Surface Infiltration Improvement of Highly Clogged Permeable Interlocking Concrete Pavements

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Abstract
Originally introduced from Germany, permeable interlocking concrete pavements (PICP) have been in use since the mid-1990s in the United States and Canada. Many permeable pavements require regular surface cleaning to prevent a decrease in infiltration rates. Unfortunately, many permeable pavement project owners either ignore or do not have funds to conduct regular surface cleaning, e.g., vacuuming at least one or two times annually. Additionally, permeable pavements demonstrate an accelerated clogging rate as a function of contributing impervious drainage area, and corresponding sediment deposition. This leads to reduced surface infiltration rates. This highly clogged condition defeats the purpose of permeable pavements to reduce stormwater runoff and pollutants. This paper provides background to PICP surface infiltration research and cleaning. This includes experience with vacuum equipment. It then presents before-and-after surface cleaning infiltration data for street, alley and parking lot projects using equipment that combines vacuum and high pressure washing. With other equipment, this technology shows promise in restoring the surface infiltration rate of highly clogged PICP with low infiltration rates that has not received regular surface cleaning.

Key Words: permeable interlocking concrete pavement maintenance; permeable interlocking concrete pavement surface infiltration; permeable interlocking concrete pavements surface cleaning

Background

The primary purposes of permeable pavements are reducing stormwater runoff and filtering sediment while providing pedestrian or vehicular pavement. Permeable pavements require regular cleaning to remove accumlated sediment from the surface. This is achieved by applying water while vacuuming their surfaces. According to Eisenberg [1], there are at least three types of cleaning equipment: (1) a mechanical sweeper generally used with no vacuum force, (2) regenerative air that recirculates air rapidly to create a vacuum force within a intake orifice about 2 m wide, and (3) a true vacuum which operates like a large-sized home vacuum cleaner with a orifice approximately a meter wide. Examples of these machines are illustrated in Figures 1, 2 and 3.

Figure 1. Street sweeper

Figure 2. Regenerative air

Figure 3. True vacuum machine

Restoration of highly clogged PICP surfaces has been demonstrated by several resarchers. Early research by James [2] revealed differences in infiltration rates by removing the top ~30 mm of sediment-filled permeable aggregate typically used in PICP. Chopra [3] clogged PICP as well as other permeable pavements with sediment and measured surface infiltration rates after cleaning with true vacuum equipment. The equipment cleaned out sediment and jointing aggregates thereby recovering surface infiltration. Drake [4] noted that PICP had a higher surface infiltration rate after cleaning than pervious concrete or porous asphalt. Winston [5] reports results from a mechanical sweeping truck with no accompanying vacuum force, a regeneratie air truck, and true vaccum truck on PICP in Ohio and North Carolina, USA. The North Carolina site was cleaned with a mechanical sweeper on successive days followed by a regenerative air machine. Unlike sweeping alone, regenerative air equipment demonstrated that its suction enabled cleaning within the PICP joints, thereby increasing surface infiltration rates. At the Ohio site, cleaning with a true vacuum truck was done twice with each cleaning separated by a year. A true vacuum truck exterts a higher vacuum force than a regenerative air machine. The initial cleaning required one pass of the truck with a vacuum truck to attain near new-construction surface infiltration rates. A year later, three passes were required to attain 9,000 to 10,500 mm/hour infiltration rates measured a year earlier after cleaning.

Without regular vacuum maintenance, the infiltration rate of PICP decreases and will require a substantial effort in cleaning. Lucke [6] showed that without regular maintenance, sediment migrates to the bedding course beneath the PICP. This author observed that the degree of sediment settling into the jointing and bedding layer aggregate explained why surface infiltration rates could not be restored to that of new PICP installation. In addition, Kazemi [7], Winston [8], and Kevern [9] among other researchers have demonstrated that the amount of adjacent area contributing impervious drainage is positively correlated to sediment deposition onto permeable pavements. Besides sediment from erosion and vehicular traffic, the authors of this paper have witnessed the erosion of adjacent (upslope) asphalt pavement as a major contributor to sediment deposition in PICP. This is illustrated in Figure 4 below.

