GEODETIC WORK WITH GEOTECHNIC MONITORING ON SLIDE AREAS

Doc. Ing. Pavel Hánek, CSc.[1)], Ing. Jan Záleský, CSc.[2)], Ing. Pavel Hánek (Jr.)[3)], Ing. Ilona Janžurová [1)]
CTU in Prague, Faculty of Civil Engineering, [1)] Department of Special Geodesy, [2)] Department of Geotechnics, [3)] Department of Mathematics

1. INTRODUCTION

Opencast brown-coal-mining was strongly damped down in North Bohemia in the nineties of the 20th century. A problem of a conceptual long-time territorial revitalization which leads to a new landscaping and reflects both changed topographical terrain situation and modern society needs has arisen into foreground. Huge soil transfer and other technical intervention result in a large and longstanding instability of reshaped terrain (slant especially). This would negatively influence the reliability and durability of buildings and architectural objects. Therefores it is necessary to pay an attention to these matters.
Geotechnical and geodetic measurements or their combinations can be applied to observe the slope failures (terrain deformations, slumping, slides, ruptures). It is necessary to establish very expensive boreholes for geotechnical measurements. On that account it is not usually possible to construct the boreholes sufficiently close and then an additional net of extra geodetic marks is used to make the network of boreholes more close.
Next we will deal with a point field and measurements in the Rabenov site. The aim of the reclamation of the locality is to create a multi-purpose culturally relax region exploiting a newly arisen water reservoir as well.

2. GEOLOGY AND INSTRUMENTATION OF THE RABENOV SITE

The site is located on the north side slope of the excavated open cast mine. In general the recently highly exploited tertiary brown coal basin is composed of clays, sedimentary / volcanic complexes, coal and Quaternary overburden – loess, gravels, sands and regionally metamorphosed rocks under Tertiary fill and coal seams. Huge waste dumps made mostly of stripped clay and loess on one side and side slope of the large pits are often unstable. High frequencies of slope movements not only due to mining activities but also natural slope structure and site conditions occur often in the basin.
The upper part of the Rabenov area is more or less “virgin” ground and it is known as springs, which are indicated by an old local name “Wasserberg”. Lower part of the site is formed by an internal waste dump located on an inclined overconsolidated clay base underlying mined coal seam.
Monitoring was designed to indicate stable and / or unstable parts of the area by geodesy and radar interferometry, above ground displacements, indication of slip surfaces locations in sliding mass, determination of displacement along the slip surfaces,

identification of contractile and / or dilative behaviour by shearing, spatial mass displacement vectors and pore water pressure distribution. The most important monitoring instrumentations are:

- **Local geodetic network established 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 establishing of reference points RAB 01÷03 and or application of sliding deformeter (both with modified inclinometer) for measuring of displacements in sliding mass.**
- **Pore water pressure monitoring using Swedish BAT system of filters and intelligent sensors installed usually in clusters by static / dynamic penetration.**

Geotechnical high precision measurements provide 3-D displacement vectors of the reference points of the local geodetic network, Fig. 1, and description of time dependent development of 3-D displacements along instrumented lines in the soil mass. Results of the displacement and pore water pressure monitoring were used for development of reliable geotechnical site model for its calibration and for stability assessment of the site. The following part is focused to geodetic measurements.

3. GEODETIC SURVEY NETWORK CHARACTERIZATION

Geodetic measurements can provide information concerning global reformation of the monitored territory including the affiliation of boreholes and connection of the local network to the national coordinate systems (position S-JTSK and vertical Bpv). Classical theodolite or photogrammetric methods or some of the satellite GPS methods can be applied. The methods of laser scanning recently push themselves as well.

The application of terrestrial technologies in case of using a special signalling instrument and marking of a discrete characteristic point on terrain makes possible, in contrast to the GPS mode, to determine in addition to 3D co-ordinates of a point also the change of inclination of the marking element. We get herewith an additional parameter which predicates the processes in upper coats of the earth in the locality of interest. More precise results from the terrestrial theodolite measurements can generally be used to test the accuracy of GPS results.

