USING SITE CASE HISTORIES OF MULTIPLE SEAM COAL MINING TO ADVANCE MINE DESIGN

John L. Ellenberger, Research Geophysicist
Frank E. Chase, *Research Geologist*
Christopher Mark, *Supervisory Physical Scientist*
National Institute for Occupational Safety and Health
Pittsburgh Research Laboratory
Pittsburgh, Pennsylvania USA

Keith A. Heasley, *Associate Professor*
West Virginia University
Morgantown, West Virginia USA

John K. Marshall, *Electronics Technician*
National Institute for Occupational Safety and Health
Pittsburgh Research Laboratory
Pittsburgh, Pennsylvania USA

ABSTRACT

The nature of competition in the coal market tends to deplete the most favorable coal reserves first, and forces subsequent development of mines in more extreme ground conditions such as those associated with multiple-seam mining. In fact, 70% of the United States coal reserves are in multiple-seam situations. The National Institute for Occupational Safety and Health (NIOSH) is conducting research to develop mine design algorithms that will result in safer multiple seam mines.

This paper presents an overview of multiple seam issues in the central Appalachian coalfields. To date, more than 50 case histories have been analyzed from 20 operating mines in Eastern KY, Western VA, and Southern WV. Each case history is classified according to the degree of multiple-seam interaction, ranging from no apparent interaction to severe interaction with direct impacts on mine safety and resource recovery. The case histories are also examined with regard to amount and geologic characteristics of interburden and overburden, and design stability factors. The sequence of mining has also been found to be critical when the lower seam is fully-extracted.

This paper compares current case histories to traditional rules of thumb. In addition two situations were modeled using LaModel software. LaModel has been upgraded to import pillar grids and topographic data from AutoCAD files. The cases presented demonstrate vertical stress capabilities of LaModel.

INTRODUCTION

Over the past decades, coal mine roof/rib falls have been a leading cause of underground fatalities and injuries. Previous NIOSH research has identified various mining practices that tend to pose greater risk to underground personnel as compared to other procedures or techniques. NIOSH is currently investigating hazardous ground conditions that may occur when reserves are mined above or below other mined areas. One may perceive the normal sequence of mining to be a progressive sequence from the top to the bottom in a geologic section such that the normal sequence would be all undermining (figure 1). However, geologic conditions often place thicker and more desirable coals lower in the section, resulting in mining of seams out of vertical sequence. This results in subsequent operations that are developed to overmine these deeper works (figure 2).

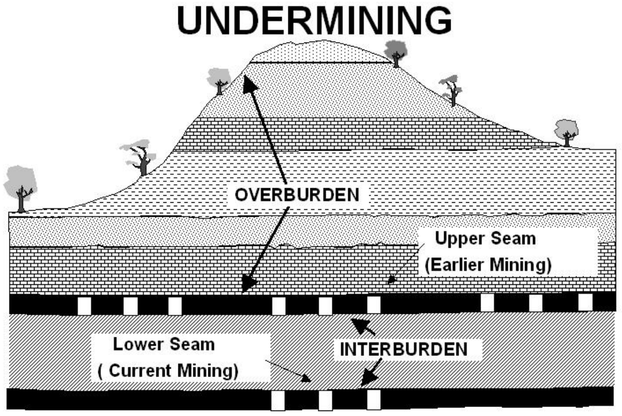

Figure 1. Schematic of an undermining situation. Upper seam mined first, lower seam mined second.

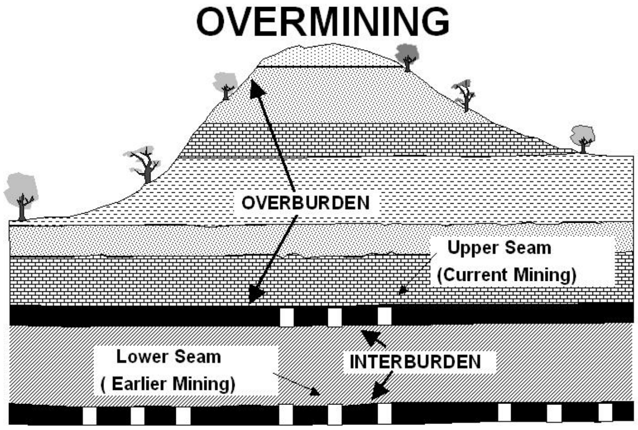

Figure 2. Schematic of an overmining situation. Lower seam mined first, followed by the upper seam.

