Ground Control Hazard Analysis in Multi-Seam Mining

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ABSTRACT

Hazard analysis utilizes interaction mechanisms in combination with geologic, structural and mining conditions to delineate areas of potential damage in seams subject to interaction. Using characteristics of conditions peculiar to multi-seam mining, such as innerburden thickness, geology and structures, initial interaction contour maps can be constructed. Geologic hazard analysis is then carried out on roof, pillar and floor conditions in the affected seam using lower seam rock properties and layout geometries in the overlying seam. Either safety factors or damage ratings can then be developed representing degree of hazard in the lower seam. The final hazard map shows both the aerial extent and magnitude of potential damage from interaction.

INTRODUCTION

The majority of the world's coal seams exist in a multiple seam environment. In parts of the United States there are up to 23 mineable coal seams in a given stratigraphic section. As mining progresses, there is increasing concern about the locations and levels of damage that both over and under-mine causes in neighboring seams. Ground control planning in these adjacent seams under such mining conditions must be based on proven multi-seam technology to forecast and quantify the magnitude and extent of this damage and the increased mining risk due to interaction. Ground control problems can result in significant losses of reserves, and a reliable estimate of recoverable coal reserves is essential to long-term planning and for conservation of energy resources. As individual seams are mined out, coal recovery from coal seams that overlie or underlie the mined-out seams may be significantly reduced, depending upon the magnitude of inter-seam interaction. Determining reserve losses and increased mining costs due to interaction is becoming an urgent problem for the underground coal industry. Ultimately, controlling the degree of interaction damage in an unmined seam must depend on the mining practices in the adjoining and affected seams. The geology, structure and spatial distance between the seams cannot be changed. Stability assessment across a mining area involves the following major factors which govern interaction:

- Mining methods and sequence used in extracting the previously mined overlying or underlying seam, as well as the seam being currently mined;
- Relative pillar sizes and locations and opening width;
- Percentage and uniformity of coal recovery in all seams concerned;
- Thickness of innerburden between the seams under consideration;
- Structural characteristics of the innerburden;
- Thickness of the coal seams mined;
- Time elapsed following the mining of the previously mined seam;
- External loading factors;
- Depth

In practice, these factors can be separated as causes, modifier, and effects as shown in Figure 1. Hazard maps may be constructed at the end of stage two or stage three.

MULTI-SEAM ANALYSIS

Previous research has identified factors that affect interaction and quantified basic interaction mechanisms for various mining and geologic conditions. A successful combination of case studies and both numerical and photoelastic modeling has resulted in significant developments in

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coal loss. Innerburden is critical in both methods of mining, but particularly longwall where interaction effects may extend a vertical distance of over 750 feet (230 m) (Scurfield, 1970). Geology of the innerburden is also very important (Szawlinski, 1979; Johnson, 1973; Haycocks, 1991). More competent material such as sandstone inhibits arch formation and reduces subsidence (Styler and Dunham, 1980), thus reducing potential interaction effects.

The complex and far ranging multi-seam research results have established the conditions under which multi-seam created interactions will occur in a neighboring seam. To facilitate transfer of this technology, it has been included in a series of computer programs, MULSIM, HUMSIM and USSAM (Grenoble, 1985; Wu, 1987; Zhou, 1988).

The limitation on the usage of these programs in practice is that they are very site specific and require the engineer to basically analyze each major change in geologic and mine structure. This naturally limits the application of the method for large scale planning. Incorporating the programs into a hazard approach allows these programs to be adapted for mine-wide layout.

**HAZARD ANALYSIS**

The use of hazard analysis for successfully predicting roof and other ground control failures in advance of mining, is being used by a number of mining operations. (Overbeek et al., 1973; Ealy et al., 1978). The hazard approach relies on extensive use of a wide range of geological, structural, and mining data, including lineaments, roof stratigraphy, extraction ratios, mining heights and fracture zones. These are then overlain in various combinations against known ground control disturbances such as roof falls to identify critical geologic and mining situations. Once features that can contribute to ground control problems are identified, hazard maps are constructed to locate potentially dangerous areas. The final hazard map shows both the location, aerial extent and severity of potential damage caused by interaction.

