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Geophysical monitoring as an information source of rock massif behaviour

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Geofyzikálny monitoring ako zdroj informácií o chovaní horninového masívu

Geofyzikálne prieskumné metódy prinášajú informácie o horninovom prostredí v reálnom čase, tzn. už v priebehu geofyzikálneho prieskumu. Geológ alebo geotechnik takto získané informácie poskytuje projektantovi za účelom projekčných a realizačných prác na stavbách. Veľmi významné sú taktiež informácie o vplyve horninového prostredia, respektíve jeho (v čase sa meniacich) vlastností na stabilizačné práce. Opakované geofyzikálne merania (gravimetrické, magnetometrické, seizmické, geoelektrické, rádiometrické a karotážne) poskytujú potrebné informácie o horninovom prostredí od okamihu uskutočnenia merania buď periodicky alebo spojito. V príspevku prezentujeme niektoré naše skúsenosti nadobudnuté počas opakovaných meraní.

***Key words**: geophysical method, monitoring, repeated measurement*

The idea of geophysical monitoring

Geophysical measurements are an integral part of engineering-geological investigation where they present a wide range of useful information about the tested geological medium and about its geotechnical qualities. Lately, repeated geophysical measurements in different time intervals have been used to judge the changes occurring in the rock massif. These measurements bear the characteristics of total monitoring. This total monitoring contains series of repeated measurements and further an integrated spectrum of linked activities including evaluation, comparison with the warning state and making a decision about taking precautions. From the range of geophysical methods and methodologies used for monitoring in full sense we may mention, for example, continuous seismoacoustic measurements in mining constructions; (which may result even in recalling of the personnel), and further, also seismic measurements in the surroundings of atomic power stations and measurements considering the protection against radioactive elements and their decay components.

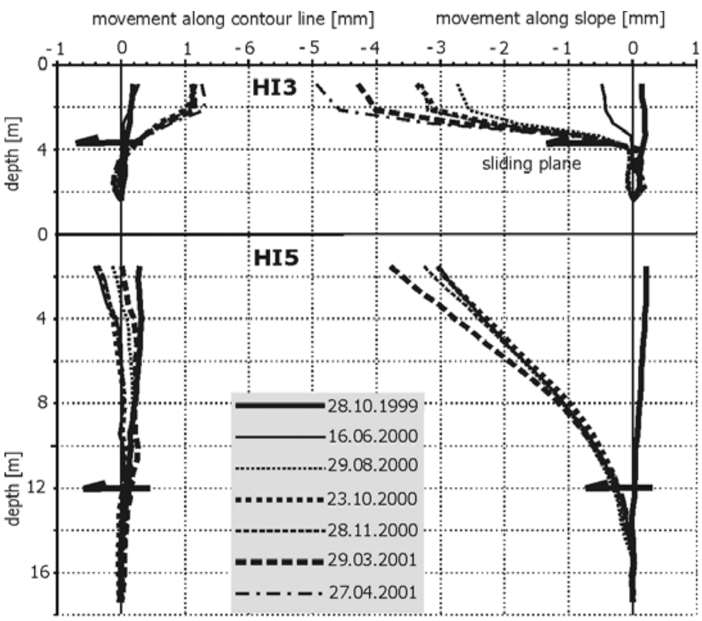

Fig. 1. Orlová-acurrate inclinometry (modified by Novosad, 2001).

As a full monitoring we may also classify measurements in dumping sites with the aid of repeated geoelectrical measurements in the system of fixed electrodes under impermeable foils. These measurements are mostly carried out from time to time followed by taking immediate action when the foil is found damaged. In practice the term monitoring is used, although not very correctly, for all periodically repeated measurements, which do not result in taking action or interference, but supply a wide range of information about the rock massif behavior in time (Bláha, 1993; Bláha and Müller, 1998a; Bláha and Müller, 1998b; Bláha and Müller, 1999; Goryainov, et al., 1983).

Some examples of repeated geophysical measurements and monitoring

In the course of inquiry into the changes in time and space, most useful seems to be the method of precise

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inclinometry (PIM) and geoacoustic method (GA) in holes mostly during the survey of slope movements. Fig. 1 shows an example from PIM measurements on a landslide in Orlová in the holes HI3 and HI5. Repeated measurements have been carried out at the intervals of approximately three months. The HI3 hole is situated on the edge of the landslide and a motion is perceptible along the sliding plane at a depth of approximately 4 meters. Separate PIM measurements show that the motion is not uniform and we may trace a slight pulsation during a careful examination of separate curves. The HI5 hole is situated in the pile wall, which serves as a maintenance element. The hole was deliberately situated in the wall to supply information about the activation of the pile, which is an active maintenance element. In the course of the first six months the activation of the pile occurred, which caused its displacement by ~ 3 millimeters (Novosad, 2001). Deformations noticed in the course of further measurements vary in the range of 1 millimeter, which are the values of measurement errors and they do not demand further consideration.

