Maintenance for Preservation and Recovery of Permeable Pavement Hydraulics: Effects of Vacuum Cleaning, High Pressure Washing, Street Sweeping, and Milling

Entretien pour la préservation et le rétablissement des caractéristiques hydrauliques de chaussées perméables : effets de l'aspiration, du lavage à haute pression, du balayage et du fraisage

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RÉSUMÉ

Les taux d'infiltration de surface (SIR) de revêtements perméables diminuent avec le temps car les sédiments et les débris obstruent les espaces poreux. Des techniques d'entretien efficaces sont nécessaires pour assurer la fonctionnalité hydraulique et la qualité de l'eau de ce système de contrôle des eaux pluviales. Huit techniques différentes d'entretien, à petite et à grande échelle, visant à récupérer la perméabilité de la chaussée, ont été évaluées sur dix trottoirs perméables aux Etats-Unis et en Suède. Ces techniques d'entretien comprenaient l'enlèvement manuel de la couche de 2 cm de matériau d'obturation, le balayage mécanique de la rue, le nettoyage régénératif de la rue avec de l'air, le nettoyage de la rue par aspiration et par aspiration manuelle, le lavage à haute pression, et le fraisage de l'asphalte poreux. Le retrait de la couche de 2 cm de matériau de colmatage n'a pas significativement amélioré le taux d'infiltration du CGP et le PICP en raison des inclusions dans la jointure et l'agrégat pendant la construction, ce qui semble suggérer que l'entretien de routine ne peut pas pallier une mauvaise construction. Pour l'entretien de l'asphalte poreux, l'aspirateur à main industriel, le lavage sous pression, et le fraisage réussissaient de mieux en mieux à restaurer le taux d'infiltration de surface. Le fraisage à une profondeur de 2,5 cm a presque mieux réussi à faire retrouver un taux d'infiltration de surface presque similaire à celui du neuf, sur un revêtement en asphalte poreux datant de 21 ans. Pour le PICP, les balayeuses à aspiration semblent avoir été préférables aux balayeuses mécaniques. En outre, le travail de maintenance deviendra de plus en plus intensif au fil du temps pour maintenir un seuil de taux d'infiltration de surface, puisque l'entretien n'a pas réussi à 100% à enlever le matériau de colmatage.

ABSTRACT

The surface infiltration rates (SIR) of permeable pavements decline with time as sediment and debris clog pore spaces. Effective maintenance techniques are needed to ensure the hydraulic functionality and water quality benefits of this stormwater control. Eight different small-scale and full-scale maintenance techniques aimed at recovering pavement permeability were evaluated at ten different permeable pavements in the USA and Sweden. Maintenance techniques included manual removal of the upper 2 cm of filling material, mechanical street sweeping, regenerative-air street sweeping, vacuum street sweeping, hand-held vacuuming, high pressure washing, and milling of porous asphalt. The removal of the upper 2 cm of clogging material did not significantly improve SIR of CGP and PICP due to the inclusion of fines in the joint and bedding stone during construction, suggesting routine maintenance cannot overcome improper construction. For porous asphalt maintenance, industrial hand-held vacuum cleaning, pressure washing, and milling were increasingly successful at recovering SIR. Milling to a depth of 2.5 cm nearly restored SIR for a 21-year old porous asphalt pavement to like-new conditions. For PICP, street sweepers employing suction were shown to be preferable to mechanical sweepers; additionally, maintenance efforts will become more intensive over time to maintain a threshold SIR, as maintenance was not 100% effective at removing clogging material.

KEYWORDS

Clogging, pervious concrete, porous asphalt, permeable interlocking concrete pavers, hydraulics

1 INTRODUCTION

Management of parking lot and roadway runoff through innovative stormwater control measures (SCMs), such as permeable pavement, is critical to watershed health and restoration of pre-development hydrology (Dietz 2007). Permeable interlocking concrete pavers (PICP), pervious concrete, porous asphalt, and concrete grid pavers (CGP) have inherent permeability. While many permeable pavement demonstration sites have been built and research into their water quality and hydrologic benefits completed, clogging and maintenance frequency and onerousness are commonly cited concerns with this SCM (Drake and Bradford 2013, Blecken et al. submitted). Newly-installed permeable pavements provide surface infiltration rates (SIR) well in excess of design rainfall rates, meaning they are capable of capturing and treating even infrequent return interval events (Bean et al. 2007, Al-Rubaei et al. 2013). However, build-up of sediment, organic material, and debris in the pavement and aggregate layers causes a decrease in SIR, hampering hydraulic functionality. Factors such as particle size distribution of the runoff sediment, the pore size distribution of the void spaces, presence of trees, surrounding land use, and winter maintenance (e.g., sand application) have been suggested to influence clogging (Bean et al. 2007).

