Innovative TDR applications for nuclear waste disposal sites

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ABSTRACT. Solexperts provides measurement technique and in situ measurements for geotechnical and hydrogeological applications such as excavations, tunnel constructions and hydro power plants. In the framework of nuclear waste disposal Solexperts has wide experience in instrumentation for research rock laboratories in Europe and Japan. In this field, moisture measurements in sealings and barriers are of great importance. For this purpose, Solexperts has developed innovative TDR sensors for high and low pressure applications.

Keywords: TDR probe, packer, bentonite, geotechnical instrumentation

1 Introduction

Solexperts AG is a provider of measurement technique for geotechnical and hydrogeological applications and in-situ experiments.

The Solexperts team consists of an inter-disciplinary group of specialist engineers and geologists in the fields of geotechnical engineering, hydrogeology and geodesy as well as IT specialists, electronics engineers and mechanics. In the office, in the workshop and on site the team is responsible for the development and production of measurement systems, executing complex measuring tasks and the implementation of new measuring techniques.

Solexperts produces and sells precision measurement instruments and complete monitoring systems including data logging, alarming and web-visualization for civil engineering risk management of projects in difficult ground conditions. For many projects customized solutions are being developed.

In the framework of research projects on nuclear waste disposal sites Solexperts has specialised in planning, instrumenting and performing in-situ testing in a large number of experiments at the Grimsel test site (CH), the Mont Terri rock laboratory (CH), Laboratoire souterrain de Meuse/Haute-Marne (F, ANDRA), Schacht Konrad (D, BfS) and for the Japanese Nuclear Safety Organization (JNES).

For the determination of moisture and of water and gas transport through sealings and barriers the TDR (time domain reflectometry) method was found to be most suitable. Recently Solexperts has been developing specialized TDR probes and systems for several experiments.

2 TDR - Time domain reflectometry

2.1 The basic principles of TDR

TDR (Time Domain Reflecometry) is a well established method to distinguish the water content in granular materials. It is a indirect and non-destructive method, which means that the water is not separated from the solid for taking the measurement. Thus it is working without taking samples and hydraulic interaction in the measured zone.

The determination of the water content using TDR (Time Domain Reflectometry) is based on the principle that the relative dielectric number of water ε_{water} is much larger than that of other soil constituents ($\varepsilon_{water} \approx 77$ to 88, $\varepsilon_{solid} \approx 3$ to 8, $\varepsilon_{air} = 1$). The dielectric number ε_{mix} of soil as a multi-phase mixture depends on the dielectric number of the volume fractions of its components. The dielectric number can be measured by determining the propagation velocity c of an electro-magnetic wave along uncoated metallic waveguides. To determine c in soil, a waveguide is installed in which very short electrical pulses are sent through. A commonly used waveguide for TDR measurements is an unshielded metallic 2- or 3-rod probe. Due to the impedance discontinuity at the end of the line the electrical pulse is reflected back and detected by a receiver. From the travel time t and the length l of the waveguide, which has been travelled along twice, the propagation velocity $c = 2l/t$ can be calculated. The water content can then be correlated using a regression curve (e.g. Topp et al. [1]) which is applicable for many soil materials. Other approaches use mixing rules.

2.2 Coated TDR sensors in conductive environment

Sealings and barriers in radioactive waste disposal sites are usually composed of bentonite or bentonite sand mixtures. The bedrock for planned future repositories is often a claystone such as in Mont Terri or in Bure (Laboratoire souterrain de Meuse/Haute-Marne).

For measurements in materials with high electrical conductivity like clay minerals or materials containing saline waters, the TDR reflection signal fades in uncoated sensors so that the travel time cannot be precisely distinguished. Therefore it is advisory to use sensors with a thin insulating coating which guarantees a better signal trace. However, the insulating makes it inevitable to distinguish special calibration curves for the signal travel time in the probe within different media.

