ASSESSMENT OF FAILURE CONDITION OF THE EXTRACTED SEAMS OF THE FIRM ROOF IN DEPENDENCE ON THE ROCK MASS CHARACTER

HODNOCENÍ STAVU PORUŠENÍ PEVNÉHO NADLOŽÍ DOBÝVANÝCH SLOJÍ V ZÁVISLOSTI NA CHARAKTERU HORSKÉHO MASIVU

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Abstract

As a result of the deposit caving, the original stress balance of the rock mass is affected; therefore, the stress always increases around the mined-out workings. The stress increase results in the stope surroundings compression distinguished by a certain surface subsidence measurable (the surface also features substantially smaller horizontal shifts as the second vector component of the general movement towards the mined-out workings metacentre). Determination of this subsidence value in relation to the extent and thickness of the mined-out workings is important to recognize the conditions under which a complete failure of the firm overlying layers occurred. At the first extraction in the area, that means failure in the whole thickness of overlying carboniferous rocks.

Abstrakt

Vlivem dobývání ložiska na zával se narušuje původní napěťová rovnováha horského masivu, proto kolem vydobytého prostoru dochází vždy ke zvýšení napětí. Důsledkem zvýšeného napětí dochází ke stlačení okolí výrubu, které se projevuje určitým, měřitelným poklesem povrchu (na povrchu dochází také k výrazně menším vodorovným posunům jako druhé složky vektoru obecného pohybu směřujícího do metacentra vydobytých prostor). Určení této hodnoty poklesu s ohledem na rozsah a mocnost vydobytých porubů je důležité pro rozeznání stavu, kdy již došlo k celkovému porušení pevných nadložních vrstev. Při prvním dobývání v oblasti to znamená porušení celé mocnosti nadložních karbonských hornin.

Key words: subsidence trough, rock mass, surface subsidence, complete failure, overlying layers

1 INTRODUCTION

The paper assesses the area of the 4th block of the ČSM mine from the time of extracting the first seams in this region. The first seam mined, No. 29, is located at the depth of approx. 750 m under the surface, the second one, No. 30, at the depth of 800 m. Both seams belong to Sucha Member of the Karviná group of strata. Extraction of the first face in the seam No. 29 began in July 1996; extraction of the last face No. 30 of the area assessed was completed in May 2002. Siting of the individual faces of the seams extracted is shown in Annex No. 1. In the assessed area of the 4th block of the ČSM mine, periodic measurements of surface point heights have been taken in six-month intervals since 1993 up to the present. The surface points are stabilized by means of pin marks in brick building plinths. The Annex No. 1 visualizes the positional interrelation between the surface observation points and the ground plan of the areas extracted. In the whole area investigated, the method of strike mining to controlled caving was applied.

2 GEOLOGIC CHARACTERISTIC

The information on geologic conditions was acquired from the ČSM 147 well and the geologic section running through this well (Fig. 1). Figure 2 shows the position of the ČSM 147 well in relation to the extracted faces. Figure 1 reveals that the given area features a large depth of cover – approx. 590 m – and there is a layer of detritus of approx. 55-m thickness between the cover and the firm carboniferous layers [1]. The first extracted seam is the seam No. 29 situated approx. 80 m under the detritus. The extracted thickness of the seam No. 29 ranges between 1.7 – 4.1 m. The extracted part of the seam No. 29 is 700 – 830 m deep under the surface. The carboniferous rocks in the roof of the seam No. 29 mostly consist of siltstone (57 %) and sandstone (30 %). The next extracted seam, No. 30, is located approx. 55 m under the seam No. 29. The extracted thickness of the seam No. 30 ranges between 2.3 – 4.5 m. The extracted part of the seam No. 30 is 750 – 880 m deep under the surface.

The interlayer between seams No. 29 and No. 30 is mostly composed of sandstone (85 %) and siltstone (15 %). The seams mentioned belong to the Sucha Member of the Karviná group of strata. The extracted area is restricted by two distinct faults, the coarse, inclination and height of which are visualized in Fig. 2. The extracted faces forefield involves a wide tectonic zone; the faces were extracted from this tectonic zone.

