# Large Scale Ground Instability Caused By Failure of Underlying Pillars: a Case Study of Dynamic Multiple Seam Interaction

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## ABSTRACT

Severe dynamic multiple seam interactions can occur when active mine workings are subsided by underlying mining activity. The most dramatic events are usually caused by longwall mining or pillar recovery beneath open, overlying entries. But pillars in abandoned workings can also fail and cause subsidence and damage an overlying mine.

This paper describes a case history in which an apparent "pillar squeeze" in the abandoned workings of a lower seam was initiated during retreat mining in an upper seam. The event subsequently extended more than 1,500 ft and ultimately closed the upper seam mine. Analysis indicated that the pillars in the lower mine were adequately sized for the lower seam mining and were not affected by the initial development above them. When retreat mining in the upper seam had progressed several hundred feet, however, the pillars located directly beneath the pillar line were overloaded, and an extensive squeeze initiated in the underlying workings. The squeeze, in turn, subsided the overlying workings, causing widespread rib falls and roof instability.

Previous examples of dynamic multiple seam interactions resulting from delayed subsidence of underlying workings have been reported in the literature. This is, apparently, the first recorded incident in which pillar recovery in an active mine triggered pillar failure in an underlying mine, which then triggered a dynamic interaction that impacted the active overlying seam.

## BACKGROUND

Multiple seam mining is very common in the mature coalfields of Central Appalachia. The incident described in this paper occurred in August 2011 in an area where mining has been conducted for decades. The Coalburg seam, the active seam in this case study, is at least the fourth seam in the area to be mined.

Figure 1 shows a portion of the geologic section of the area. The uppermost seam, the Kittanning, was mined before 1960. Due to the light cover above the Kittanning, workings in it are unlikely to have affected mining in the Coalburg. A longwall mine was later active in the Powellton seam, which is approximately 400 ft below the Coalburg seam, but the nearest longwall workings are approximately 1,500 ft to the south of the squeeze area.

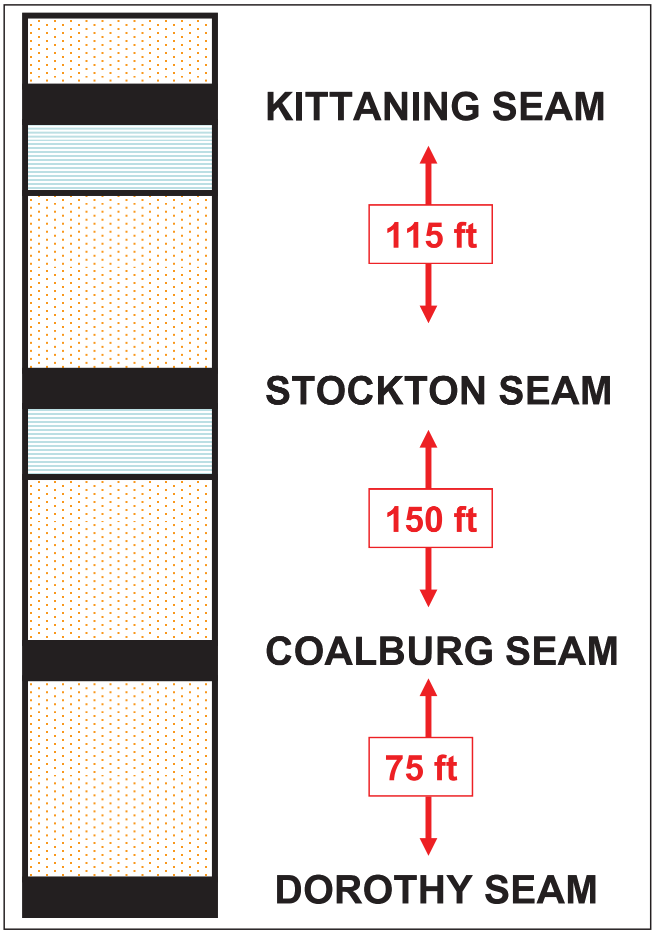

**Figure 1. Upper portion of the geologic section in the vicinity of the Coalburg mine, with approximate interburden distances.**

The most significant past mining was conducted in the Dorothy seam, approximately 75 ft below the Coalburg. The Dorothy Mine, which was opened in 1977, extracted about 3 million tons between

