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ASSESSMENT OF COAL PILLAR STABILITY AT GREAT DEPTH

Petr Waclawik¹, Radovan Kukutsch², Jan Nemcik³

ABSTRACT: The trial operation of the room and pillar method has been implemented at the shaft protective pillar of CSM coal mine, Czech Republic. Mining depth of the room and pillar trial ranged from 700 to 900 metres, being perhaps the deepest room and pillar coal mining in the world. An extensive monitoring system was implemented to measure the load profile across the coal pillars and the deformation characteristics in the pillars during mining. Stress-deformation monitoring was essential as this was the first application of the conventional room and pillar mining method within the Upper Silesian Coal Basin mines. The results of stress-deformation monitoring allowed pillar loading, yielding characteristics and coal pillar stability to be described. This data and other analyses are essential for establishing procedures for a safe room and pillar method of mining within the Upper Silesian Coal Basin. The results are also important for global mining, as many coal producers will reach higher mining depth in the near future.

INTRODUCTION

A considerable amount of coal reserves are located in protection pillars that lie under built-up areas within actively mined regions in the Czech part of the Upper Silesian Coal Basin (USCB). The commonly used controlled caving longwall mining method is not applicable in these areas because significant deformation of the surface is not permitted. For this reason the modified room and pillar method with stable coal pillars has been tested in order to minimise strata convergence. The trial operation of room and pillar method has been implemented in the shaft protective pillar (see Figure 1) where no mining was carried out in the past. Mining depth of the room and pillar trial ranged from 700 to 900 metres. It is perhaps the deepest room and pillar coal extraction in the world.

A stress-deformation monitoring program was essential as this was the first application of the conventional room and pillar mining method within the USCB. More than six kilometres of roadways were driven within three panels during the last three years. The last panel No. II was finished in September 2017. An extensive monitoring system was implemented to measure the load profile across the coal pillar and the deformation characteristics in the pillar during mining. Two monitored pillars diamond in shape and with slightly irregular sides were approximately 860 m² and 1200 m² in size in the first mined panel "V" and three monitored pillars of approximately 590 m², 590 m² and 730 m² in size were in the panel "II". The monitored pillars were selected in different geotechnical conditions to study the behaviour of rock masses.

The adequate stability of coal pillars left behind is the prerequisite to minimise strata convergence and mining subsidence. The room and pillar mining method is usually implemented on the basis of gained experience and practices used elsewhere while taking into consideration different natural conditions and depths. The coal pillar sizes, calculated using accepted empirical methods (e.g. Salamon, 1970; Hustrulid, 1976; Bienawski, 1984; Mark and sChase, 1997 and Chase, Mark and Heasley, 2003), were uncertain due to complex strata geology. As there is no relevant experience of using this method in the USCB, an extensive monitoring system was implemented to enable the mining trial to continue safely.

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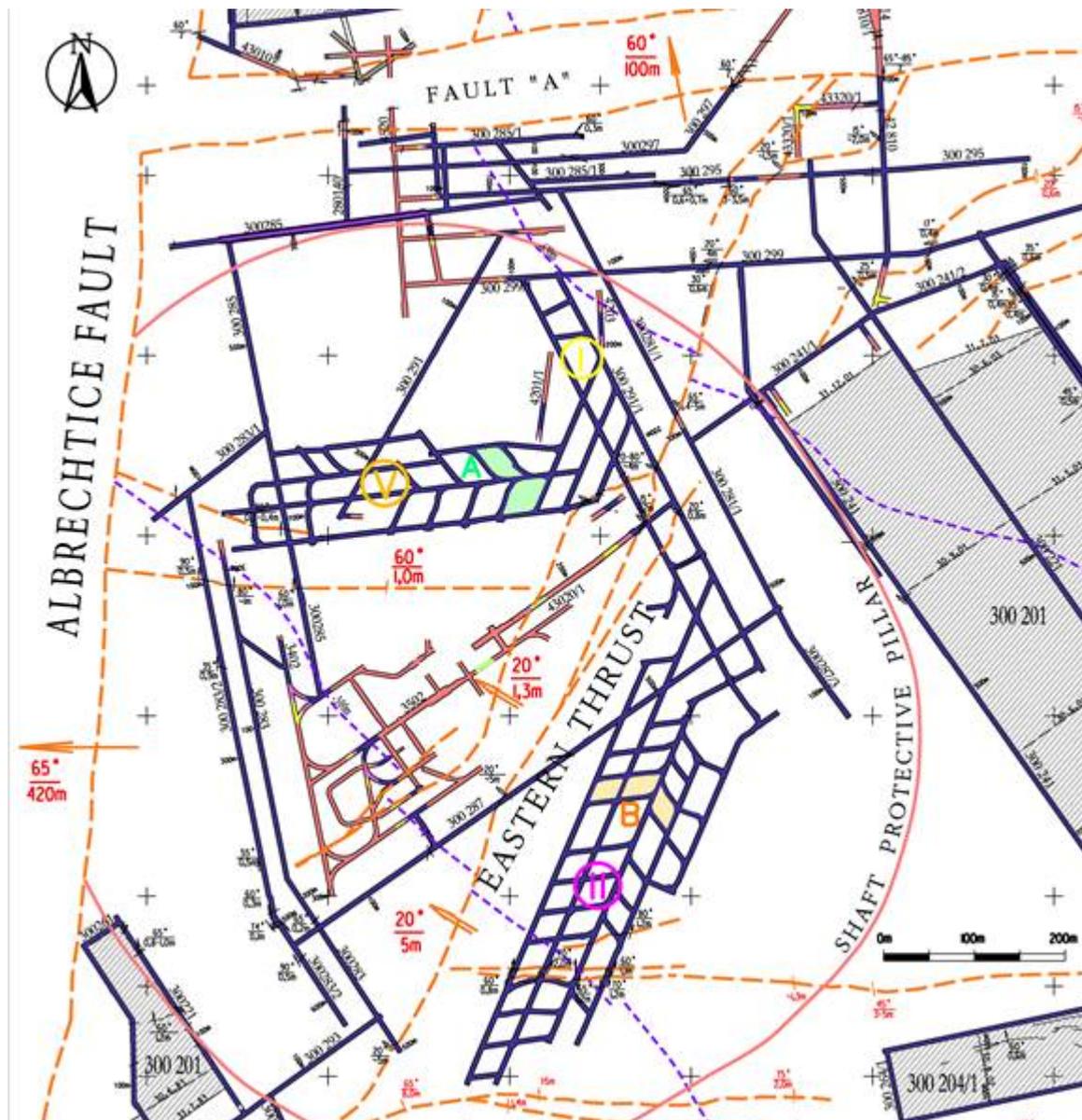


