ZESZYTY NAUKOWE POLITECHNIKI ŚLĄSKIEJ 2006
Seria: GÓRNICTWO z. 273 Nr kol. 1736

Hana DOLEŽALOVÁ, Karel MÜLLER
Institute of Geonics AS CR, Ostrava, Czech Republic
Pavel BLÁHA
Geotest Brno, a.s., Ostrava, Czech Republic

ANALYSIS OF GEODETIC SURVEYING ON THE MARGIN OF SUBSIDENCE DEPRESSION

Summary. A long-term repeated levelling on the margin of subsidence depression has pointed at repetitive upheavals and falls of support levelling points in interval of several centimetres with frequency of about 2 years. There are analysed possible causes of these height changes.

ANALIZA POMIARÓW GEODETYCZNYCH NA SKRAJU KOTLINY OBNIŻENIOWEJ

Streszczenie. Długotrwałe pomiary niwelacyjne na skraju kotliny obniżeniowej udowodniły ponowne podniesienia i obniżenia podstawowych punktów w granicach kilku centymetrów z periodycznością ok. 2 łat. W artykule jest podana analiza możliwych powodów tych zmian wysokości.

1. Preface

On the basis of ten-year repeated levelling on the margin of creating subsidence depression there was the fluctuation of height of the support levelling point observed, that several times surpasses the accuracy of levelling surveying. There are several-centimetre falls and upheavals in interval of about 2 years and though there are only preliminary results now, it seems that these changes are contingent on progressive stress-deformational changes in the surface layer on the margin of subsidence depression.

Due to underground mining there happen some physical-mechanical changes in the rock massif. The new failures may also lead to some influences of the surface where the subsidence depression starts to form due to movements and deformations.

Important factor in the question of mining influences on surface is the determination of range of these influences, i.e. the determination of margins of the subsidence depression. The subsidence depression is developing with advancing stratum forefront, but also after direct ending of mining its influences go on fading. Real margin of the subsidence depression, i.e. the line between area affected by underground mining and non-affected area, can be found out from practical field measurements. It is possible to use methods geodetic and geophysical for these measurements.

2. Levelling

Geodetic surveying for the determination of the margins of subsidence depression usually means the repeated levelling surveying in the areas of supposed margins and then the juxtaposition of measured points′ heights in a definite period.

Most frequent is geometric levelling from centre, which is based on principle of realization of horizontal level with levelling instrument. The principle of geometric levelling from centre is perceptible from picture (fig. 1): setup is formed by level instrument in the middle between two levelling-rods. On the levelling-rods we read the rods′ divisions that the line of sight of the level instrument cuts on them. First we read the backward reading l^A at the rod on point A and than the forward reading l^B at rod on point B. The height difference V_{AB} is then the difference of both rods′ divisions $V_{AB} = l^A - l^B$ and the unknown altitude of point B we count from known altitude of point A: $V_B = V_A + V_{AB} = V_A + l^A - l^B$.

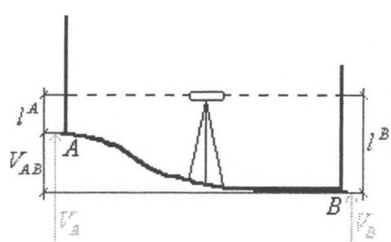

Fig. 1. Geometric levelling from centre – one setup
Rys. 1. Geometryczna niwelacja ze środka – jeden zestaw

If distance between levelling points *A, B* is too large and one setup wouldn't be enough, we put in several setups that form a levelling run of series levelling then. Height difference between two distant points is then sum of single height differences $V_{AB} = V_{A1} + V_{12} + ... + V_{n-1,n} + V_{n,B} = (l_A^z - l_1^p) + (l_1^z - l_2^p) + ... + (l_{n-1}^z - l_n^p) + (l_n^z - l_B^p)$, i.e. $V_{AB} = [l^z]_A^n - [l^p]_1^B$ (sum of backsight minus sum of foresight). Height of point *B* is then $V_B = V_A + V_{AB}$.

