Long Term Drainage Performance of Pervious Concrete Pavements in Canada

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Abstract

Pervious concrete pavement is an eco-friendly pavement system which can offer various and sustainable benefits for stormwater management. It can be considered as an alternative to impervious pavement system as the open void structure of pervious concrete pavement allows water to infiltrate very quickly through it and join the natural ground water. Though pervious concrete pavement has been used in parts of Europe and the southern United States for many years, the practice of using it in northern cold climates such as Canada is more recent.

Several pervious concrete pavement field sites were constructed by the Centre for Pavement and Transportation Technology (CPATT) at the University of Waterloo, the Cement Association of Canada, and several other industry members. Initial results from this work have been published previously, and include the performance analysis, permeability evaluation, and strength assessment. However, collecting drainage characteristic data from instruments such as the moisture gauge measurements, strain gauge at three sites have continued to be monitored. This field/laboratory study is providing insight into the short and medium term drainage performance of pervious concrete pavement.

As a continuation of previous work, this paper discusses the effect of mix design in the performance of pervious concrete, the long term drainage instrumentation performance that have been obtained from instrumentation at sites in British Columbia, Ontario and Quebec. An analysis framework is also presented in this paper. The findings from this paper will provide useful information for designers and practitioners on the long term drainage performance of pervious concrete pavement

Keywords: Pervious concrete, Stormwater, Mix design, Instrumentation performance.

1. INTRODUCTION

In recent years, pervious concrete pavement has emerged as a potential sustainable solution to traditional design. It has a porous structure with 15%-30% of voids, which renders pervious concrete the characteristics to drain water very quickly. Pervious concrete is documented as the paramount in storm water management by the United States Environmental Protection Agency (Rhead, 2012).

There are many other benefits associated with pervious concrete such as water filtration, absorbing heavy metal, pollution reduction etc. (Henderson, 2009). But the stormwater management excellence makes it novel as it has the lowest impact on the natural hydrological cycles. It is a substitute of Low Impact Development (Henderson, 2012).

Though pervious concrete has been used for years in southern parts of states, but this technology is new in cold climate like Canada (Henderson, 2008). To observe the performance of pervious concrete, the Centre for Pavement and Transportation

Technology (CPATT) at the University of Waterloo in partnership with other industry members constructed pervious concrete test sides in different provinces of Canada.

In this paper a comparative study of the performance of different sites has been conducted. From this comparison, the effect of mix design on performance can be drawn. The drainage methodology, rain event and movement of moisture in the structure, analysis criteria are also presented.

2. PERVIOUS CONCRETE SITES

Five pervious concrete test sides were constructed (Henderson, 2012). These sites include:

- Site 1, Georgetown, Ontario;
- Site 2, Campbellville, Ontario;
- Site 3, Maple Ridge, British Columia;
- Site 4, Barrie, Ontario; and
- Site 5, Laval, Quebec.

According to Koppen Climate Classification, Site 1 and 2 are in a Dfa climatic zone, which means cold winter, hot summer and adequate moisture throughout the year. Site 3 is in a Cfb climatic zone, which is mild wet winter and short warm moist summer. Site 4 and 5 are in Dfb zone, which is Cold winter, warm summer and adequate moisture throughout the year (Schultz, 2004). Figure1 shows the locations of all the sites.

Figure 1: Field Sites (Henderson, 2012)

To observe the movement of water through the pavement structure and verify the performance of pervious concrete pavement, Site 3, 4 and 5 were instrumented with moisture gauges and Site 3 was also instrumented with strain gauges as well. The detailed mix design of each site is presented in Table 1.

Table 1: Mix Detail in the Pervious Concrete Sites (Henderson, 2012)

Site Section	Aggregate		Fine Aggregate (%)	Water to Cement Ratio (W/C)	Air Entrainment	Fibres	Other Admixtures
	Type	Size (mm)					
1	Gravel	13.2	0	0.244	Yes (29.8 ml/m^3)	Yes	Super Plasticizer (350 ml/m^3) Retarder (100 ml/m^3)
2	Pea Gravel	10	0	0.231	Yes (24.9 ml/m^3)	Yes (0.6 kg/m^3)	Super Plasticizer (375 ml/m^3) Retarder (100 ml/m^3)
3A	Felsic/Mafic Volcanics	14	0	0.29	No	No	N/A
3B	Felsic/Mafic Volcanics	14	0	> 0.29	No	No	N/A
4A	Limestone	14	Yes	N/A	No	No	N/A
4B	Gravel	20	Yes	N/A	No	No	N/A
4C	Gravel and Limestone	20	Yes	N/A	No	No	N/A
5A	Granite	14	Yes (7.6 %)	0.286	Yes (250 ml/m^3)	Yes	Super Plasticizer (1.5 l/m^3) Viscosity Modifier (1.5 l/m^3)
5B/5D	Granite	14	Yes (8.2 %)	0.252	Yes (250 ml/m^3)	No	Latex (Styrene Butadene) (34.0 l/m^3) Super Plasticizer (1.5 l/m^3) Viscosity Modifier (1.5 l/m^3)
5C	Granite	14	Yes (7.6 %)	0.286	Yes (250 ml/m^3)	No	Super Plasticizer (1.5 l/m^3) Viscosity Modifier (1.5 l/m^3)

