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Infiltration of Water into the Phreatic or Groundwater Zone using Pervious Concrete

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ABSTRACT

A pervious concrete system's performance is equally determined by its mechanical strength and permeability. While permeability ensures effective water infiltration, the pavement's structural integrity is determined not only by the compressive strength of the concrete but also by the load-bearing capacity of the subgrade soil underneath it. According to research, pervious concrete has a lower compressive strength than conventional concrete, making it more suitable for applications with light vehicular or pedestrian traffic rather than heavy loads.

Experiments were conducted in this research to determine how various factors, such as the water-cement ratio, aggregate-to-cement ratio, aggregate size, and compaction techniques, affect the compressive strength of pervious concrete. Because the presence of interconnected voids, which is required for permeability, naturally reduces strength, the challenge is to find the best balance of water content, aggregate proportion, and cement binder. This balance should maximize both strength and water infiltration efficiency.

Permeable cement pavements are a long-term and environmentally friendly solution to urban stormwater management challenges. They reduce surface runoff, replenish groundwater reserves, and mitigate flooding risks by capturing and channeling rainwater into the underlying soil. Pervious concrete is becoming an increasingly valuable material in modern infrastructure design due to its dual functionality of structural support and ecological benefits.

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KEYWORDS: *Pervious Concrete, Groundwater, Aggregates, Infiltration, Water-Lodging.*

1. General Introduction

The infiltration of water into the phreatic or groundwater zone through pervious concrete represents an important approach in sustainable water resource management. Pervious concrete, characterized by its interconnected pore structure, facilitates the direct percolation of surface water into underlying soil layers and aquifers. Unlike conventional impermeable pavements, this material enables natural hydrological processes by reducing surface runoff, enhancing groundwater recharge, and mitigating urban flooding. The application of pervious concrete is particularly significant in urban environments, where rapid urbanization and extensive use of impervious surfaces have disrupted natural infiltration cycles. By promoting recharge of the phreatic zone, pervious concrete not only contributes to groundwater conservation but also supports ecological balance and long-term water availability.

2. Research Methodology

FLOW CHART

Collections of materials

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Physical test on materials

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Preparation of samples

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Testing of samples for 3,7,28 days

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Comparing compressive strength values for different cement to aggregate ratios

↓

Trial mix till 25mpa strength is achieved

2.1. Description of Materials

Cement

In today's market, various types of cement are available, some of which are listed below.

Types of Cement Available

The modern construction industry offers a wide range of cement types, each designed to meet specific performance requirements and environmental conditions. The commonly available varieties include:

- Ordinary Portland Cement (OPC)
- Rapid Hardening Cement
- Extra Rapid Hardening Cement
- Sulphate Resisting Cement
- Portland Slag Cement
- Quick Setting Cement
- Super Sulphate Cement
- Low Heat Cement
- High Alumina Cement
- High Volume Fly Ash (HVFA) Cement
- Portland Pozzolana Cement (PPC)
- Air Entraining Cement
- White Cement
- Hydrophobic Cement
- Oil Well Cement
- Masonry Cement
- Ready Set Cement
- Expansion Cement
- Concrete Grade Sleeper Cement
- Very High-Grade Cement

Figure 2.1: Cement

Aggregates

Classification:

Aggregates are generally classified according to their particle size:

- **Coarse Aggregate:** Particles larger than 4.75 mm.
- **Fine Aggregate:** Particles measuring 4.75 mm or smaller.

Figure 2.2: Coarse Aggregate

Physical Properties of Aggregates

Key physical characteristics that influence aggregate performance in concrete include:

- Size
- Shape
- Texture
- Strength
- Bulk Density
- Specific Density
- Grading of Aggregate
- Sieve Analysis

Water

Water plays a crucial role in concrete production, as it actively participates in the chemical reaction with cement. For pervious concrete, water that meets the standard requirements for conventional concrete is suitable, and no special quality specifications are necessary. The water content is determined in the same way as for regular concrete.

Research indicates that a water-to-cement (w/c) ratio between **0.27 and 0.35** achieves optimal dispersion of cement paste or mortar and provides the best coating for aggregate particles. If the w/c ratio is too low, the mix may clump or "ball." In such cases, the addition of a water-reducing admixture can enhance workability.

