Geoelectrical Monitoring behind the “Iron Curtain”

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Introduction

In the countries of the Eastern Bloc, geoelectrical monitoring began in the 1970s in the form of repeated check or regime measurements. These were particularly measurements of the hydrodynamic regime using the method of an embedded probe (the mise-a-la-masse method), resistivity measurements made in workings and exploratory tunnels, check resistivity measurements (e.g. for detecting the homogeneity of compaction of large-area embankments) and repeated geoelectrical measurements made on slope failures.

At the end of the 1980s, further development took place also in the use of geoelectrical monitoring on slope failures. This work was carried out on landslides in the Crimea, in the Caucasus, in Uzbekistan and in Czechoslovakia. Resistivity measurements made from the surface were very often supplemented by geoelectrical measurement made in boreholes. In addition to the geoelectrical methods mentioned above, measurement of “pulsation electromagnetic emissions” is sometimes used, applied also as simple monitoring on slope failures, both in the areal surface version, and more often in the borehole option. The interpretation of results obtained by this method is, however, very deceptive.

Geoelectrical monitoring became more widely applied in the use of geoelectrical measurement with a multi-electrode array in the 1990s. This is a measurement carried out on landfills of waste material. Modern landfills are constructed mostly with a system of fixed electrodes underneath impermeable sheets, thus repeated geoelectrical measurements enable the identification of damaged places in the sheet and places of possible leaks of contaminated water from landfills.

In all of the states of the Eastern Bloc, the application of geoelectrical monitoring declined at the beginning of the 1990s, perhaps with the only exception which is the check of landfills. In this case, geoelectrical monitoring applies as the check of the tightness of impermeable sheets in the basement of landfills on the one hand, and also as the check of the flow of groundwater and its quality around landfills on the other.

Applications in Construction Industry

Geoelectrical methods began to be used in construction engineering immediately at the beginning of the use of geophysical methods in construction industry. First, these mostly concerned applications in the survey of dam sites; other types of construction work were also investigated geophysically in the course of time. In the 1970s, resistivity methods were chiefly used, namely in the form of vertical electrical sounding and symmetrical resistivity profiling. Other geoelectrical methods were also used, but rarely. The first example shows the use of the mise-a-la-masse method (Fig. 1). The results of measurement presented in this figure are from 1971.

One of the hydrogeological problems encountered during the preliminary stage of a survey for dams is the need to know the direction and velocity of flow of groundwater at the dam site and at

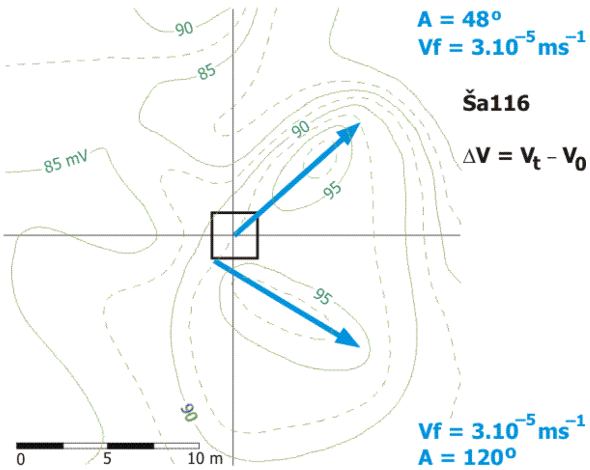

Fig. 1. Plan showing the flow pattern of groundwater determined by geoelectrical measurements in the vicinity of a test pit at the Josefův Důl dam site

sites where other buildings will be constructed, as well as in the backwater area. At this stage of the site investigation, the results of deep drilling are not yet available, so it is necessary to use all pre-existing information in combination with surface geophysics. A survey by the mise-a-la-masse method using a fixed electrode is an effective electrical procedure. An example of the application of this method in the investigation of the Josefův Důl dam site is illustrated in Figure 1. The direction and velocity of groundwater flow were interpreted using the measured difference in the direct-current potential field following salination of the water in a pit (V_0) and after an appropriate period of time had elapsed (V_t). Using these measurements, two different directions of flow were distinguished. By coincidence both of them showed the same velocity of groundwater flow. The pattern of the potential contours was used to determine the flow in the direction 120°. This method was preferred to that in which the direction of flow is given by connecting the centre of the elliptical field to the centre of the pit. In this case, the possibility that the fracture system controlling the flow of groundwater was most developed in the south-western corner of the pit could not be ruled out.