3. COMPARISON IN INITIAL PERFORMANCE

In this section a brief comparison of the initial performance of the field sites is presented.

3.1 Mix Design and Void Content

It has been noted from the data that mix design can affect the void content in the pavement. Type and size of aggregate, presence of admixture, fine aggregate, w/c ratio, proportion of all material etc. can change the mix design.

3.1.1 Type of Aggregate

As shown in Table 1, various kinds of aggregate such as felsic/mafic volcanics, crushed limestone, natural gravel and crushed granite from various sources were used in these projects. Figure 2 shows the relationship among aggregate, void content and density.

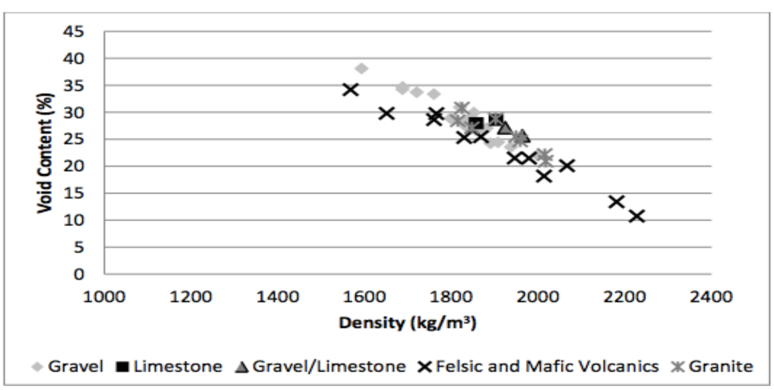


Figure 2: Void Content and Density of Cores with Different Aggregate Types (Henderson,2012)

In most of the cases, void content decreases with the increase of density. All the cores showed linear relationship between air voids and measured densities. The largest range of void content (11% to 34.9%) and density (1580 to 2210 kg/m^3) was found in cores containing felsic and mafic volcanic aggregate types. Cores with gravel aggregate show more consistency with a lower range (void content 23%-28% and density 1600-1980kg/m^3). The 20% to 30% void content range with a density range of 1800 kg/m^3 to 2000 kg/m^3 were found in cores that contained limestone, gravel and limestone, and granite.

3.1.2 Aggregate Size

The effect of aggregate size on percentage of voids and density is presented in Figure 3

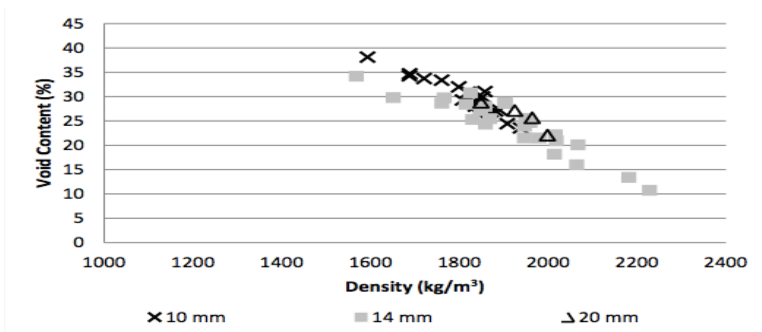
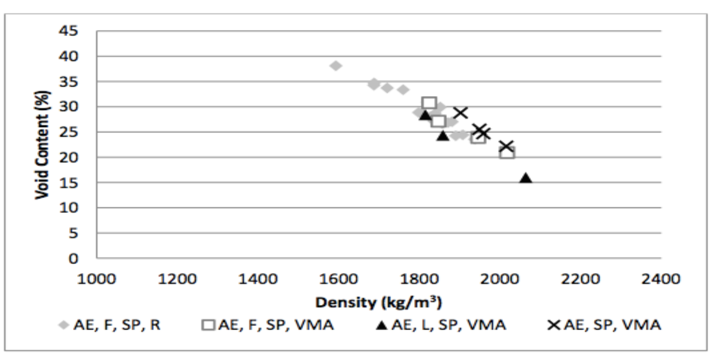


Figure 3: Void Content and Density of Cores with Different Sizes of Aggregate (Henderson, 2012)

The size of aggregate used in these projects ranged from 10 to 20 mm. A linear relationship between voids and density was found in all sizes of aggregate. A slight different visual appearance can be noticeable between 10mm and 14mm aggregate.