Figure 1: Tectonic situation and position of monitored pillars in panel V (locality A - green) and panel II (locality B - brown).

ENGINEERING GEOLOGY

The geological setting in the area of shaft protective pillar CSM-North Mine is quite complex. The targeted coal seam (No. 30) is at a depth of approximately 700 m to 900 m below the surface. The thickness of the coal seam is extremely variable (from 180 to 520 cm) within the proposed mining area. The thickness of the coal seam ranges from 300 cm to 350 cm in the monitored pillars. The strata dip oriented in the North-East direction ranges from 8° to 17°. Occasionally the dip of the coal seam can reach up to 20°. There are several faults of regional importance in the area of the CSM-North shaft safety pillar (see Figure 1). The significant regional tectonic fault zone "Eastern Thrust" (Waclawik et al. 2013, Grygar and Waclawik 2011) divides the area of the protective pillar into two separate blocks with different geotechnical conditions. The overthrust zone has a significant impact on the deformation characteristic of coal pillars.

The vertical profile around coal seam No. 30 is shown in Figure 2. The immediate roof above the seam consists of a thin 0.1 m thick sandy claystone layer. This layer is relatively weak and disturbed with slickensides present on the surrounding bedding planes. Above this is a 5 m thick siltstone overlain with 6 m thick medium-grained sandstone and a 0.3 m thick coal

seam. The immediate floor below the seam consists of a 0.5 m thick siltstone underlain by a 0.6 m thick coal seam No. 31. The interbedded siltstone and sandstone layers follow down to coal seam No. 32 located around 10 m below seam No. 30. The strata characteristics and geomechanical properties of rock mass have been predetermined for pillar loading and yielding characteristics. The strength of roof rocks is extremely high. Uniaxial Compressive Strength (UCS) of immediate roof (siltstone) determined from cores of exploratory boreholes ranges from 69 MPa to 129 MPa, 105 MPa on the average (Waclawik et al. 2017). UCS of overlying sandstone ranges from 70 MPa to 168 MPa, 116 MPa on the average. On the other hand the strength of floor rocks and the coal seam are lower. The strength of floor (clayey siltstone to siltstone) is variable depending on the content of clay. UCS of the floor ranges from 45 MPa to 80 MPa, 60 MPa on the average. UCS of coal ranges from 9.2 MPa to 22 MPa, 14 MPa on the average.

DESIGN OF GEOTECHNICAL MONITORING

The monitoring of the stress and deformation state in the rock mass is necessary precondition for a successful verification of the room and pillar method and its next application in conditions that may vary elsewhere in USCB. In the context of stress and deformation, the monitoring program covers the deformation of rock overlaying the room and pillar roadways, pre-mining stress measurements and stress change monitoring in rock and coal during mining, deformation of coal pillars, load on the installed cable bolts and roadway convergence monitoring. In addition, seismology and seismo-acoustic monitoring was carried out to characterise yielding of rock mass during and after mining. The precise monitoring of surface subsidence was also implemented within the shaft protective pillar.

Locality A

Monitoring was more complex in locality A due to missing previous experiences with strata behaviour during room and pillar excavation. The instrument locations are shown in Figure 2. To monitor roof deformation, fourteen pairs of 5-level multipoint extensometers monitored roof displacements (VE1 to VE14 in Figure 2.) and eleven strain gauged rockbolts (VS1 to VS11 in Figure 2) were installed at various locations. Four 5-level multipoint rib extensometers (VEH1 to VEH8 in Figure 2) were installed within each monitored pillar to measure displacements of all sides. Vertical and horizontal displacements together with the convergence measurements (VP1 to VP9 in Figure 2), changes in vertical pillar loads and periodic 3D laser scanning of the overall roadway displacements (roof, rib and floor heave) provided detailed data to evaluate panel stability.

To describe the pre-mining stress-state conditions of the coal pillar area, two 3-dimensional CCBO stress overcoring cells (Obara and Sugawara, 2003; Nakamura, 1999 and Stas, Knežlik and Rambousky, 2004) were used (VCCBO1 and VCCBO2 in Figure 2) and eight 3-dimensional CCBM stress change monitoring cells (Stas, Knežlik, Palla, Soucek and Waclawik, 2011; Stas, Soucek and Knežlik, 2007) were installed to measure stress changes during mining (VCCBM1 to VCCBM8 in Figure 2). Four 1-dimensional hydraulic stress monitoring cells were installed at various depths in each pillar to measure vertical stress (VSC1 to VSC8 in Figure 2), seven hydraulic dynamometer load cells measured the cable bolt loads installed at the roadway intersections (VD1 to VD7 in Figure 2).