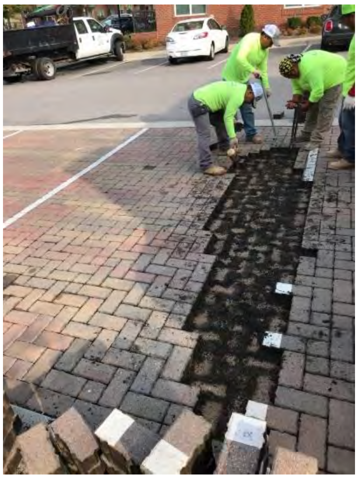

Figure 4. An adjacent asphalt surface erodes and clogs PICP

The answer to the question of when cleaning is needed varies. Boogaard [14] examined 15 PICP sites in The Netherlands with up to four years in age with no surface cleaning. These sites had surface infiltration rates between almost 50 and over 500 mm/hour. While as new pavements, they met Dutch recommendations for minimum new surface infiltration of 97.2 mm/hr (270 l/sec per ha), they would have not met the minimum 2500 mm per hour for new PICP recommended by ICPI. The reason for the difference in recommendations is ICPI guidelines recognize substantial loss of surface infiltration over time, especially if there is runoff entering from adjacent impervious surfaces. In addition, ICPI guidelines use as measurement method for infiltration that assesses the number of minutes water ponds on the surface, a key indicator of when surface cleaning is needed. This is an important consideration in surface infiltration testing because there is no established relationship of surface infiltration to rainfall intensity unless rainfall is simulated as part of the test procedure. For these reasons, ICPI recommends 500 mm/hour as a threshold for surface cleaning. This paper illustrates that infiltration rates as low as 150 mm/hr involves time-consuming, expensive multiple passes with vacuum equipment to increase surface infiltration to levels above 2500 mm/hour.

The aforementioned research and field reports motivated the Interlocking Concrete Pavement Institute (ICPI) to publish a technical bulletin on PICP maintenance called ICPI Tech Spec 23 *Maintenance Guide for Permeable Interlocking Concrete Pavements* [10]. This provides a guide for field personnel who conduct inspection and maintenance. The bulletin includes an inspection checklist and a single-ring surface infiltration test, ASTM C1781 *Standard Test Method for Surface Infiltration Rate of Permeable Unit Pavement Systems*. Besides indicating a surface infiltration rate (not related to rainfall intensity), this test indicates how long water ponds on a PICP surface prior to complete infiltration into the surface. This length of time as a function of infiltration rate is illustrated in Figure 5.

Time to infiltrate water		Approximate surface infiltration rate inches/hr (mm/hr)	
Minutes	Seconds	8 lbs. (3.6 kg) water	40 lbs. (18 kg) water
0.5	30	235 (5,913)	1,175 (29,564)
1	60	117 (2,956)	587 (14,782)
2	120	59 (1,478)	294 (7,391)
4	240	29 (739)	147 (3,696)
6	360	20 (493)	98 (2,464)
8	480	15 (370)	73 (1,848)
15	900	8 (197)	39 (985)
30	1800	4 (99)	20 (493)
60	3600	2 (49)	10 (246)

Note: $I = (K \cdot M)/(D^2 \cdot t)$, where
I = Surface infiltration rate, in./hr (mm/hr)
K = 126,870 for US customary units (4,583,666,000 for metric)
M = water mass, lbs (kg)
D = ring diameter (12 in. or 305 mm)
t = time for water to infiltrate in seconds

- Acceptable performance > 100 in./hr (2,500 mm/h)
- Plan to clean soon
- Clean immediately < 20 in./hr (500 mm/hr)

Figure 5. ICPI guidelines for PICP cleaning per ASTM C1781 results

ICPI recommends that if at least 20% of the PICP surface has an infiltration rate of less than 500 mm/hour, or remains for over 30 minutes using ASTM C1781 test method, vacuum cleaning should be conducted [10]. This recommendation is based on permeable pavement surfaces with sloped surfaces. In such cases, ponding water would run off thereby defeating the function of permeable pavement. Ponding from sediment deposition often starts the junction of permeable and impervious pavement when present.

