Acta Geodyn. Geomater., Vol. 9, No. 3 (167), 401–407, 2012

GABRIELA LOCALITY: STARTING GEODETIC OBSERVATIONS TO DETECT THE SURFACE MANIFESTATIONS FROM UNDERMINING

Vlastimil KAJZAR *, Hana DOLEŽALOVÁ,
Kamil SOUČEK and Lubomír STAŠ

Institute of Geonics, Academy of Sciences of the Czech Republic, v.v.i., Studentská str. 1768,
70800 Ostrava-Poruba, Czech Republic, Phone +420 596 979 111, Fax +420 596 919 452
**Corresponding author's e-mail:* kajzar@ugn.cas.cz

(*Received* March 2012*, accepted* June 2012)

ABSTRACT

A new observation network has been built to observe the surface manifestations of undermining at Gabriela locality. This locality lies in the Czech part of the Upper Silesian Coal Basin and the history of the hard coal underground exploitation is more than 150 years long here. Recently, the last coal mining panel was started to be exploited here. Its location and mining parameters are very suitable for the analysis of the actual and future surface changes caused by undermining. The fixed points of the observation network are surveyed by geodetic GNSS method. This method enables the evaluation of both vertical subsidence and horizontal displacements. Such complex evaluation of processes on the surface of the undermined territory makes it possible to understand the progress of the subsidence depression and to capture the final phase of the surface undermining changes, i.e. the phase of the subsidence decline.

KEYWORDS: GNSS, underground mining, mining subsidence, horizontal displacements

INTRODUCTION

The Ostrava and Karviná region in the Upper Silesian Coal Basin has been affected by hard coal mining for more than 200 years. While in Ostrava part of this region the exploitation was ended in the 90s, in Karviná part of the region, the underground exploitation of the hard coal deposits is still active. Thus, some areas suffered from multiple undermining through the decades. Gabriela locality is one of them. The history of the hard coal underground exploitation is more than 150 years long here.

The surface effects of mining of mineral deposits are generally given a great attention (Briggs, 1929; Whittaker et al., 1989). Their research in the Upper Silesian Coal Basin has been going on for decades (Knothe, 1953; Neset, 1984; Martinec, 2003). Further development in this field is today due to the use of new geoinformation technologies. Possibilities of using these modern surveying methods in the real conditions of the Upper Silesian Coal Basin were verified by e.g. (Perski, 2000; Kadlečík et al., 2010; Lazecký et al., 2010; Kajzar et al., 2011, etc.).

GABRIELA LOCALITY

The Gabriela locality is situated in the Darkov mining area in the Upper Silesian Coal Basin near the town Karviná in the north-eastern part of the Czech Republic (see Fig. 3). The locality occupies an area of approx. 3 km^2. The mining history goes back to the 19th century in this locality. In 1852 the first hard coal seam was discovered here at the depth of 104 m and two years later, the Gabriela mine was founded. Even though several disasters happened here, the mine's production was growing in the next decades. Later, the mine was renamed but it was productive until 2004.

Church of St. Peter of Alcantara, a surviving witness of the mining decades in the region, can be found approx. 400 m far from the Gabriela mine in the north-west direction (see Fig. 1). The church was built in 1736 and today it is the most leaning church in the Czech Republic. The building leans 6.8 degrees off the vertical as a result from undermining. From 1854, a total of 27 coal seams were exploited from under the church, with the total combined thickness of 46.8 m. As a result, the ground under the church subsided 37 meters. To survive the ground deformations from undermining, the building's foundations were reinforced as a part of a general reconstruction. Neighbouring buildings were demolished due to undermining.

The local environment can be characterized as a mining landscape with no permanent buildings. A vegetation begins to flourish on the former mine spoils deposits. The effects of undermining may cause significant changes mainly on the local roads and rail tracks, infrastructure projects, or on the stability of the sewage storage basin dams.

