

University of Wollongong

Research Online

Faculty of Engineering and Information
Sciences - Papers: Part B

Faculty of Engineering and Information
Sciences

2017

Stress state monitoring in the surroundings of the roadway ahead of longwall mining

Petr Waclawik

Institute Of Clean Technologies, Institute of Geonics of CAS

Radovan Kukutsch

Institute Of Clean Technologies, Institute of Geonics of CAS

Petr Konicek

Institute Of Clean Technologies, Institute of Geonics of CAS

Jiri Ptacek

Institute Of Clean Technologies, Institute of Geonics of CAS

Vlastimil Kajzar

Institute Of Clean Technologies, Institute of Geonics of CAS

See next page for additional authors

Follow this and additional works at: <https://ro.uow.edu.au/eispapers1>



Part of the [Engineering Commons](#), and the [Science and Technology Studies Commons](#)

Recommended Citation

Waclawik, Petr; Kukutsch, Radovan; Konicek, Petr; Ptacek, Jiri; Kajzar, Vlastimil; Nemcik, Jan; Stas, Lubomir; Soucek, Kamil; and Vavro, Martin, "Stress state monitoring in the surroundings of the roadway ahead of longwall mining" (2017). *Faculty of Engineering and Information Sciences - Papers: Part B*. 462. <https://ro.uow.edu.au/eispapers1/462>

Research Online is the open access institutional repository for the University of Wollongong. For further information contact the UOW Library: research-pubs@uow.edu.au

Stress state monitoring in the surroundings of the roadway ahead of longwall mining

Abstract

Accurate knowledge of the stress-strain state of rock mass, not only in their vicinity but also in the wide surroundings of mine workings, is absolutely critical for precise support designing. Investigation of the rock stress is usually carried out by interpretation of the rock mass deformation processes, which can be relatively precisely observed and measured. In order to verify the stress state of the rock mass and changes in it induced by longwall mining, monitoring of changes in the rock mass stress in connection with the mine out of the longwall No. 371 202 was carried out. The seam extracted by monitored longwall has a thickness of approximately 2 m at a depth about 1100 m and lies within the Czech part of the Upper Silesian Coal Basin. Interpretation of the initial rock mass stress tensor and verification of its changes during longwall mining were the aims of this stress monitoring. A total of five probes were installed on the roof rocks of the main gate. Two compact conical-ended borehole overcoring probes were installed to obtain the pre-mining full stress tensor and afterwards three compact conical-ended borehole monitoring probes were installed to continuously monitor the stress state in the rock mass ahead of the advancing longwall. The monitored stress development contributes to our knowledge of stress distribution and its changes during excavation at great depth in multi-seam sedimentary deposits of the Upper Silesian Coal Basin.

Disciplines

Engineering | Science and Technology Studies

Publication Details

Waclawik, P., Kukutsch, R., Konicek, P., Ptacek, J., Kajzar, V., Nemcik, J., Stas, L., Soucek, K. & Vavro, M. (2017). Stress state monitoring in the surroundings of the roadway ahead of longwall mining. *Procedia Engineering*, 191 560-567. Ostrava, Czech Republic ISRM European Rock Mechanics Symposium EUROCK 2017

Authors

Petr Waclawik, Radovan Kukutsch, Petr Konicek, Jiri Ptacek, Vlastimil Kajzar, Jan Nemcik, Lubomir Stas, Kamil Soucek, and Martin Vavro



Symposium of the International Society for Rock Mechanics

Stress State Monitoring in the Surroundings of the Roadway Ahead of Longwall Mining

Petr Waclawik^{a*}, Radovan Kukutsch^a, Petr Konicek^a, Jiri Ptacek^a, Vlastimil Kajzar^a,
Jan Nemcik^b, Lubomir Stas^a, Kamil Soucek^a, Martin Vavro^a

^a*Institute of Geonics of the CAS, Institute of Clean Technologies, 708 00 Ostrava-Poruba, Czech Republic*

^b*University of Wollongong, Faculty of Engineering and Information Sciences, Wollongong, Australia*

Abstract

Accurate knowledge of the stress-strain state of rock mass, not only in their vicinity but also in the wide surroundings of mine workings, is absolutely critical for precise support designing. Investigation of the rock stress is usually carried out by interpretation of the rock mass deformation processes, which can be relatively precisely observed and measured.

