Extreme Multiple Seam Mining in the Central Appalachian Coalfields

C. Mark, NIOSH, Pittsburgh, PA

Abstract

Coal has been mined in the central Appalachian coalfields of southern West Virginia, western Virginia, and eastern Kentucky for more than a century. The dwindling reserve base consists in large part of coal that would have been considered unmineable by earlier generations. Nearly every current operation is working on a property where coal has been extracted in the past, from seams either above, below, or both.

NIOSH is conducting research aimed at helping mine planners prevent hazardous conditions due to multiple seam interactions. To-date, more than 300 case histories have been collected from underground mines, mainly from central Appalachia. This paper focuses on several of the more challenging situations that have been encountered, including:

- Room-and-pillar development 20 ft (6 m) beneath full extraction workings at a depth of 1,000 ft (300m) of cover (Virginia)
- Pillar recovery 45 ft above full extraction workings at 900 ft (270 m) of cover (Virginia)
- Near-simultaneous room-and-pillar mining with pillar recovery with 40 ft (12 m) of interburden and 1,500-2,000 ft (450-600 m) of cover (Kentucky)
- Longwall mining directly beneath main entries in overlying seams (West Virginia)
-

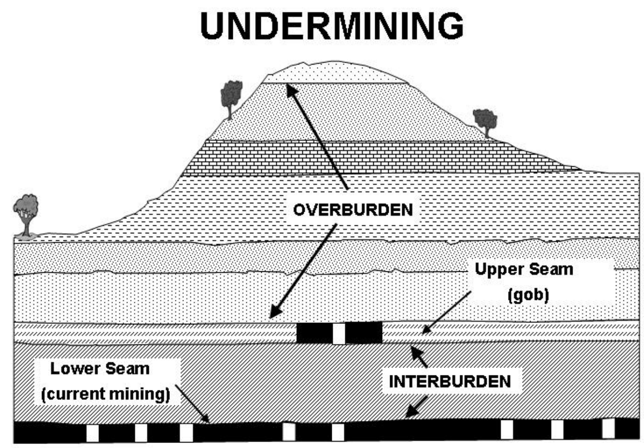
Some of these operations have been highly successful in overcoming the challenges, others less so. The lessons learned from their experience will help ensure that these and similar difficult reserves can be mined safely.

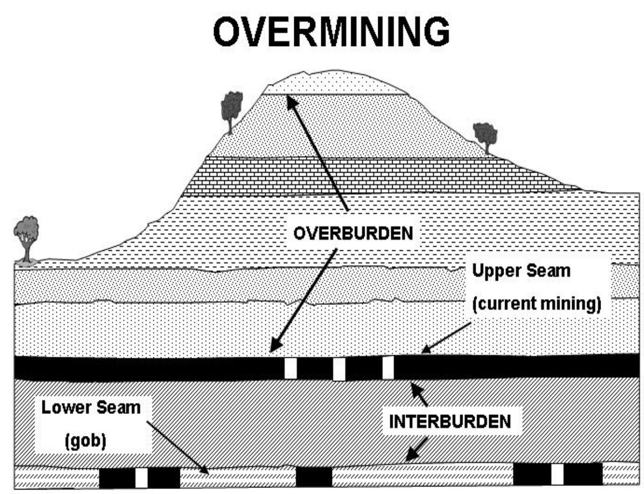
Introduction

The central Appalachian region of eastern Kentucky, western Virginia and southern West Virginia has produced more than 17 billion tons of coal since mining began there nearly 150 years ago. Production peaked in the late 1990's at approximately 275 million tons/yr (250 million tonnes/yr), and has since dropped to about 240 million tons/yr (215 million tonnes/yr). Recent studies have indicated that perhaps 70% of the ultimate reserve base in the region has already been mined (Bate and Kvitovich, 2004).

One consequence of the maturity of the central Appalachian coal fields is that nearly every remaining underground reserve has been impacted by past mining activity. The mountains of the central Appalachian colafields are honeycombed with worked-out mines, located above, below, and adjacent to today's and tomorrow's operations.