The rock mass consists of typical for the Upper Silesian Coal Basin upper carboniferous molasse

Fig. 1 The leaning Church of St. Peter of Alcantara and the Gabriela mine.

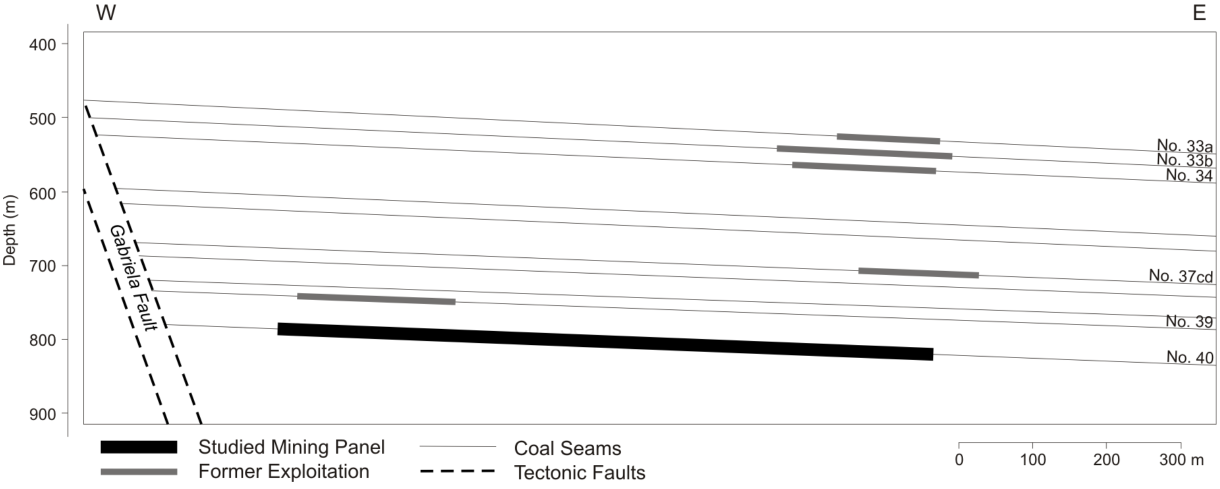

Fig. 2 Simplified geological profile along the northern edge of the studied mining panel.

sediments consisting mostly of coal-bearing siliciclastic continental deposits. The Upper Silesian Coal Basin is divided into tectonic blocks by a set of normal faults of tens to hundreds of meters amplitude (Dopita, 1997). The exploited mining panel is located east of former safety pillars of the Gabriela mine. There are two main tectonic faults in the Gabriela locality (see Fig. 3). The mining panel is located east of an important tectonic fault called “Gabriela” which intersects in the north-southward direction the above mentioned safety shaft pillar. The “Gabriela” fault has the thickness of deformation zone of several tens of meters with the amplitude of 80 m, with dip of approx. 70° to the east. Another important tectonic fault called “Ležatá” of the east west direction creates a north border of the mining block. The “Ležatá” fault has the fault amplitude of approx. 20 – 30 m and dip of 50° to the north. Two other faults are worth mentioning: "Jana" and "Eliška" bounding the area of interest on the eastern side. These tectonic faults are main geological structures, which substantially influence the stress state of the rock mass in this area (see the Fig. 3). There also occur some tectonic faults of a minor importance south of the exploited mining panel. Their total amplitude is within 5 m and the dips are up to 90° with a changing vergence to the north or south.