In order to verify the stress state of the rock mass and changes in it induced by longwall mining, monitoring of changes in the rock mass stress in connection with the mine out of the longwall No. 371 202 was carried out. The seam extracted by monitored longwall has a thickness of approximately 2 m at a depth about 1100 m and lies within the Czech part of the Upper Silesian Coal Basin. Interpretation of the initial rock mass stress tensor and verification of its changes during longwall mining were the aims of this stress monitoring. A total of five probes were installed on the roof rocks of the main gate. Two compact conical-ended borehole overcoring probes were installed to obtain the pre-mining full stress tensor and afterwards three compact conical-ended borehole monitoring probes were installed to continuously monitor the stress state in the rock mass ahead of the advancing longwall. The monitored stress development contributes to our knowledge of stress distribution and its changes during excavation at great depth in multi-seam sedimentary deposits of the Upper Silesian Coal Basin.

© 2017 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Peer-review under responsibility of the organizing committee of EUROCK 2017

Keywords: stress-state; monitoring; coal minin; longwall

* Corresponding author. Tel.: +420-596-979-701; fax: +420-596-919-452.

E-mail address: petr.waclawik@ugn.cas.cz

1. Introduction

Knowledge, which should be as accurate as possible, of the stress–strain state in rock mass is the determining factor for the proper planning of roadway supports [1]. That is why stress monitoring, primarily of the changes induced by longwall mining, is considered within this research project. The locality of longwall No. 371 202 in a mine of the Ostrava-Karvina Coalfields (Upper Silesian Coal Basin – USCB) was chosen for the research.

To obtain the pre-mining full stress tensor, the modified overcoring method with the original name of the Compact Conical-ended Borehole Overcoring (CCBO) method [2, 3, 4] was used. It uses a conical probe designed by the Institute of Geonics in cooperation with Kumamoto University in Japan. The adjustment of the overcoring method consists mainly in omitting the overcoring phase (stress-releasing phase). The probe is glued directly in the conical shaped bottom of a borehole. In addition, the data logger is implemented in the conical probe, which enables continual stress monitoring directly in the conical shaped face of the measuring borehole. This Compact Conical-ended Borehole Monitoring (CCBM) probe can continuously monitor rock stress changes induced during longwall mining as well as natural changes of rock stress fields [1, 5, 6, 7].

The probes were installed into three boreholes drilled in the monitoring station in the main gate of No. 371 222 at the stationing 602.5 m. The spatial layout of the boreholes was designed according to both the technical limits of the CCBM method during installation, which determined the maximum length and inclination of the boreholes, and the lithological conditions in the overburden of the monitoring station.

The aim of the contractual research was to monitor and interpret the rock stress state using the CCBO and CCBM probes in the forefield of longwall face No. 371 202, located in the 2nd mining block at the CSM Mine. In addition to the measurement of rock mass stress state, the deformations around the main gate No. 371222 as well as load exerted on the support were carried out in the same measurement station [8]. The joint, simultaneous measurements of roadway deformation and load together with continuous monitoring in situ stresses are a contribution to understanding roadway support behavior during longwall mining at the great depth in multi-seam sedimentary deposits of the Upper Silesian Coal Basin.

2. Methods

2.1. Natural conditions in monitored area

Longwall No. 371 202 is situated in the western part of the 2ndA block in the CSM Mine. Above the mined coal seam No. 37a (530), there is a 600 m thick complex carboniferous rock mass with overlying tertiary sedimentary rock strata of 450 m with a quaternary soil overburden approximately 20 m in thickness. The lithological sequence is complicated because the river sedimentation has markedly influenced the sedimentary process. The rock mass lithology is typical for the Sedlove Member facies. Competent rocks, especially sandstones and conglomerates, predominate in the lithological sequence. Siltstones, or claystones, occur only locally in the vicinity of the coal seams, especially in the seam floor. The head of coal seams is often eroded by overlying sandstones or conglomerates. Sometimes, the coal seams are completely eroded. The lithological sequence in the vicinity of coal seam No. 37a is presented in Fig. 3. Coal seam No. 36b is the nearest coal seam above seam No. 37a. The vertical distance between coal seam No. 37a (530) and coal seam No. 36b (546) is about 25 m. Its immediate roof consists of a coarse-grained sandstone layer that is 1.5 m thick. It is followed by 8 m thick medium-grained conglomerate with 2 m thick intercalation of coarse-grained sandstone. The lithological sequence is then formed by 7 m thick medium-grained sandstone and a 1.2 m thick siltstone layer up to the coal seam No. 36b (546).