A flowchart demonstrates the adaptation of the hazard map concept to predict roof and floor damage in a lower seam is shown in Figure 2. In carrying out this adaptation there are two major problems. The first is to accurately predict geology throughout the mining area based on data from boreholes which may be spaced up to a mile or more apart. The second is the ability to identify and predict the effects of often complex mining and geologic structures on the affected seam. To solve the latter problem a layered approach is taken, first considering spatial, then geological, and finally the effects due to mining structure. This approach also avoids evaluating areas where no interaction could possibly take place due to excessive distance.
The study of rock mechanics and geologic characteristics is crucial for the safe and efficient mining process. The interplay between the geologic structure and mining operations is complex and requires a multidisciplinary approach. Geologic features such as bedding, fractures, and faults can significantly impact the stability of mine workings. The process of loading and unloading rock during mining can cause stress transfer and deformation, which can be modeled using geotechnical and geologic principles.

In the context of multi-seam mining, the integration of geologic data with geotechnical analysis is essential. The use of geological maps and cross-sections provides a framework for understanding the spatial distribution of rock properties. This information is critical for predicting the behavior of the rockmass under various stress conditions.

The importance of geologic data in mining is underscored by the need for accurate and detailed models. These models help in planning the mining sequence and in anticipating potential risks. By integrating geologic and geotechnical data, engineers can design safer and more efficient mining operations. The use of numerical modeling and computer simulations complement geological and geotechnical analyses, providing a comprehensive approach to understanding and managing the stresses and strains in the rockmass.

This integrated approach not only enhances the safety and productivity of mining operations but also contributes to the sustainable use of mineral resources. As technology advances, the role of geologic data in mining will continue to evolve, with greater emphasis on precision and real-time monitoring. The future of mining will depend on the effective use of geologic data to optimize processes and minimize environmental impact.
shear strength, tensile strength, coal compressive strength with appropriate consideration for test sample size, and floor shear strength can also be contoured across the entire mining area. Depending on whether over- or under-mining effects are to be assessed, spatial effects including innerburden thicknesses can now be evaluated to determine if interaction is possible. Lineament studies may also be used to approximate directions of major joint sets. A typical contour plot of spatial data is shown in Figure 4.

**INTERACTIVE HAZARDS**

To demonstrate application of the hazard approach potential interaction in a lower seam was evaluated with the USEAM program. Both roof and floor stability were evaluated using single average strength values across the entire mining area for both pillar and gob/void coal interface loading conditions (Figure 5). Both seams outcropped, which produced problems in contouring safety factors where the overburden approached zero as the safety factors became excessively large.

distorting the contour plots. To avoid this, maximum safety factors are assigned as limits for plotting purposes. To avoid running USEAM for each geologic structure in the upper seam, the program was run for three typical structure sizes: minimum sized upper seam remnant structures, average structures and the gob/void coal interface. Stress transfer results were then developed by using these structural conditions together with varying spatial and geological conditions across the mining area. Since this program determines stress levels in the lower seam where strength values had been assigned, safety factors for proposed mining layette were derived. Even with this relatively simple situation a number of fault maps were developed relating such factors as roof and floor stability, and pillar strength for different design dimensions.

To limit the number of fault maps that could be constructed for different lower seam mine projections, it was found expedient to use a typical structure that was practically possible to mine. Mining widths were set at 18 feet, although pillar dimensions could be varied to suit local conditions.
As more experience is gained with the method limiting safety factors will be developed for specific lithologic conditions. In the case of overmining where damage ratings are used in conjunction with subsidence projections acceptable levels of damage can be preset by the user. A typical hazard map produced by U-SEAM is shown in Figure 6.

Figure 6. U-SEAM-based hazard map, showing mine outline, based on computed lower seam safety factors.

CONCLUSIONS

The hazard approach radically expands the application of the considerable research recently conducted on multi-seam mining to the planning of an entire mine. Interactive hazard projections clearly facilitate mine design by realistically evaluating pillar sizes and heading widths in terms of safety factors or damage levels. The method permits the engineer to select the degree of damage that can be accepted and therefore facilitates evaluation of the recoverable reserves in an affected seam. But, as with all projected planning endeavors the quality of the final product can be no better than the reli-
ability of the input data. Even with widely spaced sampling points for geologic and sampling data and irrespective of whether a damage rating or safety factor is used to predict degree of hazard, the method offers a starting point for realistic ground control planning.

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