Design and Construction of a Pervious Concrete Pavement

Chris Raymond, Ontario Ministry of Transportation
Becca Lane, Ontario Ministry of Transportation
Maria Bianchin, Ontario Ministry of Transportation
Stephen Senior, Ontario Ministry of Transportation
Melissa Titherington, Ontario Ministry of Transportation

Paper prepared for presentation

at the Introducing Innovation into Pavement Design and Rehabilitation Session

of the 2008 Annual Conference of the
Transportation Association of Canada
Toronto, Ontario

Abstract

The Ontario Ministry of Transportation (MTO) designed and constructed its first pervious concrete pavement in 2007. The pervious concrete pavement serves as a commuter parking lot located adjacent to Highway 401 near Milton, Ontario, approximately 50 km west of Toronto. The final design consists of 240 mm of pervious concrete over 100 mm of open graded clear stone, over 200 mm of granular base material, over select subgrade material, over silty sand subgrade. Pervious concrete pavements provide many environmental benefits and are deemed a stormwater management best practice. These benefits may be offset by concerns with winter durability and the potential for clogging, especially with traditional winter maintenance.

The Contractor elected to use a Bid-Well bridge deck finishing machine for placing the majority of the pervious concrete pavement. A Razorback screed (i.e. air driven steel truss) was used to construct the last section of the pavement. This paper presents the design considerations and summarizes the construction observations and lessons learned. Laboratory performance data for the pervious concrete pavement are also presented along with a description of proposed water quality monitoring.

Introduction

Our built environment continues to expand and building sustainable infrastructure is an important challenge for the 21st century. Pervious concrete pavements are an emerging technology, which can help to reduce the size of our ecological footprint. They offer a functional surface suitable for many applications, including parking lots and walkways, and are more harmonious with the natural environment than traditional impermeable surfaces.

Pervious concrete is typically a zero slump, open graded material consisting of Portland cement, coarse aggregate, little or no fine aggregate, admixtures, and water [1]. The lack of a substantial amount of fine aggregate results in a high void content, typically between 15-25 %. The high void content of pervious concrete and the presence of inter-connected pores provide a free draining pavement layer.

Pervious concrete pavements provide several advantages over conventional impervious hot mix and concrete pavements. One of the key benefits of a free draining pavement is the opportunity to eliminate or reduce the stormwater management requirements for a project. Pervious concrete pavement is recognized by the United States Environmental Protection Agency as a best management practice for stormwater management [2]. Unlike conventional impervious pavements that must be sloped for proper drainage and often require expensive stormwater facilities, pervious concrete pavements allow stormwater to flow through the pavement. Depending on the project design, the stormwater that enters the pervious concrete pavement can be allowed to percolate into the underlying soil, avoiding the need for a retention basin (or stormwater management pond). By allowing water to drain directly into subgrade there is better recharging of the groundwater. The elimination (or reduction) of a stormwater management pond from a project has several benefits including the cost savings from not having to construct and maintain the pond and the elimination of the corresponding property requirements. Further benefits include the elimination of a potential drowning hazard and the elimination of a mosquito-breeding site, which helps to control the spread of the West Nile virus. The elimination or reduction in surface runoff also minimizes the risk of flooding and the presence of standing water. In addition, water is warmed when it flows across a pavement to a catch basin or outlet. Warm water runoff can have significant negative impacts on cold-water streams and rivers. Pervious pavements allow the water to enter directly into the pavement without warming.

Pervious concrete pavements have a number of other environmental benefits. They produce a lower heat island and provide for increased illumination over a hot mix pavement. They are also reported to provide enhanced vegetation growth by allowing a greater amount of water and air through the pavement and into the ground [2]. The environmental benefits above result in pervious concrete pavements being another tool that is available to help us build a more sustainable world in which future generations can live and thrive.

Project Information

The Ministry of Transportation's (MTO) first pervious concrete pavement trial was for the construction of a commuter parking lot along Highway 401 at the Guelph Line Interchange near the town of Milton, Ontario, approximately 50 km west of Toronto as shown in Figure 1.

The contract to construct the commuter parking lot was awarded on July 27th, 2007 as part of a larger project for improvements to the interchange. The prime contractor performed placement of the pervious concrete and underlying granular materials. The material design and supply of the pervious concrete was subcontracted to a large concrete supplier.

Figure 1. Project Location

Pavement Design

The pavement design was based on both a hydrological and structural component. A further consideration was that the project was already designed and tendered as a conventional hot mix pavement design when the opportunity for a pervious concrete pavement presented itself. As a result, the pervious concrete pavement structure was designed with the intent to minimize the extent of changes to profile / elevation. As this was the first pervious pavement design by MTO, the design incorporated conservative assumptions regarding material properties. As MTO's experience develops with the design process and material properties, thinner pavement designs are anticipated.

