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EXPERIMENTAL APPROACH TO MEASURE STRESS AND STRESS CHANGES IN ROCK AHEAD OF LONGWALL MINING FACES IN CZECH COAL MINES

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ABSTRACT: The measurement and monitoring of stress in rock mass are very important tasks in mining geomechanics. With increasing mining depth and worsening of the geological and mining conditions, a suitable method to determine and monitor rock stress and stress changes due to longwall coal mining is needed. Detailed knowledge of the stress state in rock mass is very useful when designing safe mining activity, especially in rockburst areas. The paper presents a brief description of the Compact Conical-ended Borehole Monitoring (CCBM) method for rock stress evaluation and the technical details of this innovative technology. The second part of the contribution evaluates and discusses initial results and experience obtained from the use of CCBM equipment for determination and observation of mining-induced stresses during mining of selected longwall panels in the conditions of the deep coal mines of the Upper Silesian Coal Basin.

INTRODUCTION

Knowledge of the stress state in rock mass is very important in mining geomechanics, especially in rockburst areas. According to the rockburst legislation (OKD, DPB, a. s., 2005) of the Czech Republic, the range of mining-induced stresses in front of longwall faces and their influence on mining conditions needs to be determined.

The problems of rock stress and its determination have been under investigation at the Institute of Geonics for a long time. With increasing mining depth and worsening of the geological and mining conditions, a suitable method to determine and monitor rock stress and stress changes due to longwall coal mining is needed. During the past 20 years, the hydraulic fracturing method was commonly used, but this method does not appear to be fully satisfactory for these purposes because it does not allow determination of all the components of the stress tensor or continuous observation of stress changes. Due to a problem with the long-term stability of the boreholes used, the decision was made to develop a device which enables determination of all three principal stress components. Development of the device described in this paper was based on the experience of Sugawara and Obara from Kumamoto University. They were the first to develop and use the Compact Conical-ended Borehole Overcoring system (CCBO) (Sugawara and Obara, 1999; Obara and Sugawara, 2003). The conical shape of the CCBO probe provides a sufficient number of strain measurements in independent directions in one probe position in the borehole so that all values of the stress tensor can be determined. Two variants of the CCBO probe were developed at the Institute of Geonics - the first variant is equipped with a microprocessor for remote, wireless automatic recording of measured data on the probe's internal memory, and the second one can be connected to a data-logger and power supply via a cable. The latter type CCBM device, was used for long-term monitoring of stress tensor changes (Stas, *et al.*, 2005).

This paper begins with a brief description of the conical ended borehole monitoring method and the technical details of this innovative technology. The second part of the contribution evaluates and discusses results and experience obtained from the use of CCBM equipment for determination and observation of mining-induced stresses during extraction of selected longwall panels in deep coal mines.

MINING PRACTICE FOR DETERMINING THE RANGE AND EXTENT OF MINING-INDUCED STRESSES

According to the rockburst rules (OKD, 2005) of the Czech Republic, the range of mining-induced stresses in front of the longwall face and their influence on mining conditions needs to be determined. Recent mining practice in Czech underground coal mining operations in the Upper Silesian Coal Basin

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has interpreted the range of the induced stress by using the monogram based on physical modelling for approximately 30 years (OKD, 2005). This method of stress range assessment turns out to have ample security. The main input data for determining the range and extent of mining-induced stresses are the depth under the surface and the thickness of the excavated coal seam (see Figure 1). The figure serves as an example for interpretation of the mining-induced stress range in the surroundings of the longwall face mined out of a coal seam of thickness 5 m at a depth of 900 m under the surface. The resulting induced stress range is here 110 m. The disadvantage of this way of determining the induced stresses is the lack of information about their magnitude and course around the longwall block (panel). In general, the induced stress level rapidly increases in the immediate vicinity of the mined out area and then slowly decreases. A similar stress state theoretically manifests itself along the gob (old man). Therefore monitoring the induced stresses in front of the longwall faces using the CCBM probes on trial was started four years ago.