Admixtures

Admixtures are materials other than Portland cement, water, and aggregates added to concrete either immediately before or during mixing to modify its properties. They can be classified as:

- Air-Entraining Admixtures
- Water-Reducing Admixtures
- Plasticizers
- Accelerating Admixtures
- Retarding Admixtures
- Hydration-Control Admixtures
- Corrosion Inhibitors
- Shrinkage Reducers
- Alkali-Silica Reactivity Inhibitors

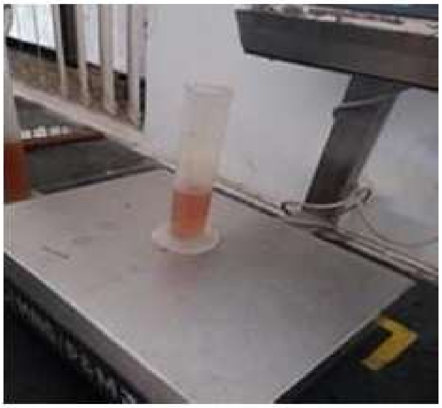

Figure 2.3: Super plasticizer

Miscellaneous Admixtures

In this research, **superplasticizer admixtures** are used to minimize the water requirement in the concrete mix while maintaining workability.

2.2. Test Result on Materials

All tests were carried out at the Laboratory of PWD (R&B) Shopian Kashmir.

2.2.1. Test for cement

Table 2.1: Test for cement

S.NO	TEST CONDUCTE D	RESULT	STANDARD
1	Normal Consistency	37%	Not Specified
2	Initial Setting Time	38 minutes	Shall not be less than 30 minutes
3	Final Setting Time	245 minutes	Shall not be more than 600 minutes
4	Specific Gravity	3.12	3.15
5	Compressive e Strength a) 3 days 5 b) 7 days c) 14 days	24.05 N/mm2 36.12 N/mm2 44.13 N/mm2	Shall not be less than 23 N/mm2 Shall not be less than 33 N/mm2
6	Fineness	3%	Should be less than 10 % of its weight

2.2.2. Test for aggregate

Table 2.2: Test for aggregates (20mm)

Basic test	Result	Standard values
Specific gravity	2.62	2.6-2.8
Dry loose bulk density	1.44g/cc	
Compacted bulk density	1.54g/cc	
Impact value	23.77%	<30%
Crushing value	27.00%	<30%
Abrasion value	40.42%	30-45%

Table 2.3: Test for aggregates (12.5mm)

Basic test	Result	Standard values
Specific gravity	2.67	2.6-2.8
Dry loose bulk density	1.46g/cc	-
Compacted bulk density	1.56g/cc	-
Impact value	22.46%	<30%
Crushing value	19.47%	<30%
Abrasion value	40.42%	30-45%

Table 3.4: Test for Fly Ash

Basic test	Results	Standard values
Specific gravity	2.37	2.1-3
Compressive strength	91.90N/mm² -	

2.3. Mix Design

The pervious concrete mix for this project was developed through trial batching, guided by values reported in various research studies. The mixture comprised 12.5–20 mm down-sized crushed stone aggregates, OPC cement, and an admixture aimed at enhancing the bond between the cement paste and coarse aggregates, thereby improving the concrete's strength.

Design Specifications
1. Water–cement ratio: 0.26–0.45
2. Fly ash: 5–25% of the total cementitious content
3. Cement content: 270–415 kg/m³
4. Coarse aggregate: 1190–1480 kg/m³
5. Fine aggregate: added only if required
6. Aggregate size: 12.5–20 mm
7. Compressive strength: 10–25 MPa
8. Permeability: 100–180 mm/min
9. Conventional concrete mix relationships do not apply
10. Minimum void content: 15%
11. Lower void content reduces permeability but increases strength; hence, a balance is necessary
12. No strict standard specifications are applicable
13. Mix proportion (kg/m³) prepared for nine cube samples

Table 3.5: Mix Proportions for nine cubes (Kg/m3)

Material	Trail 1	Trail 2	Trail 3	Trail 4	Trail 5
Cement Content (Kg/m3)	400 Kg/ m3 12.15 Kg	340 Kg/m3 10.32 Kg	300 Kg/m3 9.11 Kg 270	Kg/m3 8.20 Kg 370	Kg/m3 11.23 Kg
Coarse Aggregate Kg/m3	1400 Kg/m3 42.5 Kg	1300 Kg/m3 39.48 Kg	1260 Kg /m3 37.96 Kg	1200 Kg /m3 36.45 Kg	1360 Kg/m3 41 Kg
Admixture (Fly Ash)	25% of cement = 3 Kg	15 % of cement = 1.548 Kg	10 % of cement = 0.911 Kg	5 % of cement = 0.41 Kg	20 % of cement = 2.246 Kg
w/c ratio	0.4 Water = 0.4 *12.15 = 4.86 lit	0.33 Water = 0.33*10.32 = 3.40 lit	0.30 Water = 0.3*9.11 = 2.73 lit	0.26 Water = 0.26*8.2 = 2.132 lit	0.35 Water = 0.35*11.23 = 3.93 lit
Ratio	12.15:4.86 :42.5 = 1:0.4:3.49	10.32:1.548 :39.48 = 1:0.15:3.82	9.11:0.911 :37.96 = 1:0.1:4.16	8.20:0.41 :36.45 = 1:0.05:4.44	11.23:2.246 :41 = 1:0.2:3.65

