13th FIG Symposium on Deformation Measurement and Analysis
4th IAG Symposium on Geodesy for Geotechnical and Structural Engineering

LNEC, LISBON 2008 May 12-15

MONITORING OF A LARGE SLIDE AND SLOPE RECLAMATION IN A FORMER OPEN-PIT MINE

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Abstract: A former open-pit brown coal mine located in the north of the Czech Republic is under reclamation, but one side-slope is not stable. Area of the landslide reached about 40 hectares. The slope has two parts: the upper part with inclination about 5° consists mainly of "virgin" ground not directly affected by mining. The lower part is formed by an old open-pit mine and an internal waste dump. The unstable area has been observed since 2002 with use of coupled geotechnical and geodetic monitoring. A long anchored pile wall was built in 2007 to stabilise the upper part of the area. In the lower part a huge stabilisation embankment on the internal waste dump is under construction. The existing monitoring was extended in 2007 in order to prove efficiency of remedial measures. The embankment is instrumented and monitored with respect to its construction phases. All the gathered results will be used for reverse analysis through a numeric model, which will be calibrated and updated with use of the last measured data, including oriented stress measurements in the subsoil.

1. INTRODUCTION

The area of interest is situated in a large former open pit mine Chabarovice near the river Elbe, close to the town Usti on Elbe in the North Bohemia (Czech Republic). A man-made lake is located in the centre of the old open pit mine "Barbora", which is surrounded by side slopes. The north-east slope is unstable and consists of two parts. The upper part with very small ground inclination reaches up to a natural elevation Rabenov (local name). It is unstable, but not directly affected by open cast mining. The lower part formed by mining activities is partly backfilled by an internal waste dump.

The brown coal open pit mining contributed to slope movements in the 1970's. The land slide slowed down afterwards and was re-activated due to bad weather conditions in 1993-1994. A high-voltage line as well as a drinking water pipe-line had to be relayed from the unstable area. The land-slide area is about 40 hectares large now. The whole Chabarovice open pit mine was successfully reclamated with the only exception of the unstable site Rabenov. That's why the slope has been monitored since 2002 and remediation was proposed. In 2006 remedial measures were designed at a private consulting company. The risk analysis of the remediation was carried out at our Department of Geotechnics (Zalesky, J. et al 2005). During

2007 an anchored retaining pile wall was built in the upper part of the slope. A huge stabilization embankment of 10 m maximal height in the lower part is under construction now. The monitoring system is a combination of geodetic and geotechnical methods. The instrumentation was extended in 2007 in order to observe the efficiency of the remedial measures, figure 1.