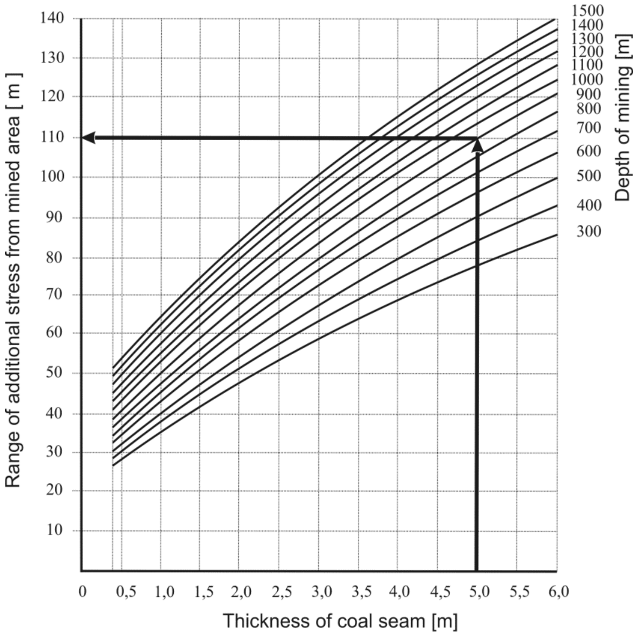

Figure 1 - Monogram for determining mining-induced stresses

FUNDAMENTAL DESCRIPTION OF THE CCBM EQUIPMENT

The CCBM probe is designed for boreholes 76 mm in diameter. The waterproof probe body has a diameter of 55 mm. Six pairs of mutually perpendicular strain gauges are mounted onto the conical tip of the probe with an apical angle of 60° (see Figure 2), at the level where the diameter is 38 mm. The geometry described above is deliberately the same (except for the number of strain gauges) as the one designed, optimized and verified for the original CCBO method (Prof. Sugawara and Prof. Obara). This allowed the wealth of their experience to be drawn on. The geometry is described in full detail in Sugawara and Obara (1999).

The probe for the CCBM was designed as an alternative to the equipment developed for CCBO. The CCBM probe, which can be connected to an external control unit by cable (see Figure 3), thus enables observation of the stress changes in the rock mass (induced, for example, by underground mining activities). The probe consists of two parts:

- A measuring conical tip containing six strain gauges - two-element 90° tee-rosettes (longitudinal gauges and tangential gauges).
- The body of the probe containing an electronic multiplexed quarter strain gauge bridge MUX, analogue to digital converter A/D, microprocessor μP, stabilized power supply and TTL/RS-232 interface.

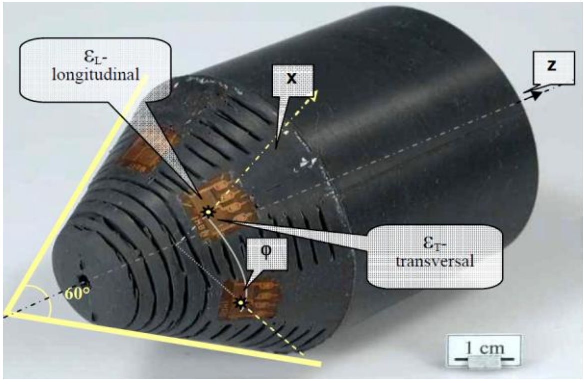

Figure 2 - CCBO gauges probe and representation of coordinate system used

Figure 3 - A gauges probe for long-term measurement of stress tensor changes (left side), registration unit PSION (right side)

Three principal modes of CCBM probe operation are available (detailed modes information can be found in Knejzlik and Rambousky (2008) and Knejzlik (2004)):

- Periodic manual reading of data using a portable computer or data-logger (notebook, Psion).
- Remote data transmission, which can be carried out using virtually any known method of computer communication.
- Implementation of the distributed control and measuring network.

The experiments described below were performed using the first mode – periodic manual data reading using a portable Psion data-logger.

