# Prediction of Strata Caving Characteristics and its Impact on Longwall Operation

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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. The joint 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. This work was validated by field measurements of caving and microseismic activity at the longwall face.

The rock fracture distribution and the caving characteristics of a range of strata sections have been simulated by computer methods. Validation studies of the method were addressed together with case studies. The interaction of caving with support convergence and face control is presented. The method allows the simulation of longwall support behaviour 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.

## BACKGROUND

The authors have been undertaking research into strata fracture and caving mechanisms about longwall panels to better understand the extent and geometry of rock fractures about longwall faces.

Recent studies of microseismic activity (Kelly, et al 1998) and abutment stress measurements about longwall panels have demonstrated that previous assumptions of caving mechanisms and stress redistributions were either too simplistic or not suited to certain geologies.

This work is being undertaken in conjunction with CSIRO Division of Exploration and Mining in Brisbane. The general scope of the project is that CSIRO undertakes microseismic monitoring to determine fracture location during mining and the authors undertake computer simulation of longwall extraction to predict 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 project was initiated to;

- predict rock fracture patterns about longwall panels;
- understand caving mechanics in differing geologies;
- optimise gas drainage drilling to intersect gas sources and flow networks;
- predict abutment stresses occurring under various geologies; and
- assess longwall support requirements.

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Key sites for the study presented here were from Gordonstone and South Bulga Mines. Recent microseismic monitoring has been conducted at Gordonstone Mine, and computer simulations have been undertaken of these and other sites.

## COMPUTER MODELLING APPROACH

The aim of the study is 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 a real longwall face.

The finite difference code FLAC (Itasca, 1995) 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. 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 by the authors to realistically simulate actual strata behaviour. In this study 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 undertaken by the authors.

Although the computational model is two-dimensional, the third dimension can be approximated by mining the distance equal to one half of the longwall face width from the reflective boundary located on the goaf side. This method allows longwall simulations of subcritical width with the front abutment stresses similar to those measured underground.

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 Fig. 1. An enlarged portion of the longwall face is presented in Fig. 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 a nominated distance to reach the zone where a convergence induced vertical load is applied to the goaf roof. The vertical load is gradually increased until the full goaf load is experienced at a nominated convergence above floor level.

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 in this project. Two examples are presented to demonstrate the variability in caving as a result of rock strength properties and stressfield.

