APPENDIX F

Assessment of Stability and Subsidence

ASSESSMENT OF STABILITY AND SUBSIDENCE

SHM HIGHWALL MINING

COALPAC CONSOLIDATION PROJECT

for

Coalpac Pty Limited

December 2011

Mining Geomechanics and Materials Engineering

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EXECUTIVE SUMMARY

To facilitate the Coalpac Consolidation Project plan for SHM highwall mining of coal reserves in the Katoomba, Moolarben, Irondale and Lithgow seams across their various mine sites Geonet Consulting Group was requested to develop a generic highwall mining plan for the most critical area of mining in the State Forest where subsidence sensitive landscapes must be preserved.

The purpose of the report is to provide an assessment of stability and subsidence associated with SHM highwall mining in the landscape around Cullen Bullen.

Based on best estimates of stable SHM highwall mining layouts, it is concluded that the total subsidence of landscape ridges induced by SHM highwall mining will be less than the 20mm criterion specified by the NSW Department of Mineral Resources Subsidence Management Plan (2003). It is estimated that the maximum subsidence will be in the range 10mm to 15mm.

The SHM site modelling identified local exceptions to this on the southern point of the western highwall where subsidence may increase to 40mm associated with exposure of unconfined joints in the highwall. These are clearly located within the open cut highwalls and as such would be excluded from the landscape subsidence criterion. Structurally controlled areas of deformation may be controlled by optimising the orientation and profiles of the open pit highwalls in relation to the major joint sets. This may be achieved by realigning and stepping all angled highwall faces to align N-S and E-W. This should promote stability in the exposed jointed highwalls and reduce subsidence to within the 20mm criterion.

From an operational point of view, the simulation of SHM highwall mining has indicated that:

- There may be some effect on seam conditions in both the Irondale and Katoomba seams from previous mining in the Lithgow seam associated with increased stress concentrations over remnant pillars and loosening of interburden rockmass joints. Once mining starts in these seams it may be necessary to review the proposed pillar dimensions.
- SHM drives in the Lithgow seam should maintain a minimum 20m offset from previous underground mining operations in order to avoid breaching any flooded workings or initiating instability from previously damaged rockmass conditions.
- Once SHM mining proceeds, then regular visual inspection of the ridges should be made.
- In order to create long term stable barrier pillars with geometry of W:H>5 it is recommended to leave one entry unmined. By locating the barrier pillars at the sub-critical spans the intermediate SHM pillars in each sub-panel will be subject to reduced overburden stress loading conditions and subsidence of surface strata will be minimised.
- The stability of highwalls in the Coalpac Consolidation Project area have not been inspected as part of this study since they do not exist at this time. These will however be considered and assessed as part of the detailed SHM panel designs required as part of the Mine Operations Plan (MOP) and in accordance with the highwall mining design criteria.
- Calculation of the potential coal recovery of 1.856 Mtonnes in one area of the project site was based on achieving the full penetration depth of 305m in every hole except in the eastern highwall where penetrations must be limited to 260m so as not to intersect with entries from the western highwall. The anticipated recoveries are estimated as:
    - 672,934 tonnes of Katoomba seam coal
    - 415,144 tonnes of Moolarben seam coal
    - 353,162 tonnes of Irondale seam coal
    - 415,332 tonnes of Lithgow seam coal

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1.0 INTRODUCTION

Coalpac Pty Ltd is developing a consolidation plan for open cut and highwall mining its coal reserves in the Katoomba, Moolarben, Irondale and Lithgow seams across their various mine sites. Since conditions vary throughout the area it was decided to develop a generic highwall mining plan for the most critical area of mining which could then be applied as a basis for other areas. An aerial image of this area of State Forest is shown in Figure 1. The area was selected as it provided a worst case scenario with the maximum overburden thickness and also the presence of underground workings in the Lithgow Seam. As such it presents the case for maximum subsidence within the project boundary.

Geonet Consulting Group was requested by Mr Bret Leisemann to develop an acceptable highwall mining design layout using SHM technology to preferentially access better quality coal plies. It was specifically requested that attention be given to analysing the potential surface subsidence. Based on current criteria for preserving landscape features it is noted that mining induced subsidence must be limited to a maximum of 20mm [1]. Given the preliminary status of this report for the purpose of assessing the risk of subsidence to sensitive landscapes, it should be noted that specific design layouts will not be included. Specific design reports must to be prepared for each area of mining prior to mining for approval by Industry & Investment NSW as part of the Mining Operations Plan.

The following information was provided for use in the design analysis:

- Plan of surface topography in selected representative mining area.
- Geological surface profiles of the various coal seams in dxf format
- Specification of cutting heights in sections of four different coal seams.

Given the limited geotechnical data provided, the analyses presented in this report are based on the following assumptions:

i) Coal strength data is based on the simulated behaviour of the logged geological profile using material properties established for the Ulan Seam (which is essentially the Lithgow/Lidsdale seam) and successfully used previously for mining geotechnical analysis at Invincible Colliery and Cullen Valley Mine.

ii) The Katoomba, Moolarben, Irondale and Lithgow coal seams are unweathered, of uniform thickness and without structural disruption due to faulting, rolls, etc.

iii) Dimensions of underground workings in Lithgow seam shown on the mine plans are accurate of the 'as-mined' condition and the present condition.

The purpose of this report is to provide a generic assessment of stability and subsidence associated with SHM highwall mining in the subsidence sensitive landscape around Cullen Bullen. This report forms a supporting appendix to the Environmental Assessment being prepared to support an Application for Project Approval under the *Environmental Planning and Assessment Act 1979* to consolidate Cullen Valley Mine and Invincible Colliery.

The geotechnical evaluation will cover the following aspects:

- Estimation of coal seam strengths for each of the proposed mining horizons;
- Recommended pillar dimensions for single pass SHM mining;
- Evaluation of highwall and overburden conditions that might affect safe and productive highwall mining operations;
- Estimation of likely subsidence over highwall mined panels, and
- Assessment of potential magnitude of subsidence on local topography.

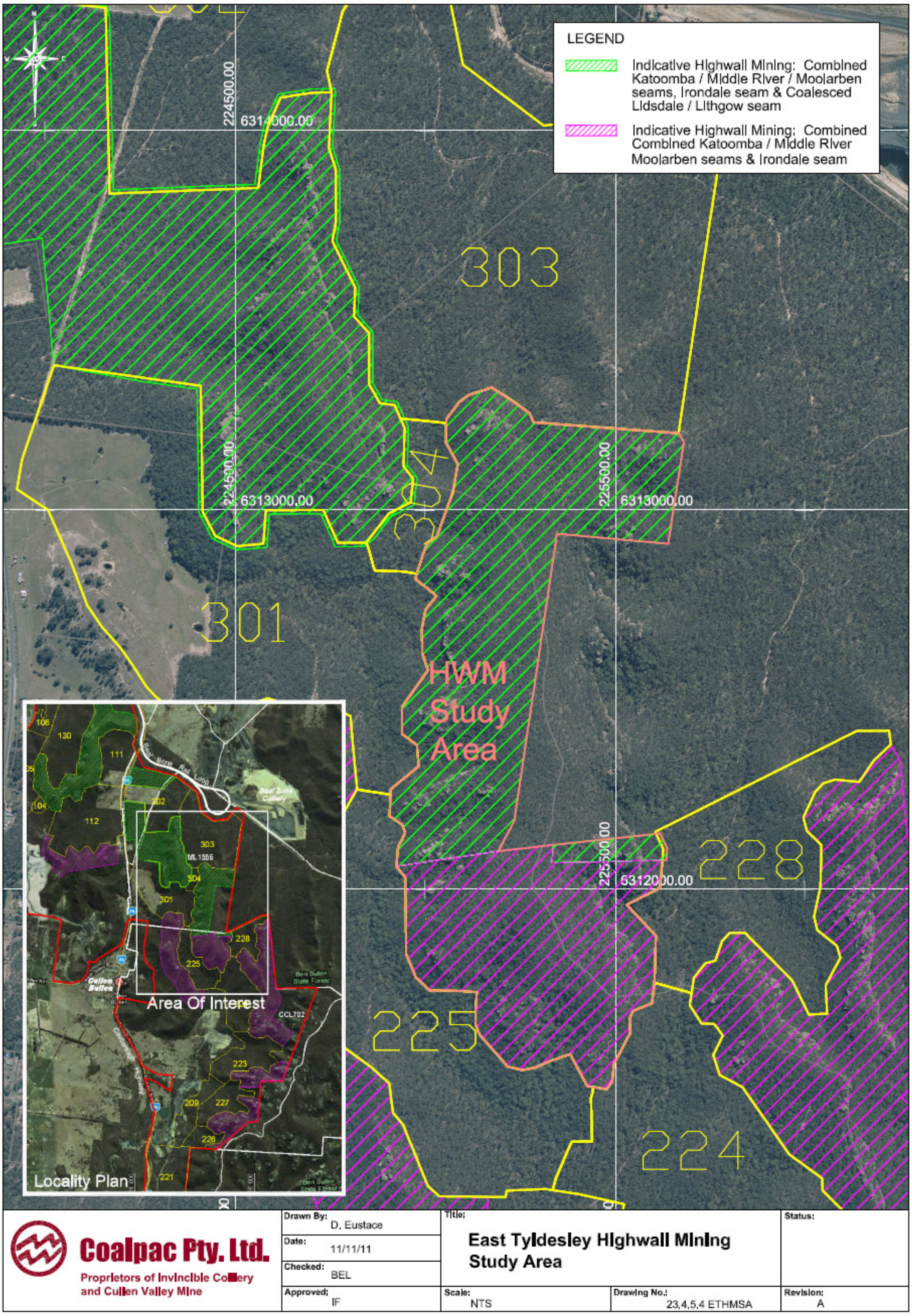

Figure 1: Location of proposed highwall mining area.

2.0 GEOTECHNICAL BACKGROUND INFORMATION

2.1 Background to Highwall Mining Technology

Highwall mining is a coal recovery technique employed from the safety of the open cut pit, whilst recovering coal from underground. The width of pillars left between the highwall mining entries can be designed and controlled, thus allowing the design of stable panels for highly variable geotechnical and geometrical conditions.

Coal is mined from coal seams by making rectangular, parallel, drives with a remotely-controlled cutterhead and coal transport system. This is controlled from a mining unit, or launch frame, positioned outside the drive, in front of the highwall, in the open cut pit.

Highwall mining originated in the 1940's in the mountainous Appalachian coal fields of eastern USA. Since then, there have been numerous technological improvements applied to the machines, to enable greater safety, greater coal recovery, and a detailed understanding of the geomechanics associated with this mining method. A major 10 year research project into the geomechanics of highwall mining was undertaken in Queensland and New South Wales (NSW) mines by the CSIRO [9]. A comprehensive understanding of the geomechanics of highwall mining in the Australian coal mining context has been established through design and back-analysis studies undertaken (both independently and in collaboration with CSIRO) by Geonet Consulting Group over the past twenty years.

Coalpac has selected the Superior Highwall Miner technology for the application of highwall mining to the Project. The Superior Highwall Miner (SHM) was introduced to the USA coal industry in 1983 and since that time in excess of 70 systems have been manufactured with the majority still in use today throughout the USA, and to a lesser extent, Russia and Australia. This system has been extensively employed in a wide variety of conditions throughout the Appalachian Coalfields of the eastern USA, in very similar topographic and geotechnical conditions to the Western Coalfields of NSW. The SHM features automated mining cycles and a superior configuration for maintaining horizon and azimuth control. The SHM recently acquired by CAT, see Figure 2(a) is a system that uses a cutter drum of a continuous miner to cut rectangular drives. The coal is transported through pushbeams consisting of two augers that are driven from the base machine. The penetration depth of this machine is 305 m, which is reached consistently, depending on geological and geotechnical constraints.

