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TEN YEARS OF DEFORMATION STUDY AND PROPOSED RESEARCH PROGRAM FOR THE AREA OF POLISH COPPER BASIN

Stanislaw Oszczak[1], Alojzy Wasilewski[1], Zofia Rzepecka[1]
Anna Szostak-Chrzanowski[2], Adam Chrzanowski[2]

[1]*Warmia and Mazury University in Olsztyn, Poland*
[2]*University of New Brunswick, Canada*

Abstract

On the basis of ten years experience and permanent yearly GPS deformation determination of control point network in the area of LGOM (Legnica-Glogow Copper Basin in Poland), the research program integrating classical (horizontal as well as vertical) with satellite measurements was elaborated and presented. The network established in LGOM covers the biggest mining area (800 km^2) in Poland, where anthropogeneric movements frequently occur. The movements influence safety of underground mining works and on-ground constructions. For these reasons a complex program of deformation monitoring is necessary for the terrain.

1. Introduction

The Polish Copper Basin (LGOM) is located in south-western part of Poland, between two towns: Lubin and Glogow. It covers an area of about 800 km^2. Since the very beginning of mining activity in this area (i.e. since 1960) investigations and measurements aiming at discover of factors shaping the deformation of rock mass and terrain surface processes have been carried out there. On the basis of such a long observation period two kinds of influences of the mining exploitation on the surface as well as on the rock mass there can be distinguished:

- direct influences, caused by displacement of the rocks towards the post-exploitation free space (filling it with breaking-down rock roofs),
- indirect influences, caused by water escape (draining effects) from the rock mass what results in displacements and deformations of the ground, changes in water conditions in the region, changes of surface properties, etc.

Detailed analysis of levelling measurement results from the period of 1960-71 proved that there exists, in higher degree than it was supposed, the indirect influence of the copper ore exploitation on the terrain surface caused by rock mass drainage. The vertical movements which followed the drainage process, began to extend and cover bigger area, considerably overrunning the area of the direct influences. Nowadays, all mining plants are within these influences, and even areas out of LGOM borders are also affected by the influences. The greatest subsidence, caused by direct influences, are located along Tertiary outcrops. The centers of troughs formed in these regions reach the maximum subsidence of 2000 - 2500 mm (the state for December, 1994). Subsidence caused by indirect influences alone (East part of LGOM) range between 30 to 450 mm. Interpretation of the subsidence caused by direct and indirect influences was carried mainly on the basis of precise levelling measurements of the vertical network of second class established on this terrain specially for these purposes.
Integral monitoring of terrain deformations requires information on 3-D displacements. Thus a horizontal control classical network on the area of LGOM was established in 1973 and then extended in 1975. It consists of 38 points. Also in 1975 a local system of coordinates named

"Pieszkowice" was introduced on this terrain. Mostly, points of the network were over-built with wooden triangulation towers.
But as the time went by the monitoring became more and more difficult (sometimes even impossible) because of very bad condition of the wooden towers (signals of geodetic points).
Looking for a solution of this problem it was decided that GPS technique should be applied in this region. In 1992 a team from Institute of Geodesy, Olsztyn University of Agriculture and Technology, in cooperation with Polish Copper Mining Inc. and Geodetic Office from Wroclaw, performed a GPS experiment aiming at checking the possibility of application of GPS technique to study of this region stability. The obtained results confirmed the possibility.
In this work, after short description of classical networks and measurements, a program of integration of classical (horizontal as well as vertical) with satellite measurements is presented. Also, since the movements influence safety of underground mining works and on-ground constructions, a complex program of deformation monitoring is necessary for the terrain. Some proposals of such an integrated approach to deformation studies are thus given in second part of the paper.

2. Integration of classical and satellite measurements on the terrain of LGOM

2.1. Classical vertical control network of second class

The vertical network covers terrain of area of about 400 km. Distances between bench-marks of the network amounts to 1.5-2 km. The first results of measurements from early sixties were devoted to engineering surveying of artificial objects. The next measurements performed in 1967, 1971, 1975 and further on every 2-3 years discovered that deformations resulting from mining activities took place on the terrain. After the deformations were discovered the time span between successive measurements was shortened to 1-1.5 month.