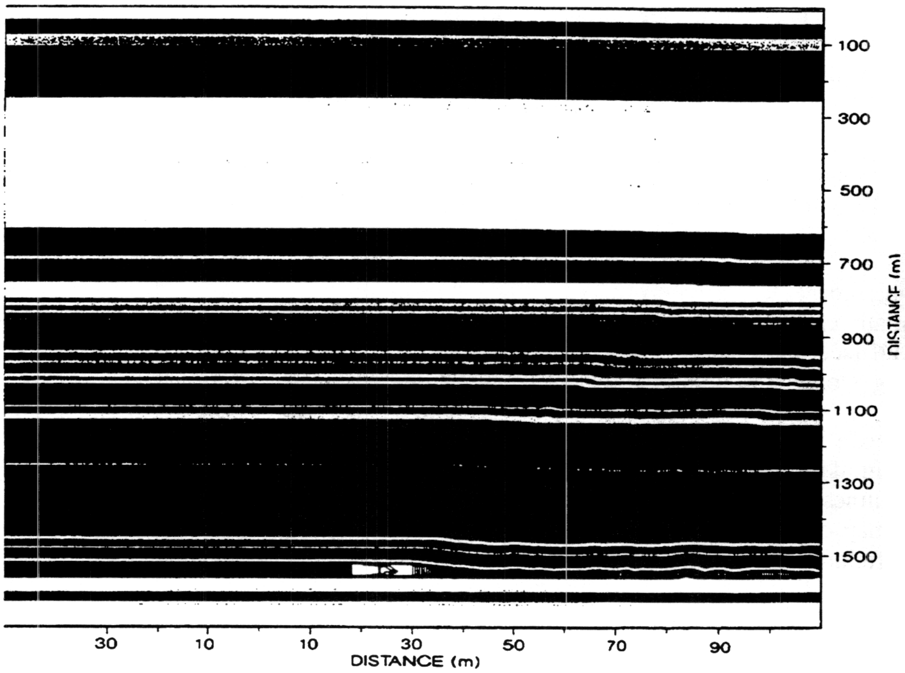


Fig. 1 Typical section of the modelled strata

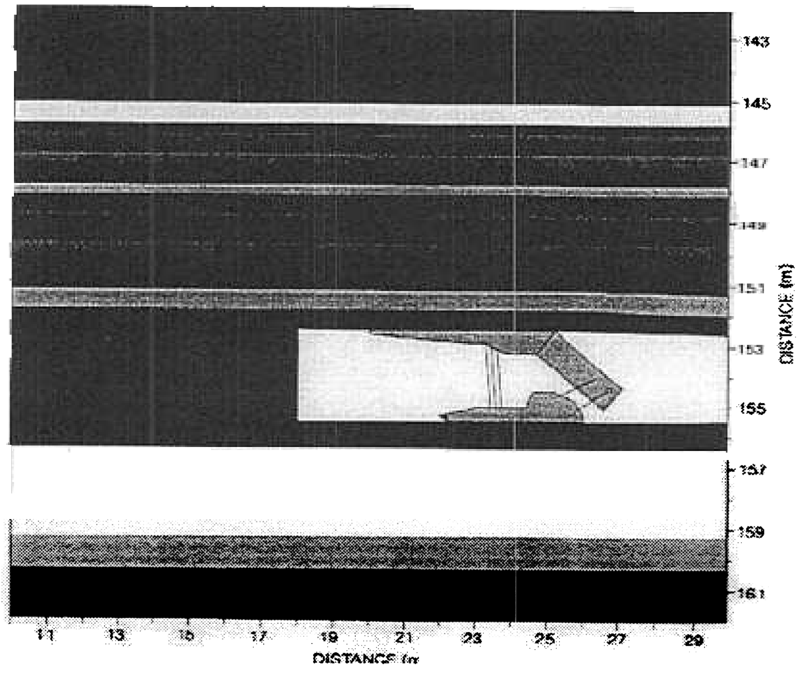


Fig. 2 Enlarged section of the Longwall face

### Example 1 - Weak strength ground - forward ground failure

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

The longwall fracture distribution presented in Fig. 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 and periodic fractures only occur on the small scale 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 which develop after each shear has been cut. On a large scale, the roof failure in weak strata can be described as non-periodic.

