In Situ Measurements in Fractured Till Using Sidewall Sensors

Selected Paper – Conference, Copenhagen May 14-16, 1998, on “Mass Transport in Fractured Aquifers and Aquitards"

Larry Murdoch1, Bill Harrar2, Bertel Nilsson2, William Slack3 and Robert Siegrist4

Subsurface parameters, such as hydraulic head, often vary markedly with depth in fine-grained glacial sediments, but sensors placed in vertical boreholes are poorly suited to resolve these variations. One problem is that conventional methods only allow one, or perhaps a few, sensors to be placed in each borehole. To address such limitations we have developed a method for accessing the sidewall of a borehole. The method uses a device that pushes sensors or sediment samplers laterally into the sidewall to distances slightly less than the diameter of the borehole. The device can obtain a core sample 15 cm long and 4 cm in diameter, and then insert a permeable sleeve for extracting water samples. The same device has been used to insert several types of electrodes capable of measuring water content (using TDR waveguides), Eh (using platinum electrodes), or electrical resistivity (using a miniature Wenner-type array). At a site near Flakkebjerg, Denmark, we installed 22 water samplers and 19 resistivity electrodes in a single borehole to measure hydraulic head gradients in detail and to monitor the vertical migration of ionic tracers. This approach can be used to install horizontally oriented TDR waveguides at virtually any depth, thereby extending the TDR technique to the study of deep vadose zones. At a contaminated site in the USA, TDR wave guides were installed to a depth of 12 m in glacial till. Other applications include measurement of Eh at a site where in situ chemical oxidation was used, and the in situ sensors provided results that are similar to data obtained from soil cores.

1) Clemson University, SC 29634, U S A
2) Geological Survey of Denmark and Greenland, DK-2400 Copenhagen NV
3) FRx Inc., Cincinnati, Ohio, U S A.
4) Colorado School of Mines, Golden, Col., U S A.
Introduction

Larry McDougal et al.
Several applications are described in more detail below:

- **In Situ Measurements in Drilled Wells**
  - The equipment and techniques for in situ measurement of physical properties of the formation are described in detail. The measurement tools include...
Sensors

...
Several clusters of convolutional wells with short (25 cm) screens completed at different depths indicated a downward vertical hydraulic gradient. Five of these wells were available in the depth range of 2 to 5 m near one of the slickenwall wells. Special measures of hydraulic conductivity in the convolutional methods suggested that the bottomflow may be expected to maintain—

...
but most were eliminated because they were unable to provide data to IR in cop-
several methods for measuring the moisture content at this site were evaluated,
A Significant site in Connecticut, USA, is mentioned by IR in cop-215-320-silo day.
Deep Vadose Monitoring

 flux is uniform with depth, which is consistent with other data from the area.
 and the 0.7 m/s in the lower zone. This case the data indicate that the vertical and 8.2 \times 0.7 m/s in the upper zone. The case the data indicate that the vertical relationship is vertical flux of 8.3 \times 10^{-2} m/s in the upper zone.

In conclusion, the heavy soil shows less uniformity than the head gradient decreases with depth. The heavy soil shows less uniformity than the head gradient.

In conclusion, the heavy soil shows less uniformity than the head gradient.

is consistent with the hydraulic gradient.

calculations made at this site. However, intermediate head the clay or clay with a.

This conclusion is supported by the data collected from the diffuser, which is consistent with the vertical flow.

In conclusion, the heavy soil shows less uniformity than the head gradient.

and head measurements were made to compare to the results from the sidewall

function of depth.

(circles) and in the lab (squares) are a

Pig. 4: Head measurements at conventional.

Pig. 3: Head measurements at conventional.

Head (m)

Elevation (m)

Depth (m)

Mudstone content (vol. percent)

Mudstone content (vol. percent)

Lamb's Humpoc at 626
data for the in situ measurements.

bonds. Recessed potential of solid cores was measured at ZL to ZE, a similar span
measured in the lab from the nets whose samples ranged from 0 to 270. The voltage
as obtained in the vicinity of the waveguides. Volume/metric properties of rock
iso-846 and CR. The results indicate the effective volume fraction of rock
shown to develop significant results at the end of the experiment. The results indicate
not significant. A Type D, Reversed Central Temperature Expansion was used in most
soil samples. The effective volume fraction of rock was calculated from the above-
the rocks. Time Domain Reflectometry (TDR at 1.980 and 1.988) appeared to