The results of detailed analysis of measurements from 1971 and later proved that there existed the indirect influence of the copper ore deposit exploitation on the terrain surface, caused by the rock mass drainage. The vertical movements which followed the drainage began to extend and cover bigger area, considerably overrunning the area of the direct influences. It caused the necessity of expanding the network. Nowadays, the levelling network covers an area of about 2300 km^2 , it consists of 1241 km of levelling polygons, 149 lines and 78 points. Measurement accuracy of the network amounts to 0.75 to 1.2 mm per 1 km.

2.2. Classical horizontal control network

The horizontal control classical network on the area of LGOM was established in 1973 and then extended in 1975. It consists of 38 points. Also in 1975 a local system of coordinates named "Pieszkowice" was introduced on this terrain. Mostly, points of the network were over-built with wooden triangulation towers. First measurement of the network was performed in 1973, and then repeated in 1975. The classical measurements were performed with accuracy given in Table 1.
Such accuracy of point position determinations made this network suitable for applications in rock mass deformation studies as well as in multi-point tying of specific engineering networks to the control points. The next classical measurements campaigns were performed in 1985 and 1988. On the basis of these observations analysis of points stability was performed. Stability of 18 points in the period of 1975-85 was proved. Similar analysis was carried out for the period of 1985-88 and then only 13 points could be regarded as stable. On the basis of all the three measuring campaigns a common reference basis of only 7 stable points was distinguished. It should be mentioned here that it was not possible to measure coordinates of all the points of the control network because of continuous destruction of the wooden triangulation towers,

constituting signals of the network points in a forestry terrain. Maintaining of the towers in good technical condition was very expensive.

Table 1. Accuracy estimation of the classical horizontal control network after adjustment

	1973	1975
Mean error of angles after adjustment m_a [cc]	3.0	2.0
Mean error of distances after adjustment m_d [mm]	5.6 mm + $0.8x10^{-9}d$	6 - 13
Mean position error m_p [mm]	53	20

2.3. Satellite network

The situation in LGOM before 1992 can then be summarised as follows:

- the terrain undergoes considerable displacements, which must be monitored,
- the monitoring had become more and more difficult (sometimes even impossible) because of very bad condition of the wooden towers (signals of geodetic points),
- the area influenced by the mining activity had grown so much that it was difficult to perform uniform classical measurements, tied to points located outside the affected region.

Looking for a solution of these problems it was decided that GPS technique should be applied in this region. In 1992 a team from Institute of Geodesy, Olsztyn University of Agriculture and Technology, in cooperation with Polish Copper Mining Inc. and Geodetic Office from Wroclaw, performed a GPS experiment aiming at checking the possibility of application of GPS technique to study of this region stability. The obtained results confirmed the possibility, but they showed the necessity of transferring the tower table observation points to the ground. The GPS technique can be successfully applied to modernisation of the horizontal control classical network of LGOM, to study points stability, to establishment of special purpose networks as well as to monitoring the terrain surface displacements in the area of mining activity.
There were two kinds of the GPS networks established: the primary and he detailed. The latter is used for current special engineering purposes. The primary network (Fig. 1) is dedicated first of all to augment studies of displacements on the terrain of LGOM.
Advantages of GPS technique in the context of LGOM problems may be listed as follows:

- resignation from signal towers over points of the network,
- increase of network accuracy,
- the accuracy becomes more uniform,
- location of reference points outside of the area of mining activity influences,
- providing one uniform reference system for all points of the the whole network,
- application of GPS points for studies of displacements of the ground,
- shortening of time needed for observations and elaboration of results,
- using GPS points to other geodetic purposes.

Particularly attractive is the accuracy of this technique (Table 2). It should be emphasized here that all the points of the network are determined with uniform accuracy in the uniform reference frame, being tied to points located far away from the affected area.
On the basis of the results given in Table 2 it is clear that the accuracy of GPS technique is sufficient for monitoring of displacements on terrain like the area of LGOM.

Table 2. Accuracies obtained from GPS measurements after adjustment - satellite system

Confidence ellipses of point positions (at 95 %) Years					
Semi – axis	1993	1994	1995	1996	1997
major [mm]	5.1 - 9.4	1.6 - 7.7	2.1 - 7.7	4.0- 12.0	2.1 - 6.8
minor [mm]	3.9 - 7.3	1.4 - 4.2	1.8- 5.4	2.5 - 8.4	1.5 - 4.7
Semi – axis	1998	1999	2000	2001	2002
major [mm]	2.0 – 5.2	2.3 – 6.1	4.1 - 10.0	4.2 - 8.1	4.6 - 9.8*
minor [mm]	1.4 – 3.5	1.6 – 4.2	3.0 – 7.0	2.8 - 5.5	3.2 – 6.7*

*) Besides one point (but belonging to the detailed network) for which the values were greater then 10 mm; it was caused with occuring obstructions.