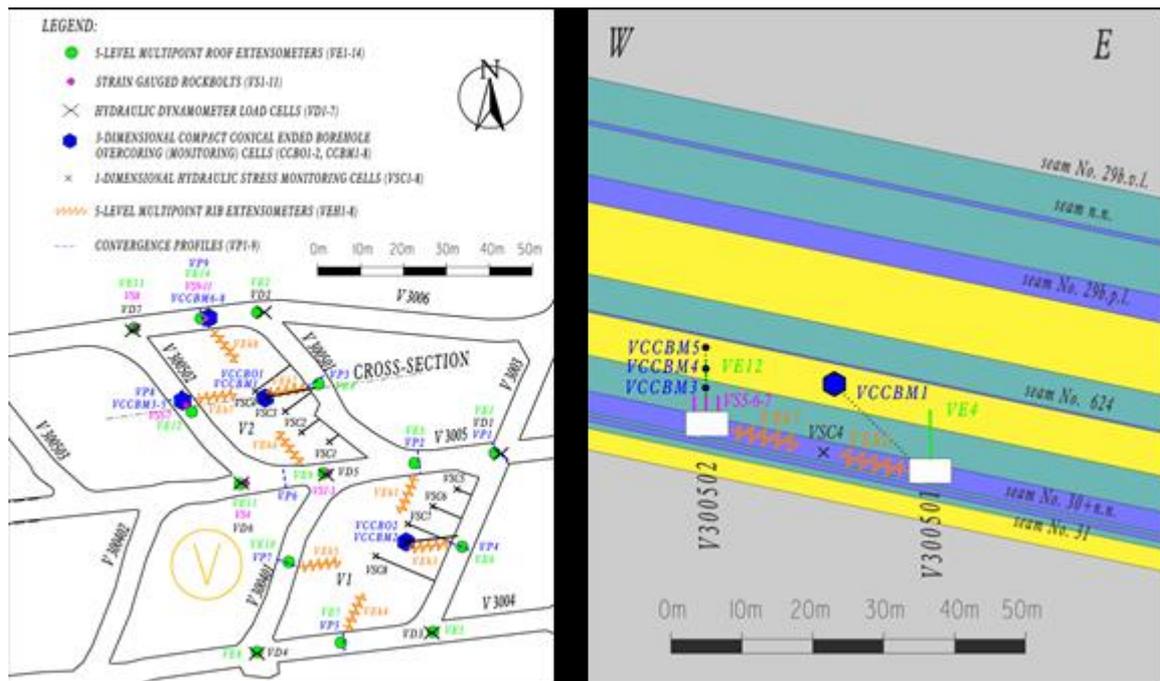


Figure 2: Positions of the monitoring equipment in locality A and cross-section across monitored pillar V2 (on the right). Coal seams – blue, siltstones – green, sandstones – yellow (Waclawik et al. 2016).

Locality B

In locality B the number of monitoring instruments was reduced and supplemented with information from the monitored results in locality A. Due to minimal roof displacements during the whole time of monitoring in locality A, the strain gauged rock bolts and hydraulic dynamometers were not installed in locality B. The vertical 5-level multipoint extensometers were substituted with the cheaper 3-level multipoint extensometers. The instrument locations are shown in Figure 3. Other instruments used in locality B were the same as the instruments located in locality A. To monitor roof deformation, nineteen of 5-level multipoint extensometers were installed in the roof (IIE1 to IIE19 in Figure 3). Twelve 5-level multipoint rib extensometers (IIEH1 to IIEH12 in Figure 3) measured displacements within three monitored pillars (II1, II2 and II3). The convergence measurements in twelve stabilised profiles (IIP1 to IIP12 in Figure 3) were carried out. To monitor the stress-state of coal pillars three 3-dimensional CCBM stress change monitoring cells (IICCBM1 to IICCBM3) and five 1-dimensional hydraulic stress monitoring cells (IISC1 to IISC5 in Figure 3) were installed. Pre-mining stress-state was verified by two 3-dimensional CCBO stress overcoring cells.

RESULTS AND DISCUSSION

The displacements and development of deformation provide the data to assess coal pillar stability. The results of pillar displacement monitoring allowed the monitored pillars deformation characteristics to be defined. The data showed that the monitored coal pillar sides displaced substantially into the roadway mainly due to a large vertical stress field and the presence of weak slickensides above and below the seam. This mechanism caused large floor heave, rib convergence and relieved some of the confining stresses that usually build up within a pillar, therefore weakening the coal and causing the pillar to yield (Waclawik et al. 2016). the deformation mechanism presented here is supported by minimal displacement of roof rocks due to its high strength.