In making future mine projections, mine planners must evaluate the potential impacts of these multiple seam interactions. When undermining (mining beneath old workings), the new developments may be subjected to excessive load transfer (figure 1). In the overmining situation (figure 2) load transfer can also occur, and in addition the ground may have been damaged by subsidence. In some cases, multiple seam interactions can be so severe and hazardous that mining is impossible. In others, it may be possible to develop pillars but not recover them. In many cases, however, the interaction may be barely noticeable[1].





Figures 1 and 2. Undermining and Overmining.

Some rules of thumb are available to aid in planning for multiple seam interactions. Westman, et al. (1997) cite traditional reserve estimation criteria which state that when the interval to mining

[1] Other hazards may arise when mining under abandoned works that are flooded or contain bad air (Michalek and Wu, 2000), but these are not discussed in this paper.

above or below is less than 40 ft (12 m) the coal is considered to be sterilized, but it is considered accessible otherwise. Haycocks (1990) found that load transfer interactions were unlikely when the interburden between the seams exceeded 110 ft (33 m), but that some factors (such as strong sandstone or a limited number of interbeds) could reduce this to as little as 60 ft (18 m). With thinner interburdens, interactions could be expected. Haycocks and Zhou (1990) also wrote that columnization of pillars “is considered the traditional approach to multiseam mining, especially when the interburden is less than 50 ft (15 m).”

For overmining situations, Luo et al. (1997) developed a technique for calculating a damage rating based on the lower seam extraction ratio. However, Lazer (1965) reported that if the lower seam has been completely extracted, the upper seam can often be easily mined. The overburden mechanics model developed by Kendorski (1990) indicates that mining might be difficult within the “caving zone” (where the interburden (I)-to-seam-thickness (t) ratio (I/t) is less than 6-10) or the “fracture zone” (I/t<24).

The time lapse between mining has also been cited as an important factor. Intervals of at least two years have been suggested to allow the gob to fully consolidate (Haycocks and Zhou, 1990). Some studies have indicated that the longer the time lapse, the better the conditions that are anticipated.

For the past several years, NIOSH has been studying multiple seam interactions with the goal of providing mine planners with more precise guidelines than are currently available. Nearly 40 mines have been visited, and a total of nearly 300 individual case histories have been documented. Approximately 80% of these case histories are from central Appalachian mines, with the remainder from northern Appalachia and from the western coalfields.

Each case history in the database has been classified according to the severity of the observed interaction. There are four levels:

- *No interaction* where conditions appear to be no different from those in areas where no past mining has been conducted;
- *Minor interactions* where minimal pillar spall or roof cracks indicate that there are some changes that can be attributed to past mining, but they had no significant effect on mining;
- *Difficult interactions* where conditions were severe enough to require supplemental support, design changes, or (on retreat) abandonment of a few pillars, and;
- *Severe interactions* where the area was abandoned and judged unmineable.

In the course of collecting the case histories, NIOSH has found that mining is being conducted under many “extreme” situations, where previous mine workings are close by the target seam. Currently available rules of thumb imply that mining should be severely restricted at these operations, but in many cases the majority of the target reserves are being mined with some success. Severe interactions have been encountered in some areas of nearly all these mines, however. The goal of this paper is to focus on a few of these extreme situations, identify those factors which have contributed to severe interactions, and discuss the control techniques which have proved to be successful.

Case No. 1: Undermining With 20 Ft (6 M) of Interburden

In southwestern VA, NIOSH visited two mines that have exploited seams that lie just 20 ft (6m) beneath previously-worked seams. In one instance, the Marker seam is being mined beneath the Taggart seam, while in the other, the Tiller is being mined beneath the Jawbone. The interburden geology is similar in both situations, consisting primarily of competent sandstone and siltstone. Lower seam Coal Mine Roof Rating (CMRR) values are typically in the mid 60’s. The depth of cover (H) ranges from 600-1,000 ft (180-300 m).

One of the mines is a two-seam operation, with both seams being worked by the same operator. All mining has been development, with no pillar recovery. The pillars have been stacked directly above one another. More than 800 pillars have been developed in this fashion, reportedly without serious incident.