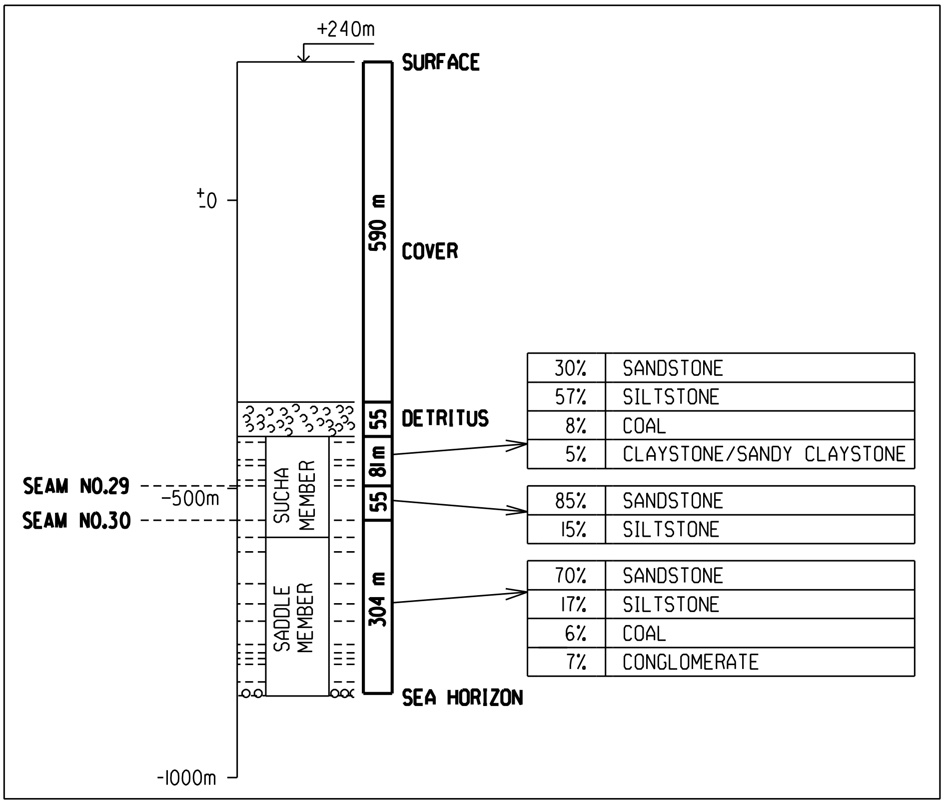

Fig. 1 Rock environment character in the ČSM 147 well line

3 ASSESSMENT OF THE MECHANICAL CHARACTER OF THE FIRM ROOF ROCKS

The undermined overlying rocks in the bedded mountain range are tensile-stressed at bending. However, it is very difficult to determine the tensile strength at bending as it cannot be examined on the well core which is oriented perpendicularly to the layers. To assess the failure of overlying rocks during mining, compressive strength is usually taken into account [3]. Table No. 1 indicates the given ranges of compressive strength values as well as directory average values for the individual macropetrographic rock types of the Sucha Member.

Tab. 1 Compressive strength values

Sucha Member	claystone	siltstone	sandstone fine-grained	sandstone medium-grained	sandstone coarse-grained	conglomerate
compressive strength σ_{Pd} (MPa)	50 – 60 55	57 – 124 80	66 – 129 90	50 – 142 90	72 – 116 90	67 – 103 80

As mentioned above, it is the first extraction in the given area. Therefore, to assess the rock mass failure, the total thickness of unfaulted overlying layers has to be taken into consideration to the carboniferous mass – cover boundary. The geological characteristic reveals that the first extracted seam No. 29 is superimposed by 81 m of firm unfaulted carboniferous group of strata. The carboniferous rocks in the seam No. 29 roof consist of siltstone (57 %), sandstone (30 %), coal seams in non-commercial thickness (8 %) and claystone (5 %). Table No. 2 indicates the individual overlying layer thicknesses h_i.