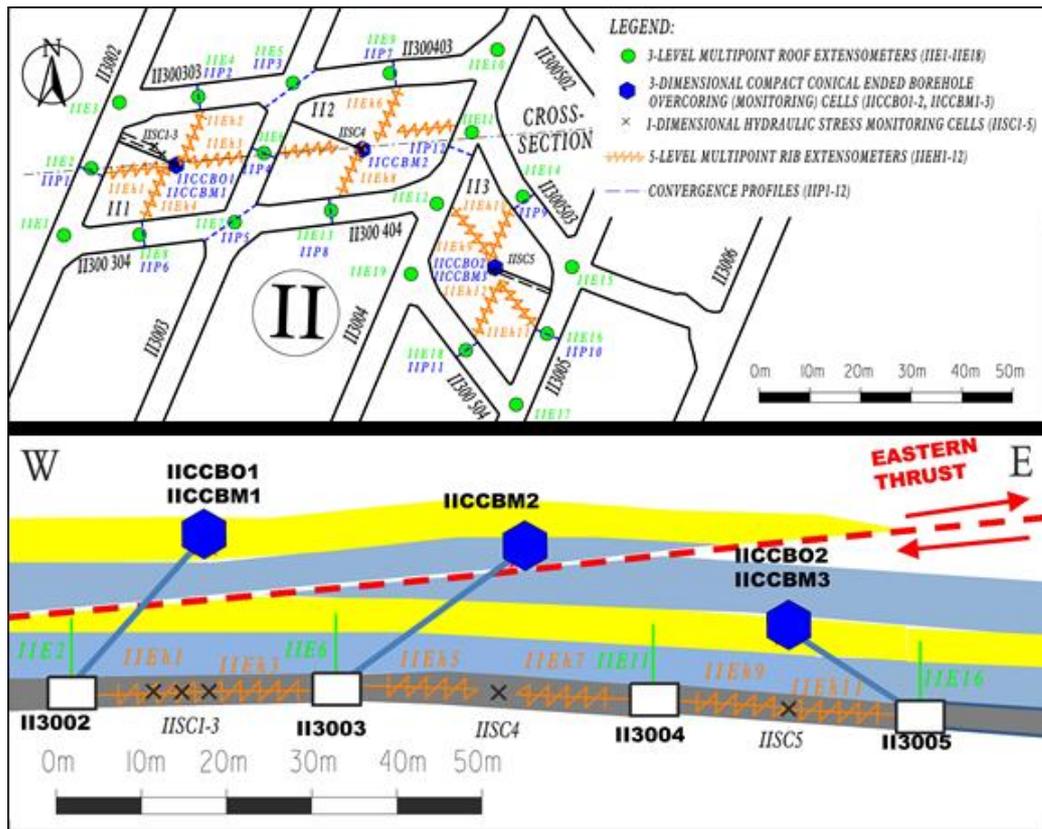


Figure 3: Instrument positions in the monitored pillars in locality B and cross-sections across monitored pillar II1, II2 and II3. Coal seams – grey, siltstones – blue, sandstones – yellow.

Vertical displacement measurements

The displacements of roof recorded by vertical extensometers reached insignificant values in both monitored areas (see Figures 4 - 6). The maximal value of displacement was only 7.6 mm in monitored locality A (maximum height of the top anchor was 8 m) for thirty two monitored months. The maximal values of displacement ranged between only 9 mm to 15 mm in monitored locality B (maximum height of the top anchor was 7 m) for 15 monitored months. These maximum displacements have been measured mainly above the intersections.

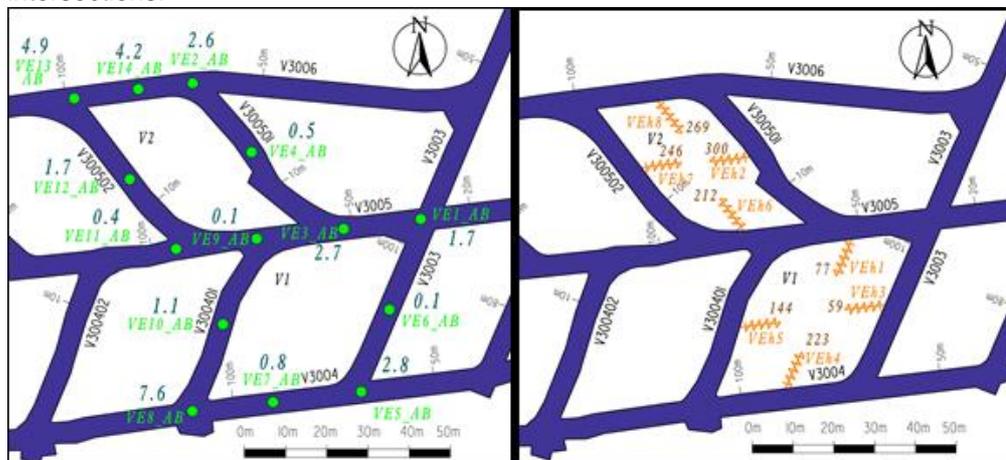


Figure 4: Roof displacements [mm] (on the left) and horizontal displacements at the right of coal pillars [mm] measured by 5-level extensometers in the monitored locality A.

Horizontal displacement measurements

The coal rib displacements recorded by horizontal extensometers are comparatively different within the monitored pillars (see Figures 4 - 7). In locality A, the largest displacements were recorded by horizontal extensometers installed in pillar V2. The displacement values ranged between 212 mm to 300 mm in monitored pillar V2. The coal rib displacements of the monitored pillar V1 ranged between 59 mm to 223 mm. These values indicate that the displacement of the coal pillar V2 is as large as monitored displacements of coal pillar V1, with higher area of loading. From the results recorded by the horizontal extensometers in location B, it is evident that the maximum horizontal displacement was 478 mm (IIEh5) in the monitored pillar II2. Also, in the monitored pillar II1, the relatively higher values were recorded (468 mm - IIEh1, 379 mm - IIEh3). Even in the monitored pillar II3, which was formed last, the displacements values of around 300 mm (IIEh9 - 344 mm, IIEh11 - 353 mm) were reached.

