Experience in Computer Simulation of Caving, Rock Fracture and Fluid flow in Longwall Panels

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Abstract: Recent advances in computer simulation together with field measurements of caving and microseismic activity about longwall panels, has allowed a much better understanding of the caving process and the variability due to geology. Research between SCT Operations and CSIRO Division of Exploration and Mining has initiated new methods of computational modelling predicting various caving patterns and strata failure far ahead of the longwall face.

The rock fracture distribution and the caving characteristics of a range of strata sections have been simulated by computer methods. The computer simulation of strata behaviour includes coupled fluid and mechanical behaviour. Validation studies of the method were addressed together with case studies. The method allows the simulation of longwall support behaviour and fluid pressure distributions about longwall panels under various geological conditions. The system also allows a prediction of the monitoring data, which is best suited to give an early warning of weighting events or signal various key caving characteristics.

Key words: computer modelling, rock caving, longwall mining, fluid pressure, longwall support

Introduction

Recent studies of microseismic activity (Kelly, et al 1998), and abutment stress measurements about longwall panels, have demonstrated that caving mechanisms and stress redistributions about longwall panels were significantly controlled by the strata distribution and stressfield at the site.

The general scope of the research presented is computational modelling of longwall extraction in various geological domains to determine fracture geometries, stresses, caving mechanics and fluid flow characteristics about longwall panels. Monitoring of longwall support pressures and convergence is undertaken in association with these investigations to assess the interaction of caving and supports under various geologies.

This work has been undertaken to:

(i) predict rock fracture patterns about longwall panels,
(ii) understand caving mechanics in differing geologies,
(iii) understand the fluid pressure distributions in the strata about the panels,
(iv) predict abutment stresses occurring under various geologies and
(v) assess longwall support requirements.

Computer Modelling Approach

The aim of the work has been to understand the ground caving mechanics under the geological and mining conditions present and the influence of longwall supports in this process. To achieve this, the model must simulate the dynamic caving process as the longwall retreats.

The progressive mining mechanism is achieved by assuming a two-dimensional longitudinal slice down the central zone of the panel and sequentially excavating 1m "shears" in the model. The advancing longwall supports are used to provide roof support at the longwall face. The stress redistributions, rock failure and ground movement then occur in response to an incrementally changing geometry thus simulating an operational longwall face.

The finite difference code FLAC (Itasca, 1993) is used to simulate the incremental excavation. A numerical model has been formulated to simulate development of fractures in the bedded strata using the FLAC "fish" routines. The programmable fish routines allow interrogation of the stress state at any point of the model and the determination of the type of fracture that may develop. Coupled mechanical rock behaviour and fluid flow routines are used. Various failure models are used to predict the type of fracture, orientation and its properties. The rock failure routines calculate the likelihood of shear and tensile fractures through intact rock and shear and tensile failure along the bedding. The fractures are simulated by changing the rock and joint properties to model the strain softening behaviour of rock derived from the triaxial rock testing.

The rock failure and permeability routines used in the code have been developed to simulate actual strata behaviour. In most studies to date, emphasis is on the rock failure, caving characteristics of the ground and longwall support behaviour. The computer simulation capability is being refined and validated as an ongoing process in association with CSIRO Division of Exploration and Mining researching longwall caving mechanics and other research projects.

The computational model is two-dimensional and best represents the central portion of longwall panels in supercritical geometries. Simulation of subcritical panels can also be undertaken by limiting the extraction geometry or by controlling ground subsidence to that equivalent to the actual width.

The modelling is restricted to two dimensions in order to maintain a close mesh and sufficient detail of the geology. Approximately 40,000 elements are used in the model.

The properties of strata used in the model are based on triaxial testing of overburden material. A typical section of the modelled strata is shown in Figure 1. An enlarged portion of the longwall face is presented in Figure 2.