Tab. 2 Overlying layers thicknesses in the seam No. 29

i	rock	percentage share (%)	roof thickness (m)	layer thickness h_i (m)
4	siltstone	57	81	46.17
3	sandstone	30		24.30
2	coal	8		6.48
1	claystone	5		4.05
sum				81

To assess the firm roof, it is optimal to choose the method of classification according to the inflexibility coefficient k_{pn}:

$$k_{pn} = 0{,}26 \cdot h_{pn} \cdot \bar{k}_{c\ pn} \cdot \sqrt{\bar{\sigma}_{pd\ pn}} \qquad (1)$$

where:

h_{pn} – firm roof thickness $[\mathrm{m}]$,

$\bar{k}_{c\ pn}$ – weighted mean of the firm roof compactness coefficient $[\text{-}]$,

$\bar{\sigma}_{pd\ pn}$ – weighted mean of uniaxial compressive strength of the firm roof $[\mathrm{MPa}]$.

The weighted mean of the firm roof compactness coefficient is determined by the formula:

$$\bar{k}_{c\ pn} = \frac{\Sigma(k_c \cdot h_i)}{h_{pn}} \qquad (2)$$

where:

k_c – compactness coefficient of the individual layers $[\text{-}]$,

h_i – thickness of the individual layers $[\mathrm{m}]$,

h_{pn} – thickness of the firm roof $[\mathrm{m}]$.

The weighted mean of uniaxial compressive strength of the firm roof is determined by the formula:

$$\bar{\sigma}_{pd\ pn} = \frac{\Sigma(\sigma_{pd} \cdot h_i)}{h_{pd}} \qquad (3)$$

where:

σ_{pd} – uniaxial compressive strength of the individual layers $[\mathrm{MPa}]$,

h_i – thickness of the individual layers $[\mathrm{m}]$,

h_{pd} – thickness of the firm roof $[\mathrm{m}]$.

Table No. 3 indicates the firm roof parameters for the seam No. 29, including the calculated values for classification according to the inflexibility coefficient.

Tab. 3 Firm roof parameters of the seam No. 29

i	rock	layer thickness h_i (m)	k_c	$k_c \cdot h_i$ (m)	σ_{pd} (MPa)	$\sigma_{pd} \cdot h_i$ (MPa·m)

4	siltstone	46.17	0.04	1.85	80	3694
3	sandstone	24.30	0.04	0.97	90	2187
2	coal	6.48	0.00	0.00	25	162
1	claystone	4.05	0.03	0.12	55	223
sum		**81.00**		**2.94**		**6265**

The values indicated in Table No. 3 are used to calculate the weighted mean of uniaxial compressive strength by the formula (3) and the weighted mean of the compactness coefficient by the formula (2). The inflexibility coefficient for the firm roof of the seam No. 29 is then determined by the formula (1). The resultant values are indicated in Table No. 4:

Tab. 4 Firm roof parameters of the seam No. 29

$\overline{\sigma}_{pd\ pn}$ [MPa]	$\overline{k}_{c\ pn}$ [-]	k_{pn} [-]
by the formula (3) 77.35 MPa	by the formula (2) 0.04	by the formula (1) 6.72

The evaluation of the mechanical character of the firm roof rocks of the seam No. 29 results in the inflexibility coefficient, the value of which equals to 6.72. This characteristic is beneficial as the resultant value k_{pn} involves all the main influence factors: thickness, strength and compactness of firm roof layers.

4 ASSESSMENT OF THE FIRM ROOF FAILURE CONDITION

To assess the firm roof failure condition, the surface point No. 210 was selected. It is roughly situated above the extracted areas centre and was located at all periodic surface height measurements. The position of the surface point No. 210 graphically represented in Fig. 2. The height values measured in April 1996, three months before extraction in the monitored area started, are regarded as the initial measurement to calculate the subsidence. Firstly, the face No. 292401 was mined within the length of approx. 196 m. Its total guide mined-out value was 220 m; the mean extracted thickness is 2.1 m. About six months after this face extraction was finished, subsidence value of 23 mm was measured at the point No. 210. In the ground plan, the monitored point No. 210 is situated approx. 25 m from the mined-out area, approximately in the middle of the guide length. The mined-out thickness exceeded 2 m, which means that the approx. 80-meter thickness of the firm roof was not broken to the detritus by mining out the face.

