PRINCIPLES OF GROUND DEFORMATION MONITORING AT OPEN PIT MINE WITH USE OF GPS TECHNOLOGY: KWB "ADAMÓW" IN TUREK CASE STUDY

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ABSTRACT

Mining as well as natural hazards can result in land subsidence and may consequently cause disasters with threat to human life and damage to human property. Determination of deformation indices at area being under influence of open pit mine requires high precision geodetic surveys in order to allow for alerting the plausible hazards. In this paper there are presented the principles of the precise determination of the three dimensional displacements with the use of GPS technology elaborated at the University of Warmia and Mazury in Olsztyn. The presented technology has been in use for several years at the area of open pit mine "Adamów SA" in Turek. The technology of field measurements together with the construction of the control network and the observational session was presented. The emphasis was put on the post-processing strategy in precise local satellite networks. Results show that it is possible to achieve 2-3 mm accuracy of 3-D coordinates of the monitored points.

INTRODUCTION

Ground deformation monitoring studies at the area of mine exploitation are highly important due to the safety of the people and their property. Results of these research provide information about actual safety level of the structures and can prevent severe disasters. Finally, displacement results are applied for the verification of assumed displacements. Many factors have influence on selection of the appropriate method of

the deformation monitoring. The main factors are: desired accuracy, construction and size of the control network, sort of displacements (relative, absolute; one, two or three dimensional) as well as speed of changes at the monitored object. In the classic surveying, precise, geometrical levelling is commonly used in order to determine vertical displacements, as well as angle-distance measurements in control network in order to determine horizontal displacements separately. GPS technology originally developed for navigation was soon adopted for conventional geodetic surveys (Hofmann–Wellenhof et. al. 2008). Application of GPS technology enables to determine 3-D displacements with use of one surveying device, with a single measurement per point. Deformation monitoring and displacement determination with GPS technology is getting more and more common and nowadays plays crucial role in these studies (Palano et al. 2008, Baryła et al. 2009a, Baryła et al. 2009b, Moss 2000, Wang et al. 2010). Scientific community carry out many research in this topic, especially at mitigation of atmospheric biases on GPS signal, as well as development of robust estimation methods. Also surveyors exploit in practice GPS technology in order to determine vertical and horizontal displacements of monitored points. However, still the accuracy of the vertical displacements determined with levelling may be regarded as more precise. In order to achieve height accuracy from GPS observations as high as from precise levelling, it is necessary to carry out studies on mitigation of ionospheric (Zou et. al 2010) and tropospheric influence on GPS signal (Wielgosz et. al 2011). On the other hand, GPS technology has advantage over the classical surveying when large scale monitoring networks are concerned. In this case, it is expected that the accuracy will be higher and time of measurements conducting will be shorter comparing to the classical surveying (so with better cost effectiveness). Important issue in deformation measurement is correct establishment of the control network. With GPS technology it is possible to establish control (reference) points farther from the monitored area, where the probability of the influence of the object on these points will be minimalized.

In the paper, the technology of determination of 3D displacements with use of GPS technique developed initially at the Department of Satellite Geodesy and Navigation and expanded here is presented. In specific, the concept of the research, the technology of field measurements together with the construction of the control network and the observational session, as well as the obtained results with estimated precision is presented. The emphasis was put on the post-processing strategy in precise, local satellite networks. The experience was gained at the open pit mine KWB "Adamów SA" in Turek.

CHARACTERISTICS OF THE SURVEY CAMPAIGN AND CONSTRUCTION OF THE ESTABLISHED CONTROL NETWORK

Deformations of terrain surface are characterized by the deformation indices like: horizontal and vertical displacements, distortions, inclinations and curvatures (Góral et al. 2004). In order to determine these indices it is necessary to observe the state of the object at at least two epochs. Surveys are usually conducted in control network which consist of reference (control) point/points and monitored (controlled) points. Construction of the network must provide mutual control of the observations (high degree of freedom). In Figure 1 there is presented the control network with the processed independent GPS baselines established in the area of the KWB Adamów SA in Turek. In order to monitor and examine the deformations, the network consisting of 3 reference points (RRxx) and 27 controlled points (KKxx) was established.

Measurements were carried out three times over 2 years on 8–13.12.2008, 24–29.09.2009 and 20–25.09.2010. The every campaign lasted 6 days. Equipment consisted of dual-frequency Ashtech Z-Xtreme receivers with ASH701975.01A antenna – 7 items, Ashtech Z-XII, with ASH700228.D antenna – 3 items and Topcon Hiper Pro+ receivers with integrated antenna – 4 items. During every campaign observations were collected twice at every controlled point for eight hours with 10s interval and 0 degree elevation mask. The reference points (RRxx) were measured in six sessions, eight hours each.

