# **Experience in Modelling Longwall Support Behaviour**

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**Abstract:** Recent advances in computer simulations of strata caving mechanisms and the response of longwall supports to strata behaviour has allowed much better understanding of longwall support requirements. The computational method allows the simulation of longwall support behaviour under a wide range of geological conditions with emphasis on comparing different support geometries and support loading conditions. This paper presents results of the computational trials to simulate various longwall support geometries including the comparison of the two leg and the four leg support options, the premature caving of strata at the canopy rear and its influence on roof falls at the longwall face.

The rock fracture distribution and caving characteristics of a wide range of strata geologies has a significant influence on the longwall support behaviour. Underground measurements and computer simulations were undertaken to investigate the caving characteristics of strata and some of the common problems typically encountered at the longwall face. The computer simulations highlight the importance of the longwall support geometry and location of the applied roof loads to minimise potential problems leading to major roof falls at the longwall face.

*Key Words:* longwall face, longwall support, strata control, numerical model

# Introduction

This paper presents a novel approach to longwall design that can be used to assess strata behaviour under a wide range of geological conditions and outlines the importance of the longwall support selection process. The aim of this study was to simulate the mechanics of strata failure under weak geological and mining conditions at longwall face and investigate the influence of longwall support geometry onto the stability of fractured roof. A range of the common problems typically associated with inadequate longwall support loading and inferior geometries were simulated under weak and friable strata conditions. The aim of the simulated problems was to outline why the problems occur and what can be done to minimise them.

#### **Description of Common Strata Problems at Longwall Face**

#### Typical Behaviour of Weak Strata at Longwall Face

The longwall fracture distribution presented in Figure 1 indicates rock failure in the immediate roof well in advance of the face (Gale and Nemcik, 1998). This style of behaviour has been verified by microseismic monitoring (Kelly et al, 1998). In this caving style, no large caving blocks are formed and periodic fractures occur on the small scale only as the ground is heavily fractured in front of the face. The peak stress concentrations are located well ahead of the longwall excavation 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 that develop after each shear has been cut. The geometry of roof failure above the canopy consists typically of small fragmented blocky rock material that can be difficult to support. If large roof spans are left exposed ahead of the canopy tip, shallow roof falls may occur that can affect stability of the longwall supports and the roof strata, leading to catastrophic roof falls at the longwall face. This situation can be accelerated by premature caving of broken strata at the canopy rear.



Fig. 1 – Typical rock failure in weak ground ahead of the longwall face.



a) Longwall support in 'closed' position.



b) Longwall support further from the face.



c) Longwall support set against severely broken roof.

Fig. 2 – The role of confining stress in the immediate roof above the longwall supports.

# Development of Roof Failure at Longwall Face

The mechanism of roof failure at the longwall face is presented in Figure 2. Underground observations and computer modelling of the longwall face indicate that if the canopy provides insufficient load to the roof strata, confinement stresses ahead of the canopy are lost and rock is free to fall out. Weak geological structure, poor operational procedures and low support loads combined with friable roof conditions often lead to reduction in roof confinement followed by fall of the broken rock onto the AFC conveyor.

If the minor roof falls occur regularly, they will affect setting of the supports against partially fallen roof. When more shears are cut, the support loads decrease as the operators try to set the canopies against cavities. The problem escalates if the strata cave prematurely at the canopy rear and the supports tilt. Further roof falls develop in response to the increased convergence and loss of the roof confinement ahead and above the canopies.

Unable to clear large pieces of rock, the AFC and the longwall is stopped. As the fall continues higher into the roof, stresses providing confinement to the fractured rock are relieved into the opening. The support loads diminish leaving a pile of broken rock above the canopy and the goaf edge at the face. Each time the supports are advanced, they cannot be set against the rubble and the cavity above. The unconfined goaf edge located at the face will try to cave each time a new shear is cut.