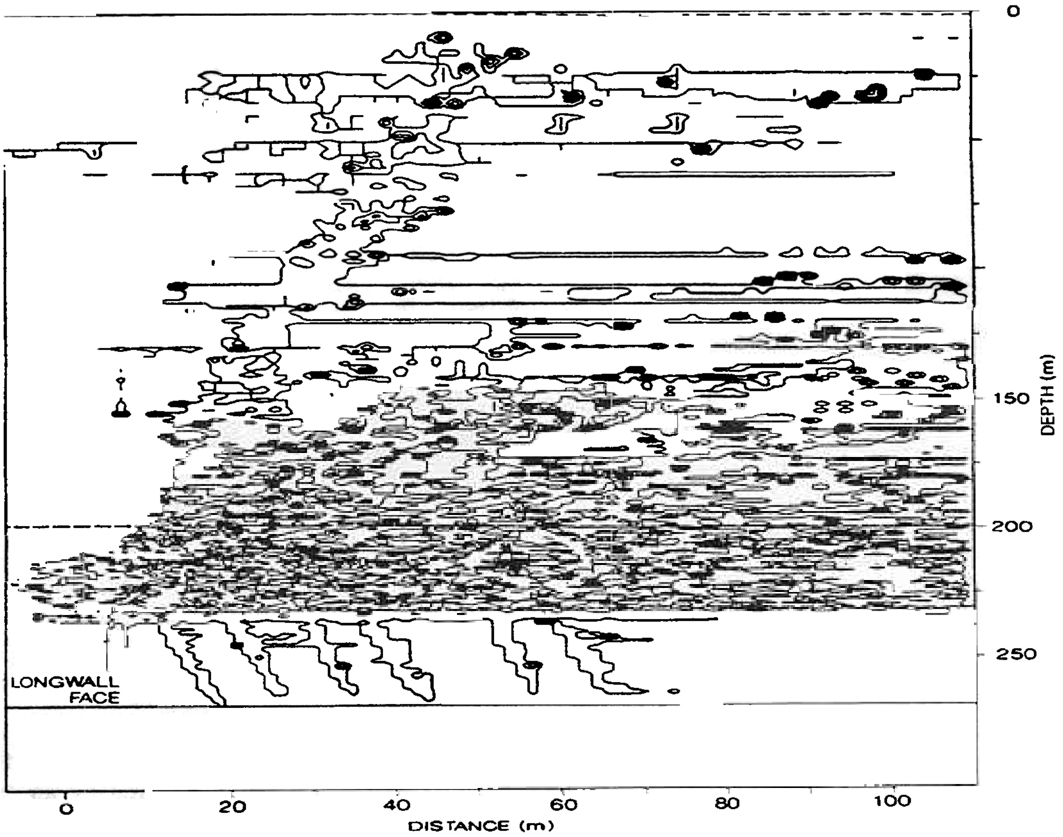


**Fig. 3 - Longwall fracture distribution – weak ground**

### 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 Fig. 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; and

(ii) a fracture network forming at this zone and extending down to meet the longwall face.

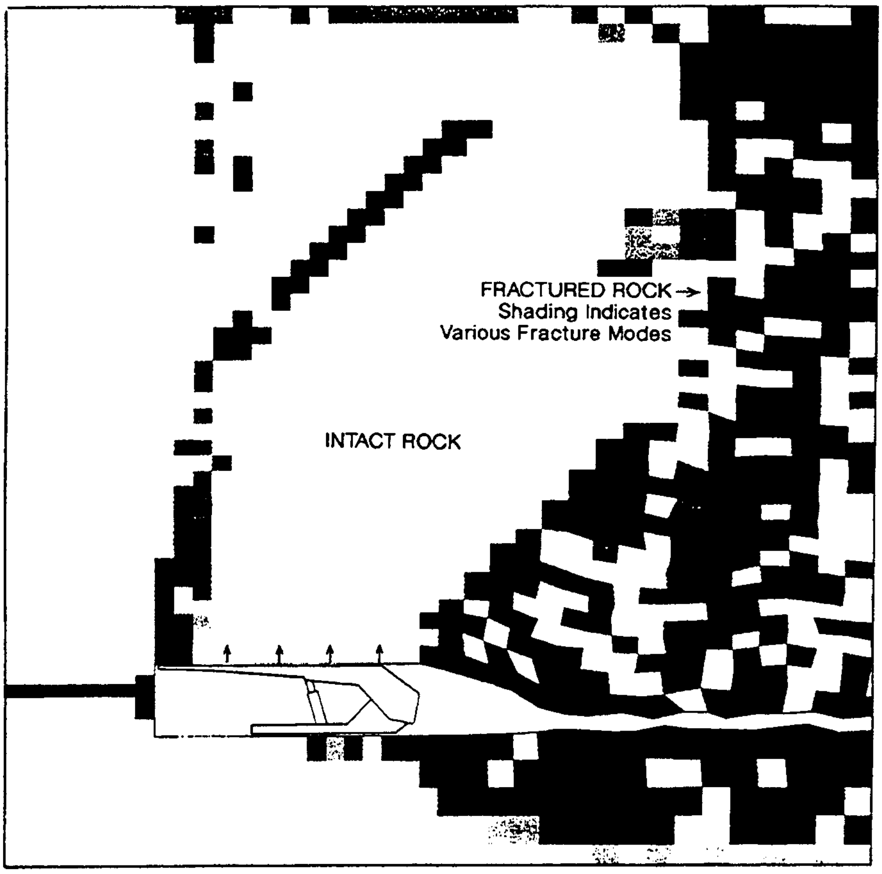


**Fig. 4 – Longwall fracture distribution – peridic weighting**

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 an extensometer extending from the surface down to the coal seam. The extensometer was located at the centre of the longwall panel. The surface extensometer results presented in Fig. 5 indicate a good correlation of strata movement between the model and the in situ measurements.

Underground monitoring of the longwall support pressures and convergence shown in Fig. 6 were used to study the frequency of periodic weighting. The results were directly compared with the leg pressures and the convergence of the modelled support. The underground data and the modelled results were showing similar trends.