Together with accurate inclinometry, also repeated geoacoustic measurements were used. These also supply good information about slope movements. Fig. 2 shows an example of measurements in the area of slope deformation Poláky (Bláha, 1997), where geoacoustic measurements are compared with penetration with the aid of a pocket penetrometer on core samples. From the curve of average geoacoustic activity Ap it is clear that the rock massif can be divided into three storeys. Repeated geoacoustic measurements supply very good information about the development and successive deteriorations of various parts of the slope deformation. The last curve in Fig. 2 represents the middle value of geoacoustic activity during the whole course of the slope deformation monitoring and it shows relative motions of the first and second storeys of the slope deformation.

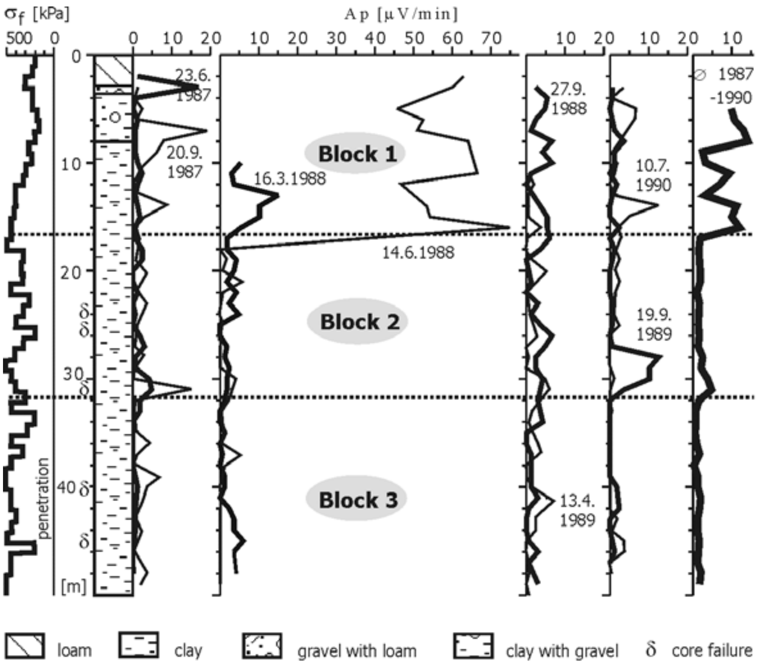

Fig. 2. Geoacoustic measurements on Poláky landslide.

The example of repeated seismic measurements giving an estimation of the rock massif state before and after non-production blasting is shown in Fig. 3 (Bláha, 1999). It shows tomography processing of seismic radiography measurement between a cross tunnel and holes in a coal mine in Ostrava-Karviná mining district. The velocity field is greatly broken before the blasting and the velocities vary to great extend, from 3.0 to 5.5 km.s^{-1}. In accordance with the course of low velocity fields, zones of higher deteriorations were determined. These were compared with the results of radioactive logging (Homola, 1997) and they correspond very well.

After the blasting, the velocity field was monitored again and the results in the form of contour lines of velocity differences before and after the blasting enable us to judge the changes that occurred in the rock massif. The velocity field shows a rather different disturbance of the rock massif than is usually assumed. The effect of the blasting

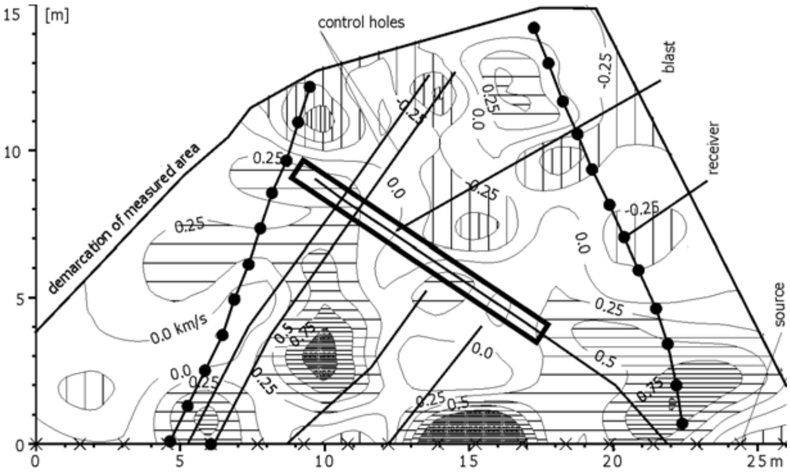

Fig. 3. Darkov – differential velocity field.