Highwall mining in the western coalfields of NSW was carried out during the 1990's and 2000's at Charbon Colliery and Ulan Mine with the Addcar Continuous Highwall Miner (a similar machine configuration as the SHM). An example of the highwall at Ulan Mine is shown in Figure 2(b).

Since the early 1990's in the Hunter and Newcastle coalfields, an auger head attachment was used to create circular entries. This highwall mining method was used at the Invincible Colliery and Cullen Valley Mine between 2007 and 2008.

A schematic of the proposed mining layout using SHM technology at Coalpac Consolidation Project is shown in Figure 2(c).

Figure 2(a): Coalpac Consolidation Project SHM mining equipment.

Figure 2(b): CHM entries in the highwall at Ulan Mine.

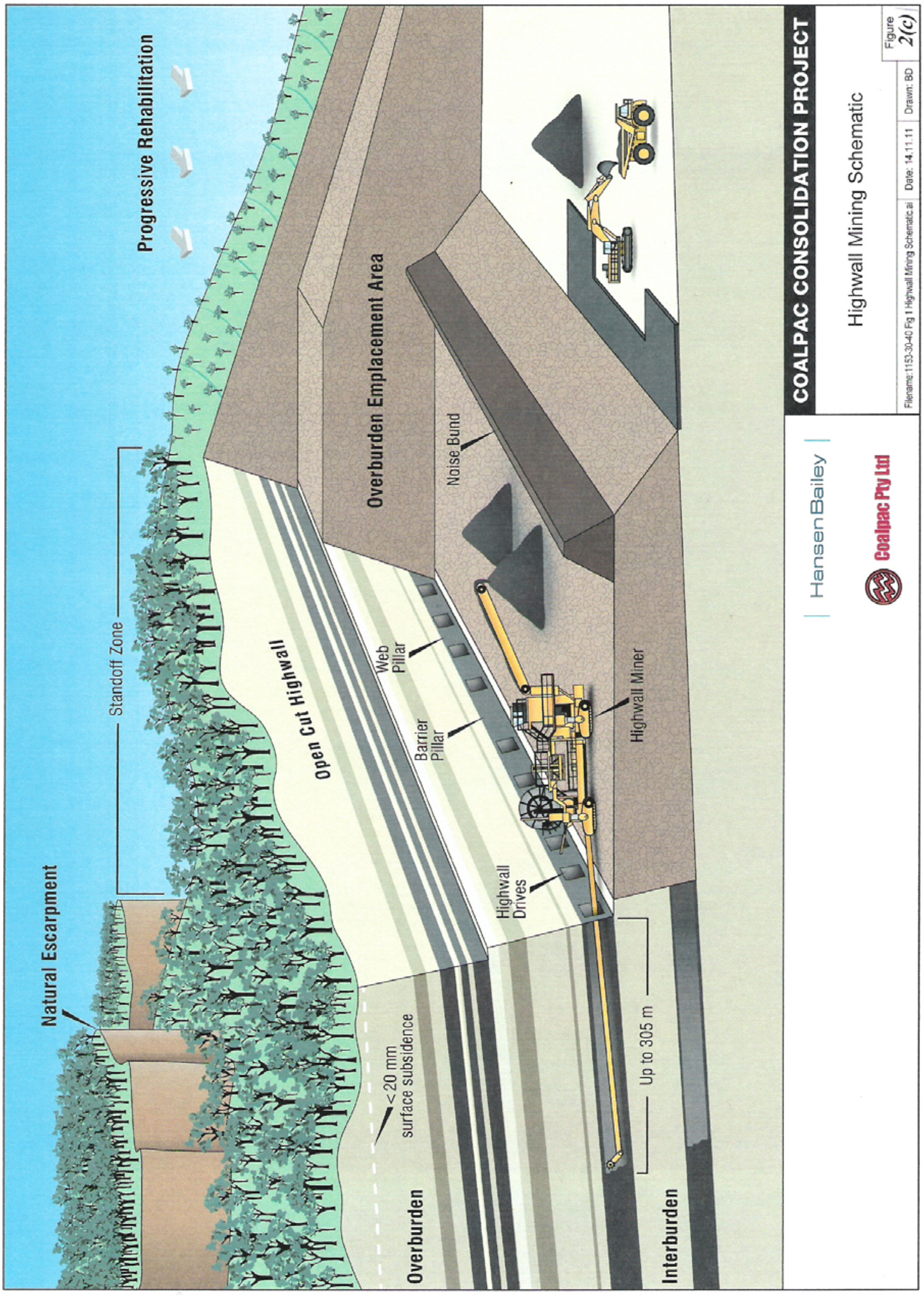

Figure 2(c): Schematic of Coalpac Consolidation Project SHM mining method

2.2 Project Area Geology

Extensive outcrops of Permian Illawarra Coal Measures occur throughout the Cullen Bullen area, overlain in regions of higher relief by the basal beds of the Triassic Caley Formation. These beds, in turn, are overlain by the basal beds of the cliff- forming sandstones of the Triassic Grose Subgroup of the Narrabeen Group.

The stratigraphic section for the general area is summarised in the table of Figure 3. The typical stratigraphic column in the mining area is located within the uppermost subgroup of the Illawarra Coal Measures and comprises coal, sandstone and shale. The overall dip of the strata is 2-3^{o} towards the northeast. The overburden sequence forms the prominent cliffs in the Blue Mountains.

The area is located within a gentle southwest to northeast trending syncline. Strata dip at approximately 2^{o} to the northeast (in the south) and east (in the north). Faults are not common, but are predominantly north-south trending normal faults with throws of less than 2m. Because the coal seams are relatively flat lying the main changes in depth are caused by rapid changes in topography. Seams tend to crop subparallel to topographic contours around valley edges. The potential base of weathering is estimated to lie between topography minus 2m and topography minus 5m. There is no indication that the coal seams have been intruded and/or coked.

Only rare isolated faults and fault zones have been encountered in local open cut mining operations. These were normal faults with the dips of the fault planes ranging from sub-vertical to low-angled. The fault with the maximum displacement was located in ML 1455 where the displacement was about 1.5 m, downthrown to the east and trended in a north-south direction. Most of the faults are orientated between NNW-SSE and NNE-SSW. It is anticipated that the major rockmass jointing will follow the same orientations.

It is proposed to highwall mine selective sections in the Katoomba, Moolarben, Irondale and Lithgow seams as follows:

Coal Seam	Seam Thickness (m)	Section to be Mined
Katoomba	4.01	Bottom 2.0m
Moolarben	3.24	Bottom 1.0m
Irondale	2.20	Top 0.9m
Lithgow	4.28	Bottom 2.2m

Typical geological logs [2] are presented for each of these coal seams highlighting proposed mining section in Figures 3(a) to 3(d), respectively [2].

NARRABEEN GROUP				
ILLAWARRA COAL MEASURES	WALLERAWANG SUBGROUP	Katoomba Coal	Katoomba Seam	**KAT**
		Farmers Creek Formation	"Burragorang Claystone"	
		Middle River Coal Member	Middle River Seam	**MR**
		Gap Sandstone		
	CHARBON SUBGROUP	State Mine Creek Formation		
		Moolarben Coal Member	Moolarben Seam	**MOOL**
		Watts Sandstone		
		Denman Formation		
		Glen Davis Formation	Upper Irondale Seam	**UIRA-UIRE**
		Newnes Formation		
			Ivanhoe Sandstone	
		Irondale Coal	Irondale Seam	**IRA - IRD**
			Bunnyong Sandstone	
		Long Swamp Formation		
	CULLEN BULLEN SUBGROUP	Lidsdale Coal	Lidsdale Upper Seam "Tuffaceous Marker" Lidsdale Lower Seam	**LIDU** **LIDL**
		Blackmans Flat Formation	"300 mm Claystone Band"	
		Lithgow Coal	Lithgow Seam "Tops" "10-foot Parting" Lithgow Seam Pillar	**LTHT** **LTHP**
		Marrangaroo Formation		
	NILE SUBGROUP			

Figure 3: Stratigraphy of Coalpac Consolidation Project mining area.

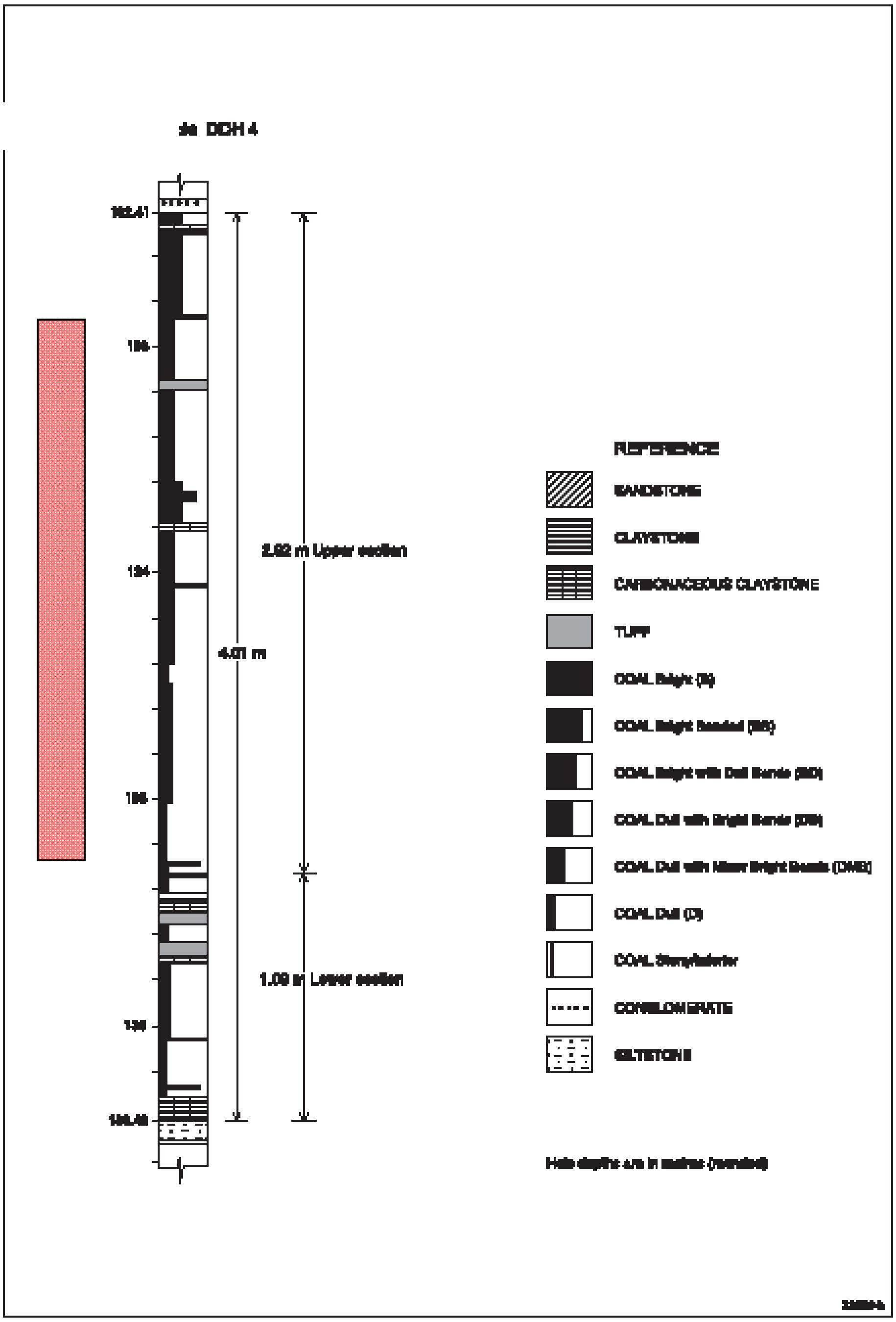

Figure 3(a): Geological log of Katoomba seam highlighting proposed mining section.