The purpose of this work was to test and compare different maintenance techniques for restoration of permeable pavement infiltration rates. While many permeable pavement applications constructed today accept run-on from impermeable pavement (as opposed to treating only direct rainfall), *none* of these have been examined for maintenance needs. All but two sites tested herein received run-on from impermeable pavement. Simulated maintenance was performed on PICPs and CGPs by removing the upper 2 cm of filling material. Full-scale maintenance was also undertaken on clogged PICPs using a mechanical street sweeper, regenerative air street sweeper, and a vacuum truck. Two clogged porous asphalt streets were maintained using pressure washing, vacuuming, and a combination of vacuum cleaning and pressure washing. Additionally, one of these streets was milled to three different depths (0.5 cm, 1.5 cm, and 2.5 cm) to test whether milling (and subsequent installation of new porous asphalt) could serve to rehabilitate porous asphalt and to determine the milling depth needed to remove the clogging layer.

2 MATERIALS AND METHODS

To test the impact of maintenance on permeable pavement SIR, nine permeable pavements up to 28 years old were visited during 2014 and 2015. The sites were located in North Carolina, USA (2), Ohio, USA (1), Växjö, southern Sweden (4), Luleå, and Haparanda, northern Sweden (2). At the Ohio site, two permeable pavement applications with different characteristics were located in the same parking lot. The sites in the United States were parking lots serving city or institutional facilities, parks, or community centers, while those in Sweden drained lightly trafficked residential or commercial streets. Sites were between 0.5 and 28 years of age at the time of maintenance and were paved with either porous asphalt, CGP, or PICP. Apart from the two porous asphalt roads in northern Sweden, all sites received run-on from impermeable asphalt. These designs are standard in North Carolina, Ohio, and Sweden where loading ratios (ratio of impermeable to permeable pavement) of 1:1, 3:1, and 5:1, respectively, are typically allowed in engineering design (ODNR 2006; NCDENR 2012). Further details on the sites in the United States, northern Sweden, and southern Sweden may be found in Winston et al. (2015), Al-Rubaei et al. (2013), and Al-Rubaei et al. (2015), respectively.

At each permeable pavement site, SIR was monitored immediately before and after maintenance. None of the sites received regularly scheduled maintenance other than occasional mechanical sweeping to remove detritus. At each site, 3-8 SIR testing locations were established for pre- and post-maintenance testing. Testing locations were chosen to capture a diversity of potential clogging factors described in past research (e.g run-on from impermeable surfaces, landscaped areas draining to permeable pavement, locations beneath trees, locations near intersections, etc; Lucke and Beecham 2011).

The single ring, constant head test described in ASTM C1781 for PICP (ASTM 2013) was utilized to measure SIR. A 30-cm diameter metal infiltrometer was sealed to the pavement surface using plumber's putty to prevent lateral leakage. To create an effective seal, plumber's putty was applied to both the inner and outer edges of the infiltrometer. A known volume of water was poured from a nearly-full bucket (typically about 19 liters) into the infiltrometer; water was transferred by pouring as close to the pavement surface as possible to prevent dislodging of the crusted clogging material near the pavement surface. The water level was kept at an approximately constant head of 10 to 15 mm above the pavement surface within the infiltrometer. The total time to infiltrate the known volume of water was recorded, and the SIR calculated as the quotient of the total depth of water applied within the infiltrometer to the time (e.g., mm/min). Duplicate SIR tests were carried out at each testing site both before and after maintenance.

3 RESULTS AND DISCUSSION

3.1 Pressure Washing and Vacuuming of Porous Asphalt

ANOVA tests for the pre-maintenance data sets at each site showed no significant differences (p-values>0.45) in SIR, suggesting existing conditions were similar where the treatments were to be applied. All maintenance treatments produced significantly greater SIRs than pre-maintenance conditions (Figure 1). ANOVA tests on the log-transformed post-maintenance data sets showed significant differences between the treatments at both Luleå (p-value = 0.0064) and Haparanda (p-value = 0.0067). Significant differences were observed between the pressure wash vs. vacuum treatments (p-values = 0.0087, 0.0328) and the pressure wash+vacuum vs. vacuum treatments (p-values = 0.0231, 0.0082) at both sites. No significant difference (p-values = 0.76, 1) was observed between the pressure wash vs. pressure wash+vacuum treatment at either site. While the vacuum treatments did improve the SIR substantially and significantly (3.5 and 6-fold increases in SIR at the two sites), pressure washing as part of any treatment provided the 'lion's share' of the benefit to porous asphalt SIR (Fig). Treatments involving pressure washing increased SIRs by a minimum of 8-fold and a maximum of 467-fold.

