Third International Conference on Sustainable Construction Materials and Technologies http://www.claisse.info/Proceedings.htm

Non-Traditional Pervious Concrete System to Manage Storm Water Run-off in Urban Neighborhoods: A Pilot Study

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ABSTRACT

In a built environment with significant amount of impervious surfaces and integration of curb and gutter systems in pavements, stormwater reaches the receiving water bodies much faster, 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. A pilot study where 1000 ft^2 of asphalt was replaced with a pervious concrete system was recently initiated by the authors in Canada. The details of such non-traditional construction technique including details of the pervious concrete are described in this paper. On-going tests to monitor the performance of this test slab are also described.

Keywords. Non-traditional pervious concrete system, stormwater management, sustainability, no-fines concrete, raveling

1.0 INTRODUCTION / RESEARCH SIGNIFICANCE

Increased urbanization of residential and commercial neighborhoods over the past many years has altered the natural water balance to the extent that stormwater management has become a concern for the cities and municipalities. 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 than natural conditions. With larger volume of surface runoff, replenishment of groundwater reduces and base flow to the stream also decreases. However, the reality is, urbanization will continue. Thus, 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 and to develop a more environment friendly infrastructure. 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 and reduces the impact on the storm water drains. 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. Use of such material can replace low permeability concrete or asphalt currently used for paving roads, sidewalks and other non-structural components in our urban built environments.

According to Sustainable Concrete Canada (Sustainable Concrete Canada, Ltd.), 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 levels which sustain our streams and drinking water, eliminating the expense of curbs and gutters while making your site more handicap accessible, reclaiming valuable property otherwise consumed by stormwater tanks and ponds, preventing harmful hydrocarbons, heavy metals, and other pollutants from reaching our waterways which commonly occur with conventional storm water systems during heavy or first flush rainfall events, and reducing the heat island effect common with development in urban areas when conventional pavement systems are utilized.

Other than the advantages noted above, there may be a possibility to modify the mix design of this material to allow the use of recycled concrete as aggregate and also to use industrial wastes such as fly-ash or silica fume, which otherwise would be dumped at a landfill. 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 usually "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). Furthermore, the use of pervious concrete can amount to LEED credits. 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:

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, Sumanasooriya and Neithalath, 2010). One issue associated with this is the requirement to maintain the slabs by frequent power washing to unclog the pores. This aspect will also be studied in this on-going project.

Abrasion resistance: As the bonding in pervious concrete is aggregate-to-aggregate rather than the aggregate embedded in a cementitious paste like in regular Portland cement 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, Huang, Shu, and Dong, 2011). This phenomenon is sometimes referred to as “raveling.”

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, Wang, and Schaefer, 2010).

To study these issues, a project was recently initiated by the authors at the British Columbia Institute of Technology in Canada. This project involves 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. As the pilot slab will be exposed to real environmental conditions and traffic, the observations and test results will study these 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.

2.0 SITE DETAILS

The site is located at the northern area of Parking Lot F. The placement size is 24’ x 40’, and will cover three parking stalls and the roadway next to it. The specific stalls chosen for the placement are numbered 794, 795, and 796. Refer to Figure 1 for the exact site location at the Burnaby campus of BCIT, Burnaby, Canada.

Figure 1: Site location at BCIT’s Burnaby campus (with an insert- zoomed in view of the test slab)

The ditch north of the site was also utilized as a space for the water collection system that is integrated within the pervious concrete. The site location was specifically chosen to study the effect of standing traffic, moving traffic, and turning vehicles. The site is also located in an environmentally sensitive area as it is on the upstream side of fish and wildlife inhabited Guichon Creek at BCIT.

2.1 CONSTRUCTION PROCESS

The construction of the concrete slab was completed in three major stages: excavation and asphalt removal, subbase fill, and the concrete placement and curing. Details during each of these stages were recorded and documented to serve as a resource for future monitoring of the test slab and while considering future projects.

2.1.1 Excavation and asphalt removal

In preparation for the excavation at the site, the existing asphalt was saw cut to form straight edges. The site was excavated 12" deep from the top of the asphalt surface. The soil below the pavement consisted of sandy soil for the top 6", and sandy clay in the lower 6". Soild samples were taken for further analysis. A small portion of the ditch north of the placement (outside the test slab) was also excavated to accommodate a water collection system to test the quality and measure the quantity of water percolating through the test slab. Sets of perforated pipes were placed below lanes 795 and 796 (west end of the test slab). One set was placed at the bottom of the clear crush and one at the bottom of the 6" thick pervious concrete slab. Separate pipes were used at each level under lot 795 and 796. The reason to do this is to study the reduction in percolation capacity (if any) of the slab by not maintaining (power washing) one of them. In this study, lot 795 will be maintained and lot 796 will be left unmaintained. These pipes were 3" in diameter, 7' in length, and made from PVC. Photo 2 shows the perforated pipes used.