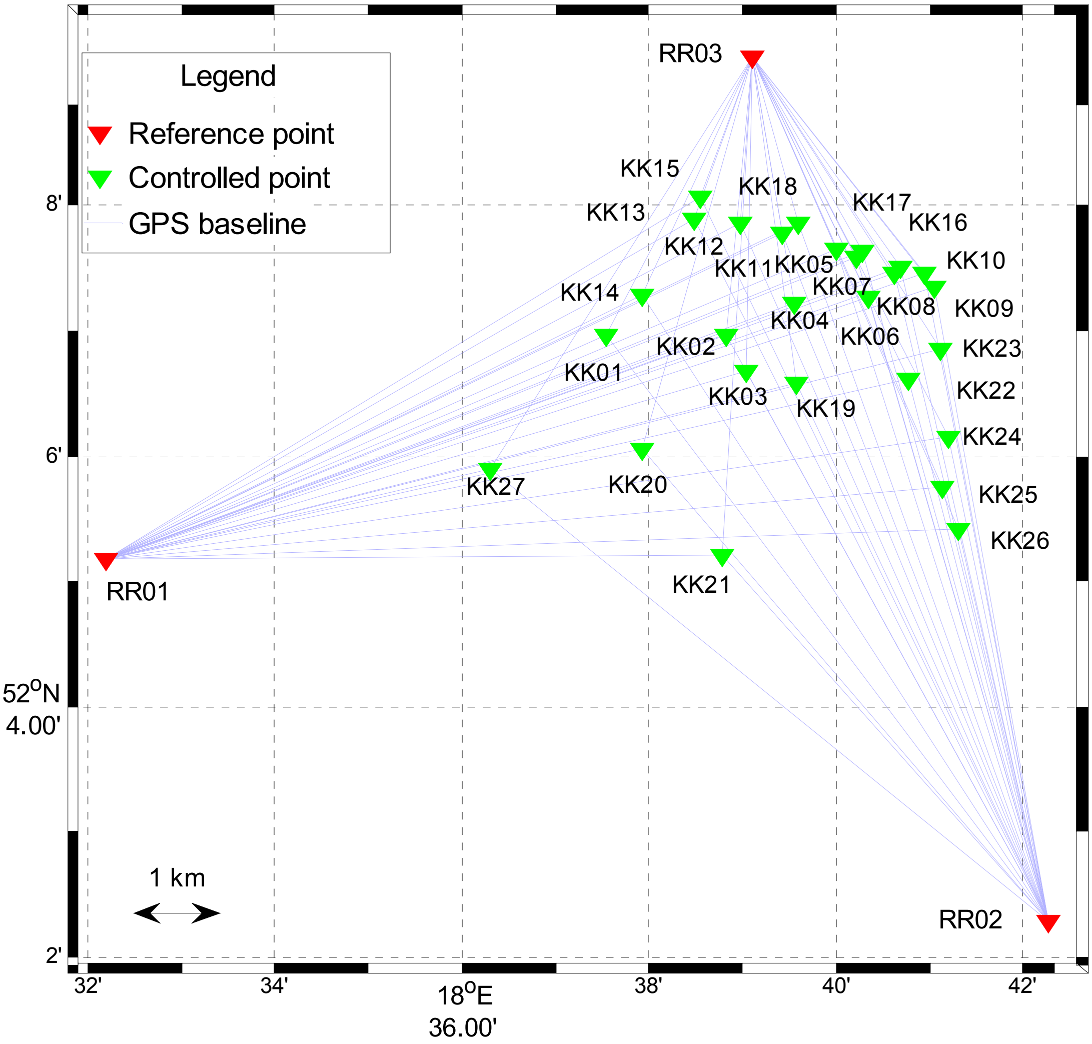

Fig. 1. Control network for deformation monitoring with GPS baselines.

In order to achieve desired accuracy level it is essential to use appropriate centering technique. At the reference points the GPS antennas were mounted on concrete pillars by means of forced centering. The antennas were removed between the sessions and mounted again at the beginning of the next session. The heights above three pillar benchmarks were precisely measured with precision of 0.1 mm and averaged. The height of the antenna over benchmarks was controlled a few times during session. At the monitoring points, the antennas were mounted using special metal poles that provided forced centering. This solution does not allow any changes of the antenna position (including its height over a point) and provide high coordinate repeatability between the observational sessions of the campaign.

Fig. 3. Antenna height measurement over one of the three benchmarks at the reference point.