At the other operation, mining in the upper seam was completed approximately 30 years ago, and included large areas where pillars were recovered. Due to the variety of upper seam pillar sizes, and uncertainty about the surveying, there has been no attempt to columnize the pillars. Nevertheless, lower seam mining has been largely successful beneath upper seam first-workings. In some areas, it has even been possible to partially extract pillars in the lower seam. Roof support beneath first-workings consists of 4-ft, no. 5, full-column resin bolts supplemented by 6-ft “superbolts” in the intersections.

Problems have been encountered when attempting to cross upper seam gob lines. On at least two occasions, mining had to be abandoned despite the use of longer bolts, cribs, and steel posts. Conditions were particularly difficult above an 80 ft wide (24 m) barrier pillar separating two gob areas. Where the gob line was successfully crossed, the pillar sizes were increased in addition to extensive supplemental support being installed (figure 3, see Appendix).

Case No. 2: Overmining With Minimal Interburden

Three mining operations, also in VA, are extracting seams that lie less than 45 ft (14 m) above previous workings. In two instances, the Jawbone is being mined above Tiller seam workings, in the third, the target seam is the Splashdam above Upper Banner workings. The Jawbone-Tiller interburden again consists of strong, competent rock, while the Splashdam-Upper Banner interval is somewhat weaker (CMRR=45 for the immediate roof). The cover is mainly in the 800-1000 ft (240-300 m) range for the Jawbone-Tiller mines, and is 500-600 ft (150-180 m) at the other operation.

At one operation, the interburden is just 20 ft (12 m). Here both seams are being mined by the same operator, and pillars have been columnized. There has been no second mining in the lower seam, but pillars have been fully extracted in four upper seam panels with abandoned first workings directly underneath. No problems were reported.

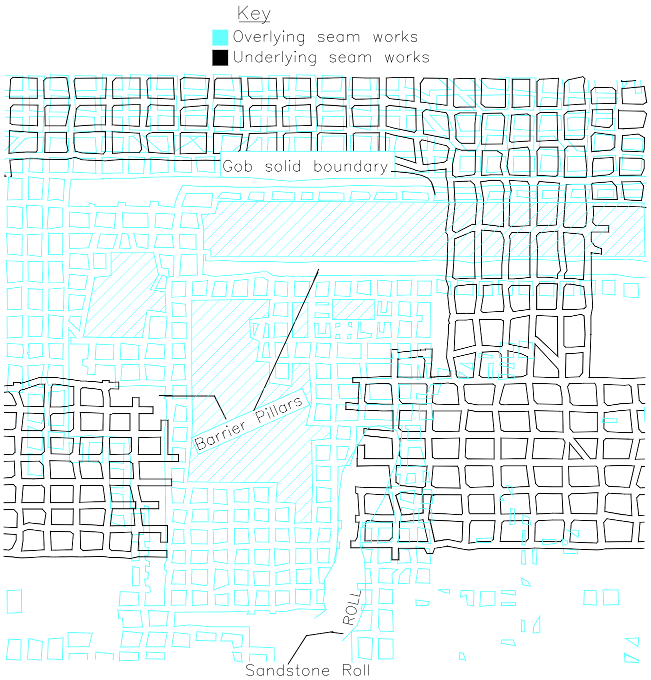
At the other two operations, the interburden is 35-45 ft (11-14 m). Extensive second mining has been conducted in the lower seams, but was completed at least 10 years ago. Recent upper seam mining has been largely interaction-free above first workings or over gob areas. These mines typically use 5-6 ft (1.5-1.8 m) resin bolts for roof support, supplemented by “superbolts” or cables when crossing lower seam structures (isolated remnant pillars or gob-solid boundaries).

The lower seams are 4-5 ft (1.2-1.5 m) thick, so the I/t ratio is approximately 9. Above lower seam structures, the roof can be severely cracked or even “pulverized” into small pieces that fall out upon mining and require short cuts. Several types of lower seam structure have been encountered:

- *Gob-solid boundaries*, where the “solid” can be either unmined coal or development pillars, and is at least 150 ft (45 m) wide;
- *Isolated remnant pillars and narrow barriers*, approximately 50-100 ft (15-30 m) wide, with gob on at least two sides,
- *Sandstone channels* that were left between gob areas. Depending on the width of the channel, these cases were classified into one of the previous two categories.