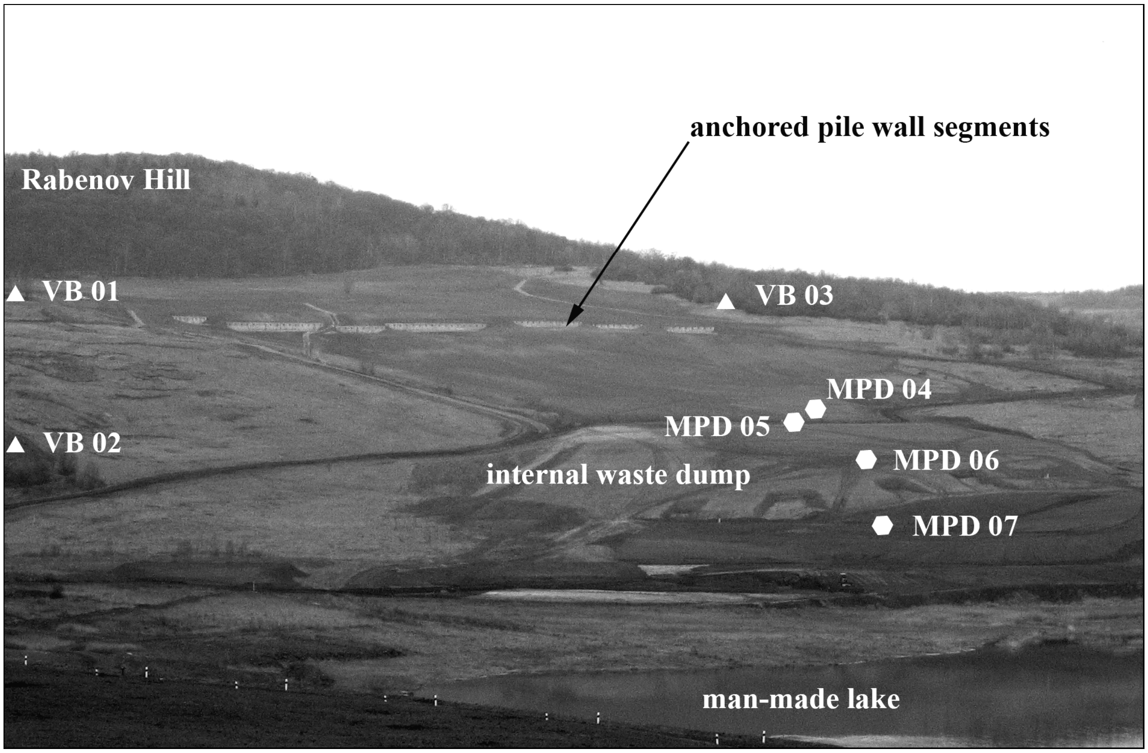

Figure 1 - View on the slope under reclamation towards the Rabenov Hill with marked reference points and deep boreholes instrumented for measurements of 3D deformations, March 2008, photo Jan Zalesky.

2. GEOLOGY OF THE RABENOV SITE

The site is located on the north-east side slope of the excavated mine. The highly exploited tertiary brown coal basin is mostly composed of clays, sedimentary / volcanic complexes, coal and quaternary overburden – loess, gravels, sands and regionally metamorphosed rocks under the tertiary fill and coal seams. Slope movements not only due to mining activities but also natural slope structure and site conditions occur often in the brown coal basin. The upper part of the Rabenov area is more or less “virgin” with several springs. The lower part of the site is formed by internal waste dump located on an overconsolidated inclined clay to clay-stone base underlying the mined coal seam, (Zalesky, J. et al 2005).

3. MONITORING OF THE UNSTABLE AREA BEFORE REMEDIATION

The slope has been instrumented and monitored since 2002 in order to observe and assess the slope movements by geodetic and geotechnical means. The most important tasks were to indicate slip surfaces, estimate the velocity of sliding and determine displacement vectors on the surface as well as in the subsoil. We established the following instrumentations:

- Local geodetic network was created in the first monitoring stage with below mentioned geotechnical instrumentation.
- Application of Swiss line-wise 3-D displacement monitoring in boreholes using high precision combined casing and sliding micrometer for establishment of reference points VB 01÷03 and application of sliding deformeter (both with modified inclinometer) for measurement of displacements in sliding mass.
- Pore water pressure monitoring using Swedish BAT system of filters and intelligent sensors installed usually in clusters by static or dynamic penetration (Zalesky, J. et al, 2006).

The network of stabilized geodetic reference points in the Rabenov area was founded in 2002 with three points VB 01 to 03 (figure 1), because an available set of reference points was located several kilometres far from the area. The points were established with use of combined casing for sliding micrometer and high accuracy inclinometer measurements in boreholes circa 24 m deep. The boreholes were located outside from the unstable area. The casings are embedded in overconsolidated clay base. We assumed the toes of the measurement boreholes as fixed points. The shifts of the top of casing were determined by comparison of a zero (initial) measurement and following episode measurements in the casing. High accuracy connection of geotechnical and geodetical measurements was provided with a special insert tool placed in high precision combined casing. Horizontal and vertical shifts of the top of the casing (insert tool) are measured and calculated with the use of geotechnical equipment and transmitted to the geodetical team. The accuracy of shifts x, y, z determination is high, at least 0,1 mm at the top of the casing (Zalesky, M. 2004). The geodetic measurements were done with total stations and since 2005 also with use of GPS (Global Positioning System).