The hydrological design followed the guidelines of the Pervious Concrete Hydrological Analysis Program software distributed by the Portland Cement Association. The design is based on a 10-year storm with a 24 hour rainfall of 120 mm (4.7 inches). A porosity value of 30 % was used for the granular base material with an exfiltration rate of 1.2 mm/hr (0.05 in/hr). The exfiltration rate was based on the hydrological properties of the native silty sand subgrade material on the project, which was intended to be used as fill. Another design consideration was to ensure that the granular base provided adequate drainage and water storage to prevent undrained water freezing in the pervious concrete layer. The analysis indicated that a 300 mm (12 in) granular base layer was required. Although water freezing in the granular layer is not desirable, it was not practical to extend the granular materials below the frost line. A sandy subgrade and some internal pavement drainage reduce the amount of water available for freezing.

The structural design followed the guidelines of the StreetPave software distributed by the American Concrete Paving Association. The design inputs were based on default values provided in the design software and included a k value of 40 MPa/m (150 psi/in) for the silty sand subgrade, and a composite k value of 60 MPa/m (250 psi/in) when 300 mm of unbound granular material is considered. Other design parameters included a 30 yr design life, 85 % reliability, low traffic, and a flexural strength for the pervious concrete of 1.7 MPa. The required concrete thickness from the software was 217 mm (8.5 inches), which was increased to 240 mm (9.5 inches) to match the top of pavement height of the original hot mix design.

The overall design thickness determined from the hydrological and structural analysis was compatible with the original hot mix pavement design thickness of 90 mm hot mix over 150 mm granular base over 300 mm granular subbase, which required no change to the original subgrade fill height and quantities.

The original design for the hot mix pavement incorporated a French drain (ie. geotextile-wrapped clear stone with a perforated subdrain) immediately below the top of subgrade. Also, the pavement surface, granular layers, and subgrade were sloped to provide lateral drainage of water on the pavement surface or in the pavement layers. These design components were not altered with the change to a pervious pavement design.

Another design consideration that occurred with the pervious concrete pavement was that the project staging was such that cut material from elsewhere on the project intended to be used as fill under the parking lot would not be available. This required imported material to be used as fill. Earth fill is typically used for this application, but to ensure adequate drainage of the subgrade, Select Subgrade Material (SSM), which is essentially a sandy fill material, was specified. This change was intended to prevent clay fill from being placed under the pavement resulting in a reduction in the internal drainage.

During construction, the contractor proposed changing the 300 mm of open granular base material to 100 mm of clear stone over 200 mm of dense graded granular base material due to difficulties in obtaining the open graded base material. The proposal was reviewed with consideration for reduced permeability and storage capacity of the dense graded granular base layer. The proposal was accepted as the select subgrade material incorporated underneath the pavement would allow for adequate drainage of the base material and meet the design objectives for the project.

The final design resulted in 240 mm of pervious concrete, over 100 mm of clear stone, over 200 mm of dense graded granular base, over sandy subgrade material.

Pavement Costs

The costs presented in this paper are based on the average bid price from the three low bidders on the project. The pavement costs represent the pervious concrete material and underlying granular material (excluding the costs for premium fill material discussed below). The cost for supply and construction of pervious concrete material was $154/m^2. This resulted in a cost for pervious concrete material of $289,091 based on a quantity of 1876 square metres. The cost for supply and construction of the intended 300 mm of open graded granular material (Granular O) was $30/tonne resulting in a cost of $83,844 based on a quantity of 2792 tonnes. As mentioned previously in this report, the contractor proposed and MTO accepted a cost neutral change to the granular base materials. When the two costs are combined, the total cost of the pervious pavement is approximately $373,000.

The cost of a comparable conventional hot mix design consisting of 90 mm of hot mix asphalt, over 150 mm of granular base and 300 mm of granular subbase material was estimated to be $152,000.

In addition to the pavement costs mentioned above, 12,029 tonnes of SSM at a cost of $21/tonne was required for the project. Only a portion of this cost can be attributed to the pervious concrete pavement, since fill material would be required regardless of the pavement type. SSM typically has an 8 percent cost premium over conventional fill material in this area of the province, which represents an estimated additional cost of approximately $20,000.

Pervious Concrete Requirements

The pervious concrete specification contained a number of material requirements. The coarse aggregate was required to have a maximum nominal aggregate size less than or equal to 20 mm. Fine aggregate (if used) could not exceed 0.11 m^3 per m^3 of concrete. The allowable total cementitious content range was between 325 kg/m^3 to 425 kg/m^3. The paste was required to be adequately air entrained to provide freeze-thaw resistance.