In the common practice the accuracy grade of technical levelling is the most frequent method of geometric levelling. TL – technical levelling is according to its accuracy double: TL with normal accuracy and TL with increased accuracy. There are longer sight distances allowed (as far as 120 m), setups can be halved by stepping, wooden four-metre folding levelling-rods can be used. Maximum permissible deviation between given and measured height difference is $d_{max} = 40\sqrt{R}$, or $d_{max} = 20\sqrt{R}$ for increased accuracy, *R* is the length of levelling run in kilometres, d_{max} is then in millimetres.

To get more accurate results from levelling the precise geometric levelling is used. PL – precise levelling run must be a double-run (measured forth and back), maximum sight distance is 50 meters, invar three-metre non-folding levelling-rods must be used. Maximum misclosure tolerance (maximum permissible deviation between height differences measured forth and back) is ${}^1d_{max} = 5\sqrt{R}$ for a levelling section and ${}^1d_{max} = 5\sqrt[3]{L^2}$ for a levelling run. Maximum permissible deviation between given and measured height difference is ${}^2d_{max} = 2 + 5\sqrt{R}$ for a levelling section and ${}^2d_{max} = 2 + 5\sqrt[3]{L^2}$ for a levelling run, *R* is the length of levelling section in kilometres and *L* is the length of levelling run in kilometres, d_{max} is then in millimetres.

The accuracy of a double levelling run is characterised by its standard kilometre error (it is a standard unit error per 1 kilometre of levelled length) $m_0 = \pm\frac{1}{2}\sqrt{\frac{1}{n}\sum\frac{d^2}{R}}$, where *n* is number of sections in the run, *d* is section misclosure in millimetres, *R* is length of respective levelling section in kilometres. The accuracy of levelled height difference is then given by the accuracy of levelling method (standard kilometre error m_0) and the length of levelling run *L*: $m_V = \pm m_0\sqrt{L}$. There are given maximum permissible standard kilometre errors for individual types of levelling: $m_{0,max} = 1{,}00 + \frac{1{,}77}{\sqrt{n}}$ for precise levelling and $m_{o,max} = 10$ mm for technical levelling, where n is number of sections in the run. Standard kilometre error of the levelled run must be less than permissible error: $m_0 \leq m_{0,\max}$ [6].

3. Locality Ujala

Locality Ujala lies near the town of Doubrava in North Moravian part of the Czech Republic (fig. 2). On the slopes of this locality there were some slope deformations detected, and their monitoring was called upon the firm Geotest Brno, a.s. Owing to a possibility of approaching of mining influences arose the need to find out, whether some landslides have a relation to a developing subsidence depression, especially because the levelling done on landslides was joined to support points, whose height stability was needed to be known. Monitoring has detected changes in heights of these surface points, which led to an increased attention and a repeated observation of height state of the points in this area.

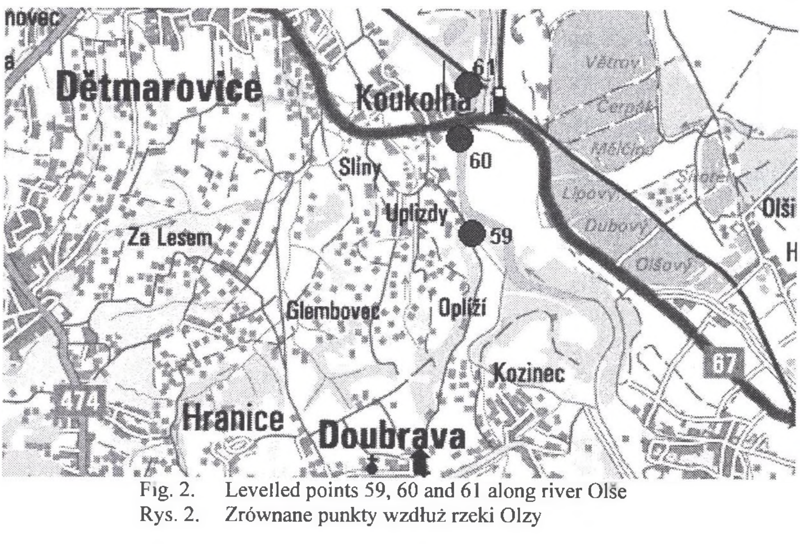

Fig. 2. Levelled points 59, 60 and 61 along river Olše
Rys. 2. Zrównane punkty wzdłuż rzeki Olzy