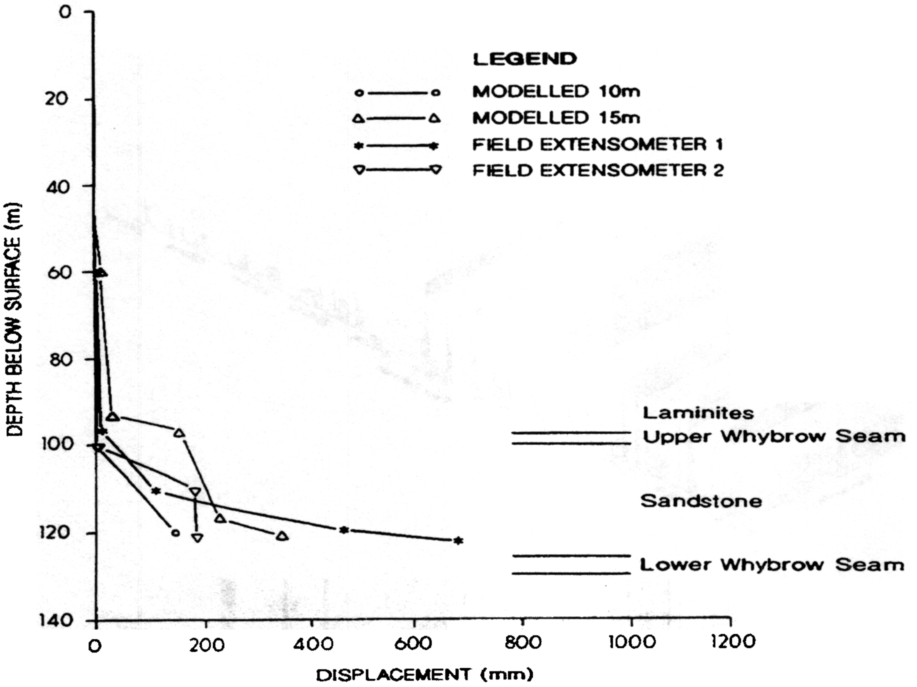


Fig. 5(a) – Comparison of modelled and measured extensometer results in the 7 – 15m range behind the face area

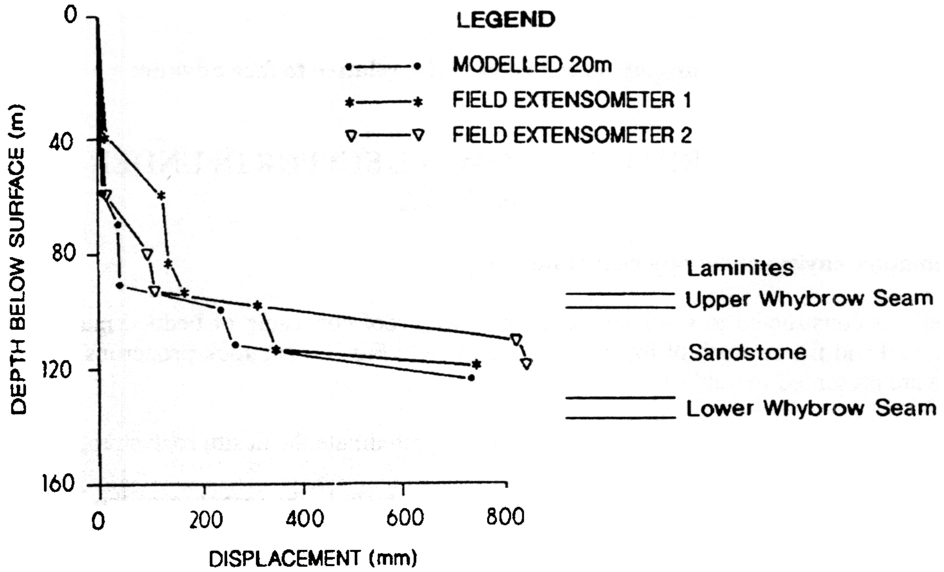


Fig. 5(b) – Comparison of modelled and measured extensometer results 20m behind the face area