Figure 4 illustrates these different kinds of structures.

At the two mines, a total of 23 crossings or attempted crossings were analyzed. In 11 of these cases, the panels were subsequently pillared. Such panels were analyzed twice, first as successful development cases, and then as retreat mining cases.



underlying workings.

Tables 1 and 2 show the results. During development, difficult or severe interactions were encountered above only two of the 16 gob-solid boundaries (13%). In contrast, of the seven isolated remnants that were overmined, 4 caused interactions that were so severe that they stopped mining completely, and a fifth resulted in very difficult conditions on advance (71% total). The two relatively successful crossings were both at relatively shallow cover.

Nine of the successful gob-solid crossings were subsequently pillared, about half with minimal problems. When pillars were retreated above the two successful isolated remnant crossings, one resulted in difficult conditions.

Table 1. Conditions encountered crossing lower remnant structures: Development (Case History No. 2).

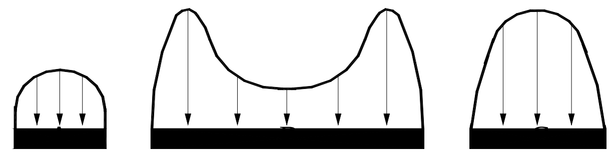
Structure Type	Condition		
	Minor/None	Difficult	Severe
Gob-Solid Boundary	9	5	2
Isolated Remnant Pillar	2	1	4

Table 2. Conditions encountered crossing lower remnant structures: Retreat (Case History No. 2).

Structure Type	Condition		
	Minor/None	Difficult	Severe
Gob-Solid Boundary	4	5	0
Isolated Remnant Pillar	1	1	0

Clearly, isolated remnants pose much more significant hazards at these mines than do gob-solid boundaries. The obvious explanation is that isolated remnants can result in much greater stress concentrations in the adjacent seams. First, they normally carry two stress abutments (one from each gob), while gob solid boundaries usually only carry one. Perhaps just as important is the load distribution that develops within the remnant. As Chase, et al. (2005) pointed out, three different kinds of pillars may be defined based on their load distributions:

- Small, yielded structures that carry relatively small loads (figure 5a);
- Wide pillars or gob-solid boundaries, that have localized high-stress zones but distribute the load (figure 5b), and;
- Isolated remnants that are highly stressed throughout (figure 5c).



structures.

Wide pillars may carry the same (or even greater) load as a remnant, but because their load is distributed over a much larger area, their "footprint" is less noticeable in seams above or below.

Case No. 3: Nearly Simultaneous Mining

A mining complex in Kentucky is extracting the Kellioka seam and Darby seams, which are separated by 40-70 ft (12-21 m) of interburden. The interburden consists largely of sandstone. The depth of cover reaches 2,000 ft (600 m), so the H/t ratio can be as high as 50.

Both mines are room-and-pillar with full pillar extraction. Mining is sequenced from the top down. During the 15 years since mining commenced on the property, a number of lessons have been learned and incorporated into mine planning.

Figure 6 (see Appendix) shows three early attempts to develop production panels beneath fully-extracted Darby seam works. In each case severe roof conditions above thin barrier pillars isolated between two gob areas. The problems were encountered in spite of modifications to the pillar size and supplemental roof support.

Subsequently, Kellioka workings have been laid out to parallel the overlying workings. The width of the Kellioka retreat panels, including slab cuts, exactly matches that of the Darby gobs. With this panel stacking design, most of the lower seam panel development and pillar recovery takes place under the Darby gob. The potential difficulty with panel stacking is that the development must cross a gob-solid boundary in order to access the reserve beneath the gob. At the time NIOSH visited the complex, seven lower-seam panels had been successfully extracted using the stacking design. Although some difficulties conditions were encountered at gob-solid boundaries, that they were much less severe than those associated with the thin isolated barrier pillars.

