CHAPTER 6

EFFECTIVENESS OF COMPOSITE POROUS CONCRETE SLAB AS DRAIN COVER

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6.1 INTRODUCTION

Road drainage is a system placed to allow surface water to drain away into ground instead of ponding on road surface. Conventional road drainage systems, typically constructed with concrete or steel road drain cover. It provides access to underground drainage systems for maintenance and inspection.

Furthermore, existing concrete cover creates challenges by increasing storm water runoff which contributes to urban flooding. At the same time, there are some common issues that could affect safety of road users as well as causing clogged drain. Meanwhile, steel drain cover is exposed to corrosion over time and poses safety hazards for motorists.

Studies have revealed that to effectively limit road spray and hydroplaning, porous pavement must contain a network of linked pores that make approximately 15% to 25% of the surface area [1]. The objective behind this approach is to create voids in the concrete so that water can flow quickly from the surface. In response to these limitations, composite porous concrete (CPC) slab emerges as a promising and sustainable solution for road drainage applications. Unlike traditional concrete comparing with CPC slab have a high porosity because fine aggregates (sand) are used in the mix to a lesser or no extent. This distinct composition allows water to percolate directly through the slab and significantly reduce surface runoff. The infiltrated water recharges groundwater aquifers, promoting healthy ecosystems and reducing the risk of urban flooding. Furthermore, CPC slab open pore structure provides some filtration capabilities, which may reduce clogging when compared to traditional designs [2].

As a potential solution, the proposed study investigates the effectiveness of composite porous concrete slabs for drainage applications. CPC slab is a different type of concrete with a high porosity used for concrete flatwork applications that allows water from precipitation to pass directly through it. This study aims to investigate the rate of infiltration of CPC slabs on drainage performance and evaluate the effectiveness of the designed CPC slab. This research is crucial as it demonstrates the potential of CPC slabs to significantly reduce flood risks in urban areas by efficiently managing stormwater runoff compared to traditional drain covers [3]. The findings provide valuable data for urban planners and engineers to make informed decisions regarding the most suitable drainage systems for specific applications, establish a benchmark for future CPC slab design improvements, and evaluate the cost-effectiveness of CPC slabs by comparing their drainage efficiency to traditional covers and assessing potential long-term cost savings through reduced flood damage and infrastructure needs [3].

6.2 METHODOLOGY OF STUDY

6.2.1 INFILTRATION TEST

This study investigates the effectiveness of CPC slabs by evaluating infiltration rates (Figure 6.1(a)). While ASTM C1701 provides a standard for testing porous concrete materials, this study adapts the method for an infiltration ring (Figure 6.1(b)) test on CPC slabs.

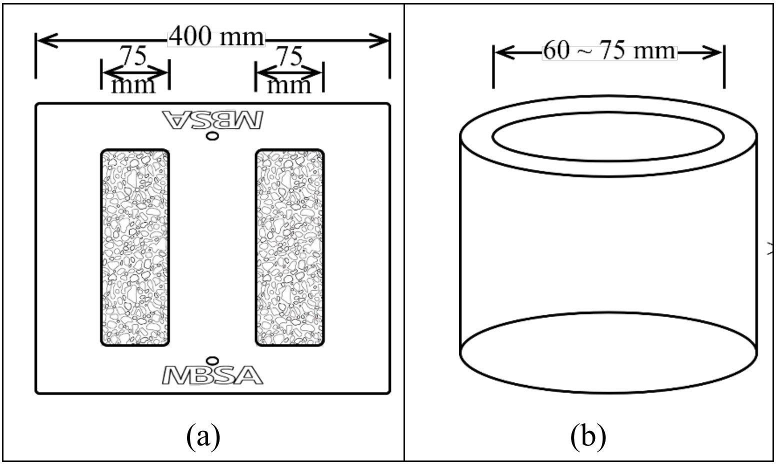

Figure 6.1: (a) Dimension of CPC slab; (b) infiltration ring

This ring test is crucial for assessing the effectiveness of the CPC slab design by comparing measured infiltration rates with previous research findings and validating performance against established standards. The tests involve applying water to the slab's porous within a confined area created by a PVC pipe and measuring the time taken for water to infiltrate. The infiltration ring, typically with an inside diameter between 60 mm to 75 mm. The minimum required height of infiltration ring is >50 mm and the bottom edge of ring with porous concrete's surface need be flat and sealed with plumber's putty.

