

Numerical Modeling Analyses of a Longwall Mining Gateroad System

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Abstract

This U.S. Bureau of Mines paper illustrates how numerical modeling analyses can be useful in evaluating the effectiveness of different mine designs toward reducing the occurrence of floor heave in the tailgate entry of an underground coal mine located in northwestern Colorado. A series of displacement-discontinuity, boundary-element models were run to simulate a current three-entry, yield-abutment chain pillar arrangement, with the yield pillar adjacent to the headgate side of the first mined panel. These models were calibrated to field data obtained from a Bureau installed mine-wide monitoring system. Using the calibrated model parameters, a suite of new models were then run to predict the effects of two proposed design changes on the floor heave problem. The first design change involved varying pillar widths, and the second consisted of reversing the current gateroad yield-abutment pillar arrangement. Model results suggest that changing pillar widths would not significantly reduce the potential for floor heave in the tailgate. However, model results from the proposed yield-abutment pillar swap design showed a maximum 33-percent reduction of core stress on the proposed design yield pillar as compared to the remaining abutment pillar of the current design. These results suggests that the second design change would reduce the potential for floor-heave in the tailgate entry, during second panel mining.

Introduction

Numerical modeling methods can be useful for addressing complex mine design problems and evaluating various mine configurations prior to and during actual mining. The U.S. Bureau of Mines continues to apply numerical modeling techniques to various mining-related problems that are common to the U.S. mining industry. One of the tasks in this process is to be able to verify or calibrate model results with real-world data. While this seems an obvious and easily implemented task, mine data are often not adequate or suitable for direct comparison with the model results. The ultimate additional step, however, is to use the calibrated model parameters to provide useful and accurate predictions about other mine designs. This step was conducted in these analyses.

Field verification of modeling results was conducted at an

underground coal mine in northwestern Colorado. The mine operates at depths of about 1,100 feet, using a three-entry, yield-abutment pillar, longwall gateroad system. The coal seam, about 10 feet thick, strikes N55E with a dip of 5 degrees to the northwest. The mine area is dissected by a normal fault oriented about N30W, and several joint-shear zones oriented about N60W.

Floor heave, the main gate-entry problem associated with this particular mine, tends to occur in the middle gateroad entry well after passage of the first panel longwall face, and in the tailgate entry ahead of the second panel face. Prior to longwall mining, the Bureau installed hydraulic borehole pressure cells (BPCs) in an adjacent pair of gate-entry pillars as well as portions of both panels. Monitoring pressure changes through a profile across adjacent chain pillars over a complete mining cycle provided the Bureau with ideal data for comparison with model results.

This paper presents the results of numerical model analyses to demonstrate the usefulness in evaluating the effectiveness of different mine design changes toward reducing the potential for floor heave occurring in the tailgate entry of an underground coal mine.

Technical Approach

The technical approach consisted of setting up and running a series of displacement-discontinuity, boundary-element models that simulated a current three-entry, yield-abutment chain pillar arrangement with the yield pillar adjacent to the headgate side of the first mined panel. The models were calibrated to actual field data obtained from a mine-wide monitoring system installed at the mine. Using the calibrated model parameters, a suite of new models was run to determine the effects that two proposed design changes might have toward reducing the potential for floor heave.

Field Study

Mine Site Description: The longwall panels are laid out for extraction in a north-to-south direction, with the individual panels being mined in a west-to-east direction. Each longwall panel is about 640 feet wide by 9,000 ft long. Gateroad development consists of a 3-entry yield-abutment system with 18-ft roadways, one yield pillar (about 35 ft wide) adjacent to the headgate, and one abutment pillar (about 80 ft wide) adjacent to the future tailgate.

Rock mechanics instrumentation (BPCs) was installed at the mine to monitor stress transfer and mine structure load changes during longwall mining operations (Hanna, Haramy, et. al). The instrumentation was installed during development of the first retreat longwall panel, Panel 1. Figure 1 shows a section of the mine, the location of the instrumentation site, and the individual cell positions.