In the early planning, the mine tried to wait at least 6 months after completion of the upper seam retreat mining before developing the lower seam works. However, experience showed that "settling time" did not have a large effect on the conditions encountered. Recently, some lower seam developments have begun as early as one month after the overlying panel was extracted.

Case No. 4: Undermining Pre-Existing Workings

In southern WV, mining on several properties has been conducted in as many as ten seams. Longwalls have mined large portions of the Powellton seam, and are currently working near the bottom of the geologic column, in the Eagle and the No. 2 Gas seams.

NIOSH studies found that there are numerous instances of successfully mining above previously longwalled areas. In most of these cases, the interburden between the target seam and the longwall gob is at least 180 ft (54 m).

There have been several instances in which longwalls undermined open entries, usually mains, in overlying mines. The results have almost always been unsatisfactory. In one instance, a mine was maintaining main entries in the 9 ft (3.7 m) Coalburg seam, 560 ft (170 m) above the 6 ft (1.8 m) No. 2 Gas. The I/t ratio in this case was nearly 100, and the overburden-interburden ratio was less than 1.0. In addition, over 50% of the overburden was sandstone, and the immediate roof consisted of competent sandstone (CMRR=70). Finally, 16 ft (4.8 m) vertical cable bolts and cable straps were installed together with standing supports (steel props).

The longwall directly undermined the mains, as shown in figure 7. Within days, the Coalburg seam subsidence measured 36-42 inches (0.9-1.1 m). The immediate roof was severely fractured, with some open apertures of 4 inches (100 mm). Numerous large roof falls resulted (figure 8).

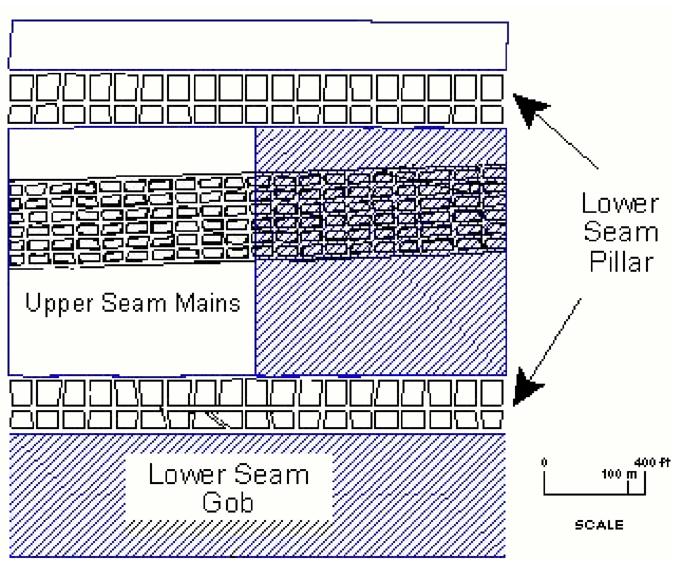


Figure 7. Longwall mining that subsided open entries 560 ft (170 m) above.

Figure 8. Damage caused when open entries were subsided.

This example, and at least 4 others in the data base, show that the normal subsidence prediction rules are completely inapplicable when open entries are involved. The reasons are not hard to understand. Referring again to Kendorski's overburden mechanics model, the Coalburg seam would normally have been safely within the "confined zone" within which the ground subsides but no new fracturing takes place. However, the entries removed the compressive confining pressure, so the rock around the mine openings was subjected to severe tensile stress. Had the mains been developed after the longwall had been extracted, there might have been no obvious evidence of its passage.

Another curious case in the data base involved a mining complex in Kentucky. A room-and-pillar panel was retreated in the Pond Creek seam, and approximately two years later a set of main entries was developed in the Cedar Grove seam, 180 ft (54 m) above. The I/t ratio was about 5, and conditions were initially excellent with just 4 ft (1.2 m) fully grouted bolts. After about two years, however, the roof began to deteriorate dramatically. Extensive supplemental support, including full cable bolting, wood cribs, and polyurethane injection, eventually had to be installed. The most likely explanation is that ground between the two seams had not fully subsided when the upper seam entries were developed. When it did subside later, it apparently caused the same kind of damage as in the longwall case described above.