We also used repeated geoelectrical measurements to check compaction of embankments. The measurement below was carried out in 1975. If we are able to perform repeated surface measurements, it is also possible to estimate the changes in absolute values of apparent resistivity. This fact was also used during the monitoring of pouring homogeneity on a large-scale waste rock and fly ash used as a foundation material for the construction of a chemical plant on the bottom-land of the Odra River in Ostrava (MÜLLER, et al., 1994, BLÁHA and MÜLLER, 2008). Every bottom surface was measured with micro-resistivity profiling with double maximum depth. Experimental works proved that the mound is homogeneously solidified when the apparent resistivity values vary from 25 to 75 Ωm. In cases when places of higher apparent resistivity were noticed, these were interpreted as places of higher porosity and were recommended for reconstruction. Fig. 2 shows the outcomes of repeated measurements before adjustments; the places recommended for adjustments were marked with section lines. After the reconstruction it is clear that apparent resistivity values have been lowered to the requested figures.

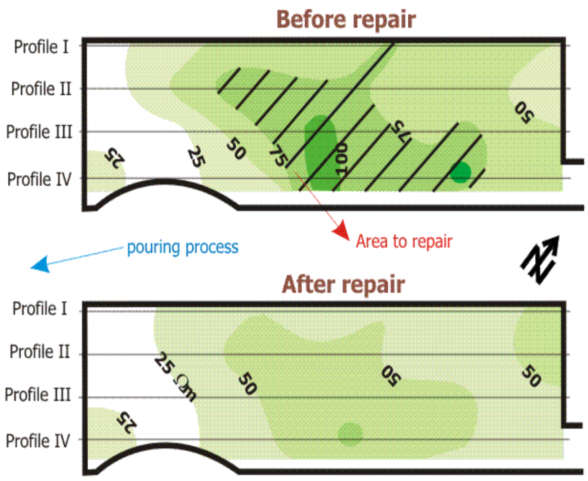

Fig. 2 Ostrava - repeated geoelectrical measurements

Applications in Mining

Monitoring of changes in the rock mass after a mine working has been excavated is one of the most important tasks of geotechnics. Some of the applications of high-frequency seismology are the most suitable geophysical methods for this monitoring. In the next figure we want to show that the application of geoelectrical measurements also yields very interesting information. Fig. 3 shows the outcomes of repeated geoelectrical resistivity measurements in the limestone massif in Viola 1 gallery in the Hrhov locality (Slovak Republic), which was considered to be the site for the construction of a pumped-storage hydroelectric plant. The measurement was carried out in 1973. Four quasi-homogeneous blocks were determined using geophysical and geological logs:

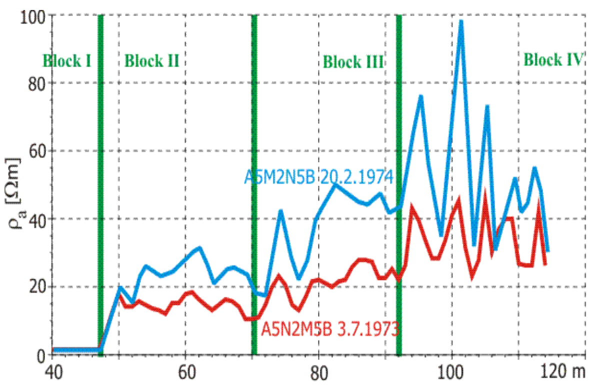

Fig. 3 Hrhov - repeated geoelectrical measurements

- Block I consisting of slope debris.
- Block II with wide cracks and fissures.
- Block III faulted with steep tension karstified fissures.
- Block IV faulted with narrow tension non-karstified fissures (Müller et al., 1976).