In terms of construction requirements, the thickness of the hardened core samples could not exceed 13 mm (1/2”) less than the specified design thickness. Cores were required to have a design unit weight of 1680 kg/m^3 to 2080kg/m^3, as determined by ASTM C29, paragraph 11, jigging procedure, and the core density based on ASTM C140 was within 80 kg/m^3 of the design unit weight. The specified void content was between 15 and 25 % based on ASTM C138, Gravimetric Air Determination for plastic concrete and ASTM C140 for hardened concrete. The minimum compressive strength of cores was specified as 15 MPa at 28 days.

Another requirement was certification by the National Ready Mix Concrete Association (NRMCA) verifying that the contractor or sub-contractor placing the pervious concrete had completed the NRMCA Pervious Concrete Contractor Certification Program.

Submitted Mix Design

The pervious concrete mix design submitted for the project was based on a pervious concrete pavement constructed by Dufferin Concrete on June 8, 2007, at their Georgetown Ready Mix Plant. The mix design used a Type GU (Type 10) cement with 25 % slag. The coarse aggregate was a 13.2 mm stone. No fine aggregate was used in the mix design. The mix design also incorporated synthetic fibres and several admixtures including a water reducer, viscosity modifying admixture, retarder, and air entraining agent.

The contractor also provided test results for the pervious concrete indicating an average density of 2034 kg/m^3, a compressive strength at 28 days of 22 MPa, and an average void content of 17 %.

Construction - Trial Slab

Pervious concrete can be supplied and placed in a similar manner to conventional concrete but knowledge of the unique characteristics of pervious concrete is required and past experience with the material is beneficial. Although the contractor had no past experience with pervious concrete, which is currently typical of most contractors in Ontario, the contract did require NRMCA pervious concrete certification and successful completion of a trial slab to demonstrate the contractor’s ability to produce, place, finish and cure the pervious concrete pavement.

The trial slab was constructed on October 10, 2007 at the concrete supplier’s Ready Mix Concrete Plant located in Burlington, Ontario. The contractor opted to use a Bid-Well bridge deck finishing machine as shown in Figure 2, instead of equipment typically used for placement of pervious concrete pavement. The finishing machine was a self-propelled unit with a power screw auger, a vibratory roller, and a rotating cylinder screed. The equipment did not meet the requirements of the contract, which specified that the equipment used for placing, consolidating and finishing the pervious concrete pavement be a vibratory steel screed or steel cylinder screed with integral internal vibration including automatic shut-off, operating on fixed forms. Another requirement was that following strike-off, the concrete be roller-compacted to the form level using a steel pipe roller spanning the width of the section placed, exerting a vertical pressure of 65 kPa to 205 kPa on the concrete, or alternatively, a hydraulically actuated rotating tube screed.

Instead, the contractor proposed to place the pervious concrete slightly higher than the forms and compact it using a steel pipe roller to achieve compaction. However, this was not carried out during construction.

Figure 2. Finishing Equipment

Longitudinal and transverse joints were constructed using a steel roller with a bevelled fin as shown in Figure 3. During the jointing process, it was observed that this equipment could not produce clean vertical cuts. Coarse aggregate was plucked up during the operation making it difficult to roll the equipment and to produce clean vertical lines. Also the contractor's decision to place the pervious concrete in 10 metre wide strips with a single longitudinal joint resulted in a wide slab, which created challenges for maneuvering the roller. Another observation from rolling the joints in the plastic concrete was that the process inhibited the timely placement of the plastic moisture barrier for curing.

During placement, the consistency of the concrete was found to vary between loads. Each load of concrete was visually inspected and adjustments were made accordingly. During construction of the trial slab, testing of the plastic concrete was determined by rodding of the concrete in three layers rather than by the specified jigging method. Air void testing was not carried out. Test results of the hardened pervious concrete were as follows:

1. The thickness of the pervious concrete exceeded the specified 240 mm and in some cases was as high as approximately 300 mm.
2. Cores for voids were extracted from a random location and were found to have an average void content of 15.6 % based on ASTM C140, which is close to the lower limit of 15 %.
3. Compressive strength at 8 days averaged 10.89 MPa, which raised concerns that the 15 MPa strength requirement at 28 days would not be met.

4. The average density was 2201.8 kg/m^3, which exceeded the design unit weight by more than 80 kg/m^3. Density of the hardened concrete failed to meet the requirements for production.