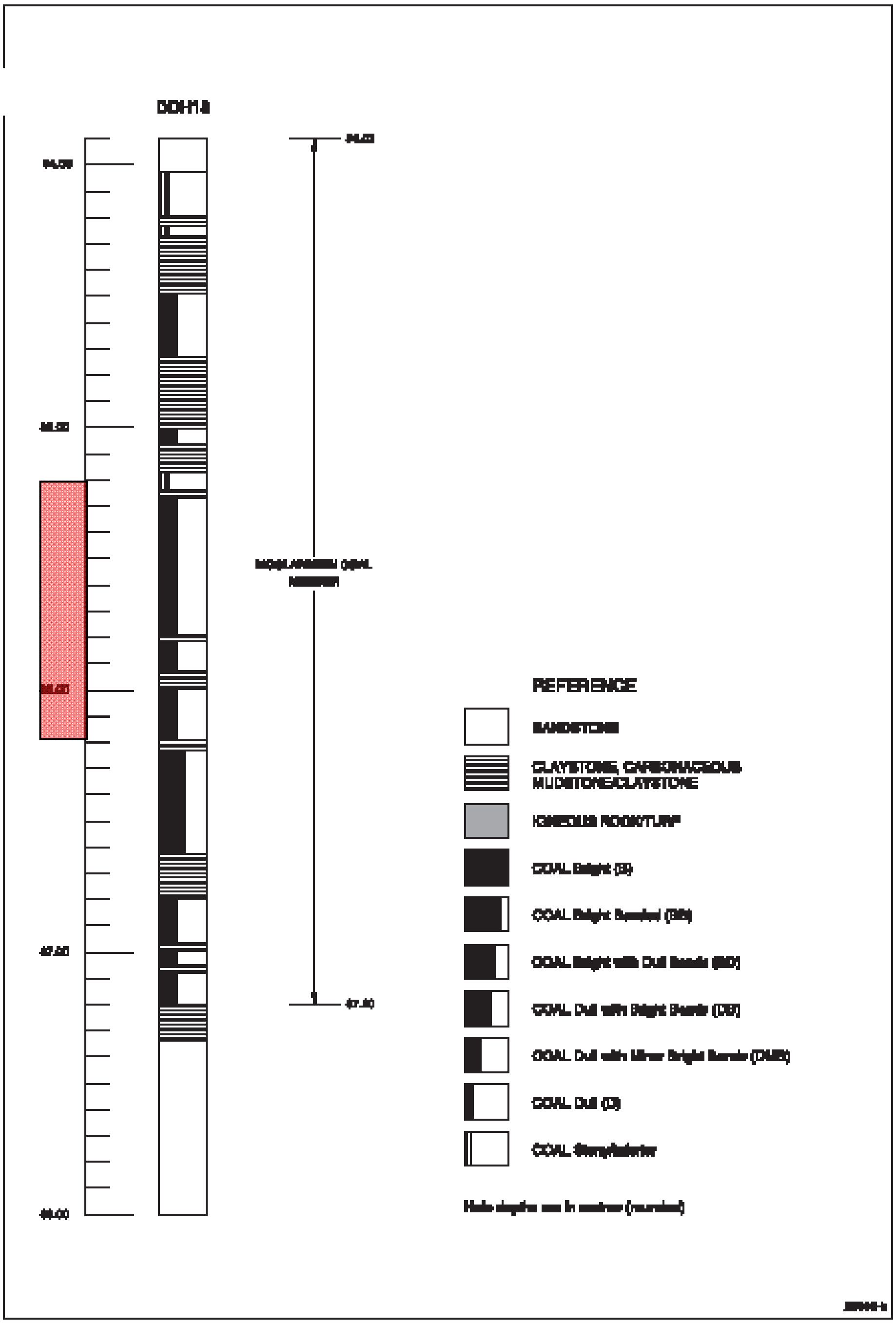

Figure 3(b): Geological log of Moolarben seam highlighting proposed mining section.

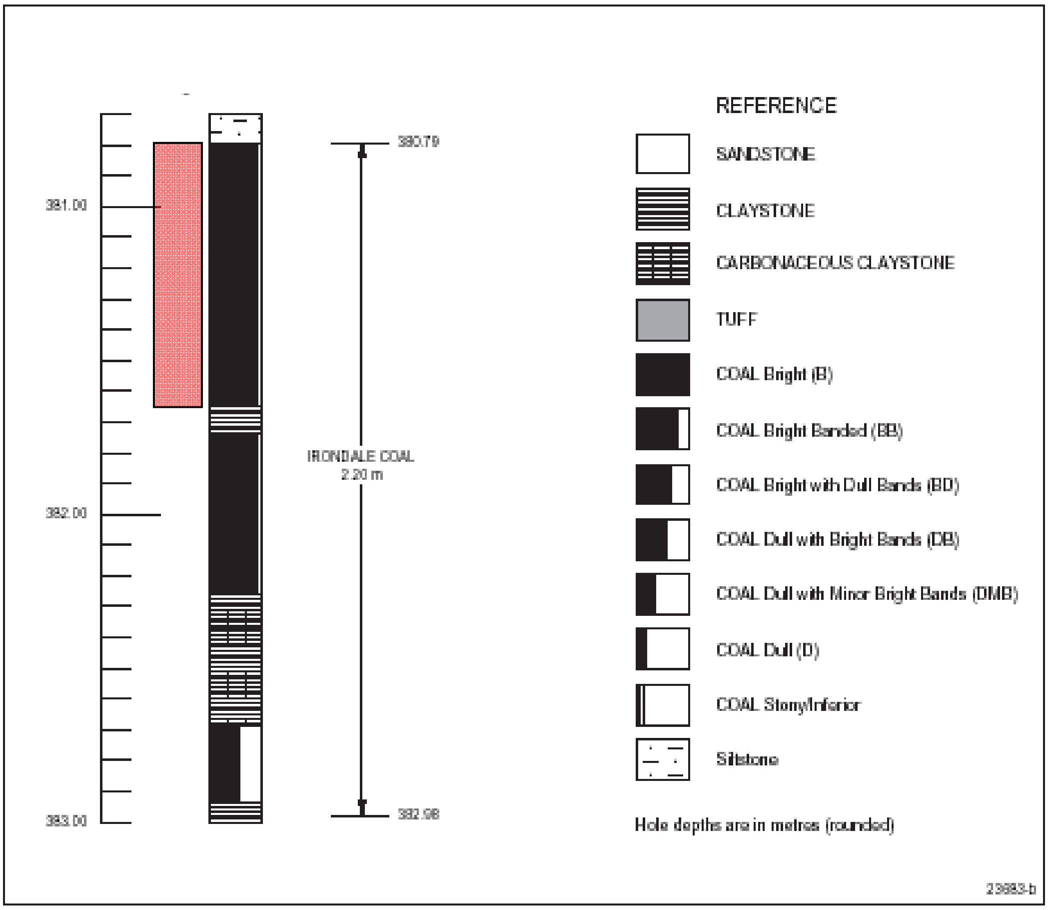

Figure 3(c): Geological log of Irondale seam highlighting proposed mining section.

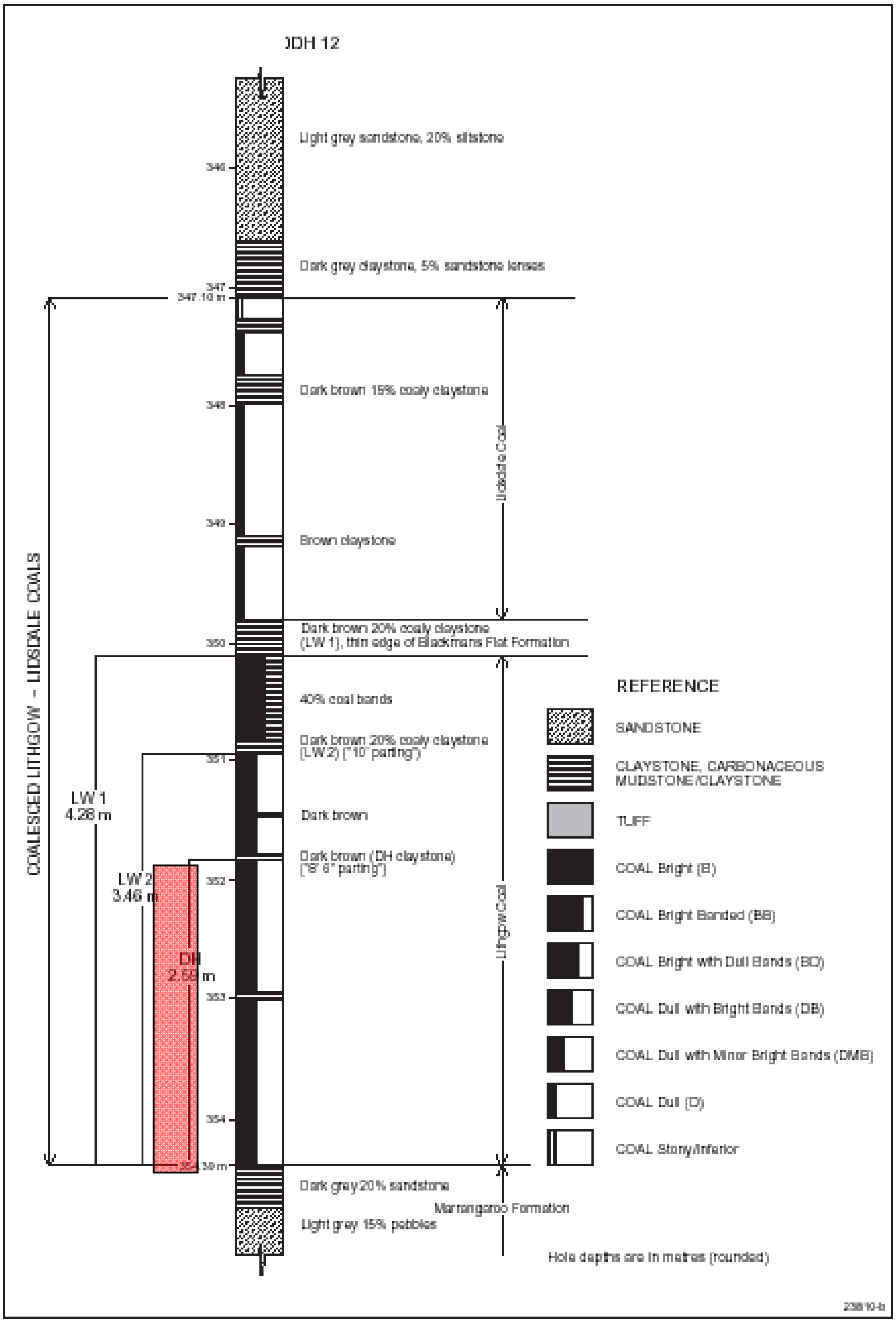

Figure 3(d): Geological log of Lithgow coal seam highlighting proposed mining section.

