2007 TAC Environmental Achievement Award Submission

Design and Construction of a Pervious Concrete Pavement

Award Nominee: Ontario Ministry of Transportation

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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 consisted 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. However, MTO is committed to exploring sustainable alternatives where possible and it is hoped that the lessons learned from this project can be applied to addressing durability concerns on future projects.

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 submission presents the design considerations and summarizes the construction observations and lessons learned. A description of proposed water quality monitoring is also presented.

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. Use of pervious concrete earns Leadership in Energy and Environmental Design (LEED) credits. 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. 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.

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.

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 submission 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.

Construction of the Pervious Concrete 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, 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.

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.

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 which is the most suitable test method for acceptance.
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 a Bid-Well bridge deck finishing machine without adequate compaction produces a pervious concrete pavement which is prone to ravelling.
3. 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.
4. 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.

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