MONITORING OF JOINT SYSTEMS TIME-LAPSE BEHAVIOUR VIA ERT

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Abstract

Electrical resistivity tomography (ERT) as a tool for monitoring the processes and time-related changes in geological environments has made great progress in recent years and has become standard for observing natural phenomena. This method is simple to use and it often provides high-quality results that are well interpreted.

Our research is based on observing time-lapse changes of the physical parameters (conductivity, for instance) of joints systems (mostly in crystalline massifs). The primary aim is to develop a monitoring system mostly for the needs of deep repositories of nuclear waste. Geophysical research of such repositories has so far dealt only with one-off research (no time-monitoring) of potential host rock´s properties. Contrary to this, our developed system and methodology is unique in continuously measuring the physical properties (in this case, electrical resistivity) of the rock massif. This system will be permanently fixed in the field and by observing changes in measured data reports if any remarkable occurrence in the EDZ zone is or was happening (for example, opening or closing of the joints or micro-fractures).

Today, our monitoring system is being developed and tested at the field base in Bedrichov (northern Bohemia). The Bedrichov gallery is approximately 2.5 km long and continuously leads through one type of granite massif. Point 792, where a significant geological fracture zone goes through, was chosen as an ideal place for taking repeated measurements via our ERT system. Currently, we test the measurement quality, such as whether our system provides real data and is able to reliably observe resistivity changes measured at ERT profiles.

Introduction

The use of geophysical methods for monitoring the status of the geological environment and its changes is currently a widespread discipline (general review in Wilkinson et al., 2011). Typical applications are mostly environmental issues, such as the monitoring of a contaminant´s movement (Sirhan et al., 2013) or surveillance of permafrost (Supper et al., 2014). In contrast, the use of geophysical methods for deep radioactive waste repositories, to our knowledge, has so far concerned only a one-time exploration of the rock massif (for example, Spilmann et al., 2010 or Zhiguo et al., 2013)

During 2003 the idea arose to use geophysical methods for continuous monitoring of the parameters of the crystalline rock massif for the needs of a future deep radioactive waste repository in the Czech Republic (summary in Barta et al., 2010 or Barta et al., 2011). Two geophysical methods, namely ERT and hammer seismics, were selected as backbone methods for this project, supervised by SURAO/RAWRA (Radioactive Waste Repository Authority). The work continued with varying success until 2013 and showed the advantages and disadvantages of the two methods for this application. At the beginning, the water supply tunnel located in Bedrichov in northern Bohemia was selected as a test base. The tunnel in its entire length of approximately three kilometres intersects one type of granite massif

(Jizera granite) and thus represents an exceptional location for the research in many disciplines. The tunnel was driven in 1982. The first approx. 900 metres were machine-driven using DEMAG technology. Following the collapse of the system the remaining part (ending below Josefuv Dul water reservoir) was driven by conventional mining methods using explosives. This gives us an ideal opportunity to study the granite massif in-situ, even with the two forms of EDZ zone disturbation due to different types of tunnel driving. Currently, the tunnel is being used primarily for water supply (the water conduit from Josefův Důl water reservoir is routed via the tunnel) and scientific purposes.

Based on the results of earlier research stages it was decided that the planned methodology should be developed so that it may become in the future a serviceable tool for long-term monitoring of the rock massif. Most of the earlier measurements conducted using ERT method often suffered from insufficient density of measured data. The data was usually collected at intervals of approx. three months, so it was very difficult to credibly interpret any short-term temporal variations in the rock. The measurements have demonstrated, nevertheless, that electric resistivities may show significant temporal variations, which indicates ongoing processes in a seemingly homogeneous medium such as granite massif around the gallery.