Secondly, the adjacent face No. 292403 was extracted; its mean extracted thickness is 3.4 m. The length of the face No. 292403 equals to that of the previous face; the total mined-out guide length, however, is 345 m. The monitored surface point No. 210 is directly undermined by the face No. 292403. The point No. 210 subsidence value was increasing during extracting this face; on completion of mining, the subsidence value of 130 mm was measured at the point No. 210. The completion of extracting the face No. 292403 was followed by a more than one-year intermission of mining in the area. During that time, the point No. 210 slightly subsided further; before starting the extraction of the next face No. 292405, the total subsidence of the point No. 210 was 180 mm (Annex No. 2). With view to the mined-out thickness, the point No. 210 situating and its subsidence, it is apparent that, even more than one year after the mining completion, no breakthrough of the rocks to the carboniferous mass – cover boundary occurred; instead, only the seam around the face was compressed and the firm carboniferous layers deflected in the place above the mined-out area [2].

Due to the tectonics, the length of the face No. 292405 was approx. 70 m at the beginning, then it was gradually extended to the final length of approx. 100 m. The mean extracted thickness of the face No. 292405 was 3.6 m. Its total guide mined-out length was approx. 420 m. After mining out almost one half of the guide length of this face, extraction of the underlying seam No. 30 started with the face No. 300401, the mean extracted thickness of which was 3.5 m. At the same time, the surface subsidence measurement was taken; the point No. 210 revealed a subsidence value of 195 mm. This means that even at that moment the mountain range had not been broken to the carboniferous mass – cover boundary.

The ground plan of the first extracted face in the seam No. 30 does not profile the overlying seam stope, but it is shifted at the extraction beginning as well as the eastern side by nearly 60 m under the unmined area of the seam No. 29. That means undermining of the surcharged rock mass area. Another surface subsidence measurement took place a month after completing extraction of both the face No. 292401 and face No. 300401. Both faces were finished at the same time; immediately afterwards, extraction of the face No. 300403 started, the mean thickness of which was 2.6 m. The surface measurement taken in April 2000 detected a high subsidence increase at the point No. 210 to the value of 530 mm. This value, as well as the overall development of the subsidence curve of point No. 210, makes it obvious that the roof rocks must have been broken to the carboniferous mass – cover boundary [2]. Simultaneous evaluation of seismic activity enables the time of breaking to be specified more precisely. The time of occurrence of the seismic phenomena, the value of which exceeds all the other seismic phenomena recorded, according to Annex No 2 can be considered the time of the breakthrough of the rocks to the carboniferous mass – cover boundary.

