EXPERIMENTS TO DETERMINE THE MIGRATION POTENTIAL FOR WATER AND CONTAMINANTS IN SHALLOW LAND BURIAL FACILITIES: DESIGN, EMPLACEMENT, AND PRELIMINARY RESULTS

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INTRODUCTION

Leaching and transport of radionuclides by water has been a primary mode of radioactive contamination from low-level radioactive waste disposal facilities. Similarly, the infiltration of water into nonradioactive hazardous waste disposal facilities has resulted in the movement of contaminants out of these disposal facilities. Although there have been many laboratory studies on water movement and contaminant transport, there is a need for more large scale field experiments. Large scale field experiments are necessary to (1) measure hydraulic conductivities on a scale typical of actual shallow land burial facilities and hazardous waste disposal facilities, (2) allow comparisons to be made between full scale and laboratory measurements, (3) verify the applicability of calculational methods for determining unsaturated hydraulic conductivities from water retention curves, and (4) for model validation. Experiments that will provide the information to do this are described in this paper.

CALCULATIONAL METHODS FOR UNSATURATED HYDRAULIC CONDUCTIVITIES

Since the hydraulic conductivity-water content relationship $K(\theta)$ is comparatively difficult to compute, the possibility of predicting the hydraulic conductivity from the matric potential-water content relationship has been widely explored. Abeele[1,2] has examined these predictive methods and their application to crushed Bandelier Tuff. In these same reports, Abeele has also reported the application of several laboratory techniques for measuring the unsaturated hydraulic conductivity of crushed Bandelier Tuff. The results obtained for the calculational methods of Millington-Quirk[3] and Campbell[4] and the experimental methods of Rijtema[5] and Gardner[6] for calculating or measuring the hydraulic conductivity of crushed Bandelier Tuff are summarized in Table I. For details see the reports by Abeele.

Generally good agreement is seen between the measured and predicted values for unsaturated hydraulic conductivity when the matric potential-water content relationship is known for the material in question. The results of the experiment described in this paper will determine whether or not these predictive methods will work as well for large scale experiments which are closer in scale to actual waste disposal facilities. These laboratory results also provide a basis for model calcu-

TABLE I

COMPARISON OF ANALYTICAL EXPRESSIONS FOR UNSATURATED HYDRAULIC CONDUCTIVITIES

EXPERIMENTAL	
Rijtema	$K = 5.44 \times 10^{-3}\ \theta_v^{7.623}$
Gardner	$K = \dfrac{2.46 \times 10^{-5}}{\psi^{2.4778} + 26.74}$
CALCULATIONAL (PREDICTIVE)	
Millington-Quirk	$K = 7.96 \times 10^{-4}\ \theta_v^{7.379}$
Campbell	$K = 1.56 \times 10^{-3}\ \theta_v^{8.113}$

θ_v = Fractional water content by volume

ψ = Matric potential in kPa

K = Hydraulic conductivity in m/s

lations that are used to plan the experiments. The results summarized in Table I provide a comparison of the predictive and measuring techniques that have been extensively applied to one well-characterized material, crushed Bandelier Tuff.

INSTANTANEOUS PROFILE METHOD

In the field experiments described in this paper, the unsaturated hydraulic conductivity will be measured by the instantaneous profile method described by Watson.[7] The application of this method and the calculational techniques are described in further detail by Hillel and coworkers[8] and by Hillel.[9] The matric potential of the soil is measured as a function of time and depth in a soil profile by means of tensiometers. Simultaneously, the soil water content is measured as the same function of time and depth in the soil profile by means of a neutron moisture probe. From these data, the unsaturated hydraulic conductivity can be calculated as a function of water content.

The procedure recommended by Hillel[9] will be used in our experiments. Tensiometers will be placed in the soil profile each 0.38 m. Water will then be ponded on the surface until the entire profile becomes saturated. The soil surface will then be covered to prevent any further water flux into the soil column from rainfall or out of the column by evaporation. As the column drains, the measurements of matric potential and water content will be made.

EXPERIMENT DESIGN

These experiments will be performed in the Experiment Cluster in the Experimental Engineered Test Facility at the Los Alamos National Laboratory. The field test facility and the Experiment Clusters have recently been described by DePoorter.[10,11,12] A plan and section view of the Experiment Clusters is included as Fig. 1. The soil column to be used is 3 m in diameter and 6 m deep with access ports along the entire height of the profile.