Researchers have investigated problems associated with multiple seam mining for over a century (1). Similar problems have been discussed as mining has evolved, and multiple seam situations have become more and more common (2, 3, 4). Researchers (5, 6) have documented and analyzed a number of specific experiences of mines operating in multiple seam configurations. For example, Haycocks, et al (7) analyzed various interburden characteristics for 25 case histories and developed guidelines on when interactions should be anticipated.

Mining variables and interaction mechanisms have been recognized in earlier literature (11). Most of the problems that result from overmining are also common to undermining. Most readily recognized is the tendency to redistribute overburden loads where barriers have been left during earlier mining. Load transfer (figure 3) results from the weight of overburden being shifted from relatively uniform overburden loading to concentrated areas where the coal has not been mined. Load transfer may be seen in both undermining and overmining situations, but during overmining, subsidence may also contribute additional problems such as fracturing and stress concentrations to further complicate mining. The amount and composition of interburden also affects the interaction with stronger rocks such as sandstone distributing loads and creating beam behavior with lesser amounts of interburden. The cases for ultra-close mining (25 feet (7.5 m) of interburden or less) (16) require quality interburden and the rocks tend to fail in shear. When ultra-close mining takes place, a failure in one seam may result in pillar instability in the other seam.

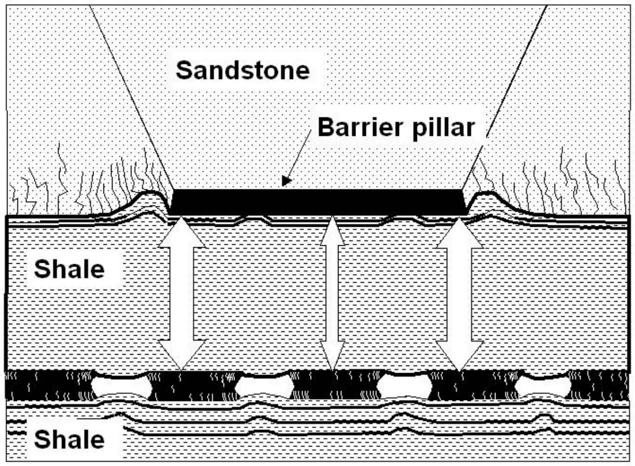

Figure 3. Load Transfer from an upper seam barrier to lower seam entries and pillars.

A number of studies have identified the various geologic parameters and mine design variables that most probably play a role in determining whether interactions are likely to occur. As computers have become available and progressively more powerful engineering tools, researchers have also developed numerical modeling methods and designed software programs to predict multiple seam interactions (8, 9, 10). The LaModel software developed by NIOSH (13, 14, 15) is a boundary-element program for modeling stress in coal mines. LaModel calculates stresses and displacements in multiple seam situations. Recent upgrades to NIOSH's LaModel program have simplified the process of developing mine grids and importing topographic files.

The goal of the current NIOSH research in this area is to determine appropriate design methodologies for mining in multiple seam extraction situations. In order to accomplish this objective, a large data base of underground case histories are being collected at mine sites for multivariate statistical analyses. In addition, case histories are being analyzed using the LaModel program for representative overmining, undermining, and subsidence case history situations.

CASE HISTORY DATA

Case histories are developed in two steps, the first being a mine visit with underground observation, where pertinent data is collected, with the second portion being detailed analysis of parameters that comprise the case history, including a variety of general and specific characteristics of each site. Involvements of operations personnel after the mine visit are generally limited to contacts for AutoCAD files and core logs, thereby minimizing impacts on mining operators.

Mine visits consist of a discussion with experienced mine officials to review maps and conditions encountered and to collect relevant information about the mines involved. This is followed by an examination of accessible areas of the mine to assess conditions and to collect Coal Mine Roof Rating (CMRR) data. One of the key pieces of necessary data is an accurate overlay map including workings of both the mine that is under evaluation and the mine that is causing interactions. Areas where interactions between the mines are identified and apparent similar areas with less or no interactions are also addressed. AutoCAD files are also collected during the visit, and core hole data are requested either during the visit, or as case histories are developed.

