CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

TRIP REPORT

SUBJECT: Soil Physics Workshop
(20-5704-025)

DATE/PLACE: March 30 - April 1, 1994
Richland, WA

AUTHOR(S): Stuart A. Stothoff and Ronald T. Green

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PERSONS PRESENT: Representatives from universities, government agencies, research institutions and private enterprises that are involved in the physics of flow through the vadose zone

BACKGROUND AND PURPOSE OF TRIP:

A Soil Physics Workshop organized by J. Wright, of Pacific Northwest Laboratories (PNL), and J. Conca, of Washington State University (WSU) was held on March 31 - April 1, 1994 in Richland, WA. The topic of the workshop centered on a centrifuge technology, called the Unsaturated Flow Apparatus (UFA), which was developed by Drs. Wright and Conca over the past 7 yr. The nondestructive technique is reported to be a extremely fast and reproducible method for measuring relative permeabilities, diffusion coefficients, and retardation coefficients in core samples of up to 100 cc. UFA has been applied for various materials ranging from gravels to Yucca Mountain tuffs, with a standard three-day sampling procedure including ten measurements at permeabilities ranging from 10^{-4} to 10^{-8} cm/s; reportedly the low end can routinely be extended one to two orders of magnitude. The workshop was not limited to UFA work, however, with various researchers from western institutions presenting their current work.

The purpose of the trip was to keep the Center for Nuclear Waste Regulatory Analyses (CNWRA) staff abreast of this new measurement technology and any other technologies presented during the workshop. The UFA equipment has been ordered by the Yucca Mountain Office, thus characterization of the proposed Yucca Mountain repository site may be partially performed using this technique and it is important to be aware of the strengths and weaknesses of the approach.

SUMMARY OF PERTINENT POINTS:

AGENDA

The agenda for the workshop is attached. The purpose of the workshop was to present the theory, applications and results of the UFA, a relatively recent laboratory technique developed by PNL and WSU to measure hydraulic characteristics of saturated and unsaturated media. In addition to discussions regarding the UFA, alternative hydraulic characterization measurement methodologies and related topics were presented and discussed.

The slides from the presentations are being collected in hard-copy form by Drs. Wright and Conca, and will be released to participants when clearances from all concerned organizations have been obtained. Several papers describing the UFA technique and results obtained using the method are available from the authors. A transcript of the workshop minutes will be available from the sponsors in the near future. The following list of objectives were provided by the participants at the onset of the workshop:

- information exchange
- comparison of techniques
- do present techniques fulfill the need for soil hydraulic characterization
- identify issues/questions in soil physics
- can experiments be designed to address these issues questions
- how do transport properties of soils and rocks compare
- null hypothesis—it is not possible to determine hydraulic conductivity of soils at pressures greater than 5 bar
- how do UFA methods apply to determination of recharge rates
- can pressure be determined from hydraulic conductivity
- how successful are centrifugation techniques to study water-soil rock interactions under unsaturated conditions
- how are input data supplied to multi-dimensional models

PRESENTERS

The presenters represented the following organizations:

- Daniel B. Stephens Co.
- U.S. Salinity Laboratories
- U.S. Geological Survey (USGS)
- Lawrence Livermore National Laboratories (LLNL)
- Pacific Northwest Laboratories (PNL)
- Idaho National Engineering Laboratories (INEL)
- Los Alamos National Laboratories (LANL)
- Washington State University (WSU)
- Interra Sciences.

Comments and questions were raised by various audience members, the vast majority arising from Rien Van Genuchten, Peter Wierenga, Daniel Stephens, Jan Hopmans, and Wilford Gardner.

SUMMARY OF ACTIVITIES:

The scheduled presentations were attended. Also, a small-group tour of the centrifuge lab the night of March 30 was attended; similar tours were offered on March 31 and April 1.

IMPRESSION/CONCLUSIONS:

OVERALL IMPRESSIONS

The workshop was well-planned and quite informative. Several scheduled discussion periods were skipped, as the presentations tended to engender lively discussions past the allotted time slot. Highlights

of the workshop included the lab tour, discussion of the centrifuge technique, discussion of an x-ray tomography technique for examining core samples, and overviews of work at PNL and INEL.

CENTRIFUGE LAB TOUR/CENTRIFUGE DESCRIPTION

The evening of March 30, a small-group tour of the centrifuge lab was led by Dr. Conca. The lab includes four centrifuges, two each of the two models of centrifuge offered for sale. The specially designed UFA rotors and associated apparatus can be purchased independently from the centrifuge, or the UFA apparatus can be purchased complete with a centrifuge from Beckman for $80,000 or $150,000. The less expensive centrifuge is $50,000 by itself.

