Pervious Concrete for Urban Stormwater Management in Kathmandu Valley

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Abstract: Urban drainage difficulties have sparked debates and conflicts because of population growth and land use. Expanding urban infrastructure has led to an increase in impermeable zones, which prevent water from seeping into the ground and percolating. Rapid urbanization, population growth, and climate change have put strain on water management in Kathmandu Metropolitan City (KMC). Urban flooding is becoming more frequent, which has a negative impact on daily life and causes major damage. This study assesses the possibilities for controlling runoff volume through stormwater management in Kathmandu Metropolitan City (KMC). To counteract floods brought on by urbanization, pervious concrete, a substance that allows water to seep through floors or seams, is essential. Dosing strategies must be used, concentrating on aggregate content and water/cement ratio (water/cement (w/c)), to obtain acceptable traces. The purpose of this study is to evaluate permeable concrete's effectiveness as a flood-prevention alternative. A review of books, journals, monographic works, and standards is included as part of a bibliographical research project. The strengths of the previous concrete ranged from 2.8 to 28 MPa, according to data gathered after 28 days, falling within the normal range of ACI 522R:06 (2006) and below the normal range of 10 MPa. The porous concrete successfully percolated precipitated water in just a short period, demonstrating its potential as a successful substitute for flood prevention.

Keywords: *Flood, Kathmandu Metropolitan City, pervious concrete, Stormwater management, Urban drainage*

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1. Introduction

The global trend of urbanization has introduced numerous challenges, particularly in managing stormwater runoff in urban areas. Nepal, despite being among the least developed countries, has experienced rapid urbanization, with urban populations growing substantially faster than rural populations (Census Nepal 2021). The Kathmandu Valley stands out as one of the world's fastest-growing urban centers. The valley's urbanization, marked by population density and increased building units, has transformed the landscape, replacing permeable soil with impermeable surfaces like paved streets, roofs, and parking lots(Population | National Population and and Housing Census 2021 Results, n.d.). This shift from permeable to impermeable surfaces has significantly impacted the region's ability to manage rainfall, resulting in urban flooding.

The issue of flooding in cities like Kathmandu Metropolitan City has become increasingly prevalent due to the combined effects of population growth and urbanization. Rapid population growth over recent decades has exacerbated the problem, leading to a higher concentration of impermeable surfaces within urban areas. Pervious concrete, among other strategies, emerges as a vital tool to address this pressing concern. Pervious concrete serves as a specialized drainage system that enables rainfall to permeate through its structure and collect within the soil's base and subbase. From there, the collected water either gradually reaches the water table through the subgrade or is directed into the city's drainage system. This innovative approach to pavement construction tackles the adverse effects of waterproofing on rainwater infiltration. Not only does pervious concrete encourage enhanced water absorption, but it also addresses the necessity for effective surface drainage in urban contexts. In response to the problem, this article undertook an experimental study with the aim of confirming the efficacy of permeable concrete as a pavement solution. Specifically targeting low-traffic areas like parking lots, walkways, cycling lanes, and squares, the study aimed to validate the practicality of pervious pavement. The observed experimental conditions served as the basis for developing solution techniques that underscore the utility of pervious pavement in controlling flooding issues within the specified urban areas. By allowing for controlled surface runoff, this technique demonstrates its potential to effectively mitigate flooding problems and presents a valuable solution for urban planners and policymakers grappling with the challenges posed by urbanization-induced impermeability.

In the Kathmandu Metropolitan City (KMC), over 50% of rainfall in heavily populated regions becomes surface runoff, and only a small percentage of the rainfall seeps into the ground. By 1990, there was around 25% more imperviousness in KMC compared to the rest of the country. In 2021, 75% of the area consisting of various zones like commercial, industrial, institutional, etc., had become impermeable, putting a considerable strain on the drainage system. This transformation has led to shortened runoff periods and peak flows, exacerbating flooding events (Pradhan-Salike & Raj Pokharel, 2017).