The installation procedure of the CCBM probe is as follows:

- Drilling a borehole to the projected length - the quality of rock is examined from the core samples.
- Forming and polishing the bottom of the prepared borehole using a special conical drill bit (see Figure 4).
- Checking the homogeneity of the shaped borehole bottom by a TV inspection system - if the surface quality of the shaped borehole bottom is unsatisfactory (discontinuities or large grains,) it is necessary to continue drilling to a more suitable position to repeat the shaping and inspection procedure.
- Drying out the borehole bottom with compressed air if the surface quality is evaluated as satisfactory.
- Cementing the probe in place - a special kind of resin glue (epoxy type) is used to cement the probes, the handling equipment is fitted with a device which detects orientation, enabling

(together with knowledge of the direction and the inclination of the borehole) the determination of the location of strain gauges oriented in the space of the rock mass.

- The probe is ready to start measurement after proper glue setting and removal of the handling rods.

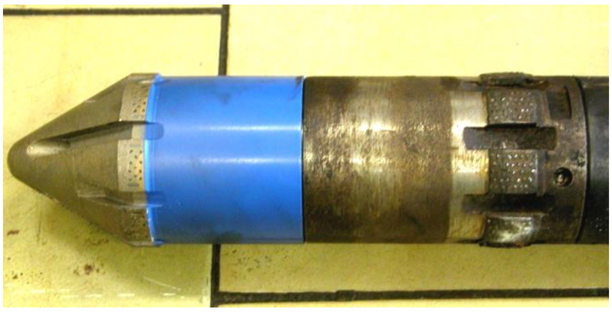

Figure 4 - Special conical drill bit used for shaping of bottom of installation borehole

COMPACT CONICAL ENDED BOREHOLE MONITORING METHOD (CCBM) - PRINCIPLES AND METHODOLOGY

The CCBM method is based on similar principles except that the 'destructive' overcoring phase is not performed. This method allows repeated measurement of strain on all sensors of the probe over a long period. In this case, however, only changes of the stress tensor in relation to the stress state at the time of probe installation (i.e. to the reference state) can be determined. This is the principal difference between the CCBO and CCBM methods. The evaluation of measurements is the same as in the case of the CCBO technique.

The dependence of the corresponding gauge sensor strain on the stress tensor for CCBO has been formulated in Sugawara and Obara (1999) and Obara and Sugawara (2003). For CCBM, it can be formulated as follows (Stas, *et al.*, 2011):

$$[\varepsilon_{\Lambda}^{\Phi j}(t_{i}) + \varepsilon_{\Lambda}^{\Phi j}(\Delta t)] \text{ x } E = |\mathbf{A}(\Lambda;\mu;\Phi_{j})| \text{ x } [\,|\sigma_{i}| + |\mathbf{S}(\Delta t)|]$$

Hence the following equation can be expressed:

$$\varepsilon_{\Lambda}^{\Phi j}(\Delta t) \text{ x } E = |\mathbf{A}(\Lambda;\mu;\Phi_{j})| \text{ x } |\mathbf{S}(\Delta t)|$$

where $\varepsilon_{\Lambda}^{\Phi j}(t_{i})$ and $\varepsilon_{\Lambda}^{\Phi j}(\Delta t)$ are strain $\varepsilon_{\Lambda}^{\Phi j}$ at the time of probe installation and differential strain related to time of installation respectively; $|\sigma_{i}|$, $|\mathbf{S}(\Delta t)|$ are stress tensor at the time of installation t_{i} and induced stress tensor (stress changes at time Δt after installation) related to stress state $|\sigma_{i}|$, respectively; E is Young's modulus and μ is Poisson's ratio. The optimal stress changes tensor of the whole system can be determined by calculating the differences of all ("j-") pairs of corresponding measurements ($\varepsilon_{\Lambda}^{\Phi j}(\Delta t)$) and ideally implied strains ($\varepsilon_{\Lambda\Phi j}(\Delta t) \equiv |\mathbf{A}(\Lambda;\mu;\Phi_{j})| \text{ x } |\mathbf{S}(\Delta t)|/E$) using the method of least squares. A scheme of the CCBM is represented in Figure 2.