In the Gabriela locality, the exploitation of the last mining panel started in July 2011. This mining panel is situated beneath the previously extracted

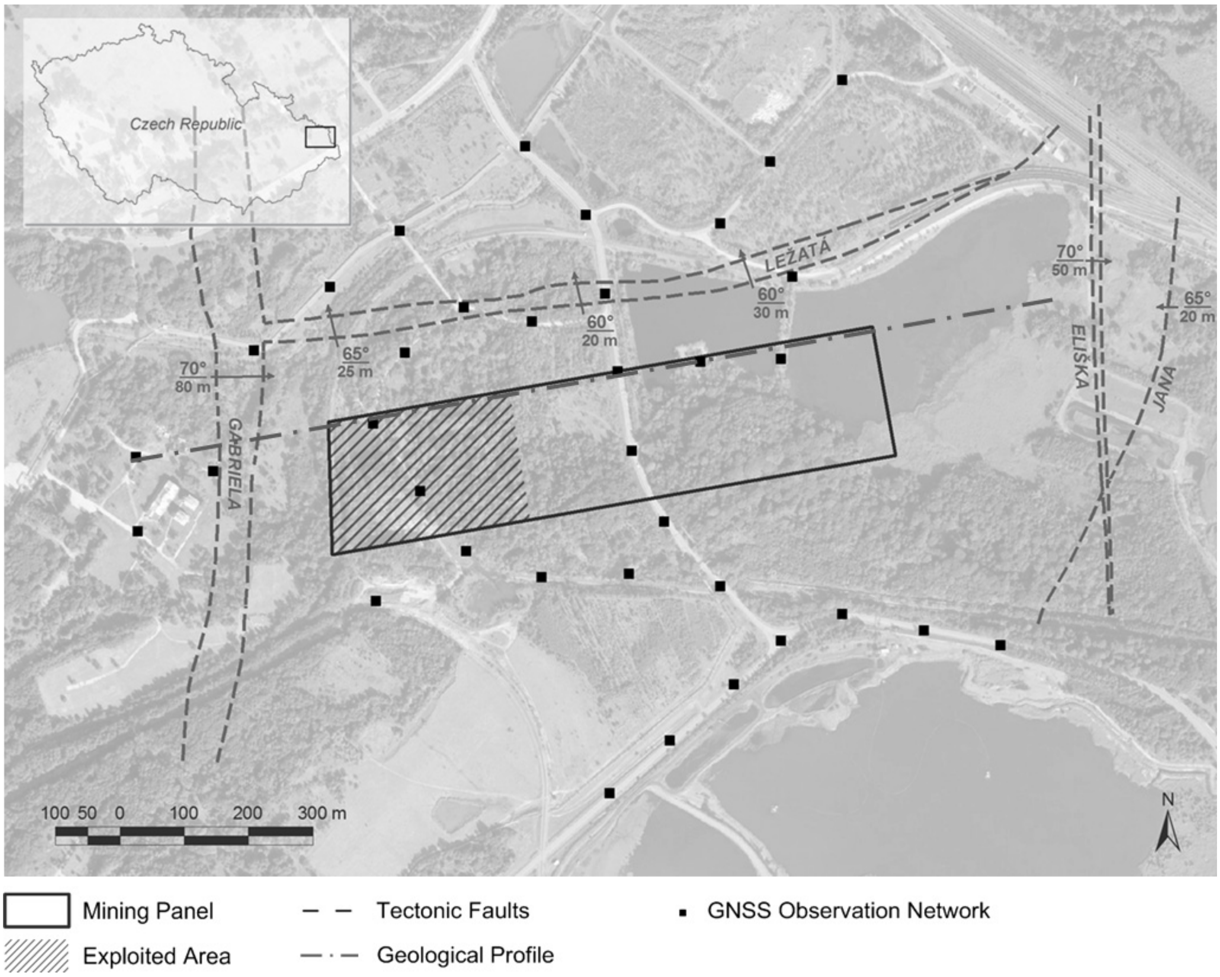

Fig. 3 Gabriela locality: GNSS observation network, tectonic faults and mining panel exploited in 2011.

mining panels and its exploited thickness is very high on local conditions. It is situated in coal seam No. 40 called "Prokop" that has a total thickness about 6 – 7 m. The depth of the coal seam Prokop varied from c. 790 m to 820 m and the seam has an average inclination of 5° to 8° in north-northeastward direction. The face length of the mining panel is 200 m and the lateral length of longwall advance is up to 900 m. The average thickness of extraction is 5.5 m and the longwall method with controlled caving was used as a mining method of this panel, proceeding from west to east. More than 20 coal seams were gradually exploited above the studied mining panel in the past. In the last decade, three coal seams No. 37cd, 37f and 39 were exploited here with the thickness varying from 2.5 to 3.5 m. Their vertical distance above the seam No. 40 was from 95 to 35 m. Seam No. 40 has been exploited since 2005 with the average thickness of 6 m. A simplified geological profile along the northern edge of the studied mining panel is presented in Figure 2 and its location is presented in Figure 3.