is certainly not symmetrically distributed around the "blasting" hole, but the disturbance of the rock massif is concentrated in the area between the hole where the blasting works were carried out and a cross tunnel.

The differences in velocities were locally compared to geotechnical tests (Šňupárek, et al., 1997). The areas of velocities lowered after the blasting correspond very well to the areas of increased fracture lengths per one meter of the hole. From the example it becomes apparent that while geotechnical tests enable the consideration of local changes only, velocity fields give us an area concept of the state and changes being in progress in the rock massif not only in natural conditions but also following a human interference.

Fig. 4 shows an example of control seismic measurements intended for the check of maintenance works on an earth subsidence caused by mining activities realized with classical seismic logging (Bárta, 1996a, b). The crater, which originated as a result of old mining activities, was first supported with concrete seal, which was later overlaid with a plate of armored concrete. The first seismic measurement was carried out after the drilling of the hole close to the crater. The following maintenance works consisted of injecting the site of the crater and its close surrounding. The other measurement was carried out after the injecting works. The picture shows the complex outcome of the maintenance works and proves their quality and effectiveness. The velocity anomaly at two meters depth corresponds with the position of the concrete seal and armored concrete plate. The overall rise in velocities from under the seal up to the final length of the hole is caused by the improvement of physical and mechanical properties of the rock massif following the injection works. It is possible to assume that the velocities will rise again after the consolidation of the injected massif.

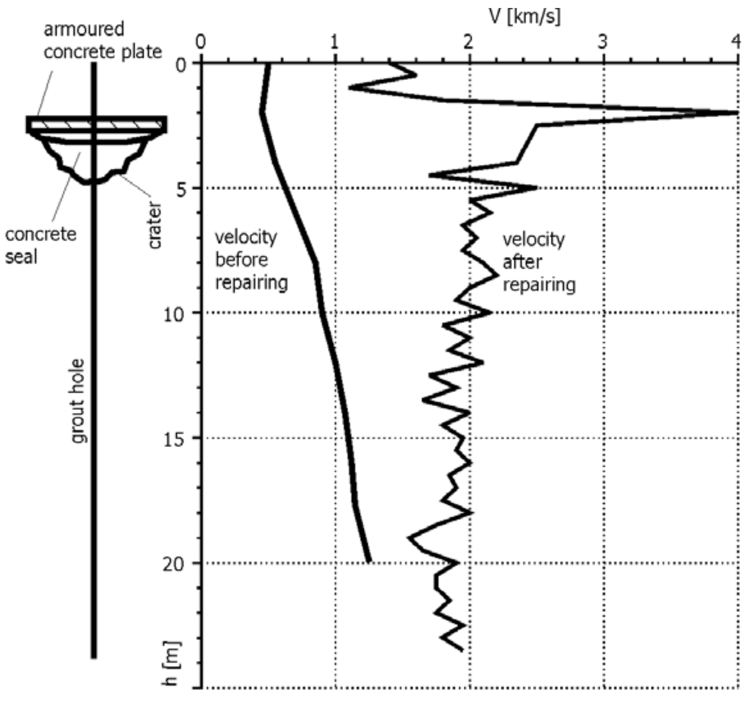

Fig. 4. Příbram – repeated velocity logging (modified by Bárta, 1996 a, b).

Repeated gravity measurements, mostly with the application of microgravimetry, were carried out in the Czech Republic partly to monitor the process of reducing of concentration over subterranean cavities (Mrlina, 1999), partly to monitor the relations between the changes in acceleration and the process of energy accumulation and release in the rock massif following underground exploitation. Lately, repeated gravity measurements have also been used in the problems of slope movement monitoring (Bláha, et al., 1998).