4. REMEDIATION PROCEDURE

The remediation began in 2007. An anchored pile wall of 300 m total length was built in several segments to stabilize the upper part of the sliding slope. The slope below the wall was partly cut off. Higher inclination of the slope was important for faster precipitation water run off. The excavated soil also partly unloaded the unstable slope and was used for re-shaping of the existing undulated area, figure 2. A stabilization large stabilization embankment will be constructed up to 10 m height in the lower part of the slope. The old dewatering system of trenches did not function properly. A new drainage system was built behind the retaining wall. Besides that several dewatering trenches were excavated to ensure decrease of pore water pressure. The efficiency of the remediation should be proven with use of extended monitoring.

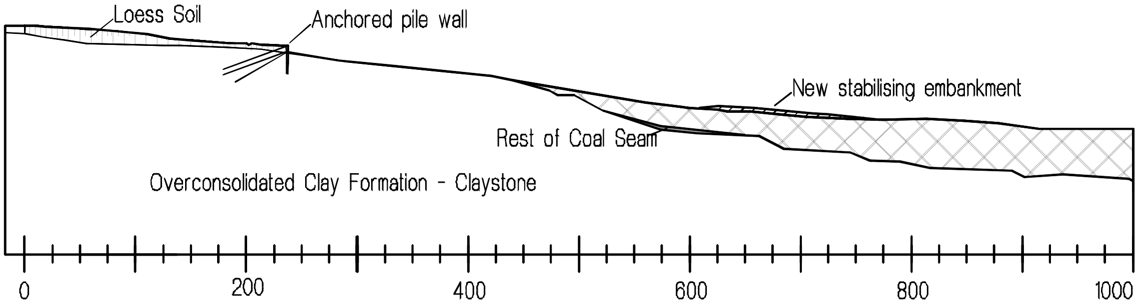

Figure 2 - Cross-section with geological profile and scheme of remedial constructions, after Zalesky, J. et al 2005.

5. EXTENSION OF MONITORING IN THE AREA UNDER RECLAMATION

Geodetic and geotechnical measurements are used to assess the efficiency of the remedial measures. Other aim is to verify the design assumptions and awaited decrease of slope movements based on measurements during the construction phases of the stabilization embankment or the retaining wall.

5.1. Geodetic measurements

A precise local triangulation network was established in cooperation with geotechnicians. It has four trigonometric points located in stable places of the area. Points VB 01, 02 and 03 are stabilized by measurement casing grouted in boreholes (see the following chapter 5.2). The total station or GPS receiver is horizonted and centred with use of a special insert tool, which is placed into the top of the borehole, when geodetical measurements are done. The point VB 04 was placed on a old large stabilized footing of former electric pole. The trigonometric network has trapezoidal shape. All perimeter sides and a diagonal connecting the points VB 01 and 03 are measured with respect to terrain configuration. Approximately uniplanar diagonal VB 01 - 03 is 419 m long. Height difference between the points VB 02 - 04 is just 65,5 m and the distance is 693 m.

A three-day episode measurement is carried out two or three times a year by three surveying teams. Nine episode measurements were carried out since 2003. We used total stations Leica TC1800 or Leica TC1700 verified according to ISO 8322 and EU ISO 17123. The first five measurement episodes were done between all points except the immeasurable foresight VB 02 - 04. The value of angular misclosures in triangles VB 01, 03, 02 and VB 01, 03, 04 ranged from –0,7 mgon to +2,7 mgon. According to the results of measurement, visibility, refraction, atmosphere vibration and illumination changes, the mean error of horizontal angle was calculated as $s_\omega = 0,7$ mgon, which represents external accuracy of measurement. This value was used for calculation of vertical angles in accuracy analysis. The vertical angular misclosures in the above mentioned triangles varies from -14,6 mm to +14,6 mm. Therefore the theoretical permitted deviation was not exceeded. Distances were measured from both points and reduced to horizontal distance. The mean error of distance measurements $s_d = 1,6$ mm complies with the technical data of the total stations and the measurement conditions.