IN-SITU MONITORING OF THE INDUCED ROCK MASS STRESSES IN FRONT OF LONGWALL FACES

The development of the mining-induced stress ahead of the longwall face can be described through *in situ* observations of the installed CCBM probes. Applicability tests of the CCBM method were performed in several localities of the Czech part of the Upper Silesian Coal Basin. Changes in the vertical component of the induced stress at different positions of the longwall faces are of interest and were evaluated through readings from the installed CCBM probes. Results of the stress measurement at the three localities are described below. The rock stress monitoring was carried out at the Lazy collieries in the Karvina Coal Sub-basin at the two longwall panels No. 140 914 and 140 912 in coal seam N^{o} 504. Next, monitoring was performed in the longwall panel N^{o} 361 000 at the CSM Mine in the Karvina Coal Sub-basin in coal seam N^{o} 36. In most cases the CCBM probes were installed only in the overburden compact sandstone beds at vertical distances of 10 m to 20 m from the working coal seams. One CCBM probe P1 was installed in the underlying bed of the working coal seam on the Lazy colliery (see Table 1). The installation boreholes were drilled from both the main and tail longwall gates at distances of 110 m to 540 m from the starting longwall face positions. Table 1 shows a basic description of the installed CCBM probes and the longwall panels.

Table 1 - Description of CCBM probe location

Name of probe	Colliery	No. longwall panel	Average coal seam thickness (m)	Average coal seam depth (m)	Length of longwall panel face (m)	Vertical probe position above (*under) coal seam (m)	CCBM probe distance from starting longwall face position (m)
L1	Lazy	140 914	4.1	690	110	16	180
L2						12	180
N1	Lazy	140 912	3.6	720	160 -180	16	540
N3						16	540
P1						*3	540
C1	CSM	361 000	1.8	980	180	16	110
C2						10	110

The first installed CCBM probes in front of longwall panel No. 140 914 showed satisfactory sensitivity to the mining activity. This finding was a strong impulse to use this probe for evaluation of the rock stresses in front of the longwall faces. The direct dependence of the stress changes on the progress of the longwall face is evident from subsequent events. The progress of the longwall face had to be temporarily discontinued due to technological problems (see the part inside the oval in Figure 5) from 20-23 February. This pause was immediately reflected in the evolution of the stress state behaviour of the rock mass during this period. Strain evolution registered by the gauges was retarded or even halted. The closer the position of the L1 probe was to the worked coal seam, the more distinctive the influence. The values of the stress changes on the CCBM probes L1 and L2 during this period are shown in Figure 5. S1, S2 and S3 in Figure 5 represent the components of the principal stresses.

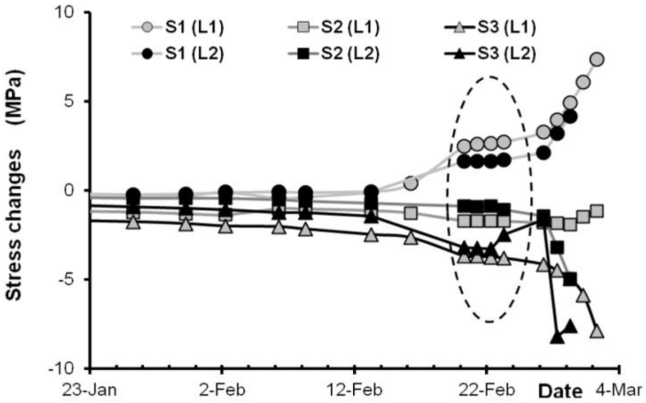

Figure 5 - Development of the stress changes on the L1 and L2 probes during longwall face stoppage

