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Visualizing and Analyzing Fluid Flow through Porous Medium

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Abstract

This CI project aims to understand and visualize how fluid flows through various porous materials and how the mesoscopic material properties influence flow process. Porous material is ubiquitous in nature and engineering and appears in many forms including sands, foams, and shredded tires.

In this project, students designed experimental devices to visualize and analyze flow process through various porous materials (geological materials such as soil, and man-made materials such as glass beads). Student also learnt basic theory behind the physical phenomenon and used computer tools (such as MATLAB) to model and assist in understanding such process.

Introduction

- Designing and ensuring safety of hydraulic infrastructure (e.g., canals, earthen and concrete dams) require understanding and analyzing seepage problem.
- The flow of fluid through porous medium is driven by the differences in potential energy (e.g., water level *h*).
- Laplace's equation of continuity provides a model to explain and predict the behavior of fluid flowing through porous material: $$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} = 0$$
- Integrated physical and numerical methods are used to visualize and analyze flow through various porous materials.

Porous Materials

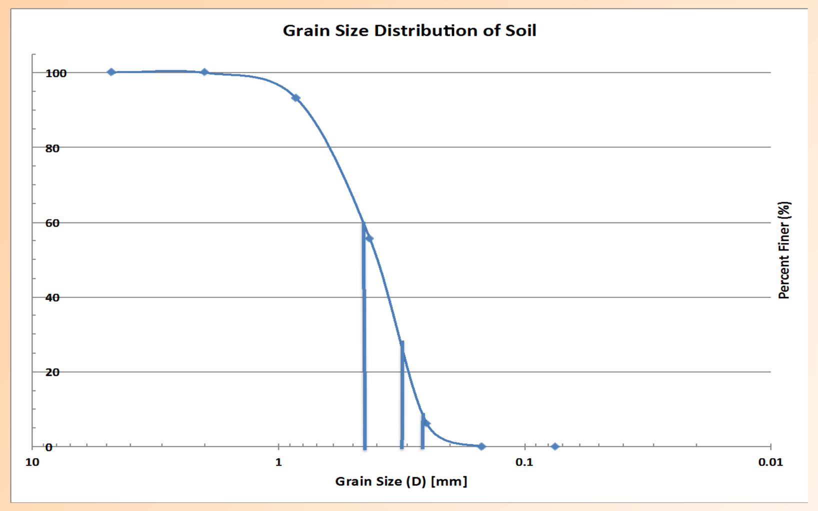

Sand


Glass Beads

Results

Material Characterization

The results of the Sieves tests are show below. The glass beads did not require a Sieves test because the grains were a known and uniform 1mm in diameter.



D_{60}	0.475 mm
D_{30}	0.33 mm
D_{10}	0.27 mm

C_u	1.76
C_c	0.85

The results of the Constant Head Permeability tests for the sand (on right) and the glass beads (on left) are shown below.

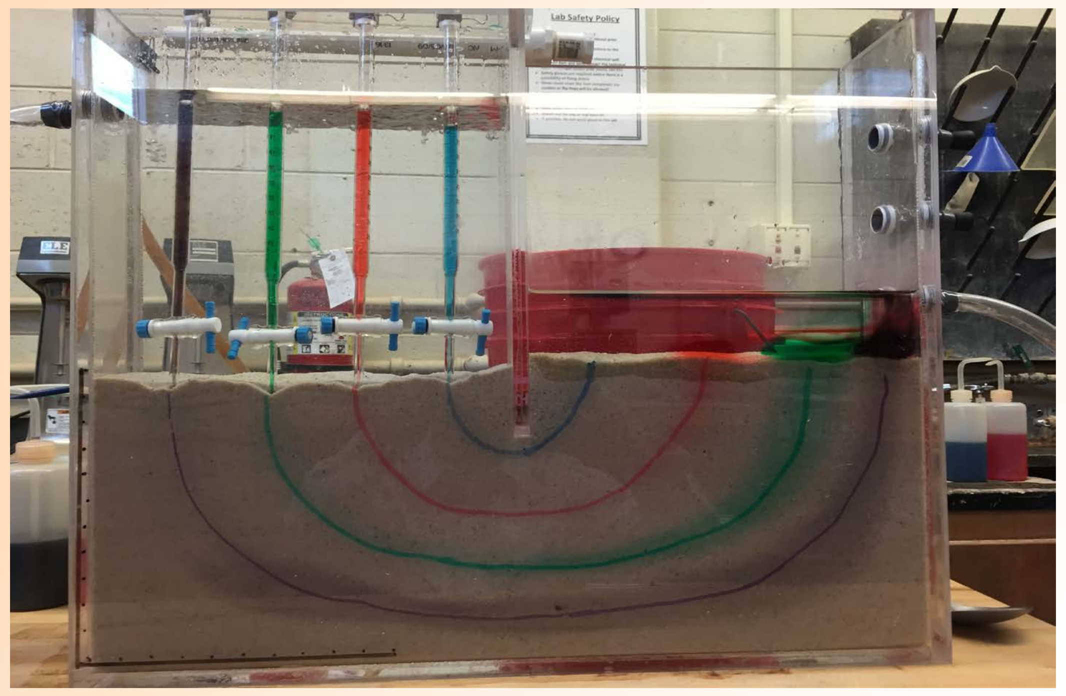
	Sand	Glass Beads
Total Flow	Q = 1040.715 cm^3	Q = 1759.925 cm^3
Volumetric Flow Rate	q = 4.336 cm^3/s	q = 58.66 cm^3/s
Hydraulic Gradient	i = 0.7623	i = 0.5850
Coefficient of Permeability	k = 0.0711 cm/s	k = 12.479 cm/s
Void Ratio	e = 0.338	* e = 0.541

