Behaviour and Performance of Pervious Concrete Pavement in Canada

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ABSTRACT

Pervious concrete offers sustainable and environmental benefits for stormwater management and urban development. The open void structure of pervious concrete allows moisture to move through the pavement structure and into the ground water without altering the natural hydrologic cycle. Pervious concrete can be used in low volume, low speed applications in urban and rural settings without creating impermeable space. Therefore it is a low impact development that does not put additional demand on the stormwater management system and in some applications will lower the demand on the stormwater management system. Recent use of pervious concrete in Canada includes four test areas that were constructed to evaluate the performance of pervious concrete in a freeze-thaw climate. The test areas are monitored regularly through surface distress evaluations, permeability and light weight deflectometer testing. Cores are extracted from the test areas and samples are prepared in the laboratory. Laboratory testing is carried out to evaluate performance in accelerated freeze-thaw testing, compressive and flexural strength, void content and permeability. Two of the test areas are instrumented with moisture sensors and static strain gauges. The moisture sensors are on sensor trees to follow the movement of moisture through the pavement structure. The static strain gauges represent the effect of the environmental changes on the pervious concrete. The data from the instrumentation is available in real time which allows for efficient comparisons and evaluations. The ability for pervious concrete to drain moisture from the surface is measured through permeability testing and development of distresses on the surface are noted in surface distress evaluations. Surface testing does not represent the movement of moisture once it leaves the surface. The moisture trees will present information related to the movement of moisture through the pavement structure which will provide pavement and environmental professionals with a better understanding of pervious concrete. The data from the static strain gauges will aid in the understanding of the effect of environmental changes on pervious concrete. This paper includes the findings to date from the various field and laboratory testings and the data collected from the instrumentation.

INTRODUCTION

Pervious concrete is an environmentally friendly, sustainable paving material. It is a concrete mixture that has little to no fine aggregate content. By reducing the fine aggregate in the mixture the void content becomes 15 to 30%. This allows for water to percolate through the pervious concrete. Pervious concrete is placed on a clear stone base that acts as a reservoir holding the water while it infiltrates into the subgrade. The rainwater therefore infiltrates directly into the groundwater reducing the need for a stormwater management system and ponds. The need for a stormwater management system will be determined by the permeability of the subgrade. Pervious concrete that is placed on a well draining subgrade will allow all water to infiltrate into the subgrade efficiently. A subgrade with a low percolation rate will require a larger clear stone reservoir or a form of stormwater management drainage. By decreasing the need for an area to build the stormwater management pond there is more land available for homes, parking or recreational activities (*1*). The structure and design of pervious concrete makes it suitable for low volume, low speed applications such as;

- Residential streets
- Driveways
- Paths
- Sidewalks
- Shoulders
- Parking lots.

By using pervious concrete in any of the applications listed above or similar ones the development has a low impact. A low impact development (LID) is ideal and is one that does not alter the natural hydrological cycle. The ability of rainwater to filter directly into the groundwater does not change the hydrological cycle as pervious concrete has an infiltration rate greater than natural grass areas (*2*, *3*).

Pervious concrete has been used in parts of Europe for many decades and has been used in the southern area of the United States for 20 years (*2*). Recently pervious concrete test areas have been placed in the northern United States and more recently Canada. The performance and behaviour of the open structure of pervious concrete in climates such as Canada and the northern United States where freeze-thaw cycles are common, is unknown. The large void ratio could be a location for water to freeze and expand causing excessive aggregate loss and failure. The high permeability rate of pervious concrete however indicates that moisture is rarely present in the top layer and is stored in the clear stone layer. The potential for failure is then decreased. An additional benefit of the high permeability rate is its ability to clear snow and slush from the surface. Test sections in climates with snow have shown that the snow and slush clears quicker from the surface than on conventional concrete due to the permeability of the pervious concrete surface (*1*).

The Centre for Pavement and Transportation Technology (CPATT) at the University of Waterloo, Waterloo, Ontario has a state-of-the-art pavement laboratory and research group. CPATT has partnered with the Cement Association of Canada (CAC), Portland Cement Association (PCA), multiple ready mix associations and industry members across Canada to carry out a comprehensive research study that analyzes the performance of pervious concrete in the Canadian climate (*4*). Test areas will be constructed in various climate regions of Canada. The test areas will represent a variety of applications such as parking lots, shoulders and laneways. Each test area will experience different loadings from full aggregate and concrete trucks to personal vehicles only (*1*). Conclusions of the research by CPATT will include but not be limited to the performance of pervious concrete in the Canadian climate, performance in various application and loading environments, rehabilitation maintenance methods, analysis of strain caused by environmental conditions within the pervious concrete layer and filtration abilities of pervious concrete.

PERVIOUS CONCRETE TEST SITES

Project construction began in the spring of 2007 and continued through 2008. Four test areas have been constructed to date. The test sites are located in Georgetown, Ontario, Campbellville, Ontario, Barrie, Ontario and Maple Ridge, British Columbia. The test area characteristics will be outlined in this report as well as the current performance of each. The locations of the test areas are shown in Figure 1.

SITE 1

Dufferin Concrete operates over 25 concrete plants throughout southern Ontario providing concrete to public and private sector projects as well as research studies. Dufferin Concrete and CPATT partnered together during the spring of 2007 to construct a pervious concrete parking lot at the Dufferin Concrete Ready Mix Plant, Georgetown, ON. The parking lot, referred to herein as Site 1, is used daily by plant employees for personal vehicles. The parking lot is approximately 630m^2 (6780ft^2). The parking lot structure consists of 300mm (12”) of pervious concrete placed on 600mm (24”) of clear stone. The clear stone is placed on a 100mm (4”) concrete mud slab. A drainage pipe was placed within the subgrade to gather all the water that travelled through the structure. This is unique from conventional practices and was done so that water can be gathered in a catch basin and tested. The pervious concrete was placed using a roller. This site receives winter maintenance each season which includes spreading of sand to half of the lot and snow removal to the entire lot using a front end loader.