Instrumentation and Monitoring System: Stress transfer information was collected during mining of Panels 1 and 2 using a Mine-wide Monitoring

System (MMS) and BPC's. The pressure cells were installed in the panels and gateroad pillars to monitor load changes during the extraction of both longwall panels. The pressure cells were attached to transducer-valve-gauge units and installed at an initial set pressure of 1,000 to 1,500 psi. The transducers were connected to the MMS, which continuously transmitted real-time pressure information from the underground instrumentation site to the mine surface computer and MMS computer laboratory at DRC (Conover, Hanna, & Muldoon). Field data corresponding to specific face positions were then used in the model calibrations and analyses.

Numerical Modeling Study

MULSIM/PC, the numerical modeling program used in this analysis, was originally developed as part of a Ph.D thesis at the University of Minnesota by K. Sinha, 1979. In the years since, the Bureau has enhanced and rewritten the code to run on personal computers (see Donato, 1992). This method is based on a displacement-discontinuity, boundary-element approach, which models the coal seam as a material-filled crack within an infinite rock mass material. One assumption in this program is that the materials exhibit perfect linear elastic behavior; thus there is no failure or yield criterion. While this limitation is inherent to MULSIM/PC, the program is of significant value to the mine engineer in that it is flexible, easily implemented, and, with a little modeling experience, quite sufficient for modeling the behavior of many mine structures.

Design and Approach: The model analyses consist of two stages: first, developing what is called a calibrated numerical model; and second, using the calibrated model parameters in a new model to analyze a different mine design geometry. Thus, results from the second model can be used to predict the response of the new design as compared to the previous design. A calibrated model is one in which the results, after interactively varying some of the model parameters, parallels the significant qualitative trends of the field data. The first step in calibrating a model is to generate a model, or suite of models, that is based on the geometry and geology of the currently used mine design within the limits of the modeling method used. The next step is to compare the pertinent results (i.e., vertical stress along a cross section that matches the field instrumentation site in this analysis) to the field data (i.e., pressure cell data in this analysis). The final step involves changing appropriate model parameters (material properties in this case), and rerunning these three steps until the results for each modeled face position, at least qualitatively, match the field data from corresponding face positions.

This longwall mining gateroad system was analyzed by generating a series of MULSIM/PC models at seven different panel face positions for the current chain pillar design. The seven face positions were chosen on the basis of available field data and because they were representative of the extraction of both panels. Each model covered a 1,000-ft by 1,000-ft area, using coarse mesh blocks (25 ft square), with an interior 500-ft by 500-ft fine mesh area subdivided into 5 ft square

elements for greater detail. Figure 2 illustrates an example of the fine mesh geometry and grid used. The seven face positions modeled and the field instrumentation line (X-X) are also indicated on this figure. The material properties utilized in the models are listed in table 1 and are reduced average values (10 pct) from laboratory testing of intact samples, (see Tadolini, 1989).

Results from these initial linear-elastic analyses tend to match the qualitative trends shown by the field data, until the coal pillars begin to yield. Based on field data and underground observations, yielding in the small pillar first began when the panel 1 face was about 400 ft past (outby) the instrumentation site. Reduced material properties (Young's modulus and Poisson's ratio) as well as the removal of pillar elements were then used to represent the yielded materials (see table 1 codes B and D). These modified material properties, although linear elastic, provide a mechanism for the realistic redistribution of stress over the modeled area. The proper degree and extent of yielding into the coal ribs are the critical parameters to be estimated by the calibrated model, and they are a function of pillar loading which is directly related to panel face position. An example of model geometries for second panel mining with the corresponding material property codes from table 1 are shown in figure 3. These parameters are also assumed to be relatively consistent throughout the mine; therefore, they are reused in the second and third suite of models to simulate the two proposed mine design changes. The same rate of element removal and element softening as was calibrated in the current design models was assumed for the proposed design models. Thus, at any particular panel face position, if one rib element width was removed in the headgate pillar (yield pillar) of the current design model, then one element width was removed in the headgate pillar of the proposed design model. These subsequent model results were then compared to the model results from the first suite to predict any relative changes.

The first proposed mine design change simply decreased the width of the yield pillar by five feet while increasing the width of the abutment pillar by five feet, thus retaining the same gateroad width. The second proposed mine design change is essentially identical to the current design except that the yield and abutment pillars were exchanged. Thus, the abutment pillar is now nearer the first mined panel and the yield pillar nearer the second panel.

