition to these properties, according to the supplier, this product has a unit weight up to 30% less than conventional concrete and is workable for up to 90 min. The placement was split into two bays to accommodate the roller screed that was used for this project, as the roller screed length

Photo 3. Downstream end of pipes feeding into a collection chamber.

Photo 4. Compaction of clear crush and simultaneous excavation.

Table 1
Target properties of pervious concrete.

Strength (MPa)		Slump (mm)	Nominal MSA (mm)	Void content (%)
Flexural	Compressive			
1.5–3 MPa	15 MPa	150	14	20

of 10 ft approximately matched the width of half the placement, or one bay. The site was prepared by adding minimal formwork to split the placement and to create straight edges along the sides, as cracks occurred in the existing asphalt surface during the excavation process. Photo 5 shows the compacted subbase prior to receiving the concrete placement.

Six inches of pervious concrete was placed on top of the compacted clear crush. The pervious concrete was then immediately leveled using rakes and an aluminum roller screed for consolidation. Photo 6 shows a construction worker leveling the pervious concrete with the roller screed in the foreground. The roller screed is essentially a hollow tube that is

Photo 5. Compacted crush ready to receive pervious concrete.

Photo 6. Roller screed and leveling of pervious concrete.

Photo 7. The second roller giving the desired finish of the concrete.

filled with water for additional weight. The roller screed was approximately 50 pounds empty, and approximately 100 pounds when filled with water.

The estimated speed of rotation of the screed was approximately 250 rpm. A smaller second roller was also used in the transverse direction to get the desired finish and compaction. Photo 7 shows the second roller in operation. The edges of the placement were further lightly compacted by using a flat metal plate. This was done to form a level surface between the existing asphalt and the pervious concrete. This process was also done to create level surfaces between the two placements of the concrete. Once the concrete was placed and consolidated, the concrete was mist sprayed with water before being protected by a thick sheet of polyethylene. This was done in accordance with the CSA A23.1-09 specifications for curing. Photo 8 shows the finished placement with the polyethylene covering the pervious concrete. The second bay of the placement was placed seven days after the initial placement. The inside edge of the concrete was saw cut to provide a smooth

Photo 8. Finished concrete slab (Bay 1) covered with polyethylene sheet.

Photo 9. Pervious concrete cross-section after saw cut.

edge prior to the second placement. Photo 9 shows the cured cross-section of the pervious concrete in Bay 1 (after 7 days of concrete placement). The second placement had similar procedures to the first placement. Once the first concrete placement was cured for 15 days and the second cured for 7 days, saw cuts were carried out. One saw cut was made to reduce the length of the placement to half (20 ft).

2.4. Concrete sample collection

There are no standard test methods that describe molding specimens for compression testing using pervious concrete, however, concrete cylinders were constructed on-site with simulated compaction for further analysis in the lab. For both placements, pervious concrete samples were collected in cylindrical molds, 4 in. in diameter and 8 in. tall. A Marshall hammer used in Asphalt testing was used to compact concrete as per the suggestion of the concrete supplier. Each cylinder was subjected to three blows with a drop of about 6–12 in.

3. On-going research and preliminary results

Even though the recommended curing time is 28 days for this product, the test slab was opened to traffic 7 days after the second bay was placed and 14 days after the first placement. The motivation to do this was to study the effect of opening traffic at an early-age when concrete is not fully cured. Performance of the pervious concrete placement is currently being monitored and some preliminary results available at this time have been described below.

3.1. Material density

Concrete densities were determined using the cylinders constructed during the two concrete placements. These measurements were averaged using a minimum of 3 cylinders. The first placement consisted of two batches, and the average density of the first batch was 1720 kg/m^3, while the second batch was 1740 kg/m^3. On the second placement date, the average density of the cast cylinders was found to be 1720 kg/m^3. These measured values are very consistent and represent a very low batch variability.

3.2. Compressive strength

Specimens were cast on-site using 4 in. concrete cylinder molds and a drop hammer to simulate approximately the energy imparted by the rolling screed on the in-place concrete. Ideally, samples can be cored from the placement, but this was not an option on this project, as closing of the parking lot for extracting samples was not an option. The cylinders prepared on site were left on-site to expose them to the same conditions as the rest of the concrete placement. The average compressive strength after 28 days for the samples was between 3 and 4 MPa.

3.3. Raveling

The pervious concrete placement has been divided into various zones: turning, driving, and parking. Visual observations after 40 weeks of exposure has indicated noticeable wheel travel paths in the vehicle turning zone. The turning zone is expected to experience high stresses and raveling forces from the turning vehicles. The paths appear to have lost between 1 and 3 aggregate layers. In the region of straight vehicle motion a uniform loss of aggregate has occurred and the parking region shows little or no sign of raveling. Photo 10 shows the current state of the pervious concrete placement. The rate of raveling observed during the first two months since placement seems to have reduced over time. As described earlier, one of the factors that may have contributed to early raveling is the fact that the placement was opened to traffic within 7 days and that a full 28 day cure was not allowed. Research is on-going to quantify the extent of raveling by using image analysis and other non-destructive techniques. It should also be noted that the extent of raveling in the turning zones at the moment is not severe enough to make the drive uncomfortable.