The fundamental objective of any porous (pervious) concrete system is to ensure sufficient interconnected porosity, enabling water to infiltrate freely through the pavement surface and percolate into the underlying sub-base or natural ground. This permeability is primarily achieved by intentionally creating air voids within the concrete matrix. Such voids are formed by minimizing or entirely omitting fine aggregates such as sand from the mix design and instead relying on uniformly graded, clean, and well-stored coarse aggregates.

In this study, the cement content in the prepared mixes was carefully adjusted to control the paste volume, thereby preventing excess paste from clogging the void structure. The proportions of coarse aggregate and water were also varied according to the specific design requirements, allowing fine-tuning of both mechanical strength and hydraulic performance.

Specimen preparation involved light compaction techniques to preserve the intended void structure while ensuring sufficient particle interlock and paste bonding. This approach maintained the balance between structural integrity and the high permeability characteristic essential to pervious concrete applications.

2.4. Test on Concrete

Fresh concrete refers to a newly mixed material that can be molded into any desired shape before setting. The properties of fresh and hardened concrete are largely determined by the relative proportions of cement, aggregates, and water in the mix.

In the mixing process, **water serves three key functions**:

1. **Uniform distribution of cementitious material** – Water helps to disperse cement or lime uniformly, ensuring that every aggregate particle is coated and brought into close contact with others, thereby promoting a cohesive mix.
2. **Lubrication and workability** – It acts as a lubricant, reducing internal friction within the mix and facilitating ease of handling, placing, and compaction.

3. **Hydration and strength development** – Water reacts chemically with cement compounds during hydration, forming a hardened binding matrix. Additionally, water crystallization within pores contributes to the strength of the hardened concrete.

2.5. Workability

Workability refers to the ease with which concrete can be mixed, handled, transported, placed, and compacted into formwork with minimal loss of uniformity and without segregation. A workable mix exhibits low internal friction between particles, allowing it to flow and settle effectively.

Factors influencing workability include:

- **Size of aggregate** – Larger, well-rounded aggregates improve workability as they have a smaller total surface area and fewer voids compared to angular or flaky aggregates.
- **Surface texture** – Aggregates with a smooth or glassy surface texture enhance workability, while rough-textured aggregates reduce it.
- **Grading of aggregate** – Well-graded aggregates, with a balanced distribution of particle sizes, minimize void content. Fewer voids mean more cement paste is available for lubrication, resulting in improved workability

2.6. Measurement of Workability

Several standard methods are used to evaluate the workability of fresh concrete:

1. **Slump Test** – Measures consistency by assessing the slump of a cone-shaped concrete sample.
2. **Compaction Factor Test** – Evaluates the ease of compaction by comparing the weight of partially compacted concrete to fully compacted concrete.
3. **Flow Test** – Determines the flowability of highly workable concrete by measuring the spread diameter.
4. **Kelly Ball Test** – Uses a hemispherical metal ball to measure the penetration depth into fresh concrete.
5. **Vee-Bee Consistometer Test** – Measures workability in terms of the time required for the concrete to change shape under vibration.

2.7. Compressive Strength Test

Compressive strength testing was carried out in accordance with the relevant IS standard for cube specimens. The test determines the maximum load the specimen can bear before failure. Failure is defined as the point where the specimen can no longer sustain an increasing load. This property is crucial as it directly reflects the load-bearing capacity and overall structural performance of concrete.

2.8. Permeability Test

Permeability testing assesses the ease with which water can pass through hardened concrete. It is a critical measure for pervious concrete applications, where adequate infiltration is necessary to meet drainage and environmental objectives. High permeability values indicate good porosity and effective drainage capacity, while excessively low values may point to clogging or over-compaction, reducing the system's hydraulic performance.

