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Évaluation des techniques d'entretien pour restaurer la fonction hydraulique des chaussées perméables

Assessing Maintenance Techniques to Restore the Hydraulic Function of Permeable Pavements

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RÉSUMÉ

Les chaussées perméables sont de plus en plus mises en place pour réduire les impacts du ruissellement sur les cours d'eau récepteurs (c'est-à-dire le syndrome des cours d'eau urbains); cependant, au fil du temps, des débris s'accumulent dans leurs espaces poreux et un entretien est nécessaire pour assurer leur hydraulique tout au long de leur durée de vie. Les taux d'infiltration de surface (SIR) ont été mesurés sur cinq chaussées en béton autobloquantes perméables (PICP) dans le centre de l'Ohio, aux États-Unis, immédiatement avant et après cinq techniques d'entretien différentes. Le véhicule de nettoyage de machine (MCV), le Rejuvenater, un nettoyeur haute pression et le Rejuvenater exécutés en série, ont considérablement amélioré les SIR médians de 16 à 26, 5 à 106 et 11 à 37 mm/min, respectivement. Le lavage sous pression seul n'a pas amélioré de manière significative le PICP SIR. Les SIR étaient significativement plus faibles après l'entretien avec une balayeuse à air régénératif ; cependant, l'entretien a été effectué par temps humide. Par temps sec, cette technique n'a pas d'impact significatif sur les SIR, ce qui était potentiellement lié à l'état relativement obstrué des chaussées (par exemple, cette technique est recommandée pour l'entretien courant plutôt que réparateur). Il a été démontré que la profondeur du colmatage variait en fonction des caractéristiques du site de chaussée perméable et, dans certains cas, était si profonde qu'elle empêchait l'entretien d'être efficace. Un entretien régulier et de routine et le remplissage des agrégats de joint dans le PICP sont nécessaires pour s'assurer que le colmatage ne migre pas plus profondément dans le profil de la chaussée.

ABSTRACT

Permeable pavements are increasingly implemented to reduce the impacts of runoff on receiving streams (i.e., the urban stream syndrome); however, over time detritus accumulates in their pore spaces, and maintenance is needed to ensure their hydraulics over their design life. Surface infiltration rates (SIRs) were measured on five permeable interlocking concrete pavements (PICPs) in central Ohio, USA, immediately before and after five different maintenance techniques. The Machine Cleaning Vehicle (MCV), the Rejuvenater, and a pressure washer and the Rejuvenater performed in series, significantly improved median SIRs from 16 to 26, 5 to 106, and 11 to 37 mm/min, respectively. Pressure washing alone did not significantly improve PICP SIR. SIRs were significantly lower following maintenance with a regenerative air street sweeper; however, maintenance was performed during wet weather. During dry weather, this technique has no significant impact on SIRs, which was potentially related to the relatively clogged condition of the pavements (e.g., this technique is recommended for routine rather than restorative maintenance). The depth of clogging was shown to vary as a function of permeable pavement site characteristics and in some cases was so deep that it prevented maintenance from being effective. Regular, routine maintenance and topping up of joint aggregate in PICP are needed to ensure clogging does not migrate deeper into the pavement profile.

KEYWORDS

Permeable interlocking concrete pavement ; clogging ; surface infiltration rate ; porous pavement ; green infrastructure

1 INTRODUCTION

Urbanization brings about increases in impervious cover, resulting in modification of the water balance and negative impacts to stream health through increased erosion and changes in channel dimension, pattern, and profile. In contrast to traditional asphalt and concrete, permeable pavements allow rainfall to infiltrate the pavement where it can be stored in an aggregate reservoir below. Permeable pavements are recommended as a stormwater control measure (SCM) since they may be used for flood control, reduce runoff through exfiltration and evaporation, do not take up developable land as many other SCMs do and improve runoff quality (Weiss et al. 2017). One type of permeable pavement is permeable interlocking concrete pavement (PICP), which are impermeable bricks with interstitial spaces that allow water to pass through the pavement. The spaces between the bricks are filled with small aggregate which must be removed during maintenance and subsequently replaced.