Development of Case Histories

While the CMRR values are included as one portion of the geologic information in each case history, additional information relating to the interburden and overburden is derived from core holes drilled in the vicinity of each case history site. Core hole data, supplemented by electric logs, when available, provides base data relating to interburden thickness, number of geologic units with beam forming potential, and the percentage of competent rock within the interburden.

The case histories are classified according to the severity of the observed interaction. There are three levels:

- *No interaction* included sections where overmining or undermining had occurred, but conditions in the subject seam did not appear any different as compared to areas where mining had been isolated in only one seam.
- *Moderate interactions* included those with notably difficult ground conditions, but mining was still possible.
- *Extreme interactions* included those situations where parts of a seam were rendered unmineable due to severe multiple seam interactions.

A number of other factors are derived from maps for each case history, including mining height, loading conditions, pillar stability factors, angle of mining intercept, and dates of mining in each seam. Estimates of average seam height for old works were included when they did not appear on mine maps, and the dates when mining occurred were often estimated on the basis of the closure of a mine.

Several factors posed unusual problems in the multiple seam evaluations. For example, mines often have their own coordinate system, and the accuracy of the case history analysis depends on correct translation of the coordinates. Abandoned workings, relating to mines closed for more than a generation, are often encountered with inconsistent pillar designs, and the evaluation of their stability may result in a range of values rather than a single value for a site.

Several factors were calculated primarily from core hole data relating to both mines in the case history: interburden to lower seam thickness ratio, interburden thickness, overburden to interburden ratio, the number of competent interburden units, and finally the percentage of competent units contained in the interburden.

Summary of the Current Case History Database

The multiple seam studies currently being conducted have contributed more than 50 case histories to a database that will continue to expand. As of this writing, the cases include 12 from Kentucky, 29 from Virginia, and 13 from West Virginia mines. Twenty-nine cases are classified as undermining, and 25 cases are classified as overmining.

The database includes 12 different coalbeds with a range of mining heights of 4.0 to 6.8 feet (1.2 to 2.1 m). Overburden ranges from 250 to 2025 feet (75 to 620 m) with 75 percent of the cases having overburden of 1000 feet (300 m) or less. CMRR values range from a low of 41 to a high of 67. Interburden ranges from 23 to 680 feet (7 to 210 m) with 34 cases being less than 100 feet (30 m) and 7 cases with interburden greater than 250 feet (75 m).

Figure 4 shows the undermining case histories, where damage to the lower seam is caused entirely by load transfer from the upper seam. The data indicate that no significant damage has been observed when the overburden-to-interburden (OB/Int) ratio is less than approximately 7.0, and the depth of cover is less than 600 ft. Extreme conditions seem most likely when the OB/Int ratio is greater than 16.

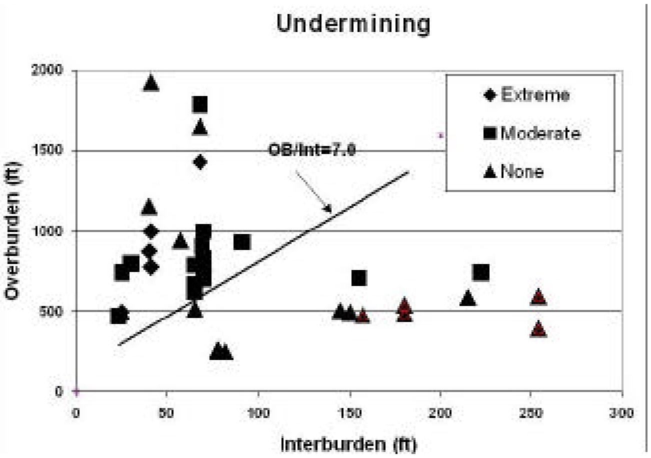

Figure 4. Undermining cases showing degree of interaction plotted by Interburden vs. Overburden (in feet).

