

HYDROLOGICAL EFFICIENCY OF PERVIOUS CONCRETE PAVEMENTS INCORPORATING MARGINAL AGGREGATES

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ABSTRACT:

This research explores the hydrological efficiency of pervious concrete pavements incorporating marginal aggregates. With urban areas facing increasing challenges from stormwater management, groundwater depletion, and urban flooding, pervious concrete offers an innovative low-impact development (LID) solution. The study evaluates permeability, infiltration rates, water storage capacity, and pollutant removal efficiency of pervious concrete made with marginal aggregates. Results reveal that marginal aggregates, despite their non-standard properties, can be effectively used in pervious concrete to achieve satisfactory hydrological performance. This research demonstrates that such pavements can play a crucial role in sustainable stormwater management, urban water quality improvement, and groundwater recharge.

Keywords: Pervious concrete, hydrological efficiency, marginal aggregates, permeability, infiltration, stormwater management, groundwater recharge

INTRODUCTION:

The rapid expansion of urban infrastructure has dramatically increased impervious surface coverage, leading to significant challenges in stormwater management. Conventional pavements prevent natural infiltration, resulting in surface runoff, flooding, and declining groundwater levels. Pervious concrete is an emerging alternative that balances structural needs with hydrological benefits. By allowing rainwater to percolate through

interconnected voids, pervious pavements mimic natural infiltration processes and reduce dependence on costly drainage systems.

Hydrological efficiency is a critical parameter in assessing the environmental benefits of pervious pavements. While numerous studies highlight the strength characteristics of pervious concrete, fewer address its capacity for stormwater management, particularly when marginal aggregates are used. This study focuses on permeability, infiltration, storage, and pollutant reduction potential of pervious concrete mixtures prepared with marginal aggregates.

LITERATURE REVIEW:

Stormwater Management and Urban Challenges:

Urban runoff carries pollutants such as oil residues, fertilizers, and heavy metals into surface waters, degrading water quality. The U.S. Environmental Protection Agency (EPA) classifies pervious pavements as Best Management Practices (BMPs) for stormwater management. Similar frameworks exist in Europe and Asia, where pervious pavements are recognized as eco-friendly infrastructure.

Hydrological Characteristics of Pervious Concrete:

Hydrological efficiency depends on void ratio, permeability, and infiltration rate. Malhotra (1976) documented infiltration rates of 480 in/hr, while Neithalath (2003) found permeability values ranging from 0.2 to 1.2 cm/s. These values far exceed natural soil infiltration rates, highlighting the capacity of pervious concrete to manage intense rainfall events.

Pollutant Removal Efficiency:

Studies in Maryland and Virginia (EPA, 2004) demonstrate that pervious pavements can reduce total suspended solids (TSS) by over 80% and nitrogen by 65–80%. Soil filtration beneath pavements plays a vital role in removing pollutants during infiltration.

Marginal Aggregates and Hydrological Performance:

Although marginal aggregates may have higher water absorption and irregular gradation, they still create sufficient interconnected voids for water movement. Their cost advantage and availability make them attractive for hydrological applications.

Research Gap:

Limited research has examined hydrological behavior of pervious concrete made with marginal aggregates under Indian conditions. This paper addresses this gap through experimental evaluation.

RESEARCH METHODOLOGY:

Materials:

- **Cement:** OPC 43 grade
- **Aggregates:** Marginal aggregates including quarry dust, crushed stone, and recycled concrete
- **Water:** Potable water
- **Admixtures:** Hydration stabilizers and retarders to improve workability

Mix Design:

Aggregate-to-cement ratios of 4.0:1 and 4.5:1 were used, with w/c ratios ranging from 0.27–0.30. Mixes excluded fine aggregates to ensure high porosity.

Experimental Procedure:

- **Permeability Tests:** Falling head and constant head permeameter methods
- **Infiltration Rate:** Double-ring infiltrometer test per ASTM D3385
- **Storage Capacity:** Determined through void ratio analysis and water retention tests
- **Pollutant Removal:** Synthetic stormwater samples containing suspended solids, phosphorus, and nitrogen filtered through specimens

Data Analysis:

Hydrological performance was evaluated against EPA and IS code standards for stormwater control.

RESULTS:

Permeability:

Permeability ranged between 0.25–0.55 cm/s, consistent with values reported in international studies. Mixes with marginal aggregates exhibited slightly higher permeability due to irregular particle packing.

Infiltration Rate:

Infiltration rates exceeded 250 in/hr (6.35 m/hr), sufficient to manage heavy rainfall events. Results confirmed suitability for urban stormwater management.

Storage Capacity:

The effective void ratio ranged between 15–22%. A 100 mm thick pavement could retain 15–20 mm of rainfall, making it suitable for initial stormwater capture and first-flush pollutant treatment.

Pollutant Removal Efficiency:

- **Total Suspended Solids (TSS):** 75–85% removal
 - **Total Phosphorus (TP):** 55–65% removal
 - **Total Nitrogen (TN):** 60–70% removal
- Pollutant removal was enhanced by filtration through subgrade soil.

Comparative Analysis:

Performance with marginal aggregates was comparable to conventional aggregates. Slightly higher permeability improved infiltration but did not compromise pollutant removal.

DISCUSSION:

Hydrological Benefits:

The experimental results affirm that pervious pavements with marginal aggregates meet global standards for stormwater management. High permeability ensures rapid infiltration, reducing surface runoff and urban flooding.

Groundwater Recharge:

By allowing direct infiltration, pervious pavements contribute to groundwater recharge. This is especially significant in water-scarce regions such as India, where declining water tables are a major concern.

Pollution Mitigation:

Pervious pavements effectively reduce pollutant loads in urban runoff, contributing to improved water quality in rivers and lakes. Integration with vegetative swales can further enhance pollutant removal.

Practical Applications:

- Residential driveways and sidewalks
- Parking lots
- Low-volume roads in semi-urban and rural areas
- Stormwater-sensitive zones such as near lakes and wetlands

Policy Implications:

Incorporating pervious concrete with marginal aggregates supports India's national water conservation policies and SDG 6 (Clean Water and Sanitation).

Municipal guidelines can include specifications for such pavements as mandatory in new urban developments.

Conclusion:

Pervious concrete pavements incorporating marginal aggregates demonstrate high hydrological efficiency, making them suitable for urban stormwater management, pollutant removal, and groundwater recharge. The study confirms that marginal aggregates do not adversely affect hydrological behavior and can reduce material costs significantly.

Future Scope:

- Long-term field monitoring of infiltration rates under traffic loading
- Integration of green infrastructure systems (rain gardens, bioswales)
- Use of supplementary cementitious materials for improved sustainability
- Development of national standards for pervious pavement hydrological design

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