Evaluating the Impact of Aggregate Size and Sediment Type on Clogging and Permeability of Pervious Concrete

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ABSTRACT

Pervious Concrete (PC) is increasingly being used in sustainable drainage systems owing to its ability to manage stormwater. However, sediment accumulation can clog pores and reduce their permeability. This study investigates the effect of various sediment types, sand, clay, gravel, and oil, on the permeability of pervious concrete samples with three different aggregate size ranges: 12.5–19.1 mm, 9.5–12.5 mm, and 4.75–9.5 mm. The concrete samples were subjected to sediment loads ranging from 0 g to 100 g, and the permeability was measured after each sediment addition. The objective was to assess the impact of sediment type and quantity on permeability reduction, and to evaluate the role of aggregate size in resisting clogging. The results demonstrate that larger aggregates maintained higher permeability and were less affected by sediment accumulation, whereas smaller aggregates experienced significant clogging and rapid permeability loss. Oil had the least impact on the permeability, whereas gravel and sand caused the greatest reduction. Permeability stabilisation occurred after sediment accumulation reached 60–70 g for all samples. These findings highlight the importance of aggregate size selection in pervious concrete designs to enhance long-term performance and resistance to clogging. Larger aggregates from 12.5 to 19.1 mm were shown to be the most effective in maintaining permeability, even under sediment load.

Keywords-pervious concrete; permeability; aggregate size; sediment; clogging

I. INTRODUCTION

As urbanization accelerates and the effects of global climate change become more pronounced, the risk of urban flooding due to heavy rainfall is increasing [1]. The prevalence of impermeable surfaces in cities impedes water infiltration and contributes to urban flooding [2]. This reduced infiltration capacity not only exacerbates surface water runoff, but also hinders groundwater recharge, leading to the depletion of critical groundwater resources. To address these challenges, porous and permeable concrete has emerged as a key approach to enhance stormwater management and regulate groundwater levels [3]. Furthermore, the utilization of permeable concrete pavements enhances a city's capacity to absorb rainfall, mitigates the urban heat island effect, and supports overall climate and ecosystem improvements [4, 5].

PC is a porous paving material composed of graded aggregates, cement, water, additives, and admixtures in defined proportions. Its porosity typically ranges from 15% to 35%, resulting in the formation of a cohesive and stable honeycomb-like structure within the concrete [6-9]. Unlike conventional concrete, PC is distinguished by its uniform and large aggregate sizes. These aggregates are bonded by a thin layer of cementitious paste, creating numerous internal pores. These interconnected pores form permeable channels that facilitate surface drainage and groundwater recharge. Research has demonstrated that areas utilizing permeable pavements experience a 7-16% reduction in peak runoff flow [10]. Similarly, permeable pavements reduced runoff volume by 33% and peak flow by 43% compared to traditional concrete pavements [11]. However, permeable pavements are prone to clogging, which can adversely impact their functionality and lead to premature deterioration [12].

Research on the permeability of PC has primarily focused on factors such as the total porosity, connected porosity, pore size distribution, and tortuosity. A study evaluated the reliability of various porosity measurement techniques and examined the relationship between porosity and permeability through permeability tests [13]. The permeability coefficients of PC with different cement-to-aggregate ratios and aggregate gradations was investigated to develop a multivariate model for predicting permeability based on the significant correlation of three representative characteristics of PC's planar pores [14]. In order to propose a revised predictive Kozeny-Carman model, the influence of pore curvature on permeability was examined by modifying matrix workability, binder content, and aggregate size, thereby preparing PC with varied microstructures and proposing a revised Kozeny-Carman model to predict the outcomes [15]. Another research group developed an approximate model using Discrete Element Modelling (DEM) to simulate the spheroidization of PC and studied the effects of parameters such as aggregate size, aggregate-paste ratio, and porosity on hydraulic conductivity and clogging potential [16].

This study aims to investigate the clogging mechanisms of pervious concrete by evaluating the influence of various sediment types and aggregate sizes on permeability. Previous research has examined factors like water-to-cement ratios, cement-to-aggregate ratios, and porosity, but there is limited understanding of how different sediments affect clogging. Additionally, while the impact of aggregate size on permeability has been studied, comprehensive evaluations of the combined effects of sediment types and aggregate sizes on clogging potential and serviceability are lacking.