A precise local survey network Rabenov was created for geodetic measurements of earth displacements. The network consists of four control stations denoted by RAB01 to RAB04. Approximate co-ordinates of the centre of the network in the system ETRS-89 are B= 50°18', L = 13°57'.

The measurements were performed by workers and students of the Department of Special Geodesy and the Department of Mathematics of the Faculty of Civil Engineering of the Czech Technical University in Prague. The points of the network were set up in cooperation with geologists and geotechnicians. Observation stations RAB01 to RAB03 are formed by inclinometric boreholes which are 24 m deep and reach the hard floor. They are equipped with the combined liners and measurements of space deformations by geotechnical methods performed by the Department of Geotechnics are possible. A special centering bar inserted into a borehole serves to assure that observation points are identical between individual stages of measurements. Point RAB04 is marked by a nail shot into the concrete foundation of a destructed power pole of a long-distance high-voltage power line.

The geodetic survey network has the form of a quadrangle where the lengths of its sides and one diagonal RAB01-RAB03 are only measured due to the configuration of terrain. The diagonal RAB01-RAB03 has length 419 m and lies along a horizontal line where the

incline of terrain is markedly changed. The difference in elevation of points RAB02 and RAB04 is about +65,5 m and the distance of the points is 693 m (see Fig. 1).
Observed points on terrain are marked by iron bars of diameter 60 mm and length 1,25 m fixed into the ground.

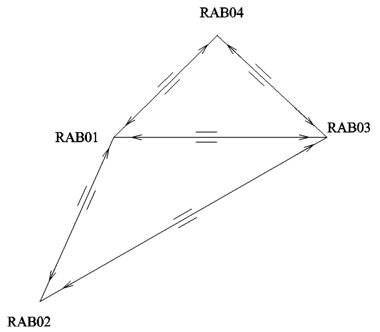

Fig. 1. The local survey network.

The top end of a bar is equipped with an internal thread sheltered by a cover. A special facilitating instrument equipped with a pair of omni-directional reflecting prisms of the Leica GeoSystems Company is screwed into the thread of the bar during the measuring. The instrument assures the direct visibility and enables measuring also during the vegetation season on the terrain overgrown with weeds and self-seeding wood species. The points to observe are also deployed outside the network on the whole territory of interest in order to characterize all the events occurring on the territory. Furthermore, additional boreholes were drilled on the territory for geotechnical measurement purposes. Their centres are determined by means of the instrument described.

4. TERRESTRIAL GEODETIC MEASUREMENTS

Two certificated total stations TC 1700 and one station TC1800 with precise prisms with target disks are used in parallel for stage terrestrial measurements. The measuring equipment and accessories are identical at each survey point during each stage of measurement; tripods with the centering plates, well-balanced and centered, are not moved during measuring. In this manner the influence of the apparatus systematic errors is minimized.
Nine stages of measurements (0 – 8) took place from autumn 2003 to the end of year 2006 (in April, July, from October to November). During the stages 0 through 4 the full extent of the survey network was spatially observed. Observation was carried out in two rounds of horizontal directions using the double sighting. Zenith angles and slant distances were measured in opposite directions implementing physical corrections and characteristics of the prisms. Work in the network was concurrently carried out by three measuring teams. The same apparatus was in turn placed on fix tripods at the points RAB02 and RAB04; there is not direct visibility between the points RAB02 and RAB04. Observed points on the terrain were sighted mostly from two survey stations with one position of the apparatus scope targeted the additional special instrument described above. Precisely known dimensions of the instrument enable, by means of the calculated coordinates of the prisms, the determination of the coordinates of a ground level point (otherwise invisible) and the change of the inclination of the marking element. A simplified measurement of the survey network was tested from the stage 5 onwards, during the years 2005-2006. This variant consists in sighting the other points only from points RAB01 and RAB03. The network measurement was twice repeated; points RAB02 and RAB04 were alternately fitted with the precise pointing or omni-directional

prisms Leica. Following analyses proved an uncertainty in determination of heights in value of approximately 3 mm using omni-directional prisms. Points on the terrain were measured in two stages.