Mining-induced stress development

The observation by CCBM monitoring of the influence of the progress of the longwall face on the range of mining-induced stresses was evaluated on the basis of the development of the real volume component I_1 (first invariant, $I_1=S_1+S_2+S_3$, where S_1, S_2 and S_3 are components of the principal stresses). The one third of the first invariant value is plotted in the graphs in the next Figures 6, 7, 8 and 9 distinguish than batter. The first signs of change (insignificant) in the mining-induced stress, at almost all of the CCBM measuring probes, were recorded at distances from the longwall face ranging from 50 m to 70 m (see Table 2 and Figures 6 and 7). The range of these distances is at a lower level than the range of the mining-induced stresses determined according to the conventionally used monogram on the condition of the Upper Silesian Coal Basin. In one case, however, this range was recorded as higher than the range of mining-induced stresses determined with the monogram, i.e., at more than 100 m (see Table 2, and Figures 8).

Table 2 - Range of the mining-induced stresses
(*) negative values represent compression loading, positive values represent relieving)

Name of probe	No. of longwall panel	Average coal seam depth / Theoretical vertical stress (m) / (MPa)	Maximal change of vertical component of induced stress *) percentage (MPa)	Distance from longwall face at maximal change of vertical component of induced stress (m)	Distance from longwall face at 10% change of the theoretical vertical stress component (m)	Influence range of induced stresses according to CCBM monitoring (m)	Influence range of induced stresses according to monogram (see Pict.1) (m)
L1	140 914	690 / -17	- 3.9	9	33	>100	93
L2			- 6,6	5	7	100 - 120	
N1	140 912	720 / -18	+7,7	20	27	50	87
N3			- 5.3	4	28	60	
P1			+2	0	1	58	
C1	361 000	980 / -23	- 3.5	22	28	51	70
C2			+13.3	3	34	70 - 80	

The more significant changes of the mine-induced stress in the overlying rock, at a 10% level of change from the theoretical vertical stress component, arise at a distance from the longwall face of c. from 1 m to 35 m (see Table 2 and Figures 6 - 8). From the development of changes in the vertical component of the mining-induced stresses and real volume component I_1 depending on the progress of the longwall faces in different mining and geological conditions, both additional compression loading and relieving of the rock mass are obvious (see Table 2 and Figures 6 - 9, where negative values of the stress changes represent compression loading, and positive values represent relieving). Figure 6 shows that cyclical compression loading and relieving of the overburden sandstone bed is probably due to its sequential caving. A different case (probe P1 placed in an underlying bed) of mining-induced stress development is represented in Figure 7. It is evident that real volume component I_1 demonstrates compression loading development of the stress, while the development of changes in the stress vertical component shows relieving up to 2 MPa. This was caused by the effect of the development of significant compression loading in a horizontal plane at the site of CCBM probe P1 (see Figure 7).