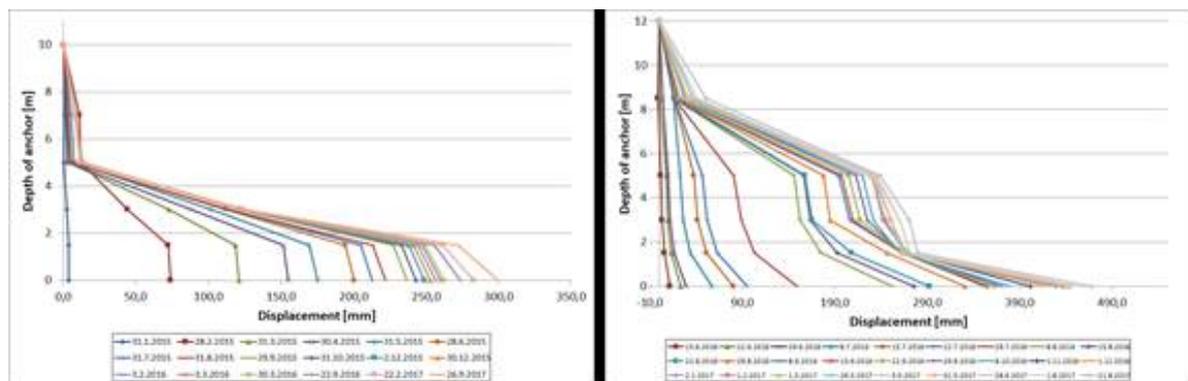


Figure 5: Course of horizontal strata displacement in rib side measured by 5-level extensometers VEH2 (on the left) and IIEH1 (on the right).

In locality A, the major strata displacement zone occurred in the area 1.5–5 m from the pillar side (see Figure 5). The displacement at the depth of 0–1.5 m was much smaller due to the efficiency of rock bolts. In two cases (extensometers VEH7, VEH8) had no influence of the rock bolts and the maximum strata displacements occurred at the depth of 0–3 m into the pillar. The reason for this was considered to be the primary pillar damage by fractures in highly stressed ground.

In locality B, the major strata displacement zone occurred mainly at the depth of 5-8.5 m from the side (see Figure 5). The significant strata separation was recorded at the deepest monitored zone 8.5-12 m (7.5-10 m in monitored pillar II2), which indicated that the monitored pillars were totally fractured. In most cases there was no measured rockbolt influence on coal behaviour and the significant strata separation occurred at the depth of 0–1.5 m into the pillar.

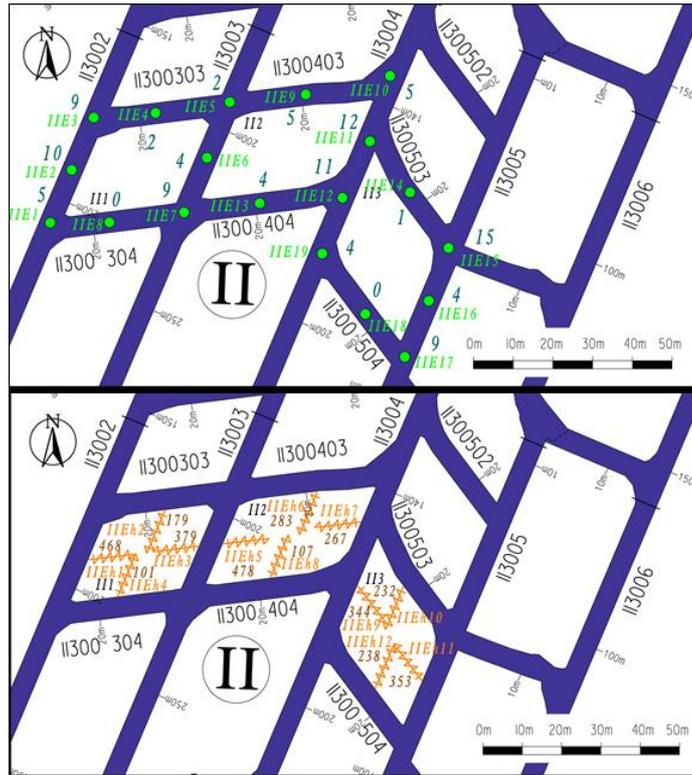


Figure 6: Roof displacement [mm] (above) and horizontal displacement of coal pillars [mm] measured by 5-level extensometers in the monitored locality B.

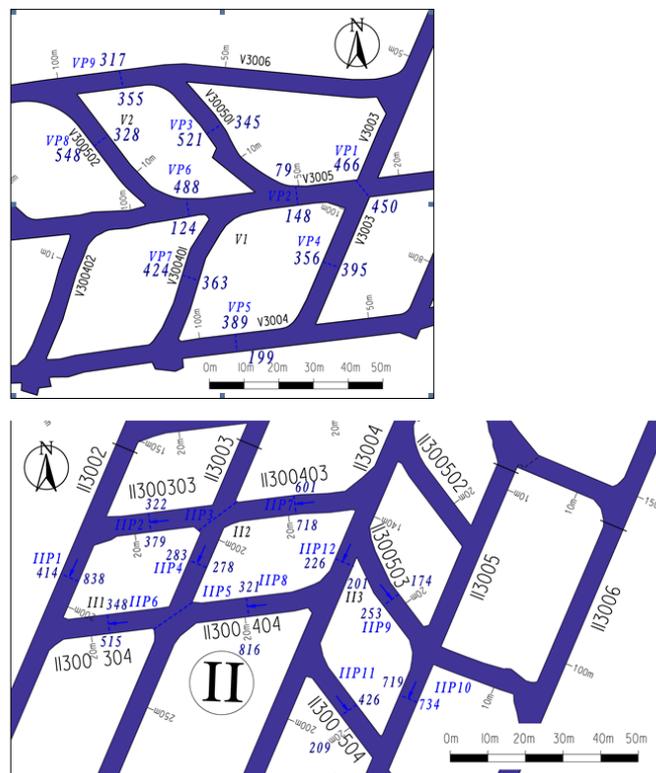


Figure 7: Rib movement [mm] from the convergence station in the monitored locality A (above) and locality B.