*assuming specific gravity of glass bead is 2.5

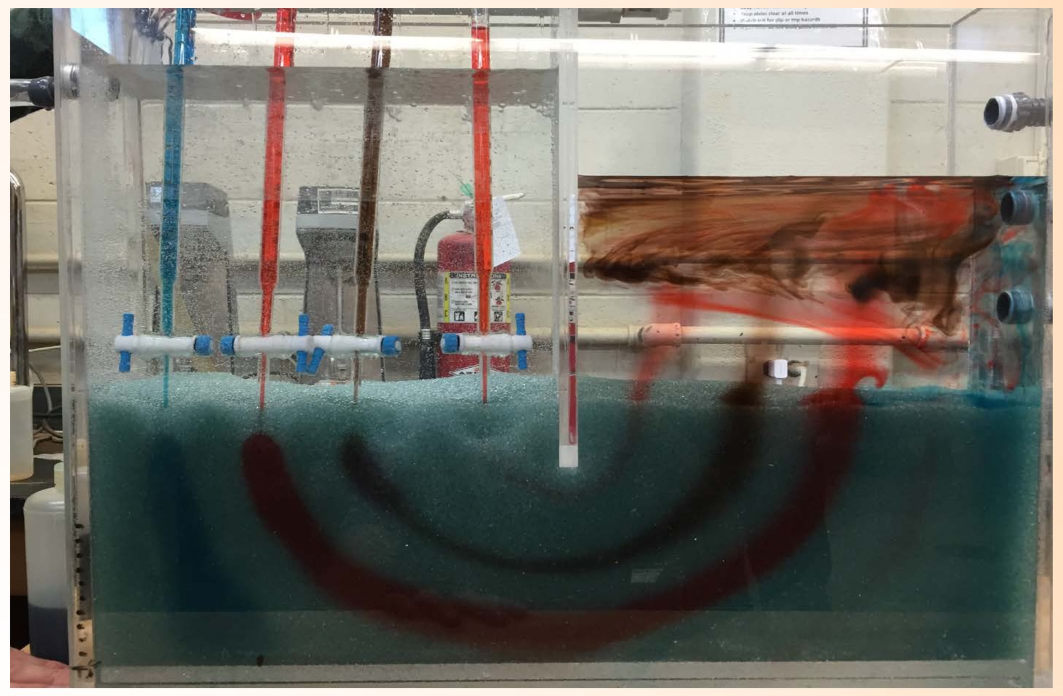
**Our soils void ratio (e) corresponds with that of typical coarse sands. Our soils coefficient of permeability (k) corresponds with that of typical coarse sands.