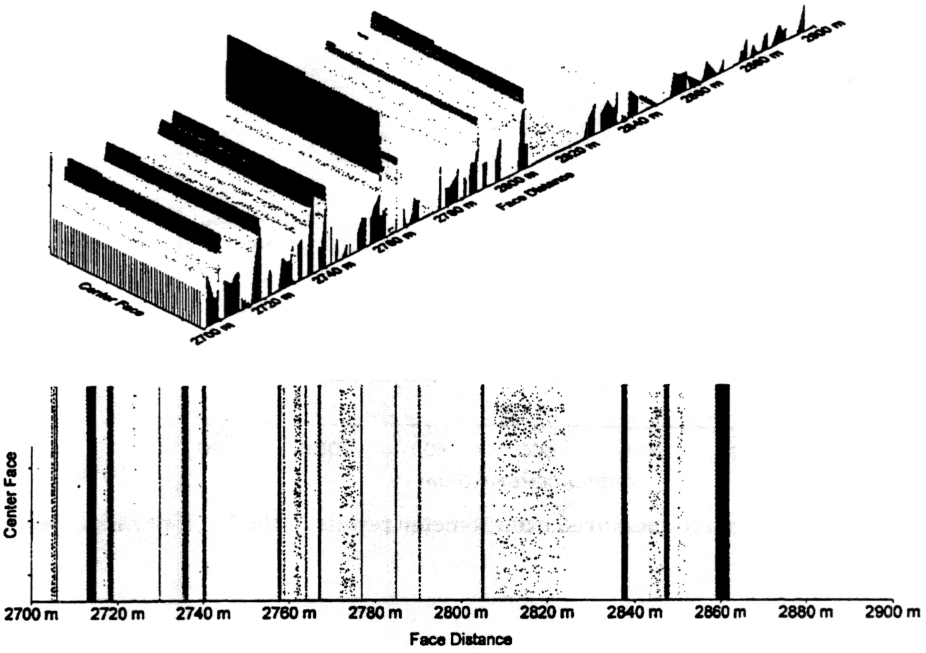


Fig. 6 - Support pressure rate rise relative to face advance

# SELECTION AND OPERATION OF LONGWALL SUPPORTS UNDER VARIABLE ROOF STRATA

## Prediction of premature caving at canopy rear (case study)

A computer model was constructed to simulate weak strata with roof consisting of bedded mudstone and siltstone. The geometry of the model and the strength of intact strata is shown in Fig. 7. The rock properties typical of weak mudstone and siltstone strata are presented in Table 1.

The strength reduction factor of 0.58 was used in the model to approximate the in situ rock strength.

The aim of the model was to simulate the premature roof caving to study the response of the longwall supports to strata movement. The coal was sequentially mined and the exposed roof supported by advancing 4-leg powered supports rated at 650 tonnes.

The study showed that the 4-leg supports failed to provide adequate support to the broken rock at the canopy tip. When the rear legs were set at 80% of their design capacity, premature yielding of the fractured roof at the rear of the support caused the canopy to rotate slightly and lower the canopy tip away from the roof. Low confining stress zones at the canopy tip can be seen in Fig. 8a where contact between the canopy tip and the roof was lost. When the rear leg pressures were reduced, the stress distribution above the canopy improved with better roof confinement at the canopy tip.