2.3 Schedule of Mining

Underlying the southern portion of the area provided for subsidence analysis are the historic underground bord and pillar workings in the Lithgow seam, Figure 4. The lower section of the Lithgow seam was mined to a height of about 1.5m. The pillars are typically 25m by 40m long with roadways 4.5m wide. These workings are located at mining depths between 100m and 140m below surface. Recent geotechnical assessment of the pillars [3] confirmed their stability with Factors of Safety in excess of 5.

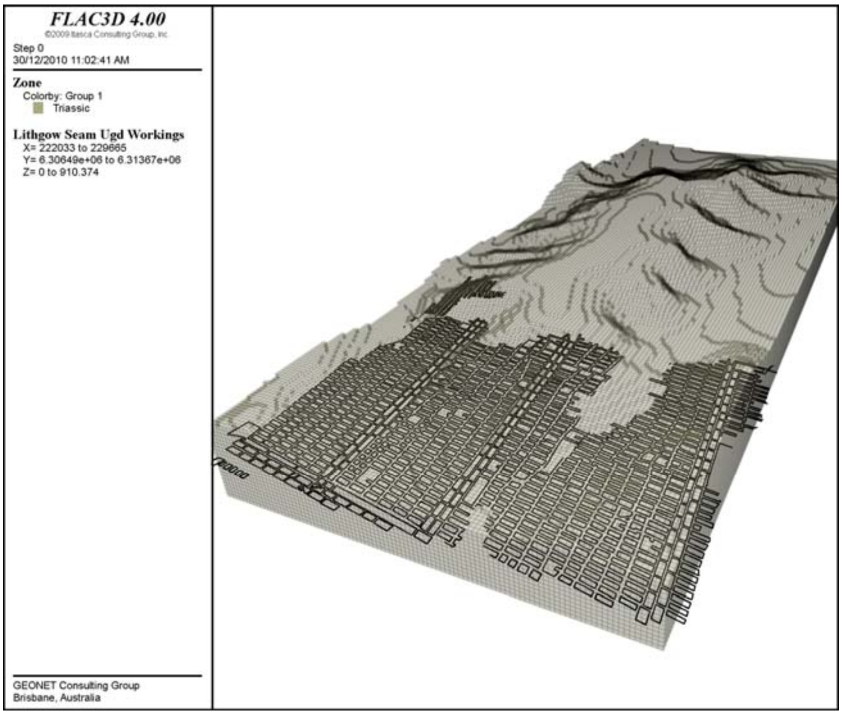

Figure 4: Location of the underground workings in the Lithgow seam.

As part of this study the schedule of mining applied in the geotechnical model simulated the following sequence:

1 Underground mining in Lithgow seam;

2(a) Open cut the northern section down to the Lithgow seam;

2(b) SHM mining successive seams from Lithgow to Katoomba;

3(a) Open cut the western wall down to the Lithgow seam;

3(b) Backfill the northern section of open cut;

3(c) SHM mining successive seams from Lithgow to Katoomba;

4(a) Open cut the southern and eastern walls down to the Lithgow seam;

4(b) Backfill the western highwall section of open cut;

4(c) SHM mining successive seams from Lithgow to Katoomba.

2.4 Estimation of Coal Mass Strength

Material properties for the various coal seams are required to analyse stability of coal pillars formed during SHM highwall mining. Since no specific mechanical strength data was available for any of the coal seams an estimate of the typical composite coal seam strength has been made based on the strengths of the different coal types and stone bands logged within corresponding seam horizons at Ulan Mine.

Generally the strength of coal in these strata is competent with unconfined compressive strengths in the range 15 MPa to 20 MPa [4]. However, given the shallow cover depths in some areas and the generally deeply incised topography it is estimated that the coal mass strength should be reduced from the intact unconfined compressive strength.

The actual peak strength of the composite coal seam depends on its geometry, particularly the width to height ratio. In a previous report [5] the stress-strain behaviour of Irondale coal was simulated for a pillar with W:H=0.5. The modelled result predicts the limit of elastic behaviour stress at 7.0 MPa and the peak strength at 8.2 MPa. The lower bound value of 7.0 MPa represents the limit beyond which time dependent deformation will occur. For long term stability it is recommended to design pillars which remain within the limit of elastic deformation.

Visual inspection of the Moolarben seam exposures suggests that the coal is similar in its strength attributes as the Irondale seam. Based on these observations the strength of the Moolarben seam coal will be simulated with the same properties as Irondale seam coal.

The Lithgow seam has a well developed section of bright coal and a substantial section of stone. Based on the geological log, the seam strength was simulated to show the limit of elastic behaviour at 7.2 MPa and the peak strength at 7.5 MPa, Figure 5(a).

Based on the simulated strength of the different coal seams it is concluded that their seam strength properties (as represented by the limit of elastic behaviour) are all similar at about 7 MPa. However, previous experience with a pillar failure in CHM mining panels at Ulan Mine back-analysed the seam strength (i.e. W:H=0.5) to 5.9 MPa [6]. This is in contrast to the original design strength estimate of 8 MPa [7]. Since the Ulan coal is effectively an extension of the Lidsdale/Lithgow seam and the coal seams in the current project area may be affected locally by previous underground mining, it is considered that the SHM design should be based on a lower bound coal mass strength estimate of about 6 MPa.

Figure 5(b) shows the simulated strength that will be used for coal seams in the Coalpac Consolidation Project mining area. The coal strength (as represented by the limit of elastic behaviour) is 6.0 MPa and the peak strength is 6.2 MPa. The post peak behaviour is notably strain softening down to a residual strength of 2.4 MPa.

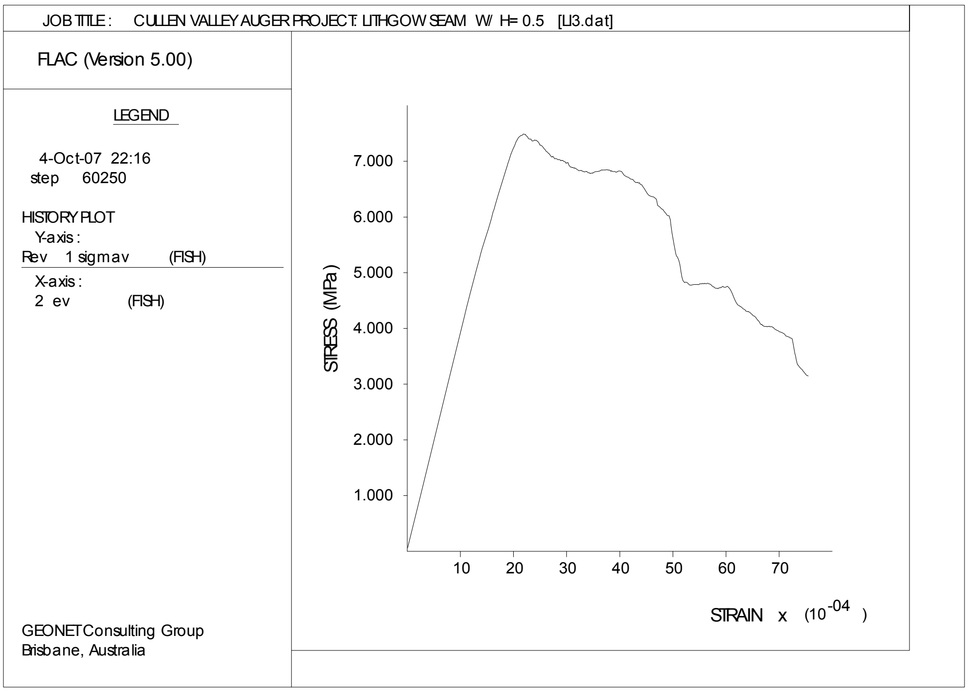

Figure 5(a): Simulated Lithgow coal seam stress-strain behaviour W:H=0.5

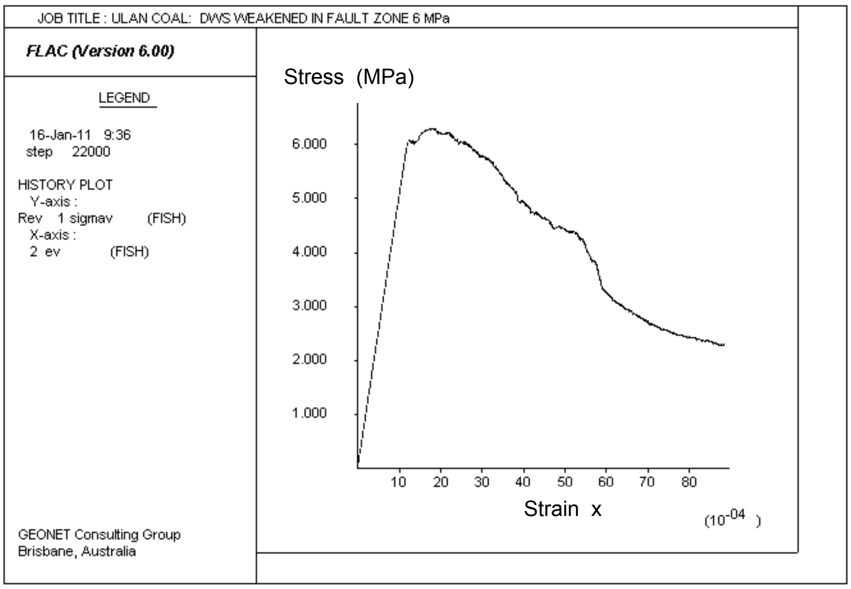

Figure 5(b): Simulated coal seam stress-strain behaviour W:H=0.5

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2.5 Rockmass Properties

Material properties used in the modelling were based on previous experience with similar rock types at adjacent mines. In order to include the effect of sedimentary bedding and jointing in the rockmass a ubiquitous joint model was superimposed. Joint orientations are input as follows: Bedding=02°/088°; J1=90°/ (045°-057°) and J2=92°/ (276 °-315°).

The value of input properties required for the Mohr-Coulomb and ubiquitous joint constitutive models are summarized in Table 1.

Table 1: Material Input Parameters for Model

Rock Type	Bulk (GPa)	Shear (GPa)	Density (kg/m^3)	Cohesion (MPa)	Tension (MPa)	Friction (o)	Dilation (o)
Overburden	4.80	3.45	2450	13.99	8.67	40	5
- Bedding Planes	-	-	-	1.40	0.86	35	1
Interburden	3.60	1.20	2450	2.40	0.80	35	2
- Bedding Planes	-	-	-	0.24	0.086	27	1
Coal Seams	5.31	1.51	1460	1.25	0.12	45	2
- Bedding Planes	-	-	-	0.25	0.021	28	1
Backfill	0.28	0.09	1850	0.32	0.008	35	6

2.6 Groundwater

In this study it was assumed that there was no groundwater present as confirmed by Australian Groundwater Consultants (2011) for all seams except the Lithgow seam. As such it was considered that there was no need to refine rockmass properties to account for effective stress conditions. Indeed, the competence and massive structure of the various strata precludes any potential for strength reduction due to groundwater.

It is recommended to investigate the condition of the historic underground workings in the Lithgow seam for their potential to have accumulated substantial groundwater volumes.

2.7 Gas Drainage

The seams in this area are noted for their very low methane content. Advice in this regard is beyond the scope of the present report. It is recommended that gas monitoring be carried out prior to SHM mining to establish the background levels of gas and to establish any potential risk.