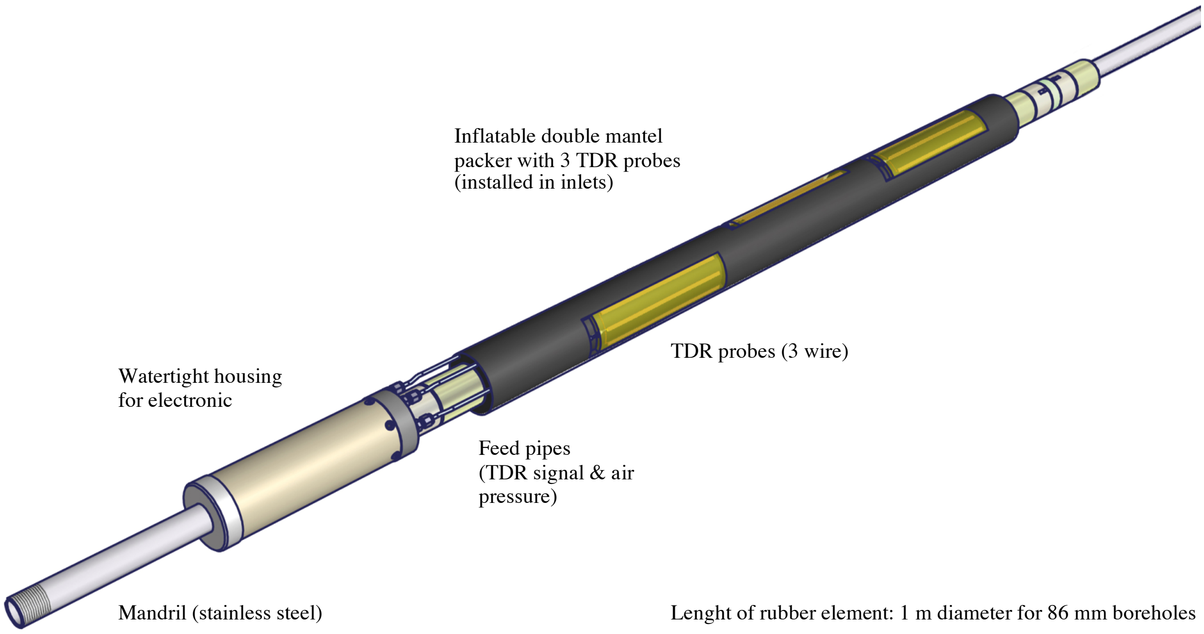
Material calibrations are advisory for exact measurements in materials with high clay content. As commonly used in TDR technology (Roth, 1996 [2]), Solexperts generally uses an empirical approach to correlate the travel time and the signal amplitudes to the actual water content. The feed lines for TDR sensors in demanding environments should be kept as short as possible. Mostly, special coax cables with low attenuation are to be recommended.

3 The Solexperts TDR packer system

3.1 Layout of the Solexperts TDR packer system

The Solexperts TDR packer system was specially developed for measuring water content in rock. It is built as a double mantle packer with a length of the packer element of 1 m. It is designed for drill holes with a diameter of 86 mm. On a 1 m packer element there are three TDR probes circularly and staggered installed. Within a housing next to the packer rubber element, a special TDR signal generator and sampler with a signal processing unit for the TDR measurements is emplaced for each probe. The signal output can be a digital BUS signal (TDR trace signal and calculated values for saturation / water content) or – by using a pre-programmed calibration curve - an analogue output (water content / saturation) for any data acquisition. In Fig. 1 an schematic layout of the packer is shown.

Fig. 1: Schematic layout of the Solexperts TDR Packer System



3.2 Advantages of the Solexperts TDR Packer System

Compared to the commonly applied TDR methods with the installation of TDR-rod probes in the rock , the Solexperts TDR packer system has the following advantages:

- Due to the installation on a packer, the TDR probe is directly pressed on the borehole surface. No medium is necessary to fill up any gap between sensor and rock surface
- Multiple probes can be installed in a single borehole, so that measurements ¨can be performed at different depths in the borehole.
- The electrical conductors of the probes are fixed. Thus, the waveguides are always ensuring the correct evaluation of the signals.
- Further instruments may be installed in the same borehole through the packer mandrel.
- Coated waveguides and an optimized TDR technology are capable for the measuring in electrically conductive materials, such as clays or mudstones.
- A signal analyzer (determination of water content from signal trace/travel time) is incorporated in the electronics (no further post-processing needed) e packer is retrievable and the position of the probes can be re-adjusted if needed

4 TDR sensors for applications at high water and gas pressures and sensors of special design

4.1 Solexperts high pressure plate sensor

For an experiment with saturation and gas migration in a cubic sealing element made of high compacted bentonite, Solexperts developed TDR sensors with following features:

- sensor lengths between 90 cm and 140 cm
- coating of the conductors to measure in electrical conductive materials(bentonite)
- single-sided measurement field (from both surfaces of the sealing material), no connectors or preferential flow paths in sealing
- high pressure water tightness (more than 10 bar) of sensors and all connectors
- standard helium gas tightness and high pressure nitrogen tightness (more than 20 bar)of sensors and all connection lines
- spatial resolution of the signals along the TDR probes

A three wired sensor design was developed by Solexperts with assistance of the CMM (Competence Center for Material Moisture) of the Karlsruhe Institute of Technology and Schlaeger mathematical solutions, Horn-Bad Meinberg.