## Premature Caving of Roof Strata

In weak roof, numerous fractures develop ahead of the longwall advance. If the support loads do not provide enough confinement to the roof, excessive roof convergence can occur causing displacements and rotation of broken rock mass. Loading and unloading of the roof and large canopy loads at the goaf edge can gradually dislodge the broken strata until rock caves prematurely at the goaf edge. If the four leg supports are used, the rear legs cannot be set properly against the severely broken roof or cavity at the canopy rear. This reduces the support capacity and the canopy tilt is likely to occur. The canopy tip moves away from the roof reducing the much needed roof support at the face. In severe cases where a large part of the immediate roof disintegrates, even two leg supports may be difficult to set. In summary the premature caving at the canopy rear may reduce the support capacity, contribute to the canopy tilt and cause unwanted reduction of roof support at the face.

## Selection of Longwall Supports Using Computer Model

# Computer Modelling Approach

The finite difference code FLAC (Itasca,1993) was used to simulate a large strain and incremental excavation of longwall face. FLAC is a two dimensional, explicit, finite, difference code which simulates rock behaviour which undergo strain softening deformation when the yield is reached. A programmable language "FISH" within the FLAC was used to simulate the rock behaviour during the execution. The rock

failure routines used in the code have been developed by SCT to realistically simulate actual behaviour of strata.

The true behaviour of strata can be achieved only if underground mining is simulated in detail. Rock failure develops in response to a change in stress while stress redistribution occurs as rock fails. To simulate strata failure as normally experienced underground, it is essential that the coal be excavated sequentially cutting "shears" of a nominated width to simulate longwall advance. The rock must be allowed to fail and the stresses redistributed before proceeding to the next cut. The model simulates advancing longwall supports and strata containing weak horizontal bedding planes which appear to dominate the roof behaviour in longwall roofs.

The model incorporates large-scale (up to the surface) geometry to establish appropriate stressfields at the longwall face area. To simulate the vertical stress within the rock, the model is gravity loaded. To ensure that the vertical stress at longwalls of subcritical width corresponds to the stress expected at the centre of the longwall face, the study is done when the reflective boundary at the consolidated goaf edge is approximately at the distance of one half the longwall width. This technique was validated by underground stress measurements (Gale and Nemcik, 1998). The virgin lateral stress usually obtained from the underground measurements is adjusted according to the rock stiffness for each rock layer. The progressive excavation of the longwall face can be captured with a "movie" file, which allows visualisation of caving cycles and stress changes as the longwall retreats.

The model was 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 determination of the type of fracture that may develop. The fractures are simulated by changing the rock and joint properties derived from the triaxial rock testing.

#### Numerical Model

The properties of strata used in the model were based on the triaxial tests of the overburden rock and coal seams of the modelled region.

The model of the longwall supports was constructed using the grid and the support elements. The canopy stiffness was varied to simulate the properties of the actual longwall support in use. The modelled supports have the ability to be advanced 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 fall freely 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 the floor level. Properties of the weak ground used in the model are given in Table 1 below.

Rock Type	Mudstone	Coal	Siltstone	Weak Bedding
Bulk Modulus (GPa)	8	3	7	-
Shear Modulus (GPa)	6	2	5	-
Normal Stiffness (GPa)	-	_	-	1e10
Shear Stiffness (GPa)	-	-	-	5e9
Cohesion (MPa)	3	0.5	2	1
Resid Cohesion (MPa)	0	0	0	0
Intact Friction	35°	35°	35°	25°
Resid Friction	35°	35°	35°	25°
Max tension (MPa)	2	0.5	2	0.5

## Table 1Rock Properties used in the Model

	Mudstone		Coal		Siltstone	
Confining Strength	Intact Strength Range	Resid Strength	Intact Strength Range	Resid Strength	Intact Strength Range	Resid Strength
(MPa)	(MPa)	(MPa)	(MPa)	(MPa)	(MPa)	(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