Flow Experiment

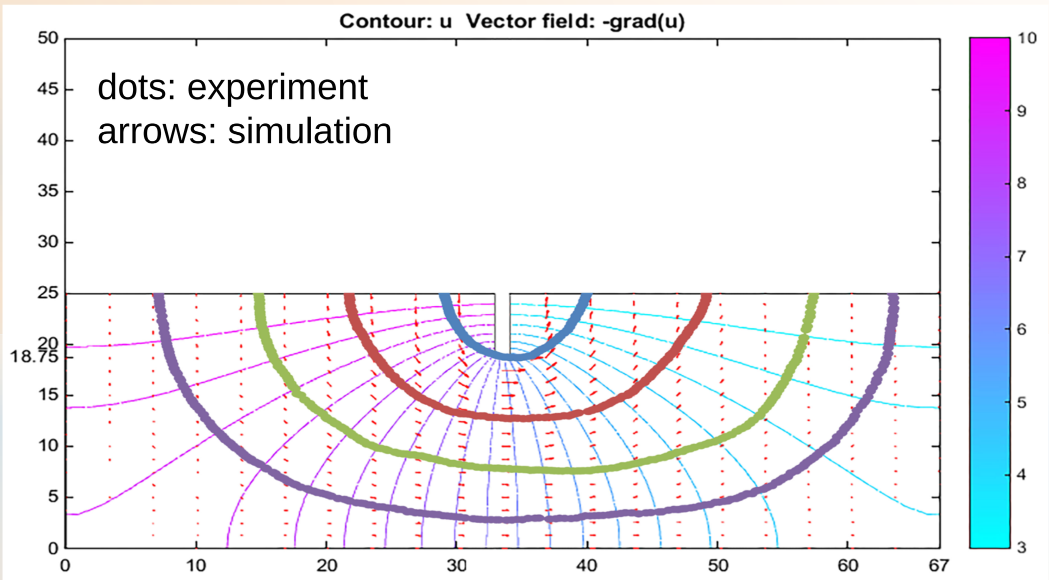
Sand

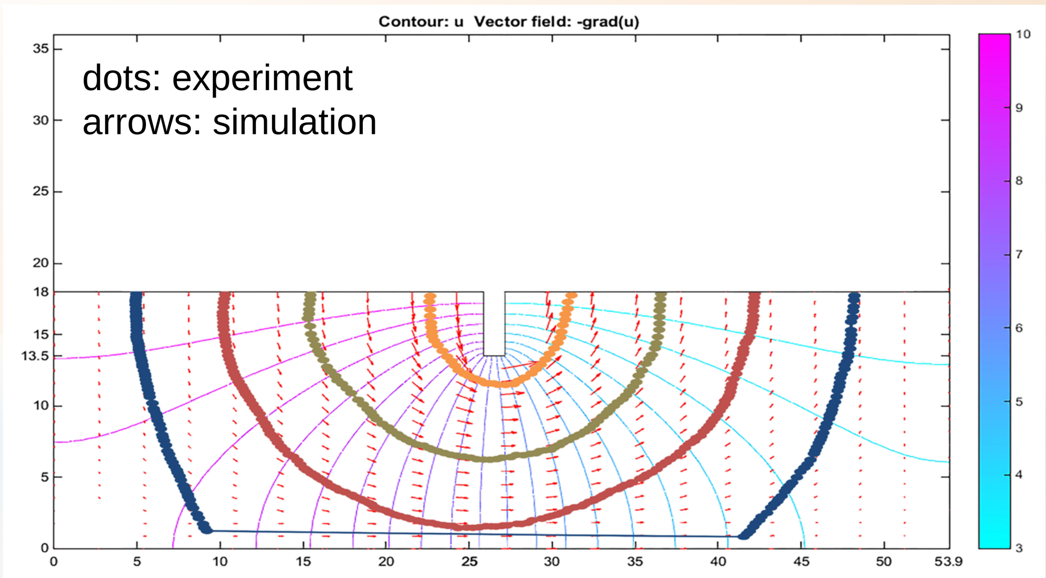


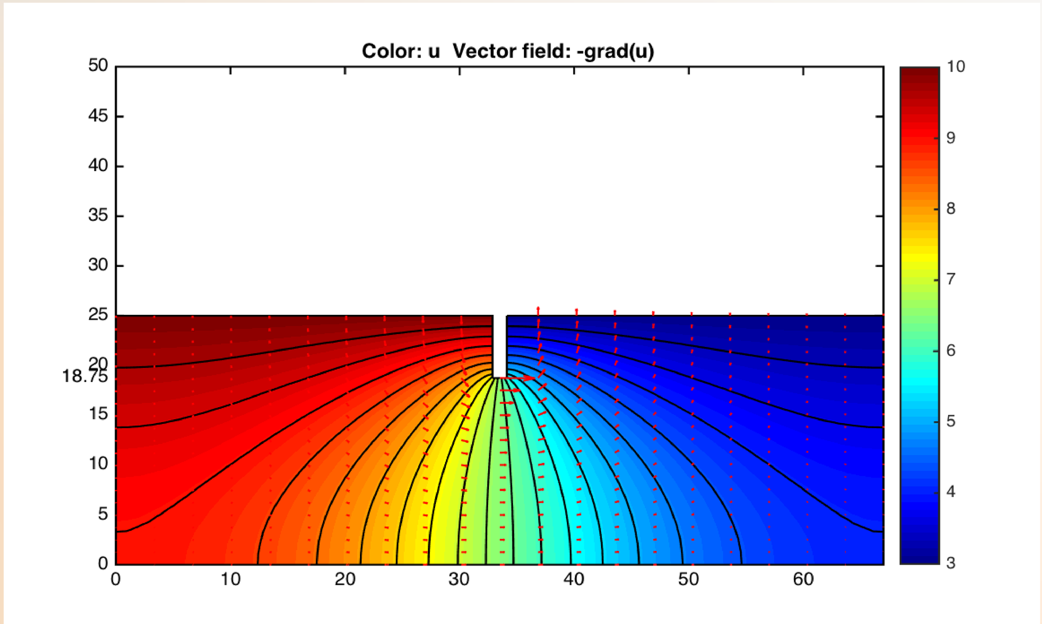
Glass Beads



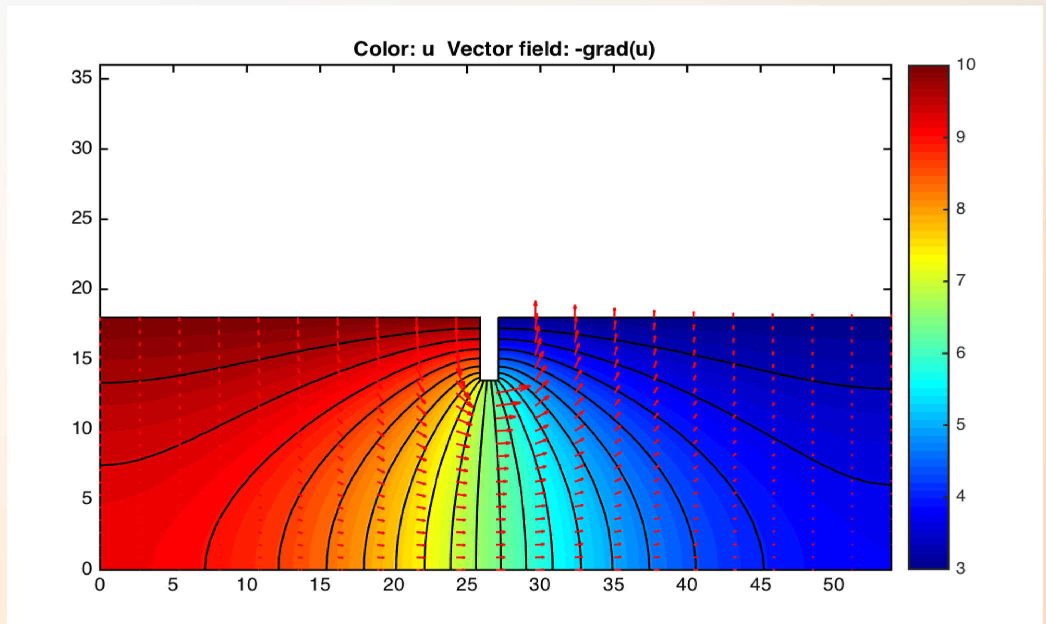
Modeling







Contour of potentials in porous sand



Contour of potentials in glass beads

Methodology

Experiment Component

Material Characterization:
In order to first characterize the materials to be used in the the flow experiment, we performed two common geotechnical lab tests. These were the Sieve tests and the Constant Head Permeability tests.

Flow Experiment
Flow through porous mediam is modled through a transparent tank shown on the left. Flow is traced through colored fluid to show the path and compares with model predictions.

Modeling Component

The Laplace equation of continuity can be used to model the flow of fluid through our porous materials. By solving the Laplace Equation in MatLab using partial differential equations toolbox, a theoretical flow model can be produced.

The model is called a Flow Net and shows equipotential lines and flow lines of the fluid. When developing this model it is important to note that we are using a homogeneous, isotropic material that is fully saturated.

Discussions

An integrated experimental and numerical study of fluid flow through porous medium is successfully carried out. The experimental situations designed, implemented, and numerically modeled in this study have wide applications in the field of civil engineering. The behavior of water flowing through sand can be quantified and predicted by use of Laplace's equation of continuity, which will guide design of canal, levee, dams and other civil engineering applications.

Acknowledgements

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