Improving Runoff Reduction Potential of Permeable Interlocking Concrete Pavements through Enhanced Detention

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Abstract :

Paved surfaces are one of the most visible features of our urban environment, and impervious surfaces such as roads and parking lots are often considered synonymous with growth and development. Increased hardscape areas contributed to a range of environmental and ecological issues like intensified flooding, riverbank erosion and degradation of water quality and aquatic habitat. Sustainable stormwater systems that follow the principles of Low Impact Development (LID) have been adopted by municipalities around the world, albeit slowly. However, in many jurisdictions around the world developers and municipalities remain skeptical of infiltration-based LID systems like permeable pavements (PP). For sites with low permeability native soils, PPs must include an underdrain to remove excess stormwater during rainfall events. These soil types, owing to their low hydraulic conductivity, do not provide the volume reduction commonly expected from full infiltration PP systems. LID researchers in southern Ontario [1], have observed that holding water temporarily in the PP aggregate reservoir enhances the volume reduction potential by approximately 85%. The current research builds upon those observations and performs testing over two years to verify whether extended detention can significantly enhance total infiltration. This hypothesis is being tested at a pedestrian walkway of Canada Masonry Design Centre (CMDC), Mississauga in Ontario, Canada. The project site has four PICP cells next to each other. Each cell is connected to flow measurement equipment and outfitted with valves. Results of this work will be used to develop best management practices over low permeability soils in the region. This demonstration project can serve to address the stringent stormwater management criterion by Canadian and other municipalities around the world. The improved volume reduction for PPs installed over low permeability soils could lead to wider adoption of PPs.

Key Words : concrete blocks clayey soil; low permeability soil; permeable interlocking concrete pavements permeable pavements detention; stormwater management

1. Introduction

With increased instances of flooding, erosion and habit degradation the management of water resources has become integral to the social and economic development of urban centres. Over time, there has been an increase in public expectations from our stormwater management systems. Permeable Interlocking Concrete Pavements (PICP) are one of the most widespread and commonly used Low Impact Development (LID) technology utilised by Canadian municipalities.

PICPs are used in place of impermeable pavers for onsite stormwater management. PICPs have open joints which are filled with washed coarse aggregate. Stormwater drains through the joints to an underlying aggregate reservoir and onward into the native soils. When a site has low permeability a partial infiltration system allows stormwater toinfiltrate to the soil while surplus water is collected in underdrains located at the base of the aggregate reservoir. The presence of low permeability soil poses a challenge in achieving desired volume reduction from PICPs even with the use of partial infiltration PP systems. Drake et al. (2014) experimented with temporary detention of stormwater by closing the outlet valves of the PP underdrain which resulted in approximately 85% [1]. These tests, however, were performed for only eight rainfall events only during months of November and April and there is a lack of statistical comparison with similar non-detention scenarios. An evaluation with a larger dataset is planned to study the improved volume reduction for PPs installed over low permeability soils through modified operational practices to increase our understanding of how detention time influences volume reductions generated by PPs. The objective of this study to evaluate whether enhanced volume reduction is achieved by temporarily detaining the stormwater in the PICP reservoir over low permeability soil.

2. Experimental Setup

The University of Toronto, in collaboration with Canada Masonry Design Center (CMDC), is conducted a study to test new operational practices for PICP installed in a pedestrian walkway connecting two building on the CMDC campus located in Mississauga, Ontario (Figure 1). CMDC property has low permeability silty clay soil [2]. This PICP walkway was a retrofit from traditional impermeable pavers. Due to partial construction and replacement of only four PICP cells, parts of the old impermeable paver sections drain towards the new PICP cell 4 causing additional inflows for PICP 4. The walkway is constructed right next to two office building, thereby also receiving additional flows from the precipitation reflected off the buildings. All the cells are constructed as partial infiltration systems and monitoring equipment is connected to measure the volume of outflows (Figure 2). Precipitation is measured on site with a Pluvio weighing precipitation gauge. The four PICP cells consist of different PICP products in a mixed configuration (color, void space etc.), shown in Figure 3 and summarized in Table 1.

Outflow response with and without extended detention was measured for PICP 2 and PICP 3 between July 2016 and November 2017. For a detention event the outlet vales were closed which led to accumulation of water in the PICP aggregate layers and slow infiltration into the ground. For the non-detention event, the valves were left open and the water could drain freely.