The use of repeated geophysical measurements to identify impacts of mining on the surface dates from relatively older times. In 1975 – 1987, manifestations of the so-called Hladnov Fracture were monitored in the mining area of the Petr Bezruc Mine in Slezska Ostrava (Fig. 4). Its delineation was required particularly in relation to the construction of a new road and the stadium Bazaly. This fracture had an effect on buildings extending from the embankment by the River Ostravice through Hladnov up to the urban park Stromovka. Conventional resistivity profiling and, experimentally, also thermal and emanation profiling were used to locate this fracture. The fracture was indicated by low apparent resistivity values and the centre of the fracture shifted by about ten metres in the course of twelve years (Hofrichterová et al., 1999, Fig. 4). In 2007, several profiles across the Hladnov Fracture were measured using multi-electrode resistivity tomography; the results showed the same indications of resistivity as in the previous years (Vašíčková, 2007).

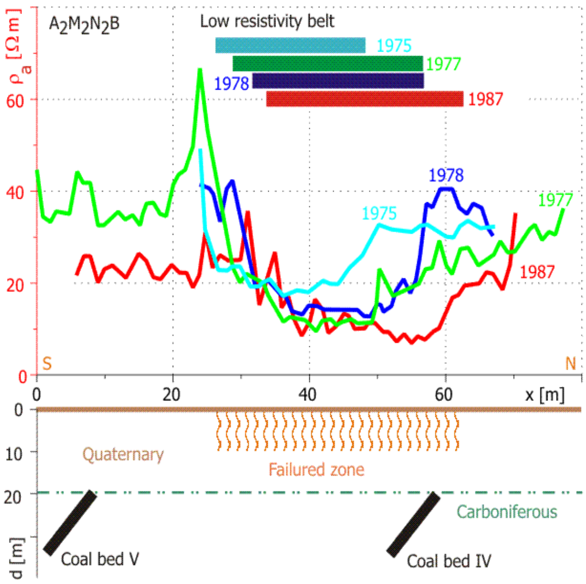

Fig. 4 Changes in apparent resistivity above the mining area (after Hofrichterová L. et al. 1999)

Applications to Slope Failures

In the 1970s and 1980s, the staff of the research institutes VSEGINGEO in Moscow and UZBEKGIDROGEOLOGIE in Tashkent (Abdullaev, 1983) carried out the most extensive study of manifestations of time changes in individual mechanical and physical properties on slope failures.

In these institutes, within the basic research, time changes in individual physical properties on slope failures were fully systematically studied, including changes in resistivity. They monitored these changes not only on natural landslides in the Crimea, in the Caucasus and in the foothill regions of Uzbekistan, but they also made model measurements that preceded field measurements. The results of these works were summarised by N. GORYAINOV and his team in a book on the study of landslides using geophysical methods, which was published by the Publishing House NEDRA in Moscow in 1987. It is natural that not only this team of authors gave attention to time changes in physical properties on slope failures, but these problems were also investigated in the Czech Republic.

The first repeated measurements were carried out in 1977 and 1987 and are given in Figure 5 showing the slope failure Trinec (BLÁHA, 1993, 1997, 2009). Measurements in both years were carried out in the same season under roughly the same climatic conditions. In the case of this particular landslide we can see that during 10 years no dramatic changes occurred in the distribution of tension and that the landslide was not developing progressively in this period. It is natural that a substantially larger amount of data can be obtained if a larger amount of measurements is available. We also tried to use perpendicular profiling. This work had an experimental character because perpendicular profiling is extremely demanding in fieldwork in terms of operation, particularly on forested terrain where the whole spacing of electrodes must again be installed for each point of measurement. An example of such work is given in Figure 5.

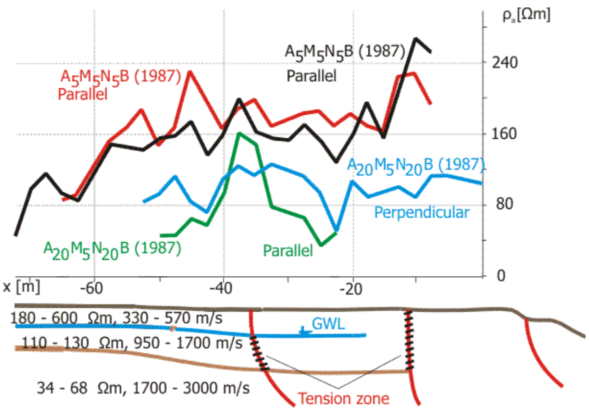

Fig. 5 Resistivity profiling on the landslide Trinec

The pattern of curves shows that parallel profiling yields substantially more jagged curves of ρ_a. The only advantage of transverse profiling is the possibility that in the case of a steep scarp we obtain results of profiling right to that scarp.