The rotors are designed to accommodate two 40 cc or 100 cc samples simultaneously. The cylindrical samples are encased in a coating of plastic or liquid aluminum, for rigidity, before measurements occur. Each sample is fed a liquid from hospital intravenous (IV) equipment, with a normal minimum flow-rate of 0.1 ml/hr. Using a syringe injector, a minimum flow-rate of 0.01 ml/hr can be obtained. With fluxes less than this, the condition that capillary forces are negligible compared to the centrifuge acceleration is in danger, which is a necessary simplifying assumption required for obtaining conductivities. Usually the liquid is water at room temperature, although other fluids can be used. Both centrifuges are able to handle fluid in the range of 0 to 100 °C; the less expensive one can handle temperatures to −50 °C.

A centrifuge is able to attain 2,500 rpm under normal operation, corresponding to 1,000 g or 4 m overburden; by evacuating air from the rotor cavity, rotations of up to 10,000 rpm can be obtained. Note that acceleration is proportional to the square of the rotation rate. With a 0.1 ml/hr feed rate and 2,500 rpm, the measured hydraulic conductivity is about 10^{-8} cm/s. Reportedly, even at such accelerations samples do not compress appreciably unless they are fluffy soils from surface deposits.

The most delicate engineering for the apparatus involves the connection between the feed equipment and the rotor. As two samples are involved, the seal between the spinning rotor and the stationary IV equipment poses difficulty. In the UFA method, a special annular piping apparatus is used, with three different bearings available for different types of tests. For tests which are to remain unsaturated, a simple teflon bearing is provided with a central axis and an annular groove. The two bearing surfaces simply press against each other, one rotating and the other stationary. These bearings must be replaced periodically due to wear, and are not suitable for fluids with low surface tension. The other two bearings apply a mechanical seal and a magnetic seal, respectively, relaxing the restrictions inherent in the simplest seal.

SCHEDULED PRESENTATIONS

Daniel Stevens (Daniel B. Stevens, Co) discussed the application of the van Genuchten relationship to a relatively coarse uniform sand. Several cautionary notes were sounded in this presentation. The material was based on work from about 10 yr ago, using what was termed nearly ideal medium sand from a New Mexico National Forest. Based on analyses of core samples, it was concluded that: (i) a good visible fit of a curve to K-Θ data points does not assure a good prediction to the K-Ψ curve; (ii) it is essential to make K-ψ measurements for dry soils; and (iii) residual saturation might be best used as a fitting parameter, rather than an intrinsic property.

Rien van Genuchten (U.S. Salinity Lab) started with an overview of how fitting curves were derived using capillary theory. Some current thoughts on numerical modelling difficulties were discussed, in

particular for fine-grained soils such as clay. It was noted that the van Genuchten curves for such soils can have K-Θ gradients approaching infinity near saturation, and for such cases a small air entry pressure on the lines of the Brooks-Corey model eases numerical difficulties. The presentation concluded with a brief discussion of some simple fracture modelling using a Klavetter and Peters model, where it was observed that the exchange term between fracture and matrix needed a conductivity much smaller than the matrix property, perhaps due to coatings. In the course of the discussion, temperature-dependent effects were mentioned. W. Gardner noted that the effects of temperature on the K-Θ relationship were well-defined with the temperature effects on viscosity, but the temperature effects on the K-ψ relationship are not well characterized as yet.

John Nimmo (USGS) discussed an alternative centrifuge technique after a short history of the subject. Rather than specifying a flux rate as the UFA does, with stationary IV equipment, this technique rotates the water source as well. A constant head or falling head technique can be used, or specified fluxes can be achieved through ceramic plates. Some work was presented which demonstrates that the Darcy and Richards formulations holds for the centrifuge as well. It was noted that compaction effects may be significant for fine materials, near-surface materials, and wet materials.

James Conca (WSU) summarized the UFA technique, much of which is repeated from the lab tour. There was significant discussion regarding a set of points representing a sand with constant grain sizes and a wide range of saturations with the same conductivity. Suggestions for further work include such issues as tensiometer testing, replication of results, and measurement of K-ψ data in addition to K-Θ data.

Gene Freeman (Westinghouse) discussed a correction to a moisture retention curve due to large gravel fractions. He concluded that a correction is necessary, otherwise excessive infiltration would be predicted. This observation is dependent on the nature of the gravel. No correction is needed for nonabsorbing gravels, but is needed for gravel with secondary porosity, (i.e., gravels that have storage).