The model of the longwall supports is constructed using the grid and support elements. The stiffness of the canopy and base parts is chosen to approximate the properties of the actual longwall supports. The modelled supports have the ability to advance forward and reset each time the coal is cut. The set loads are gradually increased to the yield value in response to the support convergence. The support loads are monitored and can be compared with the leg pressures measured underground.

The goaf behind the supports is allowed to free fall to reach the zone where a recompaction generates vertical stresses in the "caved goaf".

The progressive excavation of the longwall panel and associated ground response can be captured in a "movie" file, which allows visualisation of caving cycles and stress changes as the longwall retreats.

Modelling of Strata of Variable Strength

Vastly different caving styles have been defined from the modelling of various geological sections. Two examples are presented to demonstrate the variability in caving as a result of rock strength properties and stressfield.

Example 1 - Weak Ground - Forward Ground Failure

The properties of strata used in this example are based on the overburden rock at Gordonstone Mine.

The longwall fracture distribution presented in Figure 3 indicates rock failure well in advance of the face. This style of behaviour has been verified by microseismic monitoring but would not have been predicted by traditional approaches. In this caving style, no large caving blocks are formed as the ground is heavily fractured in front of the face. The peak stress concentrations are located well ahead of the longwall face, while the ground is de-stressed in the vicinity of the longwall face. The roof failure mechanism is characterised by the formation of frequent subvertical fractures and sheared bedding planes. On a large scale, the roof failure in weak strata can be described as non-periodic. Rock failure zones were noted to extend into the floor also. These were dominantly the result of bedding plane shear.

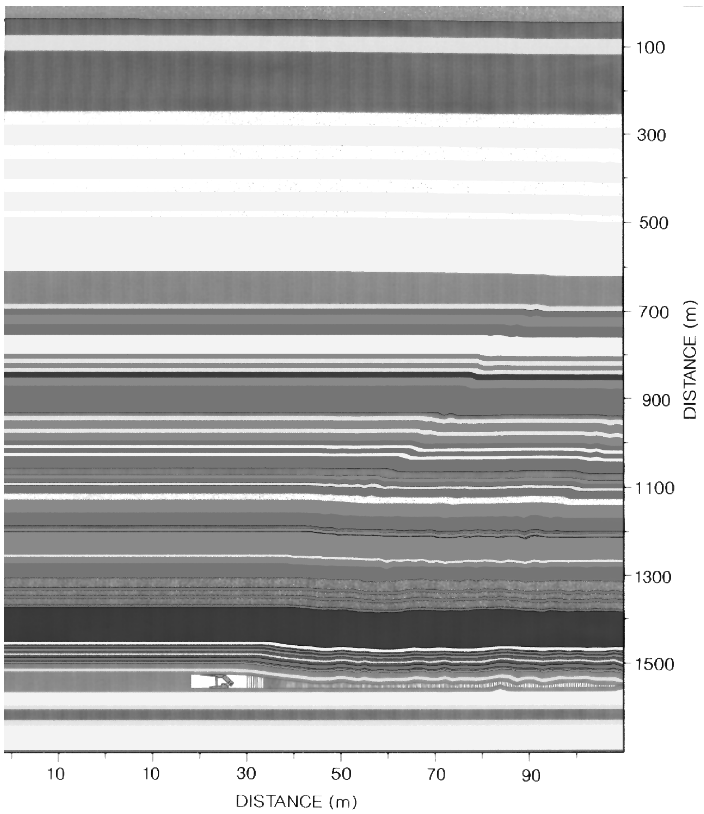

Fig. 1 – Typical section of the modelled strata.