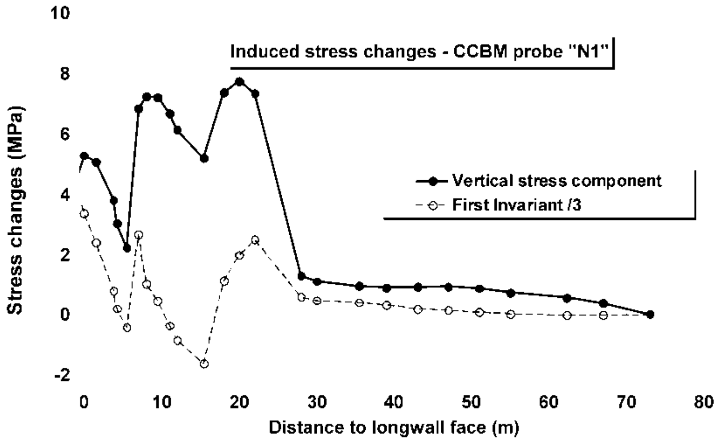

Figure 6 - Change of mining-induced stresses - CCBM probe N1

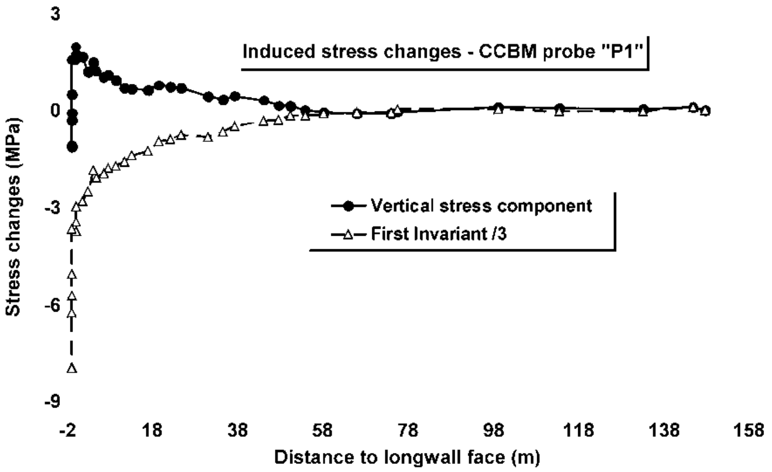

Figure 7 - Change of mining-induced stresses - CCBM probe P1

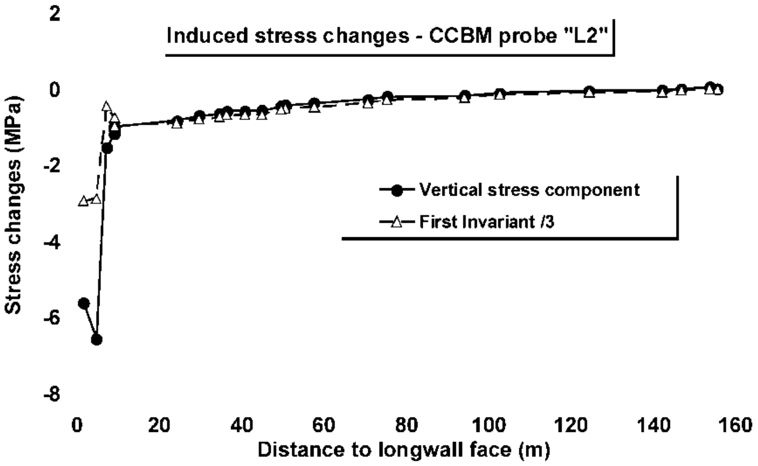

Figure 8 - Change of mining-induced stresses - CCBM probe L2

The next observed example of the development of mining-induced stress is represented in Figure 9 by measurement at the CSM colliery (Tables 1 and 2). Two CCBM probes C1 and C2 were installed in the overburden of the sandstone bed. In this area there were very simple mining conditions without any other mining work, and only the geological conditions were different at the placement of the CCBM probes C1 and C2. Probe C1 was placed in a relatively stable area without significant discontinuities and faults, while CCBM probe C2 was installed near to the regional fault "X", which probably affected the rock stress state at its location (see Figure 9). From the development of the mining-induced stresses on CCBM probes C1 and C2, we can see that the area of the rock mass lying under the inclined fault is relieved to a greater extent (about 56%) in comparison to value of the theoretical vertical stress component. The tensile character of all the principal components of the induced stress during the longwall face advance shows that the area close below the inclined fault is partially shaded, and thus the immediate influence of overburden loading might be deformed (Stas, *et al.*, 2011).

CONCLUSIONS

On the basis of the results of the trial carried out using CCBM monitoring it can be stated that using the CCBM method provides the possibility of performing more detailed analysis of the development of the rock mass stress state during geomechanical processes induced by geotechnical works or the effects of mining. The CCBM monitoring of the mining-induced stresses provided the opportunity to perform a more detailed analysis of the development of the stress state through a strata equilibrium dynamics induced by the underground mining of the coal seams by the longwall method. This method can specify the range of induced stresses in different mining and geological conditions, but for generalization or more precise conclusions it will be necessary to conduct more CCBM monitoring of the rock mass stress state in the Upper Silesian Coal Basin.