Following street sweeping with vacuum cleaning and pressure washing, the mean infiltration rate post-maintenance at Luleå was only 3.48 mm/min (Al-Rubaei et al. 2013). Ten-fold greater SIRs were achieved herein by using a hand-held pressure washer, perhaps due to the lower angle of water application (30˚ herein vs. normal to the pavement surface with the street sweeper) more easily dislodged accumulated sediment. Luleå pavement SIRs were restored to a much greater extent than those of Haparanda. This might be due to the apparent larger pore diameter in cores obtained from the two porous asphalt pavements (Al-Rubaei et al. 2013), allowing the water from the pressure washer to more deeply penetrate the pavement and dislodge sediment.

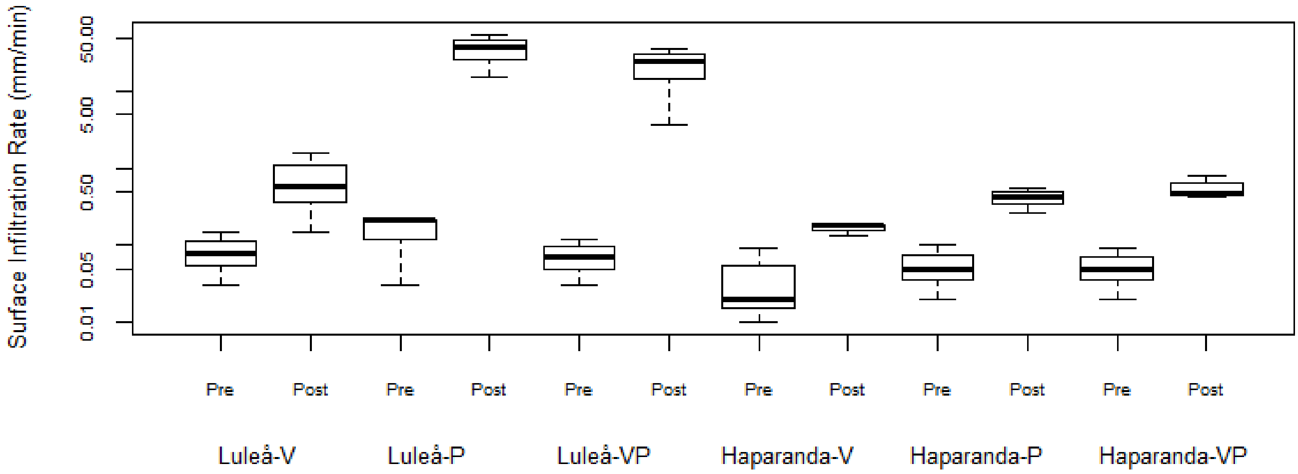

Figure 1. Effects of vacuuming (V), pressure washing (P), and vacuuming with pressure washing (VP) on porous asphalt SIR.

3.2 Milling of Porous Asphalt

Commonly, the majority of sediment accumulates near the surface of a permeable pavement (Bean et al. 2007; Al-Rubaei et al. 2013). Complete removal of the surface clogging layer might be a viable maintenance option. Standard asphalt is milled as a common maintenance practice to rejuvenate the pavement condition without needing to reconstruct the entire road cross-section (Bausano et al. 2004). Three depths of milling (0.5 cm, 1.5 cm, and 2.5 cm, **Erreur ! Source du renvoi introuvable.**) were tested at two test sections of the Luleå porous asphalt roadway to see whether milling restored SIR. Following milling, pressure washing removed debris created by the milling process.