It proved that active slope movement is responsible for the drop in acceleration of in the main tension zone and for the drop or rise of acceleration inside the sliding mass

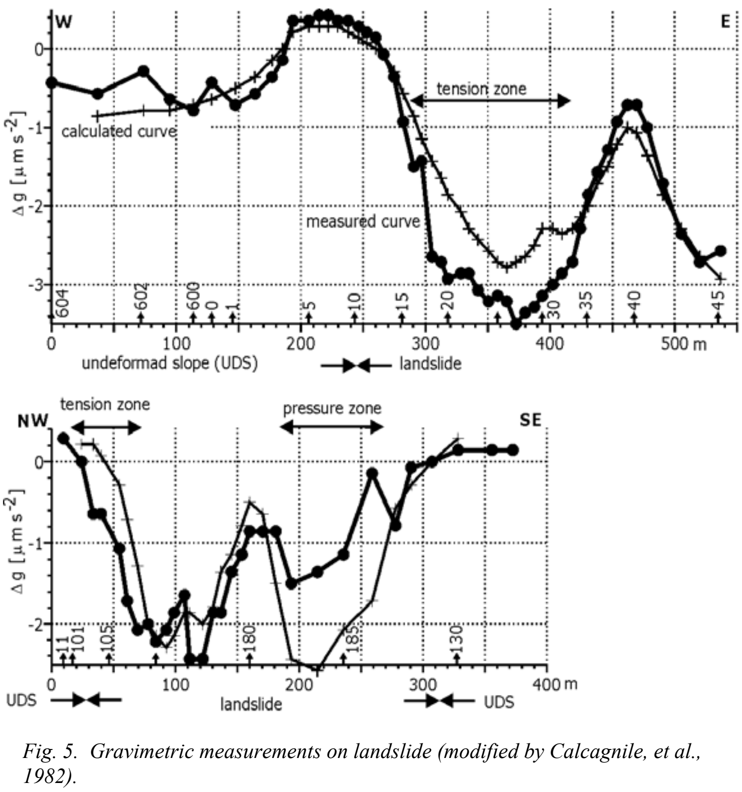

Fig. 5. Gravimetric measurements on landslide (modified by Calcagnile, et al., 1982).

depending on whether there is a concentration of tensile or compressive stress of the rock massif in the given area. These changes of gravity field on one landslide in Italy are shown in Fig. 5 (Calcagnile, et al., 1982).

Fig. 6 shows the outcomes of repeated geoelectrical resistivity measurements in limestone massif in Viola 1 gallery in the Hrhov locality (Slovak Republic), which was considered to be the site for the realization of pumped-storage power plant. Four quasihomogeneous blocks were determined leasing on geophysical and geological documentation:

Block I slope debris
Block II with wide cracks and fissures
Block III faulted with steep tension karstificated fissures
Block IV faulted with narrow tension nonkarstificated fissures (Müller, et al., 1976).

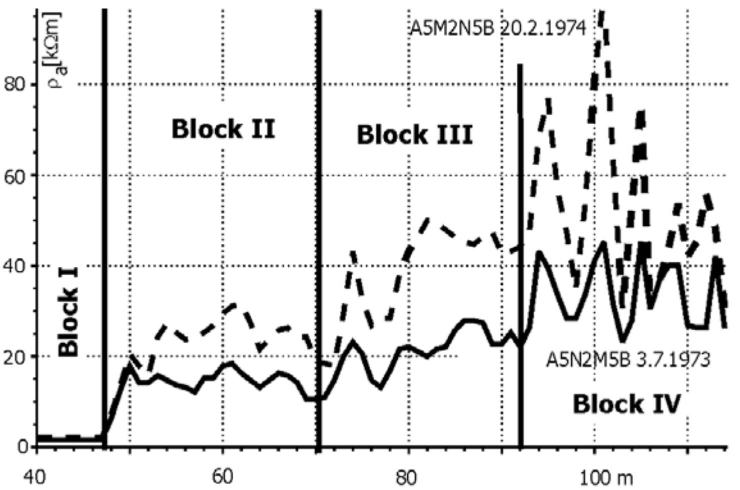

Fig. 6. Hrhov – repeated geoelectrical measurements.