Another row of examples is from monitoring geoelectrical measurement on slope failures in Uzbekistan, particularly on the landslide Chashli. The site of Chashli lies close to the Town of Almalik about 60 km SSE of Tashkent. A huge body of loess lying on the limestone mass was affected by slope movement. The loess liquefied during a strong increase in moisture following the spring thaw and subsequently flew downslope. The slope failure of the type of flow passed then into slow sliding. A series of experiments was carried out on such a consolidated slope failure, during which the landslide was again set into movement using artificial watering. The landslide was watered so that water was pumped into open cracks. The volume of water that was introduced into the landslide at the individual stages of watering is given in Figure 6. In addition to the conventional methods of monitoring of movement of slope failures, a series of geophysical measurements was made on this landslide. During this series of experiments, symmetrical resistivity profiling and vertical electrical sounding were measured using stationary and portable electrodes.

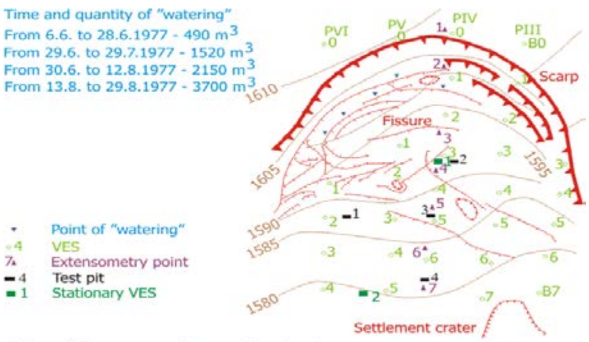

Fig. 6 Layout of geophysical measurements on the landslide Chashli

Figure 7 shows the changes that occurred before and after the renewal of slope movement. At the beginning of movement, the apparent resistivity for spacings of AB/2 being 1.5 to 6 metres records a marked decline, or the decline begins several days before the shear itself. It is possible to prove in the curve for AB/2 = 1.5 metres that tension cracks, manifested by increasing ρ_a at shallow depths, form before the shear itself. After the shear, the values of ρ_a do not change strongly anymore. Only in the spacing 1.5 metres, a slight increase of ρ_a was recorded at the turn of July and August 1977. It is possible that changes in the landslide take place in narrow spacing during its movement, i.e. that documented are the periods during which tension applied to an increased extent. This tension is accompanied by the formation of new cracks in the landslide, which are not filled by water, but by air. The increase of ρ_a for the spacing AB/2 = 11 metres is interesting. This increase, albeit negligible, agrees with the shear of the landslide in terms of time. This can prove that the shear of the shallow landslide is manifested by the change in the states of tension also in the basement of this landslide.

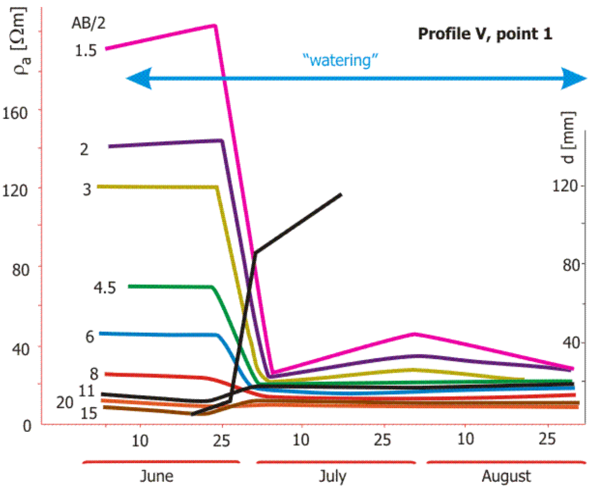

Fig. 7 Changes in apparent resistivity with moistening

Figure 8 also shows that the changes in ρ_a with moistening have mostly a similar character, i.e. that the apparent resistivity decreases. The right part of the figure shows the measured curves of ρ_a and the left part the derived parameter R, i.e. the ratio between ρ_a of moistened loess and ρ_a of loess with natural moisture content. In this manner it is possible to monitor not only changes in moisture content according to changes in apparent resistivity, but also to determine the depth of the shear plane. It is likely that the water introduced into the landslide is drained on the shear plane, and hence it is possible to determine the shear plane in the places in which the R values are approaching 1. However, we know cases from other sites that the parameter R can also assume values larger than 1. Such changes occur in the places in which newly forming pores cannot be fully filled by groundwater. It has been detected that in some cases the parameter R increases with time. This is caused by a gradual increase in porosity. However, to find a direct conversion relationship between the parameter R and porosity has not been successful, even for a given lithological type.