Influence of Support Loads on Roof Behaviour in Weak Ground

In general, reduction in support loads at the longwall face results in an increased roof convergence. The support loads were varied between 150 to 650 tonnes to investigate the roof converge above the four and two leg supports. The support loads versus the support convergence shown for both cases in Figure 3 (a) and (b) indicate that under the normal operation the load need not be high to keep the roof intact. Applied loads lower that 400 tonnes may be satisfactory to cope with the roof control, however, when the adverse conditions are experienced, additional roof supports may be required to prevent roof failure. In any case, inferior roof loads of less that 300 tonnes can cause severe roof convergence and rotation of strata that reduces the integrity of the immediate roof and increases the likelihood of premature caving at the canopy rear.



Fig. 3(a) - Roof displacement versus longwall support loads, 4-leg supports.



Fig. 3(b) - Roof displacement versus longwall support loads, 2-leg supports.

# Geometry of Powered Supports and its Influence on Roof Falls at Longwall Face

# Behaviour of Two Leg and Four Leg Longwall Supports

A model was constructed in weak ground to study the confinement stresses at and ahead of the support canopies. The 4 leg supports were initially used and the geometry was later changed to two legs to compare the stress distribution ahead of the canopy tip. The model consisted of weak immediate strata with properties shown in Table 1 and the powered supports as shown in Figure 4. The model was sequentially excavated using 1m wide shear cuts.



Fig. 4 – Geometry of 2-leg supports and strength of strata used in the model.

Under the normal operating conditions the 4 leg supports were slightly tilted downwards towards the face. The canopy tilt indicated that the full set loads applied to the rear legs were too high and the unconfined roof at the goaf edge was at yield. The canopy tip moved away from the roof minimising the effectiveness of the roof support at the face and exposing large spans of the unconfined roof. The contours of the maximum stress above the 4 leg supports shown in Figure 5 indicated that under normal conditions, roof confinement ahead of the canopy supports was very small. When the two leg supports of the same geometry were trialed, the canopy tilt did not occur and the distribution of the maximum stress was more favourable. The contours of the maximum stress above the two leg supports shown in Figure 6 indicate higher

confinement close to the longwall face. The maximum stress providing the confinement to the fractured rock in the lower roof horizon was averaged over eight shear cuts and graphed for both cases in Figure 7. The plot clearly shows that the confining stresses at the lower roof horizon are higher for the two leg supports. Roof displacements for both supports graphed in Figure 8 indicated that the roof at the canopy tip displaced considerably more for the four leg supports. This behaviour indicates that under weak roof conditions, the probability of roof failure would increase if the four leg supports are used.



Fig. 5 – Contours of maximum stress above 4-leg supports operating in weak strata.



Fig. 6 – Contours of maximum stress above 2-leg supports operating in weak strata.



Fig. 7 – Maximum stress in the lower roof horizon above 2-leg and 4-leg supports.



Fig. 8 – Roof convergence above 2-leg and 4-leg supports.

### Simulation of Premature Caving and its Influence on Support Stability

To simulate premature caving at the canopy rear, a part of the immediate roof rock was removed at the goaf edge. The 4 leg supports of 650 tonne capacity were set to the roof and the response of strata investigated. A significant tilt of the canopy occurred increasing the length of the unsupported roof ahead of the canopy. The maximum stress contours shown in Figure 9 indicated large zone of the unconfined roof strata. When the geometry of the two leg supports was used (Figure 10), slight canopy tilt was also experienced, however, the canopy roof contact was located closer to the face, providing better roof support. The effect of the premature caving was similar to the previously modelled behaviour of the four leg supports in weak strata. When comparing the maximum stress distribution in the roof shown in Figures 9 and 10, it is clear that the 2 leg supports are superior in providing better support to weak friable strata especially where the premature caving is likely to occur.