Photo 1: Pavement cross-section observed during excavation

Photo 2: Perforated pipes used to collect infiltrated water

There were two rows of perforations for each of the pipes. The spacing of the perforations was 6" apart, and the perforations themselves were approximately ½" in diameter. Photo 3 shows the location of the perforated pipes above the excavated area. The perforated pipes were set approximately an inch above clear crush. This was done to prevent any deleterious material from clogging the perforations. The perforated pipes would lead through connections and more pipes to eventually reach a holding tank for the infiltrated water. The connections consisted of PVC elbows and ABS couplings to have 12' long ABS pipes extend downhill to the holding tank. Photo 4 shows a second set of pipes above the clear crush (at the bottom level of pervious concrete). The ABS pipes would then connect to reducers of one inch and a half. These reducers were then connected to ball valves and flexible pipes to control the flow of water to the holding tank. The flexible pipe was comprised of vinyl tubing with an inner diameter of one and a quarter inch.

Photo 3: Perforated pipes above the subgrade

Photo 4: Perforated pipes on top of crush connecting to ABS pipes

2.1.2 Subbase fill

Once the excavation was complete, 6” of fractured clear crush with a maximum aggregate size of ¾” specified from the ready-mix supplier was deposited above the subgrade. The fill was then compacted using a vibratory roller and measured to gain a uniform depth of 6” throughout the placement. Photo 5 shows the clear crush being compacted by the vibratory compactor. The background of Photo 5 also showcases 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.

2.1.3 Concrete placement and curing

The concrete placement was divided into two equal bays. Bay 2 was placed after a seven day cure for the first bay. Figure 2 illustrates the different bays.

Photo 5: Compaction of clear crush and simultaneous excavation

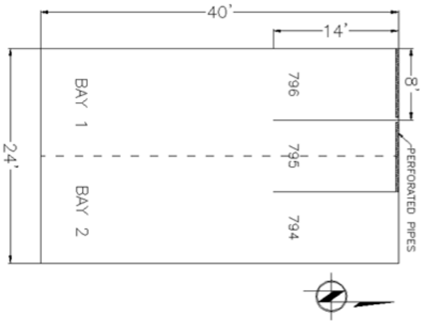

Figure 2: Schematic of Bays 1 and 2

A proprietary concrete mix was supplied by a local ready-mix supplier. The 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 90minutes. The placement was split into two bays to accommodate the roller screed that was used for this project, as the roller screed length of 10' 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 6 is a photo of the site prior to the concrete placement.

Table 1: Target Properties of Pervious Concrete

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

Concrete Placement and Finishing: Six inches of pervious concrete was placed on top of the compacted clear crush by a subcontractor that has experience working with this product. The pervious concrete was then immediately leveled using rakes and an aluminum roller screed for consolidation. Photo 7 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 filled with water for additional weight. The roller screed was approximately 50 pounds empty, and approximately 100 pounds when filled with water.

Photo 6: Site with formwork and compacted crush

Photo 7: Roller screed and leveling

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 8 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 sprayed with a minimal amount of water before being protected by a thick sheet of polyethylene. Photo 9 shows the finished placement with the polyethylene covering the pervious concrete. The polyethylene was held down using sand and smaller rocks to prevent removal of the cover. 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 edge prior to the second placement. Photo 10 shows the cured cross-section of the pervious concrete in Bay 1 (after 7 days of concrete placement). The second placement had identical procedures to the first placement.

Photo 8: The second roller giving the desired finish of the concrete

Photo 9: Finished concrete slab (Bay 1) covered with polyethylene sheet

Photo 10: Pervious concrete cross-section after saw cut

Concrete sample collection: There are no standard test methods that can be readily used to measure the fresh properties of 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 diameter and 8” tall. A Marshall hammer used in Asphalt testing was used to lightly 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 addition, cylindrical molds were placed in the concrete for the second placement. These in-situ molds would provide similar consolidated and curing conditions to the actual placement when compared to cast cylinders.

Concrete curing: Once the first concrete placement was cured for 15 days and the second cured for 7 days, saw cuts were carried out. Photo 11 shows the cured slab with the saw cuts. One saw cut was made to reduce the length of the placement to half (20’).

Photo 11: Cured concrete slab with saw cuts

3.0 RESEARCH INVESTIGATION

Even though the recommended curing time is 28days 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 is to study the effect of opening traffic at an early-age when concrete is not fully cured. The pilot slab will undergo a number of tests to analyze the feasibility of pervious concrete for future use on a larger scale. Such tests are density measurements, percolation rate, in-place filtration of the system, compressive strength, and water quality and quantity.