3.1.3 Admixture

As shown in Table 1, at different sites, different types of mix design with different admixture (i.e. air entrainment; super plasticizer; retarder; fibres; latex (Styrene Butadene); and viscosity modifier.) were used. Figure 4 describes the effect of different combination of admixture on void content and density.



Note: AE – Air Entrainment; F – Fibres; L – Latex (Styrene Butadene); SP – Super Plasticizer; R – Retarder; VMA – Viscosity Modifer Admixture

Figure 4: Void Content and Density of Cores with Admixtures (Henderson, 2012)

A linear relationship has been found. The cores without VMA shows higher void content and lower densities than the cores with it.

3.1.4 W/C Ratio

In these projects, w/c ratio ranged from 0.23 to more than 0.29 was used in all the sites. No obvious trend in relationship was detected. Though increased w/c ratio minimize the minimum void content in most of the cases but the average remains the same.

3.2 Fine Aggregate

From Table 1, it can be noted that, of the mix design of five sites, three sites contain no fine aggregate, while the other two contain fine aggregate. The influence of fine aggregate on void content and density is presented in Figure 5.

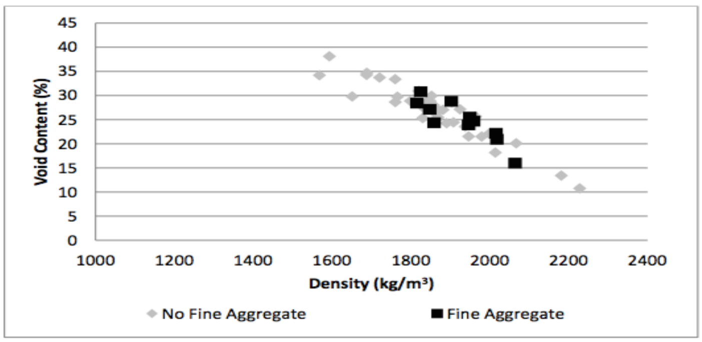


Figure 5: Void Content and Density of Cores with and without Fine Aggregate (Henderson, 2012)

With fine aggregate the result is not so poor. Percentage of void content ranges from 15% to 30% and density ranges from 1800 to 2050 kg/m3. This result represents, with proper mix design, inclusion of fine aggregate not necessarily reduce the percentage of void. Rather it also renders more durability, as there is more surface area and point of contact with inclusion of fine aggregate.

3.3 Effect on Permeability

Figure 6 presents the permeability performance of all the sites, which ranges from 24 to 48 months in-service. Initial permeability shows that Site 1, 2 and 4 provide high permeability. Site 3 and 5 exhibits a lower initial permeability rate though it was more than the maximum rainfall rate initially. From the intensity duration frequency curve, the maximum rainfall rate was calculated for each site area (Environment Canada, 2007).

Permeability gradually decreased in all the sites at a very slow rate. But decreased with a steep rate in Site 3 and 5 especially Site 3B. The probable reason behind this is the surrounding condition of the site. The pores of the pavement appear to have been sealed within a very short time.

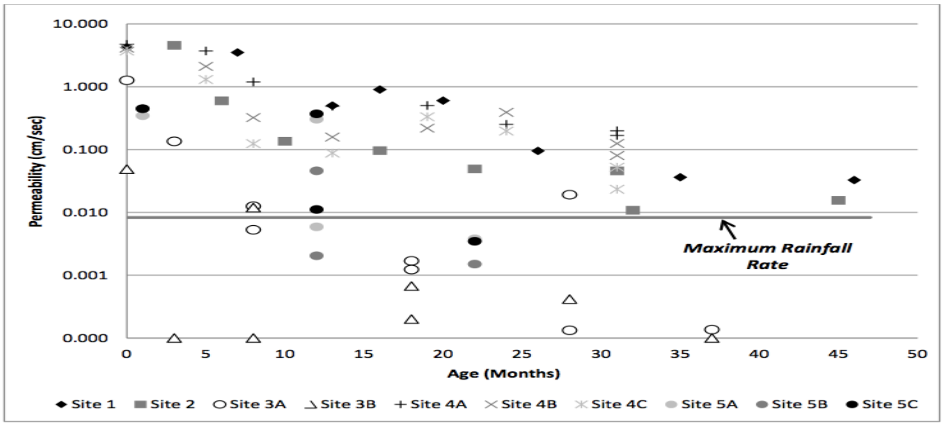


Figure 6: Field Site Permeability

3.4 Surface condition

The surface condition of all the sites at the end of observation period is presented in Table 2.