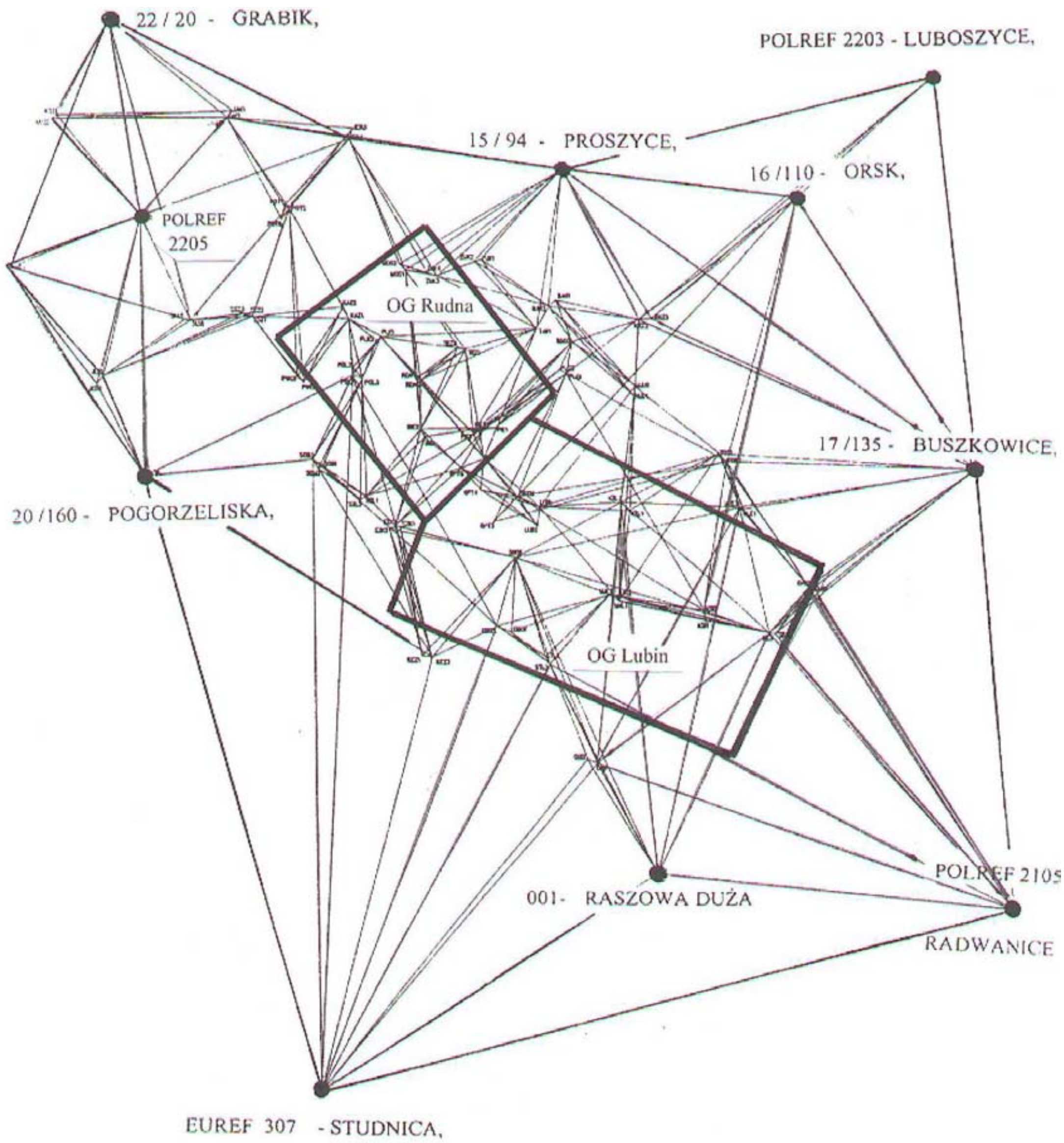

Fig. 1. Primary GPS Network

2.4. Integration of classical and satellite networks

The integration of the two networks is twofold:

a) completion of the classical horizontal network with new points, meeting requirements of GPS technique, it makes it possible to obtain updated coordinates of the old points using classical measurements (Fig. 2),

b) using GPS points to more detailed, short-distance classical measurements, in this case the GPS points provide uniform reference for all classical measurements.