4.1 Evaluation of the Network Surveying

Angular misclosures in the triangles RAB(01, 03, 02) and RAB(01, 03, 04) were calculated during 0 (basic) and from the 1st to 4th stages and they have values between -0,7 and +2,7 mgon. On their base, the empiric standard deviation s_ω = 0,76 mgon of the horizontal angle was calculated which expresses the outer accuracy of a measurement, i. e. with consideration of visibility, refraction, air vibration, lighting changes, microchanges of tripod position, but out of the influence of centering. This value was also used in accuracy analyses for the zenith angles. For the lengths measured counter-directionally and transformed through appropriate corrections to horizontal lengths the standard deviation s_d = 1,6 mm was calculated. The value obtained corresponds to the specifications provided by the producer and to the conditions during the measuring. The value of the altitudinal miscloser of the triangles above varies within the interval ±14,6 mm so that the theoretical maximum error of 20,5 mm was never exceeded.
The points of the local survey network were possible to append to the system S-JTSK by means of adopting some older points of a mine point field. However, it appears that the computed angles and lengths substantially differ (after implementation of above-sea-level elevation, earth curvature and transformation corrections) from the values measured directly during the basic stage. Especially in order to preserve the inner accuracy, the network is evaluated with respect to a local co-ordinate system with the origin at the point RAB01 and the axis +X passing through the point RAB03. Standard deviations of coordinates of station points and the parameters of ellipses of errors after the coordinate adjustment are stated in Tab. 1.

Table 1. Standard deviation and ellipse-errors parameters.

Point	Stand. deviations [mm]			Parameters	
	s_y	s_x	s_z	*a/b* [mm]	*α* [gon]
RAB 02	2,0	2,3	2,5	2,8/1,2	44,8
RAB 03	0,0	1,2	2,1	1,2/0,0	0,0
RAB 04	1,3	1,4	1,9	1,4/1,2	18,3

The calculated differences ΔX, ΔY, ΔZ of coordinates among individual stages (0 to 4) vary within the interval <-18; +37> mm, though they do not correspond to the accuracy of measurements during a stage. Then there is possible to enounce a suspicion that the vertices of the network are not stabile. A detail analyssis of horizontal angles in each stage also confirms such a conclusion. Further more, confrontation of horizontal lengths among the stages, when the limit distinction 5,6 mm is exceeded in most cases, bears the evidence of a displacement. Geotechnical measurements inside boreholes either do not eliminate a suspicion about instability of the points over time in a value of circa some few millimetres. However, the accuracy of station points is fully sufficient for a valid conclusion on displacement of the observed points on terrain. Geotechnical measurements by a micrometer inside boreholes also confirm the statements on displacement.

4.2 Displacement of points on terrain

The accuracy of position of the observed points on terrain and of the centres of bores is described by formulae for the standard deviation of the 3D polar method; the sighting of points is realized by means of an instrument fitted with a pair of prisms (Bubeník et al., 2006). A direction vector $\vec{v}$ of the straight line formed by the instrument and subsequently coordinates of the end point of the marking bar are calculated from the precisely known coordinates *X, Y, Z* of the upper and lower prisms. The direction vector $\vec{v}$ defines the axis of the instrument which coincides, with a certain proximity, with the axis of the bar marking a point on terrain. Then there is possible to derive some formulae for calculation of the space angle included by the axis of the marking bar and an arbitrary plane, for example the vertical plane passing through the axes *X* , *Y* (Hánek, 2007). The changes of angles point to an action of pressures in surface layers of the ground.

Determination of coordinates of the observed points were repeated twice. The limit when a slip is clearly proven is 26 mm implementing the confidence coefficient 2,5. Due to instability of the station points (sec. 4.1), calculations in each stage were performed on the base of new coordinates. Determination of space coordinates of all the points in terms of the national reference systems S-JTSK and Bpv became a necessity.

Various programmes and processes for transforming of coordinates of station points in a precise local terrestrial network and the points on terrain sighted from these points, into national systems determined by GPS procedures, were tested in the framework of the diploma theses. Finally, a CTU freeware product called Rosinanta was chosen. In case of using the simplified survey method (stages 5 to 8) the standard deviation of coordinates of the points RAB02 and RAB04, after consecutive transformation to the values of GPS mode, is increased by up to 55%.