The network was calculated in local orthogonal clockwise coordinate system in order to keep the internal accuracy. The coordinate system has origin in the point VB 01 and +X axis passes through the point VB 03. After the network spatial adjustment, the mean coordinate error of all control stations (points) did not exceed maximum values s_x = 2,3 mm, s_y = 2,0 mm, s_z = 2,5 mm. The parameters of the ellipse of errors are: a = 2,8 mm, b = 1,2 mm and rotation range is 18,3 - 44,8 gon. The results show, that the terrain surrounding the reference points is not stable, which means, that the stabilization of the reference points by use of geotechnical measurements is necessary. We confirmed this conclusion by detailed examination and comparison of vertical angles as well as horizontal distances measured in several episodes.

Parallel GPS (Global Positioning System) measurements have begun in the fourth measurement episode in order to enable the transformation of various stages of total station measurements. Our tests proved that the Trimble 5700 GPS surveying system with RTK (Real Time Kinematic) is suitable for this purpose. The GPS measurements are afterwards compared with the terrestrial measurement from the same time. We chose two trigonometric points which are year-round accessible and situated in acceptable distance up to 3 km from the observation area.

Measurements performed at a test field of ten points in the Central Bohemia show average differences δ_X = 0,02 m, δ_Y = 0,03 m, and δ_Z = 0,07 m. The accuracy of height determination is described by the mean error 35,3 mm (at count of measurements n = 55) and positional error s_{xy} = 12,7 mm.

Since the fifth measurement episode in the unstable area Rabenov only terrestrial measurements at points 01 and 03 have been carried out. The corresponding network accuracy after network adjustment is therefore about 60 % lower. Helmert 3D transformation followed by Jung's transformation, and separate 2D Helmert rigid transformation and height transformation by the gravity axis were alternatively used for more accurate coordinate transformation of the local network to the national coordinate system with use of the GPS surveying.

Surveying points located in the unstable slope were measured from two or three reference points (VB 01, 02 and/or 03) to determine the slope movements. The surveying points are made of steel bars (diameter 60 mm, length 1,25 m) installed by dynamic penetration into the soil. On the top of the bar is a thread (with a cover lid) where a 2,5 m long extension rod is mounted for measurements. The rod is equipped with a pair of Leica omnidirectional prisms which ensure point visibility in the field. The use of extension rod with two prisms enables also determination of tilt angles of the surveying point. Twenty surveying points were placed on the unstable slope the best terrain characterization. Additionally, displacements at the top of geotechnical boreholes instrumented with casing for measurements of 3D deformations are determined by geodetic means with use of an insert tool. The results of geotechnical measurements of the subsoil deformation development correspond at the surface with the movements measured by geodetic means.

The accuracy of measurements of survey point's positions as well as the tops of geotechnical boreholes is derived from analysis of polar survey accuracy with respect to surveying techniques and calculating methods. The average theoretical value of the maximum documented movement is 26 mm, with confidence coefficient of 2,5. Each episode measurement was calculated from the actual station coordinates determined from geotechnical measurements in the boreholes VB 01 - 03. The highest horizontal movements of 42 mm occurred in +Y axis direction, which is parallel to the slope line. Almost zero movements were measured in +X axis direction representing a horizontal line. Monthly vertical displacements were ranging from -11 mm (settlement) to +10 mm (heave).

Regarding the terrain configuration and the class of survey accuracy, Trimble GeoExplorer CE - GPS system was chosen as a suitable device for geological surveying of the slope. Phase measurement acquired better results in the open area compared to code measurement, where the highest coordinate accuracy was achieved at the points with worse reception. Variance of the phase measurement was 0,33 - 1,0 m whereas variance of the code measurement was 0,18 - 1,82 m. Comparison of the results without correction and with post-procedural processing shows that application of the pseudodistance correction on the basis of local reference station correction gives better results in horizontal position but worse results in vertical position. We recommend to use own reference station as long as the difference is considered as significant.