SITE 2

In an interest to use more sustainable technologies the Ontario Ministry of Transportation (MTO), Cement Association of Canada, Ready Mix Concrete Association Ontario and CPATT placed a pervious concrete park and ride car pool lot, referred to herein as Site 2, on Highway 401 at Exit 312, Guelph Line and Campbellville, in the fall of 2007. This area of Highway 401 is busy with traffic west of Toronto, Ontario. The parking lot is in use 24 hours a day with mainly personal vehicle loading but also a small percentage of truck traffic. The parking lot is approximately 1800m^2 (19375ft^2). Similar to the Dufferin Concrete parking lot this car pool lot was also designed to collect water for filtration testing. The pervious concrete layer is 240mm (9.5”) in depth on top of a 100mm (4”) clear stone layer. The clear stone is on a 200mm (8”) 19mm (0.75”) stone layer that collects the water and directs it to the catch basin for testing. The parking lot was constructed in four sections. Three of the sections were placed using a Bidwell Bridge Deck Paver and the fourth section was placed using a Razorback. During the winter seasons half of the parking lot is sanded for winter maintenance while the other half is not. The entire lot experiences snow removal (7).

SITE 3

To gain information and experience with pervious concrete Rempel Brothers Concrete partnered with CPATT and others to place pervious concrete test areas within the design of a new concrete plant in Maple Ridge, BC referred to herein as Site 3. The plant started production in the spring of 2008 (*5*). Rempel Brothers Concrete supplies concrete to a variety of projects in British Columbia. The test areas are within the entrance and exit driveways. The entrance driveway strip is 1m wide and runs longitudinally throughout the entire driveway. This area experiences loading from personal vehicles, empty concrete trucks and loaded aggregate trucks. A portion of this test area is in the centre of the driveway and the rest is along the edge of the main driveway. The driveway slopes towards the pervious concrete therefore allowing for not only rainfall but also runoff to infiltrate through the pervious concrete structure. The exit driveway test area is also 1m in width and runs perpendicular to the flow of traffic. The exit driveway strip will have personal vehicles, loaded concrete trucks and empty aggregate trucks. Both the entrance and exit driveway test areas have the same structural design; 250mm (10”) pervious concrete on 200mm (8”) of clear stone on top of the natural well draining subgrade. Both sections were placed using a steel roller. In general winter maintenance is not required at this location.

SITE 4

The fourth test site in this project is located in Barrie, ON at a Lafarge Ready Mix Plant and will be referenced at Site 4 for the remainder of this paper. Lafarge Canada partnered with CPATT in the fall of 2008 to construct a 10m by 50m employee parking lot to be used for research purposes and as an example for future customers. The site includes three different pervious concrete mixes for comparing performance and characteristics. All mixes are similar however consist of different aggregates. The first mix which will be referred to as Mix A within this paper contains a 14mm crushed limestone. The second mix, Mix B, contains a 20mm gravel aggregate and the third mix, Mix C contains a combination of 20mm gravel and 20mm crushed limestone aggregates. The subgrade and clear stone layers of the pavement structure were instrumented with moisture sensors to track the movement of moisture. The pervious concrete was coloured red for display and presentation purposes. The pavement structure includes 200mm (8”) of pervious concrete on a 250mm (10”) base layer which is on a well draining sand subgrade. The entire lot slopes downward toward the east. The parking lot was constructed using an ABG Asphalt Paver and a small compactor. The vibrator was turned off on the paver during construction and the crew followed closely behind the paver with the packer. During the winter seasons the entire lot was plowed using a front end loader and half of the lot was sanded (16).

SURFACE DISTRESS EVALUATION

Pervious concrete is unique from conventional concrete in terms of design mixture as well as intended use. The differences between pervious concrete and conventional concrete indicate that the same pavement surface distress evaluation form should not be used on these two rigid pavements. CPATT has carried out a literature review to determine distresses present in pervious concrete test areas across North America. In addition to this information the early performance of Sites 1 and 2 was closely monitored for changes in surface condition (*1*).

Construction techniques and practices are critical in producing a quality pervious concrete surface. Sealing of the surface has been an issue at many test areas and can be a localized problem or consistent throughout the surface. Over-compaction during construction is a common cause of sealing of the surface. When the surface is sealed the voids are clogged and therefore the surface becomes impermeable. This condition could be determined during a surface distress evaluation if ponding is present or else permeability testing would have to be done (*9*).

Pervious concrete that is forced to carry more load than it had been designed for may show cracking. When no joints are placed in the pervious concrete cracks will appear where joints should have been (*9*).

Surface abrasion and aggregate polishing have occurred in some pervious concrete projects. Surface abrasion is often due to the snow removal technique and therefore a rubber snow plow blade is recommended rather than the metal version (*10*).

The literature review and observations at Sites 1 and 2 lead to the development of the following list of possible surface distresses in pervious concrete:

- Raveling and aggregate loss
- Surface abrasion
- Polishing
- Scaling
- Joint raveling
- Cracking
- Clogging/ponding
- Joint separation.

Faulting, distortion and scaling surface distresses may develop after many years of use but have not been observed at the sites.

Pavement surface evaluations are a critical element in managing pavement as an asset. Regular surface evaluations allow agencies to perform proactive maintenance before rehabilitation or reconstruction becomes the only alternatives. Manual visual evaluations are appropriate for low traffic, low speed areas such as parking lots, driveways and residential streets. Visual evaluations are bias however and may provide a wide range of results. Many automated surface distress evaluation vehicle options are available. Examples of these vehicles include ARAN by Roadware, Digital Highway Data Vehicle by Dynatest and PathRunner by Pathway (*11*, *12, 13*). Automated distress collection can be done at highway speeds therefore increasing the safety from manual visual inspections.

Pervious concrete applications include low volume or low speed areas such as parking lots, driveways, residential streets or pathways. Manual visual distress collection can be safely carried out in these applications and is often more economical as these areas tend to have a smaller area than highways or high speed roads. Pervious concrete maybe useful for highway shoulders in the future. If these areas are evaluated the safest option would be automated distress. Quality control and quality assurance practices would have to be carried out to ensure that automated evaluations are properly detecting pervious concrete distresses.

A surface distress evaluation form was developed following the literature review for manual use in this project. The form includes the distresses previously outlined, the severity of the distress and the density of the distress. The severity is rated as one of the following:

- Very slight
- Slight
- Moderate
- Severe
- Very Severe

The density is chosen from one of the following five options:

- < 10% of the site
- 10 – 20% of the site
- 20 – 50% of the site
- 50 – 80% of the site
- 80 – 100% of the site

The form includes space for comments related to winter maintenance, general maintenance and miscellaneous. The severity and density ranges were selected and modeled after the Ministry of Transportation of Ontario (MTO) surface distress evaluation forms (14).