1983 and its final closure in 1991. Figure 2 shows the significant features of the Dorothy seam mining in the area of the incident, including the following:

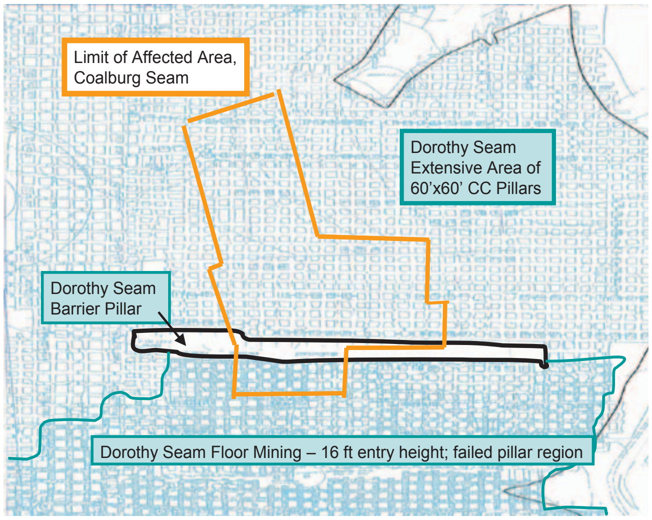

**Figure 2. Map of Dorothy seam mining (showing the outline of the area in the Coalburg seam that was affected by the event).**

- A large area of 60 x 60 ft (centers) pillars, which underlies most of the 2 Section and the Mains. No second mining was conducted in this area.
- An area where the floor was extracted, resulting in 16 ft mining heights.

The two areas are separated by a 140-ft-wide barrier. In the 60 x 60 ft area, the mining height was reportedly about 10 ft. In the area where the floor was extracted, miners familiar with the Dorothy Mine reported that the ground caved and the pillars presumably crushed.

The Coalburg Mine opened in 2005 and extracted approximately 500,000 clean tons of coal annually with 70 miners on two production units. Since the Coalburg seam is located near the top of the geologic section, the cover was relatively light. Above 2 Section, the maximum depth of cover was about 440 ft, and the minimum was only 100 ft. The original mining height in this part of the mine averaged about 11 ft.

In the area of 2 Section and the Mains, the pillars were developed on 70 x 100 ft centers (Figure 3). Where the Mains crossed the Dorothy barrier pillar, the pillar size was increased to 120 x 120 ft centers.

Conditions in the Coalburg seam Mains, 2 Section, and 1 Left off 2 Section were reported to have been excellent after development. Retreat mining was completed in 1 Left without incident beneath a maximum cover depth of 400 ft. Two rows of pillars were left in place at the mouth of 1 Left to isolate 2 Section from the abutment load.