Longwall No. 371 202 is situated in the vicinity of a protective pillar of the CSM-North shaft (see Fig. 1). There are several faults of regional importance in the area concerned. There is a wide tectonic zone of Albrechtice Fault in the western area with a total amplitude of up to 420 m. The dip of the fault ranges from 60° to 65° towards the west. Albrechtice Fault is the leading fault of Karvina Throw [9]. In the northern area, “Fault A” is a normal fault with an amplitude of up to 100 m in the vicinity of Albrechtice Fault (see Fig. 1) and a dip of 60° towards the north. “Fault B” limits the area concerned in the south. A very variable course is typical for the fault. “Fault B” is accompanied by several antithetic and synthetic faults. Inside the tectonic blocks that are surrounded by faults of regional importance, the rock mass are typically disturbed by a system of small so-called seam faults. The area described

above is only minimally disturbed by the seam faults. There are a few normal faults with E–W strike in the area of the longwall No. 371 202. Their vertical amplitude does not exceed 2 m.

The bedding of the seam is sub-horizontal. The strata dip oriented in the NE direction is 9° . Exceptionally, the local dip of the coal seam can reach up to 15° . The centre of longwall No. 371 202 is located at a depth of approximately 1050 m below the surface.

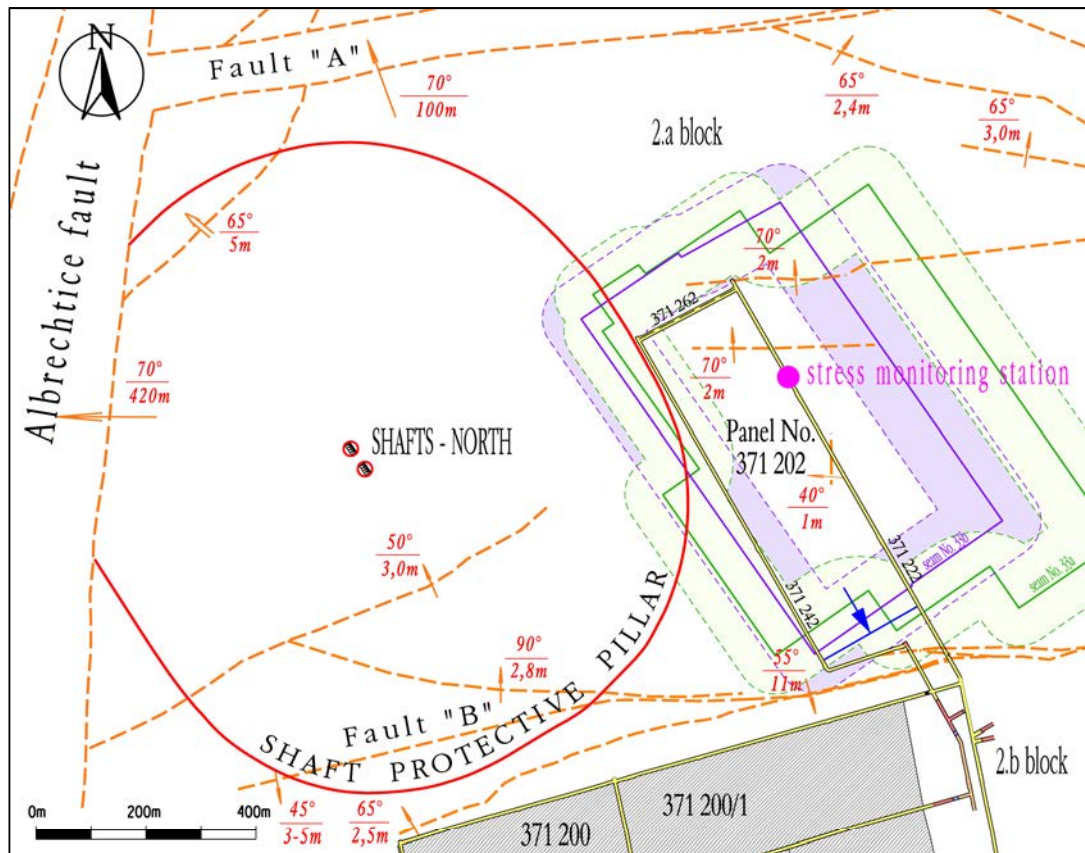


Fig. 1. Faulted structure of area concerned, position of stress monitoring station on maingate No. 371 222 and definition of influenced areas of additional stress (edges of mined out areas and zones of influence) in 37a seam.