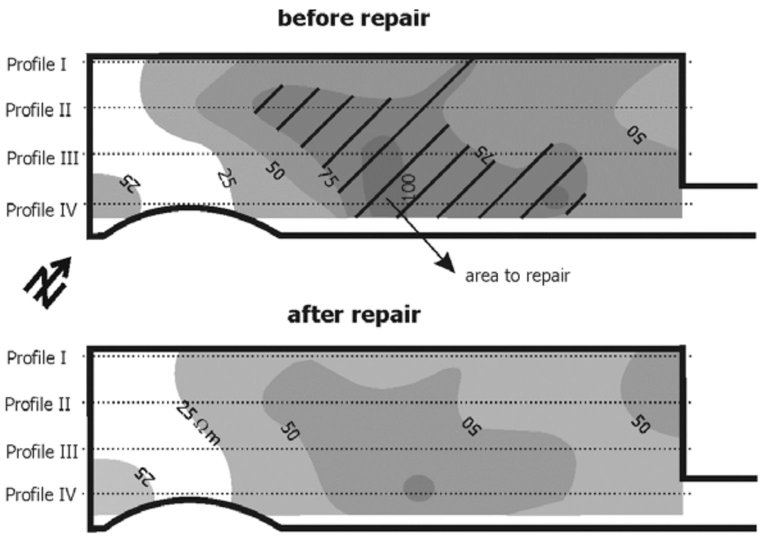

Fig. 7. Ostrava – repeated geoelectrical measurements.

Repeated measurements using the resistivity profiling method during the period of approximately eight months show that while there were no changes noticed, in Block I, a significant rise in apparent resistivity was noticed especially in Block II and Block III. These changes were explained partly by the dehydration of the rock massif and partly by the change of stress deformational processes in the limestone massif, especially due to opening of fissures.

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). Every bottom surface was measured with microresistivity profiling with double maximum depth. Experimental works proved that the mound is homogeneously solidified, when the apparent resistivity values vary from 25 to 75 ohmmetres. In cases when places of higher apparent resistivity were noticed, these were interpreted as places of higher porosity and were recommended for reconstruction. Fig. 7 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.

The reliability of this method for the judgment of construction compaction of large-scale fills can be proved by the fact that there was not a single case of uneven subsidence of any object during the period of 10 years after the construction of the chemical plant.

The evolution of slow slope movements and small deformations is commonly monitored with classical methods, like accurate inclinometry. Problems may occur in case of rapid movements and large-scale faults, as these often result in the destruction of equipment of the inclinometry hole. For similar cases we developed the method of magnetic marks, when the movement can be monitored with the aid of artificial magnetic fields. Permanent magnets – magnetic marks (Bláha, 1993) are inserted into soil medium. Insertion of magnets into the slope fault can be done in two ways. The first one is to insert the magnetic marks into the hole with drilling equipment, while the other one is to penetrate the magnet into the soils of the landslide. It is advisable to sink the magnet into a duralumin case and the second way of insertion is generally considered to be better.