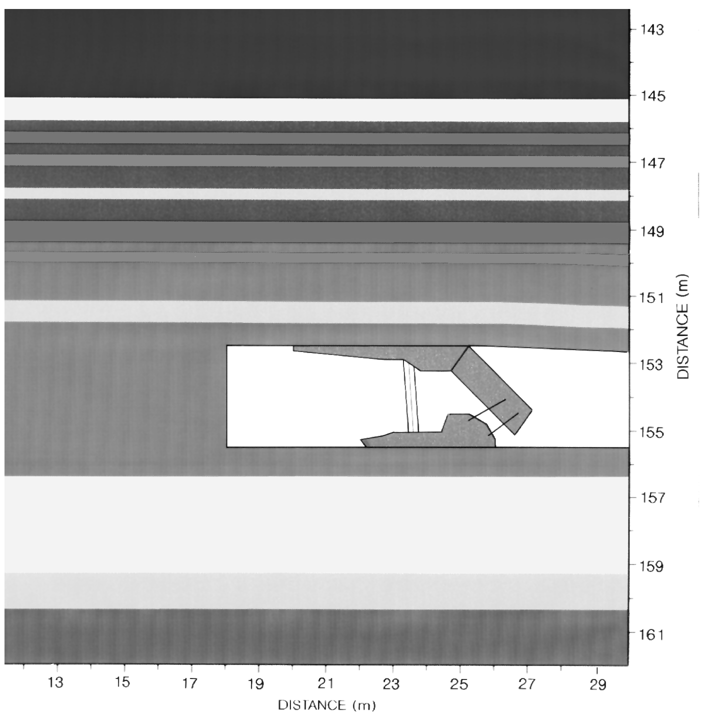

Fig. 2 – Enlarged section of the longwall face.