Numerical Modeling Results: Numerical modeling results for the current gateroad pillar configuration were compared to the pressure cell data obtained from the underground field site. Although over 10,000 fine mesh data point results were obtained from each numerical model, only the 100 data point results corresponding to cross section X-X in figure 2 were meaningful for a direct comparison. The final calibrated numerical results were compared to pressure cell data for the seven different panel face positions which are also depicted in figure 2. Four of these comparisons are illustrated in figure 4.

Numerical modeling results for the current gateroad chain pillar design paralleled several field data trends very closely. Prior to any significant pillar yielding, the pillars behave nearly linear elastically. The models accounting for first panel face positions provided very reasonable results using only one linear-elastic material property set for all the unmined coal structures as can be seen in

figure 4A. Although there are no pressure cells close enough to the coal ribs to record any peak edge pressures, the pillar core pressure trends match up well with the numerical model data. For example, face positions A through D demonstrate progressive increases in overall loading as the first panel is mined. Additionally, the increases are greatest in the yield pillar closer to the active panel, and even the active panel side of the abutment pillar loads more quickly than the side nearer to the second, unmined panel.

No pressure was recorded by any of the cells installed in the yield pillar during second panel mining. Although these pillars were still physically present, their effective load-carrying capacity had decreased to the point where pressure could not be monitored with the BPC's. Thus, in this analysis, the yield pillar was considered to have completely yielded prior to second panel mining. The models most closely simulated the field data when no yield pillar was modeled (representing the completely yielded pillar) as illustrated in figure 3. It is difficult to determine the exact extent of yielding in the remaining large pillar at any stage of second panel mining, but the BPC data suggests a substantial reduction of the pillar core. Utilizing a reduced pillar width and two softer material property sets to simulate these abutment pillars in the models provided results that demonstrated good correlation with the field data during second panel mining. See figure 4 B - D.

Figure 5 compares selected proposed design model 1 (smaller yield/larger abutment pillars) results with current design model results at corresponding face positions. Figure 5A is representative of all first panel mining results while figure 5B-D depicts model results during second panel mining. There is very little difference in the stress profiles between current and proposed design model 1 results for all modeled face positions. These results indicate that similar conditions can be expected in the gateroads of both the proposed design model 1 and the current design during first and second panel mining.

Figure 6 compares, similarly, selected proposed design model 2 results (yield/abutment pillar swap) with current design model results. Again, figure 6A is representative of all first panel mining results, showing little difference in entry system stresses for both the current and proposed design. There are significant differences between the results of the current and proposed design 2 for second panel mining, however, as is indicated in figure 6B-D. These results suggest that in this proposed design model 2 the larger abutment pillar will remain sufficiently intact to shield some of the overburden stress away from the smaller yield pillar. As the second panel face approaches cross section X-X, figure 6D, the calculated stress imposed in the core of the yield pillar is reduced by as much as 33-percent over the stress that was estimated to be on the remaining abutment pillar of the current design. If the material property assumptions prove reasonable, then these results imply that during second panel mining the overall tailgate entry loads would be significantly reduced and the potential for floor heave in the tailgate would correspondingly be reduced using this proposed design.

Conclusions

Computed model stresses, when calibrated with field data, adequately reflect observed ground behaviors at the mine. Trends and stress distributions throughout the panels and pillars match closely with measured field ground pressures. Through first panel mining, and prior to any observed pillar yielding in the field, the entry pillars behaved and were modeled as linear elastic materials. Until yielding in the smaller pillar had been detected by instrumentation and observed in the field, the uncalibrated model results were adequate. To simulate the load transfer away from the yield pillar during second panel mining, it was necessary to remove the yield pillar elements in the model to calibrate the model to field responses. Using these calibrated model parameters of reduced material properties and/or removing pillar elements, two proposed design changes were modeled. The numerical model simulating the first design change, reducing the yield pillar width by five feet (to 30 ft) and increasing the abutment pillar width by five feet (to 85 ft), indicated no significant change in the gateroad loading. Model results of the second design change, swapping the positions of the yield and abutment pillars, denoted distinct decreases in gateroad pillar core stresses. The stress decreases as much as one third when the second panel approaches the instrumentation site. These results suggest that tailgate entry conditions in general would be improved and specifically the potential for floor heave would be reduced during second panel mining.