Figure 1. Aerial view of the test site
(Mapping Source: Google Earth, 2016)



Figure 2. Tipping bucket for Flow Monitoring
Connected to HOBO ® data loggers



Figure 1. PICP products at CMDC

Table 1. Summary of PICP types

Cell number	Dimension	Product
1	4.66m × 7m	Permacon® Subterra
2	4.80m × 7m	Santerra® Terra-Flo
3	4.82m × 7m	Oaks® Hydro'eau
4	2.48m × 7m	Oaks® Enviro Passagio

3. Results and Discussion

In all, eighty-one precipitation events were monitored of which 36 included extend detention. From herein, rainfall events with extended detention in the PICP cell are referred to as "detention events" and events without extended detention are referred to as "non-detention events". Table 2 and Table 3 summarize the rainfall characteristics and stormwater volume reductions observed for detention and non-detention events. The duration of detention was affected by the subsequent forecasted rainfall and logistical issues affecting access to outflow valves at the site.

3.1 Detention vs Non-detention

Due to the presence of non-normal data, verified by Shapiro Wilk tests, detention and non-detention data were compared using Mann-Whitney test. Since the small events (i.e. < 6 mm) did not produce any discharge, sample for Mann-Whitney t-test consisted of detention and non-detention processes for medium and large size events. The data for both PICP 2 and PICP 3 was analyzed as a single group as no significant differences were present between discharge data generated from each pavement cell (non-significant difference was determined through a Wilcoxon test) s. The results demonstrated that extended detention significantly increased volume reductions, shown in Table

4. On Comparison to previous studies[1], the total volume reduction observed was very high. This can be attributed to the heterogenous soil conditions at the site. The heterogenous conditions lead to preferential flow paths thereby enhancing the infiltrationinto native soil.

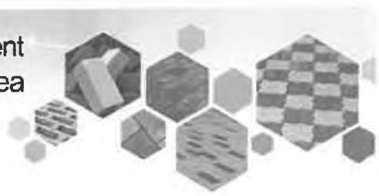

Table 2. Non-DetentionEvents

Event Size	Number of Events	Average Rainfall (mm)	Average Volume Reduction (%)	
			PICP 2	PICP 3
Small (<6 mm)	30	2	100	100
Medium (6–20 mm)	10	12	97	96
Large (>20 mm)	5	32	88	88

Table 3. Detention Events

Event Size	Number of Events	Average Rainfall (mm)	Average Detention (hrs)	Average Volume Reduction (%)	
				PICP 2	PICP 3
Small (<6 mm)	14	2	82	100	100
Medium (6–20 mm)	17	12	64	98	99
Large (>20 mm)	5	33	117	94	96

Table 4. Detention Vs Non-Detention

	Detention	Non-Detention
Mean	97.31	93.76
Mann-Whitney Test*		
Significance (p-value)	0.042	
*Medium and Large Size Events only;		
**Non-Normal Data; Normality of data verified by Shapiro Wilk test;		
***Wilcoxon test between PICP 2 and PICP 3, insignificant difference.		

Table 5 compares effect of detention on similar sized events whereas Table 6 highlights the effect of the detention duration on volume reduction. It can be observed from Table 5 and Table 6 that both detention of stormwater outperformed non-detention and increase in detention duration had a positive impact on volume reduction. Figure

6 illustrates the water level during a non-detention event which shows a sharp change at the beginning of the precipitation. In contrast, shown in Figure 7, the change in water level for a detention event was gradual in PICP

1, 2 and 4. The gradual decrease also illustrates the steady infiltration into the underlying soils during detention event, increasing the overall infiltration. A maximum water saturation of up to 29% was observed during non- detention and 56% for detention events. PICP 1 and PICP 4 demonstrated the highest maximum water level. This may be attributed to the additional surface flows received from adjacent infrastructure. The rate of drawdown had a similar trend for the PICP 1 and 4. This trend was different for PICP 2, which experienced less volume of water per unit area compared to PICP 1 and PICP 4. PICP 2 reached the steady state earlier that the other pavements after infiltration of the detained water.

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Table 5. Detention Vs Non-Detention

Category	Date	Rainfall (mm)	Detention Duration (hrs)	Volume Reduction (%)	
				PICP 2	PICP 3
Detention	10/20/2016	15.8	67	100	100
Non-Detention	06/29/2017	15.5	-	95	95

Table 6. Effect of Detention Duration

Date	Rainfall (mm)	Detention Duration (hrs)	Volume Reduction (%)	
			PICP 2	PICP 3
9/7/2016	15	11	88	89
8/16/2016	15.4	19	92	96
5/21/2017	15.30	58	98	98
10/20/2016	15.8	67	100	100