Table 2: Surface Condition adapted from (Henderson, 2012)

Site	Post construction Observation Period (months)	Overall Surface Condition	Possible Explanation
Site 1	48 (4 years)	80-100 Slight raveling, less than 10% severe raveling, less than 10% surface abrasion and 50-80% of slight joint raveling.	Climatic condition.
Site 2	48 (4 years)	80-100% moderate slab raveling, 80-100% moderate joint raveling, less than 10% very severe potholes, less than 10% cracks with raveling, 80- 100% paste loss.	Climatic condition and Improper mix design.
Site 3	36 (3 years)	80% surface sealing, 50-70% of moderate raveling in slab and joints, less than 10% of slight cracking.	Surrounding condition of the site as the climate was favorable.
Site 4	40 (3 years 4 months)	10-20% of surface raveling, 10-20% of surface abrasion, less than 10% fractured aggregate and 20-50% of moderate raveling adjacent to the joint.	Climatic condition.
Site 5	24 (2 years)	10-20% slight and moderate raveling, sand on surface, slight meandering cracking adjacent to the joint.	Climatic condition and surrounding condition of the site.

3.5 Summary

From the overall results, it was observed that Site 1 performed well compared to the other sites, though it was in the cold winter and hot summer climatic zone. With gravel aggregate, higher void content can be obtained while with the other types of aggregate and sizes of aggregate, optimum void content can be obtained. Viscosity modifier admixtures provided lower void content. But if the surface condition is also evaluated, those sections containing super plasticizer such as site 1 showed satisfactory performance. To determine the effect of w/c ratio, the two sections of Site 3, with the same mix design but the w/c ratio, can be considered. It was observed that in section 3A, which has a higher w/c ratio, more slab and joint raveling was seen. Conversely, slight cracking was more prominent on section 3B with a lower w/c ratio. Site permeability was observed to relate to both the mix design and the surrounding condition. Initial permeability at site 1, 2 and 4 was very good and with time it decreased as would be expected. This is related to clogging of the pores and with maintenance it improved. Site 3 and 5 showed moderate initial permeability but decreases steeply in a short time. The probable reason behind this could be a improper mix design. The surface condition and possible reasons is described in Table 2.

4. LONG TERM DRAINAGE VARIFICATION

As described earlier, moisture gauge sensors were installed in the field sites to observe the water movement in the pavement. In this paper the detailed description and instrumentation performance at the end of five years of one of the sites (Site 3) is presented.

4.1 Site Description

In the Spring of 2008, Rempel Brothers Concrete in partnership with CPATT and the Cement Association of Canada, constructed pervious concrete test areas in Maple Ridge, BC. Personal vehicles, loaded and unloaded concrete trucks, were the main vehicles in this parking area. 3A and 3B are the two 1m wide sections in this site. 3A is located on the entrance and 3B is on the exit driveway of the concrete plant.

4.2 Instrumentation

This site, Site 3, was instrumented with 15 moisture gauges at different heights ranging from pervious concrete layer to existing subgrade. There are two sensor trees (A and B) in section 3A and two sensor trees in section 3B (C and D). Figure 7 to Figure 10 represents the sensor trees in Site 3.