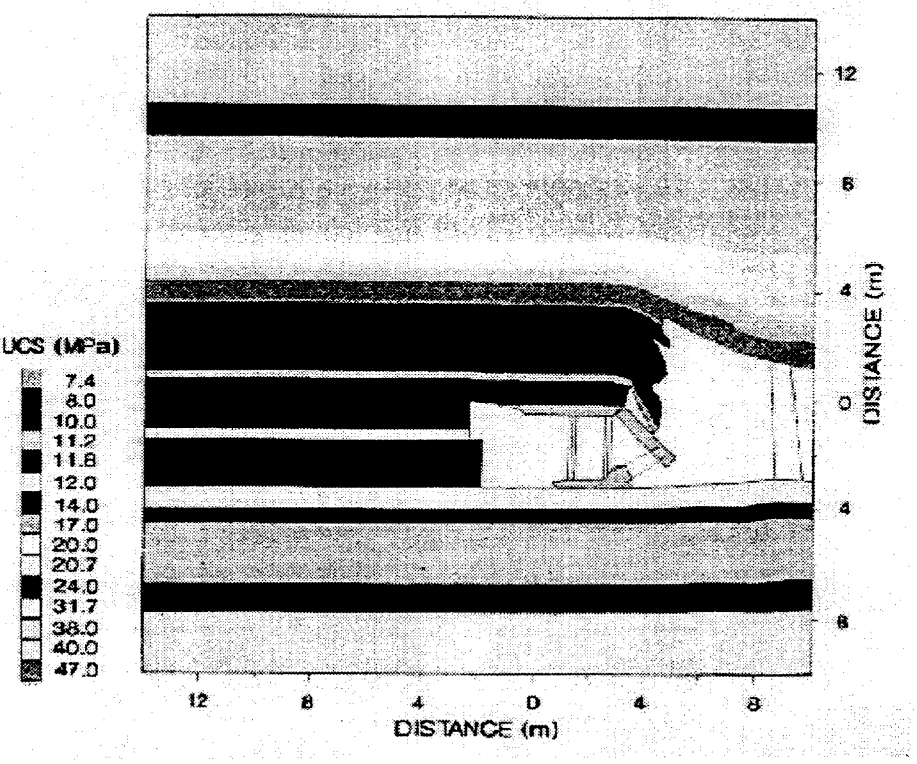


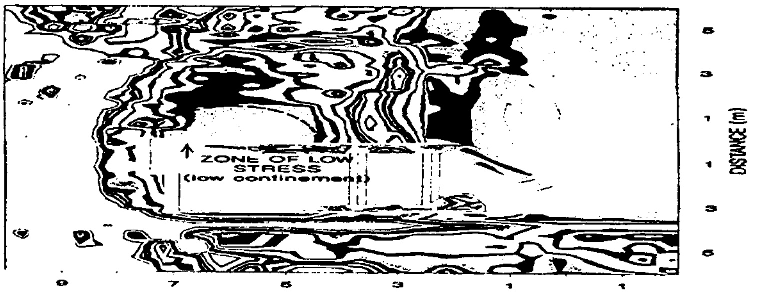
**Fig. 7 Geometry and strength of intact strata used in the model**

When trialing the 2-leg supports rated at 650 tonnes, the premature caving at the canopy rear appeared to have little influence on stress distribution above the canopy. The geometry of the 2-leg supports and the stress distribution in strata showing higher confining stresses at the canopy tip is shown in Fig. 8b. The model indicated that the 2-leg supports provided better roof support and desirable confining stress at the canopy tip.

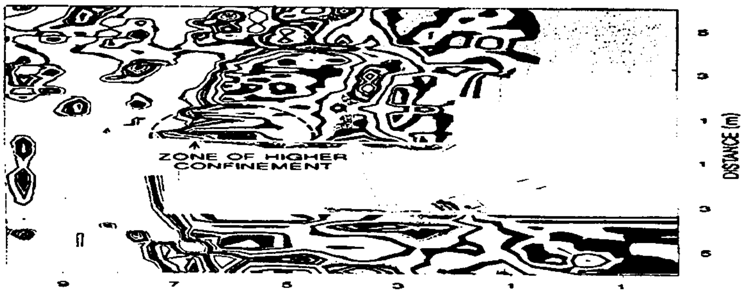
**Table 1. Rock Properties used in the Model**

| Rock Type | Mudstone | Coal | Siltstone | Weak Bedding |
|---|---|---|---|---|
| Bulk Modulus (Gpa) | 8 | 3 | 7 | - |
| Shear Modulus (Gpa) | 6 | 2 | 5 | - |
| Normal Stiff (GPa) | - | - | - | 1e10 |
| Shear Stiff (GPa) | - | - | - | 5e9 |
| Cohesion (MPa) | 3 | 0.5 | 2 | 1 |
| Residual Cohesion (MPa) | 0 | 0 | 0 | 0 |
| Intact Friction | 35° | 35° | 35° | 25° |
| Residual Friction | 35° | 35° | 35° | 25° |
| Maximum tension (MPa) | 2 | 0.5 | 2 | 0.5 |

| Confining Stress (MPa) | Intact Stress Range (Mpa) | Residual Stress (MPa) | Intact Stress Range (MPa) | Residual Stress (MPa) | Intact Stress Range (MPa) | Residual Stress (MPa) |
|---|---|---|---|---|---|---|
| 0 | 20-60 | 0.05 | 12 | 0.05 | 25-65 | 0.05 |
| 1 | 35-75 | 15 | 18 | 8 | 35-75 | 10 |
| 2 | 42-82 | 22 | 23 | 11 | 40-80 | 15 |
| 5 | 60-100 | 40 | 35 | 23 | 52-92 | 27 |
| 10 | 90-130 | 70 | 53 | 41 | 68-108 | 43 |
| 20 | 150-190 | 130 | 70 | 58 | 100-140 | 75 |



a) 4 leg supports.



b) 2 leg supports.