SURFACE DISTRESS EVALUATION RESULTS FROM TEST SITES

SITE 1

Site 1 was constructed in the summer of 2007 and has been monitored regularly since that time for changes in the surface condition. Minimal ravelling was present in localized areas of the site including joints during the fall of 2007. The severity of the ravelling was determined to be slight and on 10 – 20% of the site. During the summer of 2008 there was moderate ravelling present in 20 – 50% of the site and 20 – 50% of the joints. The performance of the site has remained consistent up to and including the spring of 2009. The distresses are distributed throughout the site with no distinct differences between areas receiving and not receiving winter maintenance. As noted previously the snow removal is carried out with a front end loader which appears to have not caused any additional distresses to the surface.

SITE 2

Site 2 was constructed in the fall of 2007. Following construction portions of the site began to experience slight ravelling in slabs and at joints. During spring of 2008 slight surface abrasion was present in 10 – 20% of the site. This abrasion was likely due to snow removal. At this time slight, moderate and severe ravelling had occurred at various areas within the site. Each severity of ravelling was present at approximately 20% of the site. In addition to slab ravelling approximately 50% of the joints had exhibited moderate or severe ravelling. During summer 2008 ravelling was present throughout the site, within both slabs and at joints and ranged in severity from moderate to severe.

At the end of the summer of 2008 the entire lot was swept and all loose aggregate was removed from the site which greatly improved the appearance. The three portions of the site that were placed with the Bidwell Bridge Deck Paver were more rough and uneven than the fourth section that had been placed with the Razorback.

During the fall of 2008 slight ravelling continued throughout the site including joints however did not increase in severity. In the winter of 2009 slight ravelling was present throughout the site and at the joints.

SITE 3

Following the construction of Site 3 in the spring of 2008 portions of the surface were sealed. The sealed portions were possibly caused by mix inconsistencies and construction. During the summer of 2008 very slight ravelling was present in a few localized areas of the site (<10%). The surface of the site was not smooth, which is likely due to the roller that was used in construction. The lack of smoothness is strictly a cosmetic distress. In the late fall of 2008 a few slight cracks had developed in <10% of the site and moderate ravelling was present in 20 – 50% of the site. The portions of the surface that were sealed following construction remained sealed up to and including the fall of 2008.

SITE 4

The construction of Site 4 proved to be very successful using the asphalt paver. The surface that was produced was durable and aesthetically pleasing. Following construction in the fall of 2008 localized ravelling was present at the construction joints. No joints were cut in the parking lot however it was placed in three strips. The construction joints between the strips both showed areas of localized slight and severe ravelling which accounted for <10% of the entire parking lot surface.

In the spring of 2009 there was aggregate failure in <10% of the site. The aggregates appeared to have fractured, which could be due to snow removal, however ravelling did not occur at these locations, only aggregate fracturing. Localized ravelling appeared within <10% of the site and is moderate in severity. The ravelling at the construction joints remained at the same severity and density as it was following construction.

PERMEABILITY

The permeability characteristics of pervious concrete are key in maintaining the functionality of the pavement as a draining surface. Permeability testing is carried out regularly at each of the four test areas to track changes throughout the seasons and life span. Permeability testing is performed using a Gilson Asphalt Permeameter. Permeability testing is repeated at the same locations throughout each site during each round of testing. The test is performed three times on each location in the site to evaluate consistency and track changes in consistency. Figure 2 shows the permeability rates of each site throughout their life.

The maximum rainfall rate for an individual event at any of the four sites is 0.0083cm/sec and is shown on Figure 2 (15). Site 3 is the only site that on average has a permeability rate that is close to the maximum rainfall rate. The other three sites are all performing with permeability rates greatly above that of the maximum rainfall rate.

Site 1 has not experienced any rehabilitation to date however it can be seen in Figure 2 that the permeability rate increased between the ages of 13 and 16 months which correspond to the late summer and fall of 2008. This increase in permeability was brought on naturally and the exact reason is unknown but anticipated to be from intense rain storms in the late summer and fall. The other sites have not shown this natural improvement yet but will be continually monitored.

Sites 1, 2 and 4 all had very high permeability rates following construction, much higher than needed to accommodate any Canadian storm. Once the sites had experienced traffic and environmental loading they have all decreased in permeability but remained well above the needed rate. The permeability at sites 1 and 2 has stabilized with Site 1 showing some fluctuation. The permeability of all three mixes at Site 4 have decreased with Mix B and C showing the greatest rate of reduction in permeability. Both Mix B and C contain larger aggregates than Mix A which may produce larger voids that are more easily clogged. All sites will be monitored to follow future permeability changes.

LIGHT WEIGHT DEFLECTOMETER

Light Weight Deflectometer (LWD) testing has been carried out at the sites to collect more information about the characteristics and performance of pervious concrete. LWD testing is done with a 20kg weight at multiply locations throughout the sites. The LWD results for deflection range from 20µm to 82 µm. This wide range of values is often present within one site and although results and testing is preliminary it is anticipated that the LWD results will be helpful in predicting permeability and changes throughout a particular site.

INSTRUMENTATION

WEATHER STATIONS

Each site includes a simple weather station that provides precise hourly environmental data for the pervious concrete test site. The weather stations including a tipping rain gauge that logs each rain event and the quantity of rain that occurred. The weather stations also include a thermometer for additional site data. The data from the weather stations helps in understanding the permeability of the pervious concrete as it records the exact start and finish of all rain events.

MOISTURE SENSORS AND RESULTS

Sites 3 and 4 were instrumented with sensor trees during construction. The sensor trees consist of two to five Watermark Moisture sensors. Watermark moisture sensors are designed for agricultural environments however appear to offer the ability to collect helpful data in pervious concrete applications. Sensors have been placed throughout the pavement structure, in the pervious concrete layer, the clear stone base and the subgrade. The intent of the moisture trees is to closely monitor the movement of moisture through the pavement structure once it drains from the surface.

Figure 3 shows a sensor tree before it is placed in the pavement structure. The Watermark Moisture sensors measure pressure in centibars which are equivalent in a 1:1 with kilopascals. The sensors are generally used to measure a range of 0 to 200 centibars with 0 to 10 centibars indicating complete saturation. References for using these sensors in agricultural applications indicate that values between 100 and 200 centibars relate to soil conditions too dry for growing purposes (16). At Site 4 there is one sensor tree in each mix and each sensor tree is identical, having four Watermark sensors. Two of the sensors are in the subgrade and two are in the clear stone base. No sensors were installed in the pervious concrete layer due to challenges that would have arisen during construction. The deepest sensor is numbered 1 and the sensor closest to the surface is 4 with 2 and 3 being located in between.

