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Predicting physical clogging of modular paver equipped with filter media

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Abstract. Porous pavements are simple to retrofit, good at improving the hydrology and quality of the water, but prone to clogging. There is little knowledge on the physical clogging processes through these systems, even though they play a significant role in the lifespan of porous pavements. This study's objectives were to comprehend the primary physical mechanisms that control physical clogging and create a straightforward hexagonal modular (HM) model that can forecast physical congestion. A filtration system with a layered filter media granular activated carbon (GAC) and sand was installed. The clogging agent was found trapped only on the mesh because of the sizes of some of the material being larger than the size of mesh opening, while the voids of the media material were found to be not of a major effect in this respect. With the GAC and sand layers combined, the hydraulic conductivity was determined to be 0.097 cm/s and this k value can be considered low for the purpose.

1. Introduction

In order to control the quantity and quality of urban runoff, porous pavements are a fairly common structure. They encourage the infiltration of rainfall and urban runoff into the underlying soil or into a storage reservoir, as their names implies. The two types of porous pavements are monolithic and modular [1]. While modular structures are built from individual pavers with a space between each paver, monolithic structures are composed of bound granular material, such as concrete or asphalt, with the fines eliminated [1]. In comparison to other stormwater management techniques, porous pavements are simple to retrofit in already-existing, dense urban areas and are capable of lowering the hydraulic connectivity of the drainage system [2]. They can achieve common stormwater management goals because they also trap pollutants [3].

One of the many variables that can affect the systems' longevity is pavement design. For instance, it has been discovered that smaller filter medium size and shape worsen clogging [4],[5],[6]. There are



rumors that modular pavements are less prone to clogging than monolithic systems [7], but further research is needed because this claim is not supported by a meaningful comparison analysis.

2. Methodology

2.1 Hydraulic Conductivity for GAC and sand

The saturated hydraulic conductivity of the combination of media GAC and sand was done according to the British Standard (BS 1377: Part 5: 1990: 5) on the “Determination of permeability by the constant-head method”.

2.2 Clogging Agent

In this investigation, soil was used as the clogging agent. At Sungai Petani in Kedah, laterite soil was used as a source of soil. The laterite soils were dried in an oven for 24 hours to make the clogging material. After being removed from the oven, dried soil chunks were crushed in a ball mill. Figure 1 is shown to show the results of the sieve analysis for soil in order to determine the size of the soil used, as shown in Table 1. According to Figure 1, more than 50% of the soil was larger than 0.075 mm. Thus, because 50% or more of it passes through sieve No. 200, it is considered as soil with fine grains.

Table 1. Gradation of soil used as clogging agent materials.

Sieve No	ASTM Sieve Size (mm)	Cumulative Percentage Passing (%)	Notes
	6.30	100.00	Gravel
#4	4.75	100.00	
#6	3.35	96.80	
#8	2.36	91.20	
#16	1.18	85.40	Sand
#30	0.600	84.20	
#50	0.300	82.20	
#100	0.150	79.60	
#200	0.075	77.60	

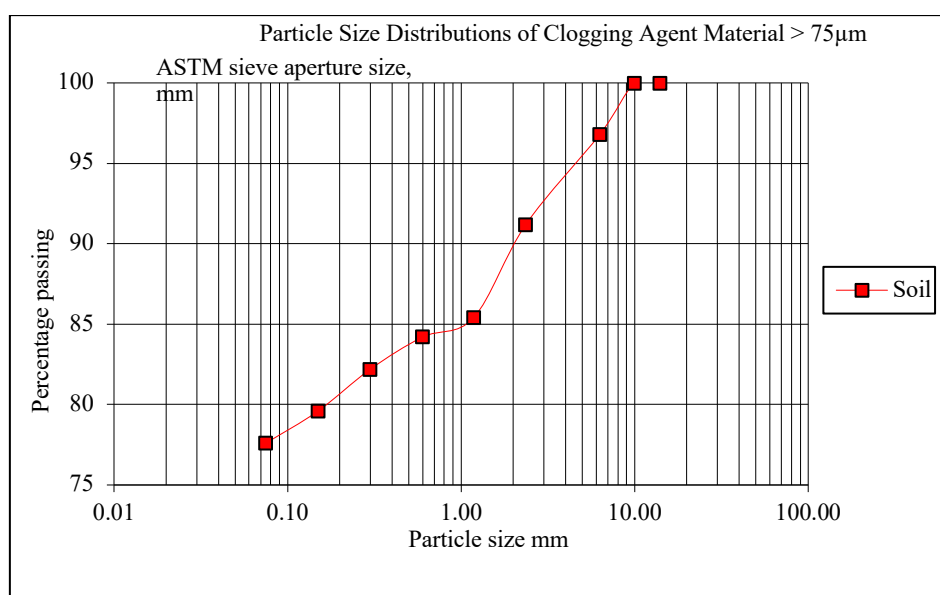


Figure 1. Particle size distribution curve of soil used as clogging agent material.