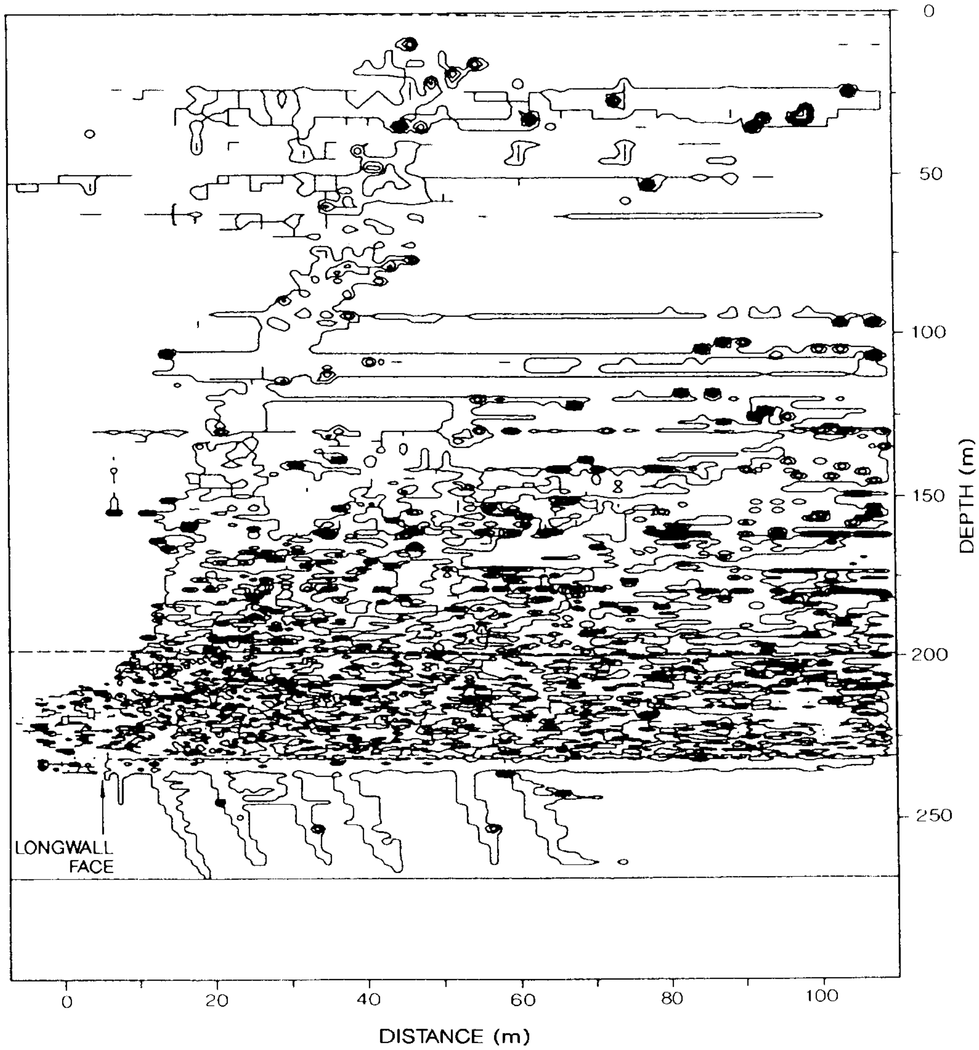

Fig. 3 – Longwall fracture distribution – weak ground.

Example 2 - Moderate Strength Ground - Cyclic Caving

The properties of strata used in this model are based on the overburden rock at South Bulga Mine.

A very different caving and fracture mechanism is presented in Figure 4. The absence of weak bedding planes in the upper roof and moderate strength of rock prevents frequent formation of fractures in the roof. Major sub-vertical fractures develop at less frequent intervals forming large caving blocks above the longwall face. The geometry of these blocks is defined by;

(i) failure along a weak layer in the roof above or ahead of the face followed by,
(ii) a fracture network forming at this zone and extending down to meet the longwall face.

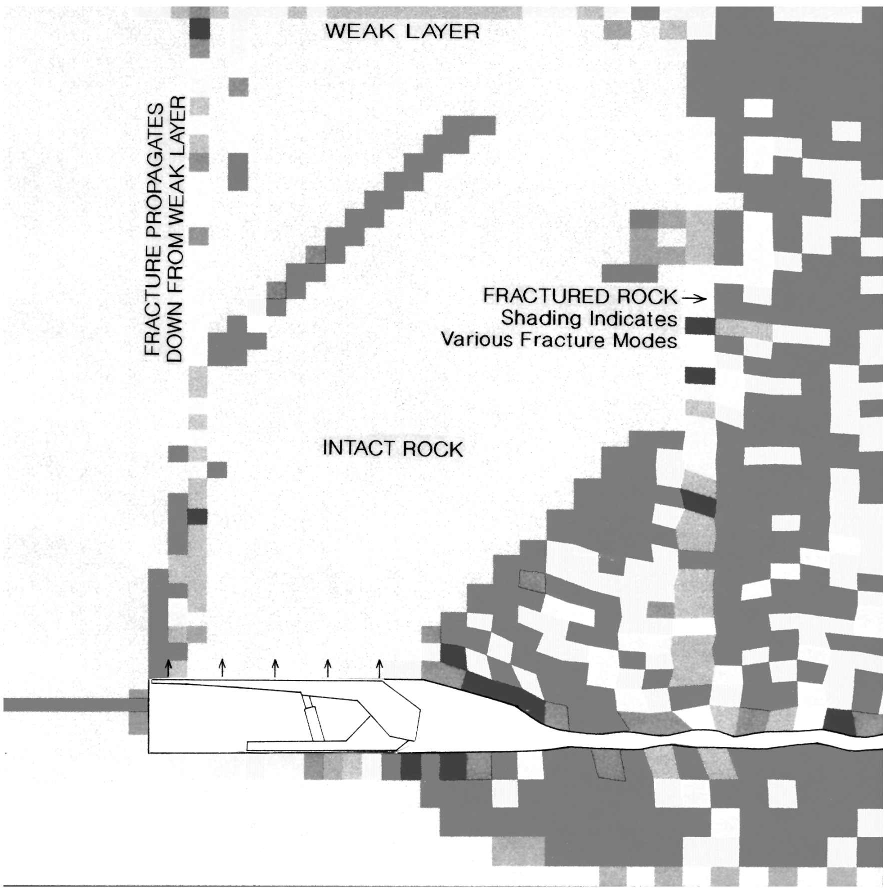

Fig. 4 – Longwall fracture distribution – periodic weighting.