Measurements of roadway deformation

The convergence stations were placed in the centre of the monitored side coal pillars (see Figure 2 and 3). The three convergence stations (VP1, IIP3 and IIP5) were installed at the roadway intersections. For the purpose of convergence measurements 2.4 m long steel rock bolts were installed in the roadway roof and rib. The measured convergence values were different both within all convergence stations and at particular convergence station. The maximum horizontal deformation of 548 mm (convergence station VP8) was recorded in locality A during thirty two monitored months. In comparison, the maximum horizontal deformation of 838 mm (convergence station IIP1) was recorded in locality B during only fifteen monitored months. Dynamics of deformation changes were more rapid in locality B due to the smaller size of the monitored pillars and added row of pillars (two rows at locality A and four rows at locality B). The presence of thrust zone in roof of monitored pillar (see Figure 3) probably also influenced the deformation characteristic. The influence of thrust zone on stress-deformation state will be analysed in the near future using numerical models.

The compact pulsed terrestrial laser scanner Leica Scan Station C10 was used for monitoring the of time dependent changes of coal pillars (Kukutsch et al. 2016). 3D laser scanning has been carried out within 11 stand-alone measurement campaigns in the case of locality A and within five campaigns in the locality B. From the beginning, the time gap between campaigns ranged from five to six weeks, followed by a widening of the campaign interval to three, later four months

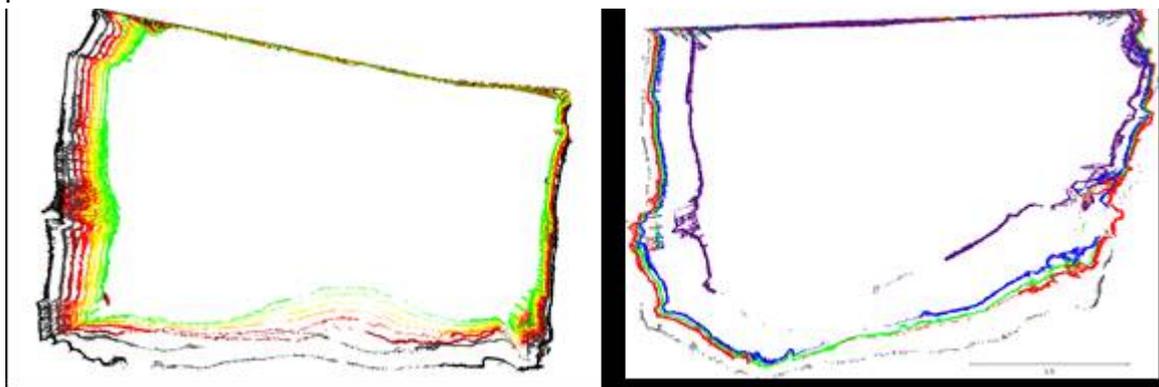
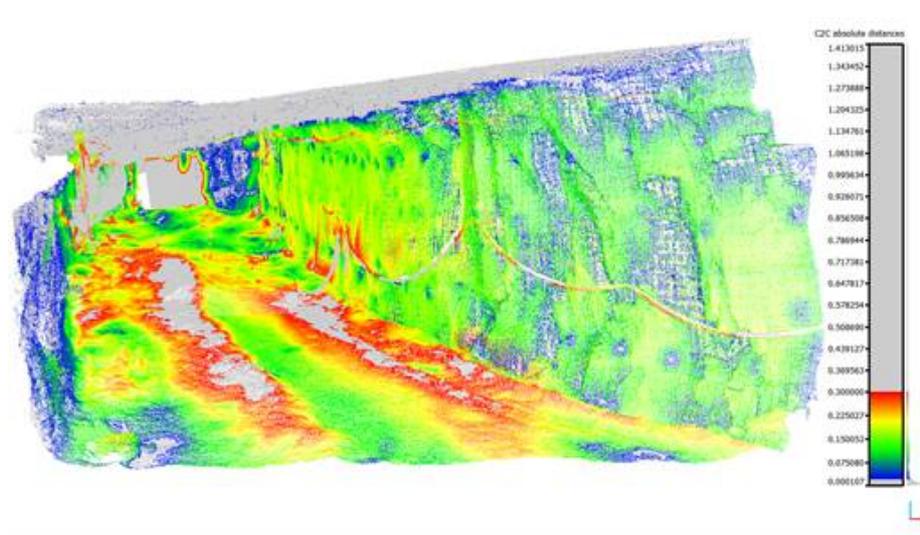


Figure 8: Example of laser scanning of the roadway profile - roadway V300501, locality A, (on the left) and roadway I13005, locality B (on the right)

In each campaign scanning was performed from at least six consecutive scan positions with scanning resolution at 10 mm / 10 m. As a result more than 14.5 million spatial points for each of the scan positions were detected and almost 90-120 million spatial points in one scanning campaign. Repeated measurements allow detecting, with a millimetre accuracy, of changes in pillar size, roadways profile and in particular the possibility of graphically expressing the dynamics of the pillar - its displacement.

The laser scan results from several subsequent surveys indicated significant coal rib convergence and floor heave. In some places the lateral displacements measured mostly at the lower rib exceeded more than 80 cm. As expected, the roof displacements were not registered. The data provided by laser scanner allowed the character of roadway deformation to be described. The results compared well with the rib extensometers and convergence measurements. The 3D laser scanning technology enables very detailed analysis to be performed to evaluate the long term coal pillar stability (e.g. Kajzar et al. 2017).