2.2. Methodology of monitoring

The problems of rock stress and its determination have been under investigation at the Institute of Geonics for a long time. Due to the impact of deep underground mining activity, a method for the determination of rock stress and its variations is currently demanded. Development of the device 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 (CCBO) system [10, 11]. 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 probe were developed at the Institute of Geonics: the first is equipped with a microprocessor for remote and wireless automatic recording of measured data in the probe's internal memory (CCBO), while the second can be connected to a data-logger and a power supply via a cable. The latter, called the 'compact conical ended borehole monitoring method' (CCBM) device, was used for long-term monitoring of stress tensor changes [3, 5, 6].

The CCBM method is based on similar principles to the CCBO method except for the 'destructive' overcoring phase, which 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. the reference state) can be determined. This is the principal difference between the CCBO and CCBM methods. The evaluation of measurements remains the same as in the case of the CCBO technique.

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°. The probe is glued directly in the conical shaped bottom of the borehole. The CCBM probe, which can be connected to an external control unit by cable, thus enables the observation of stress changes in the rock mass (induced, for example, by underground mining activities). Periodic manual reading of data can be done using a computer or data-logger. A continuous data-recording system is also used. However, the approval process allowing the use of this equipment in the explosive atmosphere is in progress. Periodic manual reading of data was carried out by Personal Digital Assistant (PDA) as part of the stress state monitoring of the rock mass ahead of longwall No. 371 202. The data concerning stress changes in all three CCBM probes were read daily with only minor exceptions (technical problems with the reading device or oxidation of cable contacts).

2.3. Design of monitoring of the stress state of the rock mass

Monitoring of the stress state of the rock mass was designed in one monitoring station at maingate No. 371 222 at the stationing of 602.5 m. Due to specific local conditions at the time of installation, the monitoring station was located about 180 m from the installation roadway No. 371 262. The spatial arrangement (see Figs. 2 and 3) of the monitoring station was designed with regard to the technical limits of installation boreholes. Especially the maximal length of the installation borehole was limited.

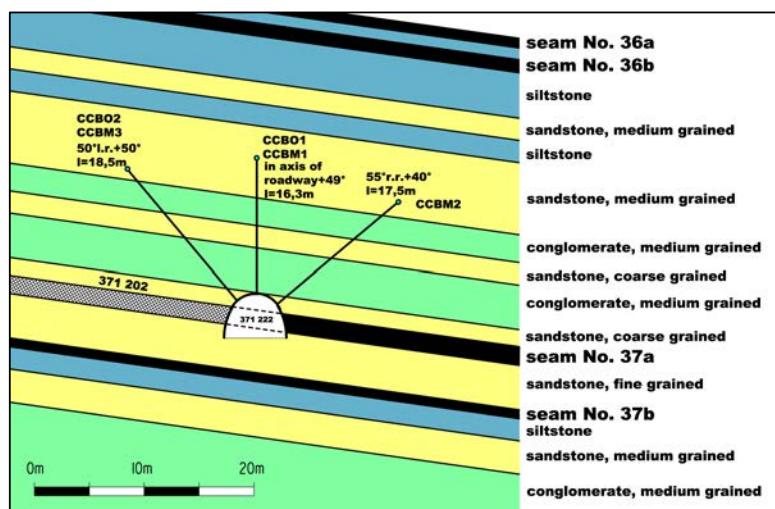


Fig. 2. The lithological sequence in the vicinity of the stress monitoring station and position of CCBM(O) gauges probes with installation boreholes – cross-section. Note: l.r. – left rib, r.r. – right rib.

Three CCBM gauge probes were installed to independently monitor the stress state of the rock mass above longwall No. 371 202 (CCBM 3), above the maingate No. 371 222 (CCBM 1) and right from maingate No. 371 222 (CCBM 2). In particular, the probe CCBM 2 was located above the area of projected longwall No. 371 204, which will be mined in the near future. In the first stage, two CCBO gauges probes were installed in order to determine the total pre-mining stress tensor. The probe CCBO 2 was installed above longwall No. 371 202 (on the left rib of maingate No. 371 222) and the probe CCBO 1 was installed above the axis of maingate No. 371 222. The positions of the CCBO and CCBM probes can be clearly seen in Figs. 2 and 3.