Slide of the observed points along the *Y*- axis averages from +10 mm to +49 mm, along the *X*- axis from -7 mm to +4 mm and along the *Z*- axis from -11 mm to -36 mm. It is clear that the greatest slide occurs along the *Y*- axis whilst a slide along the *X*-axis is nearly vanishing. This can be explained by axes orientation when the +*Y*-axis nearly coincides with the terrain fall line whilst the +*X*-axis is horizontal. There can be also deduced from the obtained values that landslip became decelerated during summer but slope subsidance went on. This is probably caused by the fact that the ground and some water springs became dry.

5. GPS MEASUREMENTS

A suspicion on instability of station points was enounced on the base of analyses of measurements in the local network Rabenov. With respect to this fact it has been necessary to join the local network on the geodetic reference system or on a large regional network. There was simultaneously needed to find out a technology for a fast geological mapping of ground ruptures and terrain deformations. The GPS mode was found as an optimal variant. In co-operation with the Department of Mapping and Cartography of the Faculty of Civil Engineering two devices of the Trimble company using NAVSTAR-GPS system are employed from the 3rd stage (from the half of the year 2004), namely the surveying apparatus 5700 and the data acquisition device of geographical information systems (GIS) GeoExplorer CE. Analyses of results and evaluation of measurements are published (Bubenik et al, 2006).

5.1 Testing of used instrumentation

Testing of the Trimble 5700 equipment was carried out in various external conditions and settings on a special test survey network with dimensions 8x9 km established about 20-35 km south of the capital Prague in the year 2003. Standard deviations of the station points lying within <0,7; 35,0> mm for position and <0,7; 43,9 > mm for heights comply with the obligatory requirements for application of the GPS measurements on points fields. The differences of space co-ordinates among stages correspond to this accuracy. The antennas of the GPS receivers were always fastened on a stand centered above the observed point. The average height of the antennas above ground level was 1,5 m for the base station and 1,7 m for the mobile equipment. The fast static method was used for measurements with the Trimble 5700 device while with the GeoExplorer equipment the phase and code measurements were recorded. The setting for receiving of EGNOS corrections was at all times turned to the maximum value of 15 sec. Measurements were organised in a such manner that it was possible to use the data obtained at the base station, which was one of the Trimble 5700 devices, for post-processing of the measurements by the GeoExplorer. Measurements were carried out during six days in autumn 2003. Both sets of equipment were limited by setting of the maximum value of PDOP (Position Dilution of Precision) to 6 for the duration of the measurements.

Different settings of the parameters of Trimble 5700 before each individual session had no obvious effect to the precision of evaluation of a point. The change of the elevation angle setting from the original value of 15° down to 13° and at the same time reducing the time from 10 to 8 minutes in case of visibility of six and more satellites were shown to be favourable. Because of this change it was possible to reduce the overall time spent at some network points. It appears that a suitable setting for the interval of recording is 5 seconds at both receivers or 1 second at the receiver of the base station and 5 second at the mobile receiver. The equipment obtained excellent results even at such points where the surroundings were not ideal. Generally, it can be said that the surroundings of the antennas had no major effect to the precision of results.

Comparison of average co-ordinates obtained by GPS measurements with the co-ordinates S-JTSK from geodetic data leads one to conclude that there is a good agreement. The average difference δ_Y = 0,03 m, δ_X = 0,02 m a δ_z = 0,07 m.

On the basis of these results it can be stated that the accuracy of the Trimble 5700 equipment satisfies the requirements for creating, renewal and densification of a minor horizontal control and hence for all work where the position precision of discrete points is required to comply with the same or less strict criteria – for example derived from a level of detectability of shifts (change of position) at measurements carried out in stages.