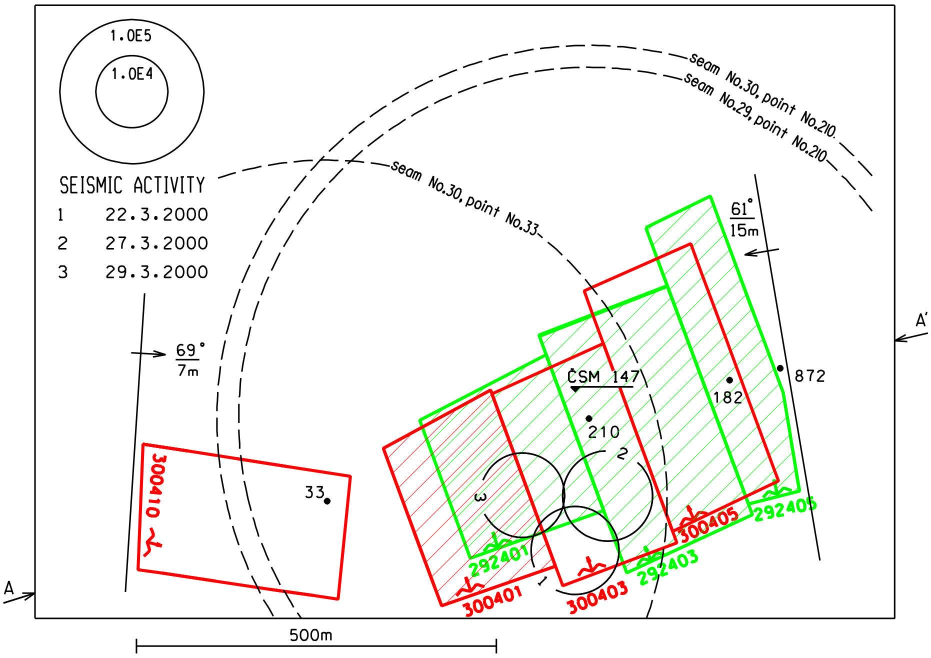

Fig. 2 Face mining-out condition at the time of breaking

After the breakthrough, the deformation quickly extends through detritus and cover up to the surface. Supposedly, the real subsidence curve gradient is very steep. Annex No. 2 indicates the assumed time of breaking the formed arch in March 2000 and the assumed subsidence of the point No. 210 before the breaking, estimated at 210 mm. The firm rock broke after the extraction of approx. 170 000 sqm of ground area of the approximate length of 550 m and width of 320 m. The hatched area in Fig. 2 represents the mining-out condition of faces in the seams No. 29 and 30 at the assumed time of the arch breaking. Section A-A graphically represents formation of the subsidence trough before (October 1999) and immediately after the breakthrough (April 2000). The section lines pass through surface points No. 33, 210, 182 and 872. Section A-A in Fig. 3 involves an overview of the mined-out face areas in the section line on the date of surface subsidence measurement. The subsequent extraction of the face No. 300403 featured a steady increase in the point No. 210 subsidence.

After completing the extraction of this face, situated right under the point No. 210, the activity was moved further eastwards in the 4th block of the ČSM mine. Extraction of the face No. 300410 started behind the boundary of the effective area of the surface point No. 210, and only after mining out of approx. one half of its guide length it entered the area affecting the point No. 210. The mean extracted thickness of the face No. 300410 was 2.6 m. With view to the great distance between the extraction area and the surface point No. 210, the situation under the face No. 300410 cannot be precisely evaluated on the point No. 210 subsidence.

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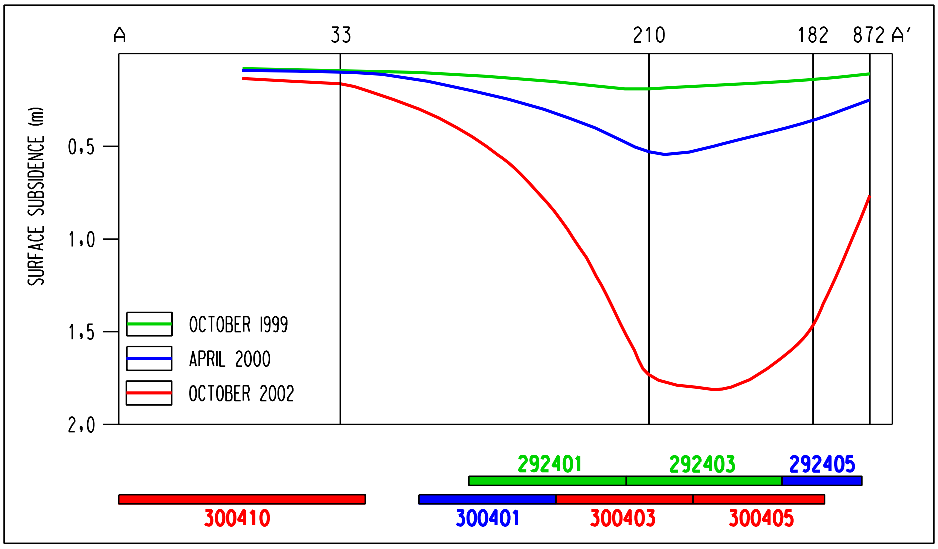


