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Stress-state monitoring of coal pillars during room and pillar extraction

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ABSTRACT

Current mining activities of the OKD mines are primarily focused on coal seams within the Karvina Formation in the Karvina sub-basin. A considerable amount of coal reserves are situated in protection pillars that lie under built-up areas. The longwall mining method is not applicable in these areas because significant deformation of the surface is not permitted. For this reason OKD is considering using alternative methods of mining to minimise subsidence. The room and pillar method has been trialed with specific coal pillars in order to minimise strata convergence. The method was implemented in the shaft protective pillar at the CSM Mine and is the first application of the room and pillar mining method within the Upper Silesian Coal Basin. Mining depth reached up to 900 m and is perhaps the deepest room and pillar panel in the world.

To determine pillar stability, vertical stress was measured in two adjacent coal pillars which are diamond in shape and located within a row of pillars forming the panel. Two pillars diamond in shape and slightly irregular sides were approximately 860 m^2 and 1200 m^2 in size and 3.5 m high To measure the increase in vertical stress due to mining, four stress cells were installed in each coal pillar. Four 5-level multipoint rib extensometers measured displacements of all sides within each monitored pillar. The results of stress-state and pillar displacement monitoring allowed pillar loading and yielding characteristics to be described. This data and other analyses are essential to establishing procedures for a safe room and pillar method of mining within the Upper Silesian Coal Basin.

1. Introduction

The Czech part of the Upper Silesian Coal Basin (USCB) region, where OKD mines operate, is densely populated with residential and industrial infrastructure. A considerable amount of coal lies under some of these areas or in protection safety pillars where subsidence is not allowed or has to be minimised. The usual longwall mining methods are not applicable in these areas. For this reason the OKD mines had to consider alternate methods of mining to ensure surface subsidence is kept at acceptable levels. The decision was made to trial the room and pillar method of mining without coal pillar extraction.

The method was trialed within the shaft protective pillar located in CSM-North Mine coal seam No. 30, where the risk of rockbursts was low and roof conditions were acceptable for bolting. However, the variable geology and several faults of regional importance complicated the mining conditions. The mining area was divided into two separate blocks by a significant "Eastern Thrust" fault zone (Grygar & Waclawik, 2011; Waclawik, Ptacek, & Grygar, 2013). Coal thickness varied considerably from 1.8 m to 5.2 m mainly due to the split of the seam. In general, the seam dip ranged from 8° to 17° with the dip occasionally approaching 20°. The mining depth ranged between 700 and 900 m and is perhaps the deepest room and pillar panel in the world.

The room and pillar mining method is usually implemented on the basis of experience gained and practices used elsewhere while taking into consideration different natural conditions and depths. The coal pillar sizes, calculated using accepted empirical methods (e.g. Bieniawski, 1984; Chase, Mark, & Heasley, 2003; Hustrulid, 1976; Mark & Chase, 1997; Salamon, 1970), were uncertain due to

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complex strata geology. As there is no relevant experience of using this method in the Upper Silesian Coal Basin, an extensive monitoring system was implemented to enable the mining trial to continue safely. The monitoring was focused on the load bearing capacity of coal pillars and strata deformation changes induced by the room and pillar mining method. The monitored database used to measure whether the room and pillar method is successful at this depth, provides the necessary information for the verification of this method and its future application in conditions experienced in the USCB.

2. Methods

2.1. Natural conditions in the monitored area

The geological setting in the area of shaft protective pillar CSM-North Mine is quite complex. The targeted coal seam, No. 30, used for the trials, is at a depth of approximately 700 m–900 m below the surface. Above the coal seam there is a 300 m thick complex carboniferous rock mass with an overlying tertiary sedimentary rock strata which is 400 m–600 m thick with approximately a 20 m thick quaternary soil overburden. 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°.

Within the proposed mining area, the thickness of seam No. 30 is extremely variable. In places the seam splits in to several separate coal seam layers. Interchangeable layers of sandstone, siltstone and coal seams are present. Seam No. 30 separates only in the south-east part of the shaft protective pillar with thickness that varies from 1.8 m to 2.2 m. The seams n.n. (untitled seam), No. 31 and No. 32 merge with seam No. 30 towards the north-west. This substantial and complex coal seam (consisting of seams 30 + n.n. + 31 + 32) has a thickness of up to 5.2 m in the northwest part of the protective pillar area.