Examples of Restoring PICP Surface Infiltration

The following presents pre- and post-infiltration rates for eight PICP sites and one pervious concrete site located in the Toronto, Ontario, region of Canada. All sites received no previous surface cleaning were three to ten years old. Most sites received runoff and sediment from adjacent impervious pavement. Sites were cleaned with a machine by Cyclone Technology LLC. This equiopment was orginially developed to clean aircraft tire rubber from runways. The machine applies a hot water, high pressure spray (up to 30 MPa) via a rapidly spinning head. The spinning creates a vacuum force sufficient to extract sediment and jointing aggregates from PICP. Extracted water and materials are stored in the Cyclone truck.

The following figures illustrate the PICP sites. Some show the extent of impervious pavement contributing runoff into the PICP. The number of passes of the Cyclone equipment are indicated.

Figure 6. Elm Drive, Mississauga parking lane center parking lot, Vaughan – 8 passes, ~5 years old

Figure 7. Gregwood Road. Mississauga parking lane – 8 passes, ~5 years old

Figure 8. Kortright Center entry – 14 passes, 10 years old

Figure 9. Kortright Centre, parking lot, Vaughan, 6 passes – 8 years old

Figure 10. Kortright Centre, parking lot, Vaughan, 6 passes – 9 years old

Figure 11. Kortright Centre parking lot, Vaughan, 6 passes – 9 years old
Figure

Figure 12. Walter Fedy AEC, Kitchener – 3 years old, 8 passes

Figure 13. Driveway/parking lot on Mill Street, Kitchener – 9 years old, 8 passes

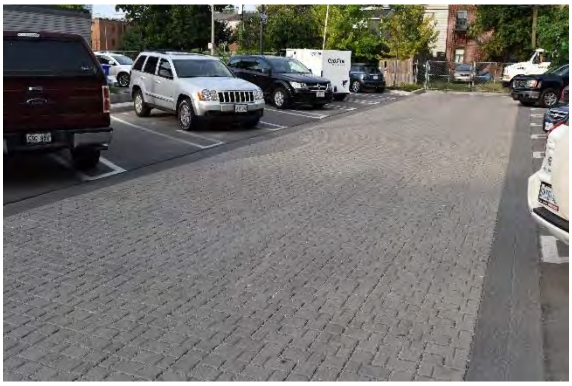

Figure 14. Broadview Avenue, Toronto – 5 years old, 10 passes

The sites shown in Figure 12 and 13 were cleaned with 8 passes of the Cyclone equipment, Figure 14 with 10.

Infiltration Restoration

The surface infiltration rates before (initial) and after cleaning are shown in Figure 15. All of the post-cleaning infiltration rates do not meet the minimum 2500 mm/hr recommended by ICPI. Two PICP sites at the Kortright Centre may have been previously clogged by using a pressure washer in an attempt to remove sediment. The low post-cleaning infiltration rates suggest that pressure washing may have moved sediment deeper into the pavement.