3.4. Percolation capacity

In-place filtration rates were measured according to ASTM C1701/C1701M, “Standard Test Method for Infiltration Rate of in Place Pervious Concrete”. This test method determines the field water infiltration rate of in-place pervious concrete. Maintenance of the pilot slab will only be done on a specific side of the slab (40 ft length of stall 796, West side of Bay 1), thus, filtration rate tests results will determine the extent of post maintenance recovery of percolation capacity. The ring used for the percolation test along with the putty during a test is shown in Photo 11. The diameter of the steel ring is 300 mm and a water head of 10–15 mm was used during the test as specified by the ASTM standard. Photo 1(b) shows the locations of the tests conducted so far. The location of each of the tests will remain the same for any future tests to determine the change of

Photo 10. Current state of raveling in pervious concrete after 40 weeks in service.

Photo 11. Ring used for the in-place percolation test.

Photo 12. Run-off being captured by pervious concrete.

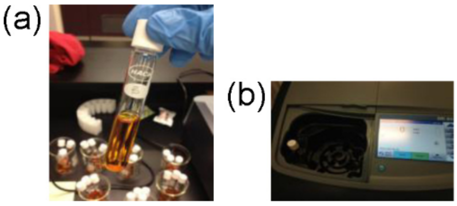

Photo 13. (a and b) Water quality tests underway in the environmental lab.

infiltration rate with time. Frequent tests will occur for each side of the slab to gather results on both maintained and unmaintained areas of the pilot slab.

The average percolation capacity of the placement after 30 weeks of service is still quite high at 60,000 mm/h for most of the slab. The portion of the pavement downstream of the rest of the asphalt parking lot is in direct contact of the surface runoff (shown by arrows in Photo 12). This portion of the pavement receives high sediment load and deleterious substances. Due to this, the percolation capacity in this south side of the pavement is 1500 mm/h which represents more than 95% reduction in the percolation capacity. However, this area represents a very small portion of the total area of the pavement. Moreover, as is evident from Photo 12 during a measured 48 mm/h 15 min storm, the pavement was effective in capturing the entire surface runoff and surface water within 2 ft of coming in contact with the pavement.

3.5. *Quality of infiltrated water*

In the ditch north of the pilot slab, a water collection system was set up to gather the infiltrated water through the four sets of perforated pipes embedded in pervious concrete. Two sets are located at the subgrade of the placement, and the other two sets are located above the 6 in. clear crush as described earlier. The perforated pipes are in distinct locations to collect water differentiated by the maintained and unmaintained areas of the slab. This is done to determine the quality and quantity of water percolating through the pavement. The collected water is controlled by valves for the individual set of pipes. Water from each of the pipes can then be held through a water tank in a pit within the ditch north of the concrete placement. The process of conducting water quality tests is shown in Photo 13(a) and (b). Initial tests indicate a slight reduction in the COD of the infiltrated water when compared to surface runoff entering the pavement. More tests need to be conducted to confirm these findings.

4. Concluding remarks

A case study is presented that describes a 1000 ft^2 pilot placement of pervious concrete in a parking lot that is serving as a non-conventional paving material in an urban environment. A network of embedded perforated pipes is being used to monitor the capacity of the pavement to absorb and detain the rain runoff and its effect on improving quality of permeated runoff. The innovative construction procedure is comparable to conventional construction and a desired finish/texture for a parking lot can be achieved. The lack of an existing technique to manufacture molded specimens for compression testing may have partly contributed to the low measured compressive strength. Higher levels of raveling are observed in the turning zones as compared to the driving and parking zones. The rate of raveling seems to be slowing over time and on-going research involves developing a non-contact technique to quantify raveling. Percolation capacity of the pavement is currently being monitored and even though some parts of the pavement have reduced percolation capacity owing to clogging, the overall capacity of the pavement and its effectiveness in capturing surface runoff remains high. Water samples collected from the embedded pipes when compared to surface run off entering the system have a slightly lower COD. Further tests are underway to confirm these findings.

Acknowledgements

The project described here was primarily funded by the Green Value Strategies Fund awarded to the author at the British Columbia Institute of Technology (BCIT). The author would like to thank the various students involved in this project: Amos Kim, Dustin Erickson, and Shaldon Dutt. The support of BCIT Parking and Security, BCIT Department of Civil Engineering (including Dr. Nazmun Nahar), the Ready mix supplier, and the subcontractors involved in the construction work is greatly appreciated.

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