Face guttering, rib spall and convergence of supports is anticipated to be most severe where fracture systems intersect the face. In these geologies, significant fracturing above the longwall face and supports may only occur every 10-20m. The caving mechanism observed in the model was compared to the overburden movement measured by two extensometers extending from the surface down to the coal seam. The extensometers were located at the centre of the longwall panel. The surface extensometer results presented in Figure 5 indicate a good correlation of strata movement between the model and the in situ measurements and indicate significant separation at the approximate level of the upper Whybrow seam. There is variability in the results between the two extensometers, which is to be expected on the basis of local variation in fracture distributions and different location within a forming block. However, the main caving mechanism of block formation is well represented in the extensometer results and modelling.

Underground monitoring of the longwall support pressures shown in Figure 6 were used to study the frequency of periodic weighting. Pressure rate rise was used as an indication of rapid load increase. Convergence data was not available on the support at this time. The results were directly compared with the leg pressures and the convergence of the modelled support. The underground data and the modelled results indicated similar trends of caving cycles in 10-20m blocks of variable severity.

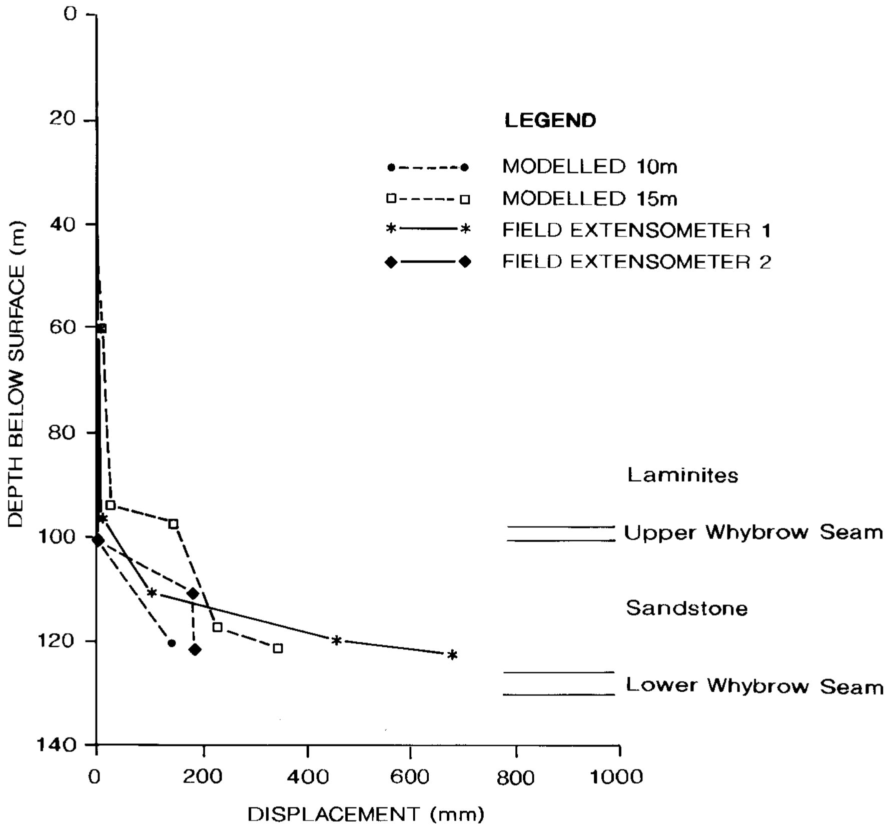

Fig. 5(a) – Comparison of modelled and measured extensometer results in the 7 – 15m range behind the face area.