Fig. 4. Collecting GPS observations at a monitored point with use of the patented pole (UWM nr 90-402/45/2007).

GPS DATA PROCESSING STRATEGIES

The collected GPS data were processed using Bernese 5.0 software (Dach et. al. 2007). At the first campaign it was necessary to use two different post-processing strategies to determine zero-epoch coordinates of reference and controlled points. First step was to

determine zero-epoch coordinates of the reference points relative to three chosen International GNSS Service (IGS) permanent stations (Lamkówko-LAMA, Józefosław-JOZE, Borowiec-BOR1) in the ITRF'2005 coordinate frame. Three independent baselines over 100 km were processed. The processing strategy assumed using wide lane & iono free (L5&L3) linear combinations of the original carrier phase and pseudorange observations. In order to obtain the highest possible precision, IGS final satellite orbits, earth rotation parameters and absolute antenna phase center variations and offsets were used (Dow et. al. 2009). In addition, a regional ionosphere model from the Centre of Orbit Determination in Europe (CODE) was used in order to remove residual ionospheric delays. The SIGMA method was applied for the ambiguity resolution. The elevation cut-off for processing was set to 5 degrees. Tropospheric delay was modeled by using a priori dry part of the Saastamoinen model + Niell mapping function with estimating non-hydrostatic (wet) delay with 1-hour interval. Additionally tropospheric gradient was estimated for every session. Final coordinated of the reference points of control network were obtained from sequential adjustment of normal equations from every of 6 sessions in ADDNEQ2 subroutine. Estimated errors of coordinates of reference points (RRxx) obtained using this strategy, were between 2.1 – 2.3 mm for every coordinate component. Obtained in this way initial coordinates of the reference points were keept unchanged during the whole period of the deformation studies.

The processing strategy inside control network differed due to the baselines length which did not exceed 15 km. The observations at each monitoring point were carried out over 2 days (every second day of the campaign, 8-hour long sessions). Thus two independent position solutions of each monitoring site were obtained. The computations were carried out using L1 carrier-phase observations with CODE ionosphere model. Only independent, manually chosen, and simultaneously observed baselines connecting reference and monitored points were processed (network solution, Fig. 1). The elevation cut-off for processing was set to 10 degrees. Tropospheric delay was modeled by application of full Saastamoinen model with Niell mapping function. It that size of network, estimation of residual ZTD (zenith tropospheric delay) does not lead to satisfactory results due to the strong correlation of ZTD between sites (Wielgosz et al. 2011). This strategy was applied to determine zero-epoch coordinates of controlled points (in first campaign) as well as actual in next two sessions.

Important issue in deformation measurement is the definition and realization of the local coordinate system. In order to determine absolute displacements it is essential to provide stable, undistorted coordinate system (Lazzarini 1977; Bryś, Przewłocki 1998; Prószyński, Kwaśniak 2006). Before every campaign, stability of the reference points should be evaluated. In the presented studies stability of the reference points were tested by using three-dimensional transformation with outliers detection from the set of the reference points.

Displacements of the controlled points were computed as the difference between the actual and zero-epoch coordinates in the local horizon coordinate system. Errors of the displacements were computed according to Gauss law using formula (on example of vertical displacements, Eq. 1):

$$m_{\Delta U_i} = \sqrt{m''^{2}_{\Delta U_i} + m'^{2}_{\Delta U_i}} \tag{1}$$

In the next step, the displacements were tested in respect of statistical significance assuming 95% confidence level (Eq. 2).

$$|\Delta U_i| \leq k \times m_{\Delta U_i} \tag{2}$$

RESULTS AND CONCLUSIONS

Table 1 presents the obtained differences of the controlled points' coordinates between the first (zero epoch) and the second and third campaings, together with the estimated coordinate accuracies (standard deviations).

Tab. 1

Coordinates' differences obtained from second and third campaign in respect to the first