3.0 SHM PILLAR DIMENSIONS

3.1 Layout Constraints

The methodology applied to highwall mining layouts has been developed over many years for both auger and continuous miners (CHM) and has been progressively modified to take into account experience of highwall mining conditions at various locations. Although the method may be conservative it provides a basis for further more sophisticated stress analysis where the designs may be altered while remaining faithful to the two principal design criteria, viz. to ensure operational safety and to maximise resource recovery. By understanding the potential failure mechanisms it will be possible to make informed judgements with respect to optimum pillar dimensions.

The model relies on establishing a sound understanding of the local geological conditions; in particular the seam conditions which are used to substantiate the geotechnical model taking into account the material properties and mining conditions. The layout is then calculated according to an established empirical design formulation described in the following section. This stage is followed up with further detailed numerical simulation of the mining sequence to confirm behaviour and to identify if there are specific geological conditions which may affect stability.

Characteristic highwall conditions of topography and seam thickness are variable over the proposed highwall mining blocks in the Coalpac Consolidation Project mining area. Where conditions vary across a face block or within a specific coal seam, the SHM layout (pillar width, set up dip, and number of passes) may be changed in order to maximise production while maintaining a minimum design Factor of Safety of 1.3.

A Factor of Safety value of 1.3 is generally followed at new sites in order to provide an element of conservatism while the operators get to feel the coal conditions. The value allows for inevitable variations in pillar dimension as a result of the entry wandering from its path and also to cope with local variations in coal seam geology and material strength.

Based on the site plan provided, the SHM design will be based on conditions over the proposed penetration depth of 305m to define the maximum overburden depth of cover.

It is considered appropriate to use the maximum overburden load to estimate stable coal pillars. In selected blocks the design may be altered in response to varying face orientations. The placement of barrier pillars will be discussed in section 5.

Probably the biggest constraint on the layout analysis is the variability of the candidate coal seam thickness. In order to ensure stability of the SHM pillars it is essential to keep well within the coal seam and preferably in the freshest material. Local areas of weathered roof may result in ground instability and possible entrapment of mining head. An intrinsic criterion for highwall mining in continuous coal seams is to maintain at least 0.1m of coal above and below the entry hole.

From a stability point of view it is preferable to maximise the thickness of roof coal. These operational criteria are probably less relevant for the geological conditions within the Coalpac Consolidation Project area since the regular sequencing of stone bands should serve to increase the overall seam strength and provide competent boundary surfaces in the roof and floor of SHM entries.

Based on the information provided, it is not possible to comment on the seam structure and the potential effect of rolls in the coal seam. No faulting was indicated on the geological plans which could impinge on the highwall mining blocks.

Finally, there will be constraints placed by virtue of the actual SHM machine configuration and dimensions. The conventional cutting design is for a 3.5m wide cutting span for excavation heights up to 3.0m. However, where seam excavation heights are to be limited to a maximum of 1m then the cutting span will be reduced to 3.0m. Thus, SHM spans of 3.5m will be made for mining in the Katoomba and Lithgow seams and spans of 3.0m will be designed for mining in the Moolarben and Irondale seams.

3.2 Empirical Design Method

The preliminary assessment of safe pillar thickness is based on empirical formulations derived for slender pillars and adapted for highwall mining opening geometries.

Pillar width (W_p) is calculated taking into account pillar strength (S_p), pillar stress (P_s) and the desired operating Factor of Safety (FOS) as follows:

$$S_p = Sc\,[\alpha + 2 * (1-\alpha) * W_p / H_p]$$

where
S_c = Strength of unit volume of coal [= 6.0 MPa]
W_p = Pillar Width
H_p = Pillar Height
α = Empirically determined material constant

The use of empirical formulae to determine pillar strength has been widely developed in the rock mechanics literature. The strength of a pillar is generally taken to be a function of the pillar dimensions, width (w) and height (h), and a constant (k) that is related to the strength of the pillar material. The basic formula is of the form:

$$\sigma = k\, w^{\alpha}\, h^{\beta}$$

The essential difference between the various proponents of this equation is in the values of the parameters k, α and β. The most recent update of the formula in relation to coal [8] published the values of the constants as:

$k = 4.0$ MPa $\qquad \alpha = 0.81 \qquad$ and $\beta = -0.76$

If it is assumed that the k parameter is representative of the pillar-scale unconfined compressive strength as estimated by numerical modelling, then for the case of Illawarra coals k could vary between 6.0 MPa and 8.0 MPa. The effect of varying the coal strength parameter k in the pillar formula is shown in Figure 6(a) where it is compared with the original value k=4 for South African coal [8].

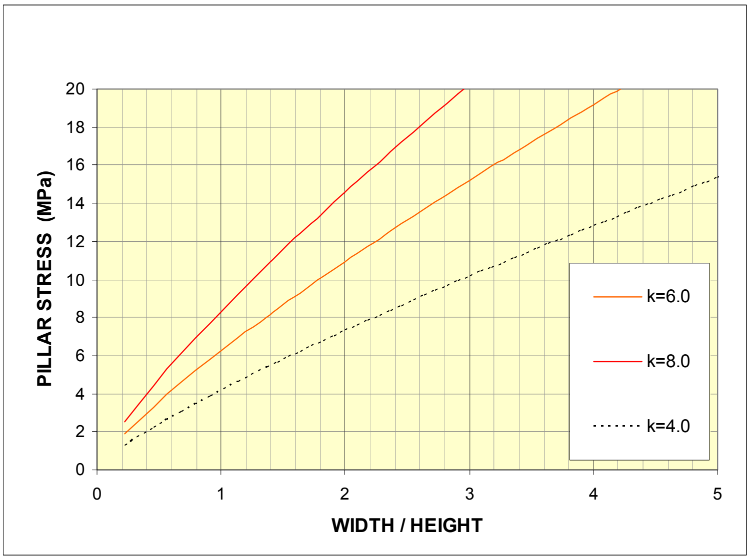

Figure 6(a): Comparison of pillar strength as a function of W:H ratio for three different material strength constants; k=4 represents coal from the original formula.

If the tributary stress pillar load profile is superimposed on the pillar stress charts then it provides a basis for defining the limits of stable pillar dimensions for varying stress conditions. Thus, Figure 6(b) allows for presentation of pillar stability in terms of the propensity for one of the following conditions to prevail:

- i) Long term stable
- ii) Progressive (time-dependent) failure
- iii) Failure
- iv) Catastrophic failure (e.g. rock burst).

To meet the objectives of the present study the SHM pillars must be designed to plot in the “Long Term Stable” sector of the graph.

Layout charts based on the different formulae are presented in Figures 7 to 10 for each of the coal seam horizons. For each Figure there are plots (a) and (b) representing the two design approaches, respectively. In each chart there are graphs for the range of overburden thicknesses that will be encountered within the mining block.

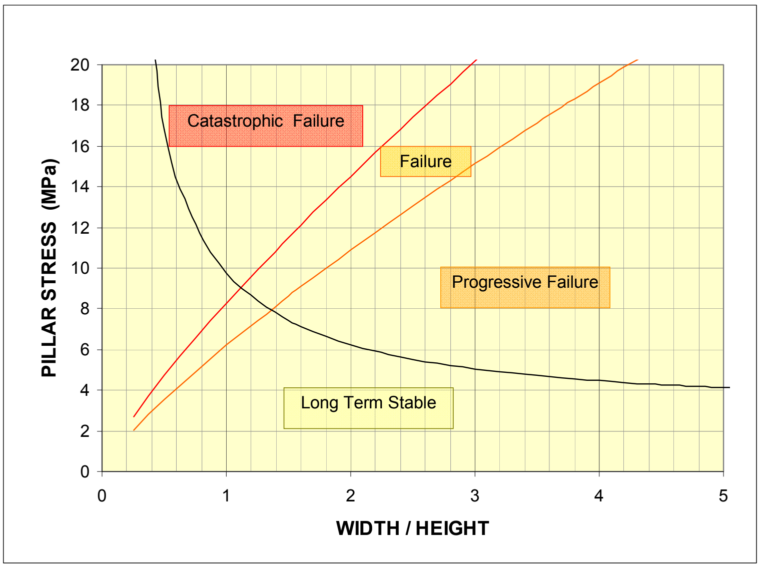

Figure 6(b): Pillar stability chart as a function of width to height ratio.

3.3 Estimated Pillar Dimensions

Based on the specified extraction horizons for each of the coal seams, the estimated pillar dimensions to provide stable pillars throughout the mining operations and into the future were measured from the respective design charts presented in Figures 7 to 10. At this stage the criterion for stability is a Factor of Safety of 1.3 which is found adequate for safe mining operations according to ACARP funded CSIRO report [9]. However, it may not be sufficient to maintain long term stability because of unknown geological and operational variations. Long term stability is essential to minimise subsidence.

The various design constraints accompanying the estimated pillar dimensions for a Factor of Safety of 1.3 under maximum overburden heights are summarised in the following table:

Seam	Peak Overburden (m)	Span (m)	Height (m)	Width (m)	W:H	Extraction (%)
Katoomba	110	3.5	2.0	2.6	1.3	57
Moolarben	135	3.0	1.0	2.1	2.1	59
Irondale	165	3.0	0.9	2.4	2.6	56
Lithgow	185	3.5	2.2	4.6	2.1	43