II. METHODOLOGY

A. Material and Sample Preparation

PC used in this study consisted of coarse aggregate, cement, and water. No fine aggregates were included to preserve the porous nature of concrete. The coarse aggregates were divided into three groups based on particle sizes: 4.75–9.5 mm, 9.5–12.5 mm, and 12.5–19.1 mm. The selected size ranges were chosen based on their typical application in pervious concrete pavements, as they provide varied pore structures, and therefore, different permeability and mechanical characteristics. Each aggregate group was carefully sieved to ensure uniformity in the particle size distribution, minimising the variation in pore characteristics between the test samples. A series of tests was conducted to investigate the properties of the coarse aggregates, as summarised in Table I.

TABLE I. COARSE AGGREGATE PROPERTIES

Test	Results	Standard
Density	1429 kg/m^3	ASTM C29 [17]
Specific gravity	2.5	ASTM C127 [18]
Absorption	2.5%	ASTM C127 [18]
Fineness modulus	7.3	ASTM C136 [19]

The concrete design mixes for this study were formulated according to the guidelines outlined in ACI 522R-10, with a standardised Water-to-Cement (W/C) ratio of 0.34 across all samples [20]. Type I Ordinary Portland Cement (OPC), conforming to the ASTM C150 specification, was used as the binder in all mixes [21]. This cement type was chosen for its suitability for structural applications and compatibility with PC designs. The mix design, which remained consistent across all three groups of aggregate sizes, involved careful proportioning of cement, water, and coarse aggregates to achieve a workable mix. The detailed proportions are presented in Table II.

TABLE II. PERVIOUS CONCRETE DESIGN MIX

Material	Aggregate size		
	4.75 – 9.5 mm	9.5 – 12.5 mm	12.5 – 19.1 mm
Coarse aggregate (kg)	1471	1370	1318
Cement (kg)	305	305	305
Water (kg)	104	104	104

To ensure consistent testing and avoid any biases during the permeability test, cylindrical samples were prepared directly within a 100 mm Poly-Vinyl Chloride (PVC) pipe, which served as the mould. Each sample had a diameter of 100 mm and a length of 200 mm, complying with the typical sample dimensions used for the permeability testing of pervious concrete. The samples were cured for 28 days under moist conditions, following standard curing practices to ensure that the concrete reached sufficient strength for testing while maintaining the required permeability properties. Curing was carried out by keeping the samples in a controlled environment with high humidity and room temperature, ensuring uniform hydration of the cement [22].

The concrete samples were grouped based on the aggregate size and tested for each of the five sediment types. Five types of sediment were selected for the permeability tests to evaluate the effect of clogging on PC: sand, clay, gravel, and oil. Each sediment type was carefully measured to ensure consistent addition during testing, and 10 g of sediment was used in each iteration. In each scenario, three replicate samples were tested to ensure statistical reliability and minimise experimental variability. This approach enabled a robust comparison of permeability under varying aggregate sizes and sediment types, with the results averaged to accurately represent each condition.

B. Experimental Procedures

A custom-built test apparatus was constructed utilizing a combination of PVC pipes and connectors, as illustrated in Figure 1. The test setup consisted of a 100 mm PVC pipe, a 50 mm pipe, a T-reducer connector of 100 mm to 50 mm, and a 100 mm pipe connector. The concrete samples were molded within a 100 mm pipe to ensure easy integration with the permeability testing system. The test setup also included a measuring cup and wire mesh for water collection, as well as a hose to supply water to the test samples. The test apparatus was designed to facilitate the examination of the permeability characteristics of the concrete samples by allowing for the controlled introduction and measurement of water flow through the samples.

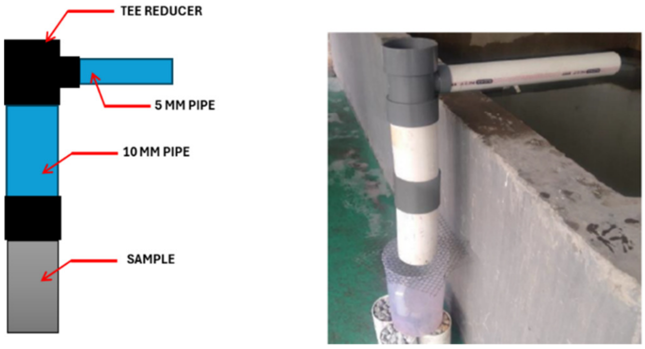

Fig. 1. Test apparatus setup.