The data also show that is possible to mine successfully, even at high cover and with large OB/Int ratios. In these cases, mining was carefully planned to take place in the stress shadow beneath fully-extracted gob areas. In these same mines, however, attempts to cross beneath remnant barrier pillars resulted in extreme interactions leading to abandonment.

With overmining (figure 5), damage can be caused by both load transfer and subsidence. The data show that when the OB/Int ratio is greater than 7.0, damage can generally be expected. However, extreme damage may also occur at low OB/Int ratios due to the subsidence effect. Timing is also a critical factor since subsidence needs a period of time to stabilize. If the upper seam is developed first, and then the lower seam is extracted, severe damage is likely during the active undermining, as is illustrated by one of the case histories described below. It seems that when the roof is strong, the probability of subsidence damage is reduced.

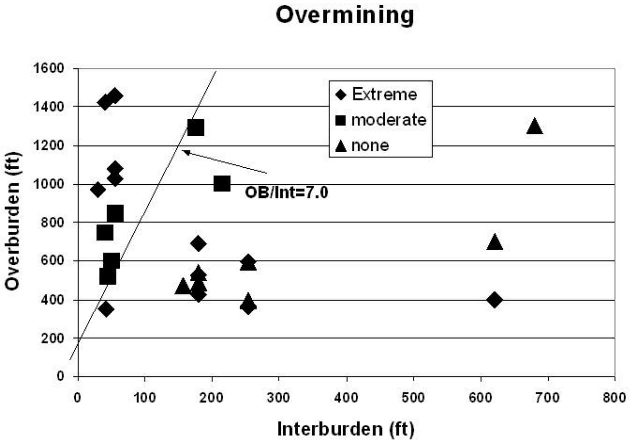

Figure 5. Overmining cases showing degree of interaction plotted by Interburden vs. Overburden (in feet).

LaModel Updates

NIOSH has recently upgraded the LaModel program and added features that include auto-meshing capabilities for inputting the mine and topographic grids (13, 14, 15). The enhanced program greatly speeds analyses of the multiple-seam case histories. LaModel can generate the mesh directly from an AutoCAD map of the pillars. Since AutoCad is used by 90% of the mining industry, maps suitable for automatic mesh generation are typically available directly from mines. Therefore, any mine having their mine map in AutoCad can quickly and easily generate meshes of parts of their mine plan for analysis using LaModel.

SPECIFIC CASE HISTORIES USING LAMODEL

The case histories presented here include an undermining and an overmining scenario. In the undermining scenario, the interburden between the two seams appeared to be sufficient that there would be only a minimal interaction; however, the magnitude of interaction caused a significant delay in mining in the upper seam. The overmining case shows a situation where an abandoned channel in the lower seam limited mining, and behaved as a barrier with regard to stress transfer to upper seam mining. The input files for LaModel were generated using the default physical properties directly from the materials wizards in LaModel, and the topographic and pillar grids were imported directly from AutoCAD files.

Case History of a Longwall Undermining Active Mining

When overmining reserves that have been fully extracted, it has been recommended that the strata be allowed to settle for two or more years (11). If two seams are concurrently being mined, dynamic interactions can occur in the upper mine when lower seam reserves are fully extracted (12). These interactions can cause difficult conditions in the upper seam due to subsidence induced ground disturbances and stresses.

In this case history, the upper seam mine was in the process of developing mains in the 9-foot (2.7-m) thick Coalburg seam. Concurrently, the underlying 5.6 foot (1.7 m) thick No. 2 Gas seam was extracted with a longwall. As shown in Figure 6, the longwall panel nearly paralleled the upper seam mains. Maximum overburden above the upper seam varied from 350-400 feet (105-120 m) and the interburden between the two coalbeds averaged 560 feet (170 m). This results in an overburden to interburden ratio of less than 1.0, and a ratio of interburden to lower seam thickness of 100; therefore, the fracture zone might not have been expected to extend to the upper seam. In addition, over 50 percent of the interburden consisted of massive sandstone, which might also have been expected to dissipate the effects of the undermining. Despite the optimistic prognosis, precautionary 16 ft (4.9 m) cable bolts were installed between the rows of primary supports in the upper seam entries before undermining. Cable bolts and cable slings were also added as supplementary support in the intersections.

