Clogging Resistance of Porous Pavements and Investigation on the Effectiveness of Various Cleansing Methods

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Highlights

- The effective lifetime of OCP, RBS, PB was > 20 years, 7 years, and 1.5 years without maintenance.
- The permeability of RBS increases as the number of times of waterjet cleansing increases.
- The higher waterjet pressure generally increases the cleansing effectiveness on RBS.

Introduction

Permeable pavement (PP) adopts porous materials which features an open network of pores to allow infiltration of stormwater through the pavement into the base/sub-base layers. As one type of sustainable urban drainage system (SUDS) measures, PP is one of the most widely used stormwater management facilities in urban areas due to its good hydrologic performance and the advantage of no occupying extra space (Li et al., 2022). The hydrologic benefits of PP include mitigating the peak and volume of surface runoff, delaying the peak flow, and enhancing groundwater recharge (Liu and Chui, 2017), etc.

PP has gained increasing attention as a sustainable measure to deal with urban flooding in recent decades. However, one of the most significant concerns with PP is its ability to withstand clogging from continual and long-term usage (Hu et al. 2020). That is, the porosity of PP shows a loss of in-situ permeability over time due to collecting solids such as sediment and organic matter in stormwater runoff. And clogging would over time degrade the performance of PP. Regular maintenance should thus be carried out to minimize clogging and to retain the permeability of PP. In fact, the loss of permeability has been studied by many previous studies using numerical simulation and laboratory experiments (e.g., Pezzaniti et al., 2009). However, less studies evaluate the effective lifetime of various types of PP (i.e., the number of years that the PP will be fully clogged). And the maintenance effectiveness of various cleansing methods such as waterjet and vacuum has been investigated (e.g., Hu et al., 2020). Nevertheless, the effects of waterjet and vacuum pressures on the cleansing effectiveness has not been well understood for different PP.

This study aims to estimate the number of years that the PP would be fully clogged if no maintenance was conducted, and to evaluate the effectiveness of typical cleansing methods (i.e., waterjet and vacuum cleansing) on restoring the permeability of clogged pavers. The main ideas are to accelerate the clogging by introducing sediments onto the PP artificially in laboratory experiments and observe the degree of depreciation in permeability of PP after continuous simulated clogging conditions. Afterwards, the different cleansing methods are performed on the totally clogged PP to evaluate their recovery effectiveness. PPs are a major focus for Hong Kong's Drainage Services Department (DSD) in their policy to implement SUDS in future stormwater management schemes. With Hong Kong's challenging geology and high levels of urbanization, the benefits of making SUDS commonplace are numerous and hence the studying and evaluation of these SUDS designs will bring great value socio-economically and in public safety in an increasingly harsh climate.

Methodology

Permeable pavement trial slabs

As the permeability of permeable paving is of main concern during the clogging and cleansing processes, several simplified permeable pavement trial slabs that only contained the surface layer of permeable pavement were built, including open cell paver (OCP), porous paver block (PB), resin bound surface (RBS) (Figure 1), etc. The trial slabs had a size of 0.5 m $\times$ 0.5 m and were laid on a drainage grille that functioned as a permeable sublayer. For PB trial slab, the gaps between the paver blocks in the trial slabs were filled by silicon sealant to avoid water infiltration through the gaps so that the water could only flow through the paver blocks during permeability tests. A flange was installed surrounding the slab to facilitate permeability tests.

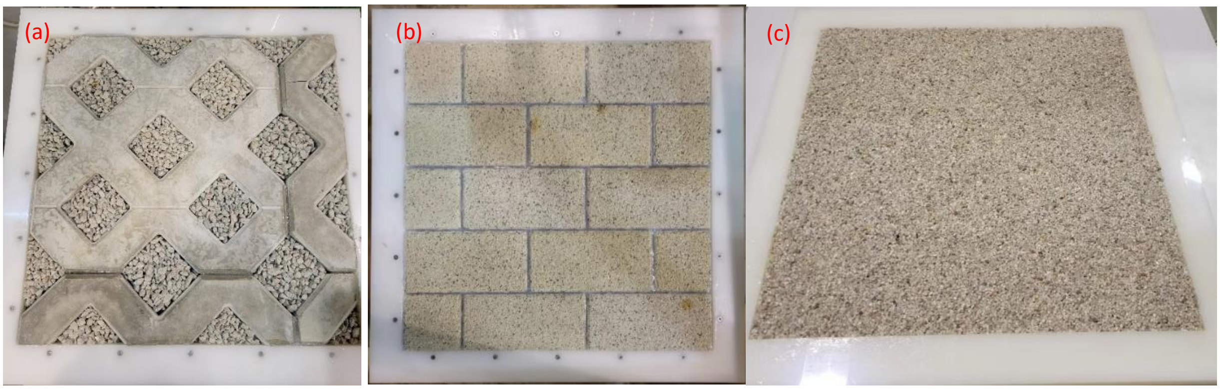

Figure 1. Pictures of permeable pavement trial slabs with a size of 0.5 m × 0.5 m built in the laboratory. (a) refers to the trial slab made of open cell paver (OCP), (b) refers to the trial slab made of porous paver blocks (PB), and (c) refers to the trial slab made of resin bound surface (RBS).