Conclusions

The case histories presented in this paper, and others contained in the NIOSH data base, clearly show that the existing multiple seam guidelines should be refined. One general point is that it is seldom possible to evaluate the mineability of an entire reserve with broad criteria based on factors like the extraction ratio or interburden thickness. Multiple seam interactions are highly localized, so it is necessary to evaluate the interaction potential from each structure left in the previously mined seam.

Experience seems to show that where the previous mining has been limited to development, it may have little impact on reserves separated by interburdens of as little as 20 ft (6 m). In one instance described in this paper, columnization was not even necessary. Similarly, mining beneath gob areas, where the ground has been largely destressed, seldom presents serious problems.

When mining above gob areas, some roof fracturing can be expected up to a distance of perhaps 24 times the lower seam height. Yet the mines described here have encountered few difficulties even just 40 ft (12 m) above gob areas.

Difficult ground conditions are often encountered when crossing from the solid into the gob (or vice-versa). However, by employing control techniques including longer pillars, narrower entries, and additional roof support, the mines described in this paper have been able to cross most of these structures.

The most serious interactions occur above or beneath isolated remnant pillars, normally 40-100 ft wide, located between two gob areas. These types of structures are apparently too wide to have yielded, but too narrow to effectively distribute the load. The high stresses associated with these types of structures have often stopped mining completely. A reserve area that contains many such isolated remnants may indeed be unmineable.

Severe interactions are also likely if an open entry is undermined by longwall or pillar extraction. A large interburden thickness, a low depth of cover, and even strong roof may be no protection from the damage caused when an open entry is subsided.

The case histories appear to indicate that the necessary time lag between mining the two seams may not be fully understood. In one instance, as little as one month appeared to be an adequate "settling time," but in another case, four years may not have been enough. The important factor may not be the elapsed time, but whether the subsidence is complete. Observations from longwall mining indicate that subsidence at the surface is often complete within weeks, while some abandoned mines have collapsed decades after mining (Iannacchione and Mark, 1990).

NIOSH is continuing its evaluation of the entire multiple seam case history data base. The results will be used to develop suggested guidelines for analyzing potential multiple seam interactions. It is hoped that these guidelines will help mine operators to more safely extract the increasingly difficult reserves in central Appalachia and elsewhere.

References

1. Bate, R.L. and J.F. Kvitovich (2004), "Quantifying the Coal Reserve Dilemma in the Central Appalachian Mining Region", *SME preprint 04-108*, 8 pp.

2. Chase, F.E., P. Worley and C. Mark (2005), "Multiple Seam Mining Interactions: Case Histories from the Harris No. 1 Mine", In *24th Intl. Conference on Ground Control in Mining*, Morgantown, WV, pp. 79-86.

3.

4. Haycocks, C and Y.Z. Zhou (1990), "Multiple Seam Mining: A State-of-the-Art Review", in *9th Intl. Conference on Ground Control in Mining,* Morgantown, WV, pp. 1-11.

5. Iannacchione, A.T. and C. Mark (1990), "Possible Mechanism for Surface Vibrations Near Maxwell Hill, West Virginia", *Bulletin of the Association of Engineering Geologists*, Vol. xxvii, No. 3, pp. 341-353.

6. Kendorski, F.S. (1993), "Effect of High-Extraction Coal Mining on Surface and Ground Waters, in *12th Intl. Conference. on Ground Control in Mining*, Morgantown, WV, pp. 412-425.

7. Luo, J, C. Haycocks and M. Karmis (1997), "Gateroad Design in Overlying Multiple Seam Mines. *SME preprint 97-107*, 4 pp.

8. Michalek, S.J. and K.K. Wu (2000), "Potential Problems Related to Mining Under or Adjacent to Flooded Workings", in *19th Intl. Conference on Ground Control in Mining*, Morgantown, WV, pp. 199-203.