Figure 3. Transverse Joint Rolling (Trial Slab)

A visual assessment of the trial slab was carried out 7 days after the concrete placement. The surface of the pervious concrete appeared to be in excellent condition with the exception of the joints, which exhibited slight ravelling. A visual assessment of permeability based on water drainage was performed in a number of areas by pouring water on the pavement as shown in Figure 4, with all areas draining freely except for one location where water ponded. The area of water ponding corresponded to the location where a visually wet load of concrete was placed.

Based on observations and test results, the trial slab was not accepted by the MTO. The contractor requested permission to place pervious concrete at the parking lot and the request was accepted with the condition that the material placed would be considered as a second trial slab subject to removal at no cost to MTO.


Figure 4. Visual Assessment of Permeability (Trial Slab)

Construction – Parking Lot

Placement of the pervious concrete at the commuter parking lot was carried out over four days: October 25, November 1, 2 and 7, 2007. All the placements occurred during cold weather (i.e. when the air temperature is at or below 5 degrees Celsius or likely to fall below 5 degrees Celsius within 96 hours). The first three sections each measuring approximately 10 m in width by 60 m in length, were constructed using a Bid-Well bridge deck finishing machine which was supported by either fixed forms, pervious concrete pavement, or curb and gutter. The fourth section, located at the entrance of the parking lot and stretching 30 m across the front of the other 3 sections, was constructed using a Razorback steel screed.

Concrete trucks drove directly on the clear stone material to place the concrete in front of the Bid-Well machine during the construction of first 3 sections. In doing so, the granular base layers were disturbed and ruts were created. Due to the orientation of the fourth section, a backhoe was used to place concrete in front of the Razorback instead of directly from concrete trucks, leaving the granular base undisturbed. To prevent moisture loss from the pervious concrete, the subgrade was pre-wetted in front of the placing operation.

The consistency of the fresh concrete varied throughout the construction of the parking lot and also within loads of concrete. Adjustments to the pervious concrete were made throughout each day's production at the concrete plant along with slight adjustments to the water content at the jobsite to achieve proper consistency. The concrete supplier, who was present during all four placements, along with the contractor, visually inspected each of the loads for consistency. Two of the loads were rejected before discharge of their load, and many other loads were rejected at the end of the load for being too wet based on a visual assessment.

The unit weight of the plastic concrete was not determined by the specified jigging method, but was modified by the contractor as follows: three lifts of concrete were equally placed in the bowl, the sides of the bowl were tapped with a mallet 10 times during each lift, the bowl was weighed and the unit weight calculated. The average unit weight of each lot was as follows: Section 1 - 1974 kg/m^3, Section 2 - 2005 kg/m^3, Section 3 - 2008 kg/m^3 and Section 4 - 1996 kg/m^3. For some loads, a comparison of unit weights was carried out using the modified, jigging and rodding methods. The results of the jigging and rodding methods were within 8 kg/m^3 of each other but significantly higher than the modified method.

Placement of the pervious concrete was carried out with minimal delays. Concrete was evenly placed in front of the finishing equipment and struck-off to final elevation. Edges were compacted by tamping to prevent ravelling. A small hand roller was utilized only in Section 4. Joints were installed at 5 m intervals. Although the special provision required the joints to be rolled into the pervious concrete during the plastic state, it was decided half-way through placement of Section 1 to discontinue this method and install the remaining joints using a dry saw cutting process (to a depth of one third the slab thickness), which involved immediately blowing the dust from the sawing operation off the pavement. Curing was drastically improved by the elimination of the jointing operation during placement and followed within a couple of metres of the finishing operation. Cold weather protection was installed at the end of each day and remained in place for 7 days. Over the course of the project, it was determined that the saw cutting of joints could be delayed until the end of the 7 day cure period without the occurrence of random shrinkage cracking.

Testing for Void Content

Test method ASTM C140 [3] was initially specified for testing of void content for the pervious concrete material. Early on in the project it was recognized that the ASTM C140 test method may not provide the best measure of void content and other available methods should be investigated further. To examine the issue with measurement, testing of pervious concrete cores for unit weight (density) and void content (porosity) was conducted using three different test methods. As all of the procedures were non-destructive, the same specimens were tested using all three methodologies.

Density is determined as the mass per unit volume and may be calculated as 'bulk density' (Gmb), i.e., the average density of the entire core, including all voids, or as 'apparent density' (Gmm), i.e., the maximum density of the solid component (excluding voids).