5.2. Geotechnical instrumentations and measurements

Measurements of 3D deformations are continued at the reference points VB01 to 03 of the local geodetic network. The position (x, y, and z shifts) of the reference points is determined with geotechnical measurements in high precision casing with respect to the fixed bottom of the casing.

Two piles of the anchored pile wall were instrumented with combined casing for sliding micrometer and inclinometer measurements. So we can obtain the deflection curves of the piles and observe the interaction of soil and the pile wall as well as get input data for reverse analysis. Instrumentation for pore water pressure measurements was installed behind the retaining wall to prove the function of the drainage system. Measurements of anchor forces are provided by sub-contractors of the construction company.

The deepest borehole MPD 04 located in the lower part of the slope was instrumented in 2004. The measurements indicated remoulded zone by large shear displacements in the depths from 17 to 21m, figure 3. The borehole was blocked by shear displacements in 2006. Three new boreholes MPD 05, 06 and 07 were drilled and instrumented for measurements of 3D deformations to continue with the previous observation of the slope movements, figure 4. The bottom of each borehole is fixed in the claystone base of the slope in depths from 36 to 56 m. The boreholes are situated in one down-hill profile.

New approach will be used for monitoring of deformations in the stabilization embankment and its subsoil. We want to determine the development of deformations of the embankment during all its construction phases. The measurement equipment for line-wise measurements of 3D displacements commonly used in boreholes will provide monitoring in the embankment during all its construction phases. As the height of the embankment will increase, the measurement casing will be prolonged step by step according to the construction progress.

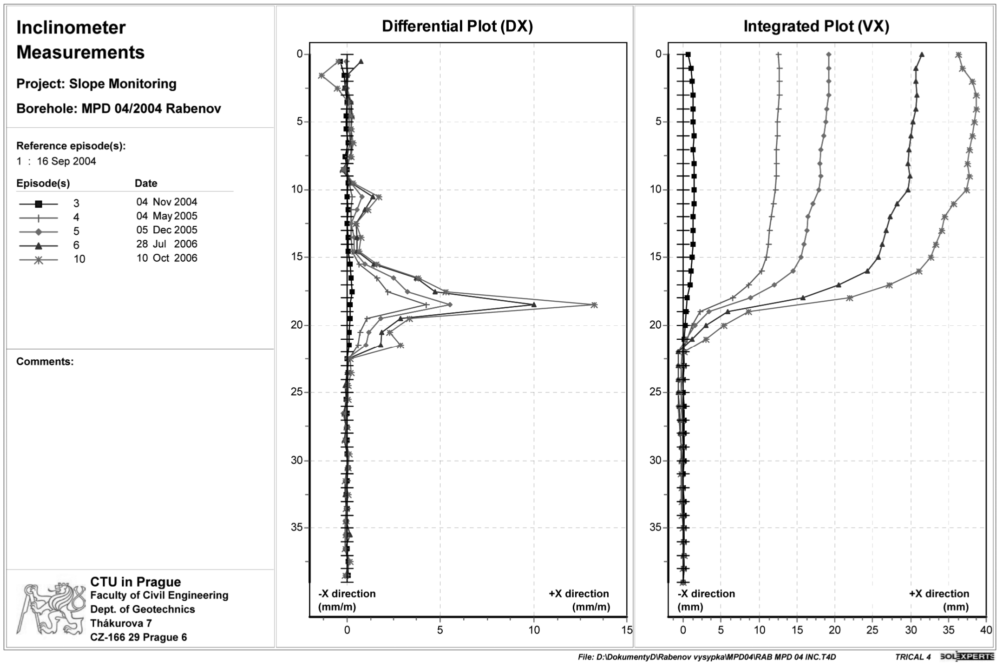

Figure 3 - Development of horizontal displacements, measured in borehole MPD 04. Direction X+ represents down-hill movements