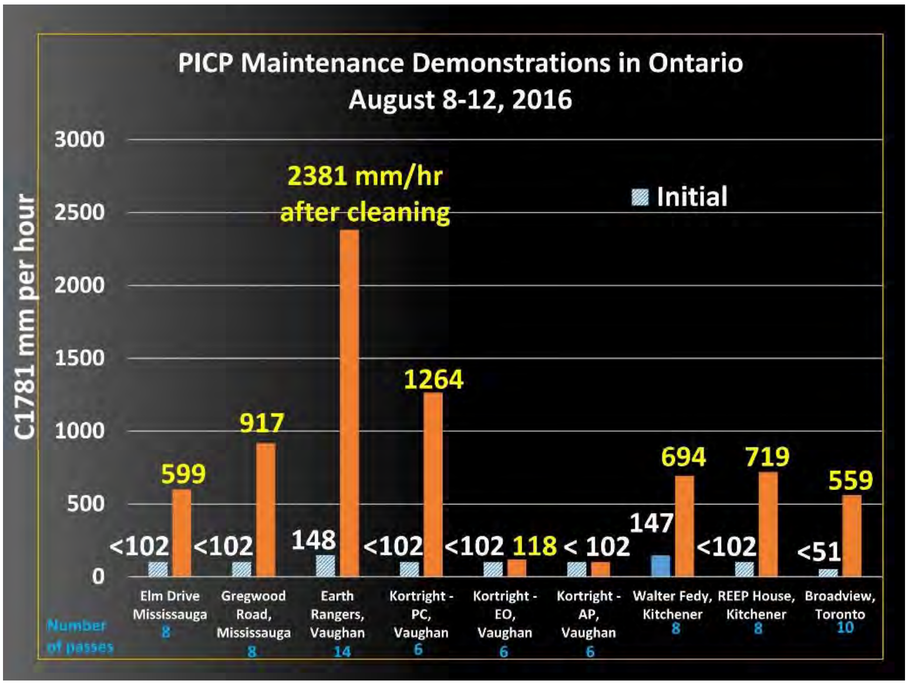

Figure 15. Pre- and post-vacuuming cleaning

Surface Cleaning in Wisconsin, USA

Non-trafficked porous asphalt, pervious concrete and PICP (three paver types) were evaluated side-by-side to measure decreases in surface infiltration and water quality improvements from stormwater runoff originating from an impervious asphalt parking lot in Madison, Wisconsin. The project has resulted in the Wisconsin Department of Natural Resources (WDNR) providing pollution reduction credits for total suspended solids when using a no-infiltration permeable pavement. WDNR provides additional pollution credits to developers for using designs that infiltrate runoff into the soil subgrade. Monitoring began in 2014 with a 10:1 impermeable contributing drainage area (CDA) from the impervious asphalt parking lot at the park. The results of two years of monitoring (ending October 2016) are reported in a detailed by Selbig [11].

The experimental design with a 10:1 CDA from the asphalt parking lot delivers sediment from the asphalt. While not recommended for permeable pavement projects, this experiment intentionally accelerated the clogging of the surface with the 10:1 CDA ratio in order to measure the sediment trapped in the surface and structure. After loading the surfaces with sediment,and monitoring concentrations for one year, the surfaces were cleaned with a Cyclone machine in 2017 and the contributing drainage area reduced to 5:1 to study differences in sediment loading. Surface infiltration rates were measured using ASTM C1701 *Standard Test Method for Infiltration Rate of In Place Pervious Concrete* as shown in Figure 16. This test method is similar to ASTM C1781, making data from each test method comparable. The white circles indicate surface infiltration measurement locations.

Figure 16. PICP surface infiltration measurement locations

Figures 17 and 18 illustrate before and after surface infiltration rates when cleaned with a Cyclone machine for PICP and for pervious concrete. There was no data available for porous asphalt due to it being removed prior to cleaning the other permeable pavements. The Cyclone machine applied water at 30 MPa pressure while the sprinkler head rotated at 1600 revolutions per minute. The water was applied at approximately 19 l/minute at 71° C. The 80 mm thick PICP was one year old and the 150 mm thick pervious concrete was approximately 9 months old. The Cyclone made one pass on the PICP with overlaps and three passes on the pervious concrete. While not shown in Figure 18, the locations for taking nine surface infiltration measurements on the pervious concrete were approximately the same as the PICP since both areas were 46 m^2. Sediment in runoff from the adjacent impervious parking lot was distributed evenly across all permeable pavements.