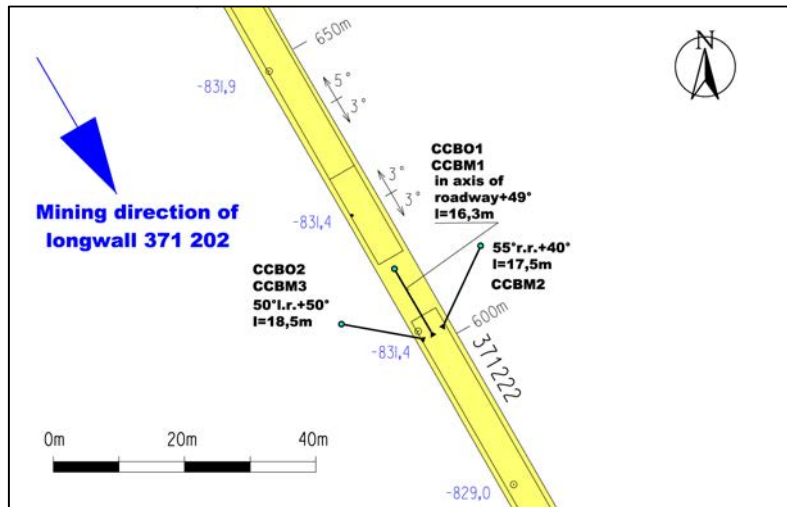


Fig. 3. Position of CCBM(O) gauges probes and installation boreholes – top view.

3. Results and discussion

3.1. Assessment of initial stress tensor

Borehole drilling, overcoring (using CCBO), and installation of CCBM probes were completed before starting the longwall excavation. The total stress tensor was detected using the overcoring CCBO method in two boreholes (see Figs. 2, 3). The interpreted principal stress values are indicated in Table 1 and Fig. 4. In Fig. 4, the maximum stress component of S_1 , the medium stress component of S_2 , and the minimum stress component of S_3 are indicated. The assessed magnitudes and spatial orientation of the principal stress components are listed in Table 1.

Table 1. Values of principal stress components and their spatial orientation (CCBO1 and CCBO2).

Probe	Maximum stress S1 [MPa]	Dip of axis S1 [°]	Direction S1 [°]	Medium stress S2 [MPa]	Dip of axis S2 [°]	Direction S2 [°]	Minimum stress S3 [MPa]	Dip of axis S3 [°]	Direction S3 [°]
CCBO1	16.0	-7	118	8.1	70	229	6.8	-18	26
CCBO2	17.0	-14	56	9.2	-73	203	6.1	9	324

The results of the spatial distribution of all stress tensors found by overcoring on the CCBO 1 probe are presented in Fig. 4. In the figure, the directions of the principal stress components are depicted using stereographic projection in the lower hemisphere. The maximum stress component axis is represented by a ring, the medium stress component axis by a square, and the minimum stress component axis by a triangle. Horizontal stresses and their magnitudes and directions are significant features of the stress distribution in the vicinity of the roadway. That is why they were analysed in the course of our experiment. In Fig. 4, their direction and aliquot sizes projected onto the horizontal plane are shown. S_H denotes the maximum horizontal stress and S_h the minimum horizontal stress. The greyish double line represents the direction of roadway No. 371 222, in whose vicinity the CCBO probes are situated.

The theoretical vertical stress at the depth of 1050 m, where the stress monitoring took place, is approximately 24 MPa. The maximum stress value S_1 (17 MPa) interpreted on the probe CCBO 2 is influenced by the protective effect of the mined out area in seam Nos. 33a and 33b in the overburden (see Fig. 1). The maximum stress S_1 (16 MPa), which was interpreted from the data of the probe CCBO 1, can be similarly interpreted. It is significant

that the magnitude of the maximum horizontal component S_H is, in the case of the probe CCBO 1, twice (vertical stress of 8.1 MPa) the magnitude of the vertical stress component. In the case of the probe CCBO 2, it is 1.7 times (vertical stress of 9.6 MPa) the magnitude of the vertical stress component. Thus, the previously observed trend of the maximum stress value being caused in the horizontal plane has been confirmed.