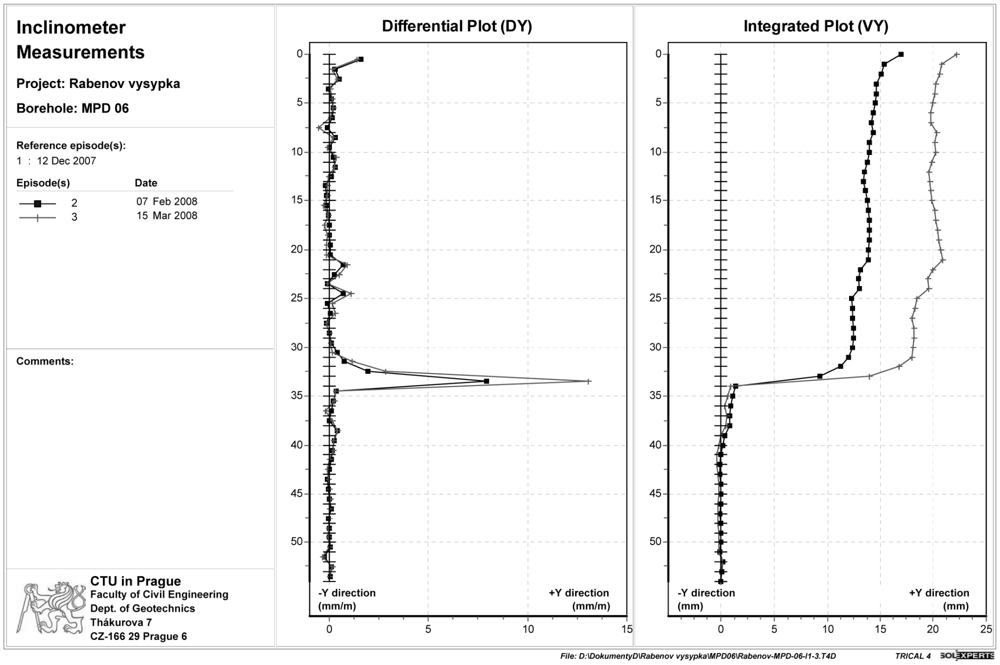

Figure 4 - Development of horizontal displacements, measured in borehole MPD 06. Direction Y+ represents down-hill movements

We applied this method successfully in a high gabion retaining wall (Zalesky, M. and Zalesky, J. 2007). The bottom part of the measurement line will be instrumented and measured as usual borehole in the subsoil of the future embankment. The reference fix point, where zero displacements are assumed will be deep enough in the overconsolidated clay or claystone base of the former coal seam. The assumptions of zero deformations at the toe (bottom point) of the borehole will be verified by a series of episode measurements.

Evaluation of measurements in a prolonged measurement line differs from the common procedure as well. Some practical examples of boreholes with measurement casing, which were shortened due to construction process (excavation, tunnelling across the measurement line) are well known (Zalesky, M. and Naterop, 2004) The interpretation of a series of measurements was done with use of special software as TRICAL (Solexperts AG, Switzerland). When borehole or a measurement line becomes shorter due to construction development, there is no problem with evaluation of the following measurement episodes. There always exists a previous episode with data to be compared with the next measurement in a shorter borehole. However, this programme does not enable evaluation of prolonged boreholes. We had to modify the procedure, because the reference (“zero”) measurement is done in several steps when the borehole is extended according to the construction of the rising embankment. The first measurement is done after the borehole into the subsoil is instrumented. Next measurement is done after the casing is extended and the next embankment stage is completed. This measurement is the second for the subsoil part of the borehole, but in the extended part it is the first (reference) measurement. The measurement line is constructed in these steps until the embankment is filled to its final height. Then the measurement line is completed. But we need to gather the very important information about development of deformations with respect to construction phases of the embankment. The sequence of instrumentation and data evaluation is illustrated in figure 5, using the example of high gabion wall.