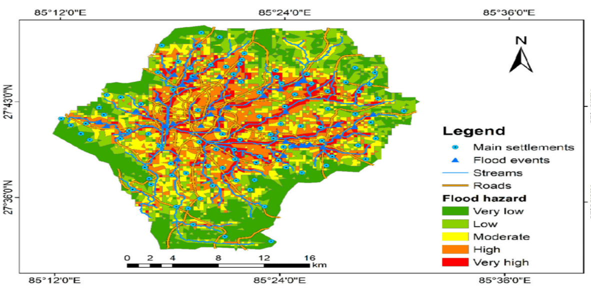


Figure 1: Flood Hazard map of Kathmandu Valley (Khatakho et al., 2021)

Figure 2: Pervious Concrete (Moretti et al., 2019a)

To address these challenges, pervious concrete emerges as a potential solution. This innovative material, depicted in Figure 1, offers improved drainage characteristics, allowing percolated water to either recharge groundwater or enter drainage networks(USB Monographs, n.d.). Permeable paving, incorporating technologies like pervious concrete, has been developed to counteract flooding resulting from urban development. Although less common in Nepal, permeable paving presents a promising technique for flood reduction in metropolitan areas. Against this backdrop, this study focuses on assessing the performance of permeable concrete in the context of Kathmandu Valley's stormwater management. By analyzing the draining properties and potential benefits of this material, the research aims to showcase its effectiveness in mitigating urban flooding—a critical concern for sustainable urban development. This study's findings not only contribute to flood prevention strategies in KMC but also offer insights that could be applied to other urban areas grappling with similar challenges.

2. Materials and methods

2.1. Pervious concrete systems

There are three typical types of practical systems that can be used to build a permeability solution. The three systems listed below are easily adaptable to build a permeable concrete foundation:

System A (Total Infiltration) allows and facilitates natural drainage by enabling all precipitation or surface water to enter through the constructed layers into the subsurface layers. This method is only practical when the earth is sufficiently porous. Composition: Total Infiltration of pervious concrete consists of a mixture of coarse aggregates, minimal cement paste, and water. The coarse aggregates are carefully selected to create an open and interconnected void structure. Working Mechanism: When rainwater falls onto the surface of total infiltration pervious concrete, it quickly seeps through the voids between the aggregates. The large void spaces allow water to infiltrate directly into the underlying soil. The water moves through the concrete and into the ground due to gravity. The interconnected voids enable rapid vertical and horizontal movement of water, reducing surface runoff. Functionality: Total infiltration of pervious concrete effectively reduces surface runoff by facilitating the quick movement of rainwater into the soil. This helps in recharging groundwater reserves and reducing the risk of flooding during heavy rainfall. As water passes through the pervious concrete and the soil, it also undergoes natural filtration, which helps remove pollutants and contaminants before reaching the groundwater.

System B (Partial Infiltration) used where the subsurface has some permeability and infiltration but does not support the expected flow from the drained region. Pipe installation is required. PVC in the middle of the subfloor layer ensures that any surplus water that cannot penetrate the soil is efficiently drained. Composition: Partial Infiltration pervious concrete strikes a balance between fully permeable and impervious designs. It uses a mix of aggregates and cement paste that allow some water infiltration while still providing a level of surface runoff. Working Mechanism: Rainwater that falls on the surface of partial infiltration pervious concrete will partly infiltrate through the voids, like total infiltration pervious concrete. However, due to the design, a portion of the rainwater will also generate surface runoff. The concrete's permeability ensures that some water infiltrates while some is carried away, striking a balance between water management and aesthetics.

System C (No Infiltration) is utilized where the soil type no longer allows for infiltration. After attenuating the surface water, the tool must download it to the correct area. This equipment requires the installation of a waterproof membrane over the subsoil as well as the placement of PVC pipes within the subbase layer. Composition: No Infiltration pervious concrete is designed with a more refined mixture, often using finer aggregates and a slightly higher cement content compared to traditional pervious concrete. Working Mechanism: While no infiltration pervious concrete retains some void spaces, they are smaller and less interconnected compared to fully permeable pervious concrete. When rainwater lands on the surface, it still passes through the voids but at a slower rate due to the reduced permeability. Some water might be absorbed into the underlying soil, but a significant portion can result in surface runoff. Functionality: No infiltration pervious concrete is often used in applications where water management is desired, but the complete infiltration of rainwater is not required. It can be used to mimic the appearance of traditional concrete while providing limited water permeability.