2.9. Permeability Measurement of Pervious Concrete

To measure the permeability of pervious concrete, a test apparatus was fabricated in accordance with the guidelines recommended by the American Concrete Institute (ACI). The schematic diagram of the permeability test setup is shown in the referenced figure. The falling head permeability method was adopted for the study, using an initial water head of 300 mm as the driving hydraulic gradient.

For the test, cylindrical pervious concrete specimens measuring 150 mm in diameter and 150 mm in height were prepared. The specimens were cast inside PVC pipes to maintain dimensional accuracy and avoid edge disturbances during demolding. All permeability measurements were conducted at the end of the 28-day curing period, ensuring that the concrete had achieved sufficient maturity for reliable testing.

The permeability coefficient (K) was calculated using the falling head method equation:

$$K=2.303\ (A1 \cdot LA2 \cdot t)$$

Where:

- **K** = water permeability coefficient (mm/min)
- A_1 = cross-sectional area of the pervious concrete specimen (mm²)
- A_2 = cross-sectional area of the standpipe or tube (mm²)
- **L** = height (length) of the specimen (150 mm)

- **t** = time taken for the water level to drop from $\mathbf{h_1}$ to $\mathbf{h_2}$ (minutes)
- $\mathbf{h_1}$ = initial water head (300 mm)
- $\mathbf{h_2}$ = final water head (mm)

This method provides an accurate assessment of the infiltration capacity of pervious concrete, which is a critical performance parameter for stormwater management applications.

3. Results

Table 3.1 Permeability Test Result Comparison of permeability coefficient (k) for different mix.

Mix	Permeability Coefficient K mm/min or mm/sec
Mix-1	60 mm/min
Mix-2	115 mm/min
Mix-3	137 mm/min
Mix-4	145 mm/min
Mix-5	95 mm /min

Compressive strength of pervious concrete cubes

3-day curing

Size of the cube is 150*150*150

Table 3.2: Compressive strength for 3 days

Mix design	Number of cubes	Compressive strength N/mm²	Average compressive strength N/mm²
1	1 2 3	38.57 35.2 35.54	36.41
2	1 2 3	17.32 16.41 14.92	16.20
3	1 2 3	10.91 10.41 11.16	10.80
4	1 2 3	14.82 17.51 11.71	14.61
5	1 2 3	21.48 22.86 26.41	23.57

Compressive strength of pervious concrete cubes

7-day curing

Size of the cube is 150*150*150

Table 3.3: Compressive strength for 7 days

Mix design	Number of cubes	Compressive strength N/mm²	Average compressive strength N/mm²
1	1	36.55	40.9 3
	2	42.82	
	3	40.43	
2	1	16.52	1816
	2	19.74	
	3	18.21	
3	1	17.31	17.10
	2	14.01	
	3	19.01	
4	1	13.32	15.26
	2	15.16	
	3	17.31	

5	1	25.50	25.65
	2	23.21	
	3	28.23	

Compressive strength of pervious concrete

Cubes 28-day curing

Size of the cube is 150*150*150

Table 3.4: Compressive strength for 28 days

Mix design	Number of cubes	Compressive strength N/mm²	Average compressive strength N/mm²
1	1	43.57	43.66
	2	43.40	
	3	44.02	
2	1	24.80	24.91
	2	25.45	
	3	24.50	
3	1	24.70	23.70
	2	21.50	
	3	24.90	
4	1	19.04	21.81
	2	21.65	
	3	24.74	
5	1	44.23	45.09
	2	45.11	
	3	45.95	

4. Conclusion

The experimental results demonstrate that the permeability and compressive strength of pervious concrete are highly influenced by the mix design. Among the tested mixes, Mix-4 exhibited the highest permeability coefficient (145 mm/min), indicating its suitability for effective groundwater recharge applications. However, this mix showed relatively lower compressive strength compared to other designs, highlighting the trade-off between strength and permeability.

On the other hand, Mix-1 and Mix-5 achieved higher compressive strengths across different curing ages, with Mix-5 recording the maximum 28-day compressive strength of 45.09 N/mm². Mix-1 also demonstrated consistently strong mechanical performance while maintaining moderate permeability (60 mm/min). This balance suggests that these mixes are structurally more viable for practical applications where load-bearing capacity and durability are crucial alongside infiltration performance.

Overall, the study indicates that while Mix-4 is optimal for maximizing infiltration, Mix-1 and Mix-5 offer a more balanced performance in terms of both strength and permeability, making them better suited for field implementation in permeable pavement systems aimed at groundwater recharge.

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