Using the weather station data it is clear when rain events occur and their duration. This information can then be coupled with the moisture sensor data to understand the movement of moisture through the pavement structure one it drains from the surface.

Figure 4, Figure 5 and Figure 6 show moisture sensor data from Mix A, Mix B and Mix C respectively from Site 4. Moisture data is collected hourly from each sensor and a portion of this data, from two rain events was included in these figures.

Figure 4 shows sensors 1 and 2 having consistently lower readings than the other two sensors. These sensors are located within the sandy subgrade and this is indicative of the subgrade continuously holding more moisture than the clear stone layer. The moisture levels around sensors 1 and 2 gradually increase following the initial rain event and then return close or to original values. The second storm event has minimal effect on the moisture levels in the subgrade. Sensor 2 does not drain completely to the condition before the first rain event and is continually more moist than sensor 1. Sensor 1 is deeper than sensor two and it is possible that moisture around sensor 2 moves horizontally more than vertically as the parking lot is sloped.

Sensors 3 and 4 follow a similar trend in that moisture from a particular rain event moves into the subgrade layer before the duration of the event. Sensor 4 is the closest to the pervious concrete layer and shows that moisture moves through the pervious concrete and into the clear stone layer quickly just as it does when it drains from the surface. Sensor 3 is at the interface of the clear stone and subgrade. Sensor 3 consistently remains the least moist of all the sensors indicating that at the interface moisture may move horizontally rather than vertically along the interface. This trend may not be present at all sites but appears possible at this site due to the site sloping in one direction.

Figure 5 shows similar trends in the moisture movement in Mix B to that of Mix A. Sensors 1 and 2 in Mix B show very similar moisture levels in the subgrade. Sensors 3 and 4 do not show changes in moisture content until almost the end of each rain event. This finding corresponds with the data in Figure 2. Figure 2 shows the Mix A has a much higher permeability rate than

Mix B and Mix C. The lower permeability rate of Mix B causes the moisture to spend more time in the pervious concrete layer before moving into the clear stone base. The increase in moisture at sensors 3 and 4 when the moisture does reach the clear stone base is faster than that of Mix A indicating that more of the moisture is moving vertically rather than spreading horizontally along the slope of the parking lot. In both Mix A and B more moisture reached the higher sensor; 4 than the lower sensor; 3. During the second rain event more moisture reached sensor 3 in Mix B than in Mix A. Further analysis of various storms is necessary and ongoing to understand the behaviour of moisture movement through pervious concrete.

Figure 6 shows that the subgrade (sensors 1 and 2) is drier beneath Mix C than the other two mixes. The sensors in the clear stone (3 and 4) show moisture from rain events moving into the clear stone layer slower than in the other two mixes which is anticipated since the permeability rate of Mix C from Figure 2 is the lowest of the three mixes. In Mix C the most moisture is present around sensor 3, the interface between the clear stone and subgrade. In the other two mixes the sensor closest to the surface (sensor 4) exhibited the most moisture in the clear stone layer. In Mix C sensors 3 and 4 also have the most similar moisture levels in comparison to the other two mixtures, this maybe the result of less moisture moving along the natural slope and more moving downward.

STRAIN GAUGES

Site 3 includes eight static strain gauges in the pervious concrete layer. The static strain gauges are used to monitor changes in the surface layer due to environmental changes and the data will be helpful in understanding the effects of freeze thaw cycles on pervious concrete.

LABORATORY TESTING

This Canada wide study is an integrated laboratory and field project. Laboratory testing includes compressive strength, void content, permeability and flexural strength. During the construction of test areas samples are prepared for testing and analysis in the laboratory. Laboratory testing also includes the analysis of various cylinder compaction methods. Pervious concrete is unique from conventional concrete and therefore conventional compaction methods using 25 rods per layer and doing three layers may not be representative of the material that is placed in the field. One compaction method that is being evaluated is doing 10 Proctor Hammer drops/layer and placing two layers of material in the cylinder. Another method that has been evaluated is doing 20 Proctor Hammer drops/layer and placing two layers of material in the cylinder. While this research is ongoing Figure 7 shows the results to date in comparison to the cores extracted from the particular locations.

In Figure 7 10P refers to 10 Proctor Hammer drops/layer using two layers, 20P is 20 Proctor Hammer drops/layer using two layers and 25R is 25 rods/layer using three layers. All the results in Figure 7 refer to 28 day compressive strength results. At Site 3 all three methods were evaluated and compared to cores that were extracted and tested for compressive strength (8). The 10 Proctor Hammer drop method proved to have the closest results and was used at Site 4. In addition to testing at Site 3 extensive laboratory testing was done at the University of Waterloo and the 10 Proctor Hammer drop method was found to have the best correlation (17). Figure 7 shows that the cores and cylinders for Mix A were similar but for Mix B and C they had a larger difference. All cylinders were 150mm by 300mm while the cores were 150mm by 134mm to 163mm. In order to get closer results further testing could include using 100mm by 200mm cylinders and extracting 100mm cores.

Figure 8 shows similar void content results for the cylinders and cores. While compressive strength is a characteristic of concrete that is often requested it should not be the determining factor for pervious concrete as the permeability is more crucial to its functionality. The void content of pervious concrete is directly related to the permeability of the material, assuming the surface is not clogged. The true representation of the void content of the material in the field through the cylinders is helpful and useful for quality control. All void content testing was done using CoreLok equipment.

CONCLUSIONS

Pervious concrete pavement is an environmentally friendly paving material that is becoming a sustainable alternative for cold weather climates. The four test areas across Canada are providing insightful data into the behaviour and performance of pervious concrete. The surface distresses that have developed in the pervious concrete test areas have not prohibited the functionality or permeability of the concrete. The occurrence of surface distresses in pervious concrete and the performance of the surface of pervious concrete is directly related to the construction practices and mix characteristics.

Permeability rates of the pervious concrete sites have decreased with time but always remained above the maximum rainfall rate for the test area regions. In general the permeability rate of a pervious concrete site decreased during the initial 10 to 12 months of life and then reached a constant rate which appears to change minimally over time. Permeability testing has indicated that over time permeability rates will fluctuate and can improve without any maintenance methods. Increases in permeability can occur due to natural causes such as rain seasons. Permeability testing will continue regularly at each site in the future.