No. of controlled point	Coordinate differences 1 – 2 campaign						Coordinate differences 1 – 3 campaign					
	dN [mm]	dN RMS	dE [mm]	dE RMS	dU [mm]	dU RMS	dN [mm]	dN RMS	dE [mm]	dE RMS	dU [mm]	dU RMS
KK01	-0.2	3.6	-0.5	3.6	-1.6	3.6	-6.1	3.2	4.8	3.2	0.7	3.2
KK02	0.3	3.6	1.7	3.6	-6.8	3.6	-2.7	3.2	3.6	3.2	-5.2	3.2
KK03	-1.2	3.6	1.1	3.6	-4.0	3.6	-2.2	3.2	-0.0	3.2	-1.8	3.2
KK04	-0.4	3.6	0.5	3.6	-3.1	3.6	1.0	3.2	-2.1	3.2	0.4	3.2
KK05	1.0	3.6	2.0	3.6	-0.0	3.6	1.0	3.2	1.7	3.2	1.3	3.2
KK06	0.4	3.6	-0.1	3.6	-0.7	3.6	-4.7	3.2	-4.3	3.2	0.2	3.2
KK07	1.7	3.6	0.4	3.6	-1.8	3.6	-0.4	3.2	1.9	3.2	-2.5	3.2
KK08	-1.5	3.6	0.8	3.6	-0.8	3.6	-0.9	3.2	0.1	3.2	1.1	3.2
KK09	0.4	3.6	-2.4	3.6	1.4	3.6	0.1	3.2	-3.4	3.2	4.2	3.2
KK10	-0.6	3.6	-0.0	3.6	1.8	3.6	-1.5	3.2	1.3	3.2	4.0	3.2
KK11	-0.8	3.6	1.4	3.6	0.5	3.6	0.8	3.2	0.2	3.2	2.8	3.2
KK12	-0.6	3.6	1.5	3.6	0.2	3.6	1.0	3.2	0.8	3.2	3.9	3.2
KK13	3.5	3.6	1.7	3.6	-3.0	3.6	-0.7	3.2	2.4	3.2	-1.5	3.2
KK14	-1.6	3.6	0.5	3.6	-2.4	3.6	-3.0	3.2	-0.0	3.2	2.0	3.2
KK15	0.3	3.6	1.5	3.6	-1.2	3.6	-0.4	3.2	0.7	3.2	0.6	3.2
KK16	-0.0	3.6	-0.1	3.6	0.4	3.6	-0.9	3.2	0.5	3.2	1.2	3.2
KK17	1.9	3.6	0.5	3.6	-0.9	3.6	-2.1	3.2	1.8	3.2	0.7	3.2
KK18	-0.4	3.6	1.6	3.6	-1.4	3.6	-0.4	3.2	-0.1	3.2	0.2	3.2
KK19	0.8	3.6	0.7	3.6	1.3	3.6	-2.3	3.2	1.5	3.2	-1.3	3.2
KK20	0.8	3.6	1.2	3.6	-5.0	3.6	1.4	3.2	1.6	3.2	-3.2	3.2
KK21	-0.4	3.6	1.0	3.6	0.1	3.6	4.1	3.2	-1.1	3.2	-1.3	3.2
KK22	2.1	3.6	-0.2	3.6	12.8	3.6	-1.5	3.2	2.8	3.2	9.8	3.2
KK23	0.5	3.6	-2.4	3.6	-7.4	3.6	1.5	3.2	-3.5	3.2	-6.1	3.2
KK24	-1.8	3.6	0.2	3.6	-0.8	3.6	-0.3	3.2	-1.4	3.2	1.5	3.2
KK25	0.2	3.6	2.2	3.6	-0.3	3.6	1.0	3.2	-3.9	3.2	0.1	3.2
KK26	2.3	3.6	0.5	3.6	-0.8	3.6	0.2	3.2	1.8	3.2	0.9	3.2
KK27	-0.6	3.6	-0.1	3.6	-2.6	3.6	-7.7	3.2	-0.7	3.2	3.2	3.2

After analysis of the results, it can be concluded that the most of the displacements are not statistically significant with 95% confidence level. Almost all of the horizontal displacements are smaller than 5 mm, and vertical than 10 mm. In the second campaign average displacements of controlled points were: dN = 1.0 mm, dE = 1.0 mm, dU = 2.3 mm, whereas maximal were dN = 3.5 mm (for KK13), dE = 2.4 mm (KK09, KK23), dU = 12.8 mm (KK22). After third campaign average computed displacements were dN =1.8 mm, dE = 1.8 mm, dU = 2.3 mm with maximal: dN = -7.7 mm (KK27), dE = 4.8 mm (KK01), dU = 9.8 mm (KK22). There was not observed any trend in the displacements of the monitored points. The directions and values of the displacements seem to be rather random. However after only three campaigns, it is too early to draw final conclusions about displacements at investigated object and about the influences of the open pit mine KWB Adamów on the adjacent areas. There is still strong need for continuous studies at this area.

The presented technology of the ground deformation monitoring with use of the GPS technology allows for achieving high accuracy displacements. Results show that it is possible to reach 2-3 mm accuracy in every component of the actual coordinates of monitored points, and 3-4 mm of displacements. Concerning larger areas, the GPS technology has advantage over classical surveys in speed of the collecting observations what directly translates into economic advantage.

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