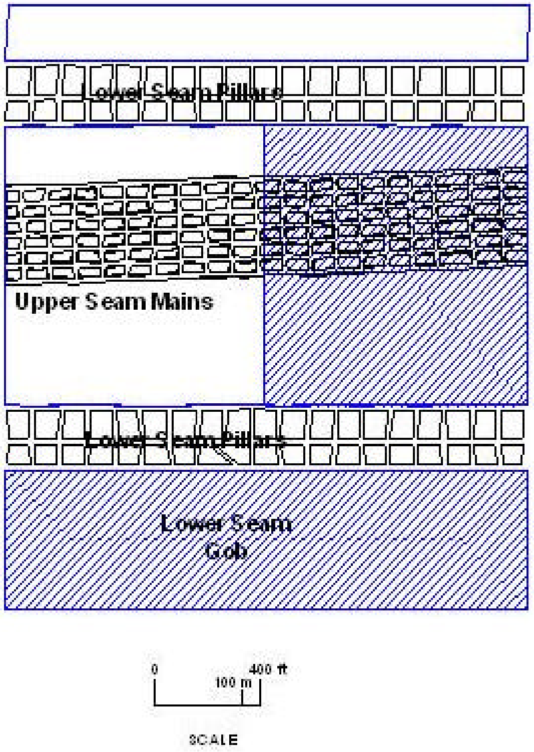

Figure 6. Mine layout. Upper seam working consist of 7 entry mains, lower seam workings consist of longwall and accompanying gob areas.

As the longwall face approached to within 70 ft (20 m) of the upper seam workings, small tension cracks began to develop. Roof/rib control problems intensified as the longwall progressed underneath and continued beyond. The majority of the damage had occurred when the face had passed by the workings a distance of 300 feet (90 m), with total damage being sustained at 1,000 feet (300 m). In terms of an undermining time frame, most of the subsidence was realized by 3.5 weeks; however, it took approximated 7.5 months for the ground to essentially stabilize. Subsidence displacement in the upper seam mine ranged from 36-42 inches (0.9-1.1 m).

In the upper seam, the competent sandstone immediate roof was extensively fractured. Fractures were measured with apertures up to 4 inches (0.1 m) and several large falls resulted. Severe rib spalling also occurred. It was apparent that the traveling wave of subsidence had caused far more damage than might have been expected. As the ground settled and reached equilibrium, the roof fractures closed and conditions significantly improved.

The LaModel program was used to determine the mining and multiple seam-induced stresses, and also to estimate the subsidence displacements. Based on the interburden characteristics and pillar dimensions, a 50-foot (15-m) lamination thickness and 5 foot (1.5 m) element width were selected. The modeled area illustrated in Figures 7 and 8 is 2,000 by 2,000 feet (600 m). Figure 7 depicts the multiple seam-induced stresses generated after one half of the lower seam longwall panel had been extracted in the modeled area. As would be anticipated, the highest stresses are concentrated in the inby tailgate chain pillars. Another highly stressed area is outby the face in the front abutment zone. Conversely, figure 7 depicts an area of stress relief in the gob. Figure 8 displays the total stress in the upper seam due to topography, development, and undermining induced stresses. As shown in figure 8, the highest stresses occur in the pillar row almost immediately above and outby of the lower seam longwall face.

As previously mentioned, LaModel was also used to calculate upper seam subsidence displacements. Based on the previously mentioned input parameters, the maximum upper seam subsidence was calculated to be approximately 9.3 inches (23 cm). Upper seam movement was measured and ranged from 36-42 inches (0.9-1.1 m). When using LaModel, more realistic subsidence displacements can be attained by calibrating lamination thickness or by using the free surface effect. Another calibration option is to use a displacement adjustment factor based on site-specific conditions. Since the primary objective in this work was to examine multiple seam stresses, the subsidence was not calibrated.