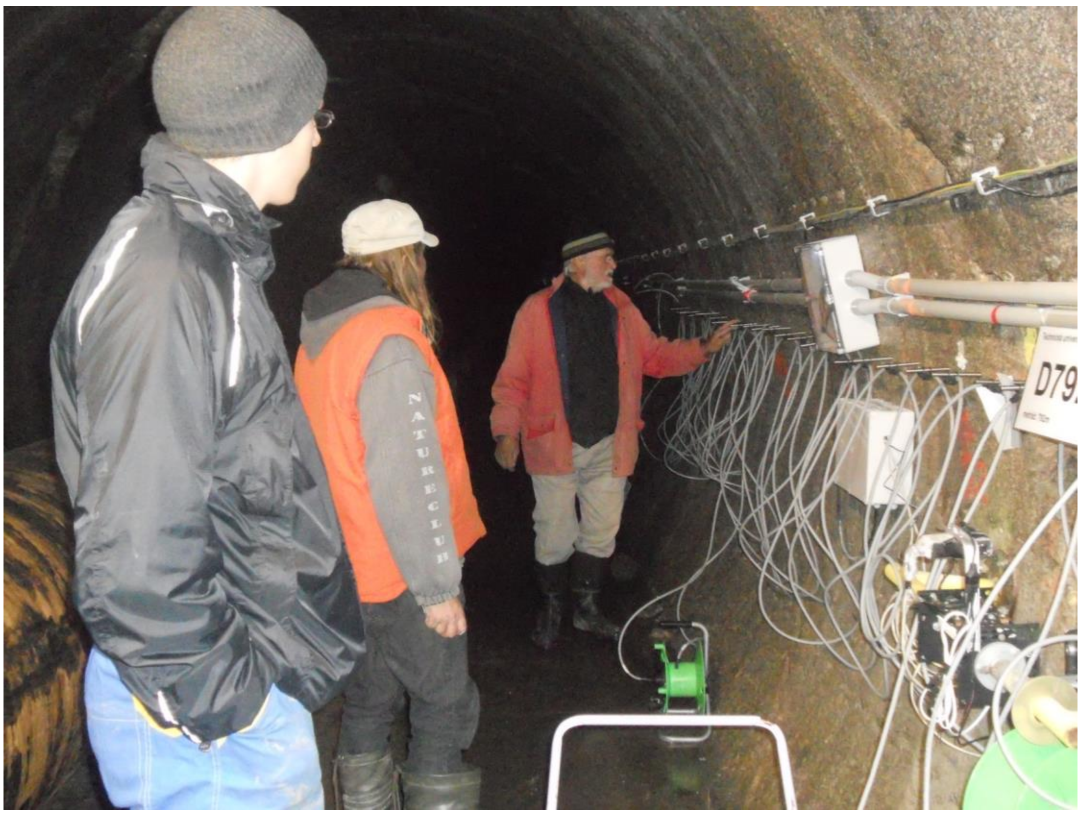

Figure 1: Field base in Bedřichov tunnel, metre 792. ERT system layout across the geological disturbance.

We decided to develop a geophysical monitoring system that, by monitoring changes in apparent resistivities and seismic signals, could indicate changes taking place in the rock massif. The results of the work carried out so far using the ERT system will be described in this abstract.

Stage 1 of our research includes laying out the system of electric tomography at a selected location in the tunnel, followed by measurement in continuous mode, at intervals frequent enough to allow us to identify any ongoing processes in the rock massif. Currently, the testing phase is underway, with measurements repeated at predetermined intervals (four hours for instance). The advantage of Bedrichov tunnel is the presence of low voltage mains, which our system can be connected to. This eliminates the need to worry about battery life. In the future, in continuous operation, measurement intervals of approx. 24 hours are envisaged. Another of the objectives of our project for the future is automatic data collection, so the measurement results (or also their automatic evaluation) could be monitored online.

Our current aim therefore is to test how accurate measurement can be using the ERT system in the crystalline rock and whether any temporal variations can be measured. Such information might be of critical importance in the future operation of deep repository, generally there is most concern in this respect – whether the selected host rock is sufficiently stable and releases of radionuclides into the environment will be avoided.