Along the River Olše the firm Povodí Odry had stabilized points of levelling run for observing height states in the surroundings of the river. These points are spikes in concrete objects along water flows. Povodí Odry does a long term height measuring on these points (namely all over the levelling run along the River Olše) using technical levelling, with interval of 2 or 3 years (measurements in 1996, 1999, 2002, 2004). Since 2001 firm Geotest Brno, a.s. pursues another height measurements (for observing the influences of mining activities on surface) on the parts hereof levelling run near location Ujala I (namely between points 59 and 60, distance c. 750 m, where point 59 is closer, i.e. southwards, to the approaching subsidence depression). Height difference between support points 59 and 60 is surveyed by geometric levelling from centre, technical levelling accuracy. Owing to local conditions, terrain accessibility and weather conditions, the observations aren't surveyed in regular intervals. In 2001 the surveying was done approximately once a month, in following years the intensity was reduced to several observations a year (however minimally 3). Measurements frequency was gradually reduced after successful landslide sanitation. In 2004 was another section added to the observation – the northern section between points 60 and 61 (distance c. 450 m), to verify the stability of originally starting point 60, because the new starting fix point of levelled section, point 61, lies up north, i.e. further from possible influences of undermining. In 2005 The Department of Geophysics of UGN took over the levelling from Geotest Brno, a.s., and continued the observation, using technical levelling on sections 59 – 60 – 61 again. Obviously all the measurements are non-equidistant in time, but their resulting accuracy in heights, or in height differences is comparable.

To verify the results of technical levelling, another surveying was done in November 2005 and April 2006, surveying of precise levelling which provides a higher accuracy (closure less than 1 millimetre in our case). First of these surveying has affirmed the correctness of previous technical levelling, because its result was practically the same as the result of technical levelling done at the same time.

The knowledge of the height state of point 59 is important especially because all the levelling realized for landslide monitoring is joined to this point. Beside levelling there are extensometric measurements, precise inclinometry measuring in bores including logging and surface geophysical surveying done on these landslides. Results of these measurements were periodically confronted with results from geodetic surveying.

4. Correctness of surveying

We decided to evaluate the levelling results relatively, i.e. to deal with height differences between levelled points instead of absolute altitudes of the points, to eliminate the eventual movement of the starting point.

Every surveying was done by closed levelling run going forth and back, so we were able to do a qualitative estimation of each of the measured height differences and we were able to define the correctness and accuracy of each result.

At first the reached misclosure (i.e. deviation between height differences measured forth and back) was compared with the permissible misclosure that is stated for each type of levelling. If the reached misclosure was smaller than maximum permissible misclosure, the levelling was right and could be involved in the further elaboration. Than the accuracy of the levelling was tested by its standard kilometre error. For each levelling the standard kilometre error was calculated and compared with the maximum permissible standard kilometre error given for individual types of levelling. If the reached standard kilometre error was within the tolerance, the final accuracy of measured height difference could be calculated.

We stated that if the vertical movement of the point, i.e. the change of height difference in some period, exceeds the accuracy of height differences measured at the beginning and at the end of this period, a change in height state of given area must have happened.

To illustrate the idea, following example is presented. In tables 1 and 2 there are two technical levelling of a levelling run 59 – 60 from April 2005 and June 2006 elaborated.