9. Westman, E., J. Luo, C. Haycocks and M. Karmis (1997), "Ground Control Criteria for Coal Reserve Estimation in Multiple Seam Mines", in *16th Intl. Conference on Ground Control in Mining*, Morgantown, WV, pp. 311-315.

10. Lazer, B. (1965), "Mining Seams Above Mined-Out Lower Seams", *Mining Engineering,* Sept., pp. 75-77.

Appendix

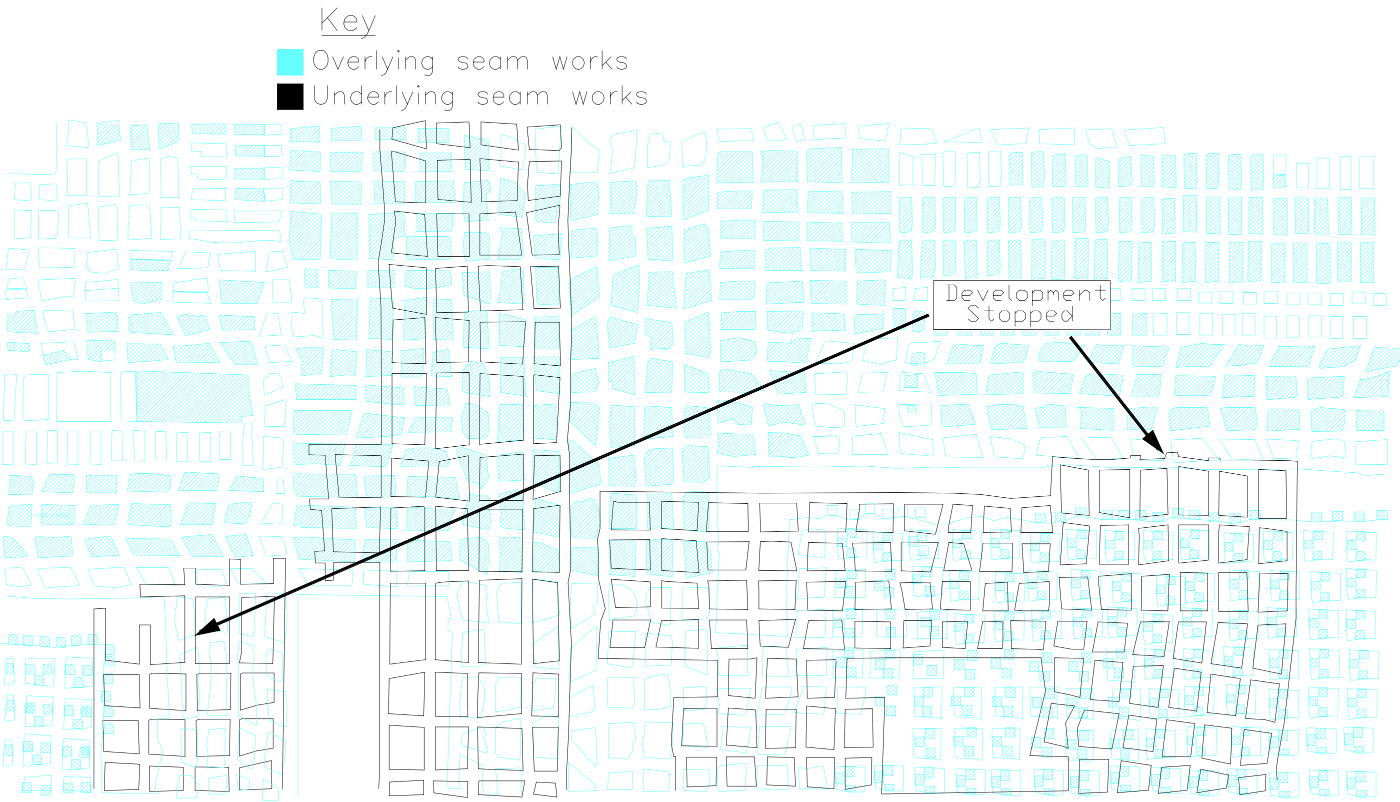


Figure 3. Interactions resulting from undermining remnant structures with just 20 ft (6 m) of interburden.