In Situ Measurements in Fissured TIII
The porewater redox values at shallow depths in the background location were in the condition (Compston and Sanders 1999) caused by the Portland cement added to seal the samples. These values are less than or equal to redox values in the soil (pH: 5 to 6) with an Eh considered less than the results from soil measurement of 0 m. The range of results were obtained between the porewater-field fractions (Fig. 5). This range may reflect the high signal background Eh was between -500 and -700 mV. Similar signals were obtained between the porewater-field fractions (Fig. 5). This range may reflect the high signal background Eh was between -500 and -700 mV. Similar signals were obtained between the porewater-field fractions (Fig. 5). This range may reflect the high signal background Eh was between -500 and -700 mV. Similar signals were obtained between the porewater-field fractions (Fig. 5). This range may reflect the high signal background Eh was between -500 and -700 mV. Similar signals were obtained between the porewater-field fractions (Fig. 5). This range may reflect the high signal background Eh was between -500 and -700 mV. Similar signals were obtained between the porewater-field fractions (Fig. 5). This range may reflect the high signal background Eh was between -500 and -700 mV. Similar signals were obtained between the porewater-field fractions (Fig. 5). This range may reflect the high signal background Eh was between -500 and -700 mV. Similar signals were obtained between the porewater-field fractions (Fig. 5). This range may reflect the high signal background Eh was between -500 and -700 mV. Similar signals were obtained between the porewater-field fractions (Fig. 5). This range may reflect the high signal background Eh was between -500 and -700 mV. Similar signals were obtained between the porewater-field fractions (Fig. 5). This range may reflect the high signal background Eh was between -500 and -700 mV. Similar signals were obtained between the porewater-field fractions (Fig. 5). This range may reflect the high signal background Eh was between -500 and -700 mV. Similar signals were obtained between the porewater-field fractions (Fig. 5). This range may reflect the high signal background Eh was between -500 and -700 mV. Similar signals were obtained between the porewater-field fractions (Fig. 5). This range may reflect the high signal background Eh was between -500 and -700 mV. Similar signals were obtained between the porewater-field fractions (Fig. 5). This range may reflect the high signal background Eh was between -500 and -700 mV. Similar signals were obtained between the porewater-field fractions (Fig. 5). This range may reflect the high signal background Eh was between -500 and -700 mV. Similar signals were obtained between the porewater-field fractions (Fig. 5). This range may reflect the high signal background Eh was between -500 and -700 mV. Similar signals were obtained between the porewater-field fractions (Fig. 5). This range may reflect the high signal background Eh was between -500 and -700 mV. Similar signals were obtained between the porewater-field fractions (Fig. 5). This range may reflect the high signal background Eh was between -500 and -700 mV. Similar signals were obtained between the porewater-field fractions (Fig. 5). This range may reflect the high signal background Eh was between -500 and -700 mV. Similar signals were obtained between the porewater-field fractions (Fig. 5). This range may reflect the high signal background Eh was between -500 and -700 mV. Similar signals were obtained between the porewater-field fractions (Fig. 5). This range may reflect the high signal background Eh was between -500 and -700 mV. Similar signals were obtained between the porewater-field fractions (Fig. 5). This range may reflect the high signal background Eh was between -500 and -700 mV. Similar signals were obtained between the porewater-field fractions (Fig. 5). This range may reflect the high signal background Eh was between -500 and -700 mV. Similar signals were obtained between the porewater-field fractions (Fig. 5). This range may reflect the high signal background Eh was between -500 and -700 mV. Similar signals were obtained between the porewater-field fractions (Fig. 5). This range may reflect the high signal background Eh was between -500 and -700 mV. Similar signals were obtained between the porewater-field fractions (Fig. 5). This range may reflect the high signal background Eh was between -500 and -700 mV. Similar signals were obtained between the porewater-field fractions (Fig. 5). This range may reflect the high signal background Eh was between -500 and -700 mV. Similar signals were obtained between the porewater-field fractions (Fig. 5).
Acknowledgements

The work was supported by DOE contract DE-AC05-96OR22464, and EPAs CR-822677.

Conclusions

A method for obtaining horizontal core samples and installing sensors in the side-wall of boreholes in sediment has been developed to address some of the problems possible scenarios. The horizontal core samples can be accurately monitored using a sidewall sensor such as a strain gage. Several hundred feet of vertical profiles of hydraulic head and strain on the core can be analyzed to provide real-time monitoring of a variety of natural processes. This allows for improved understanding of the processes and the ability to predict changes in the environment. The horizontal core samples can also be used to detect changes in the environment, such as changes in the hydraulic conductivity of the sediment. Several hundred feet of vertical profiles of hydraulic head and strain on the core can be analyzed to provide real-time monitoring of a variety of natural processes. This allows for improved understanding of the processes and the ability to predict changes in the environment. The horizontal core samples can also be used to detect changes in the environment, such as changes in the hydraulic conductivity of the sediment.
References

Larry Mirbach et al.