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Pervious Concrete Physical Characteristics and Effectiveness in Stormwater Pollution Reduction

Say Kee Ong
Iowa State University, skong@iastate.edu

Kejin Wang
Iowa State University, kejinw@iastate.edu

Yifeng Ling
Iowa State University, yling@iastate.edu

Guyu Shi
Iowa State University, shiguyu@iastate.edu

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tech transfer summary

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MTC RESEARCH PROJECT TITLE
Pervious Concrete Physical Characteristics and Effectiveness in Stormwater Pollution Reduction

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PRINCIPAL INVESTIGATOR
Say Kee Ong, Professor
Civil, Construction, and Environmental Engineering
Institute for Transportation
Iowa State University
515-294-3927 / skong@iastate.edu

MORE INFORMATION
www.intrans.iastate.edu/

MTC
Iowa State University
2711 S. Loop Drive, Suite 4700
Ames, IA 50010-8664
515-294-8103

The Midwest Transportation Center (MTC) is a regional University Transportation Center (UTC). Iowa State University, through its Institute for Transportation (InTrans), is the MTC lead institution.

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Background

Pervious concrete is an environmentally friendly and sustainable material that allows rainfall to be drained and to percolate through the concrete to the subbase/subgrade. Depending on the design of the pervious concrete system, the pavement and its subbase material may have sufficient water storage capacity to forego the need for a stormwater detention pond or swale. In addition, pervious concrete pavement can recharge groundwater and reduce pollutants by filtering stormwater runoff and retaining pollutants.

Several aspects of pervious concrete have not been fully investigated. Some of these include the pollutant attenuation properties of different pervious concrete mixes, the impact of the concrete pore structure (e.g., the pore surface area and flow path characteristics) on pollutant removal, the mechanism of pollutant abatement, and the potential for pervious concrete to contribute to subsurface contamination.

Project Objectives

The objective of this research was to investigate the physical/chemical and water flow characteristics of various pervious concrete mixes made of different concrete materials and evaluate their effectiveness in attenuating water pollution.

Research Description/Methodology

Four pervious concrete mixes were prepared with a target porosity of 20%. The mixes differed only by their binder materials: one mix contained pure Portland cement, and the other three had 15% of the Portland cement substituted by either fly ash, slag, or limestone powder. For each concrete mix, the key engineering properties were evaluated, including the workability and unit weight of fresh concrete and the compressive strength, air void structure, and water permeability of hardened concrete.

A total of five concrete cylinders were cast for compressive strength and permeability (hydraulic conductivity) tests and pore structure characterization. A sixth cylinder was cast within a plastic column for pollution abatement experiments.

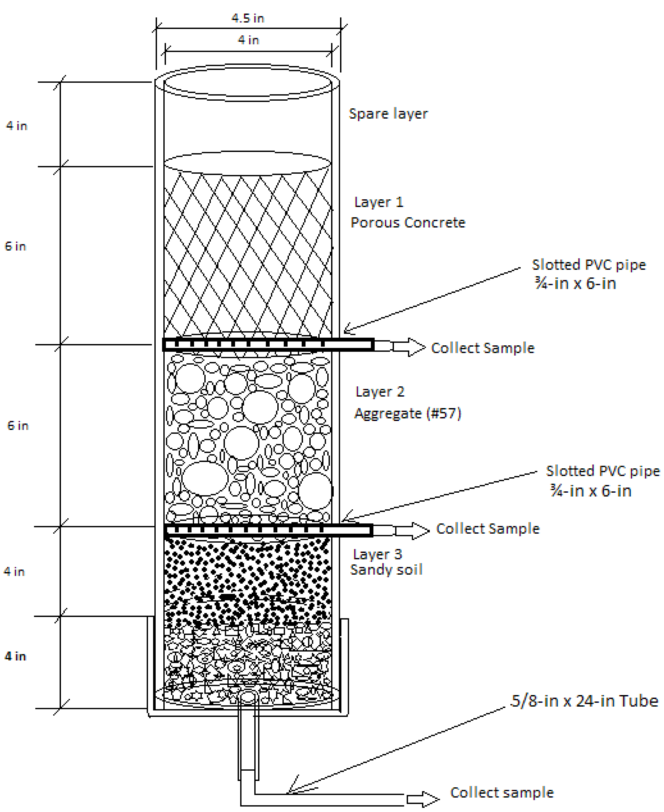
The air voids, specific surface areas, and spacing factors of the pervious concrete samples were measured using both the RapidAir and flatbed scanner methods. Permeability (hydraulic conductivity) tests were performed using a falling head permeameter.

