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Numerical Study on the formation of an injectable barrier in the subsurface

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ABSTRACT

Numerical experiments were performed to investigate horizontal barrier formation in unsaturated soils by permeation grouting through multiple vertical injection pipes. The results were compared with the horizontal barrier formation achieved by using multiple horizontal injection pipes. It was observed that the point injection of the vertical pipe system generates a gel barrier that has a less lateral area than the injection through the horizontal pipe.

Key words : gel barrier, subsurface barrier, grouting, numerical model, containment, Colloidal Silica

1. INTRODUCTION

Barrier systems are employed for contaminant migration control or as an integral part of in-situ remediation processes. The chemical grout-based barriers are constructed by pumping a chemical grout (e.g., Colloid Silica) into the high-permeability soils and letting it solidify to plug the pore spaces.

Colloidal Silica (CS), a stable aqueous dispersion of discrete nonporous particles of amorphous silicon dioxide (SiO_2) is destabilized with the addition of appropriate electrolytes such as NaCl. As the gelation process proceeds, the solution viscosity continues to rise and finally the solution becomes a gel. A higher NaCl concentration causes a faster viscosity increase. Consequently, the time when a rapid viscosity increase starts, which is named the gel-point, is observed at an earlier time for the higher NaCl concentration. The CS gel system has various advantages such as low permeability ($<10^{-11}\,cm^2$), easy injectivity, and minimal environmental problems. The gelled CS is not affected by syneresis, and degradation processes by bacteria.

The gel barrier formation by injecting a CS solution (Nyacol 1440) in the unsaturated medium has been investigated.[1),2),3)] Kim and Corapcioglu[3)] developed a numerical model to simulate the placement of a gel barrier. In this study, that numerical model was extended to multi-dimensional one to investigate the construction of horizontal gel barriers by CS injection through multiple vertical injection pipes in the unsaturated zone.

2. NUMERICAL EXPERIMENTS

The system consisting of vertical pipes placed in a staggered format is designed to allow the overlapping of gel bulbs injected radially at the bottom of adjacent pipes and form a horizontal gel curtain. An illustrative example of a barrier system constructed with three CS bulbs are shown in Fig. 1b) with the schematic diagram of a system consisting of three vertical pipes in Fig. 1a) (drawn not to scale).

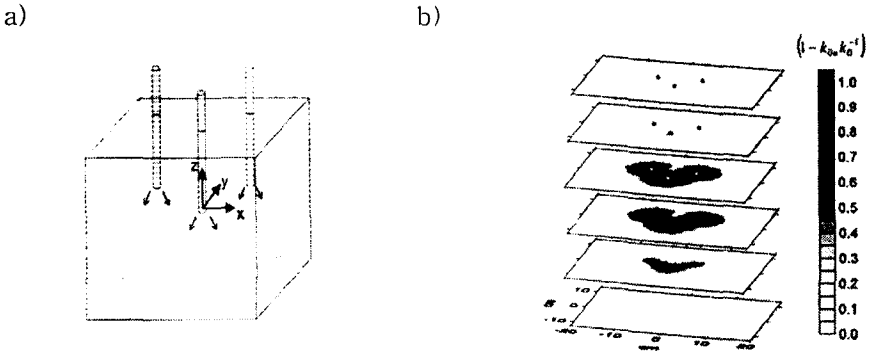

Fig. 1. a) Schematic diagram of a system with multi vertical pipes. b) Intrinsic permeability reduction at t=150sec with an injection pressure head of 10cm for a solution with a gel-point of 75sec for a soil with an initial intrinsic permeability k_o of $2.04\times 10^{-6}cm^2$. The black represents the maximum intrinsic permeability reduction of 100%, which corresponds to the new intrinsic permeability k_{on} of zero.

With a single vertical injection pipe, the dependency of the barrier performance on operating parameters such as injection pressure head H_i and gel-point $t_{0.5}$ (a property relevant to the gelation rate) was quantified. Then, the results were compared with other system in which a gel barrier is formed by injecting a CS through horizontal injection pipes. According to the results, both systems show the similar results as follows:

As the gel-point is increased (i.e., NaCl concentration in the CS is reduced), the extension of the barrier becomes more dominant in the vertical direction, especially downward, compared to the horizontal direction (Fig. 2).