The experimental configuration and instrument emplacement is shown in Fig. 2. In addition to the horizontal neutron moisture probe access tubes, which extend 1.5 m into the soil column, there is also one vertical neutron probe access tube. These tubes are aluminum, with a 50.8 mm outside diameter. The thermocouples are copper-constantan and have all been calibrated at the ice point and at the boiling point of water at Los Alamos elevation, approximately 93°C. The two large thermocouple harnesses are emplaced to determine the temperature variation across the soil column at two elevations. The other thermocouples are to determine the temperature as a function of depth in the column. The thermocouple harnesses were the only instruments emplaced during the filling operation. All other instruments are emplaced after the units were backfilled and compacted.

EXPERIMENT EMPLACEMENT

For these experiments, two of the 3-m diameter by 6-m deep caissons were filled with crushed Bandelier Tuff. This required the preparation, delivery, loading, and compacting of approximately 80 m^3 of materials. Because of this large volume, the personnel and equipment of the Zia Company at Los Alamos were used in the filling procedure. The tuff used can be described geologically as a volcanic ash flow composed mostly of silicic glass and having a grain size distribution close to that of a silty sand.

Front end loaders were used to mine the tuff, which was then crushed by running the front end loader over it repeatedly. The crushed material was then loaded into trucks and hauled to the Zia batch cement plant where it was screened. All material that passed through a 12.7 mm screen was stockpiled for mixing with water. Known amounts of water were added to the crushed and screened material in the batch plant. The moist tuff was then loaded into cement trucks for delivery to the experiment.

In the filling process with the finely crushed Bandelier Tuff, great care was taken to work with tuff that was homogeneously mixed with water, trying to approach, but staying below, the optimum water content. This optimum water content is the amount of mixing water for a given tuff and compaction process which will give a maximum of dry tuff mass per volume. The tuff was dynamically compacted with "jumping jacks." The actual obtained dry density ranged from 91.3 to 101.4% of what is considered optimum dry density for crushed tuff, indicating that the amount of moisture used, mostly between 10 and 13% by mass, is close to the optimum moisture plateau. Water content, dry density, and wet density were measured at several heights during the filling operation by a Portaprobe Model MC-2 Per-

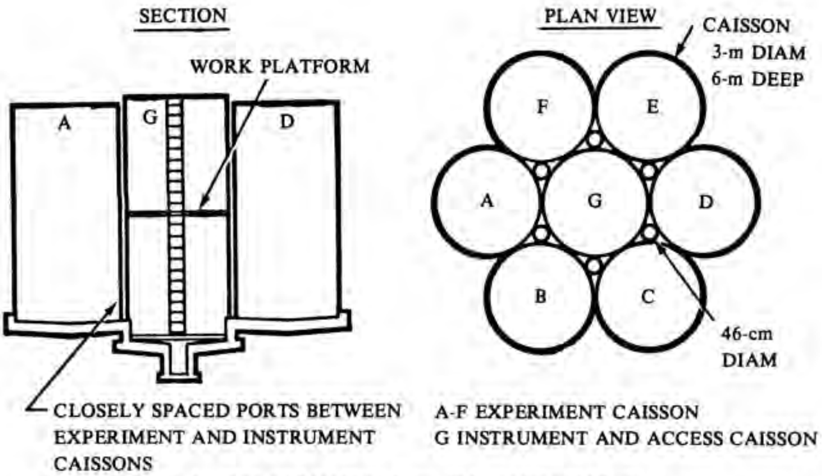

Fig. 1. Plan and Section View of Experiment Clusters

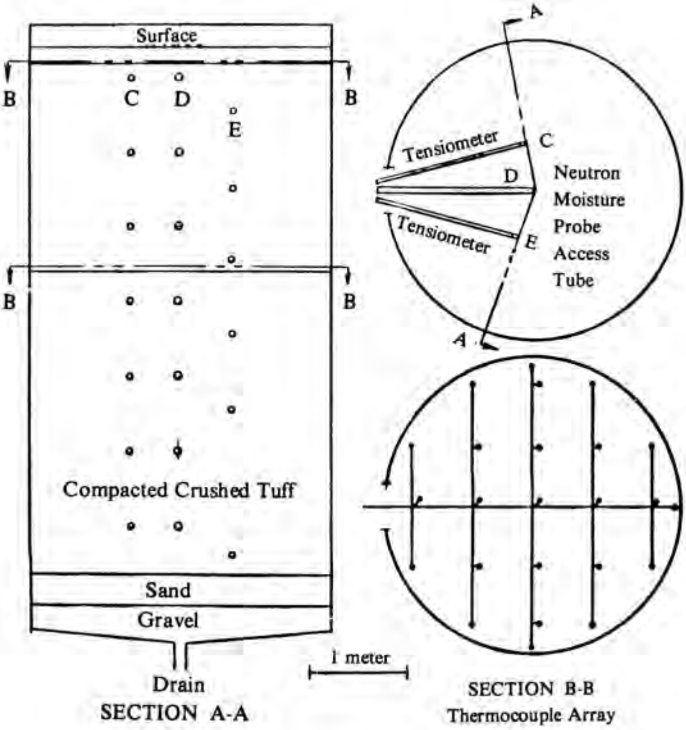

Fig. 2. Experiment Design Details

cent-Test Nuclear Meter. Results of these measurements will be discussed later. The crushed tuff was loaded into each caisson in an amount to give a compacted layer of from 15 to 20 cm, and then compacted as described above.

