

APPENDIX D. SOIL-BENTONITE/SODIUM CHLORIDE COMPATIBILITY TESTS

In this appendix, the results of two compatibility tests (CT1 and CT2) are described. The compatibility tests measured the influence of sodium chloride concentration on soil-bentonite hydraulic conductivity. The tests were performed in anticipation of using a sodium chloride tracer to probe pilot-scale soil-bentonite cutoff walls constructed at the SBTF. Tracer tests at the SBTF were ultimately not performed due to several technical difficulties.

The compatibility tests were performed in a consolidometer permeameter. Before forming the test specimens, silicone was applied to the inside of the consolidometer ring to minimize sidewall leakage during the hydraulic conductivity testing. A soil-bentonite mixture of 1% bentonite and 99% Bedding Sand, by weight, was used for the tests. The water content of the soil-bentonite (PFW was used to make the soil-bentonite) was 33%. The soil-bentonite was rodded into the consolidometer to remove air voids and to form good contact with the consolidometer ring. Finally, the top of the soil-bentonite was scraped flush with the top of the consolidometer ring, producing a specimen of height 2.54 cm.

Both specimens were consolidated under an effective pressure of 11 kPa, and then unloaded to an effective pressure of 6.2 kPa. These stresses were chosen to match conditions in the anticipated soil-bentonite cutoff walls for the tracer tests. After the consolidation phase, falling headwater/constant tailwater hydraulic conductivity tests were performed using PFW as the permeant. The direction of flow through the specimens was upward. Both the maximum pore pressure at the bottom of the specimens and the magnitude of the pore pressure change during the falling head tests were kept low, so that the effective stress ranged from approximately 5.3 to 5.7 kPa at the bottom of the specimens. For the entire permeation phase, the vertical strain of each specimen was measured.

After the hydraulic conductivity of each specimen was measured with PFW as the permeant, sodium chloride solutions (NaCl in PFW) of increasing concentration were permeated through the specimens. An old solution was replaced by a new solution by flushing the new solution through the burette used for the falling head tests, the line from the burette to the consolidometer, and the bottom of the consolidometer in contact with the bottom of the specimen. For each sodium chloride concentration, the hydraulic conductivity of the specimen was measured continuously using the same falling headwater/constant tailwater procedure used for the PFW permeant¹. The volume of permeant seeping through the specimen was recorded with time. Figure D-1 shows the measured hydraulic conductivity versus the number of pore volumes passed through the specimen. Arrows indicate where the sodium chloride concentration was increased.

¹ In order to avoid a build-up of NaCl in the top reservoir of the consolidometer due to evaporation of water, the solution in the top reservoir was replaced with PFW approximately 2 times per day.

In CT1, the first sodium chloride solution was introduced earlier (after a smaller number of pore volumes) and much higher concentrations were eventually reached compared to CT2. In CT2, PFW was permeated through the specimen for over five pore volumes. The tests were not performed simultaneously; CT1 was started before CT2.

For CT2, the hydraulic conductivity of the specimen increased slightly during permeation with just PFW, as seen in Figure D-1. However, for both CT1 and CT2, the largest increase in hydraulic conductivity occurred during permeation with the 820 mg/l NaCl solution. Small compressive vertical strains accompanied the increases in hydraulic conductivity. The specimen in CT2 strained 0.01% during permeation with 410 mg/l NaCl and 0.36% during permeation with 820 mg/l NaCl. The total strain at the end of CT2 was 0.39%. The specimen in CT1 strained 0.38% during permeation with 820 mg/l NaCl and 0.36% during permeation with 1,650 mg/l NaCl. The total strain at the end of CT1 was 0.75%. As seen in Figure D-1, the predominant increases in hydraulic conductivity in the tests occurred during permeation with the solutions causing the predominant vertical strains.

The water contents of the specimens in CT1 and CT2 after the tests were 26% and 27%, respectively.

It was observed that the hydraulic conductivity in CT2 did not increase during permeation with 410 mg/l NaCl, but increased under the next highest concentration: 820 mg/l. The following theoretical argument may explain this experimental finding.

The bentonite, before being mixed into a slurry and added to the silty sand base soil, has predominantly sodium as the cation in its double layer. When mixed with PFW to make the slurry, the calcium and magnesium in the PFW, with valences of 2 compared to 1 for sodium, have the tendency to displace the sodium in the double layer². With calcium and magnesium in the double layer, the thickness of the double layer (the distance to the center of mass of the cations from the bentonite particle surface as determined by the Gouy-Chapman theory³) is estimated to be about 32 angstroms (estimated using the calcium and magnesium concentrations given in Table 4-3 for PFW). When the NaCl solutions are permeated through the specimens in the compatibility tests, the sodium, with a low replacing power, may eventually displace by mass action the calcium and magnesium. For the time being, it is assumed that even at the low sodium chloride concentration of 410 mg/l, the sodium displaces the calcium and magnesium and controls the thickness of the double layer. Using the Gouy-Chapman theory, the new thickness would be 36 angstroms. In this case, an increase in hydraulic conductivity would not be expected because the double layer thickness did not decrease.

² Mitchell (1993) discusses cation replaceability in the double layer.

³ See Mitchell (1993) for a discussion on the Gouy-Chapman theory. The double layer thickness, $1/K$, is expressed as:

$$1/K = [(\epsilon_0 D k T) / (2 n_0 e^2 v^2)]^{0.5}$$

where ϵ_0 = permittivity of vacuum, D = dielectric constant, k = Boltzmann constant, T = temperature, n_0 = reference ion concentration, e = electronic charge, and v = ionic valence.

With the same assumptions, the thickness of the double layer is 26 angstroms for a NaCl concentration of 820 mg/l. In this case, a higher hydraulic conductivity would be expected to correspond to the lower double layer thickness, and a higher conductivity was in fact measured in the compatibility tests at this concentration.