METHODS

The exploitation of the last mining panel in the Gabriela locality brings a unique opportunity to monitor the surface changes from undermining in rare conditions: the last mining activity in the area of a long mining history (many previously exploited mining panels, many pillars left in the rock massif), difficult geomechanical situation with tectonic faults, and huge exploited thickness of the last mining panel. It is important to point out that there occurs a hard to find opportunity to monitor not only the surface changes during the process of the exploitation but also to monitor the following phase of the subsidence desisting (surface stabilization phase) after the termination of the mining activities in this locality (this phase usually cannot be detected elsewhere in the region due to consequential active mining). That is why the scientists from the Department of geomechanics and mining research of the Institute of Geonics decided to monitor the Gabriela locality. In July 2011, the observation point network was fixed on the surface of the Gabriela locality. The points were fixed in profiles and also scattered on the surface, with

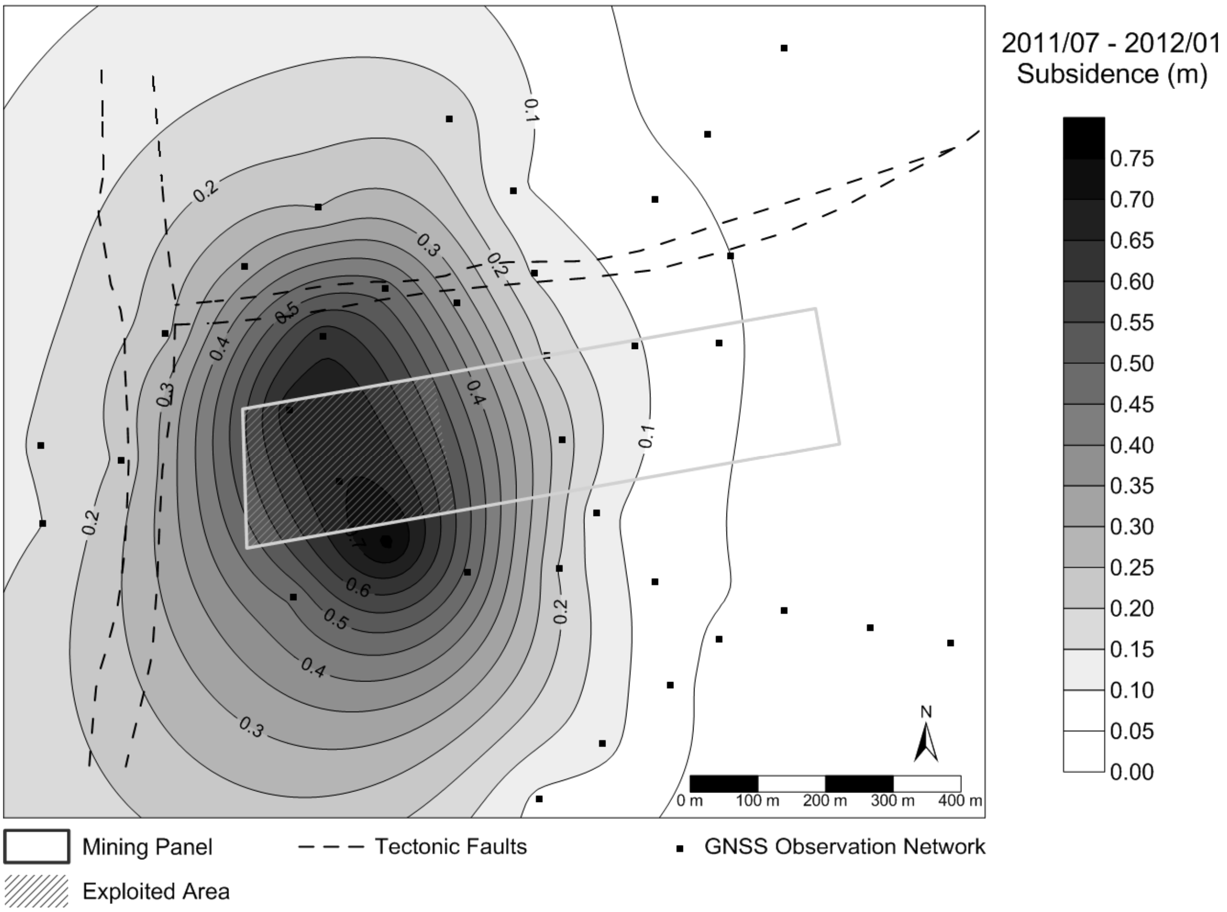

Fig. 4 Subsidence analysis from July 2011 to January 2012.

nails in the roads and metal bars in the ground (a total of 35 points; see Fig. 3). The position of individual points was also suited to the limitations of the GNSS surveying. The points are repeatedly geodetically surveyed by the GNSS method with Leica GPS System 1200 equipment which provided data on spatial positions of the points. Individual points of the observation network were surveyed by means of a rapid static method with observation period of at least 11 minutes for each point. A trigonometric point with defined coordinates in S-JTSK and in ETRS-89 system was selected for a GNSS reference station, outside the assumed reach of undermining in the distance of several kilometres from the observation