The infiltration ring test, adapted from ASTM C1701, begins with preparing the test location by cleaning the porous concrete surface. An infiltration ring is then placed on the surface, sealed with plumber's putty to prevent water leakage. Pre-wetting is performed by steadily pouring approximately 1 liter of water into the ring, and the time taken for the water to infiltrate is recorded. Two consecutive tests can be conducted at the same location within 5 mins, with the final infiltration rate calculated as the average of both tests. However, ASTM C1701 guidelines recommend no more than two tests at the same location on the same day.

6.2.2 CALCULATION OF INFILTRATION RATE I

In this study, ASTM C1701 defines infiltration rate as the rate at which water penetrates in pervious concrete surface by measured in SI units of mm/hr (Eq. (6.1)).

$$I = \frac{KM}{D^2 t} \tag{6.1}$$

where, M = mass of poured water (kg), D = diameter of inner ring (mm), t = time required for amount of water infiltrated (s) and K = constant factor = 4.583×10^9 in SI units or 126 870 in inch-pound.

6.3 RESULTS AND FINDINGS

6.3.1 OVERVIEW OF THE INFILTRATION TEST

The experiments were conducted at a location in a commercial area at 49, Jalan Snuker 13/28, Tadisma Business Park, 40100 Shah Alam, Selangor between July and September 2024 (Figure 6.2). To ensure accurate results, the test area must remain dry for at least one day prior to testing, as per ASTM C1071 guidelines.

Results were presented as infiltration rate against infiltration time, with at least two tests conducted at each location to minimize errors. Figure 6.2 provides an initial visual representation of the case study area, captured on April 18, 2024.

Figure 6.2: The site where experiments were conducted

6.3.2 FIELD OBSERVATION OF INFILTRATION TEST

(a) Infiltration rate when directly poured with 1.5 L of water

A fixed volume of 1.5 L of water was poured onto the porous concrete surface and the time required for infiltration was strictly recorded when the water touched on porous concrete surface (Figure 6.3). Table 6.1 outlines the outcomes of an infiltration rate test conducted on a composite porous concrete slab by field observation. The data reveals a consistent decline in the infiltration rate over successive tests.

This trend is likely attributed to factors of repetitive water being infiltrated through the porous concrete from Test 1 until Test 6. Notably, the initial tests exhibited significantly higher infiltration rates because as water flows through the porous concrete, fine particles and debris from the water can become trapped within the pores. This clogging reduces the effective pore size and the overall infiltration rate of the porous concrete slab.

Figure 6.3: Infiltration ring on CPC slab by directly pouring 1.5L of water

Table 6.1: Result of infiltration rate by directly pouring 1.5L of water

Mass *M* (kg)	Diameter *D* (mm)	Test no.	Time *t* (s)	Infiltration rate *I* (mm/hr)
0.754	80	1	40.44	26563.80
		2	41.97	25595.43
		3	45.08	23829.64
		4	49.79	21575.42
		5	55.91	19213.74
		6	63.95	16798.12

Figure 6.4 illustrated the infiltration rate over time for the CPC slab reveals a distinct downward trajectory from Test 1 to Test 6. This pattern signifies a gradual decrease in the slab’s ability to absorb water as time progresses. Firstly, Test 1 recorded a high infiltration rate of 26,563.80 mm/hr in 40.44 s, demonstrating the slab’s potential for rapid water absorption. However, as the testing progressed the infiltration rate gradually decreased. Ultimately, Test 6 resulted at 16,798.12 mm/hr of infiltration rate in 63.95 s.

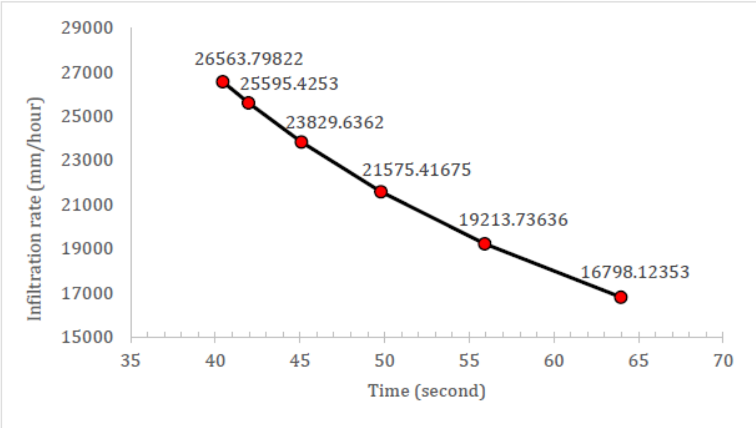

Figure 6.4: Relationship between infiltration rate, I and time, t of CPC slab directly poured with 1.5 L water

(b) Infiltration rate when poured with water of 12 cm depth

Figure 6.5 shows the infiltration ring test conducted with water of 12 cm depth poured into the ring.

