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Geotechnical considerations for concurrent pillar recovery in close-distance multiple seams

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A R T I C L E I N F O

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A B S T R A C T

Room-and-pillar mining with pillar recovery has historically been associated with more than 25% of all ground fall fatalities in underground coal mines in the United States. The risk of ground falls during pillar recovery increases in multiple-seam mining conditions. The hazards associated with pillar recovery in multiple-seam mining include roof cutters, roof falls, rib rolls, coal outbursts, and floor heave. When pillar recovery is planned in multiple seams, it is critical to properly design the mining sequence and panel layout to minimize potential seam interaction. This paper addresses geotechnical considerations for concurrent pillar recovery in two coal seams with 21 m of interburden under about 305 m of depth of cover. The study finds that, for interburden thickness of 21 m, the multiple-seam mining influence zone in the lower seam is directly under the barrier pillar within about 30 m from the gob edge of the upper seam. The peak stress in the interburden transfers down at an angle of approximately 20°away from the gob, and the entries and crosscuts in the influence zone are subjected to elevated stress during development and retreat. The study also suggests that, for full pillar recovery in close-distance multiple-seam scenarios, it is optimal to superimpose the gobs in both seams, but it is not necessary to superimpose the pillars. If the entries and/or crosscuts in the lower seam are developed outside the gob line of the upper seam, additional roof and rib support needs to be considered to account for the elevated stress in the multiple-seam influence zone.

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1. Introduction

Room-and-pillar mining accounted for about 40% of underground coal production in the United States in 2016. Pillar recovery, practiced in about one-third of the room-and-pillar mines, represents about 10% of the coal mined underground, yet it has historically been associated with more than 25% of all ground fall fatalities [1]. In some U.S. coal fields, particularly central Appalachia, many coal mines are operating under geological conditions with multiple coal seams. The risk of ground falls during pillar recovery increases under multiple-seam mining conditions [2,3]. The hazards of pillar recovery associated with multiple-seam mining include roof cutters, roof falls, rib rolls, coal outbursts, and floor heave [4–11]. Pillar retreating creates abutment pressure, not only in the currently mined seam, but also in the overlying or underlying seams. Multiple-seam interactions become more pronounced as overburden depth increases and interburden thickness decreases. To safely recover the pillars in multiple seams, it is critical to properly plan the mining sequence and panel layout to minimize potential multiple-seam interaction.

The degree of multiple-seam interaction can be influenced by the sequencing of seams, pillar and entry design, and the layout of workings [12]. Seams can be mined by two basic seam sequences: in descending order with mining completed in the upper seams before any mining is initiated in the lower seams, or in ascending order with mining completed in the lower seams before any mining is initiated in the upper seams. A descending order of pillar recovery is considered the most preferable practice to minimize multiple-seam interactions. Seams mined in this order are influenced by the abutment stress transferred from the overlying pillars, gob-solid boundaries, and barrier pillars. Seams mined by ascending order can also experience interactions resulting from subsidence fractures if full pillar extraction is previously conducted in the lower seams. Multiple-seam interactions could become more complicated where mining is between previously mined seams. Multiple-seam interaction can be minimized if the pillars in the lower and upper seams are designed concurrently to account for the stress transfer through the interburden. In planning, the layout of workings in multiple seams, there are two basic

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approaches to laying out room-and-pillar panels in successive seams: superposition or offset of panels or workings. Superposition of panels is optimal when the upper seams are developed first and then pillared. The pillars developed under the upper seam gob can be designed for single-seam conditions [12]. However, the outer entries in the lower seam are influenced by the load transferred from the overlying barrier.

Although mining sequence, panel layout, and pillar size are critical for the planning of concurrent pillar recovery in multiple seams, the size of leave blocks, stump size, and roof and rib support should also be carefully designed to minimize multiple-seam interaction during pillar recovery. This paper addresses geotechnical considerations for concurrent pillar recovery in two coal seams with 21 m of interburden under about 305 m depth of cover at the lower seam.

2. Panel layout for pillar recovery in two coal seams

This study concerns concurrent pillar recovery of two adjacent panels in two coal seams. Fig. 1 shows the overlay of the panel layout in both seams. The upper seam is the peerless coal seam and the lower seam is the Powellton Seam. Fig. 2 shows a typical geologic column of the interburden strata. The interburden consists of shale, sandstone, and the 2-gas coal seam. The maximum overburden depth is 284 m in the upper seam and 305 m in the lower seam where the interburden between the two seams is about 21 m.

The panels in the upper seam were developed with a 6–9-entry system and 21 m by 27 m center-to-center pillars. The overburden depth over the two panels ranges from 152 to 284 m. The barrier pillar between the two panels is 27–43 m center-to-center. The entry width is about 5.8–6.1 m, and the entry height is about 1.8 m. The immediate roof consists of shale and sandyshale. The roof is supported by four 1.5-m, 19-mm-diameter, fully grouted resin bolts on 1.2-m spacing for primary support and five 3-m, 15.2-mm cable bolts at intersections for supplementary support.