Fig. 3 Section A-A´

Therefore, the surface point No. 3, directly undermined by the face No. 300410, was selected for the assessment. In the ground plan, the monitored point No. 33 is situated approx. 30 m from the mined-out area from the end of the working face advance (Fig. 2). The overall development of the subsidence curve of point No. 33 features a distinctive surface heaving measured in October 2000 (Annex No. 2). Compared with the previous measurement, the surface heaving is 8 mm, which points to the fact that this once considerably overloaded area was relieved immediately after the breakthrough. This heaving was measured at all surface points of the northern and western surcharged area, ranging from 7 – 11 mm. It should be observed that the heaving value is reduced by the subsequent quick surface subsidence after the breakthrough, as six months passed from the time of the breakthrough to the first subsequent measurement. It is obvious from the following development of the subsidence curve of the point No. 33 that, though the face advanced from distinctive tectonics, a strutting arch formed above this face and the firm rocks were not broken to the carboniferous mass – cover boundary [2]. Finally, the face No. 300405, next to the face No. 300403, was extracted. The mean extracted thickness of the face No. 300405 was 3.3 m. During its mining, the point No. 210 subsided distinctively to the value of 1788 mm about six months after the extraction was completed. Fig. 3 shows the condition of the subsidence trough along the section line A-A in October 2002 as well as the schematic outline of the mined-out areas.

Comparing the range of the subsidence trough at the times immediately after the breaking and at the extraction completion, it is observed that no further flat expansion of the deepest places of the subsidence trough occurred and therefore the firm layers did not gradually break to the carboniferous mass – cover boundary. The subsidence trough range has practically remained the same, only the subsidence at the breaking zone increases; specifically, immediately after the breakthrough, the largest subsidence was measured at the point No. 210, while upon the extraction completion the point No. 420 featured the largest subsidence (for the location of viewpoints No. 210 and No. 420, see Annex No. 1). This shift in the largest subsidence places is associated with the slide of layers along the distinctive tectonics running at the eastern edge in close vicinity to the faces.

5 CONCLUSION

During the time period from July 1996 to March 1998, the faces No. 292401 and 292403 were mined out; followed by a 15-month mining intermission during which the surface movements gradually settled down. The assessment indicates the following:

- an arch formed over the mined-our area, at which the failure of the above located carboniferous rocks stops;
- an arch formed over the mined-out area, resulting in high surcharge in the mined-out area surroundings;
- compression of rocks around the mined-out area. This results in the roof subsidence within the whole affected zone, including the arch subsidence over the mined-out area. A characteristic subsidence trough forms on the surface, but the subsidence does not correspond to the mined-out thickness.

During the time period from June 1999 to February 2001, the faces No. 292405, 300401, 300403 and 300410 were mined out; followed by a 10-month mining intermission during which the surface movement started to settle down. This period assessment features the following aspects:

- assessment of the rock mass condition, based on monitoring of the surface subsidence and extracting of the individual faces, reveals that at the beginning of extraction of the face No. 300403 the firm roof was broken to the carboniferous mass – cover boundary;
- the time of breakthrough of the arch formed in the firm roof was determined more precisely by evaluating the seismological records of the area in question;
- at the surface point No. 210 affected by the extraction (directly undermined by faces No. 292403 and No. 300403), a subsidence of 195 mm was measured, as a result of the rocks compression before the arch failure. With respect to the assessment of the subsidence development preceding the arch failure, the point No. 210 subsidence value may in fact have been up to twice as high. About 5 months passed between the last subsidence measurement and the arch failure time. Within that period the mined-out area was extended by the face No. 300401 stope and finishing stope of the face No. 292405;
- in the specific case evaluated, the firm 81-m roof was broken to the carboniferous mass – cover boundary after mining out of approx. 170,000 sqm of ground area of the approximate length of 550 m and width of 320 m. The rock environment mechanical character featured the inflexibility coefficient value of 6.72. It should be observed that there is a distinctive tectonic failure along the eastern stope edge;
- as a result of the breakthrough within the total thickness of the firm rocks, the once disintegrated or infirm cover rocks start relocating quickly;
- the subsidence speed is high owing to filling of the clearances with infirm rocks;
- the firm roof breakthrough causes the stress reduction in the once considerably surcharged area around the stope. This induces decompression of the rocks and thus their upward shift. A relative surface heaving may thus occur in the once considerably surcharged area;
- the surface heaving is partly eliminated by the quick increase in the surface subsidence after the breakthrough;
- in the case assessed, the surface heaving ranging between 7 – 11 mm was measured at the surface points situated in the northern and western parts of the area monitored;
- the subsidence values measured in the surface point No. 33 imply that no breakthrough has yet occurred in the arch formed in the roof over the mined-out face No. 300410.