Permeable pavements clog over time as detritus accumulates in poor spaces and the pavement begins to function similarly to a soil with a finer grain size distribution (Winston et al. 2016). This clogging is spatially heterogeneous and varies with local rainfall patterns, run-on ratio (i.e., the ratio of impervious drainage area to the permeable pavement surface area), wind-borne sediment and debris, snow plowing practices in colder climates, and traffic patterns. Several studies have suggested that clogging occurs in the upper few centimeters of the permeable pavement cross section and causes the pavement surface infiltration rate (SIR) to decline over time. Permeable pavement maintenance practices are generally split into two categories : routine and restorative. Winston et al. (2016) found that regenerative air street sweeping, which applies suction to the pavement surface, was more effective in improving PICP SIRs than mechanical street sweepers or manual removal of the upper 20 mm clogging material (Winston et al., 2016). Drake and Bradford (2013) tested small-scale (i.e., hand sweeping, low/high suction vacuum, and pressure washing) and large-scale (i.e., vacuum truck and regenerative air street sweeping) maintenance on PICP in Canadian parking lots. Wide-ranging results were obtained with hand sweeping, low suction vacuums, high suction vacuums, and pressuring washing increasing SIRs by -50 to 550%, 300 to 11,650%, 0 to 6,625%, and $\geq 1,325\%$, respectively.

The objective of this research was to test various PICP maintenance techniques on pavements that had already moderately clogged. This research adds to the current knowledge of pressure washing and regenerative air street sweeping for PICP maintenance. Further, two maintenance technologies which combine pressure washing and street sweeping were explored: the Rejuvenater and Machine Cleaning Vehicle (MCV). We provide evidence that operational factors (speed of maintenance, number of maintenance passes) and depth of clogging help to explain the variability in maintenance effectiveness observed in this and other research studies.

2 MATERIALS AND METHODS

Maintenance techniques were trialed on five PICP systems which were moderately to heavily clogged in the greater Columbus, Ohio, USA, metropolitan area; four were permeable residential streets while one was in a commercial parking lot. These techniques included a pressure washer, the Rejuvenater, the MCV, regenerative air street sweepers, and a pressure washer and the Rejuvenater in series (Figure 1). The Rejuvenater is a walk behind purpose-built permeable pavement maintenance device with a 0.6-meter-wide deck equipped with a rotating, high-pressure nozzles. This deck was attached to a Model 210® Tymco regenerative air street sweeper to remove dislodged debris (Figure 1). A regenerative air street sweeper maintained all five PICP systems at regularly schedule intervals and with varying number of passes. Visual inspection of debris removal from the joint spaces was used to determine the number of passes at each PICP. The MCV is a modified Bobcat® Toolcat 5600 (Figure 1) with a rotating pressure washer and built in suction line to remove the debris / water mixture from the pavement.

Measurement of SIR was performed following procedures in ASTM C1781 (ASTM, 2013). SIR tests were performed immediately before and after (within 24 hrs) maintenance was conducted at pre-determined locations. These locations were used for both pre- and post-maintenance SIRs to determine net change in SIR after maintenance. With the notable exception of regenerative air street sweeping at the Commercial site (which was done during rainfall), maintenance was performed after a minimum antecedent dry period of 24 hours. Joint clogging was further investigated at the residential street PICPs by excavating joint material to 2, 4, and 8 cm (i.e., bottom of the brick paver). Surface infiltration rate tests were performed after each depth of excavation to identify the depth to which the majority of clogging material had migrated.



Figure 1: Examples of maintenance techniques testing in this research: pressure washer (A), Rejuvenater (B), Regenerative air street sweeper (C), Machine Cleaning Vehicle (D).

The primary metric used to evaluate the difference between pre- to post-maintenance SIR was percent change. Since data were paired and non-normally distributed, Wilcoxon signed rank tests were used to test for statistical significance between pre- and post-maintenance SIRs. Differences in regenerative air street sweeping performance during wet and dry weather conditions were determined using the Kruskal-Wallis test. Data analysis was done in R statistical software. A 95% confidence interval ($\alpha=0.05$) was used to evaluate statistical significance.

3 RESULTS AND DISCUSSION

Observed improvements in SIR were highly varied among the PICP maintenance techniques tested (Figure 2). Median percent changes in SIR were -28, 67, 149, 505, and 1075% for the regenerative air street sweeper, MCV, pressure washer, pressure washer and Rejuvenater in series, and Rejuvenater, respectively. The most effective techniques were those which employed a high-power pressure washer and suction in combination. These were able to loosen accumulated debris in the joint space and subsequently remove it from the PICP. The Rejuvenater was the most effective of the maintenance practices tested, perhaps because of its slow operational speed (walk-behind), which provided more time for removal of debris via pressure washing and suction.

Regenerative air street sweeping performed at the Commercial PICP was negatively affected by rainfall during maintenance (Figure 2); the percent change in SIR for this maintenance technique was significantly different when it was performed during dry versus wet weather conditions. It improved SIRs on moderately clogged PICP in residential streets by a median of 11 percent when antecedent dry period was greater than 24 hrs (i.e., dry conditions). However, during wet weather the regenerative air street sweeper caused clogging material to consolidate into a mat-like network in the joint spaces, thereby reducing post-maintenance SIRs by a median of 59 percent.