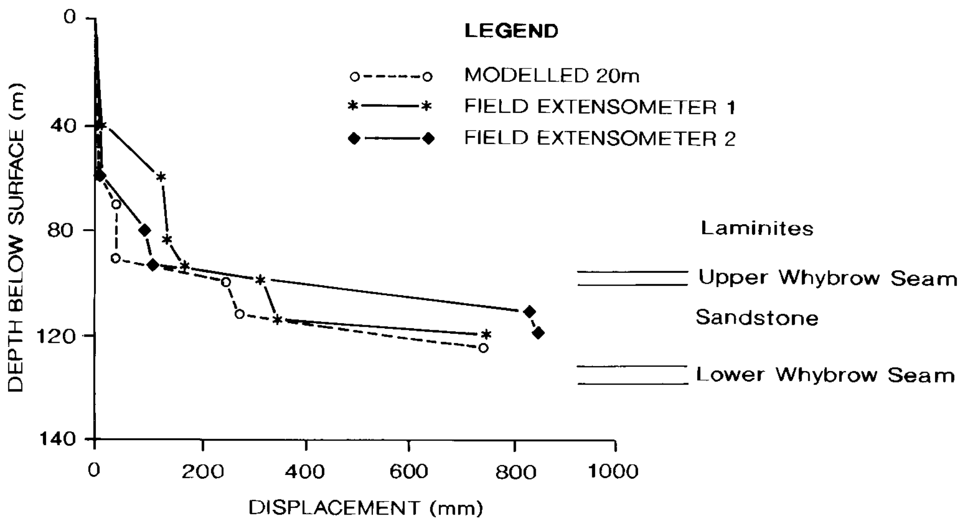

Fig. 5(b) – Comparison of modelled and measured extensometer results 20m behind the face area.