**Figure 9: Displacement of the coal pillar in the early phase of trial development
Dynamics of displacement changes**

In addition to absolute values of pillar displacements, data from horizontal extensometers, convergence measurements and the 3D laser scanning provided important information on dynamics of coal pillar behaviour. Concerning the dynamics, we could see a decrease of displacements during the whole evaluation period.

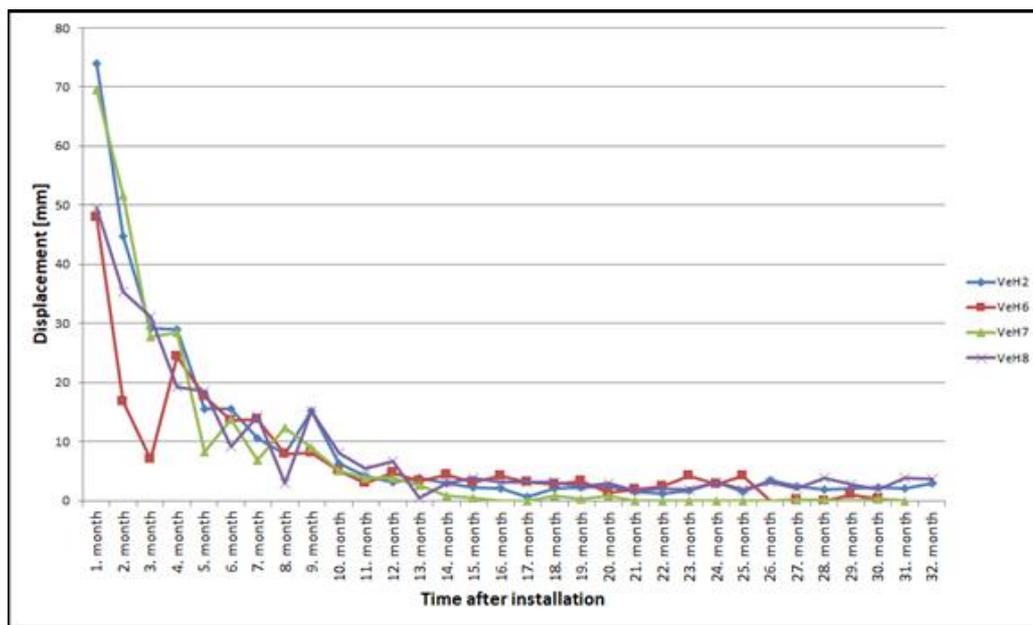


Figure 10: Rate of the V2 coal pillar displacements versus time.

In the locality A, the monthly gain of displacements reduced up to 25 times during monitoring period of 32 months (see Figure 10). The monthly gain of displacements stabilised at 3 mm/month during the last eighteen month of the monitoring period. Similarly, the 3D laser scanner provided convergence measurements and showed the dynamics of roadway deformation. Continuous deformation processes indicate, that yielding of coal pillars is still in progress therefore the long-term stability of coal pillars has not been established yet. The monitoring of conditions at locality A still continues.

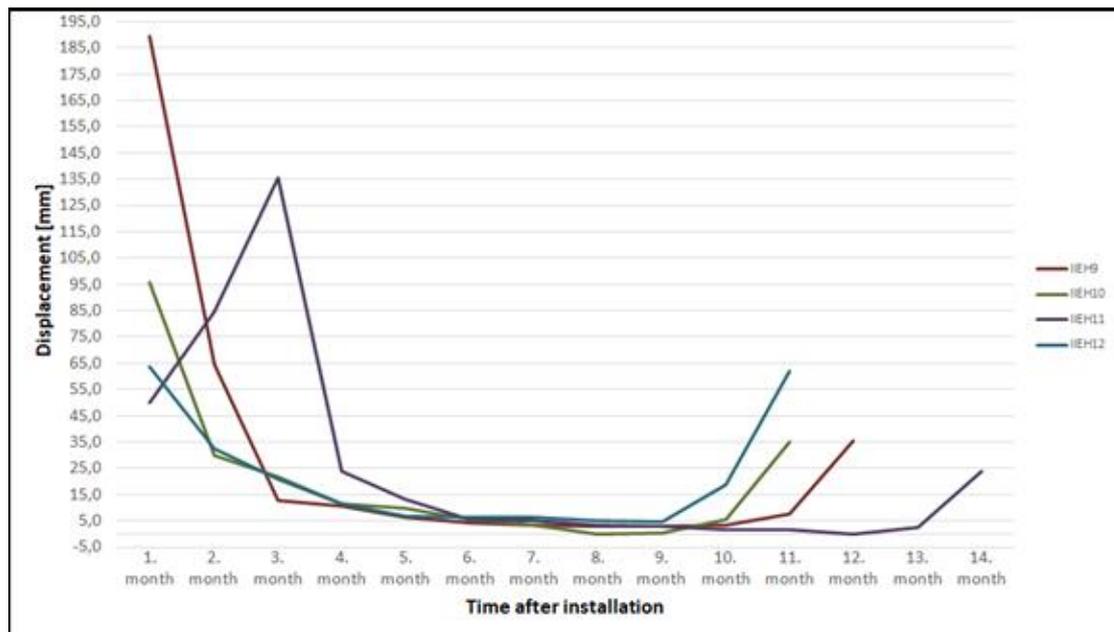


Figure 11: Rate of coal pillar II3 displacements versus time.