# Roof Support Using Canopy Tip Extensions

The extended canopy tip was modelled to investigate its benefits in providing roof stability at the longwall face. The extension was later angled upwards at  $5^{\circ}$  to investigate whether the roof support loads at the extension tip would improve stability of the longwall face. Both canopy extensions appeared to provide a benefit in minimising face rock falls onto the AFC conveyor. The modelled contours of the maximum stress shown in Figure 11a and 11b indicated that the canopy extension with the raised tip (Figure 11b) did not seem to provide extra roof support and the load was concentrated at the canopy tip and the canopy rear only. Such load distribution can cause greater roof displacements at the canopy centre leading to premature caving at the goaf edge. The canopy extensions can be beneficial when mining under friable roof, operating in one web back mode or experience coal spall at the face.



Fig. 9 – Distribution of maximum stress above 4-leg longwall supports experiencing premature caving at the goaf edge.



Fig. 10 – Distribution of maximum stress above 2-leg longwall supports experiencing premature caving at the goaf edge.



Fig. 11(a) – Maximum principal stress contours above extended canopy tip.



Fig. 11(b) – Maximum principal stress contours above extended canopy tip angled upwards at  $5^{\circ}$ .

## Conclusion

SCT research into computational modelling of strata behaviour and caving mechanisms about longwall faces has demonstrated the complexity of issues associated with strata control at the longwall face. The computer model constructed to simulate complex interactions between the fractured strata and the powered supports predict a range of solutions to common problems at the longwall face. Ongoing measurements of microseismic activity, computational modelling and monitoring of the longwall supports has demonstrated that previous assumptions of caving mechanisms, stress redistributions at longwall face and general strata behaviour were either too simplistic or not suited to certain geologies.

A range of common strata control problems at the longwall face was studied using the computational simulation of moving longwall. The study shows that it is possible to simulate detailed ground behaviour and investigate stability of the longwall supports.

The model has demonstrated that the behaviour of the fractured roof depends on the strata type, the support loads and the support geometry. Study of the variation in support loads indicated that under normal operation the support loads do not need to be high to control roof strata. The model indicated that the support loads lower than 400 tonnes can be adequate under normal conditions, however, higher load capacities are desirable to cope with adverse conditions. Higher support capacities are selected to control strata when unusual loading conditions are expected such as periodic weighting or when mining geologically disturbed zones.

The simulation indicated that under weak roof, the two leg supports are superior in controlling roof strata. The two leg supports provided better confinement to the broken roof close to the face, while maintaining the overall support stability.

The model shows that the effect of the premature caving at the canopy rear can influence the stability of the powered supports. The caved roof above the canopy rear can reduce the supports loads, tilt the canopies and minimise the canopy tip loads. The premature caving at the canopy rear appeared to affect the stability of the four leg supports, while the two leg supports appeared to be more stable.

Simulation of the canopy extensions indicated benefits in minimising rock falls onto the AFC. The longer canopies can be beneficial when mining under weak friable roof, where the one web back operations are common and where excessive face spall is experienced at the longwall face. The model indicated that when elevating the canopy tip at an angle of  $5^{\circ}$ , the point loads were experienced above the elevated canopy tip and the canopy rear with no support at the canopy centre. The uneven load distribution can lead to greater roof displacements at the canopy centre weakening the roof and contributing to the premature caving at the goaf edge.

The longwall model has proven to be of a significant value and further development is envisaged to provide better service to the mining industry.

#### References

W.J. Gale and J.A. Nemcik, Prediction of Strata Caving Characteristics and its Impact on Longwall Operation, Proceedings of the 1<sup>st</sup> Australasian Coal Operators Conference COAL98, University of Wollongong, NSW, Australia

M. Kelly, W. Gale, P. Hatherly, R. Balusu and Xun Luo, Combining Modern Assessment Methods to Improve Understanding of Longwall Geomechanics, Proceedings of the 1<sup>st</sup> Australasian Coal Operators Conference COAL98, University of Wollongong, NSW, Australia

Itasca, 1993, Fast Lagrangian Analysis of Continua, FLAC User Manual, Version 3.2, Itasca Consulting Group Inc., Minneapolis, Minnesota, USA