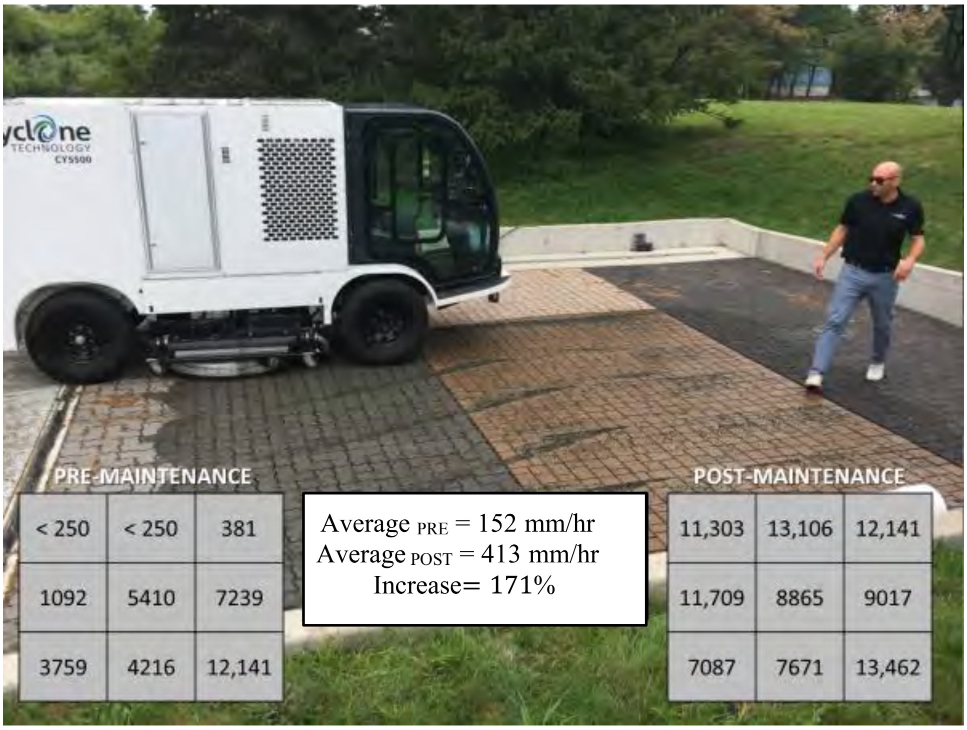

Figure17. PICP Surface infiltration results

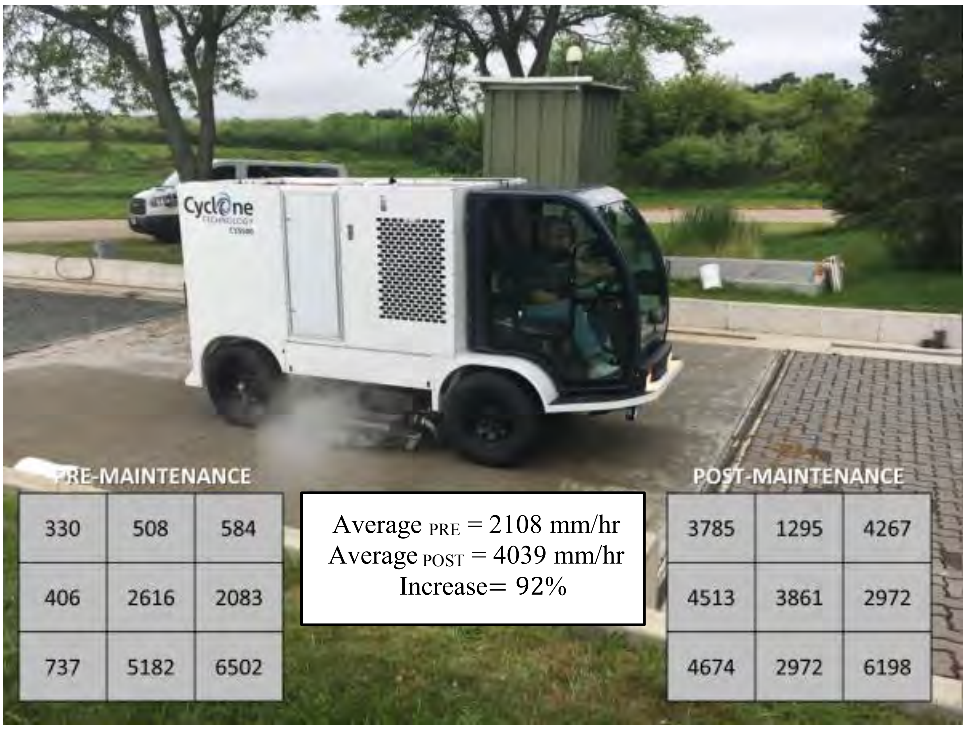

Figure 18. Pervious concrete surface infiltration results

Besides true vacuum equipment, the Cyclone machine can be used to restore low-infiltration rate PICP. The machine must not be overloaded with sediment and jointing aggregates as they can jam machine operation. This happened at one of the PICP Toronto region sites and on the Wisconsin site.

Conclusions

Never intended as a controlled experimental study, this paper presents case studies that demonstrate the difficulty in restoring surface infiltration rates if regular surface vacuum cleaning is neglected. The PICP sites in the Toronto region had no cleaning and most were over five years old. Their response to cleaning was simultaneously impressive and disappointing. The impressive aspect is cleaning increased infiltration rates from 4 to over 10 times the pre-cleaning infiltration rate. The disappointing aspect is that most of the post-cleaning infiltration rates remain in the range for cleaning per ICPI recommendations, i.e. under 500 mm/hour. This suggests that their low recovery of infiltration after vacuuming likely positions them toward almost complete clogging unless vacuum cleaned regularly.

The Wisconsin site demonstrates the improvement from cleaning within a year of installation. A benefit to this site is that, unlike the Toronto area sites, it did not receive any vehicular traffic that often further pushes sediment into PICP the joints, as well as into the pervious concrete surface. However, that data does demonstrate the potential for rapid reduction of surface infiltration rates with a high contributing drainage area and concomitant sediment deposition. Additonally, all post-cleaning infiltration rates well exceeding 2500 mm/hour rate for acceptance of new PICP and pervious concrete as recomended by their respective industry guidelines.