The procedure described above was followed for all coarse aggregate size groups and all sediment types. Each test was conducted under consistent conditions to ensure an accurate comparison of the permeability results across different combinations of aggregate sizes and sediment types.

The permeability value k was calculated for each test sample using the recorded time and the following permeability equation:

$$k = \frac{QL}{Aht} \quad (1)$$

where Q is the volume of water collected, L is the length of the test sample, A is the cross-sectional area of the sample, h is the constant head, and t is the time taken to collect the water.

III. RESUTLS AND DISCUSSION

The permeability tests were conducted to assess the impact of sediment clogging on pervious concrete with three different coarse aggregate sizes: 12.5–19.1 mm, 9.5–12.5 mm, and 4.75–9.5 mm. The results of the permeability tests using clay sediments are presented in Figure 2. The results indicate a progressive decrease in permeability as the amount of clay sediment increased. The overall trend highlights a clear relationship between aggregate size, sediment accumulation, and reduction in permeability.

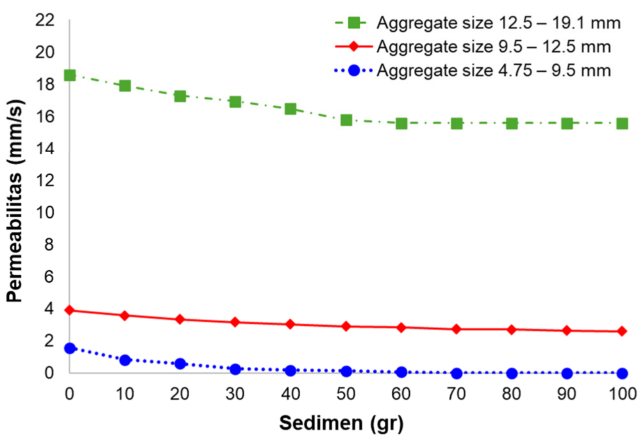

Fig. 2. Permeability test using clay sediment.

The largest aggregate size, 12.5–19.1 mm, exhibited the highest permeability. As sediment was incrementally added, the permeability decreased gradually, reaching a stabilised value of 15.60 mm/s at 60 g of sediment, which persisted up to 100 g. This behaviour suggests that while the large pores in this aggregate size allow for better drainage, they are also susceptible to clogging, although to a lesser degree than smaller aggregate sizes. However, the reduction in permeability was relatively moderate, with only a 16% decrease from the initial permeability when 100 g of sediment was added. This performance can be attributed to the larger pore size created by the coarse aggregate, which allows water to flow more freely, even as sediment accumulates. The decrease in permeability, while present, remains within the acceptable limits for typical pervious concrete applications. These findings are consistent with prior research indicating that large aggregate sizes contribute to higher initial permeability values, but are still subject to partial clogging over time.

In contrast, the smallest aggregate size exhibited the lowest overall permeability and the most significant reduction with the addition of sediment. The initial permeability was recorded at 1.56 mm/s, with the introduction of 10 g of sediment, the permeability dropped sharply to 0.82 mm/s. With increasing sediment accumulation, the permeability continued to decline until reaching 0 mm/s at 70 g of sediment. This complete clogging indicates that the smallest aggregate size is highly susceptible to clogging when exposed to fine particles, such as clay, rendering the material impermeable after moderate sediment accumulation. This result underscores the inherent trade-off between the aggregate size and permeability in pervious concrete. Although smaller aggregates create a denser concrete matrix that might improve strength, they are highly vulnerable to clogging. These findings are consistent with those of previous studies, which indicate that smaller aggregates, while providing a more uniform structure, significantly reduce the ability of concrete to maintain water flow under sediment-loading conditions.

A comparison of the three aggregate sizes highlights a clear trend: larger aggregates provide higher permeability and are less affected by sediment accumulation. In contrast, smaller aggregates resulted in lower initial permeability and were prone to complete clogging after the introduction of relatively small amounts of sediment. This trend can be attributed to the larger pore sizes associated with coarser aggregates, which are less likely to be obstructed by the sediment particles. These findings suggest that the use of larger aggregates is preferable in environments prone to sediment accumulation, as they can better maintain permeability over time. However, a balance between mechanical strength and permeability must be considered, as smaller aggregate sizes may improve the structural integrity of concrete while sacrificing its permeability performance.