In the monitored pillar area (pillars *V1* and *V2* in Fig. 3) and in the panel *V* trial area the 3 m thick seam consists of coal seams 30 and n.n. The monitored pillars are at a depth of approximately 850 m below the surface. The vertical profile around coal seam No. 30 is shown in Fig. 2. The immediate roof above coal seam No. 30 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 5 m thick siltstone overlain with 6 m thick medium-grained sandstone and 0.3 m thick coal seam No. 624. The roof of seam No. 624 consists of 5 m thick siltstone overlain with a 10 m thick bench of fine-grained sandstone and 4 m thick coal seam No. 29b.sp.l. The vertical distance between seams No. 30 and No. 29b.sp.l is around 26 m.

The immediate floor below mined seam No. 30, located in the pillar monitoring area, consists of 0.5 m thick siltstone underlain by 0.6 m thick coal seam No. 31. The interbedded siltstone and sandstone layers follow down to coal seam No. 32 located some 10 m below the monitored pillars (seam No. 30).

There are several faults of regional importance in the area of the CSM-North shaft protective pillar (see Fig. 1). There is the wide tectonic zone of the Albrechtice Fault with a total throw of up to 420 m located in the west area. The dip of this fault ranges from 60° to 65° towards the West. In the northern area "Fault A" is present with a throw of up to 100 m and a dip of 60° towards the North. "Fault B" in the south part of the area has a throw of around 10 m with a dip ranging from 55° to 70° towards the South.

The significant regional tectonic fault zone "Eastern Thrust" (Grygar & Waclawik, 2011; Waclawik et al., 2013) divides the area of the protective pillar into two separate blocks with different geotechnical conditions. According to existing knowledge, the Eastern Thrust has a very small dip ranging from 10° to 35°. The Eastern Thrust strike is generally in the NE–SW direction with a dip towards the NW. Vertical displacement fluctuates around 5 m, but the range of horizontal displacements is usually much greater and can range from tens to hundreds of meters. Characteristic changes in the Eastern Thrust dip with depth have been observed and may be correlated with the transition to interlayer slips. Experience shows that these thrust fault features have a significant effect on the geotechnical conditions within rock mass.

Inside the protective pillar area, which is surrounded by faults of regional importance, the rock mass is typically disturbed by a system of small so-called seam faults. The uplift on these seam faults is mostly greater than 0.1 m but typically does not exceed 1 m.

2.2. Monitoring equipment

Monitoring of stress and the deformation state of rock mass is an essential requirement for the design of a safe and successful room and pillar method that can be applied in the Czech part of the Upper Silesian Coal Basin. The room and pillar mining method is usually carried out on the basis of experience and practices that have been gained and used under different geological conditions and depths. The geology in the area and the depth of cover indicated that empirical methods of calculating the pillar loads (e.g. Bienawski, 1984; Chase et al., 2003; Hustrulid, 1976; Mark & Chase, 1997; Salamon, 1970) may not be appropriate and could be unreliable. No experience of room and pillar method exists within the USCB area therefore pillar monitoring had to be used to measure the capacity and the deformation characteristics of the coal pillars.

An extensive monitoring system was implemented to measure the load profile across the coal pillar and the deformation characteristics in the pillar during mining. The monitoring was performed in two coal pillars within panel V (location A). The pillars which are diamond in shape and have slightly irregular sides were approximately 860 m^2 and 1200 m^2 in area and 3.5 m high.

In the context of stress and deformation, the following areas were covered:

- Deformability of rock overlaying the room and pillar roadways,
- Measuring pre-mining stress and stress change monitoring in rock and coal during mining,
- Deformability of coal pillars,
- Load on the installed cable bolts,
- Roadway convergence monitoring.

To monitor roof deformation, fourteen pairs of 5-level multipoint extensometers monitored roof displacements (VE1 to VE14 in Fig. 3) and eleven strain gauged rockbolts (VS1 to VS11 in Fig. 3) were installed at various locations. Two 3-dimensional CCBO stress overcoring cells (Nakamura, 1999; Obara & Sugawara, 2003; Stas, Knejzlik & Rambousky, 2004) were used to measure the pre-mining stress in the area (VCCBO1 and VCCBO2 in Fig. 3) and eight 3-dimensional CCBM stress change monitoring cells (Stas, Knejzlik, Palla, Soucek, & Waclawik, 2011; Stas, Soucek & Knejzlik, 2007) were installed to measure stress changes during mining (VCCBM1 to VCCBM8 in Fig. 3). Four 1-dimensional hydraulic stress monitoring cells were installed at various depths in each pillar to measure vertical stress (VSC1 to VSC8 in Fig. 3), four 5-level multipoint rib extensometers measured displacements of all sides within each monitored pillar (VEH1 to VEH8 in Fig. 3), seven hydraulic dynamometer load cells measured the cable bolt loads installed at the roadway intersections (VD1 to VD7 in Fig. 3) and the roof and rib convergence was measured at key locations.