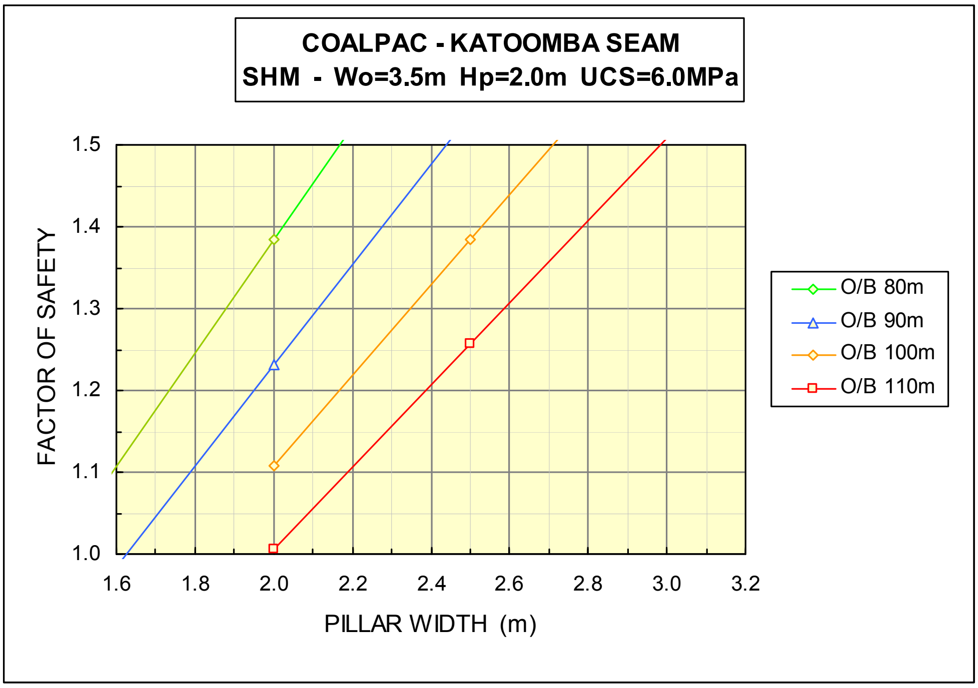

Figure 7(a): SHM Pillar Design Chart for Katoomba Seam

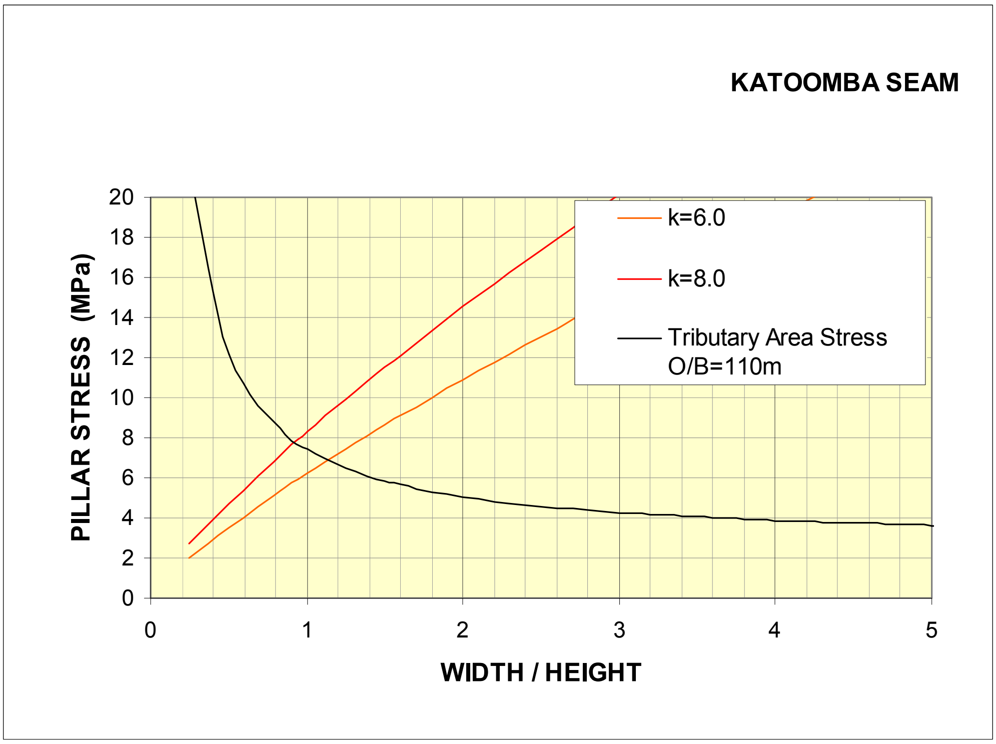

Figure 7(b): Generic SHM Pillar Stability Chart for Katoomba Seam

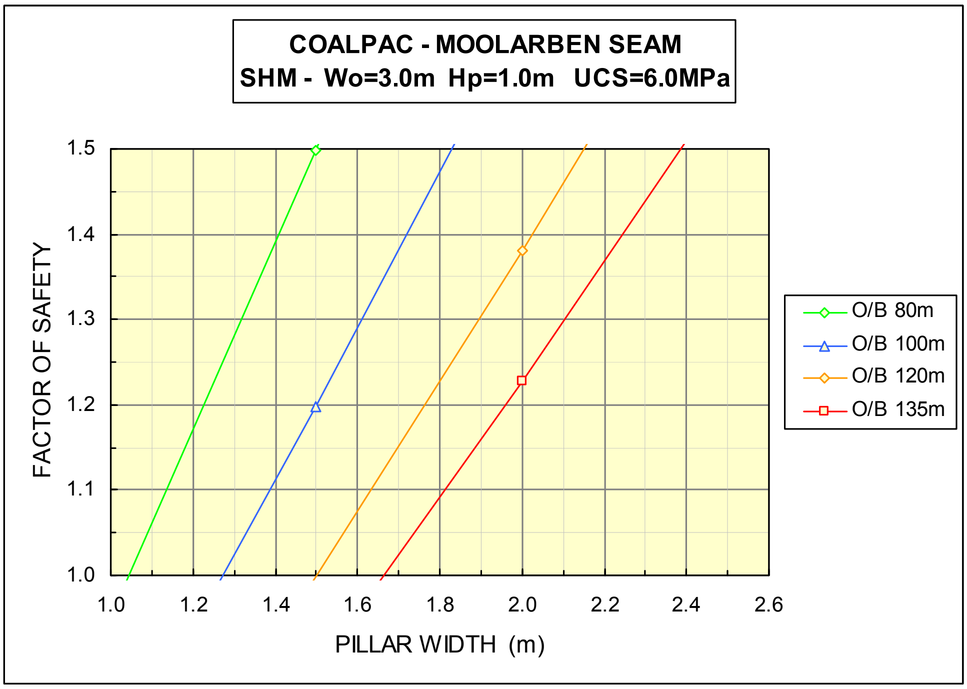

Figure 8(a): SHM Pillar Design Chart for Moolarben Seam

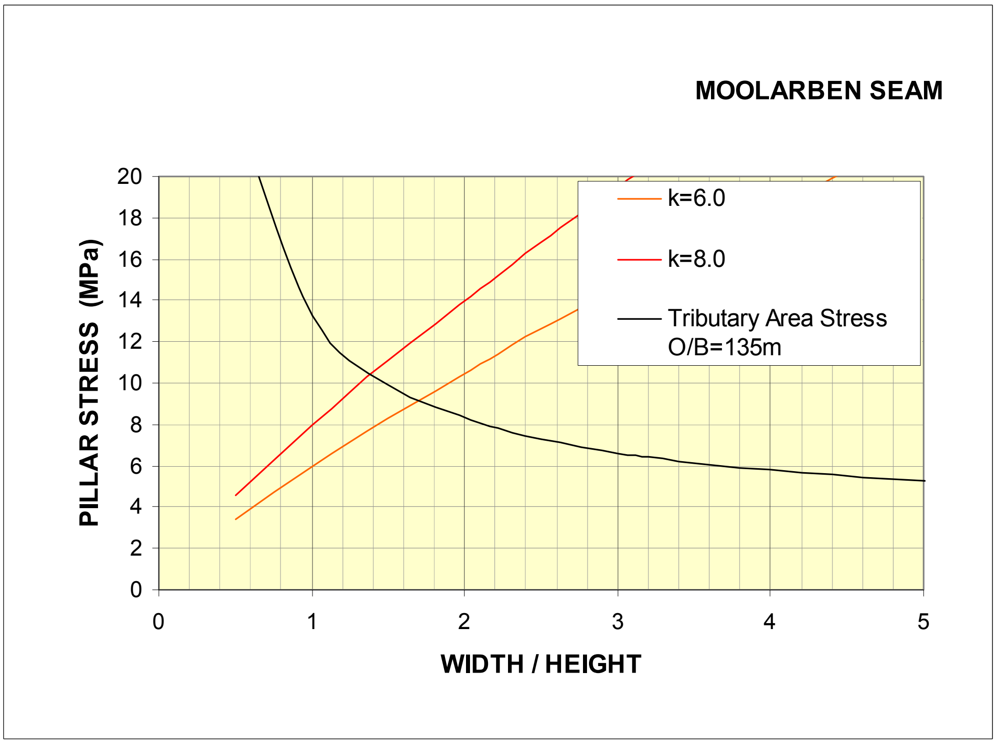

Figure 8(b) Generic SHM Pillar Stability Chart for Moolarben Seam

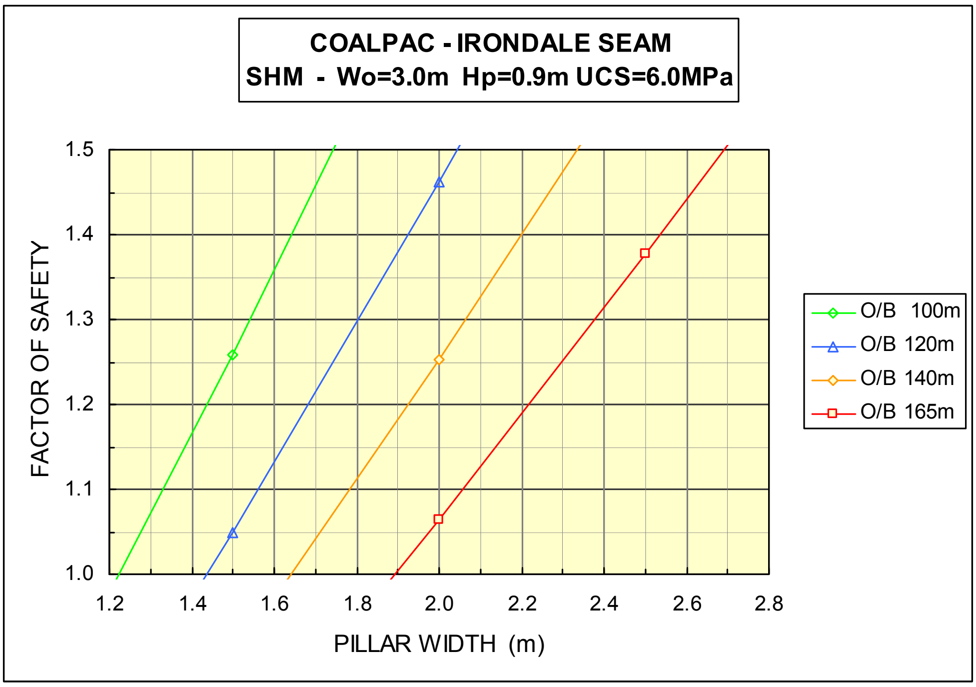

Figure 9(a): SHM Pillar Design Chart for Irondale Seam

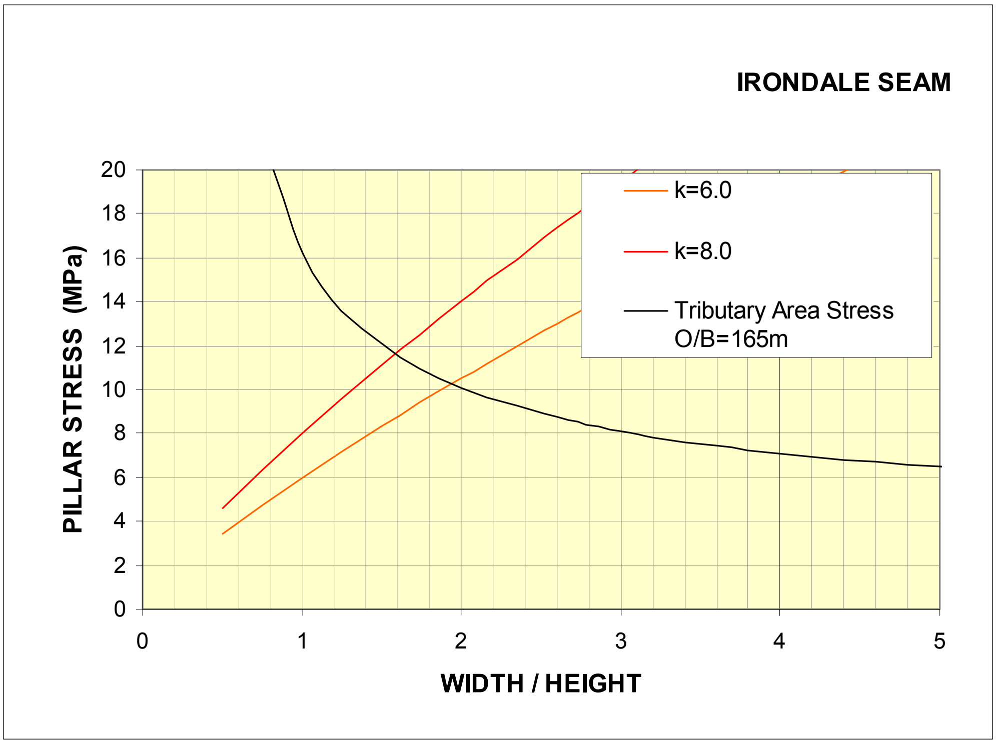

Figure 9(b): Generic SHM Pillar Stability Chart for Irondale Seam

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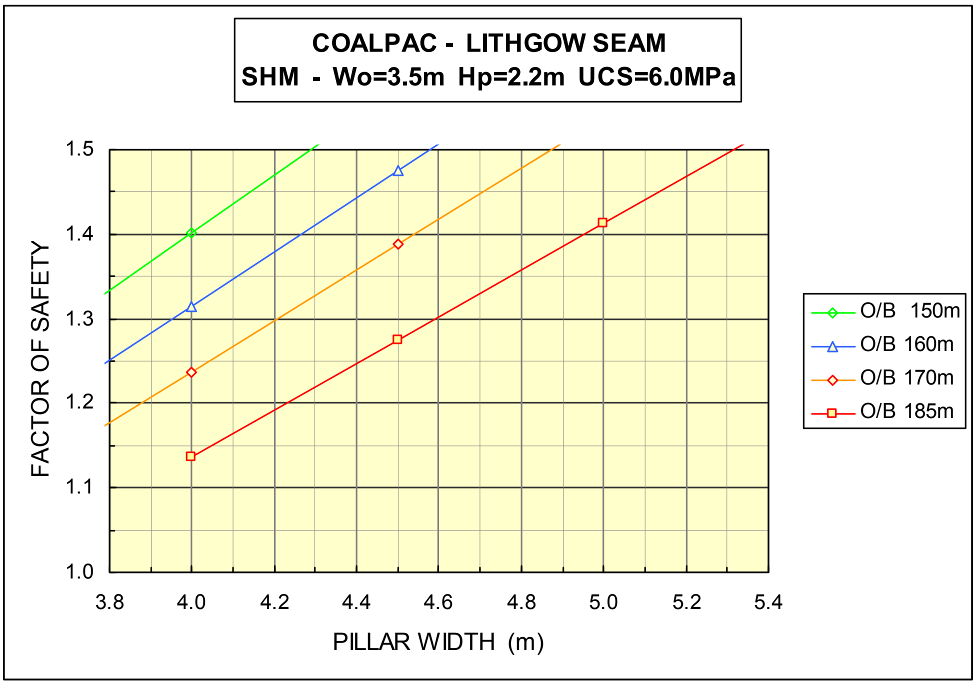

Figure 10(a): SHM Pillar Design Chart for Lithgow Seam

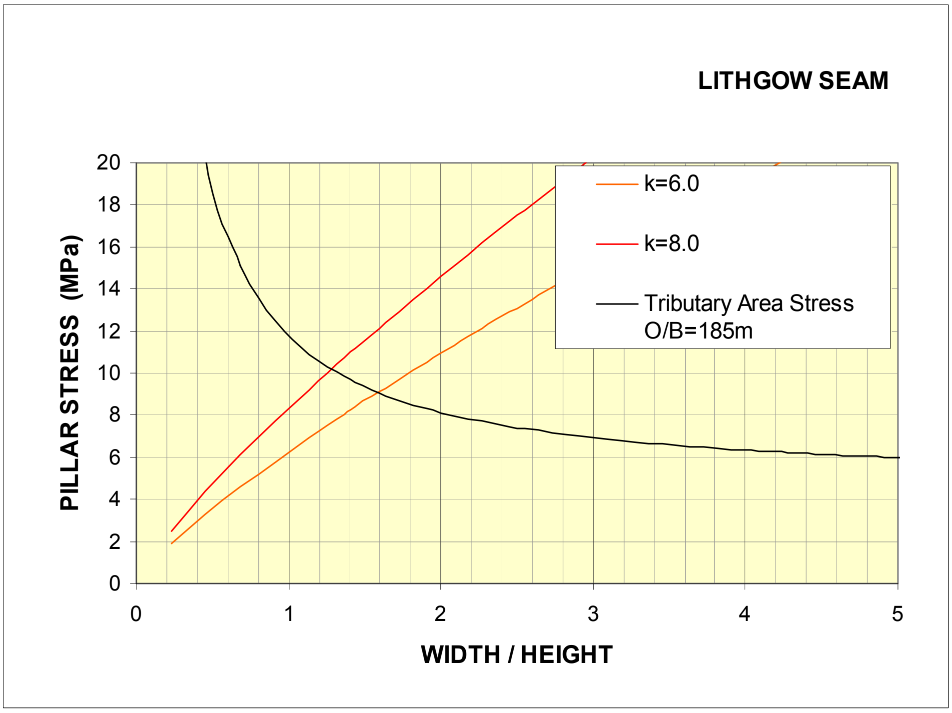

Figure 10(b): Generic SHM Pillar Stability Chart for Lithgow Seam

4.0 GEOMECHANICAL ASSESSMENT OF SHM PILLARS

4.1 Objectives of Analysis

In order to verify the empirically derived minimum pillar dimensions a series of finite difference models were made taking into account the interaction of specific local geology, insitu stress, excavation sequence and relative strata strength properties.

The objectives for carrying out the SHM highwall mining simulations were:

- To verify that the recommended pillar dimensions will be stable,
- To identify potential failure mechanisms in coal pillars and roof and/or floor strata.
- To estimate the potential subsidence that may develop under overburden ridges.

4.2 Modelling Method

Models were set up to simulate SHM mining under a range of overburden thicknesses. The stratigraphic sequence was modelled based on geological cross sections provided.

The insitu stress field was initialised in the rockmass according to the anticipated condition for similar incised terrains where the major horizontal stress (N-S) is double the overburden stress and the minor horizontal stress (E-W) is equal to 1.5 times the overburden stress. The overburden stress is due to gravity and overburden thickness.

4.3 Rockmass Stress Conditions