Xioabing Chen, Judith Wright, and James Conca focussed on the hypothesis that particle-size distributions are well-correlated with conductivity curves. Two cases were presented, one supporting this hypothesis and one not. The case not supporting the hypothesis had similar particle distributions but the clay fraction, although only 2- to 3-percent, consisted of different types of clays. It was concluded that the shape of the K-Θ curve depends on the particle size distribution and the location of the curve on the Θ axis is affected by the mineralogy. In addition, results from a field investigation were presented. A total of 70 UFA measurements were made on samples collected from eight boreholes. Hydrostratigraphic maps were prepared from the K(Θ) measurements. Hydrostratigraphic units were designated according to the characteristics of the K(Θ) curve.

Carolyn Bishop (INEL) presented an overview of contamination problems at INEL and measures being taken for remediation. It was mentioned that there is a ton of plutonium distributed underground. A large field experiment is being prepared now, where a seven-acre holding pond is being constructed for an infiltration study. Field-scale hydraulic and retardation measurements will be compared to similar results measured in the laboratory. Results from the field study are expected in the fall.

Jake Turin (LANL) noted that Los Alamos is currently evaluating the hypothesis that contamination will not migrate through bedded tuffs to the underlying aquifer. Previous work at the site was performed with crushed tuffs rather than the native material, and there is interest in trying to correlate the extensive crushed-tuff results to the native materials so these results can be used. This is to be tested using the UFA method. Determinations of K(Θ) made using the UFA will be used to predict infiltration and travel times

from the surface through the Bandolier tuff to the water table at a depth of 300 m. The ensuing discussion raised the issues of variability and fractures. P. Wierenga noted that the only way to get recharge data is with long-term measurements performed with a deep lysimeter and that plants limit the amount of recharge. W. Gardner added that recharge can be expected to be extremely spatially variable due to the spacing of plants.

J. Conca (WSU) summarized a paper on nonlinear Selenite retardation, available from the authors on request. Measurements of retardation and $K(\Theta)$ were conducted on nonzeolitized tuff from G-Tunnel using a UFA. These measurements were made under partially-saturated conditions.

David Hudson (USGS) discussed the hydraulic properties of tuff samples collected from surface outcrops for inclusion into the DOE information base. Results from these studies were compared with values determined from calculations made using measured sorptivity measurements. Saturated hydraulic conductivity values measured with a constant head permeameter were up to four orders of magnitude different from conductivity values determined using measured sorptivity values. This difference has been attributed to the inadequacy of the constant head permeameter. Future measurements of saturated hydraulic conductivity may be made using a UFA to avoid difficulties associated with the permeameter.

Dorothy Bishop, Joe Iovenitti, and Ken Lee (LLNL), in a series of presentations, gave a fairly generic description of the LLNL site and contamination problems, featuring rather heterogeneous soils and contamination levels slightly above regulatory limits. A suite of relatively standard measurement techniques are being performed on the site, with heterogeneity characterization being heavily emphasized. One of the activities that generated much discussion was an attempt to correlate saturated conductivity with the D40 grain size, with W. Gardner suggesting that the conductivity at maximum field saturation would be a far more valuable measurement. He further commented that, in general, accounting for the fluxes at domain boundaries and using effective parameters inside is often surprisingly accurate, much more so than modeling interior heterogeneity. A particularly interesting x-ray tomography technique for nondestructively examining soil core samples for integrity, without removing the original core casing, was presented, a videotape showing simulated horizontal and vertical slicing of a representative 3-in. core. Voids, fractures, and particles are clearly visible. The software is also able to selectively display only the largest rock fragments. Coupled with the reported 10 micron resolution obtained from the 160 kV X-ray source with 1,024 photodiodes, this suggests that a good portion of a grain-size analysis may be performed nondestructively.

A portion of these talks described some of the capabilities of NUFT (Nonisothermal Unsaturated Flow and Transport), the new code by J. Nitao (LLNL) intended to replace the TOUGH series. This is a modular code; simple modules include a combined saturated/Richards equation module, single-component transport with Richards equation, and a full three-mobile-phase, multicomponent compositional module with either isothermal or nonisothermal options. Currently the code is being tested in the 1D mode, although it can handle 2D and 3D as well.

Niall Kline presented research addressing anisotropy due to layering at a location in the Hanford site. Macrodispersivity theory by Yeh and others in 1985, combined with saturation-dependent anisotropy as espoused by J. McCord, was compared with PORFLO-3 simulations and field data. The comparisons presented showed only vague similarity. Incorporating saturation-dependent anisotropy did improve the comparison between field data and PORFLO-3 simulations.