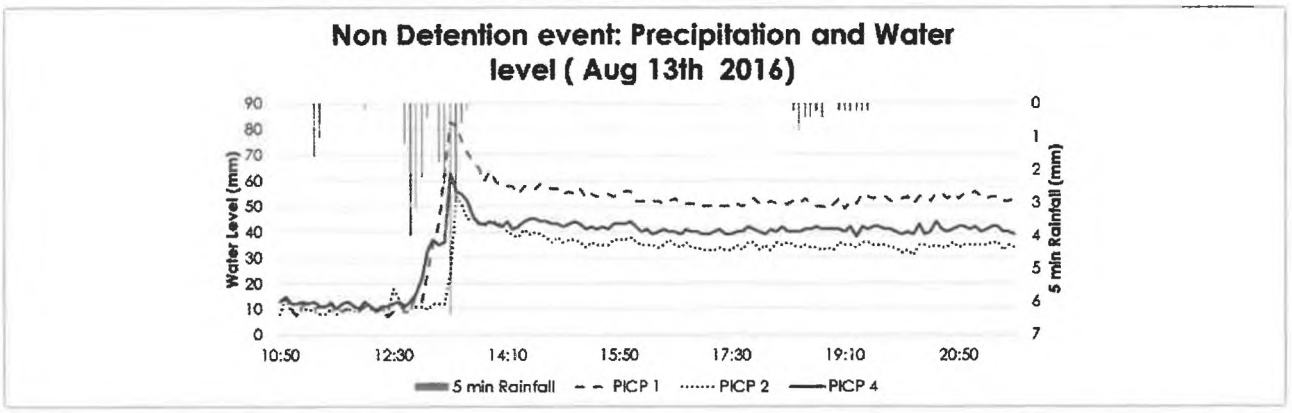


Figure 4. Water Level During Non-Detention

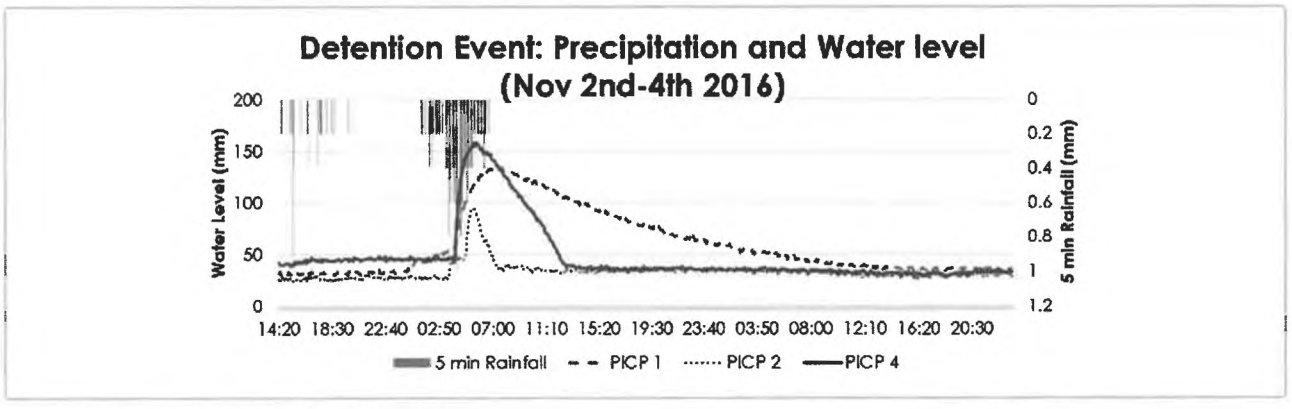
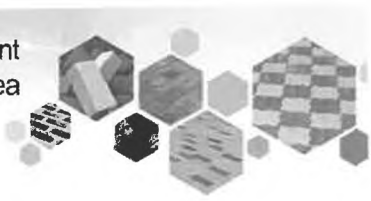


Figure 5. Water Level During Detention

4. Conclusions

It is often difficult to achieve the volume reduction expected from PICP systems on sites with low permeability soils. Eighty-one precipitation events were monitored during with thirty-six detention and forty-five non-detention processes for the infiltrated stormwater in the PICP reservoir. Two PICP cells (PICP 2 and PICP 3) had similar response to volume reduction. For these cells, it was observed that detention of stormwater significantly enhanced the volume reduction in low permeability soil. The duration of detention had a positive effect on the volume reduction. These results present a possibility of achieving a pre-development flow regime and increasing infiltration in low permeability soils by modifying operational practices. Further research and monitoring of precipitation events would be conducted in the third year to monitor more detention and non-detention scenarios which will lead to adoption of smart adaptive infrastructure and modification of best management practices.



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