Figure 3: Pervious Concrete System(Watch This: ‘Thirsty’ Concrete Drinks 4,000 Litres of Water in 60 Seconds 3 - MaterialDistrict, n.d.)

2.2. Developing parameters for the porous concrete mix

Depending on its composition, the permeable pavement has great porosity and good drainage. Because of the tendency to enable water to penetrate through their porous structure, the utilization of these structures, when properly designed and implemented, can have a considerable impact on the peak flows that occur during rainstorm events in each site. Hydraulic binder, uniformly sized crushed material, water, and little to no fine aggregate make up pervious concrete(Moretti et al., 2019b).

Some sorts of additives that allow the material to have improved properties, such as better strength, durability, performance, and workability, can also be utilized in the formulation of this type of concrete. To create a paste that forms a thick coating around the aggregate particles, the proportion of water and hydraulic binder that are employed in the composition of permeable concrete are carefully managed. To create a material with a high void content that will show good drainage to the interconnectivity of its voids, the mixture must have little to no fine aggregate. For the drainage process to function properly, it is crucial to emphasize that the usage of porous concrete only works when it is combined with a high-quality base and sub-base layers.

2.3. Laboratory study requirements

We first sought to identify what might be the potential factors used to conduct further studies to direct what will be done in this initial stage. Given that pervious concrete is a relatively new material in Nepal, for permeable concrete, the properties that must be evaluated in the material while it is still in its new stage, the methods used to prepare and elaborate test specimens, and the attention given to quality control are different from those used in conventional concrete(Ibrahim et al., 2014).

Because porous concrete does not use sand, it has a different workability than conventional concrete, which results in a slump that is typically less than 20 mm in permeable concrete slump tests. This is because the combination of materials in pervious concrete enables a more rigid mix than that obtained in traditional concrete. As a result, the values decrease and shrink significantly when compared to conventional concrete, leaving the approach useless because it is impossible for the values to accurately represent the combination. Since there are no procedures or specifications in Nepal for the laboratory study of this material, it is essential that the tests be based on American standards set by the American Concrete Institute (ACI), the American Society for Testing Materials (ASTM), and past research(C1747/C1747M Standard Test Method for Determining Potential Resistance to Degradation of Pervious Concrete by Impact and Abrasion (Withdrawn 2022), n.d.).

2.4. Dosage method: ACI 211.3R-02 (2009)

In addition to ACI 211.1 (1991)(Aci 211.1-91 Topic, n.d.), which acts as a criterion for the creation of porous concrete mixes, the ACI 211.3R-02 (2009) guidance allows proportions with slumps in the range of 0 to 25 mm and consistencies below this range, for aggregates with a maximum size of 75 mm(American Concrete Institute. Committee 211., 2002).

In this manual, tables and graphs are supplied together with laboratory testing of the physical characteristics of coarse and fine aggregates (only coarse aggregates in this study), which provide information for determining concrete proportions for an experimental mixture. Additionally, this standard provides an appendix on the proportions for mixing various forms of concrete, including permeable concrete for drainage reasons, roller compacted concrete, concrete tile, concrete masonry units, and more. Still, certain examples of calculations appropriate for these unique applications are presented to aid in the development of the calculation of evidence.

3. Results and discussion

Based on the relevant bibliographies, the qualities utilized in this study were defined empirically to employ the best water/cement (w/c) ratio and the best range of values for the fraction of required and recommended aggregates and to produce porous concrete as efficiently as possible. Given that this is the only standard that permits more exact control of the dosing method of this type of special concrete, the ACI dosage guidelines 211.3R-02 (2009) were followed from the adoption of such parameters(American Concrete Institute. Committee 211., 2002). This allowed for the determination of cement consumption at 268 Kg/m3 and coarse aggregate consumption at 1567 Kg/m3, resulting in a cement/aggregate ratio of 1:5.8 which is represented in table below.

Table 1: Consumption used

MATERIALS	UNITS	VALUES
Cement Consumption	kg/m³	268
Aggregate Consumption	kg/m³	1567
Cement/Aggregate mass ratio	-	1:5.8

The water/cement (w/c) ratio was set at 0.30 because, among the examined research, it yields the greatest outcomes when combined with the number of aggregates. Ratios set at 0.45 are excessive, resulting in an excess of fluid paste that clogs the pores, which are a crucial component of the investigation. The concrete is extremely dry and devoid of any alloy when the ratios are set at 0.26, making it impossible to work with. On the other hand, the ratios set at 0.26 add the least amount of water to the set (Vélez Moreno, 2008).