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Table 1. Material Property Values used in MULSIM/PC Models

	Code	E(psi)	ν
Overburden	--	300,000	.25
Intact Coal	A	100,000	.35
Yielded Coal	B	50,000	.40
Yielded Coal	D	25,000	.42
Gob	C	6,000	.45

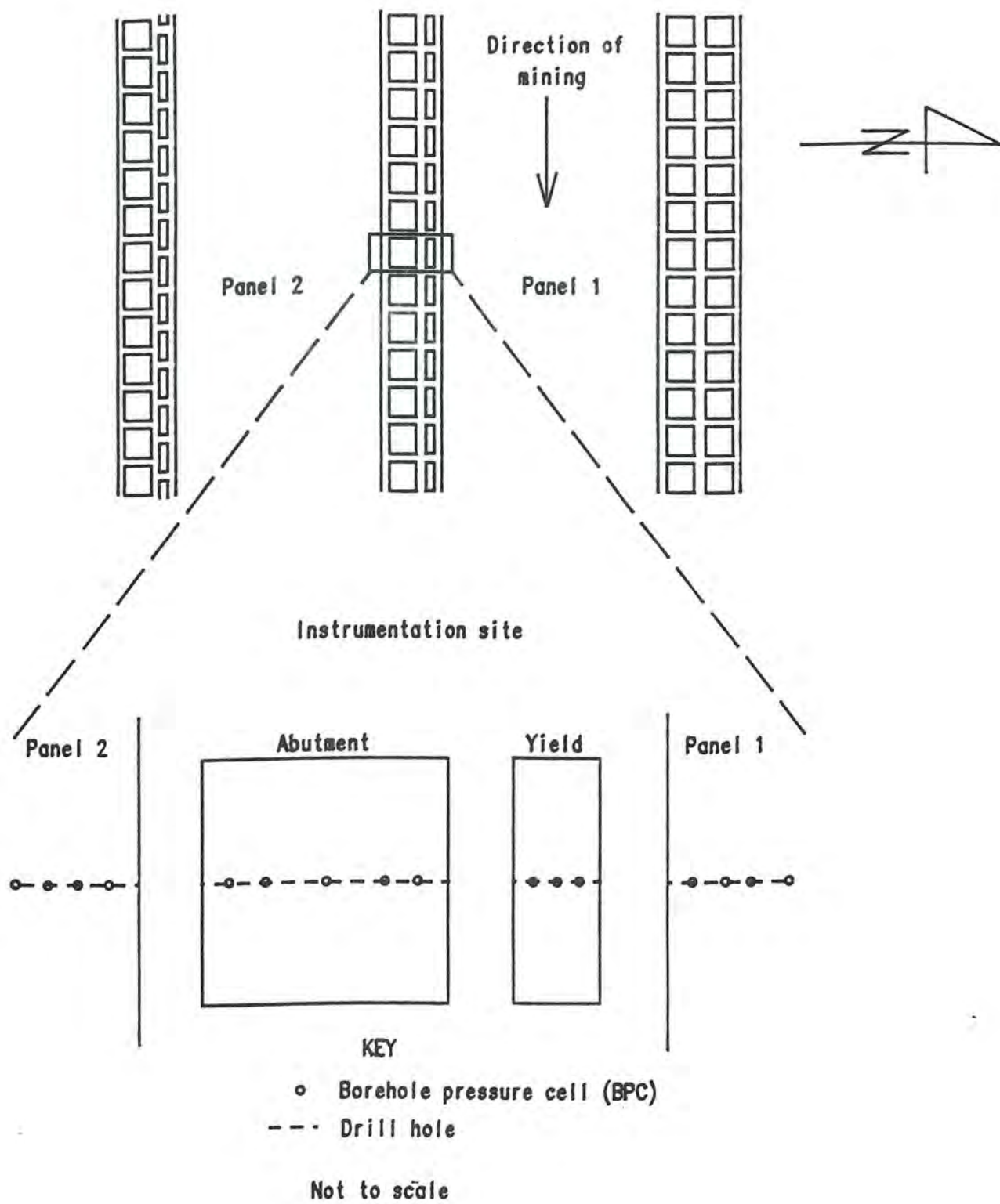


Figure 1. Mine plan plus enlarged instrumentation site.