For constructional reasons and to guarantee the single-sided measurements, the PE-coated sensor line is welded on a PE mounting plate (Fig. 2). In the injection-moulded sensor head an electrical feed-through made of glass prevents the gas flow (helium) along the feed pipe. To guarantee the high pressure tightness, the coax cable is guided inside a metal tubing to a multiple o-ring / flange system. The signals are automatically recorded with a TDR DAS System consisting of a CSI TDR-100 and several multiplexers. Through an internet connection, automatic analysis and visualization on the web can be performed.

Fig. 2: Solexperts TDR high pressure plate sensor

A total of 38 sensors are installed in the experiment at both faces of the sealing with the aim to monitor the saturation with water and to detect the gas break-through in the sealing during the gas migration phase. The experiment was built up in the first half of 2010 and saturation is planned to start in the following weeks.

4.2 Solexperts high pressure rod probe

In another experiment for installation in a sand-bentonite layer of an engineered barrier, TDR rod probes were required which would resist the material compaction during the emplacement. For the experiment purpose, gas-tightness is required along the feed cables which was achieved by the use a glass feed-through between the feed cable and the sensor conductors, similar to the plate sensors described above. The coax cable is guided inside a stainless steel line through the fitting in the reservoir wall.

A photography of the TDR probe during the installation in the experiment is shown in Fig. 3.