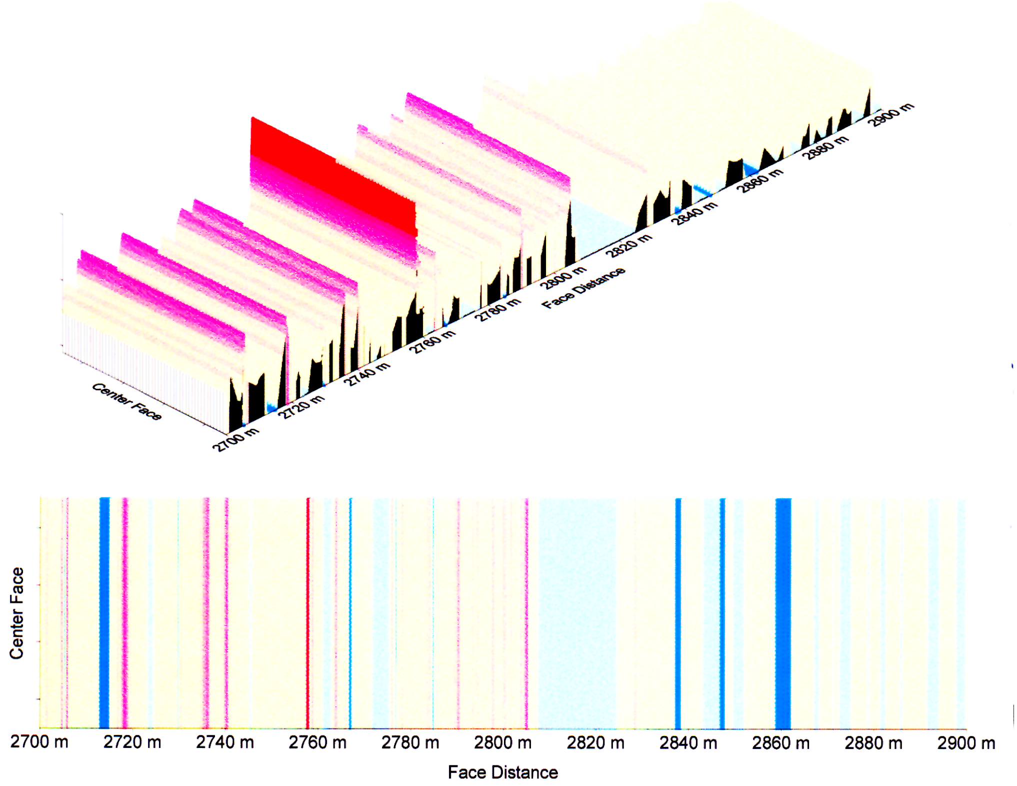

Fig. 6 – Support pressure rate rise relative to face advance.

Fluid Pressure Effects

Coupled fluid flow within the models allows an understanding of pore pressure redistributions about the extraction panel and pore pressure effects on the total stress redistributions.

The pore pressure determined is restricted to water and does not account for gas desorption from coal. For the purpose of this study, it is assumed that the initial gas and water pressures are in equilibrium.

Permeability is directional in the horizontal and vertical planes. The permeability is defined on the basis of effective stress normal to each direction.

The permeability is derived from insitu down hole injection testing. The permeability of fractured material is the subject of ongoing studies (under confined conditions) and for these examples, it has been assumed to be 50% greater than unfractured flow. Porosity is calculated from the moisture content of sealed samples.

The results obtained with coupled flow relate to the scale of roadway and that of a longwall panel.

In thick seams the effect of pore pressure changes or the behaviour of the ground about the roadway has been found to be significant. In one example, the fluid pressure drop about a panel (of two roadways) was found to extend at least 300m.

Computer simulation results and field monitoring of water pressure within the mined seam is presented in Figure 7. The modelled and actual measurements display very similar trends and indicate that the total stress about such roadways will be modified. The vertical stresses appear to be only marginally affected, however, the horizontal stresses can be significantly reduced depending on seam geometry. These stress changes would continue over time as the fluid pressures come into equilibrium with the mine geometry. Ongoing ground displacement and stress changes reflect the fluid pressure changes within the system. In certain situations, reversal of ground displacement about the roadway may occur.

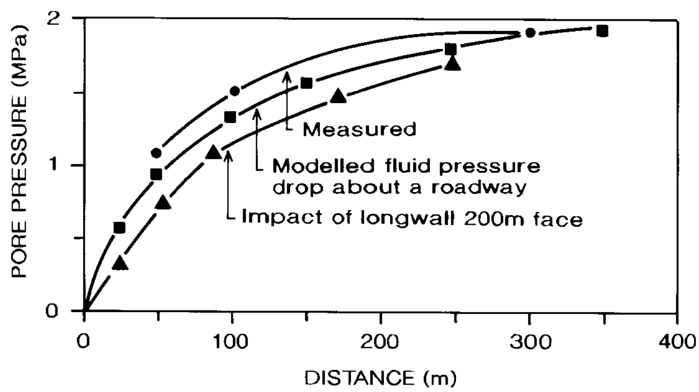

Fig. 7 – Example of modelled and measured fluid pressure relative to a roadway.

On a large scale, the fluid pressure redistributions developed about the longwall panels are complex and relate to the rate of stress change in the panel and permeability of the particular strata.

Ahead of a longwall panel, transient increases in pore pressures are noted in certain units (termed "bow wave effect"), whereas above and below the goaf areas, depressuation of the ground occurs. An example is present in Figure 8. Field measurement of pore pressures within coal seams confirms the increased pore pressure front about the longwall panels (Kelly, et al, 1998).

The increased rock failure is often related to pore pressure causing effective stress changes.

The coupled fluid effects appear to be most apparent in low stiffness, saturated materials.