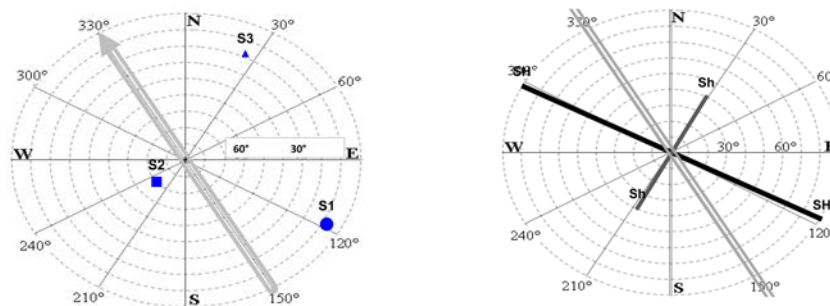


Fig. 4. Spatial orientation of principal stress components (on left) and directions of the maximum horizontal S_H component and minimum horizontal component S_h (on right) calculated from CCBO1 probe (greyish double line represents the direction of the roadway No. 371 222).

In comparison with previous results of stress state monitoring in the rock mass of the CSM mining area [13,14,15], it is evident that in the surroundings of roadway No. 371 222, the direction of the maximum horizontal stress component (S_H) is rotated in relation to the formerly interpreted direction (roughly NNW–SSE). This is probably caused by an irregular stress distribution on the boundary of the shaft protective pillar, where multiple additional stresses are caused by the edges of the mined out areas in the seam overburden, which are stopped in a similar vertical line.

3.2. Monitoring of stress changes ahead of longwall face

Longwall mining started on 1 May 2015. Stress changes of the stress tensor components of Sigma 1, Sigma 2, and Sigma 3 ahead of the longwall face advancing toward the probes CCBM 2 and CCBM 3 are documented in Fig. 5. The stress tensor components are graphically distinguished. Unfortunately, some strain gauges on the probe CCBM 1 stopped working correctly and thus they were not used for the calculation of the full stress tensor. It was probably caused by local fracturing of the rock mass in the area of the probe installation.

The dependence of the stress changes (Sigma 1, Sigma 2, and Sigma 3) on the distance to the longwall face measured on the probe CCBM 3 is depicted in Fig. 5. This probe was installed into the roof rocks of the seam over the mined area of the longwall (see Figs. 2 and 3). The increase in significant stress changes started at a distance of 60 m from the longwall face, as is evident from the graph (Fig. 5). The minimum stress component of Sigma 3 declined and oscillated at negative (tensile) values, as did the medium stress component of Sigma 2. In contrast, the maximum stress component of Sigma 1 increased and reached its maximum (13.6 MPa) at the closest distance to the longwall face (4.9 m; 13 October 2015). The development of changes of the stress components monitored by the probe CCBM 3 corresponds to the experience of stress changes ahead of the longwall face during the longwall mining in the Czech part of the USCB. The range of additional stresses from the advancing longwall face detected by the probe CCBM 3 corresponds to the range of additional stresses for the conditions of longwall No. 371 202 (parameter $L = 70$ m), which is calculated within the local rockburst prognosis [6, 12].

The dependence of stress changes (Sigma 1, Sigma 2, and Sigma 3) on the distance to the longwall face measured on the probe CCBM 2 is shown in Fig. 5. This probe was installed into the roof rocks east of the mined area of longwall No. 371 202 (see Figs. 2 and 3). This was the only probe that monitored stress changes even behind the longwall face. Stress changes started to increase significantly at the distance of 25 m from the longwall face, which is evident from the graph (Fig. 5, Sigma 1). The minimum stress component of Sigma 3 oscillated at negative (tensile) values ahead of the longwall face as well as behind it. A similar development was recorded for the medium stress component of Sigma 2, which, however, changed rapidly at the distance of 25 to 27 m behind the longwall

face. Insignificant changes in the middle part of the graph in Fig. 5 (mainly of Sigma 2 and Sigma 3) can be interpreted as a local response of the rock mass where the probes were installed. In contrast, the stress component of Sigma 1 increased behind the longwall face and reached its maximum at the distance of 40 m behind the longwall face (31 MPa). When we compare the development and magnitude of the stress changes on the probes CCBM 2 and CCBM 3 (Fig. 5), we can conclude that an important increase of stress changes on the probe CCBM 2 in the area of the non-mined longwall (outside of the longwall contour) occurred considerably later (i.e. behind the longwall face) than on the probe CCBM 3. This situation corresponds to the geomechanical conditions in the area of the investigated longwall. The roof rocks outside of the area of the longwall fractured later (close to the longwall face) than the roof rocks in the area of the mined longwall (probe CCBM 3). The magnitude of the stress changes (e.g. Sigma 1) is considerably higher than that on the probe located in the roof rocks in the area of the mined longwall. This situation can be explained by the increased loading of competent roof rocks outside of the longwall. The rock mass in this area is fractured less than in the area of the mined longwall, as there is no caving behind the longwall face.