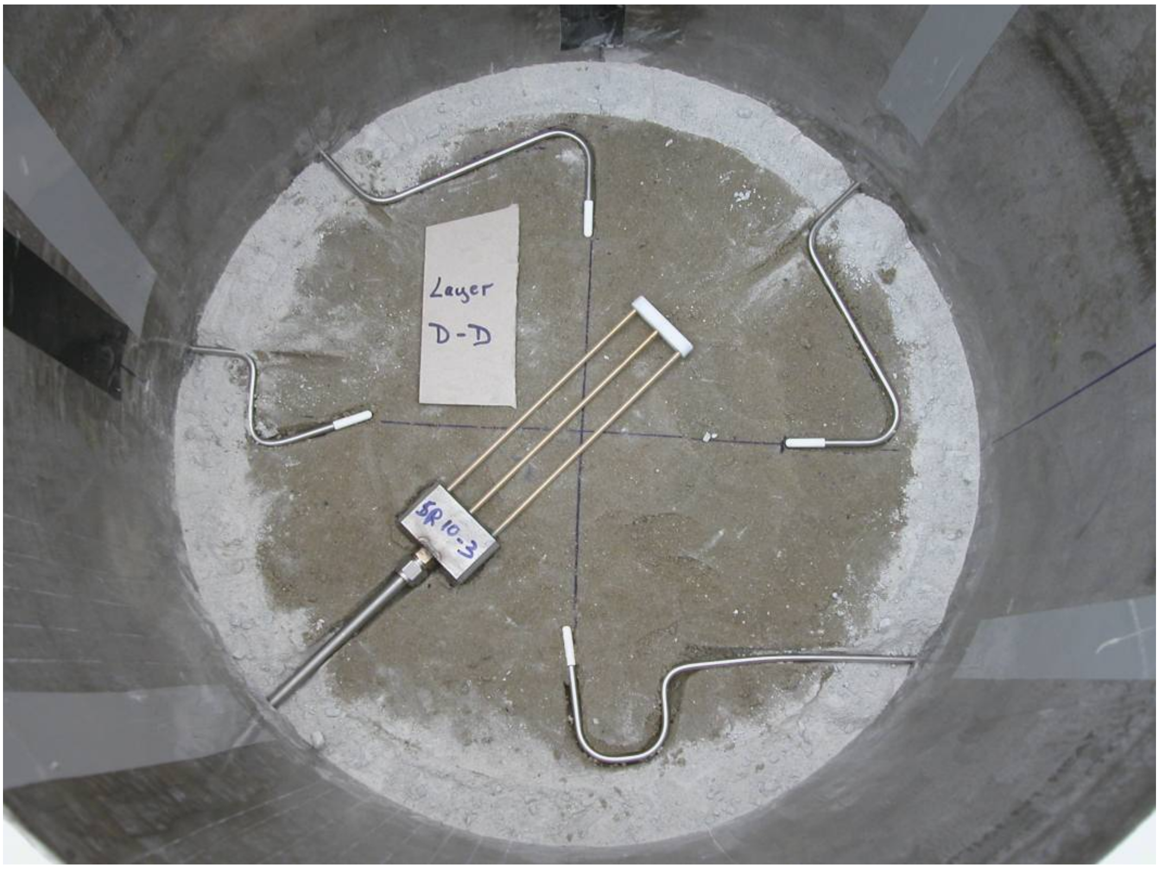


Fig. 3: Solexperts TDR high pressure rod sensor (and tensiometers) during installation for an experiment

4.3 Solexperts TDR ring sensor

To detect lateral water and gas flow along the wall of a cylindric container, a TDR sensor was developed as a ring type sensor (Fig. 4) emplaced between the sand-bentonite material and the cylinder wall.

The gap between the sensor and the steel container is filled with resin to prevent gas and water flow along a preferential flow path (Fig. 5). The copper lines are coated with 0.5 mm of PVC. To ensure high pressure tightness, the coax cable is conducted in a steel lining and a specially designed connector at the sensor head is mounted.

Signals recorded with the TDR ring sensor are shown in Fig. 6. To test the special resolution of the sensor, material with different dielectric permittivities were emplaced on different sections of the sensor (between 2 and 4 o'clock, 4 and 6 o'clock and so on). The recorded signal can be analyzed visually and with simple mathematical algorithms to identify relative changes of water content along the boundary of the sand bentonite sealing.

Fig. 4: Solexperts TDR ring sensor before emplacement

Fig. 5: Solexperts TDR ring sensor after emplacement: The gap between sensor and reservoir wall is filled with resin to prevent gas and water flow

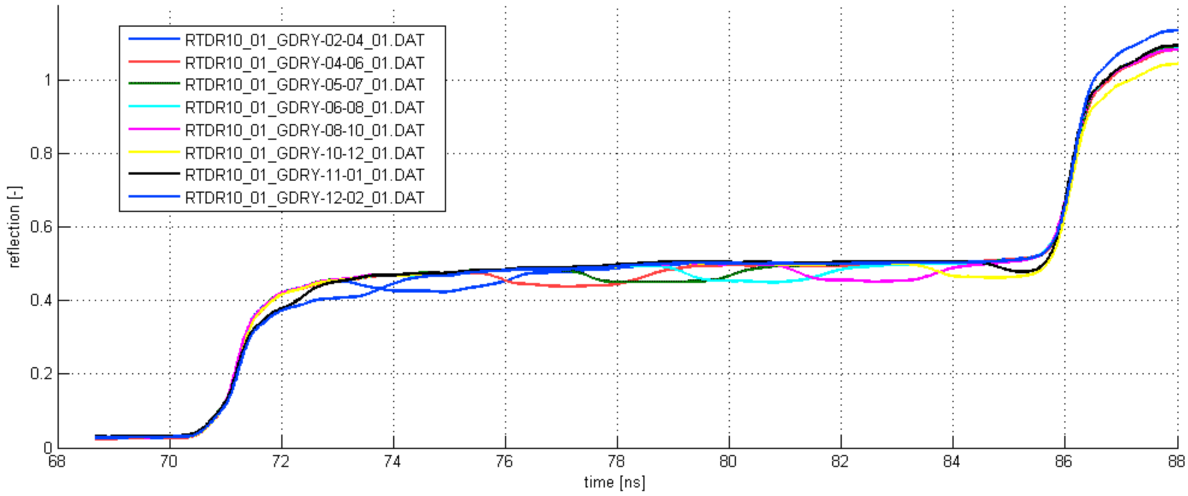


Fig. 6: TDR signals measuring spacially changing dielectric permittivity along the ring sensor

5 Summary

The TDR method is regarded as a most suitable measuring method for the determination of water content changes in barriers and sealings of radioactive waste disposals with a high potential for future applications in projects with similar objectives. Solexperts AG has developed several types of TDR sensors for different experiment setups in the framework of research projects for nuclear waste disposal sites. A TDR packer sensor system for in-situ moisture measurements in bedrock boreholes is presented together with different TDR sensor types for the installation in different environments. The presented customized TDR solutions could provide detailed knowledge of gas and water transport in impermeable barrier elements and will lead to improvements in the TDR sensor construction and analysis for future projects.

References

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