network. Such surveying methodology has been tested and validated on a similar locality nearby (Louky) where an observation network was created in 2006. The results of the GNSS monitoring in locality Louky from 2006 to 2011 were published in e.g. (Doležalová et al., 2009; Doležalová et al., 2010; Kajzar et al., 2009; Staš et al., 2009). The first (fundamental) GNSS surveying of the Gabriela observation network was performed on July 7th, i.e. one week before the exploitation of the mining panel started. So far, the GNSS surveying was performed six times in Gabriela locality from July 2011 to January 2012. For the used GNSS equipment, the stated accuracy for static surveying with subsequent post-processing is in horizontal position of a point 5 mm + 0.5 ppm and in vertical position of a point 10 mm + 0.5 ppm. Since the surveyed points were only few kilometres far from the reference point, constellation geometry was controlled during the whole observation and precise ephemeris were input into post-processing, the obtained accuracy of a spatial position of surveyed points may be estimated within interval from 10 to 30 mm. Tests that were done in given locality confirmed this presumption.

The geodetic GNSS method provided space coordinates of individual points. As the surveying was repeated five times during the months after the start of the exploitation of the mining panel, the change of the point coordinates in time was analyzed in the way of both vertical and horizontal movements, i.e. subsidence and horizontal displacements.

The subsidence evaluation is the most common way of analyzing the surface effects of undermining. Generally, the vertical component of the general movement of the undermined surface point is major than the horizontal component. Although the size of the horizontal displacement from undermining is much smaller than the subsidence, its analysis together with the analysis of the horizontal displacement directions effectively complements the