Table 1

Accuracy elaboration

Date	Length	Height Difference [m]		Misclosure [mm]		Accuracy	
	R [km]	Forth	Back	d	d_{max}	m_0 [mm]	m_V [mm]
IV.05	0.794	1.621	-1.633	12	18	6.7	6.0
VI.05	0.794	1.658	-1.649	9	18	5.1	4.5

Table 2

Movement elaboration

Date	Height difference	Change [mm]	Total error [mm]	Min. movement [mm]	Max. movement [mm]
IV.05	1.627 m ± 6.0 mm	27	10.5	16.5	37.5
VI.05	1.654 m ± 4.5 mm				

Maximum permissible deviation between height differences measured in a run going forth and back is $d_{max} = 20\sqrt{R}$ (increased accuracy), i.e. $d_{max} = 18$ mm for the length of run 59 – 60 being $R_{59\text{-}60}$ = 0.794 km. As the reached deviation between height differences measured in a run going forth and back was d = 12 mm (April) and d = 9 mm (June), we can say that the condition $d < d_{max}$ is fulfilled in both cases and both levelling are right.

The accuracy of double levelling run, characterised by its standard kilometre error $m_0 = \pm\frac{1}{2}\sqrt{\frac{1}{n}\sum\frac{d^2}{R}}$, is $m_0 = 6.7$ mm (April) and $m_0 = 5.1$ mm (June), which means that the maximum permissible standard kilometre error for technical levelling $m_{0,\max} = 10$ mm was not exceeded and the accuracy of both levelling is sufficient ($m_0 \leq m_{0,\max}$).

The accuracy of levelled height difference given by $m_V = \pm m_0 R$ is $m_V = 6.0$ mm (April) and $m_V = 4.5$ mm (June), so the final results of levelled height differences can be written: $V_{59\text{-}60}$ = 1.627 m ± 6.0 mm (April) and $V_{59\text{-}60}$ = 1.654 m ± 4.5 mm (June).

According to these results the height difference $V_{59\text{-}60}$ changed of 27 mm from April till June 2005. As the sum of variations is 10.5 mm, we can state that the height difference $V_{59\text{-}60}$ changed of at least 16.5 mm and at most 37.5 mm from April till June 2005.

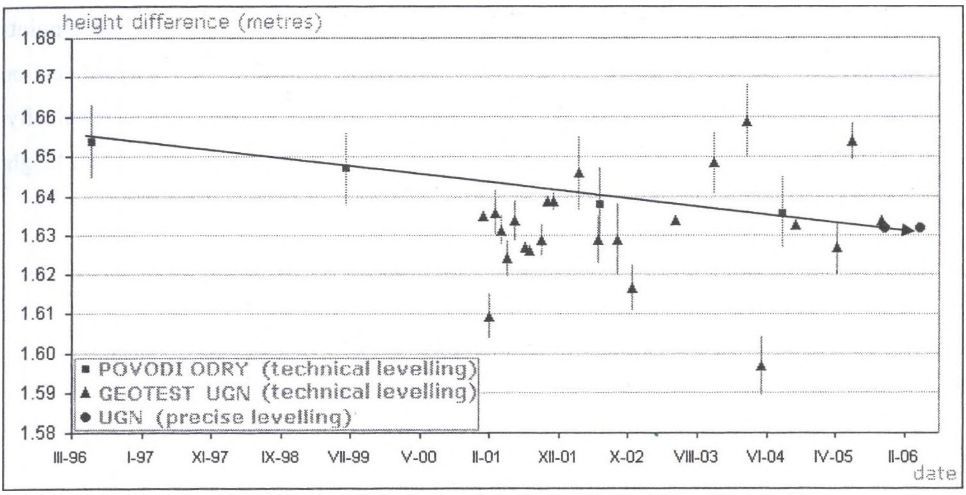

Fig. 3. Height differences (and their errors) between points 59 – 60 since 1996
Rys. 3. Przewyższenie (i ich błędy) pomiedzy punktami 59 – 60 od 1996 roku

On fig. 3 there are depictured height differences between points 59 and 60 from all the geometric levelling since 1996, together with their accuracies.