The stress conditions that will be encountered around SHM entries under the topography are shown for a section at 6311900N as:

i) contours of vertical stress, Figure 11(a) and
ii) contours of horizontal (E-W confining) stress in Figure 11(b).

In these plots the modelled effect of underground mining in the Lithgow seam is clearly evident as shown by zones of increased stress (red contours at 5 MPa) in the existing Invincible Colliery pillars. The associated stress concentration on these pillars is predicted to extend into the Irondale seam. SHM entries through these zones of higher stress may experience conditions similar to the effect of mining through stronger (harder) coal.

Modelled horizontal stress contours show a stress arch to form over the underground workings. A tensile zone is predicted to form in the Katoomba seam located 50m into the western highwall and 30m into the eastern highwall, extending for at least 100m along the seam. These altered stress conditions are established prior to simulating the SHM mining. During highwall mining this condition may be experienced as weaker (loose) rock which may promote spalling in the roof and sidewalls. It is noted, however, that auger holes in the Irondale Seam located above underground workings have remained stable since excavation two years ago suggesting that stable conditions should prevail [10].

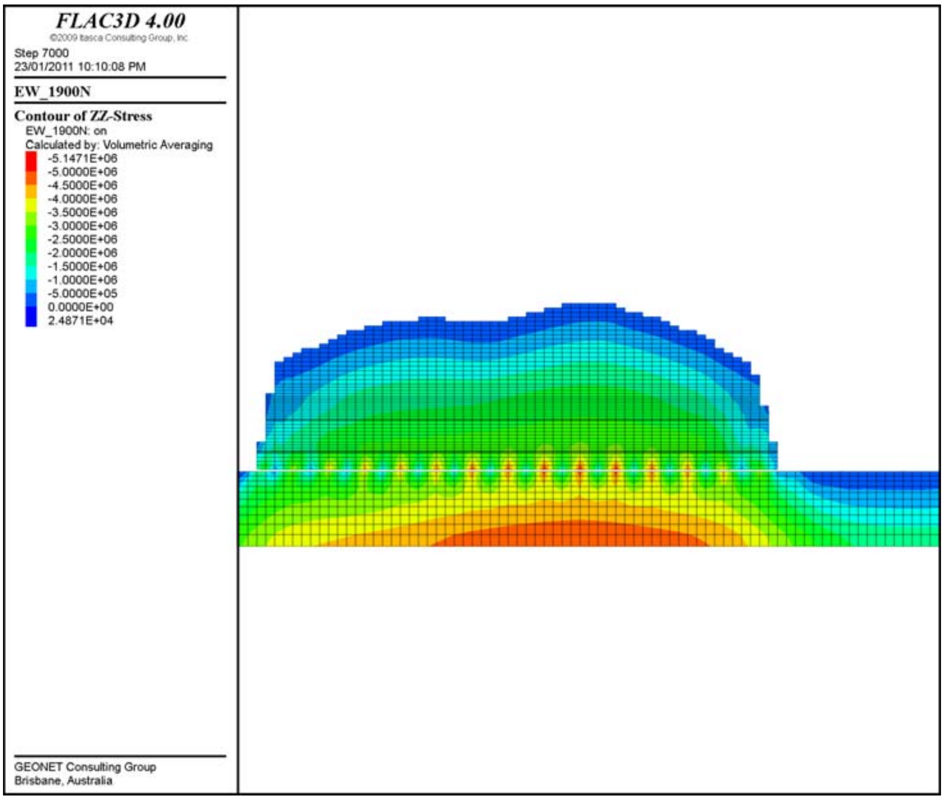

Figure 11(a): Vertical stress contours in topography at 1900N prior to SHM mining

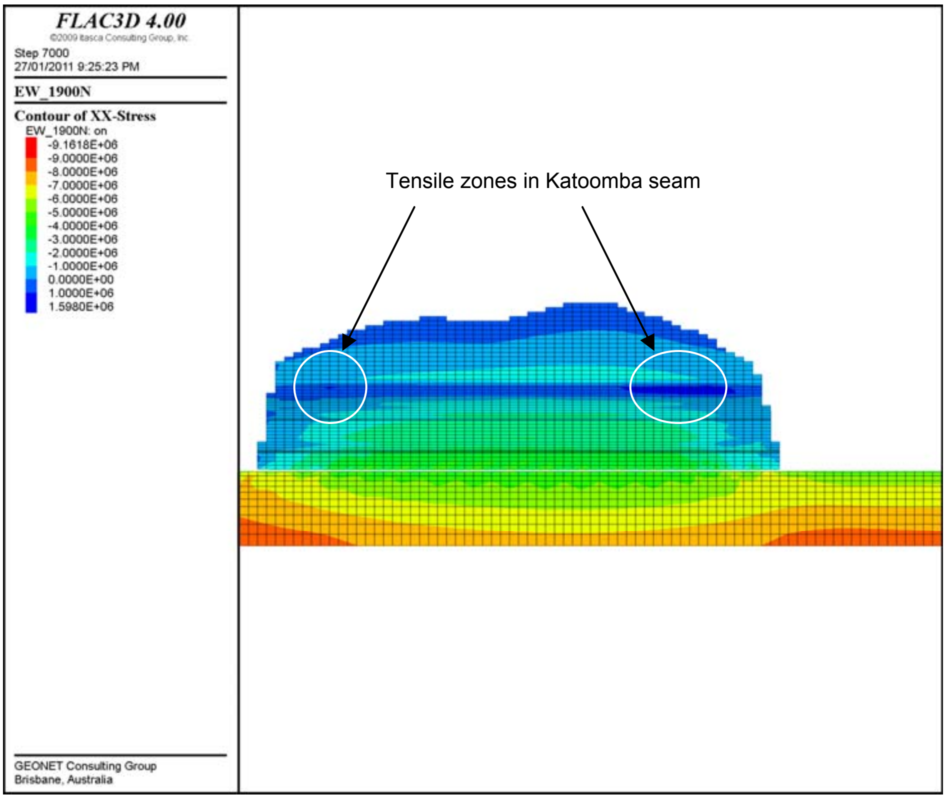

Figure 11(b): Horizontal stress contours in topography at 1900N prior to SHM mining

4.4 Pillar Strength, Stress and Stability

In a previous section of this report the intrinsic coal mass strength in all seams to be mined within the Coalpac Consolidation Project area was considered to be 6 MPa. However, the strength of the coal pillars formed in each of the respective coal seams will be dictated by the pillar dimensions of width and height. Hence, the effective coal pillar strengths will be simulated for the recommended stable pillar dimensions in each seam.