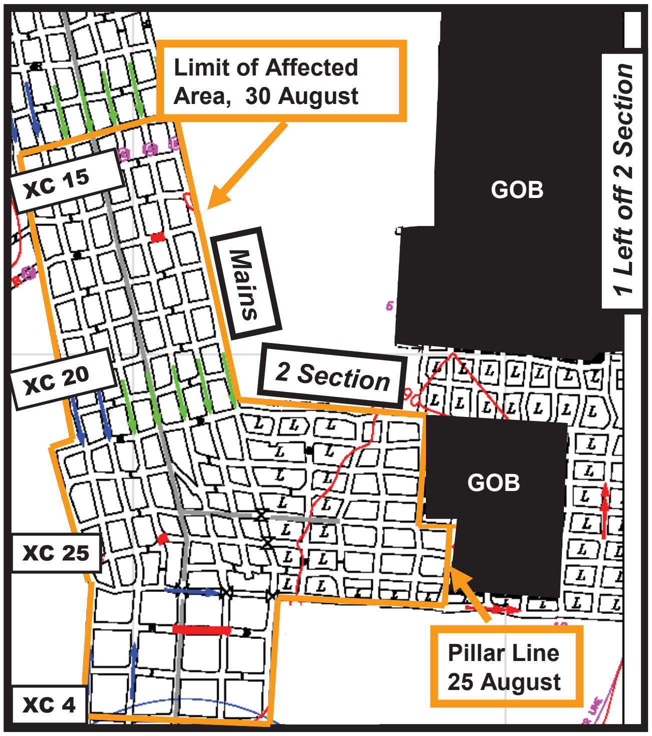

**Figure 3. Map of Coalburg seam mining, illustrating the sequence of events.**

## EVENTS DURING THE INSTABILITY

Retreat mining was then initiated in 2 Section after leaving two rows of pillars near the outcrop to establish a bleeder. Four rows of pillars were extracted, and the pillar line was beneath the maximum depth of cover of 440 ft. At this point, (Figure 3. Pillar Line Aug 25), the rib conditions near the pillar line were so poor that the section was abandoned, and the equipment was removed to the mouth of the panel. Over the course of next two days, the squeeze rode out about 800 ft from the pillar line into the mains, causing pillar conditions to deteriorate and the operator to withdraw all miners from the area. Ventilation controls were crushed out, and the main water sump for collection of water went dry suddenly. In the following days, the squeeze continued to spread in both directions up and down the Mains.

Subsequent mapping (Figure 3) indicated that the worst conditions in the Mains were located directly over the Dorothy Seam barrier pillar, from approximately crosscut 24 in the small pillar area to crosscut 2 in the large pillar area (see the photos in Figures 4 and 5). The area from crosscut 18 to 24 was also severely damaged, with long radial tension cracks in the mine roof that ran parallel with the center of the entry. These cracks had intermittent crossing cracks, which further weakened the roof. The fact that no falls occurred in these areas was a testimony to the strength of the sandstone roof. There were also intermittent areas of slight bottom heaving. Virtually every rib had shed large pieces of broken coal and rock. Further damage was noted to crosscut 14 in the north and crosscut 4 in the south.

**Figure 4. Floor heaving and rib roll has completely covered a belt drive located above the Dorothy barrier pillar.**

**Figure 5. Coalburg entry above the Dorothy barrier pillar almost filled with broken coal, leaving only a 14-ft-wide by 6-ft-high triangular opening.**

## ANALYSIS

A global instability of this magnitude almost always means that pillars have failed. In this instance, there are two sets of pillars that may be responsible, the ones in the Coalburg and the others in the Dorothy. To make things more complicated, activities in one seam can also affect the other (in other words, there can be interactions). The rock mechanics analysis presented in the next section will attempt to unravel the sequence of events.

The analysis was conducted using the NIOSH pillar design software packages Analysis of Retreat Mining Pillar Stability (ARMPS) and Analysis of Multiple Seam Stability (AMSS). The analysis begins with the original development of the 60x60 ft pillars in the Dorothy seam. For the maximum depth of cover [1] of 465 ft and an assumed 10 ft mining height, the ARMPS SF=1.59. Since this value exceeds the NIOSH suggested value of SF=1.5 (Mark 2010), it seems likely that these pillars were intact before mining commenced in the Coalburg seam. Note also that the floor mining in the Dorothy seam has very little effect on the 60x60-ft blocks because the analysis indicates that the 140-ft barrier shields them from the abutment load.

Next, we begin the evaluation of the Coalburg workings with the 2 Section. Because the underlying pillars in the Dorothy can initially be assumed to be intact, and 2 Section does not cross the Dorothy barrier, it seems appropriate to conduct a single-seam ARMPS analysis (rather than an AMSS analysis). For the same location analyzed above, the Coalburg depth of cover is 390 ft, and the calculated ARMPS SF = 3.03. Even if some side abutment load from the floor mining area is added (by adjusting the input parameters to include a side gob and a reduced barrier pillar width of 30 ft), the SF drops to just 2.82. These SF values are well above the NIOSH criteria, so the pillars would have been expected to be stable.

The development mining in the Coalburg seam is also unlikely to affect the stability of the Dorothy pillars. Therefore, with adequate pillar SF values for both seams, the analysis predicts the good conditions that were actually encountered in 2 East before pillar extraction commenced.

The next step is to conduct a single-seam analysis of the effect of pillar recovery in the Coalburg seam. The pillaring increases the load on the Coalburg seam pillars but only reduces the SF to 1.96 (or 1.85 if the effect of the side gob is considered). Again, since these values still exceed the NIOSH recommendation of 1.5, the pillars should have been stable *if there were no multiple seam effects*.