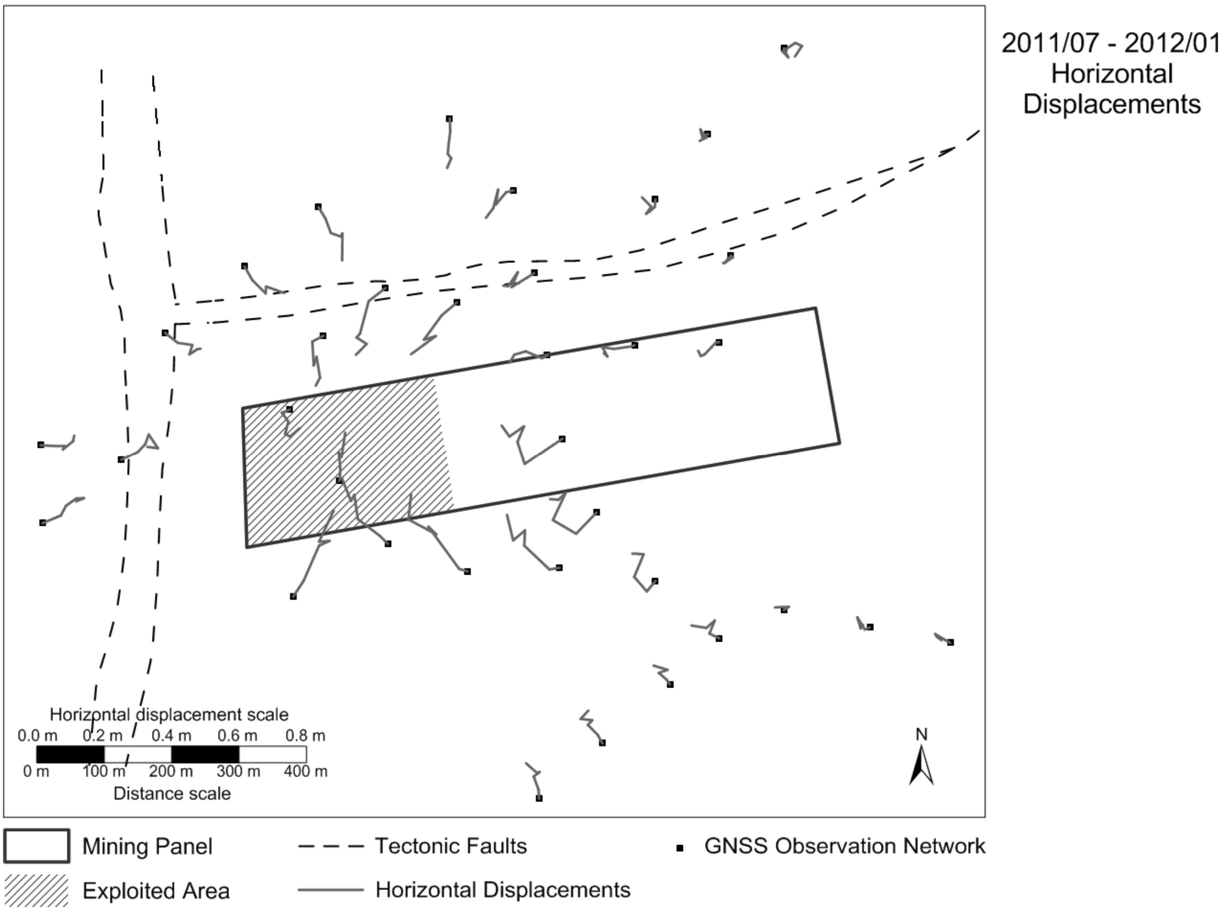

Fig. 5 Horizontal displacements analysis from July 2011 till January 2012.

evaluation of the surface changes from undermining. Such complex analysis of processes on the surface of the undermined territory makes it possible to understand the progress of the subsidence depression and to capture the final phase of the surface undermining changes, i.e. the phase of the subsidence decline.

RESULTS

Thanks to the layout of the points of the GNSS observation network it is possible to do the areal analysis of the surface subsidence. In Figure 4, there is a subsidence map of the observed locality made from GNSS data that were surveyed on fixed points of the observation network from July 2011 to January 2012. The contour map was prepared from the point data of an irregular network using the geostatistical kriging interpolation method into the regular network of points. Selection of a suitable interpolation method and input parameters settings has a significant impact on the final subsidence model. Therefore Cross Validation verification method was used to facilitate the selection of an optimal interpolation method. From the contour map, the shape of the creating subsidence depression can be seen. The current centre of the symmetric subsidence depression was created above the exploited part of the mining panel and the subsidence reached up to 0.75 m here. The shape of the subsidence isolines and the subsidence range respond standardly to the geometry of the exploited part of the mining panel.