The pollution abatement properties of pervious concrete mixes were studied using column experiments. Each column consisted of a long polyvinyl chloride (PVC) pipe with a cap at the bottom. The column was filled with about four inches of gravel at the bottom, four inches of fine-grained sand to simulate the subgrade, six inches of aggregate for the subbase, and six inches of concrete mix to form the pervious concrete layer.

Two small holes were drilled 8 and 14 inches from the bottom of the column. In each hole, a small PVC pipe with 10 upward-facing slots was inserted for water collection. A small hole was drilled in the center of the bottom cap to allow water to be collected from the bottom of the column.

Simulated rainfall was pumped from a storage tank continuously through a sprinkler placed above the columns. The pollutant used in the simulated rainwater was naphthalene at a concentration of 30 mg/L. For each column, 3.6 liters of simulated rainwater was applied over a six-hour period, equivalent to a 3 in. rain event per hour.

After six hours of rainfall, infiltrated water samples were collected from the water collection pipes and from the bottom of the column. The samples were analyzed using a high-performance liquid chromatograph (HPLC) with a quart pump and an unltraviolet (UV) diode array detector.



Column setup for the pollution abatement test

Hand-formed ball of the pure Portland cement specimen for the workability test (left) and cross-section of the 15% fly ash specimen prepared for testing with the RapidAir method and the flatbed scanner method (right)

Key Findings

- All four pervious concrete mixes had acceptable workability. The mixes made with pure Portland cement and 15% fly ash replacement appeared to have better workability than the other two mixes.
- The unit weights of the fresh mixes ranged from 115.9 lb/yd^3 (15% slag mix) to 119.6 lb/yd^3 (15% fly ash mix).
- The 28 day compressive strengths ranged from 1858 psi (15% slag mix) to 2285 psi (pure cement mix). The compressive strength generally increased with unit weight and decreased with total porosity.
- The hydraulic permeabilities ranged from 340 in./hr (pure cement mix) to 642 in./hr (15% slag mix). The permeability generally decreased with unit weight and increased with total porosity.
- The total porosities (air void ratios) ranged from 24% (15% slag mix) to 31.41% (pure cement mix) using the flatbed scanner test method. The total porosities ranged from 18.93% (15% slag mix) to 24.15% (pure cement mix) using the RapidAir method.
- The total porosities of the mixes measured by the flatbed scanner method were all higher than those measured by the RapidAir method, but the specific surface areas measured by the flatbed scanner method were all lower than those measured by the RapidAir method.
- The pollutant abatement experiments showed that the mixes with fly ash and limestone powder removed about 30% of the influent naphthalene concentration. The mix with pure cement removed 10% of the influent naphthalene concentration, and the mix with slag removed only 0.5% of the influent naphthalene concentration. Less than 1% of the water was retained in the experimental column setup.

Conclusions and Recommendations for Future Research

- Further study is needed to determine why the total porosities of the mixes were not correlated to their unit weights.
- The flatbed scanner might have captured some large voids that were not captured by the RapidAir test method. Because it uses a microscope camera, the RapidAir device is generally unable to capture voids larger than 3 mm. However, due to the good imaging resolution of the microscope camera, the RapidAir test method might have captured a larger quantity of small voids.
- In its ability to capture large voids, the flatbed scanner test method has a clear advantage over the RapidAir test method for pervious concrete. However, the flatbed scanner may also capture the background aggregate particles in some large voids and make false identifications regarding the size of these voids. Further study is needed to further improve this test method.
- The pollutant abatement experiments showed that the mixes with fly ash and limestone powder removed more of the influent naphthalene concentration than the other mixes.

Implementation Readiness and Benefits

Pervious concrete is an environmentally friendly and sustainable material that has the potential to recharge groundwater, reduce stormwater, and mitigate pollutants. The results of this research will be available to all who are interested in using slag, fly ash and limestone powder as a partial replacement of Portland cement in their pervious concrete.

Companies and state agencies interested in using waste materials in the manufacture of pervious concrete can follow the procedures outlined in this study and the test methods in analyzing and characterizing pervious concrete for field applications.