The possibility of computing the updated coordinates of the points of the old classical horizontal network is of great importance, since it enables studies of the point behaviour since the very beginning of mining activity on this terrain (see example in Fig. 3).
In case of vertical measurements it seems that there is a possibility to replace the precise levelling with the GPS technique. In spite of that it is obvious that precise levelling provides better accuracy for short distances than GPS technique, but when the subsidences are of the order of ten's of centimeters it seems that about 1 cm of height determination accuracy given by GPS is sufficient here (for example: see Table 3).

Table 3. Comparison of values of subsidence obtained from GPS and precise levelling (years 1996-97) for chosen points

Point ID	H GPS [m]	H levelling [m]	Difference [m]
2272	- 0.083	-0.098	-0.015
M0S2	- 0.036	-0.026	0.010
2035	-0.015	-0.034	-0.019
2022	-0.046	-0.066	-0.020
2377	-0.084	-0.099	-0.015
0P24	-0.013	-0.053	-0.040
1524	-0.045	-0.052	-0.007
1531	- 0.047	-0.065	-0.018
0556	-0.037	-0.025	0.012
0650	-0.023	-0.055	-0.032
1920	-0.286	-0.308	-0.022
1936	-0.455	-0.447	-0.002
2398	-0.411	-0.392	0.019
2195	-0.107	-0.084	0.023

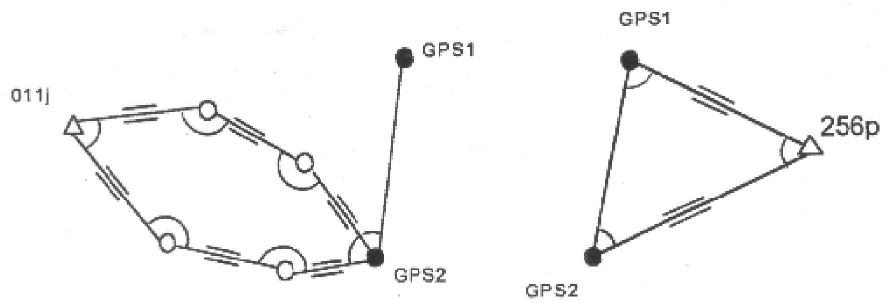

Fig. 2. Examples of tying of GPS points to points of classical horizontal network using classical measurements