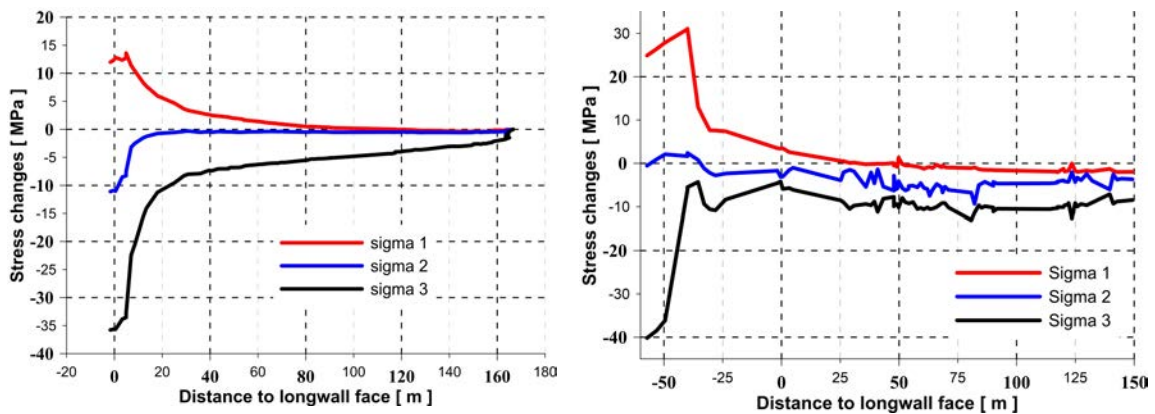


Fig. 5. Dependence of stress changes components on distance to longwall face - CCBM3 on left and CCBM2 on right.

4. Conclusion

The objective of the stress monitoring carried out in the forefield of coalface No. 371 202 was to verify the original state of the rock mass stress tensor and to study its changes during the coal seam exploitation. In this case, stress changes in rock can be expected due to the coalface (longwall) pressures. In addition, the impacts of the previous mining activities were considered.

The theoretical vertical stress at a depth of 1050 m, where the primary rock stress measurements were carried out, is approximately 24 MPa. The interpreted maximum rock stress of S1 (17 MPa) from the probe CCBO 2 is affected by the additional stress of the mined seam Nos. 33a and 33b in higher overburden. The maximum stress of S1 (16 MPa) measured by the probe CCBO 1 can be interpreted similarly. The magnitude of the maximum component of the horizontal stress (S_H) is significant. In the case of the probe CCBO 2, the maximum horizontal stress component (S_H) is 1.7 times higher than the observed vertical stress S_v (9.6 MPa). In the case of the probe CCBO 1, it is almost twice as high as the observed vertical stress S_v (8.1 MPa). The previously observed trend for the maximum stress value to be caused in the almost horizontal plane was thus confirmed.

The expected changes in the rock stress caused by the loading ahead of the longwall face were recorded by the CCBM monitoring probes. The course of changes in the rock stress confirmed the knowledge based on the distribution of rock stress fields and deformation processes occurring in the vicinity of the longwall gates during the coal seam exploitation. The considerations and theoretical assumptions concerning the distances, where the additional stresses caused by different sources affect the rock mass stress state, were also proven to be correct. In addition to the coalface pressures in the forefields, the effects of mined out edges in the overburden, goafs in the mined seams, and major faults representing brittle fractures in the rock mass were analysed. Significant

anisotropy of the rock mass was reconfirmed. The anisotropy represents significant local changes of the geological properties and, consequently, causes changes in the geomechanical properties of the rock mass.

The verification of the total stress tensor and its changes in relation to the changes of sequential deformation of a stress field due to the stress induced ahead of the longwall face can be considered as essential. Although some technical problems occurred in the electrical strain gauges of one probe, it was generally confirmed that the maximum increase of the largest rock stress component reached 2.27 times its original value. As already mentioned, the expected distance at which the increase in the rock stress occurred in front of the longwall face was also confirmed. In the particular case of the probe CCBM 3, the rock stress increase was observed at a distance of 40 m in front of the longwall face. However, a gentle increase of the value of the maximum rock stress component had been already monitored at a distance of 60 m. This corresponds to the existing concepts based on the long-term observations of stress manifestations in the Carboniferous rock mass in the Upper Silesian Coal Basin [1, 6, 7].