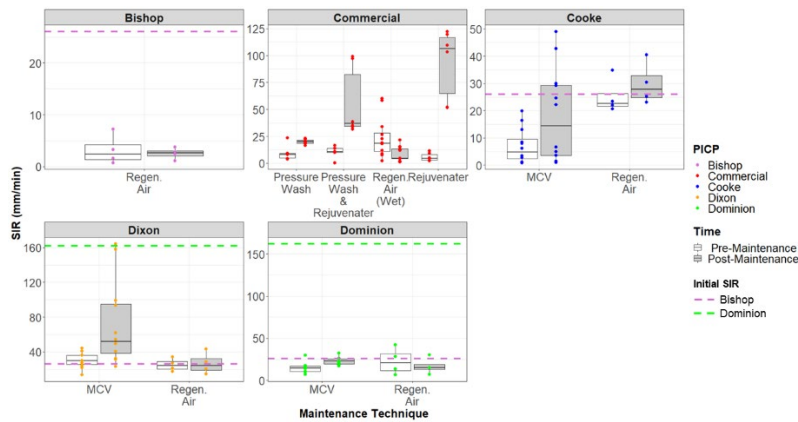


Figure 2: Boxplots of pre- and post-maintenance surface infiltration rates (SIRs) for various maintenance techniques (e.g., pressure washing, regenerative air sweeping performed during dry weather [“Regen. Air”] and wet weather [“Regen Air (Wet)”], Machine Cleaning Vehicle [MCV], and the Rejuvenater). Horizontal lines correspond to median initial SIRs at the Bishop and Dominion PICPs.

Compared to other studies which have tested the MCV and regenerative air street sweeper for permeable pavement maintenance (Drake and Bradford, 2013; UNHSC, 2019; Winston et al., 2016a), these techniques had smaller improvements in SIRs herein. This may be due to the moderately clogged initial conditions in the residential streets monitored herein, wherein a technique that is recommended for routine maintenance (e.g., regenerative air street sweeping) may not be able to restore pavement hydraulics. However, the MCV was developed for deep cleaning of highly clogged permeable pavements; thus, its relative underperformance in this study was examined further. It was surmised that clogging in the residential street PICP systems had progressed to greater depths than the approximately 3 cm noted in other studies, causing clogging to be harder to remediate. The cause of this deeper clogging progression was suspected to be a lack of joint aggregate replacement following routine maintenance, causing the clogging front to move deeper into the pavement profile. Surface infiltration rate tests were conducted after systematically removing 2, 4, and 8 cm of joint aggregate and any accumulated clogging material and compared against the SIR measured at the same location with all joint aggregate in place. At two of the road PICPs, large increases in infiltration rate after removing 2 and 4 cm of accumulated material suggested most of the clogging occurred in the 0-4 cm depth. At another road PICP site, clogging occurred at depths greater than 4 cm below the surface, with clogging material beginning to penetrate the bedding course. These conclusions were supported by Weiss et al. (2017) who also suggested that clogging layers may migrate deeper than ~3 cm in certain instances. Greater than 300 mm/min SIRs were observed after removal of all joint material indicating that the bedding layer was still relatively clean. These results highlight the need to keep clogging material near the surface of the pavement as vacuuming becomes particularly ineffective when an air gap exists between the vacuum and the material which one is trying to remove. Despite testing several techniques which were touted as restorative techniques for pavement hydraulics for highly clogged PICP, none of the maintenance techniques tested restored the pavement SIRs to like-new conditions. This highlights the need for regular, routine maintenance to prevent clogging from taking its toll.

4 CONCLUSIONS

In order to test various permeable pavement maintenance techniques, SIRs were measured on newly installed PICP and pre- and post-maintenance once the systems had been allowed to clog. All maintenance techniques tested during dry conditions which applied high pressure water (with or without suction) to the pavement surface significantly improved SIRs compared to pre-maintenance conditions. Regenerative air street sweeping caused a significant decline in SIRs when performed during wet conditions due to matting of clogging material and did not significantly change SIRs during dry conditions since the pavements were already moderately clogged (and this technique is meant for routine maintenance). Based on these results, additional testing of other maintenance techniques should be done during wet weather to determine whether similar poor performance is observed. Adding joint aggregate to PICP immediately following maintenance is critical to prevent clogging from migrating deeper into the PICP profile. Where this was not performed, clogging was observed at depths greater than 4 cm below the pavement surface, substantially reducing maintenance efficiencies measured herein compared to previously published work. Of the maintenance techniques studies, the combined effects of a pressure washer and vacuum suction improved SIRs to the greatest extent.

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