Extraction of the face No. 300405 took place from December 2001 to May 2002. Five months passed from completion of this face mining to the last surface subsidence measurement. The period of extraction in the face No. 300405 features a quick increase in subsidence in the already formed area of largest subsidence, whereas no gradual flat extension of this area occurs any more.

REFERENCES

[1] JIRÁNKOVÁ, E., PETROŠ, V. *Hodnocení porušování podrubaného pevného nadloží na základě povrchového výškového měření*. Současnost a perspektiva těžby a úpravy nerudních surovin III, strana 111 – 118, VŠB – TU Ostrava 2005, ISBN 80-248-0826-9

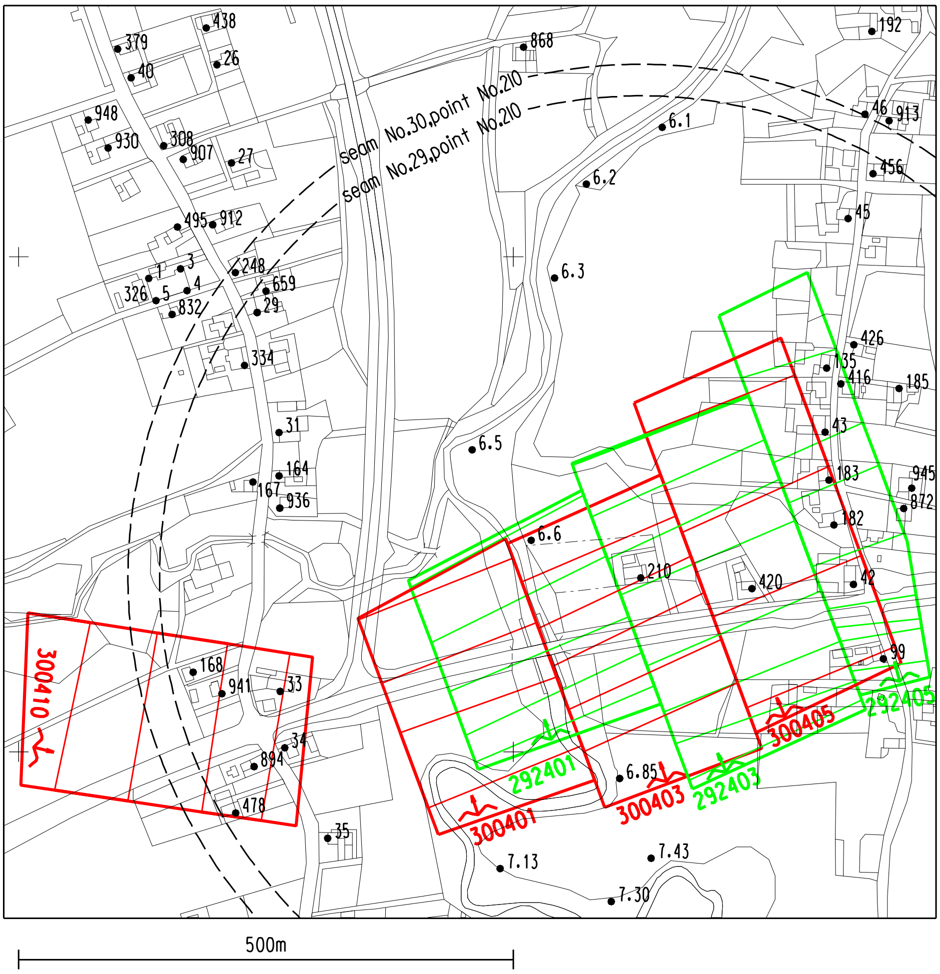
[2] JIRÁNKOVÁ, E., PETROŠ, V., KONESZ, K., KUBICA, P.: *Use of Surface Height Measurements for the Evaluation of Undermined Firm Roof Failure*. MPES 2005 and CAMI 2005, page 547 – 572, Banff, Alberta, Canada 2005, ISBN 1712-3208