2.3 Hexagonal Modular (HM) with Media Preparation

Given that the hexagonal modular (HM) is a porous mixture of media, permeability plays a significant part in demonstrating the capacity of the HM to permit water to pass through the pores. The sample's permeability was assessed using a permeability test. To evaluate the permeability of Marshall specimens, a water permeameter was created in a facility at Universiti Sains Malaysia that is identical to the one created at Leeds University by Hamzah [8]. A permeability test involves filling a Perspex tube with water, allowing water to flow from one predetermined location to another while timing the flow, and recording the results. The same idea holds true for this study. In Figure 2, the falling head permeameter is depicted. Then tests were performed on a hexagonal modular unit that had been placed with GAC at the top with a 5 cm thickness and sand at the bottom with a 5 cm thickness as well. Water was able to flow through the specimen from h_1 to h_2 , as indicated on the stand pipe, due to the hydraulic gradient that was established across it. The time spent was measured in seconds and was rounding to the nearest 0.1 seconds (t). The specimen's permeability was finally assessed using an average of three observations. The specimen was left to drain the extra water after the permeability had been established.

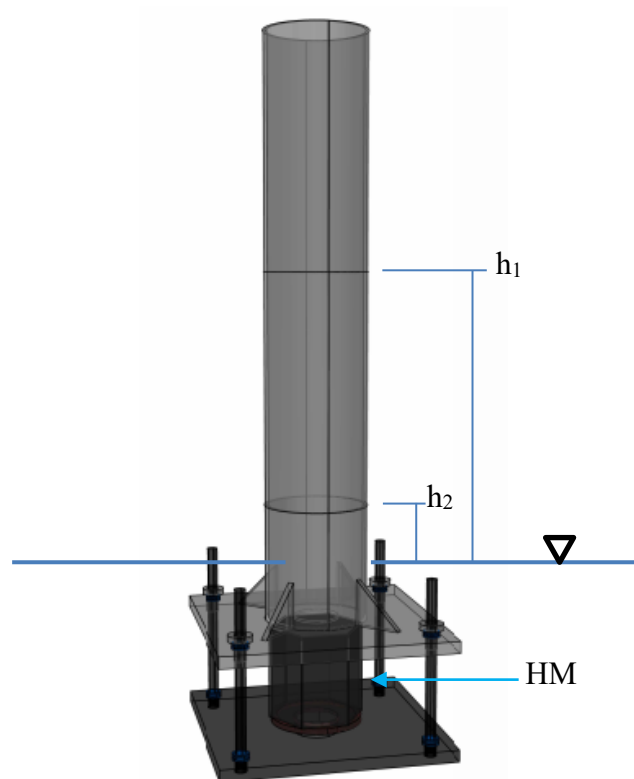


Figure 2. Falling head permeameter.

2.4 The Proposed Clogging Test

Hexagonal modular media is prone to clogging. One of the biggest issues with media is clogging. The permeability advantages of media will gradually disappear due to the open nature of the media, which allows dirt and other particulate matter to penetrate into the spaces and gradually plug the voids.

To replicate progressive clogging that occurs in the field and routine cleaning to clear the pores, the clogging test approach was modified from works by Hamzah [9]. According to a paper from the Transportation Research Laboratory (TRL), the minimal coefficient of permeability is 0.03 cm/s [10].

Fresh sample permeability was assessed using tap water, and the initial discharge time was noted. Then, as shown in Figure 3, permeant concentrate was made by dissolving 2 g of soil in 1 litre of water. This concentrate was then allowed to clog the sample's pores. The discharge time was then calculated using regular tap water. Until the terminal discharge time was exceeded, the clogging process was repeated. The retained discharge time was then calculated using the specimen discharge time. Eight cycles of blockage were conducted in the process. The clogging process can be summed up as follows:

1. To assess discharge time, a permeability test was performed on a fresh sample (without a clogging agent).
2. For many minutes, 2 g/L soil and water were aggressively mixed and swirled.
3. To clog the sample, the soil-water mixture was put into the permeameter tube.
4. Tap water was used to establish the discharge time. Some soils were still stuck to the mesh, though.
5. Repeat steps 3 and 4 as necessary to reach the terminal discharge time, which is larger than 267 s. There is one loading in steps 1 through 4.
6. The discharge time was determined using tap water as permeant.
7. The ultimate discharge duration was exceeded after eight cycles of repeating Steps 3 and 4 in this method.