The panels in the lower seam were developed with a 9-entry system and 21-m by 27-m center-to-center pillars. A barrier pillar of 61 m center-to-center was left between the two panels. The immediate roof is dark shale and sandstone, and the immediate floor is dark gray fireclay. The entry width is about 6.1 m, and the mining height is 1.8 m. The coal in the Powellton Seam is about 1.2 m thick, and about 0.6 m of top rock is mined to make a mining height of 1.8 m. The roof is supported by four 1.5-m, 19-mm-dia., fully grouted resin bolts on 1.2-m spacing for primary support and five 3.6-m, 15.2-mm-diameter cable bolts at intersections for supplementary support.

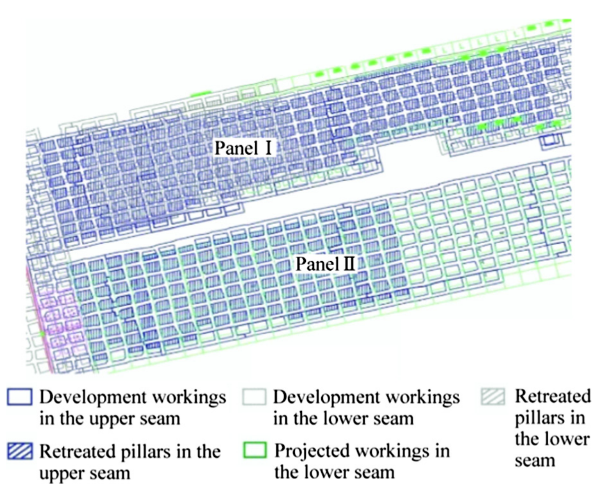

Fig. 1. Overlay of panel layout in the upper and lower seams.

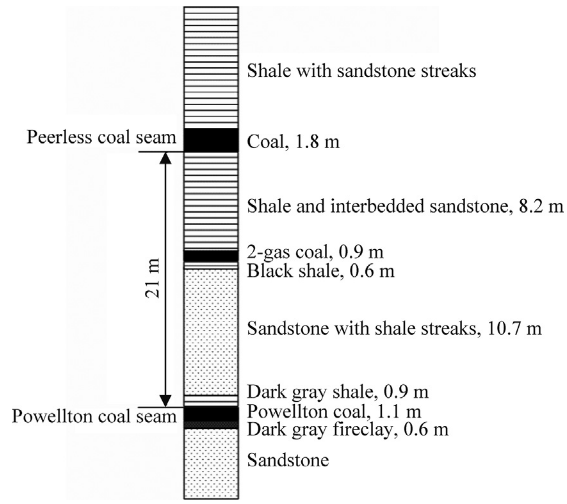

Fig. 2. Geological column of the interburden strata.

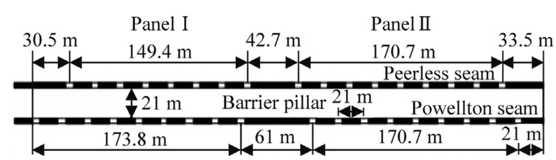

Fig. 3. Entry layout in the upper and lower seams.

The panels in the two seams were developed with different numbers of entries, and the workings were offset 6–21 m. Fig. 3 shows the vertical layout of the entries in the upper and lower seams. Fig. 4 shows the sequence of development and retreating in the upper and lower seams. The multiple-seam mining took place in the two coal seams in descending order. The first panel in the upper seam was developed and then retreated first. The concurrent mining took place in the second panel in the upper seam and in the first panel in the lower seam. The two panels were developed first and then retreated. The second panel in the lower seam was developed and retreated last.

The pillars in the retreat panels were designed by the mine engineers using the NIOSH-developed software, Analysis of Retreat Mining Pillar Stability (ARMPS) (NIOSH, 2010) and the numerical modeling software, LaModel (West Virginia University, 2011). LaModel was used to calculate the stability factor of the pillars over the area under maximum overburden depth of 305 m in the lower seam. The pillar sizes in both seams in the study meet the stability factor requirements established in the ARMPS and LaModel software programs.

3. Numerical modeling of multiple-seam interaction

LaModel software was used to model the distribution of abutment pressure around the retreat panels [13]. Figs. 5 and 6 show the modeled area and dimensions of the models in the upper and lower seams. To make the model conservative, the highest overburden depths of 284 m in the upper seam and 305 m in the lower seam were used. To model the effect of retreat mining in the upper seam on stress change in the lower seam, the model was set up with both panels in the upper seam retreated, but with Panel I in the lower seam developed. The model used 3-m element and symmetrical boundary conditions. The gob model was calibrated with lamination thickness and gob pressure. Lamination thickness of 15.2 m and final gob modulus of 2069 MPa were set in the model

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