As the point network is irregular, the subsidence values are interpolated in the areas of fixed points, while the subsidence values are extrapolated in the boundary areas of lack of fixed points. Although the model results are close to expected values, the actual subsidence values may be different in the boundary parts of the contour map as the model may suffer from bias here.

The analysis of horizontal displacements of surface points effectively complements the evaluation of movements and surface deformation processes in the undermined area (see Fig. 5). The analysis of horizontal displacements is semiautomatic with a specially designed utility. The process output is a set of curves, expressing the course of changes in the horizontal position of individual points relative to each surveying. For clarity, the resulting curves are enlarged adequately to scale view, in this case 500 times. Outputs are in ESRI Shapefile format data, now the general standard for rendering spatial data. For individual segments of curves, the individual time periods can be identified thanks to connected attributes, including the possibility to determine the actual length of the horizontal displacement.

It is yet too early to do a detailed analysis of the behaviour of the surface points according to the horizontal displacements, as the one that is presented in (Doležalová et. al., 2012). Generally speaking, the surface reacts to the extraction progress in a very short time. This is mainly due to the influence of the major rock mass failure caused by previous mining in many of the overlying strata. The fixed points of the observation network move towards the gravity centre of the subsidence depression, as expected, and the size of the horizontal displacement seems to be adequate to the position of the points.

So far, both the analysis of vertical and horizontal movements based on the GNSS surveying show on almost regular development of the subsidence depression. It seems that the impact of the tectonic faults does not exercises its influence on the progress of the surface changes as it was for example in a nearby locality Louky, where both subsidence and horizontal movements analysed from the GNSS surveying proved an important influence of a tectonic fault (Doležalová et. al 2010).

Together with the monitoring of the subsidence depression above the mining panel, seismic and geomechanical monitoring of the rock mass behavior during the extraction of coal seam Prokop is in the progress. This means:

- Monitoring of the seismicity induced due to the caving of the overlying rocks during the extraction. Geophysical methods are established tools for continuously evaluating of the development of stress–strain conditions due to an underground excavation. Thus, extensive seismic monitoring was carried out during the exploitation of the observed mining panel using a local seismic network, a regional seismic network (that of the Karvina sub-basin) and geophones in each gate-road.
- Monitoring of the in-situ stress changes, which are measured at different mining stages by Compact Conical-ended Borehole Monitoring.
- Monitoring of the effects of the destress rock blasting used to influence the properties of the rock massif. The main goal of the destress rock blasting was to weaken the strength/massiveness of the overlying competent rock strata before the underground mining began (improving the ability of the overlying rocks caving). The release of local stress concentrations due to the blasting is estimated with the help of seismic effect, which is calculated for every stage of the adopted destress rock blasting. The seismic effect of destress rock blasting is expressed as a ratio of two parameters, E_{Seis} and E_{VT}, where E_{Seis} is the seismic energy released by the rock mass during blasting and E_{VT} is the energy of a particular detonated charge.

In the next period, after the end of the exploitation, the space-time correlations will be carried out of the subsidence depression progress and the results of seismic and geomechanical in situ monitoring. This monitoring is carried out during the extraction of the observed mining panel and it gives information about the behavior of rock massif, primarily information on caving of both higher and immediate overburden.

CONCLUSIONS

The analysis of the performed GNSS surveying in the Gabriela locality show on these conclusions:

- The subsidence depression is progressing as expected.
- The current centre of the subsidence depression was created above the exploited part of the mining panel.
- So far, the subsidence reached 0.75 m in the centre of the subsidence depression.
- The analysis of the horizontal displacements shows that the fixed points of the observation network move towards the gravity centre of the subsidence depression, as expected.
- The impact of the tectonic fault can not be stated so far.
- Further analysis should follow both on the behaviour of the surface and the rock massif based on in situ surveying and measurements.