We decided to test in a series of experiments whether we are able, using the ERT system, to answer the above question. The experiments should answer questions related to the measurements – what is the appropriate spacing between the electrodes, is the measurement stable and accurate over time? Some measurements have already been conducted, others will follow. The idea of these experiments is to conduct a series of repeated measurements (for different periods of time, at different intervals) in the tunnel. We assume that the granite medium in intact state is in principle very stable, therefore, we should not find any changes in geophysical signals at first. However, if we believe that changes occur in joint zones in the rock massif, we should be able to capture such changes and possibly interpret their cause. Our measurements take place at metre 792, which is intersected by a significant geological fracture zone, therefore, we can assume variation in the measured signals, e.g. due to a change in saturation of the medium with groundwater, a change in state of stress of the rock massif or due to opening/closing of micro-fractures. Our field base is shown in Figure 1.

Methodology and data processing

The parameter which we most take into account and which we consider to be the most important are the differences between the values of measured apparent resistivities. Since our interest is to monitor temporal changes occurring in the rock massif, we have to require that the apparatus is able, in the repeated measurements, to measure electric resistivities as accurately as possible, i.e. ideally, the values measured at short time intervals should show only minimum differences. To assess the difference between the measured points we use either a simple difference between corresponding points (that is, in Ωm), or their ratio as a percentage, using the formula:

$$\text{Diff} = (\text{value\_1}/\text{value\_2} - 1) * 100\ [\%] \qquad (1)$$

The value of value_1 is always identical in calculations (September 2013) to allow us to assess the effect of manipulation of the electrodes. In data processing, the emphasis is primarily placed on the original data which is not affected by potential errors caused by the inverse process. This could even be incorrect in our case, without applying a correction to the effect of the 3D tunnel body.

So far we have carried out test measurements in a classic setting (layer of weathered overburden – sandstone bedrock) and at the field base in Bedřichov. The very first test included measurement at a location in Svor (northern part of the Czech Republic), in a common geological environment. The apparatus was powered by a 12 V car battery. The monitoring profile was laid out using four passive resistivity sections with a spacing of one metre between the electrodes (stainless steel). The measurement was carried out for a total of four profiles in identical layout, at an interval of one hour.

This test showed us that it was necessary to pay close attention to contact resistance at the electrode-rock contact and also perfect the cable–electrode contact. Any correction of these deficiencies in monitoring is possible only for the initial measurement, others then follow automatically.

After verifying the functioning of the apparatus in a common geological environment we approached further tests that were conducted in Bedřichov tunnel. The measurement in this tunnel is very specific, we encounter high contact resistivities (typically around one hundred thousand Ωm) and also relatively high resistivity values of the granite environment (higher thousands Ωm). Here, therefore, the question arises – is the apparatus able, at very low introduced currents (tenths mA) and high contact resistivity between the electrodes and the rock environment, to measure electric resistivity with minimal error, showing stability over time, i.e. without erroneous effects of the apparatus? Transmitter parameters of the applied instrument are certainly of critical importance. In our case, we used the apparatus ARES II with the following parameters: maximum applicable power 850W, introduced current of up to 5 ampere and internal resistivity of the apparatus 20 MΩ.

Assuming high contact resistivity values, it is important to ensure the best possible contact between the stainless steel electrodes and the rock. The electrodes are placed into pre-drilled holes approx. 2-3 cm deep. A thin coating of water is usually maintained in the bores, which improves the introduction of current into the rock. The advantage of our test base is the presence of low voltage mains which, using the converter, can feed the apparatus. Four passive sections were laid out at our test base at metre 792 (on the wall at a height of approx. 1.2 m), with a spacing of twenty centimetres between the electrodes (in total 48 electrodes). One of the tests demonstrated that smaller spacings showed worse signal-to-noise ratio and the measured data were less stable over time (standard deviation for the differences in data measured at a spacing of ten centimetres was up to four times greater, compared to a spacing of twenty centimetres). The applied combination of arrays was in all cases set at Wenner-Schlumberger HD, in imaging the data into resistivity cross sections the depth of the point is approximated by a fifth of the distance between current electrodes, i.e. AB/5. The measurement parameters were set up more or less by default, i.e. the length of the current pulse 200 ms, the minimum potential 1000 mV, the maximum measurement error 5 percent.