The installation of instrumentation in the pervious concrete test areas allows for the collection of data relating to moisture movement and strain related to environmental changes. The moisture data is preliminary but indicates that moisture moves through various pervious concrete mixes differently and generally moves through the pavement structure slower than it drains from the surface. The surface permeability rate however correlates to the drainage rate of the pervious concrete layer and time required to reach the clear stone base, subgrade interface point. The moisture sensors will be useful in understanding the vertical and horizontal movement of moisture through the pavement structure. The combination of weather station data and moisture data will be essential in understanding the movement of moisture through the pavement structure in greater detail.

While research is ongoing it is apparent that the conventional method of consolidating cast cylinders does not produce samples representative of those placed in field applications. Consolidating cylinders using 10 Proctor Hammer drops per layer and two layers produces samples that are similar in void content to pervious concrete in the field. Consolidation with 10

Proctor Hammer drops per layer and two layers can also produce compressive strength results similar to those of field samples however compressive strength should not be considered a sole performance predictor of pervious concrete.

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FIGURES

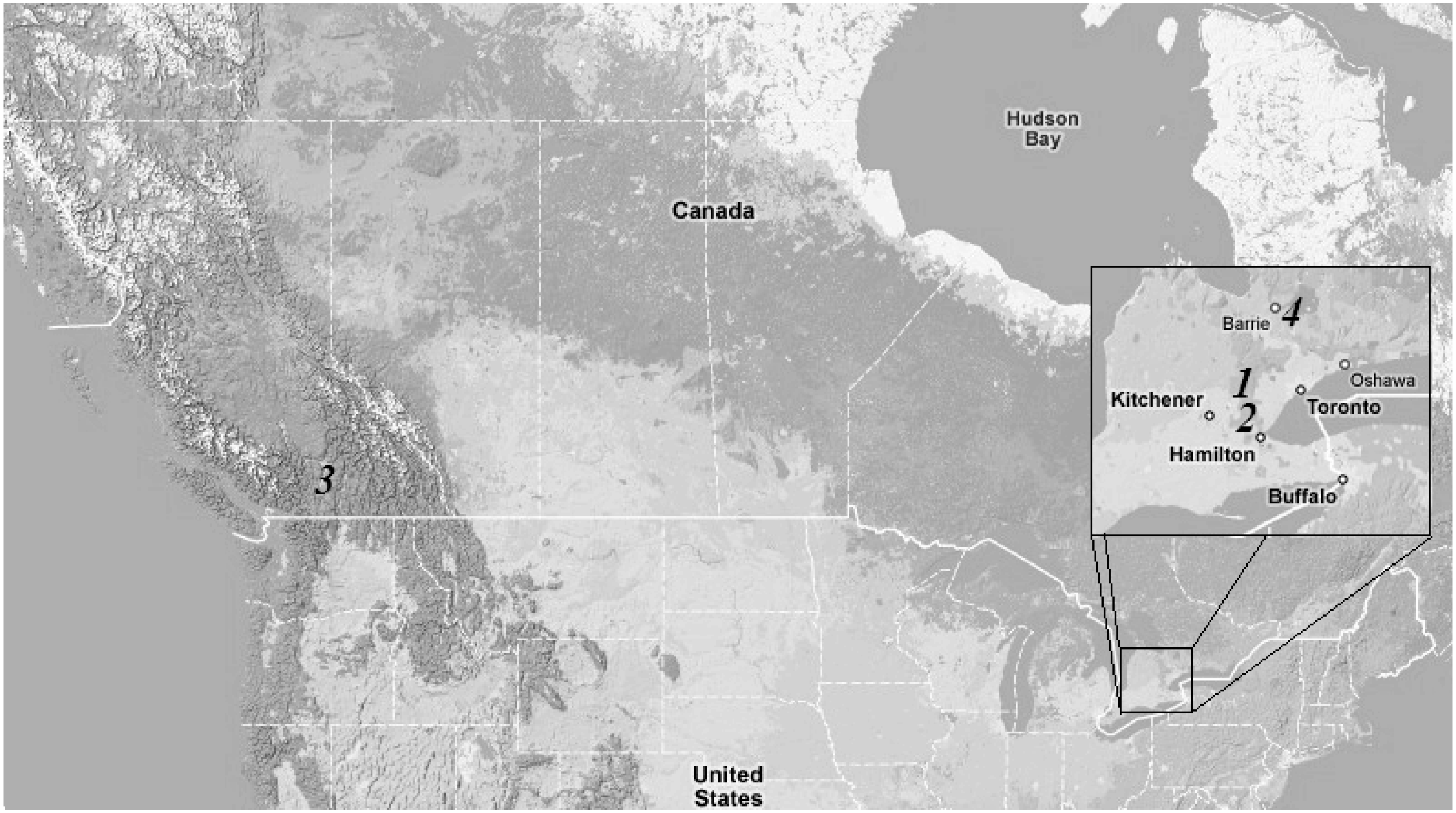

Figure 1: Test Site Locations

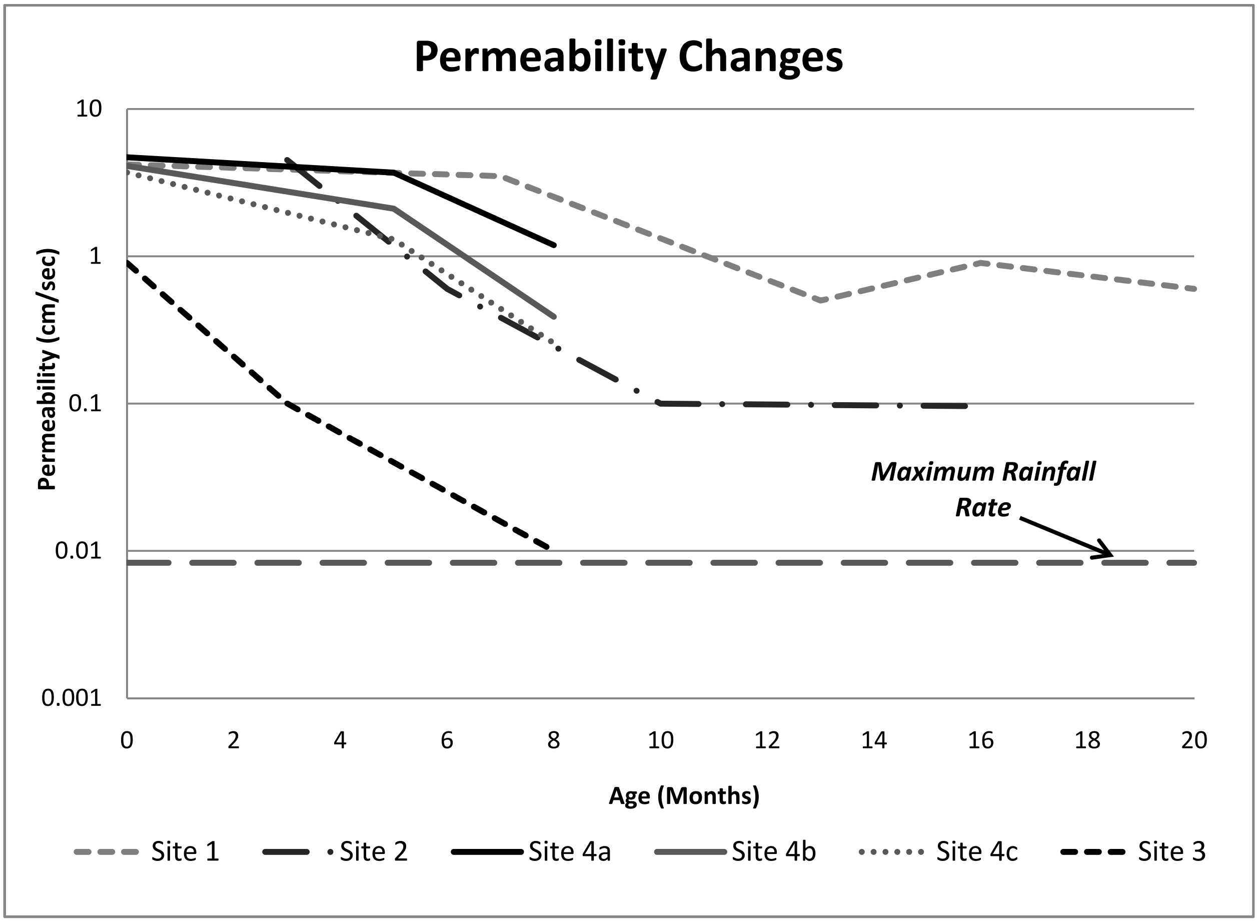