ACKNOWLEDGEMENT

This paper has been prepared in connection with project ICT CZ.1.05/2.1.00/03.0082 (Institute of clean technologies for mining and utilization of raw materials for energy use) supported by Europe Union and from the means of state budget by the Ministry of Education, Youth and Sports and it was also supported by the European Regional Development Fund in the IT4Innovations Centre of Excellence project (CZ.1.05/1.1.00/02.0070) and by the project SPOMECH - Creating a multidisciplinary R&D team for reliable solution of mechanical problems, reg. no. CZ.1.07/2.3.00/20.0070 within Operational Programme 'Education for competitiveness' funded by Structural Funds of the European Union and state budget of the Czech Republic.

REFERENCES

Briggs, H.: 1929, Mining Subsidence. London: Arnold and Co.

Doležalová, H., Kajzar, V., Souček, K. and Staš, L.: 2009, Evaluation of mining subsidence using GPS data. Acta Geodyn. Geomater., 6, No. 3 (155), 359–367.

Doležalová, H., Kajzar, V., Souček, K. and Staš, L.: 2010, Evaluation of vertical and horizontal movements in the subsidence depression near Karviná. Acta Geodyn. Geomater., 7, No. 3 (159), 355–361.

Doležalová, H., Kajzar, V., Souček, K. and Staš, L.: 2012, Analysis of surface movements from undermining in time. Acta Geodyn. Geomater., 9, No. 3 (167), 389–400.

Dopita, M. et al.: 1997, Geology of the Czech part of Upper Silesian Basin. Praha, MŽP ČR, 278 pp, (in Czech).

Kadlečík, P., Schenk, V., Seidlová, Z. and Schenková, Z.: 2010, Analysis of vertical movements detected by radar interferometry in urban areas. Acta Geodyn. Geomater., 7, No. 3 (159), 371–380.

Kajzar, V., Doležalová, H., Staš, L. and Souček, K.: 2009, Analysis of horizontal movements accompanying development of subsidence depression in non-trivial geomechanical conditions. SGEM 2009. International Multidisciplinary Scientific GeoConference (9.) - Modern Management of Mine Producing, Geology and Environmental Protection. Conference Proceedings. Sofia: SGEM, 2009, 735–739.

Kajzar, V., Doležalová, H., Souček, K. and Staš, L.: 2011, Aerial Photogrammetry observation of the subsidence depression near Karviná. Acta Geodyn. Geomater., 8, No. 3 (163), 309–317.

Knothe, S.: 1953, Profile equation of final subsidence depression, Archives of Mining Sciences I (1953), 1, (in Polish).

Lazecký, M., Jiránková, E. and Böhmová, D.: 2010, Usage of InSAR techniques to detect and monitor terrain subsidence due to mining activities. GeoScience Engineering, 2010, 4, 32–49.

Martinec, P. et al.: 2003, Maps of influence of reduction of deep hard coal mining in the Czech part of the Upper Silesian coal basin on the surface and the environment. Documenta Geonica. Praha: Milan Čermák Publishers. Neset, K.: 1984, Effects of undermining. SNTL Praha 1984, (in Czech).

Perski, Z.: 2000, The Interpretation of ERS-1 and ERS-2 InSAR data for the mining subsidence monitoring in Upper Silesian Coal Basin. International Archives of Photogrametry and Remote Sensing. Amsterdam: ISPRS.

Staš, L. et al.: 2009, GPS monitoring of subsidence depression progress on undermined area. Nowoczesne metody eksploatacji węgla i skał zwięzłych. Kraków: AGH, 99–106.

Whittaker, B.N. and Reddish, D.J.: 1989, Subsidence: Occurrence, prediction and control (Developments in Geotechnical Engineering). Amsterdam: Elsevier Science Publishers B. V.