The volume of a core (bulk volume) can be calculated directly as the volume of a regular solid (cylinder), provided the ends are trimmed by saw cutting perpendicular to the core axis. Alternatively, the volume of an irregular solid may be determined by water displacement or buoyancy. In this case, the measured volume is equivalent to the apparent weight loss of an object when submerged in a liquid (Archimedes' principle). Submersion in a liquid (typically water) may also be used to determine the bulk density or the apparent density of a core, depending on its condition. If a core sample is placed directly in the water and allowed to saturate, the apparent density is measured (only water permeable voids are taken into account). If a core is sealed to prevent water infiltration into the pores, the bulk density can be determined.

The methods used during the investigation of the pervious concrete project included water submersion and saturated surface dry determination using ASTM C140/ASTM C642 [3], direct determination of porosity by measurement of water volume intake using MTO LS-627 [4], and water immersion/vacuum sealing using ASTM D6857/ASTM D6752 [5].

The original specification for the project referenced ASTM C140 paragraph 8.3.1, as the procedure for obtaining saturated and oven dry weights of each specimen. For this procedure, as-received cores were weighed and submerged in water for 24 hours. Each specimen was then weighed in water to obtain the immersed weight (W_i). Specimens were then removed and allowed to drain for 1 minute before obtaining the surface dry saturated weight (W_s). An oven dry weight (W_d) was then obtained after drying to constant mass. Bulk density of the core (g/cm^3) was calculated as follows: Gmb = $[W_d/(W_s-W_i)]$. Further to this, calculations from ASTM C642 were applied to determine void content and apparent density (Gmm). ASTM C642 was not included in the specification documents, but was applied later as a means of using data from the 24 h submersion conducted in ASTM C140. Results are shown in Figure 5.

A second method for determining bulk density and void content, MTO test method LS-627 was completed on the same permeable concrete cores as tested under ASTM C140. LS-627 uses equipment borrowed from the Iowa Pore Index Test, which consists of a modified concrete air meter so as to obtain information on aggregate pore size distribution as it relates to freeze-thaw durability and D-line cracking of concrete pavements [6]. The apparatus allows for the direct measurement of water volume required to fill the open, permeable pores in a pervious concrete core, thus allowing the porosity (void content) of the test specimen to be determined. Also the core ends were trimmed by saw cutting to obtain bulk volume by direct measurement of the cores's height and diameter. The sample was then oven dried to obtain its dry mass. These values were used in subsequent calculations for bulk density and apparent density. For this procedure, the prepared core is placed in the Pore Index apparatus, which is filled with water up to a predetermined level. The system is then pressurized to increase the level of saturation of the permeable pores. The porosity (n) of the specimen is calculated as follows with test results shown in Figure 5.

$n = [V_c + V_a - V_t)]/ V_c$, where:

V_c = Volume of core (by direct measurement)
V_a = Volume of water added
V_t = Total volume of the empty system (predetermined, constant).

The third test method for determining porosity of the cores samples utilized the existing technology of the CoreLok® system that uses a 1.25 hp vacuum pump and specially design plastic polymer bag to seal samples while they are under near absolute vacuum. This apparatus was specifically designed to provide an accurate method for measuring densities of open, permeable materials and has been incorporated into ASTM procedures ASTM D6857 and ASTM D6752 for bituminous paving mixtures. Methods for determining sample porosity followed those given in the CoreLok® Operator's Guide. For this procedure, oven dried specimens are weighed in air, vacuum sealed and submerged in water. The mass of the submerged sample is recorded to obtain the bulk volume (including voids). The polymer bag is then opened under water to allow the sample to saturate. Since the sample is originally under vacuum, a high degree of saturation is achieved. Once the saturation is complete, it is weighed once more, thus obtaining a measurement of the void content and apparent density of the specimen. Test results are shown in Figure 6 and Figure 7.