There are only two measurements done by Povodí Odry until 2001 (in 1996 and 1999). Later firm Geotest Brno, a.s. complemented the measurements. This surveying from 2001 to 2005 shows relatively markedly scattered values of height differences between points 59 and 60, where maximum deviation is more than 6 cm and this change shows on changes in height ratios in given locality. Measured values of height differences reflect on iterative trend of fall and subsequent upheaval of points, while fall is always more penetrative (in time) than upheaval that lasts for a longer time. Falls (in sequence since 2001 according to fig. 3) occurred during 2, 7 and 2 months, whereas upheavals abided 11, 16 and 13 months. Changes, which the measured height differences between points show, magnify in time. Falls occurred of 25, 29 and 62 mm, upheavals of 36, 42 and 53 mm. So the changes show on iterative and growing trend of fall and subsequent upheaval of points in consequence of changes in stress concentration in the foreground of subsidence depression. General trend of changes in height difference between points 59 and 60 shows on fall of about 3 cm (arrow on fig. 3).

Since the changes in height differences between points 59 and 60 were growing and denoted the still major changes in altitudes of these points, arose the demand of observing the height state farther northward, i.e. in the area farther from possible influences of undermining. In 2004 there was also more northern section of the levelling run, namely the part between points 60 and 61, included to the surveying. And so the stability of point 60 started to be checked. Results of surveying of height difference between points 60 and 61 show that the point isn't quite fix, but acts as a quasi-fix point. Changes in height differences between points 60 – 61 and 59 – 60 reflect on the same tendency (fig. 4), but height difference of section 59 – 60, that is closer to the creating subsidence depression, is changing more dramatically: while the height difference 60 – 61 changed of 36 mm in first measured period, the height difference 59 – 60 changed of 62 mm in the same period.

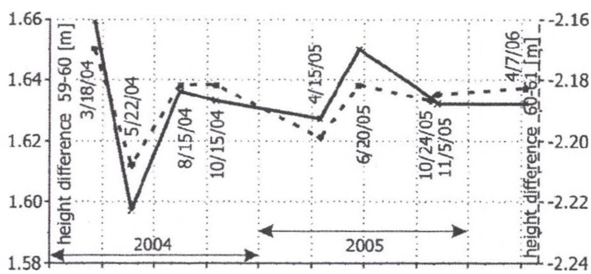

Fig. 4. Height differences between points 59 – 60 and 60 – 61
Rys. 4. Przewyższenie pomiędzy punktami 59 – 60 i 60 – 61

There are still only preliminary results, but it seems that the ascertained fluctuation of point 59 (fig. 3) on the territory touched by mining activity is a dynamic matter that can be given by changes in stress-deformational state in the surface layer. It is impossible however to exclude the possibility that at the same time there exercises an influence (pressures, changes in permeability) of groundwater – i.e. changes of drain ratios. There may act also the river activity itself, because it may infiltrate to the rock massif behind the banks. Further there is the possibility of influences of hydro meteorological conditions, because the points possibly aren't stabilized in sufficient depth. There is another complication with the point 59 and its position below the foot of slopes, whose stability is indifferent. In addition, on the fluctuation itself has influence the prime stability of points, accuracy of measurements and its time incongruity.

On fig. 5 there are the graphs of height differences between points 59 – 60 and 60 – 61 together with the course of groundwater level in bore on the landslide Ujala – Kováč. At the first glance there is apparent the identical course of these curves in the time period after restoration of balanced state of groundwater by sanitation of the landslide. The decrease of groundwater leads to the decrease of pore pressures in the rock massif. That probably causes the change in the "compactness" of materials of the dam and its close surroundings, in which the control points are stabilized. These changes may then lead to changes in the height differences between control points. Anyway, we may state that the regime of groundwater has an influence on the changes of heights of terrain in the area of interest.