## MULTIPLE SEAM INTERACTION

However, pillaring in the Coalburg seam did have additional affects on the Dorothy seam. The Dorothy pillars directly beneath the Coalburg pillar line now lie beneath a “gob-solid boundary” in a high stress abutment zone (Figure 6). This situation was modeled in AMSS by making the Dorothy the “active seam,” and subjecting it to the effects of overmining in the Coalburg seam. The AMSS analysis indicated that, under these conditions, the SF of the Dorothy pillars in the abutment zone is reduced to just 0.97 (assuming an 8 ft mining height). Therefore, it seems likely that pillar recovery triggered a pillar failure in the Dorothy seam. Once the process began, the failed pillars in the Dorothy shed load onto the adjacent intact pillars, which caused them to fail in turn. In this manner, the failure in the Dorothy could have propagated for some distance because there were no barriers or other large pillars to arrest it.

Failure of the Dorothy pillars beneath the open Coalburg workings created what is called a “dynamic multiple seam interaction” (Mark, 2007). The best example of a dynamic interaction is when a lower seam is longwalled beneath open overlying workings, causing them to subside. Dynamic

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[1] Note that the depth of cover used in an ARMPS or AMSS analysis is *not* the absolute maximum depth of cover. Rather, it is an *approximate average* of the depth of cover above the “Active Mining Zone” that is being analyzed. See Mark , 2010 for more details.

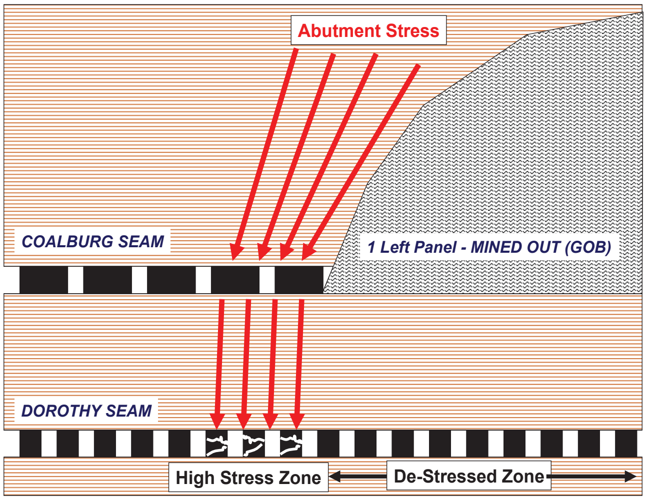

**Figure 6. Cross-section sketch illustrating the creation of the high stress abutment zone, which initiated the failure of the Dorothy seam pillars.**

interactions cause far more damage than typical multiple seam interactions. Most can be avoided by careful mine planning, but there have been instances in which delayed subsidence of underlying works has had the same destructive effect on overlying entries as active mining. In one published instance, a set of mains at a Kentucky mine was developed 180 ft above pillared works, and conditions were excellent for two years. Then the roof began to deteriorate dramatically, and heavy supplemental support was required to prevent major roof collapses. Apparently, the ground had not fully subsided until the two years had passed.

*The current case may be the first recorded example of pillar recovery in an active mine triggering a pillar failure in an abandoned mine, which in turn triggered a dynamic multiple seam interaction that affected the active mine.*

As the pillar failure progressed in the Dorothy seam, the interburden subsided, and the effects were obvious in the Coalburg seam. In addition, the squeeze in the Dorothy seam had the effect of throwing extra load onto the Dorothy barrier, turning it into an "isolated remnant pillar." An AMSS analysis shows that the SF of 70x100-ft pillars above the barrier would be reduced to 1.10, meaning it is likely that they would be highly distressed. The 120x120-ft pillars on the south side of the barrier would fare better, with an SF of 1.99, but the predicted entry conditions are still "red" even with an assumed strong roof (CMRR=65). Again, the analysis seems to align with the underground observations of the most severe conditions in the vicinity of the barrier.

Over the subsequent days, the squeeze continued up the Mains, finally coming to rest approximately 700 ft from the mouth of 2 Section. The depth of cover at this location is approximately 320 ft. Treating the failed area as an active gob, an ARMPS analysis yields an SF of 1.51 for a 10-ft mining height.

## CONCLUSIONS

Coal mining in Central Appalachia will continue to be conducted in complex multiple seam situations. In this instance, pillar recovery in an active mine had unforeseen consequences on underlying abandoned workings. The back analysis presented in this paper indicates that the consequences could have been avoided if they had been predicted in advance. The case history underlines the necessity for careful mine planning to consider all the potential modes of failure.

## REFERENCES

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