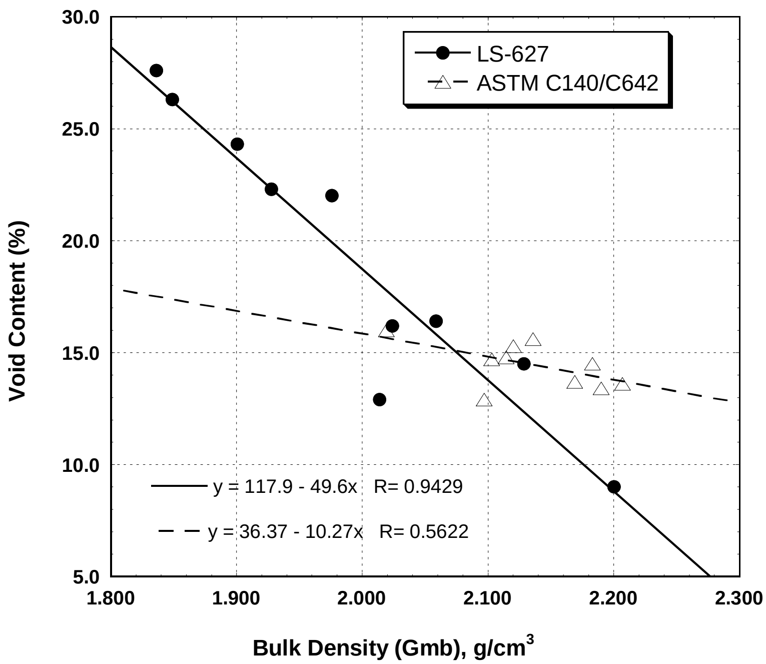

Figure 5. Comparison of MTO LS-627 and ASTM C140/C642 Test Results for Bulk Density and Void Content for Pervious Concrete

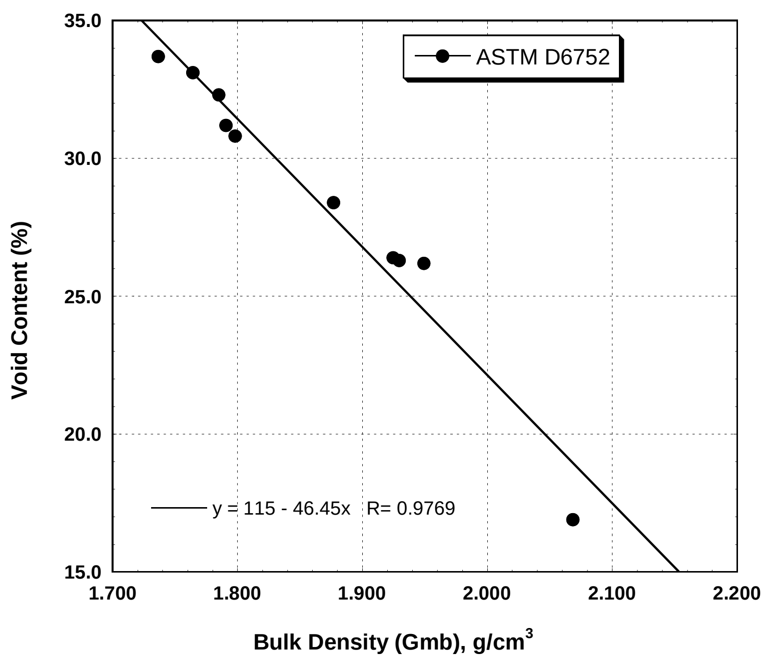

Figure 6. Plot of Void Content and Bulk Density of Pervious Concrete as Determined Using Vacuum Sealing Method ASTM D6752

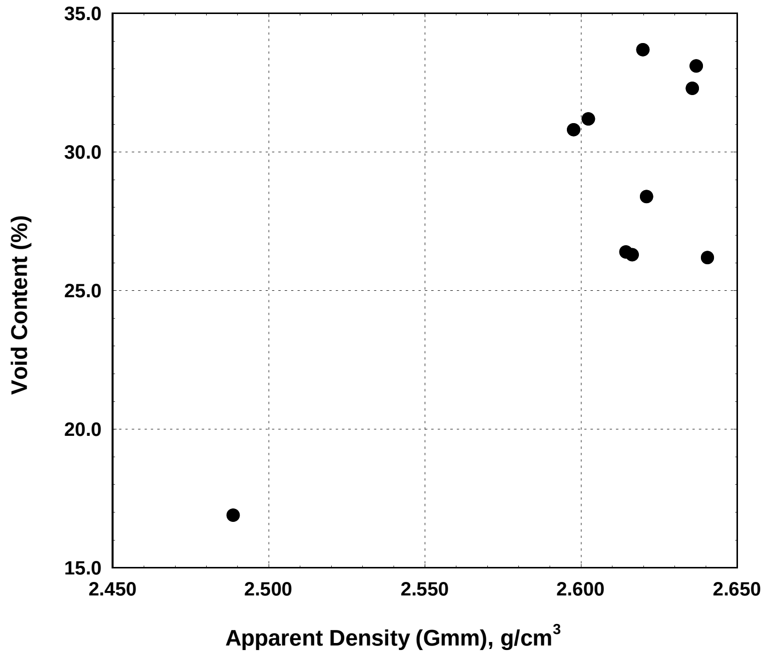

Figure 7. Plot of Void Content and Apparent Density of Pervious Concrete as Determined Using Vacuum Sealing Method ASTM D6857

Of all the methods used, the procedure referenced in the specification (i.e. ASTM C140) yielded the most unreliable results. The most significant drawback of ASTM C140 is that saturated surface dry (SSD) conditions are not achievable with rapidly draining materials such as pervious concrete. Thus errors in density determinations and subsequent errors in void content resulted.

