Physical Modeling of Flow Nets in Groundwater and Determination of Hydraulic Conductivity

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Abstract

The goal of this study is to physically model the paths that water particles take through soil, and estimate hydraulic conductivity for several soil configurations. This study attempts to demonstrate Darcy's law with a physical groundwater model.

This project consists of four phases: design, construction, testing, and analysis. At the time of this presentation, the design phase is complete and the construction phase is active. Upon completion of the construction phase, testing will begin using four configurations of sand. During the analysis phase, hydraulic conductivity is to be calculated. Discrepancies in hydraulic conductivity compared to theoretical values will demonstrate how closely experimental sand resembles ideal coarse and fine sand.

Physical Model

The design of this project includes a rectangular tank constructed of acrylic glass with a width of 0.5 inches. The tank is open on the top with a vertical barrier placed in the center of the tank. The footprint of the tank is 24 inches by 48 inches, and the tank is 24 inches tall. The barrier is 12 inches by 24 inches. The center barrier has adjustable height. The barrier can be moved vertically in increments of 1 inch, with its lowest and highest heights measured from the bottom of the tank being 1 inch and 12 inches, respectively.

A goal of this study is to produce a flow net using a physical model. An example of a flow net is shown below in Figure 1 [1]. A flow net consists of flow lines and equipotential lines. A flow line is a path that a water particle travels as it moves from the upstream to the downstream side through a soil medium. Equipotential lines are orthogonal to flow lines, and represent paths along which potential head is equal at all points.

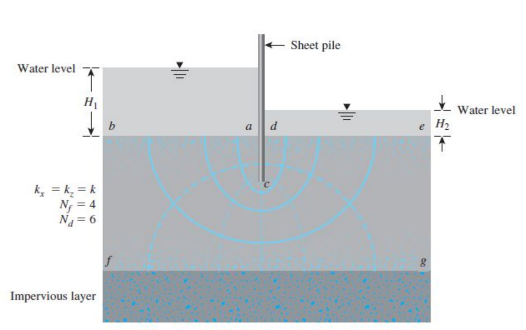

Figure 1. Example of a flow net

The model will be tested by injecting dye into the sand and water tank using four sand configurations.Experimental configurations are as follows, in no particular order:

1. Coarse sand, loosely placed
2. Coarse sand, dense as a result of shaking
3. Fine sand, loosely placed
4. Fine sand, dense as a result of shaking

Experimental Setup

For each configuration, water is to be poured into the tank after sand is placed. One side of the barrier is designated the upstream side, and has a higher water level. The other side of the barrier with a shorter water level is called the downstream side. The downstream side of the tank is 14 inches tall from the bottom of the tank to allow water to flow out of the tank through the overflow lip. A pump is used to maintain steady-state head loss of the system. The experimental setup is shown in Figure 2.

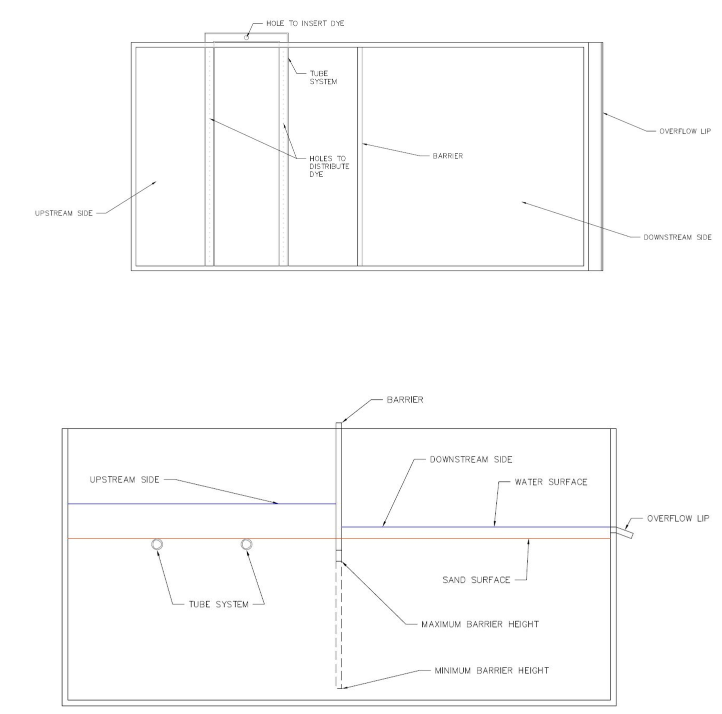

Figure 2. Drawings of Experimental Setup, Plan and Profile drawn in AutoCAD Civil 3D 2018

In order to visually demonstrate pathways that water particles take, potassium permanganate (dye) is to be inserted in two parallel lines at the top surface of the sand. Water flow, q, is measured by placing a container under the overflow lip of the downstream side of the tank. A timer is set for one minute, and the volume of water in the outflow container is measured. This yields the flow or rate of seepage, q, in volume per minute.

Sieve Analysis

Coarse and fine sand are separated and collected using a series of sieves placed into a mechanical sieve shaker and shaken for ten minutes. Standard U.S. Sieve Sizes are shown below.For this study, sieves will be placed in the following order from top to bottom: ¼", 4, 16, 50, 100, 200.

Sieve No.	Sieve Opening (inches)
¼"	0.25
4	0.187
16	0.0469
50	0.0117
100	0.0059
200	0.0029

Testing and Analysis

If clear flow lines are formed, the tank profile is to be photographed and orthogonal equipotential lines are to be drawn on the photo to form a flow net. The following equation will be used to calculate hydraulic conductivity where q is flow, H is the difference in water depths from the upstream to downstream side, Nf is the number of flow channels, and Nd is the number of drops in pressure (one less than equipotential lines).

$$q = k\,H\,(N_f/N_d)$$

If clear flow lines cannot be formed in the experiment, rate of seepage is still measured. Hydraulic conductivity is approximated using Figure 3.

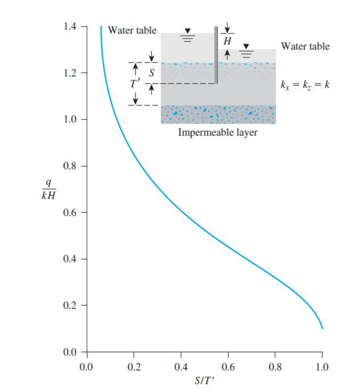

Figure 3.

Project Deliverables and Results

As the testing phase has not been completed at the time of this presentation, no results have been collected. Once testing is complete, results shall be reported as the following deliverables, to be prepared after completion of the analysis phase:

1. Photographs of prototype tests, observations made during prototype testing, and any adjustments made to the experimental setup through prototype testing.
2. Photographs of experimental setup for each test trial and sand configuration, and observations made during testing.
3. Drawings of flow net, if it is possible to discern clear flow lines.
4. Water Flow Data Sheets completed during testing.
5. Calculation of hydraulic conductivity using one of two methods described in Methodology section and summarized in Figure 5.
6. Additional analysis, including discussion and conclusions related to the applicability of Darcy's law, practical use of flow nets, and effectiveness of sand collection.

Conclusion

At the time of this presentation, the design phase was completed and the construction phase is in progress. The primary goals of the design phase are to determine objectives for the study and devise methodology to achieve the objectives. Design phase goals were accomplished; experimental setup and procedures have been defined according to project objectives. Completion of construction and the testing and analysis phases are to follow and are scheduled to be completed August 2019.

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References

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