Figure 3. Clogging of specimen.

3. Results and discussion

3.1 Hydraulic conductivity

Sand and GAC medium combined produced a result of 0.097 cm/s. According to Table 2, this laboratory finding is within the range of the saturated hydraulic conductivity values for coarse sand suggested by [11], [12], and [13]. Table 2 demonstrates that the combination of GAC and sand has a medium level of permeability. This study also shows that sandy gravel, clean sand, and fine sand are the appropriate soil types for these medium. The coefficient of permeability and porosity are positively correlated.

Table 2. Hydraulic conductivity in different medias. Classification of soils according to permeability [14].

Soil	Hydraulic conductivity k (cm/s)	Degree of permeability	Sand + GAC k (cm/s)
Gravel	Over 10^{-1}	High	
Clean sand	10^{-1} to 10^{-3}	Medium	0.097
Very fine sand	10^{-3} to 10^{-5}	Low	
Silty sand	10^{-5} to 10^{-7}	Very low	
Clay	Less than 10^{-7}	Practically impermeable	

3.2 Result of permeant concentration of clogging

The term "permeant concentration" describes the amount of clogging material, measured in gram/litre of water, that is present. Higher concentrations would cause the specimen to quickly clog. The quantity of clogging material subjected to the samples is indicated by the number of loads. The terminal value used to indicate a clogged sample was 267 seconds. Samples that are clogged are no longer effective as permeable layers. The sample needs to be cleaned in order to continue functioning.

10 g of clogging agent material was used for the preliminary trial. The soil was combined with 5 litres of water, or 2 g/L in concentration, which matched the permeameter tube's volume. A preliminary test was performed on HM sample with 5 cm GAC and 5 cm sand layers. Table 3 presents the outcomes. t_1 to t_8 are the discharge times for the first to eighth loading cycles.

Table 3. Discharge times of HM sample.

Soil Concentration (g/L)	Initial Discharge Time (s)	Discharge Time For Each Loading Cycle (s)							
		t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8
2	17.9	19.47	20.75	21.66	22.28	23.25	24.67	24.89	25.98
4	17.9	21.10	22.87	24.25	25.4	26.03	27.85	29.63	43.21
6	17.9	22.23	23.56	26.65	30.05	34.46	41.32	54.44	65.56
8	17.9	23.82	27.41	30.72	33.78	40.9	50.38	75.18	96.57
10	17.9	23.90	25.47	28.75	35.78	53.59	62.56	88.58	160.31
12	17.9	25.01	27.00	40.65	55.65	90.51	156.23	190.34	230.54
14	17.9	30.32	35.54	42.75	50.12	92.22	165.31	204.32	290.12
16	17.9	34.23	45.22	50.87	66.03	99.54	167.67	250.05	301.12

The results in Table 3 show that after 8 loadings at a concentration of 2 g/L, the HM fitted with GAC and sand sample was not blocked. The samples clogged after 8 loadings when the test was

repeated with a greater concentration of 16 g/L. As a result, it was agreed to use 128 g/L of water as the permeant concentration in the following clogging tests.

Using a falling head permeameter, which was also used to gauge the samples' permeability, the clogging of voids was evaluated. Prior to starting the clogging test, initial readings were taken on the complete fresh sample. Until the clogged state was reached, the permeability at each cycle of loading the clogging material was noted. After the cleaning procedure was completed on the clogged sample, the retained permeability was next assessed. It was discovered that the initial discharge time was 17.9 s. The experiments demonstrated that HM clog caused permeability to increase, prolonged the time required for discharge, while the cleansing process caused a notable improvement in permeability.

As the samples through the cleansing procedure, there was a considerable maintenance in the number of loading cycles for each cycle. The particles of the clogging material filling up the mesh during the addition of clogging material causes the loading cycles to rise. Because some clogging agent sizes are bigger than the size of mesh, the clogging agent will typically adhere to the mesh. In this case, the blockage is not brought on by media voids.

4. Conclusion

Generally, the clogging agent was trapped on the mesh because the sizes of some of the material were larger than the size of the mesh. The voids of the media material were not found as the cause for clogging in this situation. With the GAC and sand layers combined, the hydraulic conductivity was found to be 9.7×10^{-2} cm/s and this k value can be considered low. Therefore, the GAC and the sand in combination and in the said arrangement can be considered suitable for use as the surface layer in the hexagonal modular porous pavement system.

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