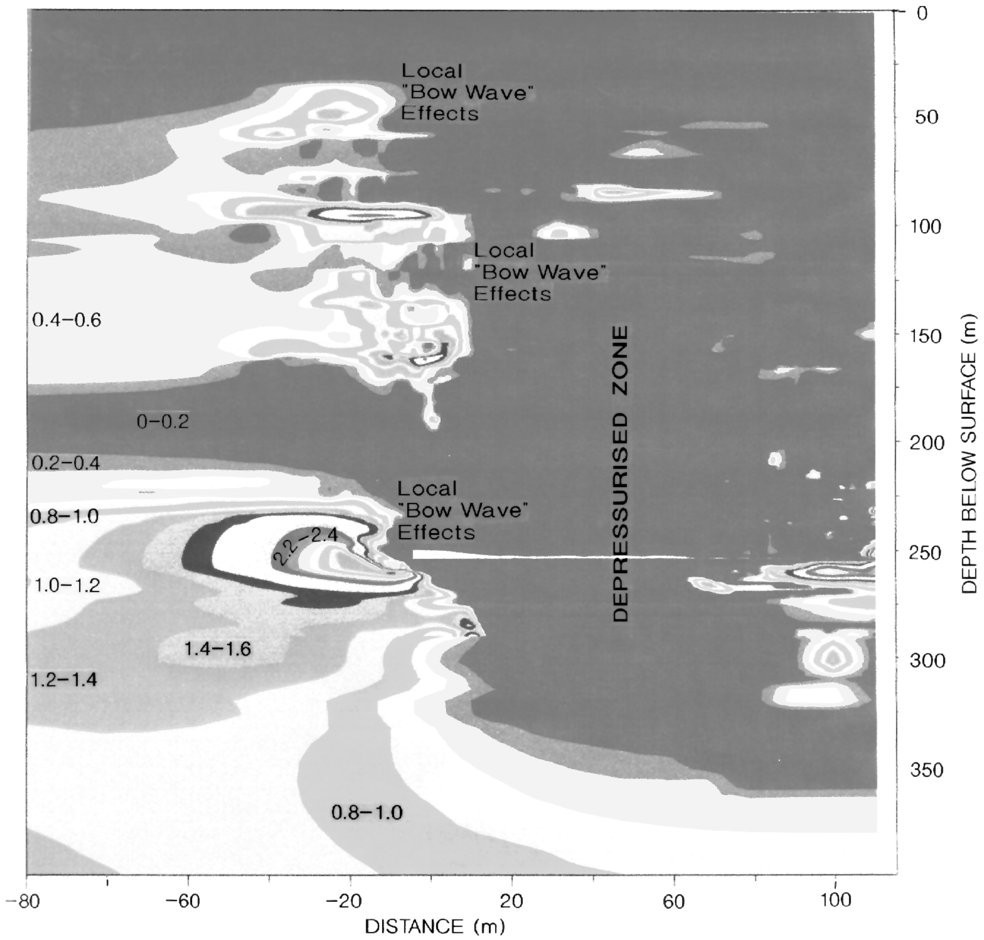

Fig. 8 –Fluid pressure variations about the face of a longwall panel. Note transient pressures above and in front of face are a function of rate of advance.

Conclusions

Computer modelling of strata about the longwall panels is providing a greater understanding of the mechanics of caving. It is apparent that the distribution of rock types and stress conditions about the panel will significantly influence rock failure geometries and caving style.

The out of plane three-dimensional issues related to the modelling is recognised but have not been found to significantly affect the outcome. As hardware speed increases, the extension to three-dimensional models will be undertaken.

The application of coupled fluid flow in the models is necessary to understand the behaviour of thick coal and also assess the fluid pressure changes caused by ground movement and caving.

This type of analysis is being used to assess longwall support requirements and management procedures applicable to various caving styles. It has also been applied to the mining into pre-driven roadways and gas drainage studies.

The application of these results is typically made in association with field monitoring and on the basis of the ground failure mechanics observed in the model.

References

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