Compaction was necessary to minimize, if not eliminate, future subsidence which would be detrimental to the knowledge of the location of the instruments used to make the measurements necessary for the instantaneous profile method. Also, subsidence might cause deformation in the horizontal neutron moisture probe tubes. Compaction will decrease the saturated hydraulic conductivity, but more important, increase the unsaturated hydraulic conductivity known to exist at the moisture contents normally prevailing in the Bandelier Tuff. Hydraulic conductivity decreases sharply with increasing soil moisture tension. This is most evident in materials with coarse pores and/or low packing and less so in materials with fine pores and/or high packing. Somewhere the two curves will intersect; the worst case is if highly packed material is used at the low moisture conditions that are normal in the Bandelier Tuff because higher unsaturated conductivities will take place at finer pore size distributions, provided the degree of unsaturation is high enough.

To obtain the homogeneity and high density required for the experiments, the wet tuff had to be compacted with minimum interference from emplaced instruments. The only exceptions were the two thermocouple harnesses which were carefully emplaced, covered with crushed tuff, with careful compaction in the next layer to prevent damage.

Immediately after filling was completed, emplacement of the horizontal neutron moisture probe access tubes was started. The horizontal tubes are about 1.5 m long with an aluminum cap welded on the end. Thus, a hole in the tuff was necessary in which to place the tube. The hole was made by driving a stainless steel tube of the same diameter with a sharpened end into the compacted material using a 4.5 kg sledge hammer. The hole was driven in about 100 mm increments and the tube removed and emptied. The tubes were maintained horizontal to within one degree. In the portions of the experiment where the tuff was the wettest, emplacement was practically impossible by this method, whereas, in the drier material, this method worked quite well.

The tensiometers will be emplaced by augering holes and then inserting the tensiometer. The other thermocouples will be emplaced by drilling a small hole and then inserting the thermocouple. Work is in progress to emplace this other instrumentation.

When the instrumentation is complete, procedures will be started to use the instantaneous profile method to measure the unsaturated hydraulic conductiviy *in situ* as a function of water content in an experiment on a scale typical of that of a low-level radioactive waste disposal facility or a hazardous waste disposal facility. The columns will be flooded and allowed to saturate by ponding a layer of water about 50 mm thick on the surface. During flooding, measurements of water content and soil matric potential will also be made. When the columns are saturated, measurements of the saturated hydraulic conductivity will be made. Then the units will be sealed as described above and allowed to drain. During drainage, measurements will be made as a function of time and depth of both water content and soil matric potential. Then the instantaneous profile method will be applied and evaluated.

APPLICATION OF RESULTS TO SHALLOW LAND BURIAL OF LOW LEVEL RAIOACTIVE WASTES OR HAZARDOUS CHEMICAL WASTES

The results of these experiments will have applications for both the shallow land burial of low level radioactive wastes and the disposal of hazardous chemical wastes. These experiments will provide results that can be used in model verification for system performance. This type of data on experiments done at this scale have not been available, and are necessary for validating unsaturated transport models and other models used to predict long term system performance.

Even though these experiments are done on crushed Bandelier Tuff, most models use physical properties of the backfill material such as density, porosity, and water retention curves. For this reason, once the models are validated in these experiments, they can be applied with confidence to other materials as long as the material properties are well characterized. In addition, from known water movement rates, calculable from the results of these experiments, requirements for other parts of the system such as liners, water diversion systems, and system cap requirements can be determined.

Lastly, the results of these experiments and their use in model verification will provide a sound scientific basis on which to base decisions on system requirements and system design.

ACKNOWLEDGMENTS

The assistance of the Zia Company personnel under the field direction of Peter S. Carlson is gratefully acknowledged. Barry J. Drennon, Ed Lopez, and Wilfred Herrera provided valuable assistance in thermocouple fabrication and calibration and in the filling of the caisson units. Technical discussions with Peter J. Wierenga of NMSU on the experiment design are acknowledged. This work was performed under the auspices of the US DOE.

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