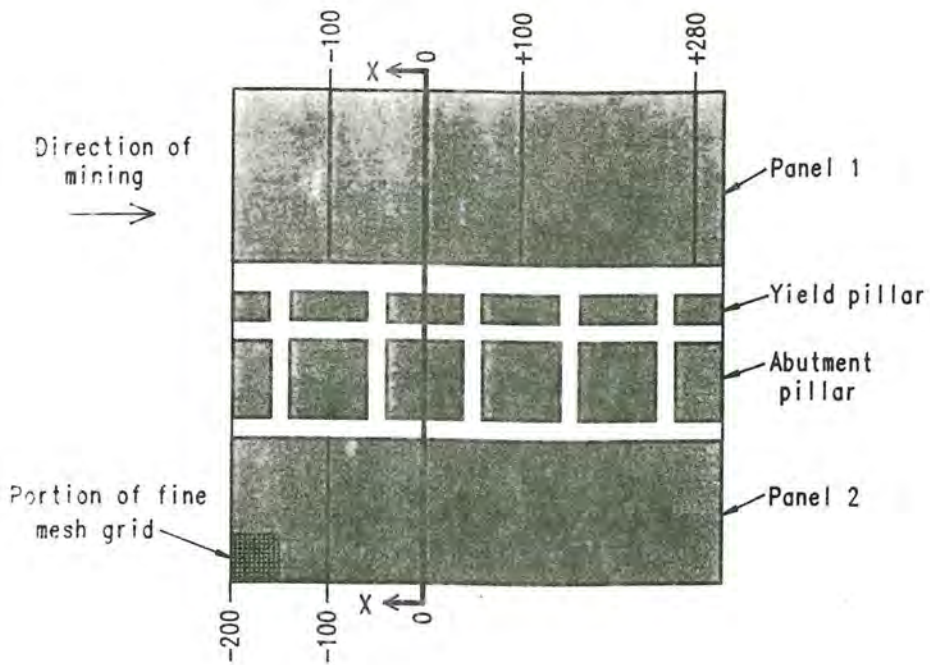
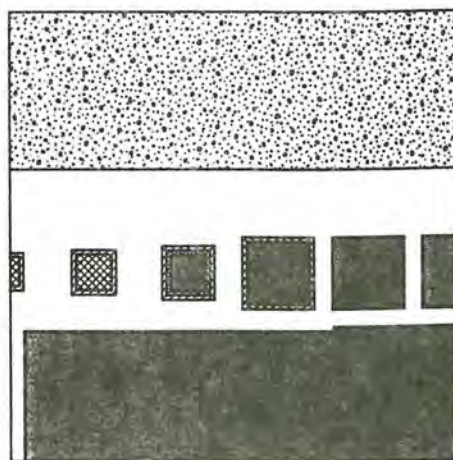


Figure 2. Model fine mesh area with instrumentation site cross-section (X-X) and seven modeled face positions.



KEY





-  Yielded coal (stronger)
-  Yielded coal (weaker)
-  Intact coal
-  Gob

Figure 3. Calibrated model area showing typical material properties and yielded area simulations for second panel mining. Refer to table 1 for corresponding materials.

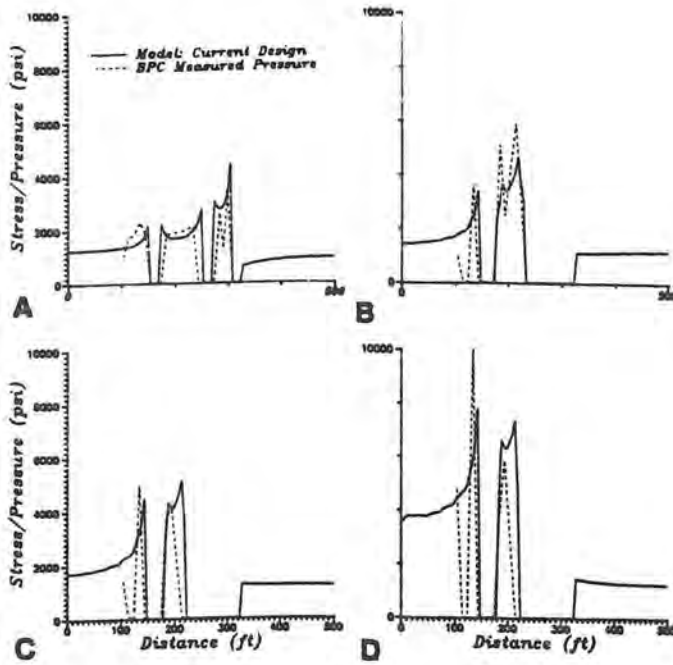


Figure 4. Calibrated model results profiles vs. field data for a. face position +100 ft, first panel; b. -200 ft, second panel; c. -100 ft, second panel; and d. -0- ft, second panel. Locations relative to instrumentation site.