The two alternative methods, direct porosity and vacuum sealing proved much more reliable. Both methods reveal the fundamental relationship between the bulk density and porosity. However, differences between the two data sets are apparent. LS-627 determined much lower porosities, and slightly higher densities, which is most likely a result of incomplete saturation of the sample due to incompressibility of entrapped air within the inner pores of the specimen. Saturation under vacuum conditions is a much more effective method of ensuring all permeable pores of the specimen have been filled with water.

Of the three test methods, both MTO LS-627 and the CoreLok® apparatus (i.e. ASTM D6752/D6857), gave consistent results and would be more effective as a specification than ASTM C140. Test results compared very well with actual sample conditions and confirmed the range in expected values. Some specimens clearly lacked sufficient voids while others were openly porous. Acceptance requirements would vary, depending on which method would be included in the project specifications. Specific requirements should be correlated with field performance tests.

Quality Assurance Testing

The acceptance criteria for the pervious concrete pavement was based on thickness, compressive strength, density and void content. Testing was carried out on cores extracted from the pervious concrete to ensure samples reflected the placement methods used and the consistency of concrete. A total of six 100 mm diameter cores and one 150 mm core were extracted, full depth, from each of the sections and delivered to MTO for testing. The results of the tests were as follows:

1. Thickness – All of the thicknesses measurements exceeded the specified 240 mm requirement.
2. Compressive Strength at 28 Days – The compressive strength failed to meet the specified 15 MPa at 28 days. The strengths ranged from 6.10 MPa to 17.38 MPa. The average compressive strengths of each of the sections were as follows: Trial = 11.89 MPa; Section 1 = 11.96 MPa; Section 2 = 13.71 MPa; Section 3 = 8.30 MPa; and Section 4 = 10.41 MPa.
3. Density and Void Content – The density and void testing was carried out on the top and bottom portion of the cores. The results are summarized in Table 1. It was observed, from the visual examination of the cores, that the concrete was not consistent throughout the cores. Larger voids were evident in the bottom portion of the cores. The majority of the cores were denser at the top. One of the cores, located in Section 4, was plugged in the bottom portion, as a result of rejectable material being incorporated into the work.

Table 1: Pervious Concrete Density and Void Results

Section	Core Size	Core Section	Density (kg/m^3)	Voids (%)	Average Voids (%)
1	Large	Top	1720	35.3%	32.7%
		Bottom	1830	30.2%	
2	Large	Top	2007	23.6%	28.0%
		Middle	1897	28.3%	
		Bottom	1793	32.1%	
3	Large	Top	2005	24.5%	26.8%
		Bottom	1888	29.1%	
4	Large	Top	1899	28.8%	30.9%
		Bottom	1791	33.0%	
1	Small	Top	1973	25.7%	27.7%
		Bottom	1867	29.8%	
2	Small	Top	1988	25.4%	27.5%
		Bottom	1882	29.5%	
3	Small	Top	1979	26.1%	29.1%
		Bottom	1822	32.2%	
4	Small	Top	1964	26.4%	27.9%
		Bottom	1883	29.5%	

Post Construction Inspection

A post construction inspection of the commuter parking lot was carried out on January 4, 2008. The pervious concrete in Sections 1, 2, and 3 was exhibiting raveling throughout with the most severe raveling occurring in Section 2. The northern part of the parking lot in each of the three sections had a few loose aggregates on the surface. Progressing southerly towards the entrance area, the amount of loose aggregate increased. The most severe areas were located in the traveled portions of the parking lot especially where vehicles are turning into the parking spots as shown in Figure 8. In the most severely raveled areas, joints are difficult to identify. Section 4, which was constructed using a Razorback, did not exhibit any raveling. The surface appeared to be consistent throughout, with some areas not meeting the surface tolerance. Contamination was evident in some areas of the parking lot; mainly from sawdust, granular, asphalt and oil spills.

Figure 8. Areas of Severe Raveling

Water Quality Monitoring

Water quality monitoring of the project will be led by the Centre for Pavement And Transportation Technology (CPATT) at the University of Waterloo. The goal of water quality monitoring is to determine if the pervious concrete system is a true filtration system by comparing rainfall quality to the stormwater quality after filtration through the pavement. To accomplish this goal, a YSI 600XLM multiparameter water quality sonde and a HACH Sigma SD900 portable sampler are planned for installation in early 2008. The sonde will measure water pH, temperature, and conductivity. The portable sampler will retrieve water samples that will be tested for common variables related to general chemistry, nutrients, bacteria, metals and polycyclic aromatic hydrocarbons. These tests will identify the majority of contaminates found in runoff from parking lots. Weather information will also be gathered from MTO's Remote Weather Information System (RWIS).