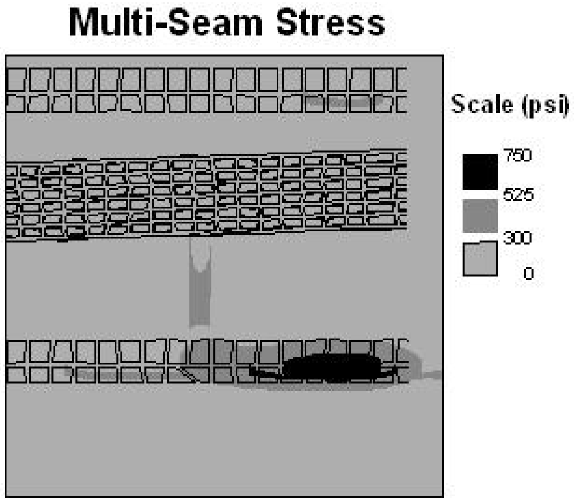

Figure 7. Plan view of multiple seam stress from LaModel when the longwall face progressed under the overlying mains.

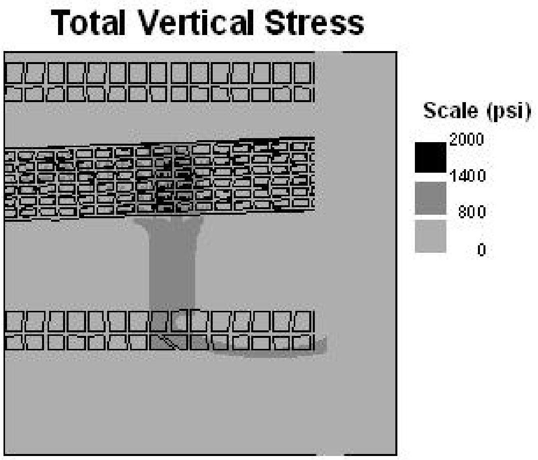

Figure 8. Plan view of total vertical stress from LaModel when the longwall face progressed under the overlying mains.

Case History of Overmining a Sandstone Channel

The second case modeled using LaModel involved a situation where the Upper Banner coal seam had been mined, and delimited the boundaries of an abandoned channel. Nearly 50 years later, overmining was initiated in the Splashdam seam approximately 50 feet (15 m) above the first mine. The overburden averaged 600 feet (180 m) on the active mine. Both mines were recovering approximately 4.5 feet (1.4 m) of coal. In view of the extended period of time between the development of the two seams, one may have expected to see little or no interaction; however, operations in the upper seam encountered frequent interaction in areas where the underlying channel had prohibited mining. In fact, three rows of pillars were abandoned in the middle of the upper panel in Figure 9. As a result, a portion of this mine was selected to be one of the first case histories modeled using LaModel.

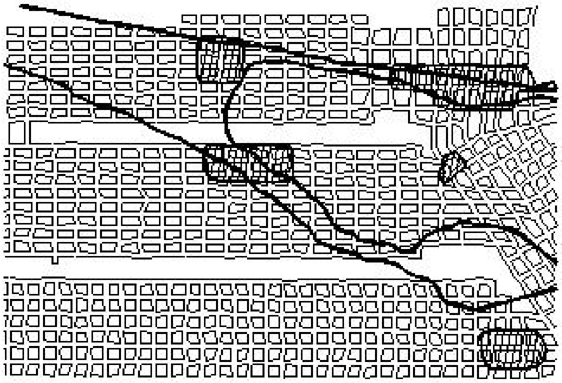

Figure 9. Plan view showing room and pillar panels and bad mining condition areas overlying sandstone channel.

The area selected for the study was 2500 by 2500 feet (750 by 750 m), and an element size of 10 feet (3 m) was selected for the seams, and 50 feet (15 m) for the lamination thickness. The grids were also rotated to give the appearance of East/West and North/South entries and cross cuts. Coal strengths and yield zone properties were accepted at the defaults from LaModel, and the final modulus for a strain hardening gob was set at 300,000 psi (2000 MPa). The channel was treated the same as coal while running the program, assuming that it may have coal underneath it in places, and was viewed as a barrier pillar. Lamination thickness was set at 50 feet (15 m).