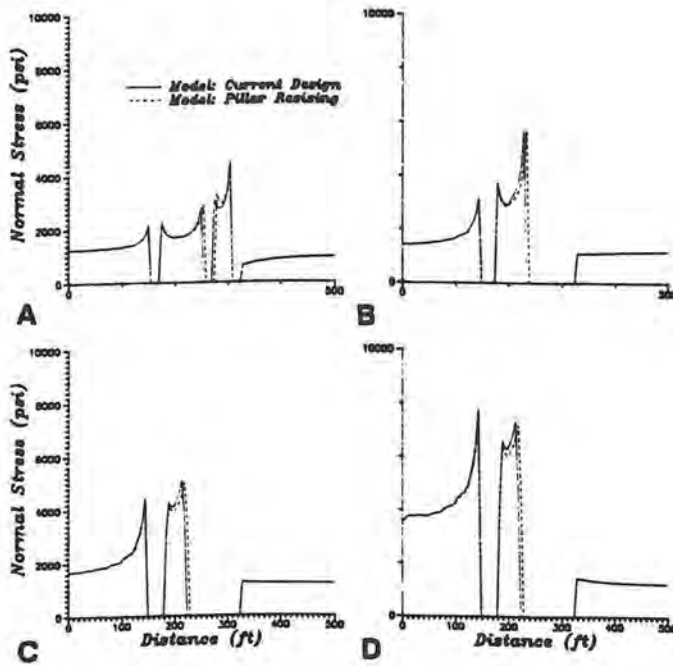


Figure 5. Proposed (resized pillars) design results vs. current design results for a. +100 ft, first panel; b. -200 ft, second panel; c. -100 ft, second panel; d. -0- ft, second panel. Locations relative to instrumentation site.

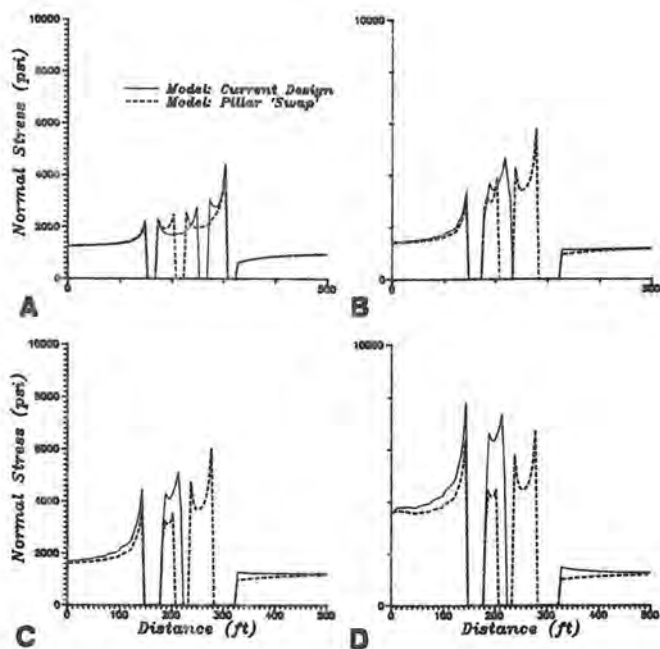


Figure 6. Proposed (pillar swap) design results vs. current design results for a. +100 ft, first panel; b. -200 ft, second panel; c. -100 ft, second panel; d. -0- ft, second panel. Locations relative to instrumentation site.

Proceedings Fourth Conference on Ground Control For Midwestern U.S. Coal Mines

held at

**Ramada Hotel
Mt. Vernon, Illinois**

November 2-4, 1992

Editors

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November, 1992