The first systematic pilot project of the rock stress monitoring by the CCBO and CCBM methods will be performed at the Lazy Colliery in coal seam No. 504 during mining of longwall panel No. 140 704 next year, 2013. The depth of cover of the coal seam is about 750 m, the length of the longwall face is 205 m and the thickness of the mined coal seam is 6 m. There will be 12 monitoring stations with both CCBM and CCBO probes in different mining and geological conditions in the area surrounding the longwall panel of interest (see Figure 10). From Figure 10, it is evident that monitoring stations are to be placed in different areas with different rock mass stress states. The original rock stress state is influenced by previous mining workings in the surroundings, with both overlying coal seams and coal seam No. 504. The main and tail gates of longwall panel No. 140 704 mostly pass through areas with additional rock mass stress as a consequence of mining seams in the overburden (coal seams No. 512 and 530) and in the level coal seam No. 504 (adjacent to longwall panel No. 140 702).

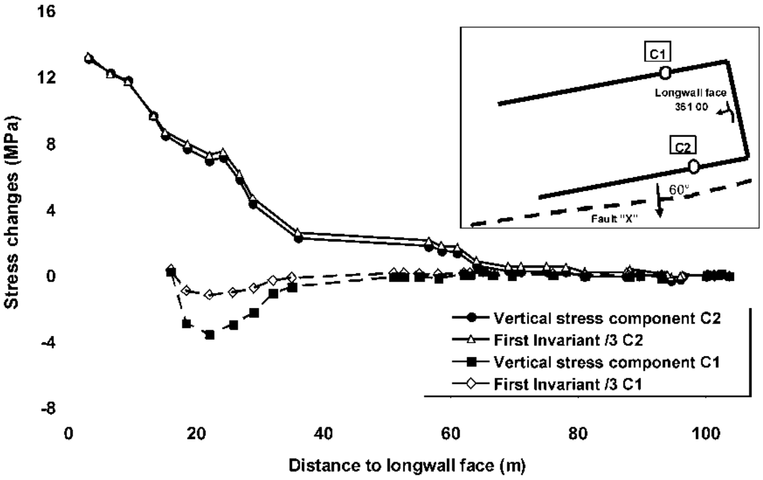

Figure 9 - Change of mining-induced stresses - CCBM probes C1 and C2

Figure 10 - Project for rock stress monitoring by CCBO and CCBM methods

Continuous knowledge of the stress state development can help to determine appropriate measures for managing the situation of high stress concentrations during mining below the competent roof strata for the next planned longwall panels in similar mining and geological conditions. This approach can also be helpful in ensuring the stability of underground structures, the selection of reinforcement systems and the *in situ* characteristics of the coal/rock mass.

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REFERENCES

Knejzlik, J and Rambousky, Z, 2008. Recent solution of the distributed control and measurement system in the Jeronym Mine - modular system, *Acta geodynamica et geomaterialia*, 5(2):205-212.

Knejzlik, J, 2004. Data transmission from seismic stations via network AGNES using GSM-GPRS technology, *Acta Montana. Ser. A, B*, 1(1):73-76.

OKD, DPB, a s, 2005. Working rules of rockburst prevention in OKR (in Czech), Paskov.

Obara, Y and Sugawara, K, 2003. Updating the use of the CCBO cell in Japan: overcoring case studies, *International Journal of Rock Mechanics and Mining Sciences*, 40:1189-1203.

Sugawara, K and Obara, Y, 1999. Draft ISRM suggested method for *in-situ* stress measurement using the compact conical-ended borehole overcoring (CCBO) technique, *International Journal of Rock Mechanics and Mining Sciences*, 36:307-322.

Stas, L, Soucek, K, Knejzlik, L, Waclawik, P and Palla, L, 2011. Measurement of stress changes using a compact conical-ended borehole monitoring, *Geotechnical Testing Journal*, 34(6):685-693.

Stas, L, Knejzlik, J and Rambousky, Z, 2005. Conical strain gauge probes for stress measurement, in *Proceedings of Eurock 2005 - Impact of Human Activity on the Geological Environment*, Leiden: A.A.Balkema Publishers, pp 587-592.