**Fig. 8 - Distribution of maximum principal stress indicating the level of roof confinment at the longwall face for 2 and 4 leg supports set at 650 tonnes**

In summary, the model showed that premature caving at the canopy rear may reduce the overall support capacity, contribute to the canopy tilt and cause unwanted reduction of roof support at the longwall face potentially leading to roof failure.

The model further indicated that for strong overhanging immediate roof, 4-leg supports can provide a more favourable reaction to the roof. If the immediate roof caves readily or premature caving at the canopy rear is anticipated, then 2-leg supports will provide better roof control.

## COMPARISON OF METHODS TO SELECT POWERED SUPPORTS

### Role of the powered support

The underground observations, computational modelling and microseismic survey provide evidence that:

Fractures in the strata are induced by stress concentrations ahead of the longwall face. Longwall supports have little influence on the formation of fractures within the roof. The role of longwall supports is to assist already broken roof strata to remain reasonably intact until caving occurs behind the canopy. If the support canopies do not exert enough force onto the immediate roof, opening and displacement along the mining induced fractures can occur reducing the integrity of strata and affecting stability of the longwall face.

### Longwall support capacity requirements

Historically, the increase in load capacity of the powered supports in Australia coincided with better production rates and fewer strata problems at the longwall face. In search of further increase in production, the mine management urged the longwall manufacturers to gradually increase the capacities of the shield supports. This ongoing trend is restricted by the cost of the supports and the potential wastage if the support geometry or load capacities are not suitable for the strata conditions.

Selection of the longwall supports has traditionally been determined on the basis of:

- Minimum force required to support the immediate roof;
- Additional loading of the roof;
- Unexpected loads when negotiating geologically disturbed zones;
- Increased loading during the longwall recovery;
- A margin to cover shortfalls in the hydraulic system health; and
- Previous experience in the mine.

As demonstrated, current development in computer simulation techniques can provide more appropriate selection of the powered supports. The computational model is also more suitable to indicate whether the further increase in the support capacity would provide any benefits at the longwall face.

## USING THE COMPUTATIONAL MODEL AS THE LONGWALL SUPPORT DESIGN TOOL

The traditional method of longwall selection allowed for basic designs only while the computational models backed by the underground measurements can provide a wider range of solutions to select appropriate powered supports.

The computer model has the unique ability to compare how different powered supports cope with identical mining conditions. Repeating the study for all possible conditions that can be encountered in the mine allows the best support type to be selected to suit the prevailing underground conditions.

To show the diversity of the problem that can be solved using the model, some are summarised below:

The computational models can:

- Provide information to assist with the selection of new powered supports;
- Evaluate the effectiveness of existing powered supports;
- Estimate the minimum safe site specific support loads to control roof strata;
- Assist in selecting the best mining method;
- Estimate the maximum safe roof exposure at the face;
- Estimate roof stability when using one web back system;
- Predict likelihood of premature roof caving at the canopy rear and indicate the best operational techniques to minimise the canopy tilt;
- Show the influence of the longwall panel width on strata behaviour;
- Indicates strata behaviour when change in geology occurs;
- Assist with prediction of periodic weighting;
- Indicate the possibility of major roof failure;
- Help to predict strata behaviour when negotiating faults;
- Assist with roof reinforcement design at the longwall finish line;
- Predict the extent of fracture propagation in the roof at the longwall face; and
- Study the behaviour of failed roof.

## CONCLUSION

This work is "breaking new ground" in understanding and demonstrating techniques to predict ground behaviour about longwall panels. The results of this work are being applied to support design at a number of mines, and demonstrate the benefit of diverse skills within the collaborative research team. The up-to-date results from the model have provided a new understanding of how the longwall supports respond to different strata and stress environments. This would not be possible using the more conventional approaches to longwall design. The study demonstrates that the computational modelling can provide accurate predictions of strata behaviour at the longwall face leading to greater safety, improved costs and higher production levels. The longwall model has proven to be of significant value and further development is envisaged to provide better service to the mining industry.

## REFERENCES

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Kelly, M., Gale, W., Hatherly, P., Balusu R., Luo, X. 1998. *Combining Modern Assessment Methods to Improve Understanding of Longwall Geomechanics.* The Institute of Mining Metallurgy, Coal98 Conference, Wollongong University, New South Wales.