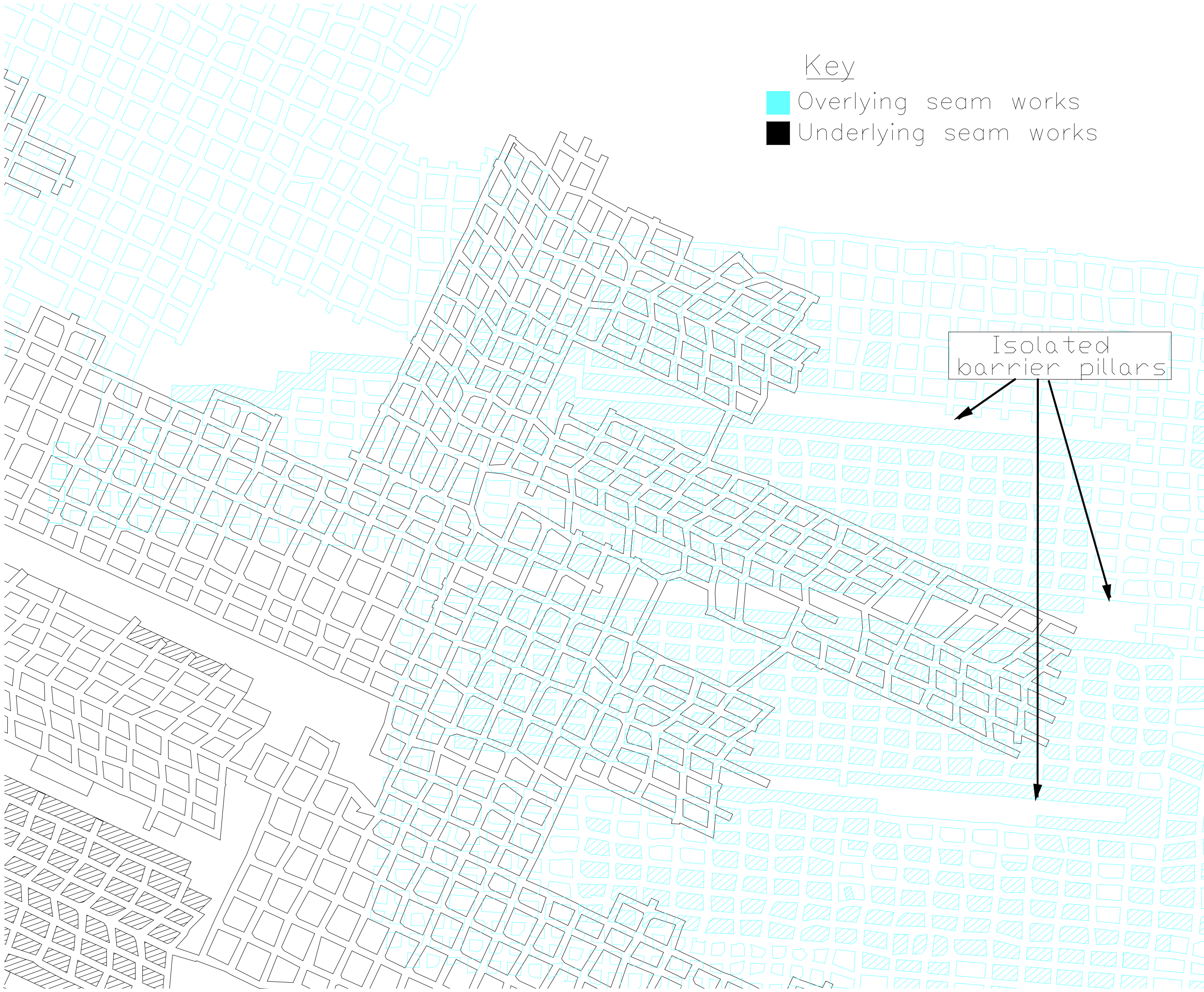


Figure 6. Interactions caused when trying to undermine thin isolated barrier pillars in an overlying seam.