Figure 2: Permeability of the Four Test Sites

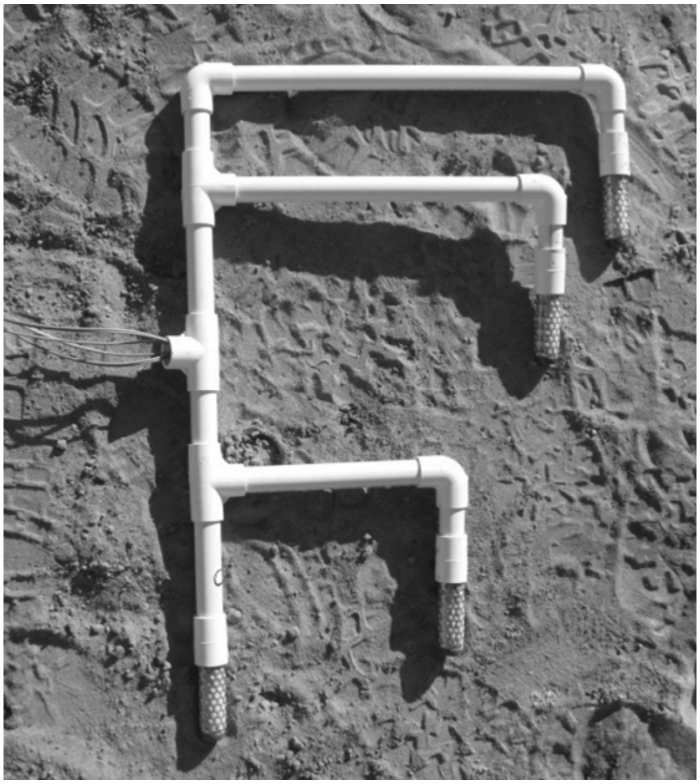

Figure 3: Watermark Moisture Sensor Tree

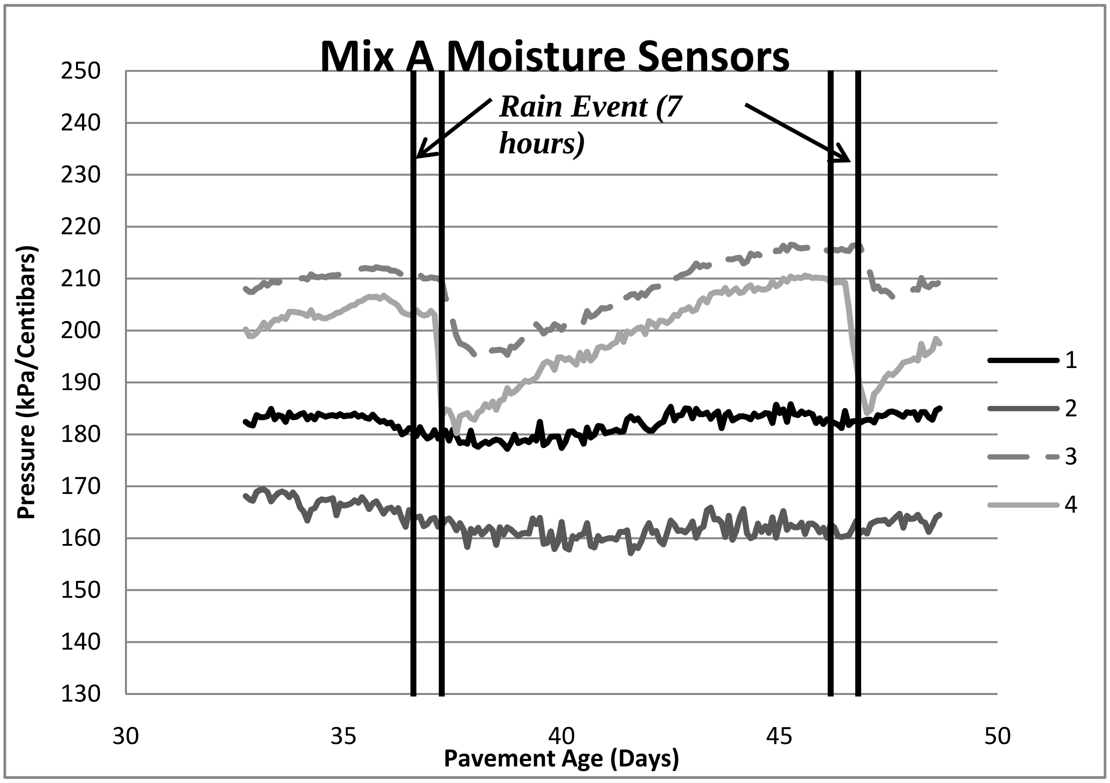

Figure 4: Mix A Moisture Sensors

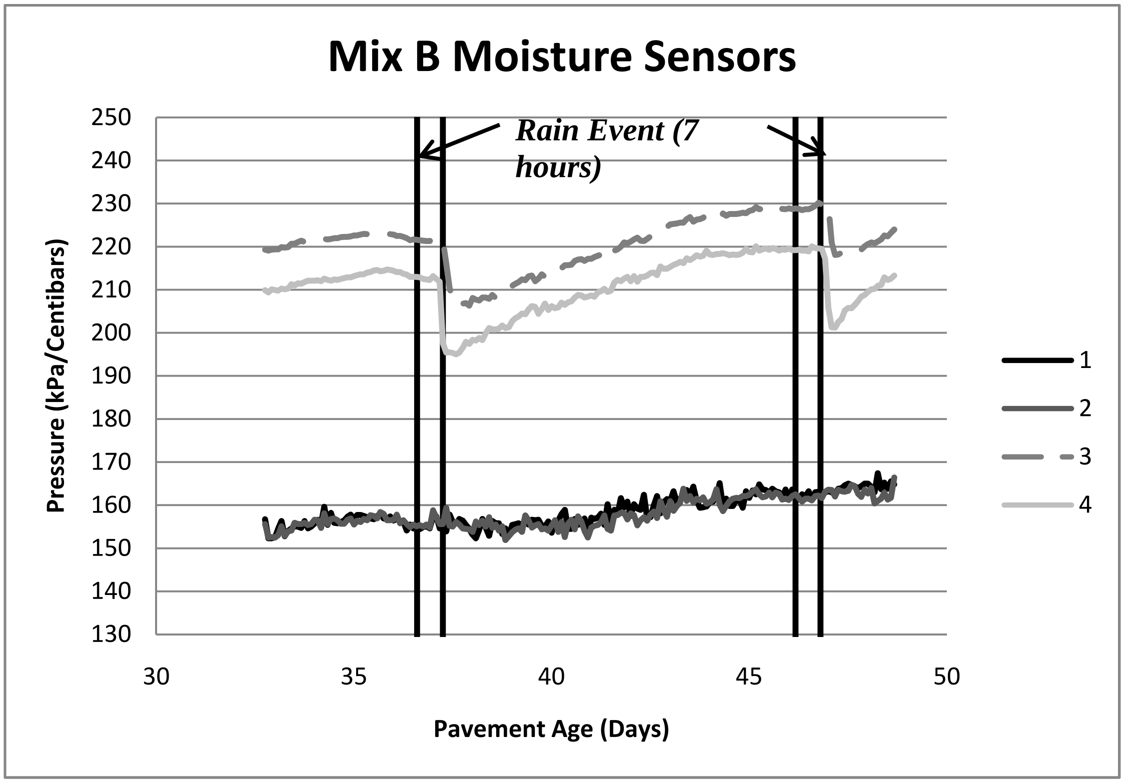

Figure 5: Mix B Moisture Sensors

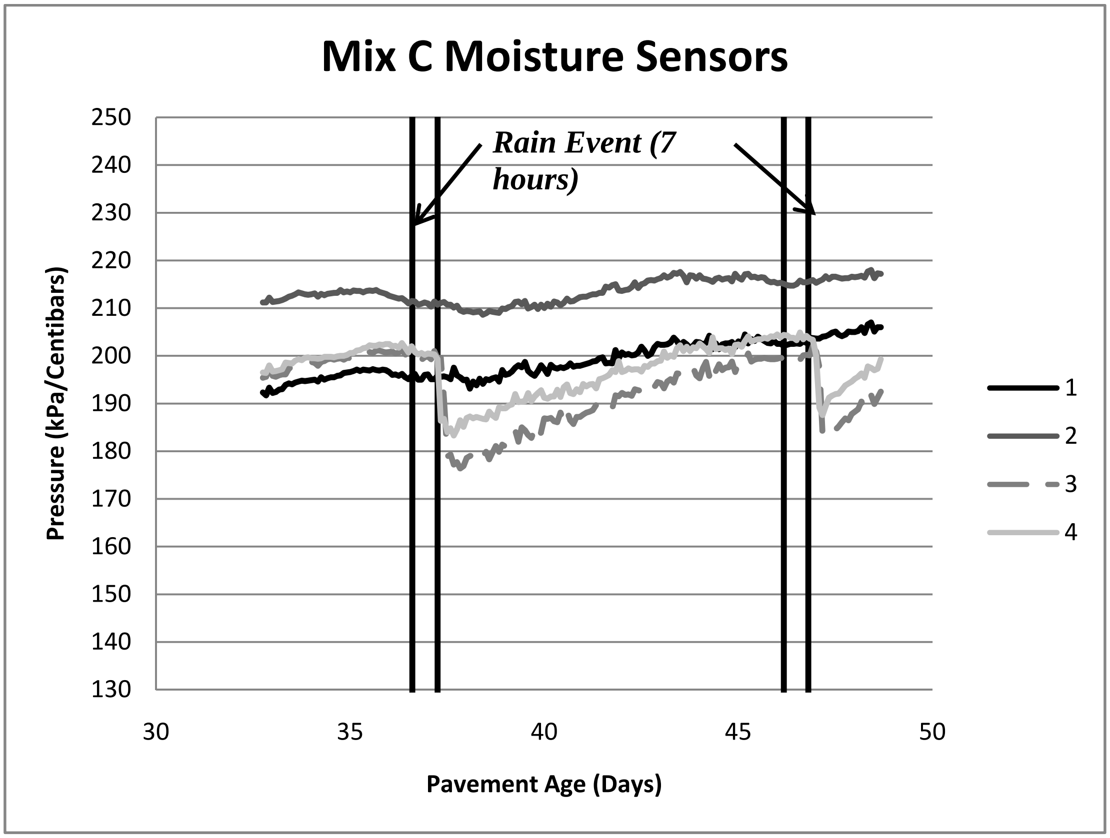

Figure 6: Mix C Moisture Sensors

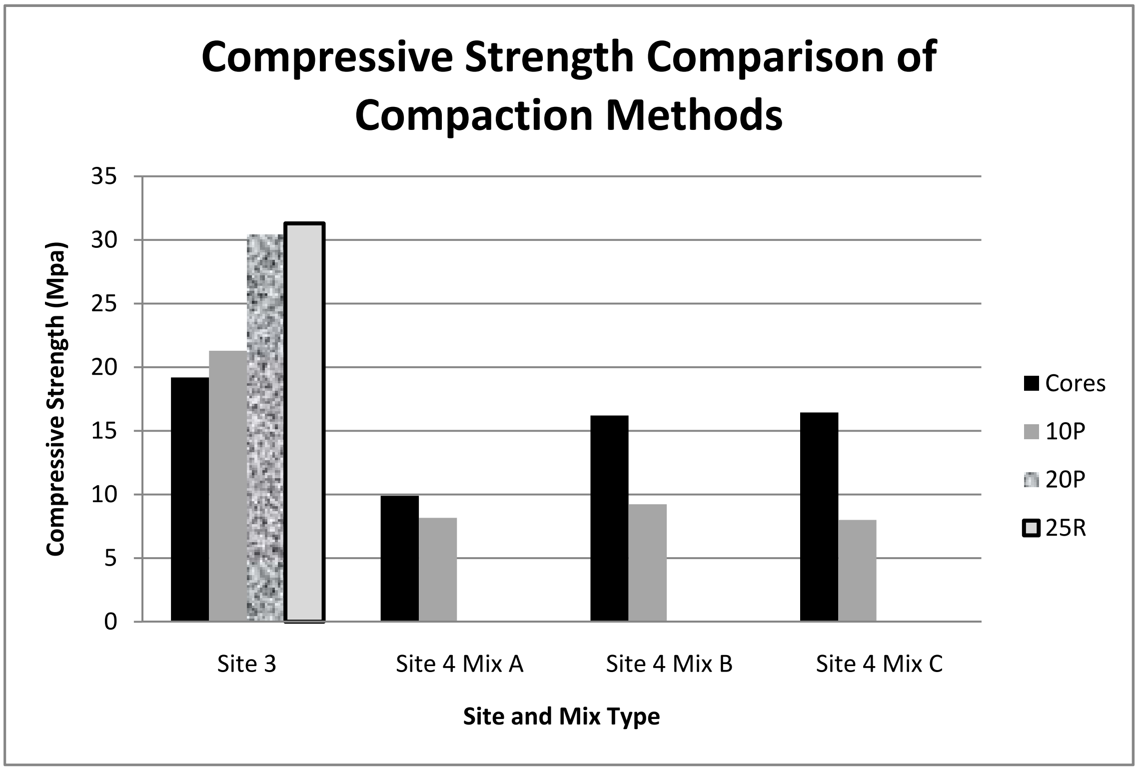

Figure 7: Compressive Strength Results of Compaction Methods (6, 8)

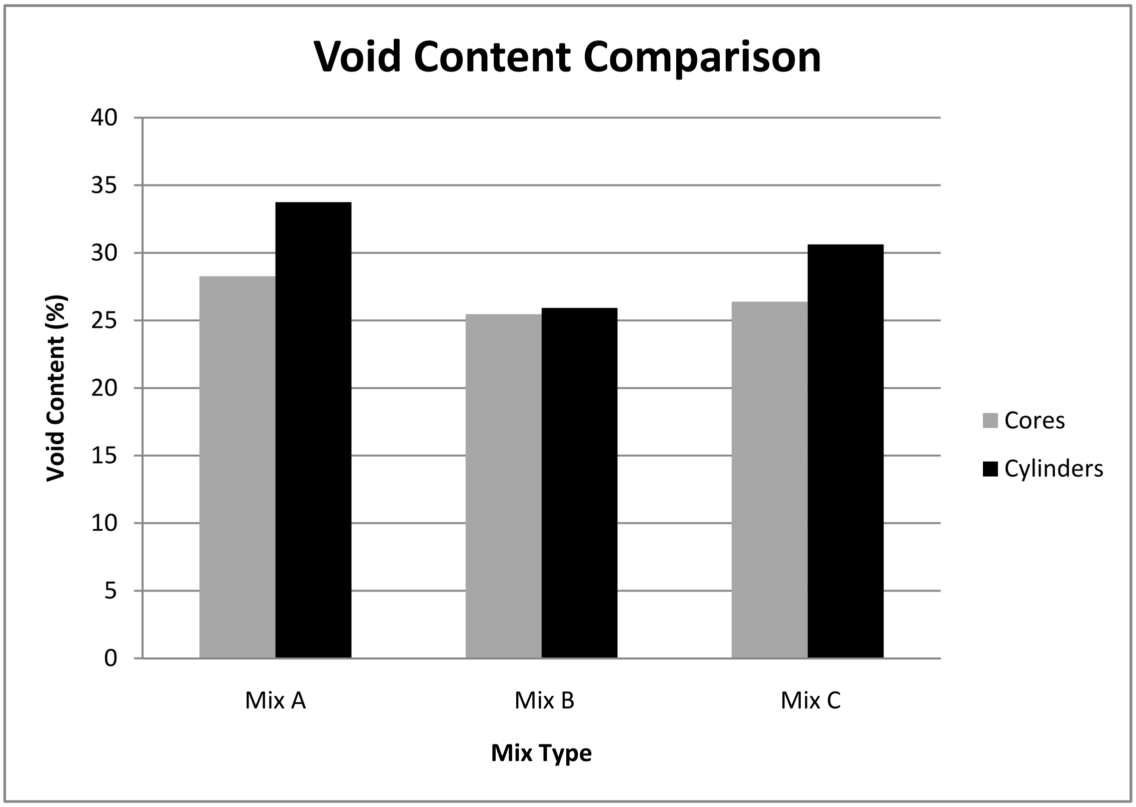

Figure 8: Void Content Comparison (6)