Recommendations

The authors provide the following recommendations based on their experiences related to this project:

1. Proper control on batching of all of the ingredients is necessary to ensure structural adequacy, hydraulic performance and minimum clogging potential of the pervious concrete.
2. Supporting documentation used to verify compliance of the pervious concrete mix should be based on the same mix, utilizing the same placement techniques.
3. Acceptance based on cylinders should not be permitted.
4. Testing of plastic concrete needs to be further evaluated to determine more suitable acceptance criteria that addresses variability within each load.
5. Each load of concrete needs to be tested for acceptance.
6. Pervious concrete not meeting the acceptance requirements needs to be removed completely from the work.
7. Compaction of the pervious pavement is required through the use of a steel pipe roller. This will reduce the occurrence of surface ravelling.
8. Bridge deck finishing machines should not be used without a separate compaction operation.
9. Due to the rapid hardening and high evaporation rate, a maximum time limit should be specified for the completion of consolidation from the time of placement (e.g. 15 minutes).
10. Curing should commence immediately behind the finishing equipment. If joints are installed in the plastic pervious concrete, a maximum time limit should be specified from the time the concrete is deposited into the work (e.g. 20 minutes).
11. Additional requirements should be added to prevent the placement of the pervious concrete during weather conditions that may adversely affect the quality of the work. High ambient temperatures and windy conditions should be taken into account.
12. Installation of joints in the plastic concrete using a steel roller should be eliminated. Dry saw-cutting of joints provides an acceptable process for installing joints.
13. Installation of joints needs to be further evaluated since there is minimal shrinkage cracking in the pervious concrete pavement.
14. Furthering monitoring should be conducted to evaluate the performance and environmental benefits of pervious concrete pavements.

Conclusions

The authors provide the following conclusions based on their experiences related to this project:

1. Pervious concrete pavement is a promising technology provided that the material and construction requirements, including compaction, are achieved during construction.
2. The use of ASTM C140 for determining the void content of pervious concrete provides an unreliable measure of pavement voids.
3. The use of porosity as measured by MTO LS-627 or void content as measured with a CoreLok® vacuum system provide a reliable measure of the pavement void structure of a pervious pavement.
4. The use of a Bid-Well bridge deck finishing machine without adequate compaction produces a pervious concrete pavement which is prone to ravelling.

5. Joints constructed in the plastic pervious concrete using a steel roller can produce unacceptable joints, which are prone to raveling. The steel roller can also delay the application of curing.
6. Improper compaction increases the occurrence of surface ravelling.

MTO supports sustainable infrastructure and pervious concrete pavements are another tool for achieving sustainable infrastructure. Pervious concrete pavements can lessen the environmental impact of our built environment. Pervious concrete has been used successfully in other jurisdictions and is a promising new green technology. MTO is committed to being a leader in environmentally sustainable infrastructure and will build on the lessons learned from this project.

Acknowledgements

The authors would like to acknowledge the support and assistance provided for this pervious concrete pavement trial from Rico Fung of the Cement Association of Canada, Bart Kanters of the Ready Mix Concrete Association of Ontario, and Dr. Susan Tighe of CPATT at the University of Waterloo. The authors would also like to recognize the cooperation of the contractor Facca Incorporated, the pervious concrete supplier Dufferin Concrete, the contract administration consultant MCPD Consultants, and all MTO staff involved in the project.

References

1. American Concrete Institute (ACI), Pervious Concrete, Report ACI 522R-06, ACI, Farmington Mills, Michigan, 2006.
2. NRMCA, *Text Reference for Pervious Concrete Contractor Certification,* NRMCA Publication 2PPCRT, 2007.
3. American Society for Testing Materials International (ASTM), Annual Book of ASTM Standards, Volume 04.02 Concrete and Aggregates, West Conshohocken, Pennsylvania, 2007.
4. Ministry Of Transportation (MTO) Laboratory Testing Manual, Downsview, Ontario, Canada, 2007.
5. American Society for Testing Materials International (ASTM), Annual Book of ASTM Standards, Volume 04.03 Road and Paving Materials; Vehicle-Pavement Systems, West Conshohocken, Pennsylvania, 2005.
6. Myers, J. D. and Dubberke, W., *Iowa Pore Index Test*, Iowa Department of Transportation, Materials Laboratory Research Report MLR-8002 (Interim Report), Iowa Department of Transportation, Ames, Iowa, 1980.