In the locality B, the monthly gain of measured displacements reduced up to 25 times during the first nine months (see Figure 11). The monthly gains of displacements stabilised at 2 mm/month. Finally, the monthly gains of displacements have been significantly influenced by roadway advance. Due to significant deformation of the main roadways it was decided to form a fourth row of coal pillars at the last phase of monitoring. The new roadway I13006 was driven and the resulting stress re-distribution reactivated deformation of monitored coal pillars. The monthly gain of displacement increased up to 62 mm per month in the most influenced monitored pillar II3. However, the follow-up monitoring was not possible due to closure of the panel II.

Stability of coal pillars

Based on the development of deformation characteristics, the stability of the left coal pillars can be concluded. Due to the long-term monitoring (up to 32 months) and the development of deformations, it is possible to determine the *operating stability* and *long-term stability* of coal pillars. It can be stated that the operating stability of not only the monitored coal pillars but also of all coal pillars left in the trial area of the room and pillar method has been confirmed. Any of the coal pillars have not been destroyed during the whole monitoring period.

Due to the fact that the deformation process is still currently in progress and that the size of the monthly gains of deformation has not significantly diminished during the last eighteen monitored months, the long-term stability of coal pillars have not been confirmed yet. For this reason the monitoring continues at the locality A, as the panel is still accessible.

CONCLUSIONS

The room and pillar method was trialled in the shaft protective pillar at the CSM Mine located in the USCB. Coal pillar monitoring was essential as this was the first application of the room and pillar mining method in USCB mines at great depth. In total, five coal pillars located in seam No. 30 were intensively monitored to ensure stability of the panel and safe mining procedures. Based on the measurements, numerical modelling and other analyses were possible to assess stability of the coal pillars at the great depth. The results are also important for global mining, for the largest coal producers will reach higher mining depth in the near future.

Based on the long-term monitoring (up to 32 months), it was possible to determine the operating stability and long-term stability of coal pillars. Safe operating stability has been

proven for all coal pillars formed within the trial operation of the room and pillar method. The long-term stability of coal pillars has not been confirmed yet because a small deformation process in coal pillars is still in progress. Further ongoing monitoring of pillar movement at locality A is in place as the locality is still accessible and monitoring devices are still operating.

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REFERENCES

- Bieniawski, Z, T, 1984. *Rock mechanics design in mining and tunnelling*, A.A. Balkema, 272 pp.
- Grygar, R and Waclawik, P, 2011. *Structural-tectonic conditions of Karvina Subbasin with regard to its position in the apical zone of Variscan accretion wedge*, Acta Montanistica Slovaca, Vol. 16, No. 2, pp 159-175.
- Hustrulid, W, A, 1976. *A review of coal pillar strength formula*, Rock mechanics, Vol 8, p115-145.
- Chase, F, E, Mark, C and Heasley, K, 2003. *Deep cover pillar extraction in the US Coalfields*, in Proceedings 21st International conference in ground control in mining, Morgantown, WV. p77-80.
- Kajzar, V, Kukutsch, R, Waclawik, P and Nemcik, J, 2017. *Innovative Approach to Monitoring Coal Pillar Deformation and Roof Movement Using 3D Laser Technology*. Symposium of the International Society for Rock mechanics, 20-22 June 2017, Procedia Engineering. Volume 191, pp873-879.
- Kukutsch, R, Kajzar, V, Waclawik, P and Nemcik, J, 2016. *Use of 3D laser scanner technology to monitor coal pillar deformation*, in Proceedings of the 2016 Coal Operators' Conference. Wollongong: The University of Wollongong, 2016 - (Aziz, N.; Kininmonth, B.), pp109-117.
- Mark, C and Chase, F, E, 1997. *Analysis of Retreat Mining Pillar Stability (ARMPS)*, in Proceedings of New technology for ground control in retreat mining, NIOSH, IC 9446, p. 17-34.
- Nakamura, N, 1999. *Rock stress measurement for limestone open pit mine*. in Proceedings. 5th Int. Symp. on field Measurements In Geomechanics, Singapore, Balkema, Rotterdam (The Netherlands).
- 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, Vol.40, pp1189-1203.
- Salamon, M, D, G, 1970. *Stability, Instability and design of pillar workings*, International Journal of Rock Mechanics and Mining and Mining Sciences, Vol. 7(24), p. 613-631.
- Stas, L, Knejzlik, J, Palla, L, Soucek, K and Waclawik, P, 2011. *Measurement of stress changes using a Compact Conical-ended Borehole Monitoring*. Geotechnical Testing Journal, Vol. 34, No. 6, pp685-693.
- Stas, L, Soucek, K and Knejzlik, J, 2007. *Conical borehole strain gauge probe applied to induced rock stress changes measurement* in Proceedings of 12th International Congress on Energy and Mineral Resources, pp507-516.
- Waclawik, P, Snuparek, R and Kukutsch, R, 2017. *Rock bolting at the room and pillar method at great depths*. Symposium of the International Society for Rock mechanics, 20-22 June 2017, *Procedia Engineering*. Volume 191, pp575-582.
- Waclawik, P, Ptacek, J, Konicek, P, Kukutsch, R, and Nemcik, J, 2016. *Stress state monitoring of coal pillars during room and pillar extraction*, *Journal of Sustainable Mining*, Vol. 15, Issue 2, pp. 49-56.
- Waclawik, P, Ptacek, J and Grygar, R, 2013. *Structural and stress analysis of mining practice in the Upper Silesian Coal Basin*, *Acta geodynamica et geomaterialia*, Vol. 10, Issue 2, pp. 255-265.