Acknowledgements

This article was written in connection with the Project Institute of Clean Technologies for Mining and Utilization of Raw Materials for Energy Use (reg. no. CZ.1.05/2.1.00/03.0082 and MSMT LO1406), which is supported by the Research and Development for Innovations Operational Programme financed by the Structural Funds of the European Union and the Czech Republic project for the long-term conceptual development of research organisations (RVO: 68145535). This research project was subcontracted to the company OKD, which was one of the participants in the solved project of Coal & Steel – AMSSTED (Advancing Mining Support Systems to Enhance the Control of Highly Stressed Ground, RFCR-CT-2013-00001).

References

- [1] J. Ptacek, P. Konicek, L. Stas, P. Waclawik, R. Kukutsch, The rotation of principal axes and changes of stress due to mine induced stresses, *Canadian Geotechnical Journal*, 52, No. 10 (2015) 1440–1447.
- [2] L. Stas, J. Knejzlik, Z. Rambousky, Development of conical probe for stress measurement by borehole overcoring method. *Acta Geodyn. Geomater*, Vol.1, No. 4 (2004) 93–98.
- [3] L. Stas, J. Knejzlik, Z. Rambousky, 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 2005; pp. 587–592.
- [4] P. Waclawik, L. Stas, J. Nemcik, P. Konicek, T. Kalab, Determination of stress state in rock mass using strain gauge probes CCBO, *Procedia Engineering* 149 (2016) 544–52.
- [5] L. Stas, K. Soucek, L. Knejzlik, P. Waclawik, L. Palla, Measurement of Stress Changes Using a Compact Conical-Ended Borehole Monitoring, *Geotechnical Testing Journal* 34(6) (2011) 685–693.
- [6] K. Soucek, P. Konicek, L. Stas, J. Ptacek, P. Waclawik, Experimental Approach to Measure Stress and Stress Changes in Rock ahead of Longwall Mining Faces in Czech Coal Mines, in: *Proceedings of the 2013 Coal Operators' Conference*, Wollongong, Australia, 14–15 February 2013, pp. 115–123.
- [7] L. Stas, K. Soucek, J. Knejzlik, Z. Nohejl, T. Rutar, L. Palla, P. Waclawik, Measurement of stress tensor and stress changes induced by progress of long wall, in: *Prace naukowe GIG, Mining and Environment*. Vol. 7 Katowice: Zespol Wydawnictwi i Usług Poligraficznych GIG, 2008, pp. 245–258.
- [8] Z. Lubosik, P. Waclawik, P. Horak, A. Wrana, The influence of in-situ rock mass stress conditions on deformation and load of gateroad supports in hard coal mine, *Procedia Engineering* (2017), in print.
- [9] R. Grygar, P. Waclawik, Structural-tectonic conditions of Karvina Subbasin with regard to its position in the apical zone of Variscan accretion wedge, *Acta Montanistica Slovaca* 16 (2) (2011) 159–175.
- [10] K. Sugawara, Y. Obara, 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 (1999) 307–322.
- [11] K. Sugawara, Y. Obara, Updating the use of the CCBO cell in Japan: overcoring case studies, *International Journal of Rock Mechanics and Mining Sciences* 40 (2003) 1189–1203.
- [12] OKD, DPB, a. s., *Working rules of rockburst prevention in OKR (in Czech)*, 2005, Paskov.
- [13] J. Ptacek, R. Grygar, P. Konicek, P. Waclawik, The impact of Outer Western Carpathian nappe tectonics on the recent stress-strain state in the Upper Silesian Coal Basin (Moravosilesian Zone, Bohemian Massif), *Geologica Carpathica* 63 (2012) 3–11.
- [14] P. Waclawik, J. Ptacek, P. Konicek, R. Kukutsch, J. Nemcik, Stress-state monitoring of coal pillars during room and pillar extraction, *Journal of Sustainable Mining* 15 (2) (2016) 49–56.
- [15] J. Ptacek, P. Konicek, K. Soucek, L. Stas, P. Waclawik, R. Grygar, Exploration of the recent stress fields in the Czech part of the Upper Silesian Coal Basin, in: *Proceedings of European Rock Mechanics Symposium, EUROCK 2010*, Lausanne, Switzerland, 2010, pp. 685–688.