Performance of the Colloidal Silica Barrier Installed at Brookhaven National Laboratory, a Computer Modeling Study

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Abstract

At the U.S. Department of Energy (DOE) Brookhaven National Laboratory (BNL) site, a small volume of unsaturated sand around a subsurface-located radioactive facility was impacted by radioactive contamination. To limit the contamination load reaching the water table, the contaminated soil was solidified by injections of colloidal silica (CS), which gels in place. This remedial technology was applied to alter water retention properties of the contaminated soil, and consequently limit the magnitude of atmospheric-water flux that leaches the contaminants toward the water table. Because of physical limitations for testing the barrier's performance, various computer modeling approaches were exercised instead. The modeling efforts which used data collected from sand-box studies, as well as from the CS field-tests, indicate that the performance goal for the barrier was met.

Background Information

The Brookhaven Linear Accelerator Isotope Producer (BLIP) located at the BNL site on Long Island, New York, has impacted the unsaturated sand with tritium and sodium-22. The contaminated soil is located approximately 7 m beneath the BLIP facility and 8 m above the water table. To minimize the rainwater flux through the contaminated soils, and subsequently minimizing the transport of contaminants to the aquifer, the emplacement of a viscous liquid barrier (VLB) was selected as the preferred remedial alternative. The VLB was constructed by injecting the low viscosity colloidal silica (CS) grout into the contaminated soil where it gelled in place to fill the void space. The resulting soil/grout system altered the soil-water retention characteristics, making the new medium less permeable. Because of physical limitations for testing the performance of the barrier, a computer modeling approach was exercised instead.

Modeling Approach

Computer modeling to predict the flow rate through the solidified block of soil was conducted using PORFLOW™ (ACRI, 1999), and included the following simulations:

1. Pre-emplacement modeling of a steady state and transient flow to evaluate applicability of CS for the installation of the VLB.
2. Pre-emplacement modeling of a slug of contaminated water that would be pushed out from the contaminated sand while injecting the CS grout.
3. Post-emplacement modeling to verify performance of the VLB using field measured saturated hydraulic conductivity values and moisture retention curves developed from previous sand-tank samples.

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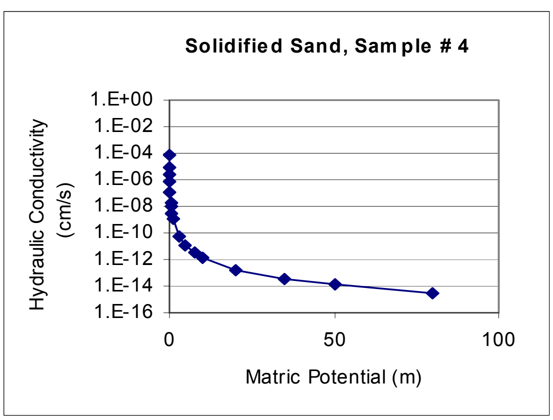
The simulation of unsaturated flow was conducted using a simplified 3-dimensional approach, i.e., cylindrical coordinates. The cylinder was set vertically with the upper circular surface simulating the land surface and the lower circular surface simulating the water table. The cylindrical domain is 17.98 m high and has a radius of 13.41 m. The model simulated the flow conditions within a 1-radian portion of the cylindrical domain. To simulate the impact of the solidified material on the post-injection flow conditions, a smaller cylindrical region, with the material properties of the CS-solidified sand, was introduced in the modeled domain. This cylindrical object is 3.35 m high with a radius of 3.35 m. Its axis is collinear with the axis of the entire modeled domain. Boundary conditions for the simulated domain were set as:

- Constant flux boundary with 0.3048 m/year flux at the land surface;
- Constant pressure (hydraulic head) boundary of 0 value at the water table;
- Constant flux boundary with 0 m/year flux along the cylinder axis; and
- Constant flux boundary with 0 m/year flux at 17.98 m from the axis.

The soil parameters used for modeling were based on measurements taken in a soil laboratory where moisture retention curves were determined for samples of the native Brookhaven sand, and the same sand solidified with CS. The CS solidification process was simulated in laboratory conditions using columns and large sand tanks (Manchester et al, 2000). The moisture retention curves were fitted to the laboratory data using van Genuchten formulas (van Genuchten, 1980).

Examples of water retention curves shown in Figure 1 include such curves for non-solidified native-Brookhaven sand and for solidified material. While the minimum (at matric potential 80 m) hydraulic conductivity for both media is the same, the water retention curve for the solidified sand is significantly steeper than that for the native sand.



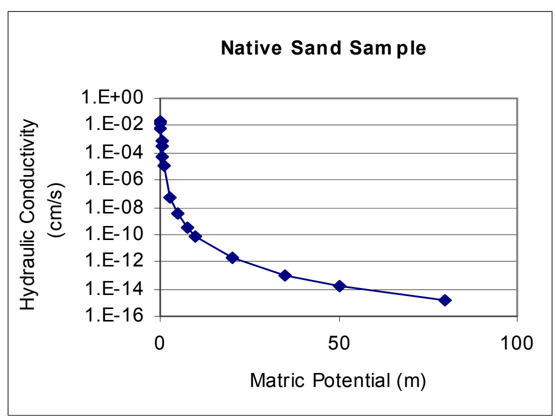


Figure 1. Moisture retention curves for the native and CS solidified sand.

Modeling Results

Pre-emplacement modeling of steady state unsaturated flow (Zaluski et al, 2000 a) was conducted by assigning to the solidified region the moisture retention curve as determined from a laboratory column studies, the only curve available at that time. Such simulation indicated that the flux through the solidified block of sand would be 0.0017 m/year. This flux is 23.5 times smaller than the performance goal set for the VLB to reduce the flux from 0.3048 m/year to 0.04

m/year (1.67 m^3/year to 0.22 m^3/year). The results of the transient flow simulation indicated that the steady-state conditions are yet to be achieved after 30 years of flow simulation, with the final flux of 0.00174 m/year.

It was calculated that a 2.4 m^3 slug of contaminated water would be displaced while injecting the CS grout. This volume was calculated as the product of the volume of the soil affected by grouting and its pre-grouting volumetric moisture content. A conservative assumption was made that this water would be released to the unconsolidated sand over 2.2 days. Results from the modeling indicated that the bulk of the released water would reach the water table within 10 to 25 days.

Post-emplacement modeling, to verify performance of the VLB (Zaluski et al, 2000 b), included six additional simulations, each performed using different moisture retention curves for the CS-solidified sand. These new six moisture retention curves were determined for the solidified samples retrieved from a sand tank. Total outflow (Q in m^3/year) from the solidified medium appears to be related (Equation 1) to the lab-measured values of saturated hydraulic conductivity (K_s in cm/s).

$$Q = 38.97 (K_s)^{0.714} \quad (1)$$

This power-function relation was then used with the in situ measurements of the saturated hydraulic conductivity for solidified sand in the test panel installed adjacent to BLIP facility. The outflow rates determined according to this function indicate that the performance criterion for VLB was met.

Acknowledgments
Work was conducted through the DOE National Energy Technology Laboratory at the Western Environmental Technology Office under DOE Contract Number DE-AC22-96EW96405.

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