Pre-milling SIR did not vary among the testing locations (ANOVA test, p-value = 0.939), and little variability existed in pre-maintenance pavement SIR (Figure 2). Differences in milling depth treatments were statistically significant (ANOVA p-value = 0.0244). No significant difference existed between the 0.5 cm and 1.5 cm (p-value = 0.87) or the 1.5 cm and 2.5 cm milling treatments (p-value = 0.07). However, the 2.5 cm treatment produced significantly better SIR (p-value = 0.027) than the 0.5 cm treatment. All post-milling SIRs were significantly better than those of pre-milling, and post-milling rates were at least 3 times greater than pre-milling SIRs. Post-milling SIRs also were at least twice those from pressure washing maintenance treatments at the same site.

Milling to a 2.5 cm depth appeared to be the best treatment, producing SIRs roughly three times those of the 0.5 and 1.5 cm depths. In fact, the median infiltration rates of 243 mm/min for the 2.5 cm milling depth was essentially the same for that porous asphalt immediately after construction (290 mm/min, Stenmark 1995), 21 years prior to the milling. The marginal increase in SIR from 0.5 to 1.5 cm milling depth suggested little sediment was present between 0.5-1.5 cm below the pavement surface. However, clearly additional clogging factors were eliminated when milling to a 2.5 cm depth. Three possible explanations for this exist: (1) sediment accumulated at 1.5-2.5 cm depth (not likely based on core samples presented in Al-Rubaei et al. (2013); (2) asphalt binder draindown restricted flow at 1.5-2.5 cm depth, or (3) removing 2.5 cm of asphalt allowed the pressure washer to penetrate more deeply into the bedding course, since the pre-milled pavement thickness was 4.5 cm. Considering all factors, milling (regardless of depth) appeared to be the best method tested for rejuvenation of (even completely) clogged porous asphalt SIRs.

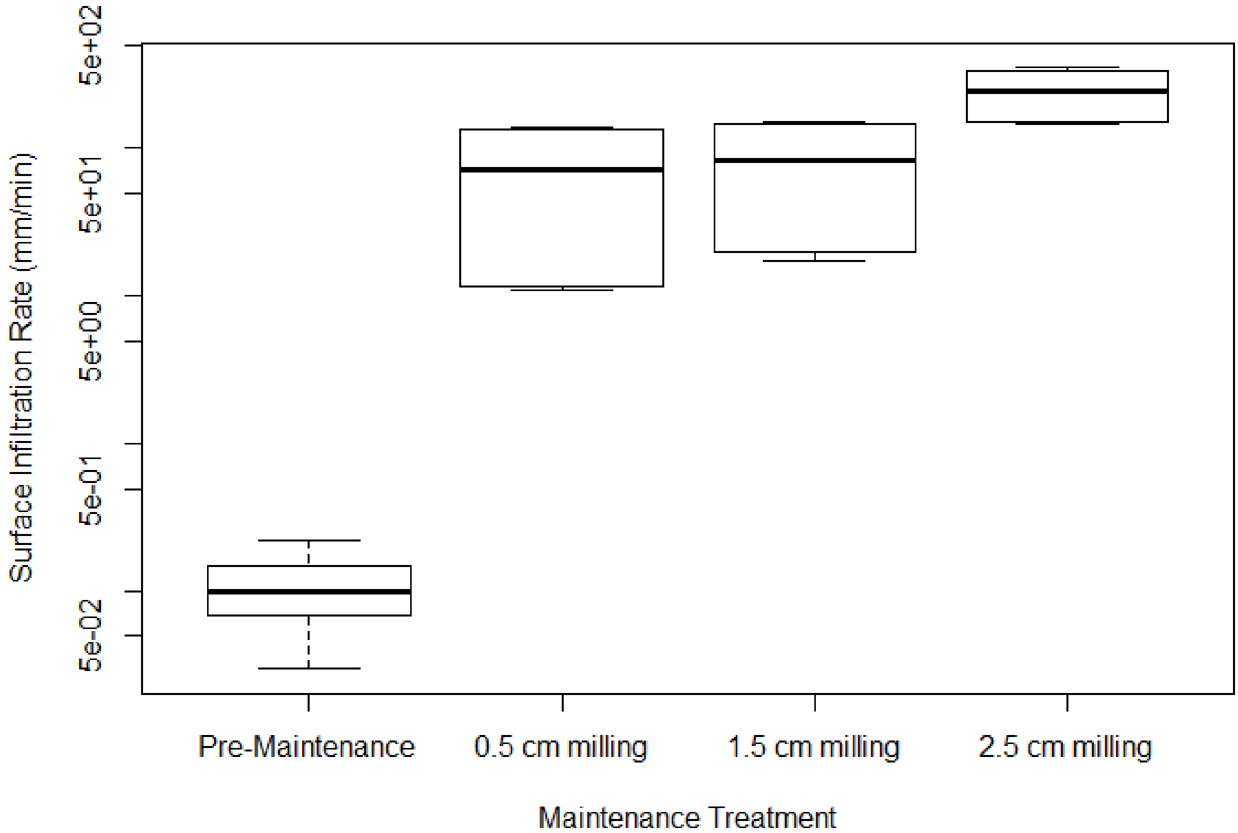

Figure 2. Effects of milling on porous asphalt SIR at Luleå.