Effective lifetime of permeable pavement

To assess the number of years that PP will be fully clogged (i.e., effective lifetime) without cleansing, an automatic water-adding device was developed to perform the clogging tests (Figure 2a). The clogging process of PP was assumed to be a daily accumulation of sediments during rainy seasons. Thus, the device mimic the daily clogging process by releasing a daily runoff volume with some sediments each time. The tank at the top of the device stored a volume of water that corresponded to that a 0.5 m × 0.5 m surface in Hong Kong collected in 0.5 year (i.e., 600L). The 0.5-year sediment loading was calculated based on the average sediment concentration of stormwater (i.e., 200 mg/L from Pezzaniti et al. 2008), which equaled to 60 g. The rainy days in HK last for approximately 200 days (Hong Kong Observatory), thus, the volume of water released by the device each time is approximately 3 L. A tank permeameter (0.5 m × 0.5 m) with a flange was made and attached to the flange of trial slab using eight G-clips to ensure that all the release water went through the trial slab. The permeability of the trial slab was measured using falling head method after it collected 1-year water and sediments. The permeability tests were repeated five times to derive the averaged results. The clogging tests and permeability measurement were repeated until the permeability fell below a certain threshold (i.e., 0.01cm/s, Blick et al., 2004).

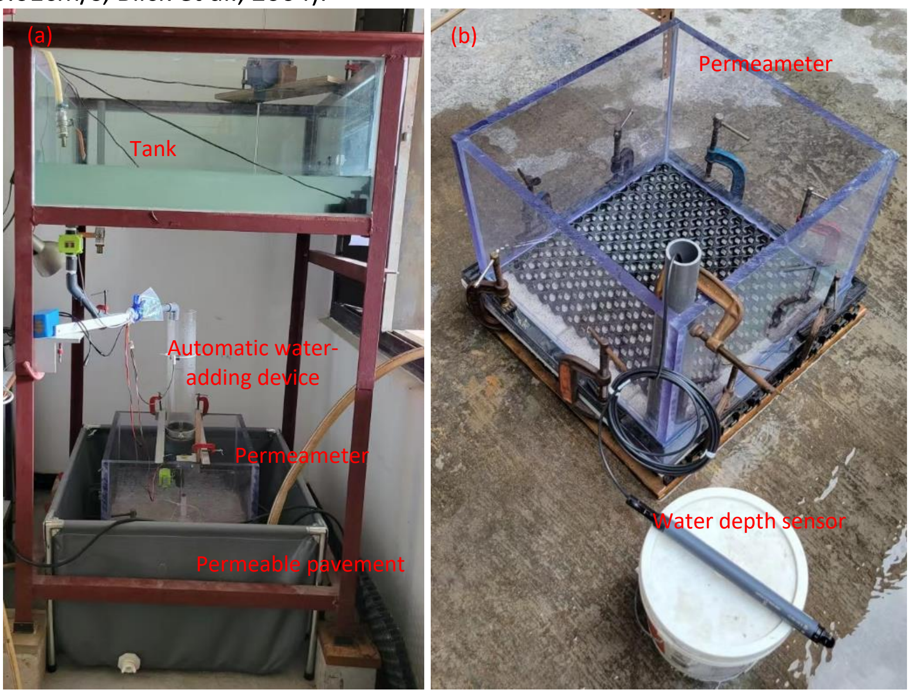

Figure 2. Pictures of (a) the automatic water-adding device and (b) the tank permeameter for permeability test.

Effectiveness of waterjet cleansing

To examine the effectiveness of waterjet cleansing in "rescuing" clogged porous pavement, a series of tests were performed. The totally clogged permeable pavement trial slabs after the clogging tests in previous section (permeability < 0.01cm/s) were used. The clogged trial slabs were divided into 9 sub slabs, which was 0.167 m × 0.167 m for each. Waterjet cleansing was then be performed on the sub slab to "rescue" the porous pavement. The waterjet was installed on rails and the speed of waterjet was controlled by a motor and a controller, which ensured the sweep speed of waterjet was the same for all the tests (Figure 3a). It should be noted that during the waterjet cleansing of one sub slab, the remaining eight sub slabs were covered by a plank to avoid cleansing overlapping. After cleansing, a circular permeameter with a diameter of 0.15 m was made to measure the permeability of each sub slab to determine the effectiveness of cleansing (Figure 3b). That is, waterjet cleansing was firstly performed and the permeability test was conducted to evaluate the recovery effectiveness, forming a test cycle. The test cycle was repeated five times to evaluate the possible contribution of the number of waterjet cleansing. Besides, to compare the effects of various waterjet pressures, three sub slabs were selected and each was tested using a different waterjet pressures, i.e., 100 bar, 150 bar and 200 bar, respectively.

Figure 3. Pictures of (a) the waterjet cleansing on a permeable pavement trial slab in the laboratory (b) the circular permeameter for permeability test.