3.1 Density measurements

Concrete densities were determined using the cylinders constructed during the two concrete placements. These measurements were on an average of 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 placament 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. These measurements were consistent with pervious concrete journals where recorded densities of pervious concrete were 1500 kg/m^3 to 2000 kg/m^3 [2]. Table 2 summarizes these findings.

Table 2: Pervious concrete density results

	Batch #1	Batch #2
Placement 1	1720 kg/m^3 (North side of Bay 1)	1740 kg/m^3
Placement 2	1720 kg/m^3	-

3.2 In-place filtration

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 also only be done on a specific side of the slab (40’ length of stall 796, West side of Bay 1), thus, filtration rate tests results will determine whether maintenance helps retain percolation capacity of the slab. Initial in-place filtration results are listed in Table 3 for the first half of the slab (Bay 1). The ring used for the percolation test along with the putty used during the test in shown in

Photo 12. The diameter of the steel ring is 300mm and a water head of 10-15mm was used during the test as specified by the ASTM standard.

Photo 12: Ring used for the in-place percolation test

Table 3: In-place filtration rate results

TRIAL	PREWET MASS (kg)	DURATION (s)	INFILTRATION RATE (mm/hr)
1	3.60	3.5	49100
2	3.60	3.5	49100
3	3.60	2.9	59200
TRIAL	TEST MASS (kg)	DURATION	INFILTRATION RATE (mm/hr)
1	3.60	3.6	47800
2	3.60	2.7	63700
3	3.60	2.9	59300

The location of each of the tests will remain static for any future tests to determine the change of infiltration rate with time. Tests will occur monthly for each side of the slab to gather results on both maintained and unmaintained areas of the pilot slab. Figure 4 shows the locations of the tests conducted so far. In-situ cast cylinders will also be used to determine percolation rates of the pervious concrete alone (Figure 4).

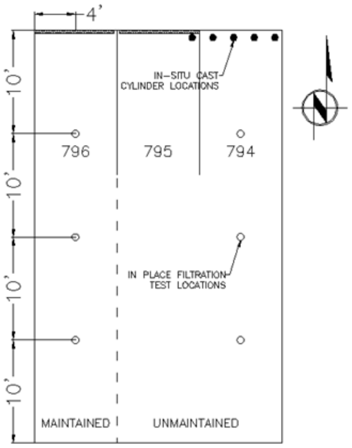

Figure 4: Locations for in-place filtration tests and in-situ molds

3.3 Compressive strength

Compressive strength tests will be performed on the cast cylinders collected during the concrete placements. The tests will occur after the samples have cured for a minimum of 28 days.

3.4 Water quality assessment

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” 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 water quality tests to be performed will be confirmed at a later date.

4.0 FUTURE SCOPE OF RESEARCH

Table 4 lists some of the future tests that have been proposed for monitoring the test slab.

Table 4: Proposed tests

TEST	FREQUENCY
In-place percolation	Monthly
Percolation of in-situ cylinders	Monthly
Compressive strength	Specific curing days
Water quality and quantity	Weather permitting

Other than these tests some of the other aspects that need further investigation are: speed and cost of construction as compared to conventional asphalt, developing a model to predict percolation of the pervious concrete system given the capacities of the various constituents, and developing tests that can be used to evaluate the fresh properties of pervious concrete.

5.0 CONCLUSION

A 1000ft^2 pilot placement of pervious concrete was completed in a parking lot to serve as a non-conventional paving material in an urban environment. The placement width was three stall wide and 40' long in the other direction. A network of embedded perforated pipes will assist in monitoring of the percolation capacity of the pavement and its effect on improving quality of permeated runoff. Initial observations indicate that the construction procedure is comparable to conventional construction and a desired finish/texture for a parking lot can be achieved. Variation in properties, especially density within two different batches seems to be very low. On-going tests include compression testing of cylinders cast during construction and measurement of percolation capacity of the concrete itself. This placement will allow studying the performance of this innovative material under static, moving, and turning traffic. As the testing of the pilot slab is at a young stage, further research and results are required before the determination of the feasibility of using pervious concrete at a larger scale. The current issues of pervious concrete are being investigated, including clogging, abrasion resistance or raveling, and free-thaw durability.

6.0 ACKNOWLEDGEMENTS

Authors would like to thank the following organizations who have helped with this project. BCIT Parking and Security, BCIT Department of Civil Engineering (including Dr. Nazmun Nahar), the Ready mix supplier (name not disclosed at the request of the supplier), BCIT Facilities, and the subcontractors involved in the construction work. The project described here was primarily funded by the Green Value Strategies Fund (GVSF) administered by the School of Construction and the Environment at the British Columbia Institute of Technology (BCIT). Without this support, this project would not be possible.

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