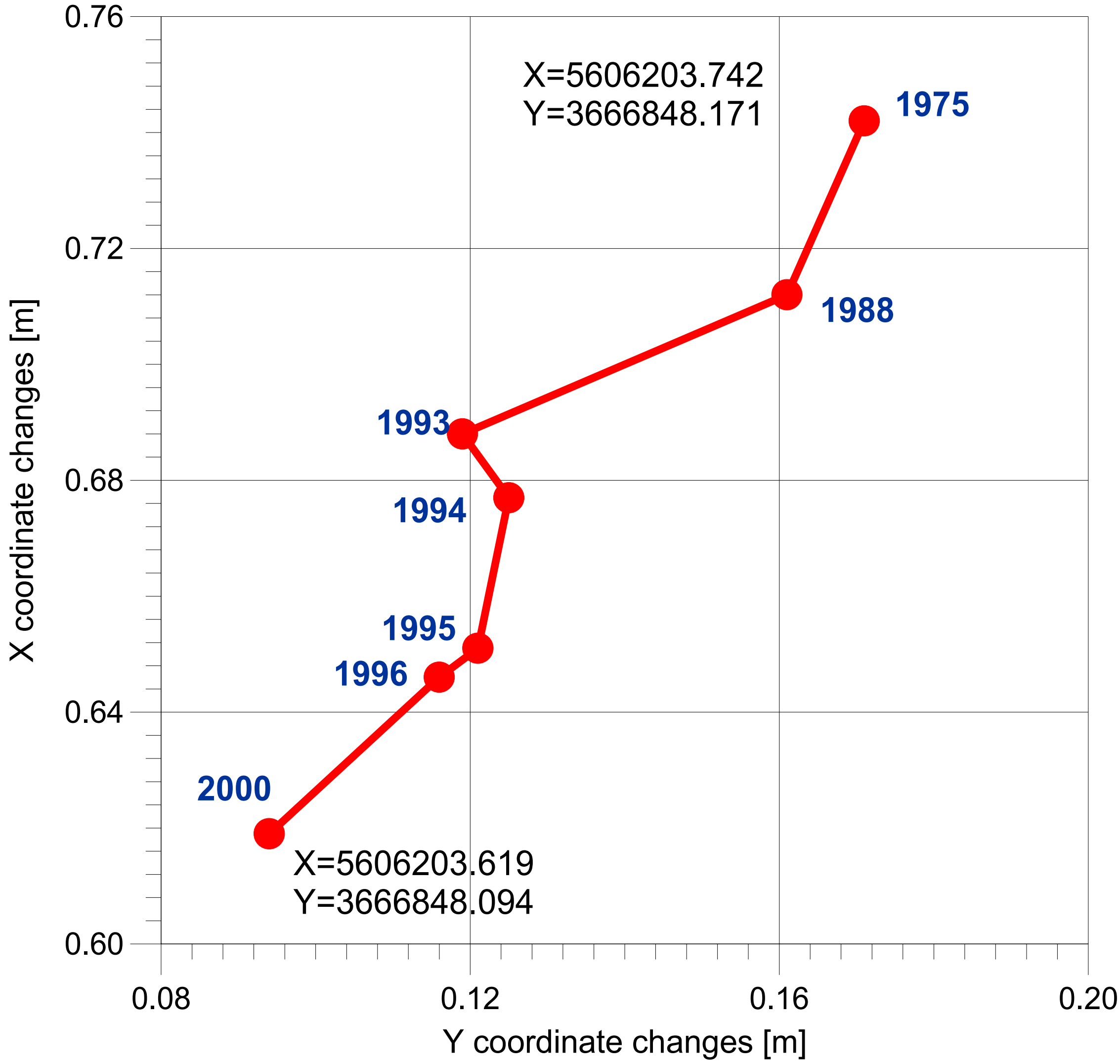

Fig. 3. Computed displacements of the point *16 Pieszkowice*

3. Complex program of deformation monitoring

Classical vertical network consists of measuring lines, with the points located along selected profile lines over mined panels. Such localization does not enable monitoring of the whole terrain, with its direct and indirect influences of mining activities. On the other hand the classical horizontal network, with its 38 points also does not provide good basis for integral terrain monitoring. Therefore, the program should be started by densifying both networks. They should be completed and connected with GPS 3-D points using both the already existing as well as newly projected. GPS technique considerably shortens the time needed for the observations to be perform ed. Observations of the whole network, even its densified version, can be completed in 3-4 days. It provides possibility of near real-time monitoring of the displacements of the terrain.

It is planned to apply the surface monitoring results in a finite element modelling of stress changes in the rock mass above the underground workings using the methodology developed at the University of New Brunswick (Chrzanowski et al., 1999; Chrzanowski et al., 2000). Thus it is hoped that having the geometrical model of terrain changes it will be possible to derive deterministic model of the stress accumulation and identify dangerous zones of possible roof failures in the excavated mining areas.

In the context of displacement monitoring, it is planned to establish 4 GPS reference stations within LGOM area. They will be equipped with Trimble GPS receivers and radio link for communiation with rover stations. One of them will be chosen as master station. Its task will be to gather data from all other reference stations, from rover receivers, to elaborate raw data, send results to authorized users and check integrity of obtained positions. Since the terrain is mostly covered with woods, the radio link will often be corrupted. For this reason it is planned to prepare some points having the coordinates in ETRF'89 system, which can be used as temporary local reference stations, they will be activated in case of need at the near area.
The system of reference stations will be based upon a proper software, like eg. HYDRA 3-D by Magellan. The softawre and hardware, properly co-working, will provide the following:

- real-time display of horizontal and vertical position and displacement for each site being monitored,
- real-time strip chart display of current and past rate of change,
- real-time strip chart display of current and past displacement,
- real-time numerical display of current azimuth and plunge,
- real-time graphical and numerical display of error estimates,
- alarming.

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