Figure 6.5: Infiltration ring test on CPC slab when poured with water of 12 cm depth

Table 6.2 and Figure 6.6 present the results of an infiltration rate test conducted on a composite porous concrete slab using a 12 cm water depth. The data reveals a consistent downward trend in the infiltration rate over time. The initial test, Test 1, recorded a substantially higher infiltration rate of 63,152.6 mm/hr, requiring only 15.31 seconds for water infiltration. In contrast, Test 5 exhibited a lower infiltration rate of 34,592.71 mm/hr, taking a longer duration of 27.95 seconds for the same amount of water to infiltrate.

Table 6.2: Result of infiltration rate by directly pouring 12 cm depth of water

Mass *M* (kg)	Diameter *D* (mm)	Test no.	Time *t* (s)	Infiltration rate *I* (mm/hr)
		1	15.31	63152.60
		2	18.80	51429.06
0.60319	80	3	21.46	45054.35
		4	24.19	39969.67
		5	27.95	34592.71

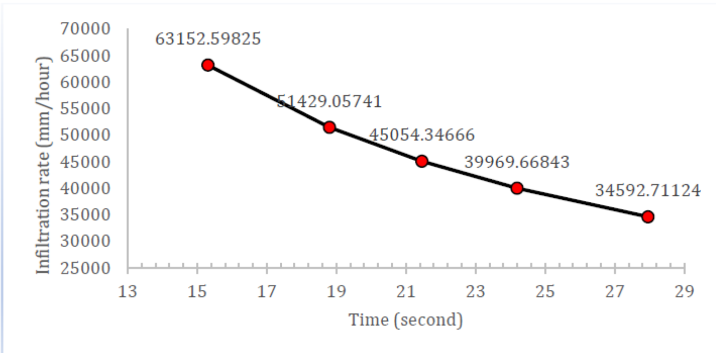

Figure 6.6: Relationship between infiltration rate I and time t of infiltration when water of depth 12 cm is poured on CPC slab

(c) Infiltration rate measurement for every 5 second (s) while pouring water

Table 6.3 outlines the outcomes of an infiltration rate test conducted on a composite porous concrete (CPC) slab (Figure 6.7). Figure 6.8 represents data and it would likely depict a downward trend, with the initial infiltration rate being the highest and gradually decreasing over time.


Figure 6.7: Infiltration ring test on CPC slab with measurements every 5 seconds

Table 6.3: Result of infiltration rate with measurements at every 5 seconds

Time *t* (s)	Test no. 1		Test no. 2		Test no. 3	
	Depth in inner ring (mm)	Infiltration rate *I* (mm/hr)	Depth in inner ring (mm)	Infiltration rate *I* (mm/hr)	Depth in inner ring (mm)	Infiltration rate *I* (mm/hr)
0	298.4	-	298.4	-	298.4	-
10	150.0	53424	150.0	53424	150.0	53424
15	75.0	5400	100.0	36000	120.0	21600
20	10.0	46800	35.0	46800	75.0	32400
25	0.0	7200	0.0	25200	20.0	39600
30	0.0	0	0.0	0	0.0	14400

A constant water volume of 1.5 L was maintained throughout the test, and the infiltration rate was measured every 5 seconds. The data reveals a consistent decline in the infiltration rate over time. Test 1 and Test 2, both last 30 seconds, exhibited identical infiltration rates of 35,808 mm/hour (Table 6.4 and Figure 6.8). However, Test 3, extended to 35 seconds, resulted in a lower infiltration rate of 30692.57143 mm/hour. The observed reduction in infiltration rate over time, evident from the decrease between Test 1, Test 2 and Test 3 can be attributed to several factors.

Table 6.4: Averages of the three sets of experiments

Time t (s)	Volume of water (L)	Infiltration rate I (mm/hr)
30	1.5	35808.0
30	1.5	35808.0
35	1.5	30692.6

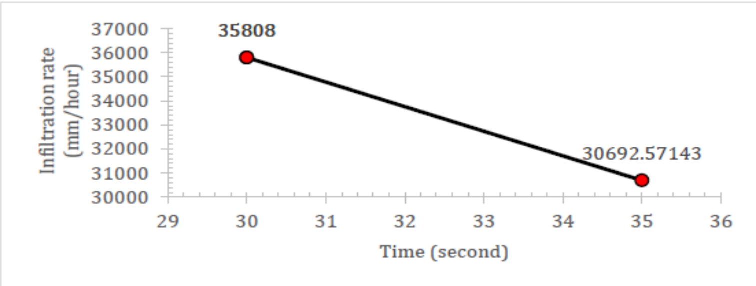

Figure 6.8: Relationship between rate of infiltration I and time t of CPC slab measured at every 5 seconds