Following the initial analysis of the effects of aggregate size on permeability, the investigation was expanded to evaluate the performance of pervious concrete under four additional sediment types: sand, clay, gravel, and oil. As shown in Figure 3, each sediment type exhibited unique effects on the ability of concrete to maintain permeability, highlighting the relationship between the particle size, type of material, and clogging potential of pervious concrete systems. The results show that while pervious concrete is generally resilient to sediment accumulation, the type of sediment significantly affects its long-term permeability.

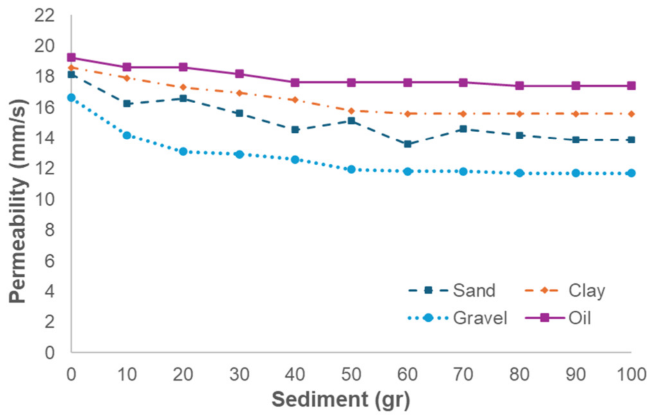

Fig. 3. Permeability test of PC with aggregate size 12.5–19.1 mm using different sediments.

The results demonstrate that different sediment types have varying effects on the permeability of PC. Among solid sediments, gravel showed the highest potential for clogging, followed by sand and clay. Oil, which is a liquid contaminant, had the least impact on permeability. This trend can be correlated with the particle size and packing behaviour of the sediment. Larger particles, such as gravel, quickly obstruct flow paths, while finer materials, such as clay, infiltrate the matrix more gradually. In contrast, liquid contaminants, such as oil, tend to coat the internal surfaces without immediately filling the pores, leading to more gradual permeability reductions. The varying effects of different sediment types on permeability have important implications in the design and maintenance of pervious concrete systems. In environments prone to sand or gravel accumulation, maintenance strategies, such as surface vacuuming and periodic washing, may be necessary to restore permeability. In areas where clay or oil contamination is a concern, more frequent and aggressive cleaning techniques may be required to prevent the long-term degradation of the system.

IV. CONCLUSIONS

This study investigated the effects of various sediment types, sand, clay, gravel, and oil, on the permeability of Pervious Concrete (PC), focusing on samples with different aggregate sizes. The primary objective of this study was to evaluate the clogging potential and permeability reduction of PC under different types of environmental contaminants. The results of the permeability tests revealed several key conclusions.

1. Aggregate size: Larger aggregates, 12.5–19.1 mm, consistently demonstrated higher initial permeability and greater resistance to clogging than did smaller aggregates, 4.75–9.5 mm, which showed rapid permeability loss and complete clogging with relatively small amounts of sediment.
2. Impact of sediment type: The results indicate that the type of sediment plays a critical role in determining the permeability of pervious concrete. Among the tested sediments, gravel caused the most significant permeability reduction of 29.6%, followed by sand with 23.5%, clay reaching 16%, and oil, which had the least impact of 9.5%.
3. Sediment accumulation: PC exhibited relatively high resilience to clogging when subjected to sand and oil contamination. However, the significant reduction in permeability owing to gravel and clay highlights the vulnerability of pervious concrete systems in environments with larger particulate sediments.
4. Pore saturation: For sediment types, the permeability reached a point of stability beyond a certain threshold. Both clay and gravel sediments demonstrated that once the pores in the PC matrix were sufficiently blocked, approximately 60–70 g of sediment. Further additions had negligible effects on the permeability.
5. Recommendations for maintenance and application: The varying effects of different sediment types suggest that maintenance strategies for PC systems must be tailored to the predominant sediment type in a given environment. For instance, areas prone to gravel or clay accumulation should implement more frequent and intensive cleaning methods, such as mechanical vacuuming or pressure washing, to prevent rapid clogging and to ensure long-term functionality. Environments in which sand and oil contamination are more common may require less frequent but regular maintenance.

To the best of our knowledge, the findings quantify the impact of contaminants on permeability reduction, providing insights into aggregate size and sediment-specific clogging mechanisms. This study can help engineers design and maintain pervious concrete systems, and develop effective solutions to ensure long-term sustainability and functionality.

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DATA AVAILABILITY

Experimental data: https://zenodo.org/records/13939204.

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