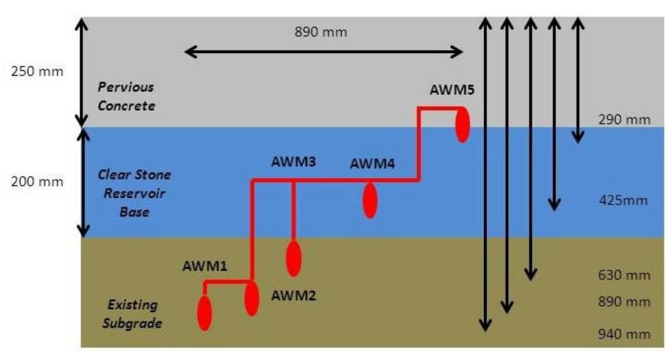


Figure 7: Sensor Tree A at Section 3A

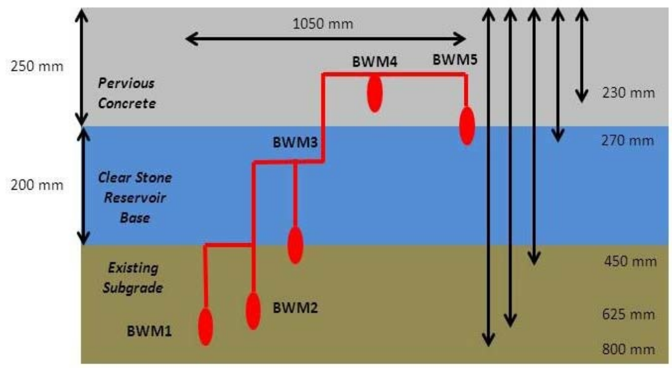


Figure 8: Sensor Tree B in section 3A

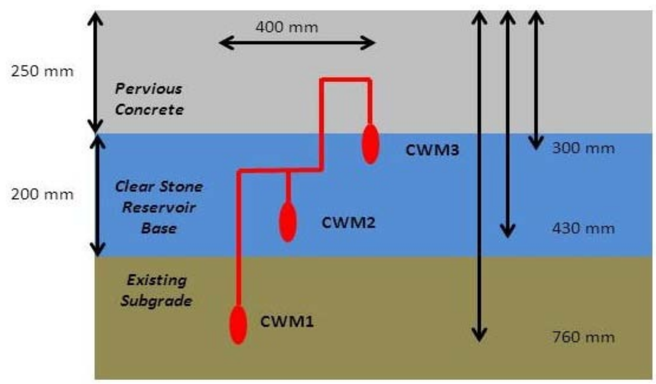


Figure 9: Sensor Tree C in section 3B

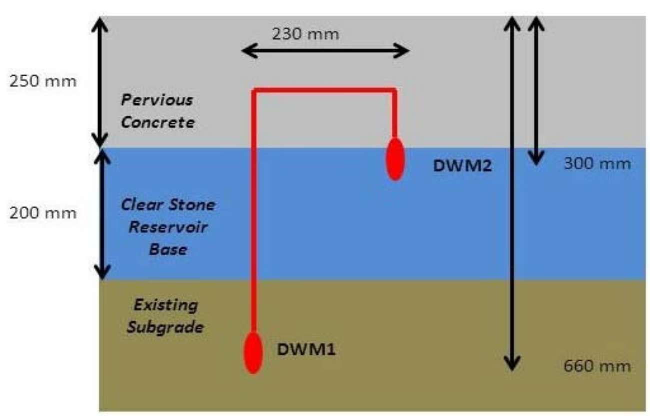


Figure 10: Sensor Tree D in section 3B

A weather station was installed at the site to collect the temperature and precipitation (rain) data. Most of the weather data was collected from the weather station. It was decided that, during the winter, the weather station was brought indoors due to site security and lack of activity at the location and the missing data was collected from the Environment Canada weather station at West Abbey, which is about 15 km away from the site.

4.3 Analysis Methodology

The intent of this paper was to build on the previous work of Henderson to produce moderate term performance measurements. The analysis methodology is thus consistent with the previous work (Henderson, 2012). To represent the season, the weather data is divided in four groups annually. They are: Winter (December to February), Spring (March to May), Summer (June to August), Fall (September to November). To understand the movement of water in the pavement structure, the soil water potential (SWP) data of the largest rain event of each season is presented in this paper. To evaluate the largest rain event of the season from the daily rain data, continual summation of five days rain was used. Preferably a rain event, which was large in quantity and had minimal rain after and before for several days, is taken into account in this paper. It was expected that considering this situation, it would be easy to follow the moisture movement in the structure.

4.4 Instrumentation Functioning

The moisture tree in the pervious concrete field sites was designed to evaluate how water moves through the structure and how water drains through the structure. Field permeability can show only the surface percolation rate but with moisture gauge the drainage methodology can be found out by collecting and analyzing the data. Generally SWP in centibar (cb) is collected from the moisture gauges. When the availability of water is higher then the SWP is lower and vice versa. For example SWP data of the moisture gauge AMW5, which is closest to the surface, during a rain event of 100 mm over 7 days is presented in Figure 11.