Results and discussion

Figure 4 shows the change in the permeability of OCP during the clogging test. The results show that the permeability of OCP remained almost the same despite it collected 20-years of water and sediments. It indicates that OCP is not sensitive to the sediment accumulation and its effective lifetime can last more than 20 years. On the contrary, the permeability of PB and RBS significantly reduced as they continuously collected water and sediments over time and PB and RBS was totally clogged at 1.5-years and 7 years, respectively (not shown in the figure). The results reflected that the effective lifetime of PB and RBS was 1.5 years and 7 years without maintenance. Comparing among three permeable pavements, PB exhibited an the most dramatic decrease in clogging resistance. This is possibly because the average sizes of the pores of PB are the smallest.

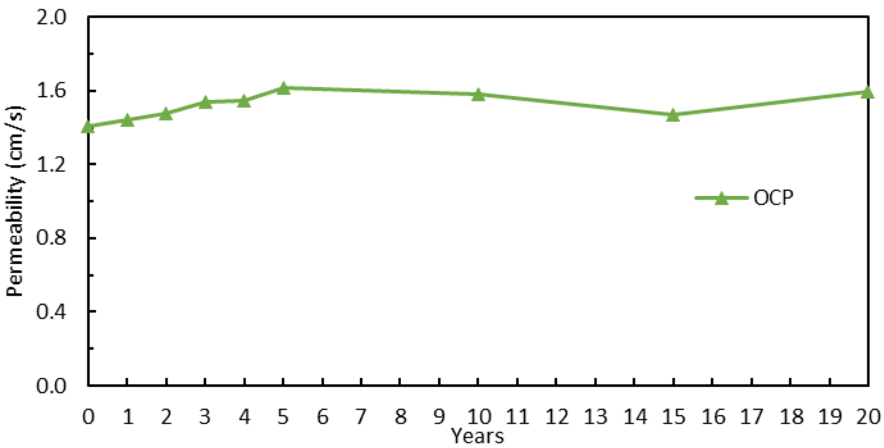

Figure 4. Effective lifetime of various permeable pavements without maintenance. Abbreviations: OCP: open cell paver, PB: porous paver block, and RBS: resin bound surface.

Figure 5 illustrates the effects of various waterjet pressures and the number of waterjet cleansing on the permeability of RBS. For all three waterjet pressures, the permeability of RBS increases as the number of cleansing increases, indicating the greater number of times of waterjet cleansing, the better the permeability of RBS recovered. Comparing the results of 100 bar and 200 bar, the permeability of RBS under 200 bar cleansing was slightly higher than that under 100 bar. It suggested that a higher waterjet pressure can provide better recovery in permeability of RBS. However, the permeability of RBS under 150 bar cleansing was slightly lower than that under 100 bar. This was possibly due to the difference in the initial permeability of various sub slabs.

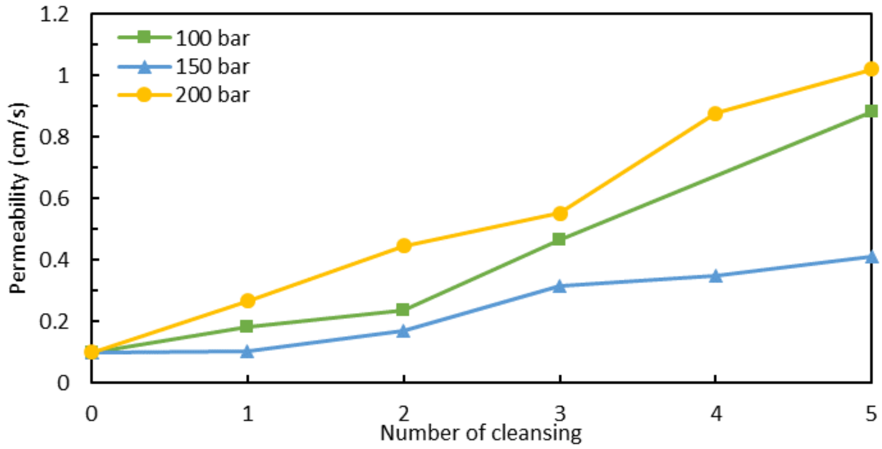

Figure 5. Effectiveness of waterjet cleaning on resin bound surface (RBS): effects of different waterjet pressures and the number of waterjet cleansing

Conclusions and future work

Different permeable pavements are found to have significant differences in the resistance of sediment clogging, i.e., effective lifetime, if no maintenance was conducted. The effective lifetime of open cell paver, resin bound surface, porous paver block was > 20 years, 7 years, and 1.5 years without maintenance. Waterjet cleansing is able to significantly recover the permeability of resin bound surface. The permeability of RBS increases as the number of times of waterjet cleansing increases. The higher waterjet pressure generally increases the cleansing effectiveness on RBS.

Future work to be conducted including the clogging test for more permeable pavements such as permeable concrete pavement. And another typical cleansing method, i.e., vacuum cleansing, will be performed and the effects of the number of vacuum cleansing and various vacuum pressures will be evaluated and compared with the results of waterjet cleansing.

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