As water infiltrates through the porous concrete, the pore slowly fills up and reduces its ability to absorb more water. This saturation effect becomes increasingly pronounced as the test duration extends, leading to a decrease in the infiltration rate. Moreover, pore clogging may also contribute to this trend. Over time, fine particles from the water or surrounding environment can obstruct the pores of the concrete and further hinder water infiltration. The interplay of these factors is likely contributed to the observed decline in infiltration rate.

6.3.3 ESTIMATION OF INFILTRATION RATE

Figure 6.9 illustrates the estimated infiltration rate over time for three different water application methods on a CPC slab: 1) directly pouring 1.5 L of water, 2) pouring water to a depth of 12 cm, and 3) pouring water while recording depth at every 5 seconds. The produced equation, infiltration rate I (mm/hr) = $725793t^{-}0.899$, mathematically models the relationship between infiltration rate I and time t for the CPC slab.

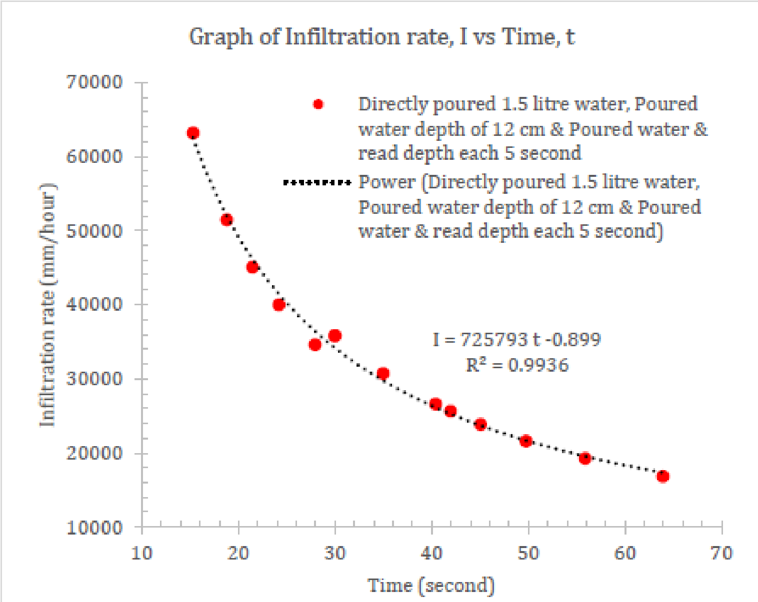

Figure 6.9: Rate of infiltration based on time of flow

As time increases, the infiltration rate decreases, as indicated by the negative exponent. The high R^2 value of 0.9936 signifies that the equation is highly accurate in predicting the infiltration rate based on the given time. The equation provides a strong fit to the combined data from the three methods, indicating that the infiltration rate decreases as time progresses. This is consistent with the expected behaviors due to the gradual saturation of the CPC slab's pores.

The analysis of the infiltration rate data for the CPC slab indicates a decline in infiltration capacity over time. This trend is likely influenced by factors such as the accumulation of debris within the pores and changes in the material's ability to conduct water. The strong correlation between infiltration rate and time, as evidenced by the high R^2 value of the fitted equation, highlights the reliability of the model. Nevertheless, it is crucial to acknowledge that other variables, including water quality, the specific properties of the CPC material, and environmental conditions, may also impact the infiltration process. To gain a comprehensive understanding of the long-term performance of CPC slabs and optimize their design for effective drainage, further investigation and experimentation are recommended.