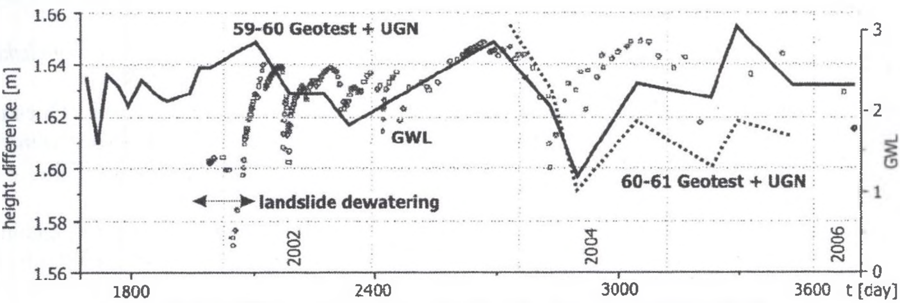

Fig. 5. Height differences between points 59 - 60 - 61 and groundwater level
Rys. 5. Przewyższenie pomiędzy punktami 59 - 60 - 61 i lustro wody podziemnej

5. Conclusions

Levelling on the support points on the margin of subsidence depression (despite of some quite high standard errors of levelled height difference, within the range of 0 – 9 mm) had shown that the repetitive upheavals and falls are small and they reach at the most 6 cm with frequency of about 1.5 – 2 years. What is the cause of these changes keeps being an open problem so far. It can be especially the connected stress-deformational processes and changes on the margin of subsidence depression that were proved by repeated geophysical measurements [1]. Noticeable similar behaviour of groundwater-level fluctuation and height changes denotes a significant influence of changes of hydro geological regime on height fluctuation. If one of these influences dominates, or both causes have an effect on height changes, will ensue from next levelling.

Acknowledgement

This contribution was enabled thanks to a financial support of Research project AS CR OZ 30860518 and a financial support of Ministry of Finance CR to sanitation and monitoring of landslides of the III. category.

REFERENCES

1. Bláha P. et al.: *Doubrava – Ujala I – Monitoring 2004.* Geotest Brno, 2004, MS.
2. Bláha P., Pavlík J., Duras R.: *Doubrava, závěrečná zpráva, mapování sesuvů a geofyzika. (Doubrava, final report, mapping of landslides and geophysics).* Geotest, Brno, 5/2000, MS.
3. Bláha P., Pavlík J., Duras R., Lincer L.: *Doubrava, Pod Ujalou I - doprůzkum. (Doubrava, Pod Ujalou I – post-prospecting).* Geotest, Brno, 12/2000, MS.
4. Doležalová, H.: Problematika pohybů a deformací na poddolovaném území. (Questions of movements and deformations on the undermined territory). In *Proceedings of conference JUNIORSTAV 2003.* Brno: FAST VUT v Brně, 2003. ISBN 80-7204-265-3, s. 23-26.
5. Doležalová H.: Sledování změn v poklesových kotlinách geodetickými a geofyzikálními metodami. (Observing of changes in subsidence depressions using geodetic and geophysical methods). In *Electronic proceedings of conference JUNIORSTAV 2004.* Brno: FAST VUT v Brně, 2004. ISBN 80-214-2560-1.
6. Doležalová H.: Určování výšek bodů geometrickou nivelací. (Stating points´ altitudes using geometrical levelling). In *Proceedings of 14th conference Modern mathematical methods in engineering.* Ostrava: VŠB-TUO, 2005. ISBN 80-248-0951-6, s. 19-23.
7. Doležalová H., Kaláb Z., Müller K.: Komplexní geodetická a geofyzikální měření v poklesové kotlině. (Complex geodetic and geophysical measurements in subsidence depression). In *Proceedings of 10th annual conference of Society of Mine Surveyors and geologists.* Ostrava: VŠB – TU, Ostrava 2003. ISBN 80-248-0463-8.
8. Schenk J.: *Měření pohybů a deformací v poklesové kotlině. (Measuring of motions and deformations in the subsidence depression).* Ostrava, VŠB - TUO, 1999, s.144. ISBN 80-7078-711-2.

Recenzent: Dr hab. inż. Stanisław Kowalik, prof. nzw. w Pol. Śl.