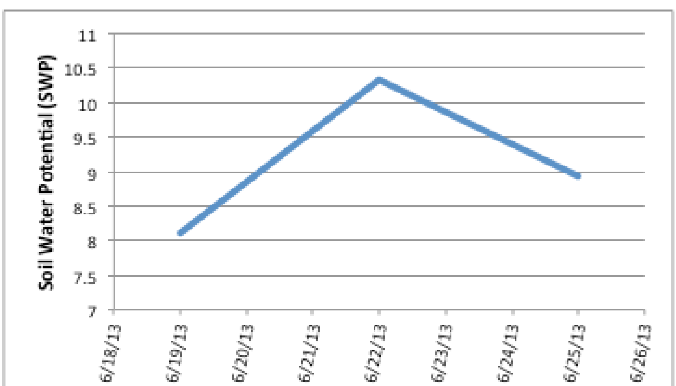


Figure 11: Example of SWP data

It shows that from June 19th to 22nd the slope is positive, which means water is draining away from the instrumentation at a higher rate than it is coming into the area, therefore availability of water is decreasing providing dry soil. After that the slope becomes negative, which indicate the amount of water moving into the instrumented area is higher than that is draining away from it. So, the soil is wet.

4.5 Long Term Performance

One of the initial rain events after construction in winter 2009, with a five days total rainfall of 183 mm, is presented in Figure 12. From the figure it is clear that the SWP value of the moisture gauge AWM5 is the lowest with the high amount of rainfall. It can be easily understood that as AWM5 is the closest to the surface, water is more available to it after rain and the more the water is available the less the SWP value is. SWP of AWM1 (which is lowest in the subgrade) is the highest as it can be assumed that the amount of water is less in the subgrade than surface because of absorption, evaporation etc.

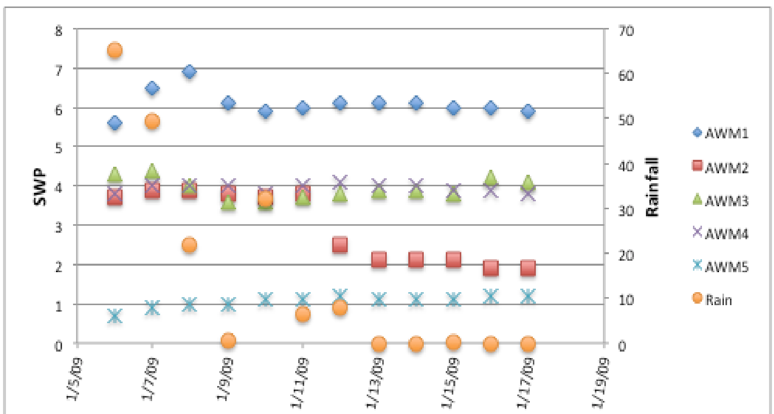


Figure 12: SWP value of sensor tree A in Winter 2009

Figure 13 represents the SWP value of sensor tree A in winter 2013. At that time the amount of rain was much lower than that of winter 2009. From the Figure 12, it can be seen that the SWP values are just opposite of the result of winter 2009. The explanation of this condition is, as less water is available on the surface, SWP of AWM5 is high. But in general subgrade soil can hold some moisture, it remains wetter than the surface, so the SWP of AWM5 is lower.

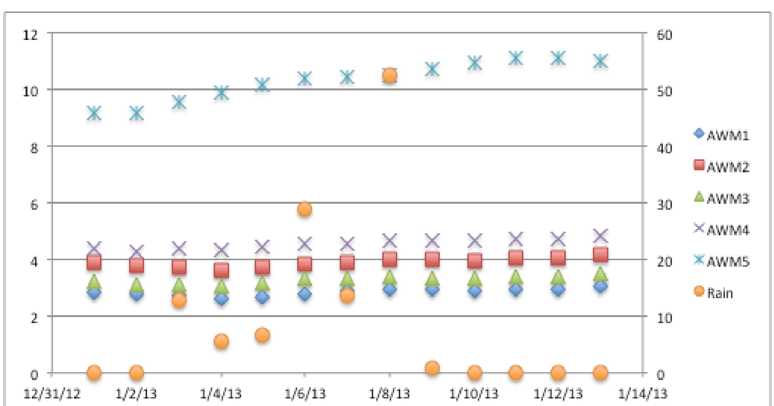


Figure 13: SWP of the Sensor Tree A in Winter 2013

Comparing these two figures, the changes is in SWP value with rain is prominent. It can be assumed that the instrumentations have been working properly.

4.5.1 Moisture Movement with Rain Event

In Table 3, shows the moisture movement into the structure from winter 2013 to fall 2013 (data of recent last one year). Previous moisture movement data (after construction until winter 2011) was presented in work by Henderson (Henderson 2012). The continuation of that work and long term instrumentation performance is presented in this paper.

To evaluate the movement of moisture through the structure, rain event in each season is collected. As noted earlier, rain over five days was initially considered. But, in some cases, extensive amount of rain would occur over more than five days. When deemed appropriate, these events were also included.