[3] PETROŠ, V., JIRÁNKOVÁ, E., KONESZ, K.: *Investigation of rock mass destruction during mining*. Eurock – Impact of human Activity on the Geological Environment, page 461 – 466, Taylor & Francis Group plc, London 2005, ISBN 04-1538-042-1

RESUMÉ

Časoprostorové vytváření poklesové kotliny je ovlivňováno geologickou a mechanickou charakteristikou pevných hornin v nadloží, mezi které patří mocnost, pevnost a celistvost pevných nadložních vrstev. U první dobývané sloje se za mocnost pevných nadložních vrstev považuje celá mocnost karbonských hornin v nadloží. U dalších dobývaných slojí se uvažuje mocnost meziloží k předchozí dobývané sloji, u které došlo k prolomení pevného nadloží. Pevnost nadložních hornin se běžně hodnotí v prostém jednoosém tlaku. Diskontinuity v pevných nadložních horninách můžeme vyhodnocovat podle celistvosti vrtného jádra. Pro hodnocení rozložení napětí a pro stanovení jeho hodnoty v průběhu dobývání je rozhodující zjištění, zda již došlo k prolomení pevných nadložních hornin, nebo je zde ještě vytvořena klenba. Prolomení pevného nadloží lze určit na základě hodnocení poklesů povrchu vzhledem k průběhu dobývání. Stav, kdy došlo k prolomení, je možné podstatně upřesnit současným hodnocením seizmické aktivity. Parametry vydobyté plochy, při které dojde k prolomení pevného nadloží je nutné dát do závislosti na charakteru pevného nadloží. Zde se jeví jako optimální vyjadřovat charakteristiku pevného nadloží pomocí součinitele neohebnosti pevného nadloží k_{pn} . Výhodou je to, že výsledná hodnota k_{pn} zahrnuje všechny hlavní ovlivňující činitele, kterými jsou mocnost, pevnost a celistvost pevných nadložních vrstev.

ANNEX



Annex No. 1: Situation of the extracted faces and surface points

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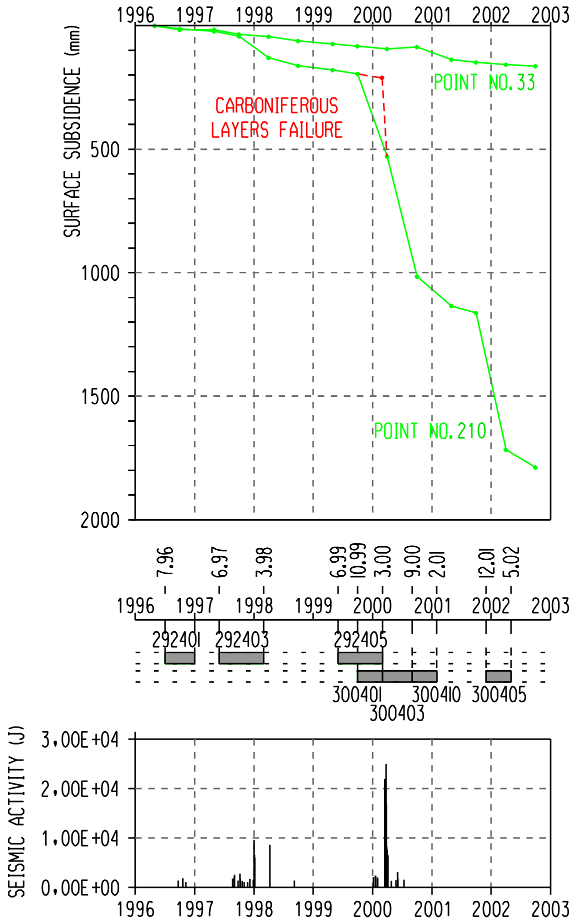

Annex No. 2: Subsidence curves and seismic activity of the assessed area