Another parameter in which it is possible to monitor time changes in sliding is the coefficient of anisotropy. Figure 9 shows an example taken from a paper in which the ratio of the major semi-axis of the ellipse of anisotropy to its minor semi-axis is plotted, namely for the beginning of sliding and for the developed stage of slope movement. This example is taken from the landslide Krasnogorsk, which lies in the same region as the landslide Chashli and has a similar geological structure as well. In the areas lying outside the slope failure (KV1 and KV9), we can see that the changes outside the landslide are minimal. At these sites, only extreme curves are plotted for a better arrangement of the figure (all curves were measured). The central part of the figure shows curves from the landslide (KV4 and KV5). At first sight it is obvious that in these curves far greater changes in the size of the apparent resistivity of loess occur with time. The values of the coefficient of anisotropy in sliding are up to double the ones before sliding. This is also one of the possible methods how to monitor the development of a slope failure or how to determine the depth of a shear plane. In this way it is possible to determine the depth of the shear plane on point KV4 at about 18 metres and on point KV5 at 10 metres.

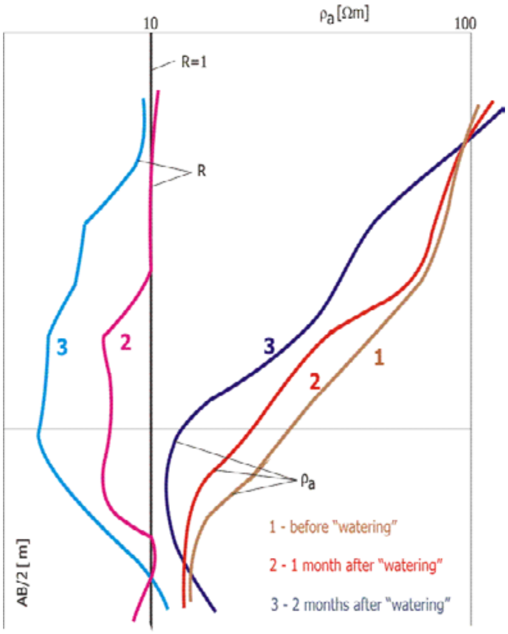

Fig. 8 Changes in ρ_a in VES curves

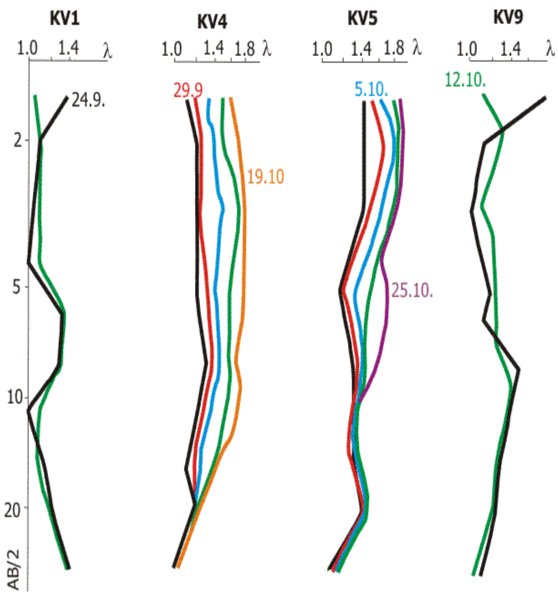

Fig. 9 Time changes in the coefficient of anisotropy

Conclusion

In this paper we show the readers which paths the development of applications of geoelectrical methods took in monitoring the time development of changes in the rock mass in the countries of the former Eastern Bloc before 1989. We paid attention not only to the changes governed by natural processes, but we made efforts to show the specialists from other branches the possibilities of using geoelectrical methods also in monitoring the changes caused by human activity. During the presentation at the December workshop, we tried to show our experience gained from the entire branch of geoelectrical monitoring. In this paper we focused only on applications in construction industry and mining and on monitoring slope failures.

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