Values obtained by the GeoExplorer were analysed in several parts. A set of calculation does not employ the corrections from the base station and the second set investigates the effect of implementation of the difference corrections. Both sets of results are presented for all measurements taken together as well as for the phase and code measurements separately. Based on observed characteristics for the accuracy of determination of co-ordinates of a net-point achieved in both sets of results we can deduce that the phase measurements provide better accuracy in the open terrain, while on the other hand the code measurements yield higher accuracy at points with worse reception.

The Trimble GeoExplorer CE equipment with EGNOS signal reception turned on, but without exploitation of the base station, i. e. without implementation of corrections, can be advantageously employed for locating the survey control points. In this manner it is also applicable to various special-purpose mappings with scales 1:5000 and less, provided that the accuracy of altitude components determination is not of primary importance.

The mean difference at a co-ordinate by comparison with the co-ordinate values given by geodetic data is δ_Y = 0,86 m, δ_X = 0,71 m a δ_Z = 0,96 m.
For evaluation with post-process corrections the data files already presented in the above paragraph were augmented with the data obtained at the base station with the Trimble 5700 equipment. Evaluation on a PC demonstrated a complete mutual compatibility of both sets of GPS equipment (produced by the same company but differing in their parameters). The mean difference at a co-ordinate in comparison with the co-ordinate values given by geodetic data is δ_Y = 0,37 m, δ_X = 0,62 m and δ_Z = 0,88 m. The use of this equipment would still primarily be only for special-purpose mappings, under the conditions stated it could also be used for mapping from the scale 1:2000. However, it would be necessary to consider whether the method remains economically viable. The comparisons of both types of evaluation show that the possibility of introduction into the calculations of the pseudo-distance giving the corrections from a local base station makes the result more precise as to position, but it makes the altitude component worse. If the distinction in position were to be considered important, then there would be an advantage of using its own base station or a VRS base station (for example in the national network CZEPOS).

5.2 Application of GPS mode in the local network rabenov

Obtaining transformation data between individual stages of measurements performed by total stations was the primary aim of GPS measurement. Tests proved that Trimble 5700 equipment is suitable for this purpose. In the course of a preliminary stage 9 trigonometric points was found where 2 of them distanced about 3 km far from the locality and accessible throughout the year were chosen and verified. An auxiliary close point is always newly determined which is afterwards used as a base station for measuring of detailed survey points on terrain.
The project is aimed at determination of displacements by the Trimble 5700 equipment employing the RTK (Real Time Kinematic) method and comparing the results with terrestrial measurements carried out at the same time. The GeoExplorer CE aparatus is suitable for geological mapping of a whole slope with respect to the properties of terrain and the size of ruptures. The precision of the equipment is sufficient for this purpose. Configuration of the network was changed in the 8th stage in autumn 2006 when the point RAB04 was cancelled and a new point RAB05 was established on a borehole 42 m deep in a made-up ground at the bottom of the slope near a nascent water reservoir.
A series of diploma theses concerning these problems was successfully worked out at the Department of Special Geodesy.
This paper was supported by the research project MSM 6840770001 „Reliability, Optimalization and Durability of Building Materials and Constructions“, the part „Geodetic Monitoring for Assuring the Reliability of Constructions“.

REFERENCES

Bubeník, F. - Hánek, P. (Jr.) - Hánek, P. - Janžurová, I.: 2006, Geodätische Messungen von Hangrutschungen (Geodetic Measurements of Slope Slides). Allgemeine Vermessungs-Nachrichten *113,* No. 1, P. 310-315.
Hánek, P. (Jr.): 2007, Sledování svahových sesuvů při obnově pohornické krajiny (Slope

Slides Monitoring at Reclamation of Former Mining Landscape), Aktuální problémy inženýrské geodézie 2007 (Topical Issues in Engineering Geodesy 2007), ČSGK (Czech Union of Surveyors and Cartographers), Brno 2007.

Záleský, J. - Bohadlová, M. - Bubeníček, M. - Záleský, M. - Hánek, P. - Bubeník, F. - Hánek, P. (Jr.): 2006, Coupled application of geotechnical and geodetical slope movement monitoring. 3RD IAG Symposium on Geodesy for Geotechnical and Structural Engineering and 12th FIG Symposium on Deformation Measurement. CD Rom, Baden 2006.