3.3 Street Sweeping

Three types of street sweepers (mechanical, regenerative air, and a vacuum truck) were utilized to maintain PICP in North Carolina and Ohio, USA (Table 1). All methods of maintenance produced significantly higher post-maintenance SIRs. However, maintenance of the NCCU site on successive days with a mechanical sweeper followed by a regenerative air sweeper showed that suction provided by the latter more deeply penetrates clogging layers and therefore SIR benefits. For monitoring locations with high debris loading (i.e., near the PII, beneath trees, etc.), maintenance needs are more intensive than locations with few clogging stimuli. Multiple passes with a regenerative air street sweeper or vacuum truck, and even stopping over heavily clogged locations, were needed to create acceptable post-maintenance SIRs. At Willoughby Hills, maintenance regimens were performed with a vacuum truck and were separated by one year. To reach similar post-maintenance SIRs (median 150-175 mm/min), one pass with the vacuum truck was needed during the first maintenance effort; 3

were needed one year later. To maintain a desired threshold SIR, the frequency of permeable pavement maintenance will likely increase with time.

Table 1. Summary statistics pre- and post-maintenance SIR using various types of street sweepers on PICP.

Site	Maintenance Type	Number of Tests	Range (mm/min)	Median (mm/min)	Mean (mm/min)	σ (mm/min)	p-value	Statistical Test
NCCU	Pre-maintenance	10	0.44-4.71	1.00	1.41	1.28	-	-
	5 passes mechanical sweeper	10	0.65-18.5	2.40	6.38	6.71	0.0293	Student's t-test
	3 passes regenerative air sweeper	10	4.45-31.9	14.1	15.7	9.07	0.0035	Student's t-test
Piney Wood	Pre-maintenance	12	1.3-10.8	1.76	3.43	3.69	-	-
	5 passes regenerative air sweeper	12	9.4-165	154	111	75.4	0.0167	Student's t-test
	Pre-maintenance	12	135-315	231	229	77.7	-	-
	1 pass regenerative air sweeper	12	103-193	143	146	36.7	0.0975	Student's t-test
Willoughby Hills	Pre-maintenance	16	1.54-361	64.4	100	108	-	-
	1 pass vacuum Truck	16	33.9-381	173	173	114	0.0148	Student's t-test
	Pre-maintenance	16	0.81-190	4.39	36.4	63.7	-	-
	3 passes vacuum truck	16	8.52-699	148	202	192	0.0020	Student's t-test

4 CONCLUSIONS

Hand-held industrial vacuum cleaning, pressure washing, and a combination of vacuum cleaning and pressure washing all significantly improved the SIR of two clogged porous asphalt sites in northern Sweden. Treatments with pressure washing were significantly different from vacuuming alone. At Luleå, post-maintenance SIRs were 0.6 mm/min for the vacuuming treatment, and 21-36 mm/min for treatments involving pressure washing. This suggested appropriately applied pressure washing was capable of restoring porous asphalt permeability, especially if applied at a low angle to the pavement surface.

Milling of the porous asphalt at Luleå was tested to restore SIR at three different depths: 0.5 cm, 1.5 cm, and 2.5 cm. All depths of milling were successful in restoring pavement SIR to a median rate of at least 70 mm/min. The 2.5 cm milling depth yielded a median SIR of 245 mm/min, near the 290 mm/min infiltration rate measured immediately after construction (21 years earlier). This was the only maintenance technology tested capable of rejuvenating pavement SIR to nearly-newly installed rates.

Testing of street sweepers for maintenance of permeable pavements suggested that sweepers providing suction perform better than standard mechanical sweepers. The suction more deeply penetrates the clogging layers, providing better post-maintenance SIR. In cases where the pavement was heavily clogged, stopping the street sweeper or undertaking multiple passes over the pavement surface helped to improve maintenance results.

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