Results

The first field test conducted in the environment of a layer of weathered overburden – sandstone bedrock demonstrated that the values measured at hourly intervals without manipulation of electrodes showed only minimum variations and were virtually identical over time (the differences are in the order of tenths of Ωm, standard deviations σ then almost virtually 0). The resulting resistivity cross sections of four repetitions, here marked A – D, are shown in Figure 2. Apparent resistivities were used for construction of cross sections, i.e. these are not the inverted models.

A total of three experiments have been conducted in Bedřichov up to now. The test in September 2013 showed mainly that the layout at a spacing of twenty centimetres was favourable to that of ten centimetres. The introduced currents here are of multiple values (1-4 compared to approx. 10 mA), as well as a registered signal. Also DOI of the measurement is logically greater, approx. 1.5 metre for spacings of twenty centimetres. To be able to assess how significant a change in apparent resistivities must occur to be considered real, we have added to the individual images of the differences in the values the calculation of statistical parameters – the average and standard deviation. It shows for a spacing of twenty centimetres that the average value ranges between 1 and 3 Ωm and the standard deviation typically takes values of around 30 Ωm. Should some of our measurements demonstrate greater differences, some kind of geological cause could be assumed. To quantify possible changes in resistivities in dependence on saturation with granite water, we performed laboratory measurements. They demonstrated that even minor changes in saturation of the fracture medium with granite water can cause changes in measured resistivities even in the order of hundreds of Ωm.

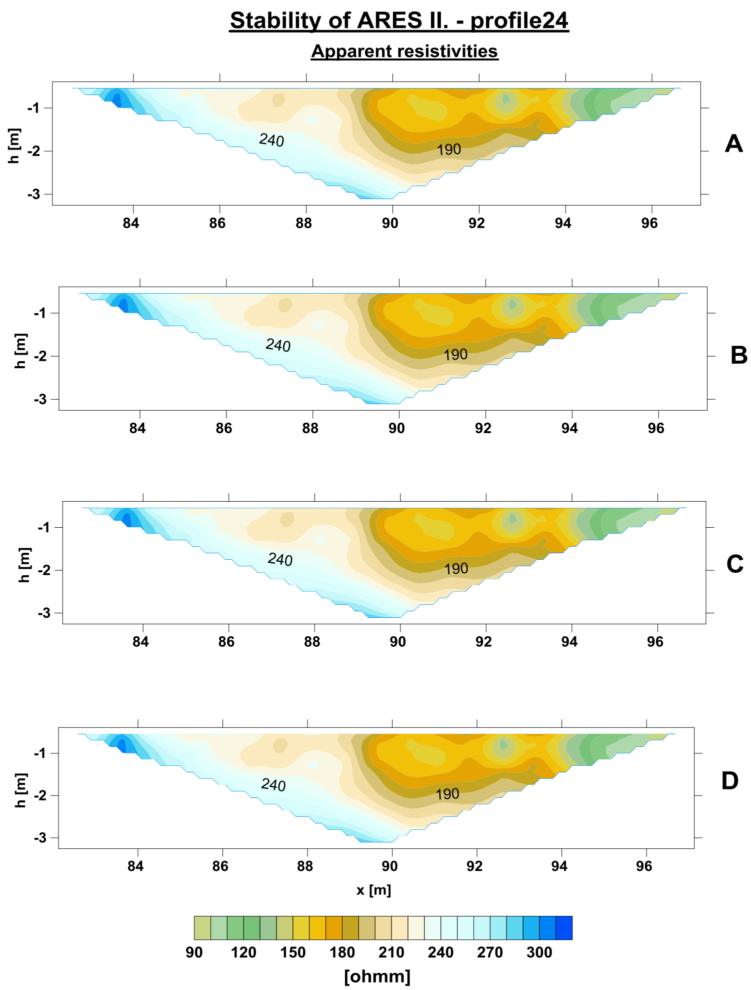

Figure 2: Resistivity cross sections measured at four hourly intervals at the location of Svor. Y-axis is the depth in metres (approximated by the value AB/5).