The study area included over 600 pillars in the active workings. The channel outlined by the abandoned workings was represented as a series of pillars in direct contact with each other across the study area in order to facilitate gridding. Several areas of bad mining conditions were outlined on the map of the upper seam (figure 9). Pillar remnants along the edges of the channel were assumed to have failed, and were assigned gob values in the grid. For purposes of modeling, all pillars in the panels were left in place in the first step of mining, and in step two all the pillars that were recovered up to the point where three rows of pillars were lost were removed.

The results of the LaModel analysis of vertical stress are shown in figures 10 and 11. It should be noted that the areas having higher than normal vertical stress are located directly above the remnant sandstone channel with a peak stress of 4077 psi (28 MPa), and when the pillars are removed, a peak vertical stress of over 6300 psi (44 MPa) is shown with its location being at the pillar line where pillars had to be abandoned.

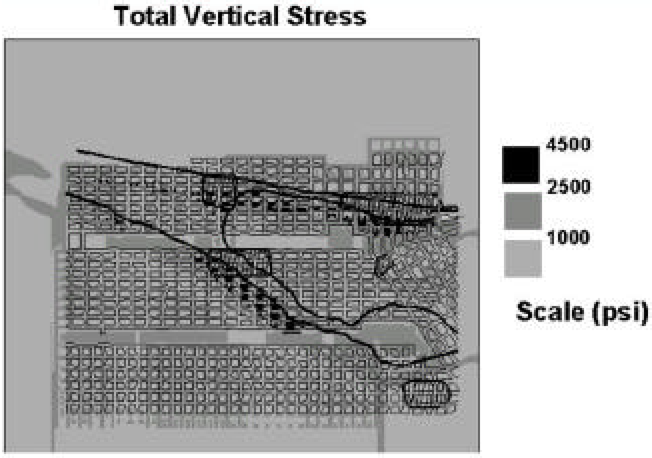

Figure 10. Plan view of total vertical stress from LaModel indicating stress concentrations above sandstone channel from development.

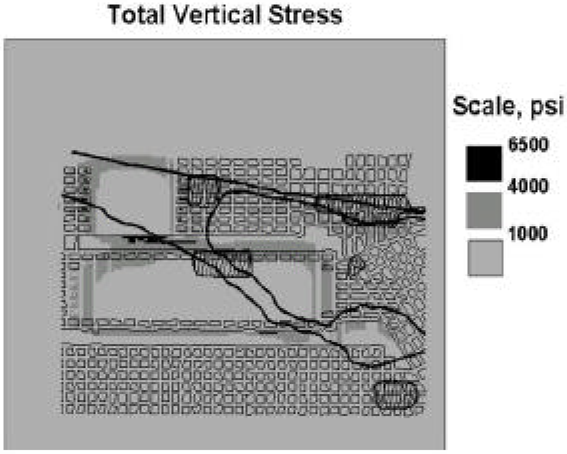

Figure 11. Plan view of total vertical stress from LaModel indicating stress concentrations above sandstone channel with pillars removed.

RECOMMENDATIONS AND CONCLUSIONS

Several conclusions can be drawn from the case histories and the specific LaModel evaluations discussed in this work.

1. No significant damage has been observed when the overburden-to-interburden (OB/Int) ratio is less than approximately 7.0 and the depth of cover is less than 600 ft (180 m).
2. Extreme conditions seem most likely when the OB/Int ratio is greater than 16.
3. It is possible to mine successfully, even at high cover and with large OB/Int ratios when mining is carefully planned to take place in the stress shadow beneath fully-extracted gob areas; however, attempts to cross beneath remnant barrier pillars may be cause extremely adverse conditions relating to load transfer from the upper mine.
4. When the roof is strong, the probability of subsidence damage is reduced.
5. Timing is also a critical factor. If active workings are undermined, severe damage to the upper seam is likely.
6. Vertical or near vertical load transfer appears to occur frequently in both undermining and overmining cases where a seam is not completely extracted. The sand channel case presented in this paper is an excellent example of this transfer.

With the current estimate of 70% of mines operating in multiple seam situations, the problems encountered by the industry will continue for the foreseeable future, and modeling of the interactions will continue to have an important role. NIOSH expects that its current research will provide the mining community with additional design tools to minimize exposure to the hazardous ground conditions associated with multiple seam mining.

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