In the most cases water initiates or increases the rate of slope movements. Several clusters of pore water pressure measurement filters were installed in both parts of the unstable slope in order to better understand the effect of water level in the subsoil. Based on our measurements, we can say that there are multiple water levels with different pore pressures ranging from hydrostatic to artesian levels.

Instrumentation for monitoring of oriented stresses is going to be installed into the stabilization embankment subsoil. The gained measurement data should be used for calibration of the numeric slope stability model.

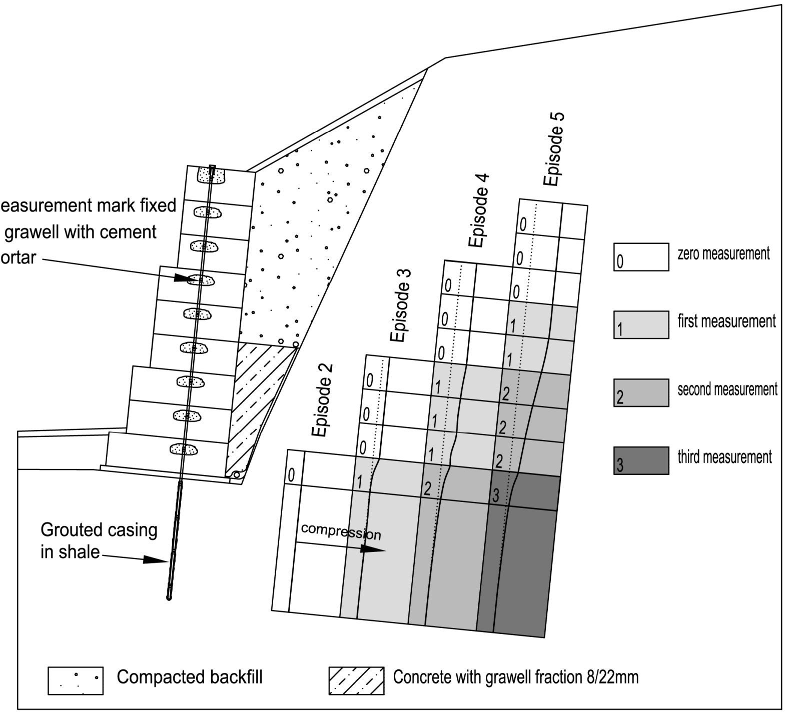

Figure 5 - Scheme of instrumentation and measurement sequence in the body of a high gabion wall, axial deformation drawn as an example, after Zalesky, M. and Zalesky, J. 2007.

6. CONCLUSIONS

Geomonitoring can be used as a powerful tool especially in solving complicated geotechnical problems, where interaction of variable factors is to be considered. The geodetic and geotechnical observation of the unstable Rabenov area in the former open-pit mine started in 2002 and helped to determine as well as describe some serious reasons of the slope movements. The results of field measurements were also used in risk analysis of remediation, which has been started in 2007.

The monitoring system was extended in order to acquire data for verification of remediation measures efficiency. The efficiency can be assessed through time dependent results of 3D subsoil deformations measurements, development of strain distribution, pore pressure as well as surface shifts geodetic observation.

The aim is to create a reliable geotechnical model for stability analysis. Geological and geotechnical investigation followed by both laboratory and field (in-situ) tests yields discrete information, which is not sufficient in areas with complicated subsoil structure and history. The model of this type of site should be calibrated as well as verified using data from a complex set of field measurements. Only then an appropriate stability analysis followed by prediction of probable development scenarios can be computed.

The continued measurements should indicate decrease of slope movement activity, later termination of sliding as the awaited result of remediation. The probability of future failure is to be examined finally.

Acknowledgments

The authors would like to thank the Czech Science Fund. The publication of this paper was sponsored by the Project Nr. 103/07/0246 “Monitoring of slope deformation and slope stability modelling in real time”. The authors greatly appreciate support of the research project MSM 6840770005 sponsored by the Czech Ministry of Education with respect to development of methodology of local network supported with geotechnical instrumentation.

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