The granulometric curves and the applied water/cement (w/c) ratio served as the study's primary focus. It was discovered after reviewing the literature that some writers mixed coarse particles with distinct granulometric curves. Some people employed uniform grading curves, employing just one aggregate diameter, but others utilized two or three distinct aggregate diameters.

The decision was made to study three mixtures of a single grading curve (Gravel 0), with the only difference between them being the diameters used, as shown in table below. This was done after evaluating the results from previous studies, considering the permeability/ resistance ratio, where it is intended to go, and seeking a good variation of the parameters of mechanical resistance and permeability (Dinh et al., 2016).

Table 2: Percentage of aggregates used in mixture.

MIXTURES	% WITHHELD		
	4.5 to 6.5 (mm)	6.5 to 9.3 (mm)	9.3 to 12.5 (mm)
Mixture 1	100	0	0
Mixture 2	0	100	0
Mixture 3	0	0	100

It is important to note that all combinations used the same mix, maintaining the same water/cement (w/c) ratio and material usage while just varying the Gravel 0 sizes. Given that this concrete has an extremely low slump that ranges from 0 to 20 mm, as demonstrated in all previous research, this type of dosage cannot be achieved using conventional concrete(Vélez Moreno, 2008).

The specimens dosed in plates and cylindrical molds, respectively, displayed the structure shown in figures below.

Figure 4: Φ 4.5 to 6.5 (mm)

Figure 5: Φ 6.5 to 9.3 (mm)

Figure 6: Φ 9.3 to 12.5 (mm)

Figure 7: Concrete slabs after stripping Φ 4.5 to 6.5 (mm)

Figure 8: Concrete slabs after stripping Φ 6.5 to 9.3 (mm)

Figure 9: Concrete slabs after stripping Φ 9.3 to 12.5 (mm)

3.1. Specific mass, void index, and water absorption

The findings of water absorption, the voids index, and the dry and saturated specific masses are all shown in the given table.

Table 3: Results of the Specific Mass, Void Index and Water absorption tests.

Tests	PROOF BODIES		
	4.5 to 6.5 (mm)	**6.5 to 9.3 (mm)**	**9.3 to 12.5 (mm)**
Water absorption (%)	5.06	5.35	4.37
Index of voids (%)	12.3	12.88	10.84
Dry specific mass (g/cm³)	2.43	2.41	2.48
Specific saturated mass (g/cm³)	2.55	2.54	2.59

3.2. Compression resistance

The compressive strength of concrete without fines for porous concrete without additives ranges from 12 to 19 MPa. Resistances ranging from 2 to 12 MPa were reported in the updated literature. Strengths were obtained ranging from 9.4 MPa for the 1:3 mix to 10.7 MPa for the 1:4 mix(Sriravindrarajah et al., 2012). With a single 1:4.44 mix, concretes with strengths ranging from 6.02 to 10.17 MPa(Batezini, n.d.). With a 1:5 ratio, obtained strengths ranging from 3.17 to 9.10 MPa(Ayobami et al., 2021). With 1:5 and 1:4 characteristics, attained strengths between 2 and 12 MPa(Alsubih et al., 2016).

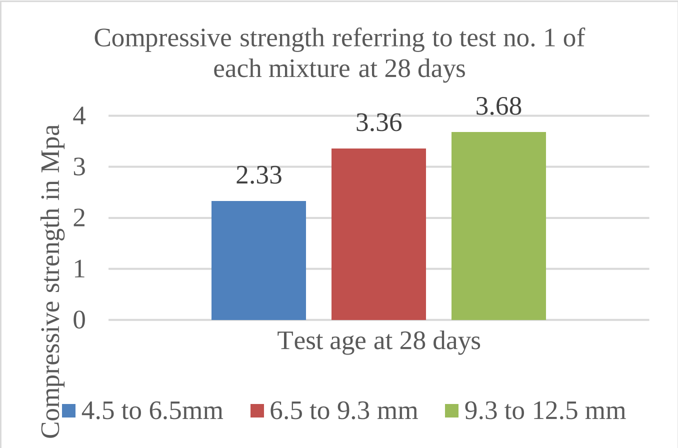
In this sense, it analyzed the resistances obtained through this research, which used the 1:5.8 ratio with a water/cement (w/c) ratio of 0.30. The resistances obtained are described in Table below:

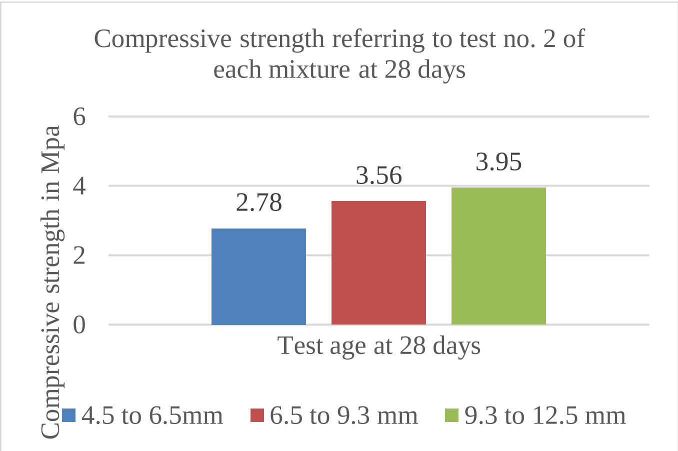
Table 4: Results of Compressive Strength tests.

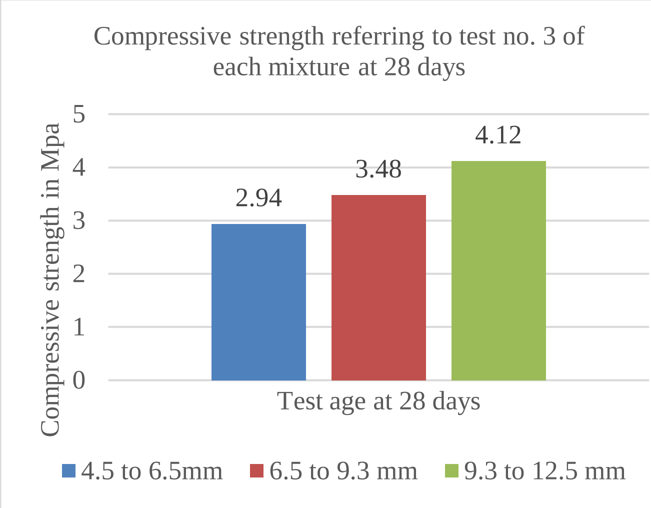
Size	Test No.	Weight (g)	Maximum load (Kgf)	Resistance to 28 days (MPa)	Average (MPa)
4.5 to 6.5mm	1	2682	1870	2.33	2.68
	2	2672	2227	2.78	
	3	2694	2431	2.94	
6.5 to 9.3 mm	1	2784	2690	3.36	3.47
	2	2747	2849	3.56	
	3	2783	2781	3.48	
9.3 to 12.5 mm	1	2698	2946	3.68	3.91
	2	2696	3032	3.95	
	3	2689	3156	4.12	

It is first possible to determine that none of the four minimum strength requirements defined by the standard are met by the concrete strengths acquired in this research at 28 days. Since just the compression efforts were examined, it should be highlighted that the resistance needed for this research should satisfy the first two types of coating(Nazeer et al., 2023). Although the strength values obtained are extremely close to the lower end of the range of values reported in the examined literature where the compressive strength in porous concrete ranges from 2 to 12 MPa as already mentioned. It is well known that the high void ratio, which is this type's primary distinguishing feature, is fully responsible for the reduced resistance values(Elizondo-Martinez et al., 2019).

Concrete with a brittle structure is produced by a low water/cement (w/c) ratio, bigger particles, and higher amounts of coarse aggregates. In this regard, it was determined that a characteristic with a low water/cement (w/c) ratio tends to have more variance in the outcomes. This investigation was made feasible by the observation that permeable concrete's lack of workability during the molding process was a prominent feature in its production. Graphs 1, 2 and 3 shown below demonstrate the compressive strength relating to the tests of each mixture according to their numbering at 28 days(Zhong & Wille, 2015).