Maintenance Guidelines

The pervious concrete maintenance guide by NRMCA [12] recommends cleaning if there is an average infiltration rate decrease of 25% from the initial value, or an infiltration rate less than 2500 mm/ hour. The guide also suggest that projects never cleaned and completely clogged should be cleaned to a rate of 2500 to 5000 mm/hour. By comparison, ICPI [13] recommends cleaning when the infiltration rate is below 500 mm/hour or if there is at least 20% area of water ponding on the PICP surface immediately after a typical rainstorm. Compared to 2500 mm/hour as suggested by NRMCA, 500 mm/hour recommended by ICPI may suggest a higher PICP tolerance for sediment deposition prior to cleaning.

After cleaning, ICPI also recommends refilling the joints with clean aggregate and test the surface infiltration to see if a minimum 50% increase in infiltration occurs, or above 500 mm/hour. Besides a minimum twice annual cleaning, ICPI also recommend adjusting the cleaning intervals depending on sediment deposition, intensity of use by vehicles, and climate. ICPI further recommends the following maintenance actions annually:

- Replenish aggregate in joints if more than 13 mm from chamfer bottoms on paver surfaces
- Inspect vegetation around PICP perimeter for cover and soil stability, repair/replant as needed
- Inspect and repair all paver surface deformations exceeding 13 mm
- Repair pavers offset by more than 6 mm above/below adjacent units or curbs, inlets, etc.
- Replace cracked paver units impairing surface structural integrity
- Check drain outfalls for free flow of water and outflow from observation well after a major storm

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