The column “Entering Area” in the Table 3 refers to the SWP results showing a negative slope, as shown in Figure 11. Therefore more moisture was draining into the instrumented area than out of it and, which render wet soil. The column entitled “Draining Area” refers to the SWP results showing a positive slope, which renders dry soil as shown in Figure 11. The day that the rain event started is numbered 0. The values in the “Entering Area” and “Draining Area” represent the day(s) after the initiation of the rain event that the behaviour was noticed in the SWP results. The rain event of the year 2013 is presented in Table 4.

Table 3: Moisture Movement in Site 3

Moisture Gauge Location	Date	Time from Rain Event to Instrumented Area (Days)							
		Entering Area				Draining Area			
Pervious Concrete Layer (230 mm) BWM4	Winter 2013	6,8				0,1-5,7,9			
	Spring 2013	0-1,3-5,8,9,13				2,6-7,10-12			
	Summer 2013	4-5, 7-8				0,1-3,6, 9-10			
	Fall 2013	6				0,1-5, 7-9			
Pervious Concrete and Clear Stone Interface (270 mm – 300 mm) AWM5 BWM5 CWM3 DWM2	Moisture Gauge	AWM5	BWM5	CWM3	DWM2	AWM5	BWM5	CWM3	DWM2
	Winter 2013	0,1,2,8	8	3-5,7,8		3-7,9	0,1-7,9	0,1-7,9	
	Spring 2013	0,1,3-6,8,9,11	0,1,3-9,11	0,1-3,7-9,11,13	3,5,7,8	2,7,10,12,13	2,10,12-13	4-6,10,12	0,1,2,4,6,9-13
	Summer 2013	4-10	1,10	1-3,5-9	2-9	1-3	2-9	4,10	0,1,10
	Fall 2013	0,1	3,4,8	0,1,3,6,8	0,1-4,8	2-9	0,1-2,5-7,9	2,4,5,7	5-7,9
Clear Stone (425 mm) AWM4 CWM2	Moisture Gauge	AWM4		CWM2		AWM4		CWM2	
	Winter 2013	0,1,6,8,9		0,1,5,6,8,9		2-5,7		2-4,7,	
	Spring 2013	2-5,8,9,11		0,1-3,7,8,11,13		0,1,6,7,12-13		4-6,9,10	
	Summer 2013	0,1,3-5, 8		0,1-8		2,6-7,9-10		9,10	

	Fall 2013	0,1,3,8,9	3-6,9		2,4-7	0,1-2,7,8	
Clear Stone and Subgrade Interface (450 mm) BWM3	Winter 2013	2,4,6,8,9			0,1,3,5,7		
	Spring 2013	6,10,11			0,1-5,7-9,12,13		
	Summer 2013	1,5,6,7			2-4, 8-10		
	Fall 2013	0,1,5			2-4,6-9		
Subgrade (630 mm - 660 mm) AWM3 BWM2 DWM1	Moisture Gauge	AWxM3	BWM2	DWM1	AWM3	BWM2	DWM1
	Winter 2013	0,1,6,8,9	1,6,8,9	0,2,5,6,8,9	2-5,7	0, 2-5,7	1,3,4,7
	Spring 2013	2-5,9,11	0,6,10,11	0,2,3,6-9,11,13	0,1,6-8,12-13	1-5,7-9,12-13	1,4-5,10,12
	Summer 2013	0,1,4-6,	0,1,5-7	0,1,2,5,6	2,7-10	2-4,8-10	3,4,7-10
	Fall 2013	1-3,8,9	0,1,5	1-3,8,9	0,4-7	2-4, 6-9	0, 4-7
Subgrade (760 mm – 800 mm) CWM1 BWM1	Moisture Gauge	BWM1	CWM1		BWM1	CWM1	
	Winter 2013	0,1,5,8,9	0,1,8,9		2-4,6,7	2-7	
	Spring 2013	2-5,9,11,13	0,3-6,8-10		0,1,6-8,10,12	1-2,11-13	
	Summer 2013	0,1,5	5-6		2-4,6-10	0,1-4,7-10	
	Fall 2013	0,1-3,8,9	3,8,9		4-7	0,1-2,4-7	
Subgrade (890 mm) AWM2	Winter 2013	0,1,6,8,9			2-5,7		
	Spring 2013	2-5,9,11			0,1,6-8,12-13		
	Summer 2013	0,1,5,6,8			2-4,7,9-10		
	Fall 2013	0-3,8,9			4-7		
Subgrade (940 mm) AWM1	Winter 2013	0,1,6,8,9			2-5,7		
	Spring 2013	2-5,9-11			0,1,6-8,12-13		
	Summer 2013	0,1,5,6,8			2-4,7,9-10		
	Fall 2013	0-3,8,9			4-7		