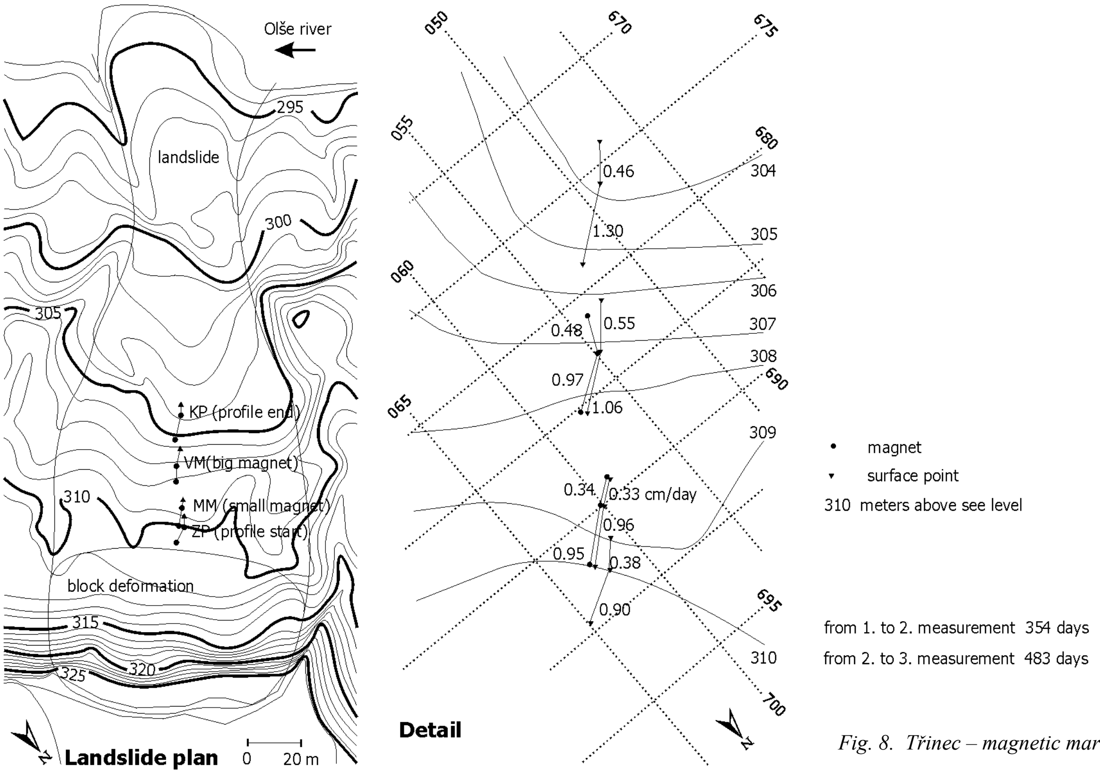

Fig. 8. Třinec – magnetic marks.

The example of magnetic marks usage comes from the Třinec landslide and is shown in Fig. 8. A small magnet was inserted into the base of very shallow surface soils and a large magnet with the magnetic moment six times higher was inserted at a depth of approximately 3 meters.

Repeated measurements of the total vector ΔT were carried out in microareas 2 ∗ 2 meters with measured interval of 0,2 meter. Measured velocities of the slope movement were 0,9 – 1,3 cm/day during the period of 1985 – 1986, 0,33 – 0,46 cm/day during the period of 1986 – 1987. Hereat, at a depth of three meters, lower velocities than on the surface were detected, even though the displacement vectors on the surface and at a depth were practically parallel.

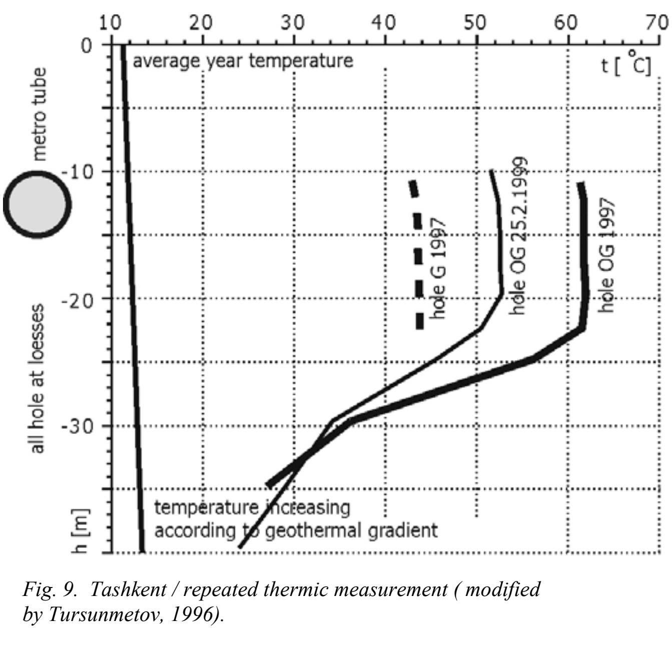

Fig. 9. Tashkent / repeated thermic measurement (modified by Tursunmetov, 1996).

The example of repeated thermal measurements comes from Uzbekistan (Tursunmetov, 1996) – Fig. 9.

The temperature of groundwater reaches up to values exceeding 60°C. The rise in temperature in the rock massif in the surrounding of an underground station was caused by hot water leakage from hot-water pipelines. From a closer look upon the temperature changes we may deduce that at depths of 50 to 60 meters the temperature reaches the normal level of thermal layout inside the rock massif. Further inspections indicated that the rise in temperature was due to hot water leakage. Having stopped the hot water outflow (autumn 1998) we noted the drop in subsoil water temperature to the level of 44°C (25th February 1999). However, the equalization of temperature to the original field will take a lot of time.

Conclusion

The geophysical works in the shape of the time repeated measurements enable to get information on the rock massif behaviour in time and its tension and strain changes on the base of geophysical field changes. These important findings essentially widen the results of the geological, engineering geological and geotechnical investigations and enable design better both the constructions and stabilization works. Geophysical measurements help to determine the warning states and to make decisions leading to increasing security. Geophysical monitoring has a substantial place in the geotechnical and mining practice in the process of many practical task solving.

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