Kyle Roberson (PNL) gave an overview of activities occurring at PNL. The main thrust of PNL research reportedly concerns constitutive theory, much of which turns out to be require rather accurate numerical simulations. Numerical dispersion in simulators is minimized using work out of Rice University based on the modified method of characteristics. A code requiring a high degree of user expertise is now or will soon be available, called STOMP (Solute Transport Over Multiple Phases). This is a modular code; only the modules of interest are compiled for a particular case. A free predecessor code, MSTS, is currently available. Other current work involves hysteresis modelling and dual gamma attenuation investigations in an intermediate scale tank (roughly six foot by three foot).

Mick Apted (Interra Sciences), based on worldwide experience in engineered barrier systems, suggested that the strategy for most applications is to eliminate advection as a mechanism for transport. The recommended procedure for eliminating advection is through a conductive barrier layer (i.e. a sloping sand layer atop a gravel layer). This removes purported difficulties in measuring advection, leaving only relatively well-understood diffusion as a transport mechanism. Diffusion and retardation measurement techniques occupied part of the talk, where the benefits of using the UFA apparatus were discussed. Further applications suggested for the UFA apparatus include studying gas permeability, fingering, episodic fracture flow, colloidal behavior, and microbe viability under varying saturations.

The UFA technology has been under development for over five years. Centrifugation has been used for media characterization for longer periods by the USGS. These methodologies are frequently the only techniques capable of providing critical data needs. DOE has placed significant emphasis on using this technology in their media characterization investigations. Future plans by DOE and their contractors include the use of UFA and other centrifugation techniques to characterize media properties.

PROBLEMS ENCOUNTERED:

None

PENDING ACTIONS:

None

RECOMMENDATIONS:

The utility of the UFA technology should be evaluated at CNWRA. This technology would assist in the measurement of saturated and unsaturated hydraulic conductivities, particularly of low permeable media. Additionally, UFA provides the means to measure sorption and diffusion in media under less than fully hydraulically saturated conditions.

REFERENCES:

See authors for copies of papers distributed at the workshop, including "Selenite Transport in Unsaturated Tuff from Yucca Mountain", by J. Conca and I. Triay (1994), "Verification of van Genuchten-Mualem Relationships to Estimate Unsaturated Hydraulic Conductivity at Low Water Contents", by R. Khaleel, J. Conca, and J. Relyea (1993), "The UFA Method for Site Characterization and Remediation," by J. Wright and J. Leather (1993), "Direct Determinations of Unsaturated Flow and Transport," by J. Conca and J. Wright (1992).

SIGNATURES:

Stuart A. Stothoff — 5/11/94
Stuart A. Stothoff
Research Scientist
Date

Ronald T. Green — 5/3/94
Ronald T. Green
Senior Research Scientist
Date

CONCURRENCE SIGNATURES AND DATE:

Robert G. Baca — 6/3/94
Robert G. Baca
Performance Assessment &
Hydrologic Transport Manager
Date

Budhi Sagar — 6/2/94
Budhi Sagar
Technical Director
Date

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AGENDA

PRELIMINARY AGENDA

FOR

SOIL PHYSICS WORKSHOP ON SUBSURFACE TRANSPORT

Thursday, March 31

8:00 - 8:30 a.m.	**Bagels, coffee and juice.**
8:30 - 9:00	**Introductions, workshop goals and agenda.**
9:00 - 10:00	**Three to four short presentations on empirical work using the UFA method and other centrifugation methods.**
10:00 - 12:00	**General discussions led by presenters (please mail/fax topics you would like to have addressed and/or volunteer to make a presentation).**
12:00 - 1:00 p.m.	**LUNCH - Catered by Emerald of Siam, vegetarian & non-vegetarian Thai cuisine. Charge is $10 per person.**
1:00 - 2:30	**Several presentations on issues and data needs to address fundamental questions in soil physics.**
2:30 - 4:00	**General discussion led by presenters (again, mail/fax topics you would like to discuss and/or volunteer to present).**
4:00 - 5:00	**Development of experimental design to address specific questions/issues/problems.**
7:00 - 9:00 p.m.	**No-Host Dinner at Las Margaritas, 627 Jadwin Ave., Richland.**

Friday, April 1

8:00 - 8:30 a.m.	**Muffins, fruit and coffee.**
8:30 - 9:30	**Presentations on modeling and applications.**
9:30 - 11:00	**General discussions led by presenters (send questions, ideas or volunteer).**
11:00 - 12:00 p.m.	**Conclusion and discussion of future activities.**