From the graphs above, it can be observed that, although having equal resistance values, crushed stone with a wider diameter offers a stronger resistance gain in response to the age of the concrete. The lack of a sufficiently robust structure in pervious concrete to de-mold after 24 hours, as is the case with ordinary concrete, is another issue that needs to be covered in this topic. As a result, seven days after it had been molded, the concrete used in this investigation was demolished. This suggests that the healing process for them took a while to complete, which may have influenced the strength gain(Yang & Jiang, 2003).

In essence, it was discovered that the water/cement (w/c) ratio and the quantity of aggregates utilized have an impact on the specimens' configuration and compressive strength. Remembering that a higher proportion of aggregates and a lower proportion of water in the mixture results in limited workability, which makes it challenging to mold the specimens and gives them some deformations at their ends

3.3. Permeability Coefficient

The given table below provides a summary of the permeability test's findings.

Table 5: Results of the permeability test

TEST OF PERMEABILITY	SAMPLES		
	A1 **Φ4.5 to 6.5 mm**	**A2** **Φ6.5 to 9.3 mm**	**A3** **Φ9.3 to 12.5 mm**
percolation time	32 sec	24 sec	20 sec
percolated water	3.95 I	3.94 I	3.96 I
Plate weight after test	1810g	1763 g	1920g

According to the results, the analyzed samples meet the permeability requirements, as stated in the table above, because the precipitated water percolated efficiently in both samples in a short period of time. The samples' high permeability is attributed to their short vibration period of only 10 seconds. According to the literature, the reduced vibration inhibits paste segregation because this sort of mixture has few binders(Singh & Goel, 2019). This explains the permeability test efficiency because attention was given to the vibration of the analyzed samples, allowing the concrete to fulfill its principal role of permitting water percolation via its structure. Another component that was investigated was the relationship between the proportion of aggregates and the water/cement (w/c) factor. The low cement consumption, with no fines consumption and greater consumption of coarse aggregates, together with the decreased water consumption in the mixture, results in a paste with a high void ratio. As a result, the pores in the concrete structure might infiltrate the water that passes through them.

Finally, when the three samples were compared, it was discovered that the sample with the biggest diameter, 9.3 to 12.5 mm, was the sample in which the water precipitated in the shortest time. Furthermore, the shorter the water percolation time, the greater the diameter of the gravel(Alsubih et al., 2016).

4. Conclusion

This investigation enabled certain conclusions to be drawn regarding what was intended and achieved, which are described more below. Regarding the destructive tests, it was discovered that there is a bigger variety in the findings than what is accomplished in test specimens of porous concrete, and this variation is explained by the high rate of voids, which is a key aspect of this form of concrete. In this regard, the compressive strength findings from this study remained in the region below 10 MPa, indicating what is thought to be low resistance. Permeable concrete, on the other hand, falls within the ACI 522R:06 (2006) strength range, with strengths ranging from 2.8 to 28 MPa.

It is obvious that additional research is required to increase the strength of porous concrete. However, the capacity of these concretes to enable water to percolate through them is the fundamental goal sought after. Given that the findings of the permeability test were positive, it was found that permeable concrete behaved well as a draining medium in the mixes that were studied. As a result, it may be possible to use some additions to increase the mechanical resistance without reducing the permeability factor in the upcoming comprehensive surveys, as well as a specific number of fine particles. Given that the findings of the permeability test were positive, it was found that permeable concrete behaved well as a draining medium in the mixes that were studied. As a result, it may be possible to use some additions to increase the mechanical resistance without reducing the permeability factor in the upcoming comprehensive surveys, as well as a certain quantity of fine particles. Additionally, it should be emphasized that the three combinations utilized in this study did not produce results that were noticeably variable because they provided values that were almost the same for virtually all the evaluated parameters. Consequently, the qualities of the material are not significantly influenced by the difference in diameter from the greatest to the smallest.

Based on all that was said regarding the primary goal of this study, it was determined that permeable concrete is unquestionably an option to floods brought on by the effects of urbanization in Kathmandu Metropolitan City (KMC) because it has attained its primary property, permeability. It should be mentioned that the mechanical qualities of this kind of concrete can be enhanced by the addition of minerals, chemicals, and fibers, enabling it to function well by combining resistance and permeability.

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