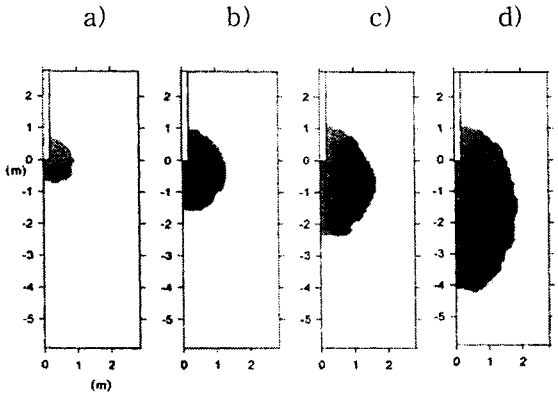

Fig. 2. Vertical cross sectional views of gelled CS-saturated areas at different gel-points a)0.75hr, b)2.67hr, c)6hr, and d)13hr at an injection pressure head of 10m for a soil with an initial permeability of $2.04\times10^{-7}cm^2$

Contrary to the increase of gel-point, with increasing injection pressure head, the lateral extent of the barrier is expanded compared to the vertical direction, maintaining the ratio of the vertical distance to the upper boundary to the vertical distance to the lower boundary from the injection pipe almost the same (Fig. 3).

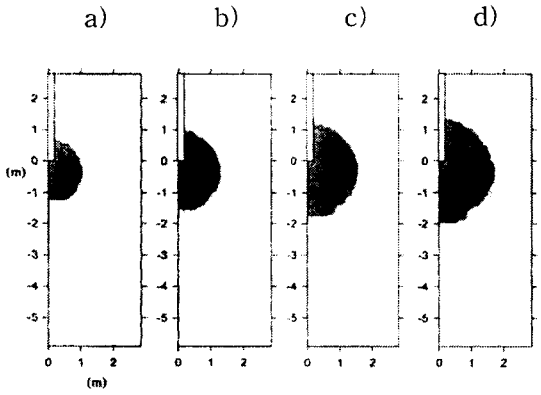

Fig. 3. Vertical cross sectional views of gelled CS-saturated areas at different injection pressure heads a)5m, b)10m, c)15m, and d)20m for a solution with a gel-point of 2.67hr for a soil with an initial permeability of $2.04\times10^{-7}cm^2$.

Independent of different soil initial intrinsic permeability values, similar patterns are observed, with a more profound trend for the soil with a higher initial intrinsic permeability.

The correlation of the lateral extent L(m), to the injection pressure head H_i(m), and gel-point $t_{0.5}$(hr), was obtained as $L \propto (t_{0.5})^{0.16 \pm 0.07}(H_i)^{0.40 \pm 0.19}$, and $L \propto (t_{0.5})^{0.22 \pm 0.05}(H_i)^{0.41 \pm 0.09}$, for the soil intrinsic permeabilities of $2.04 \times 10^{-6} cm^2$, and $2.04 \times 10^{-7} cm^2$, respectively, with the uncertainties at 95% confidence interval. Each of the above correlations is compared with the one obtained for the system of horizontal pipes, $L \propto (t_{0.5})^{0.39 \pm 0.05}(H_i)^{0.36 \pm 0.95}$, and $L \propto (t_{0.5})^{0.45 \pm 0.08}(H_i)^{0.52 \pm 0.13}$, respectively. The horizontal pipe system shows a greater sensitivity of the lateral areal extent to the increase of gel-point than the horizontal pipe system.

In terms of the horizontal area, the vertical pipe system appears to have a stronger response to the injection head than that of the horizontal pipe system. According to test simulations, the vertical pipe system generates a less lateral area than the horizontal pipe system with the consumption of the same amount of the CS solution.

3.CONCLUSIONS

The vertical pipe system shows a greater sensitivity of the lateral areal extent to the increase of gel-point than the horizontal pipe system. The estimations of the lateral areal extent and total CS mass injected into the soil indicate that the point injection of the vertical pipe system is less effective than the injection through the horizontal pipe in generating a horizontally extended gel layer.

4. REFERENCES

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