The logical assumption for our measurements is that the measured data should show only minimal differences – the rock environment of the underground tunnel is stable in depths of around 40 metres below the ground level and therefore no significant events should usually take place there. Most of the data measured so far confirm this assumption – the differences are minimal. A very interesting result, however, was shown by measurements of November 2013. In November, a total of 22 repeated measurements were conducted, at an interval of four hours (the whole measurement took approx. 3.5 days). A continuously evolving anomaly around metre x=7.3, y=-0.73 is of interest even at the first comparison of resistivity cross sections. As described in equation (1), we subtract November profile values from September profile values. There are two data points causing the evolving anomaly mostly – they are shown in Figure 3. Here we can observe a continuous decline in values first and then a gradual rise. We believe that this is a real result (not an erroneous effect of the apparatus), especially because the values are not too high (7-8000 Ωm), which should not be a problem for the apparatus to measure credibly. The data clearly show a trend course – with no random illogical values. The decline reaches a value of approx. 200 Ωm – this value should already be detectable, as we know from the statistical comparison of the measured data. In addition, the data comes from a depth of approx. ¾ metre, which is far from the maximum measured depth – therefore, the data should be real.

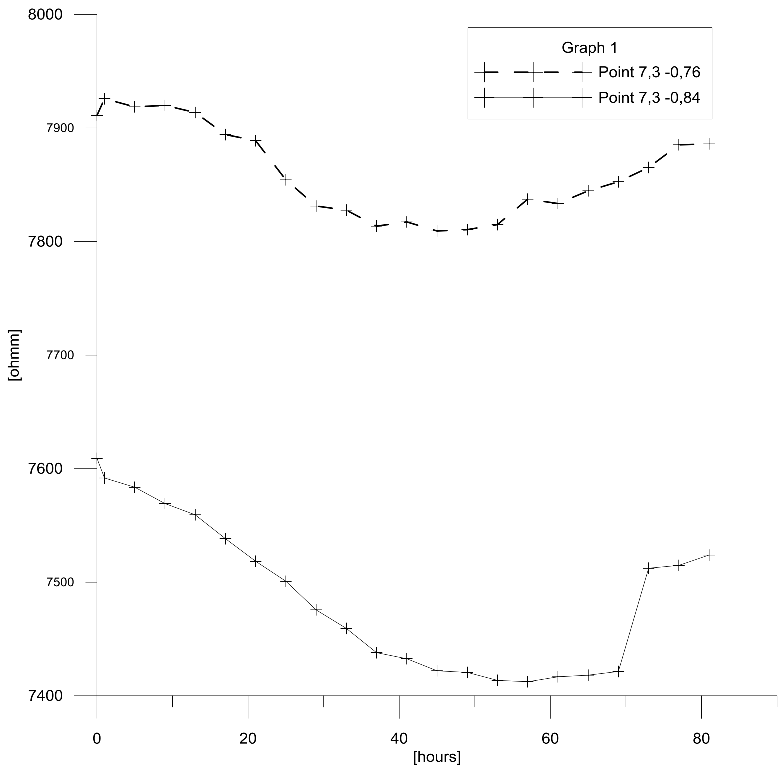

Figure 3: The trend of resistivities at two specific points – November 2013.

Conclusions

The measurements carried out so far have allowed us to find a few facts for the objective of our task. Spacing of twenty centimetres proves to be suitable for our purposes (greater DOI, better signal-to-noise ratio). Our experiments conducted so far show a very good stability of repeated measurements, therefore, we believe that we will be able, using ERT, to observe and identify short-term changes occurring in the rock massif. One such change was captured by measurements in November – its range is approx. 200 Ωm, it is of continuous nature and was measured in real conditions. Opinions on its geological interpretation may vary, but we believe that it may be a gradual change in granite micro-fractures saturation with water (its drying out or change in concentration). For possible uses in the future, i.e. monitoring of deep radioactive waste repositories, even such a change in the rock massif can be significant.

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