Table 4: Rain Event of 2013 adapted from Environment Canada Mission West Abbey Climate Data (2014)

Winter			**Spring**			**Summer**			**Fall**		
Date	Day	Rainfall	Date	Day	Rainfall	Date	Day	Rainfall	Date	Day	Rainfall
1/3/13	0	12.8	3/1/13	0	36.6	6/19/13	0	41.4	11/1/13	0	34.8
1/4/13	1	5.6	3/2/13	1	14.6	6/20/13	1	33	11/2/13	1	0
1/5/13	2	6.6	3/3/13	2	0	6/21/13	2	0	11/3/13	2	0.6
1/6/13	3	28.8	3/4/13	3	0	6/22/13	3	0	11/4/13	3	2.8
1/7/13	4	13.6	3/5/13	4	0	6/23/13	4	10.2	11/5/13	4	20.4
1/8/13	5	52.4	3/6/13	5	9.6	6/24/13	5	3.8	11/6/13	5	31.4
1/9/13	6	1	3/7/13	6	2	6/25/13	6	11.8	11/7/13	6	3.6
1/10/13	7	0	3/8/13	7	0	6/26/13	7	8	11/8/13	7	0
1/11/13	8	0	3/9/13	8	0	6/27/13	8	1.2	11/9/13	8	0
			3/10/13	9	2.6	6/28/13	9	0	11/10/13	9	0
			3/11/13	10	19	6/29/13	10	0			
			3/12/13	11	76.8						
			3/13/13	12	14.6						
			3/14/13	13	18.2						

From majority of the results from the moisture tree A, it seems that water moves vertically through the structure. For example, in spring, 2013, on day 0 and 1, there was a large rainfall of 36.6 mm and 14.6 mm respectively. It was found that moisture moves through the AWM 5, which is 290 mm below from the surface on day 0 and 1. From day 2 and onwards, moisture was found to move the depth from 425mm to 940mm (from AWM 4 to AWM 1). Moisture moves through all the layers instrumented by sensor tree B on day 0,1 and 2, which indicates that moisture moves from the depth 230 mm to 800mm. Data from sensor tree C also follows the same trend. But DWM 2 does not show any evidence of movement of moisture before day 3, though DWM 1 (which is in subgrade, at the depth 660mm) shows the presence of water from day 0 and 1.

BWM4 and BWM5 did not show any presence of water before day 6 in winter 2013. The probable reason could be that, as the amount of rainfall was not heavy until day 4, water might got absorbed or evaporated before reaching the moisture gauge BWM4 at the depth 230mm. As a heavy rainfall (52.4mm) occurred at day 5, presence of moisture is prominent at day 6 and onward. Although, BWM3, BWM2 and BWM1 show the movement of water from day 0/1.

In some cases, Sensor Tree C and Sensor Tree D act different in comparison to the other sensor tress. Sometimes, CWM3 and CWM2 show continuous increase in moisture though the availability of water from rain was not that high.

4.5.2 Summary

To verify the functionality the analysis of moisture movement is presented in this paper. From the above discussion it is obvious that it is difficult to identify the vertical movement of water in the pavement structure. It can be assumed that continuous movement of moisture has not occurred from the surface to the subgrade due to low permeability, loss of water due to evaporation, absorption etc. In many of the movement data, it was found that rain event occurred but water did not enter even the closest instrumented area. The possible reason of this could be water remains on the surface and evaporated before it started to drain. However, from the moisture gauge results, it can be assured that moisture is moving and draining through various parts of the structure.

5. CONCLUSIONS

As pervious concrete is a growing new technology on Canada, it is very important to research the optimum mix design, the effects of various mix design on the performance, drainage characteristics through the structure in cold climates. In this paper a brief comparison has been done among the field sites that were constructed in Canada. Again, the verification of instrumentation at the end of five years is also presented in this paper, which describes and proves the significant characteristics of pervious concrete pavement to drain water. This paper provides significant information for the designers and practitioners.

6. RECOMMENDATIONS

This research provides unique information related to behaviour and performance of pervious concrete pavement in various provinces in Canada. From the field results, it can be anticipated that pervious concrete pavement can perform well in the severe cold climate of Canada if well designed. Future research related to determine the optimum mix design, relationship between construction method and hardened concrete void content; quality control and quality assurance test methods, routine permeability renewal maintenance program, hourly analysis of SWP data etc. are recommended.

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