6.3.4 COMPARATIVE RESULT OF INFILTRATION RING TEST WITH PREVIOUS STUDIES

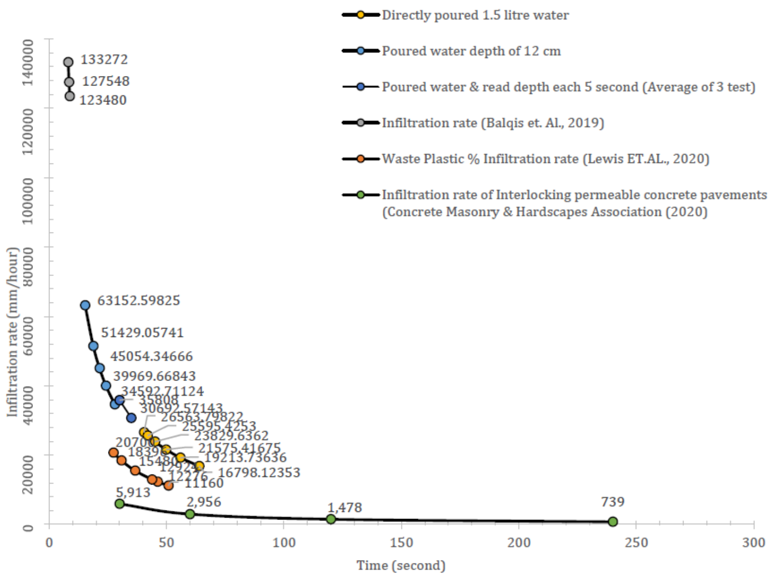

Figure 6.10: Comparison of infiltration rates from current and previous studies

The infiltration ring test results demonstrate a significant variation in infiltration rates across various methods on CPC slabs (Figure 6.10). Among the three methods of infiltration rate tested, the poured water depth of 12 cm shown the highest initial infiltration rate of approximately 63,152 mm/hr, followed by the directly poured 1.5 L water method shown with an initial rate of around 30,692 mm/hr. The poured water and read depth method showed a slightly lower initial rate of about 51,429 mm/hr but maintained a relatively high rate for a longer duration in seconds.

Compared to previous studies, the infiltration rates observed on the CPC slabs are generally higher, indicating the enhanced permeability of this material. For instance, the initial infiltration rate of the directly poured 1.5 L water method on CPC is significantly higher than the 20,709 mm/hr observed in a previous study for a similar method. Similarly, the steady-state infiltration rate of the CPC slab is higher than that of previous case studies.

The decreasing trend in infiltration rates over time for all methods is attributed to the gradual saturation of the CPC slab's pores. The steady-state infiltration rate reached after approximately 250 s, with a value around 1,478 mm/hr, represents the maximum capacity of the CPC slab to absorb water under the given conditions. These results suggest that CPC slabs can effectively improve infiltration rates compared to traditional concrete surfaces. Further research is needed to optimize the design and construction of CPC slabs to maximize their infiltration capacity and durability.

6.4 CONCLUSION

This study investigated eco-friendly CPC slabs made with recycled materials to assess their potential for improving drainage. Using a modified ASTM C1701 infiltration ring test, this study found that these slabs exhibited significantly higher infiltration rates than those in previous studies. The 12 cm water depth method yielded the highest initial rate of 63,152 mm/hr. Analysis showed a rapid initial infiltration that gradually decreased over time, confirming the effectiveness of CPC slabs for stormwater management. Although this research provides valuable insights, further studies with larger datasets and considering various environmental factors are needed to optimize CPC slab design and application in sustainable urban drainage systems.

6.5 RECOMMENDATIONS

The standard ASTM C1701 test method for measuring pervious concrete infiltration rates may not fully account for the influence of surface conditions on the initial water absorption capacity of the slab. The presence of surface layers, such as dust, debris, or curing compounds, can significantly affect the initial infiltration rate. To obtain more precise and reliable infiltration rate data for CPC slabs, a modification to the standard test method is proposed.

To improve the accuracy and reliability of infiltration rate testing for composite porous concrete (CPC) slabs, a modification to the standard ASTM C1701 test method is proposed. This modification begins by covering the porous concrete surface with a blocked layer to prevent direct water infiltration before reaching the maximum depth of the infiltration ring. After a set amount of time, the obstructed layer is eliminated, allowing for direct water absorption. This method takes on the possible influence of surface conditions on the initial infiltration rate by measuring infiltration time beginning when the water depth reaches the desired level. This enables simultaneous penetration and more precise data collecting. This improvement allows researchers to acquire more exact and trustworthy data, resulting in a better knowledge of CPC slab performance and improving the accuracy of infiltration rate statistics.

BIBLIOGRAPHY

[1] Georgia Concrete and Products Association (GCPA) (2006). *Guide for Construction of Portland Cement Concrete Pervious Pavement.* Tucker, Ga. Online: http://www.gcpa.org/ (Dec 11, 2006).

[2] MBSA (2019). Drainage Cover. Majlis Bandaraya Shah Alam (MBSA). https://compositeporousconcrete.com/drainage-cover/

[3] Ahmad, F.H.M., Jamal, M.H. & Sam, A.R.M. (2019). Green technology and sustainable urban drainage systems using eco-composite porous concrete: A preliminary study. *IOP Conference Series. Earth and Environmental Science* 220, 012039.