The actual stress levels developed in the coal pillars under the maximum overburden thickness was then simulated to establish the average pillar stress and the extent of stress induced damage that may be incurred in the coal pillar. The model geometry for these simulations is shown in Figure 12(a). Based on the average pillar stress and pillar dimensions the stability condition can then be defined.

The results from these various simulations are presented as six separate plots:

(a) Coal pillar geometry
(b) Coal pillar strength
(c) Average Stress in Coal pillar
(d) Stress damage in Coal pillar
(e) Generic SHM Pillar Stability Chart
(f) Pillar and span displacement profile

and compiled in Figures 12 to 15 for each of the coal seams, respectively. The results are discussed in detail in the following sub-sections and summarised in the following table.

Seam	Width (m)	Height (m)	W:H	Pillar Strength (MPa)	Pillar Stress (MPa)	Max Pillar Deformation (mm)	Stability*
Katoomba	2.6	2.0	1.3	10.2	6.0	3.0	LTS > PF
Moolarben	2.1	1.0	2.1	29.1	8.0	3.6	LTS
Irondale	2.4	0.9	2.6	33.5	8.8	3.7	LTS
Lithgow	4.6	2.2	2.1	22.5	7.0	3.0	LTS > PF
Combined	-	-	-	-	-	13.3	-

* LTS: Long Term Stable (Refer to Figure 6(b) on page 16)
LTS > PF: Long Term Stable tending towards Progressive Failure

The accumulated pillar deformation over all seams totals 13.3mm thus meeting the maximum subsidence criterion [1]. This represents a first estimate of subsidence in the local topography associated with SHM panels. It should be noted that this value is calculated with respect to the maximum overburden heights.

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4.4.1 Katoomba Seam

Figure 12(a) shows the SHM coal pillar and span geometry. The detailed geology of the Katoomba seam is included according to geological log shown in Figure 3(a). In this model the coal cleat is explicitly modelled as are the bedding planes and joints in the overburden and interburden strata.

Figure 12(b): The simulated stress-strain behaviour of the Katoomba coal pillars are shown for the first two adjacent pillars. It can be seen that non-linear behaviour initiates at about 6 MPa and continues up to a peak stress of 10.2 MPa in the first pillar and 12.5 MPa in the second pillar. The residual strength of both pillars is the same at 8.4 MPa.

Figure 12(c) shows changes in SHM coal pillar stress during sequential excavation. The pre-mining stress in the coal seam is 3.0 MPa associated with the maximum 110m of overburden strata. Mining the first entry creates an abutment in which the stress increases to 4.0 MPa. Isolation of the coal pillar, when the second entry is driven, results in the first pillar stress increasing to 6 MPa while the new abutment stress increases to 4 MPa. Subsequent entries push the second formed pillar stress to 6 MPa. Note that the first pillar stress has not fully stabilised and looks to be increasing.

Figure 12(d) shows the condition of coal, cleat and bedding in the coal pillars and surrounding rockmass strata subject to the maximum 110m overburden load. In the pillar side walls loosening of cleat is predicted to a depth of about 200mm behind the face. There is further contiguous shear/tensile activity on cleat extending through the entire pillar. This indicates that the pillar is likely to develop time dependent (progressive) damage. Further loading and damage in the coal pillar will be driven by spalling of the roof coal causing the effective pillar height to increase. There is potential for a maximum of 1m of roof coal to spall progressively into the drive excavation.

Figure 12(e) shows the stability of the coal pillar to locate inside the Long term stable sector. However, given that the pillar stress may increase slightly to 6.2 MPa and the effective pillar height may increase to 3.0m (i.e. W:H=0.86) then the data point could plot in the sector of Progressive Failure.

Figure 12(f) shows the displacement profile over the SHM spans and coal pillars at the elevation of the top of SHM opening. Over the pillars the displacement will be about 3mm compared with a maximum of 22mm over the spans.

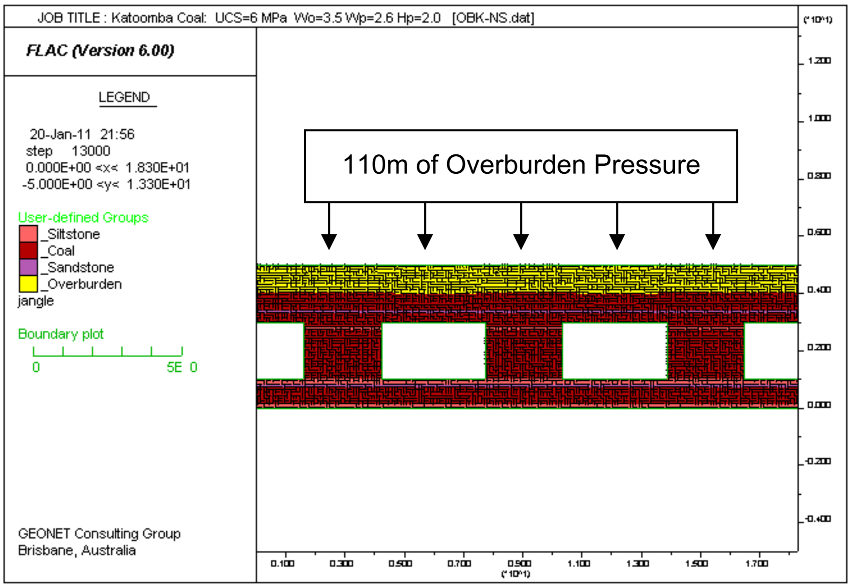

Figure 12(a): Coal pillar (W:H=2.6:2.0=1.3) geometry – Katoomba Seam

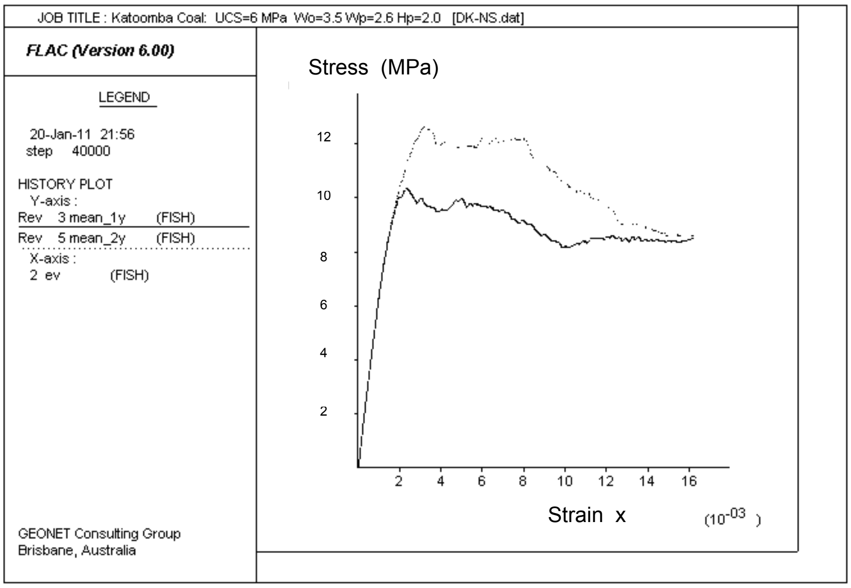

Figure 12(b): Coal pillar (W:H=2.6:2.0=1.3) strength – Katoomba Seam

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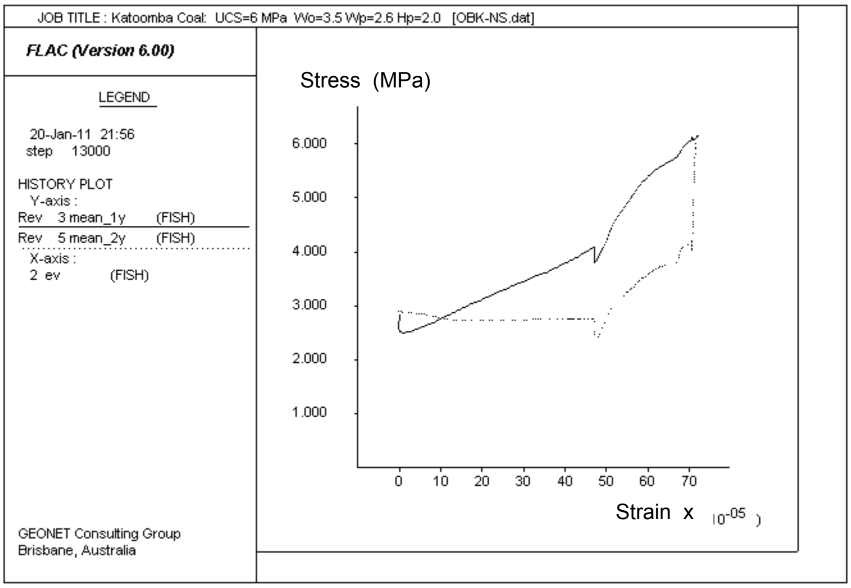

Figure 12(c): Average Stress in Coal pillars (W:H=2.6:2.0=1.3) – Katoomba Seam

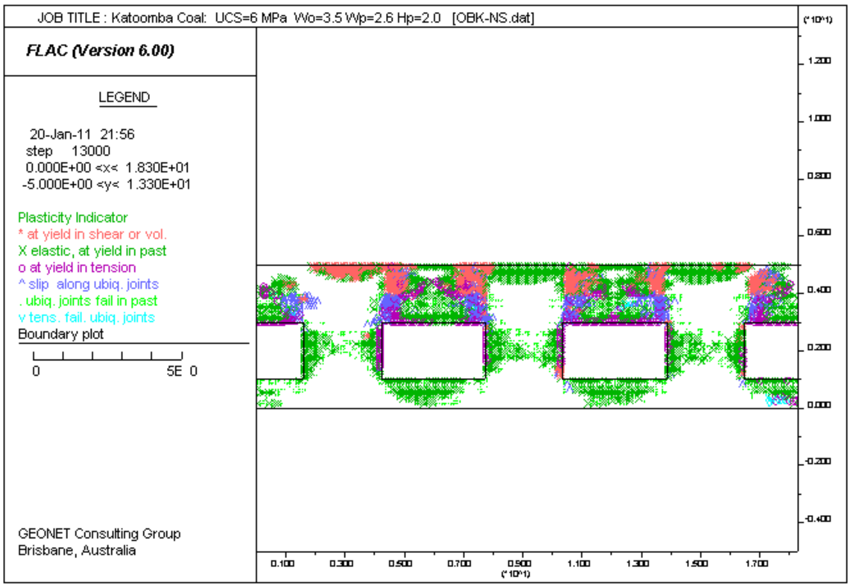

Figure 12(d): Condition within Coal pillar (W:H=2.6:2.0=1.3) – Katoomba Seam

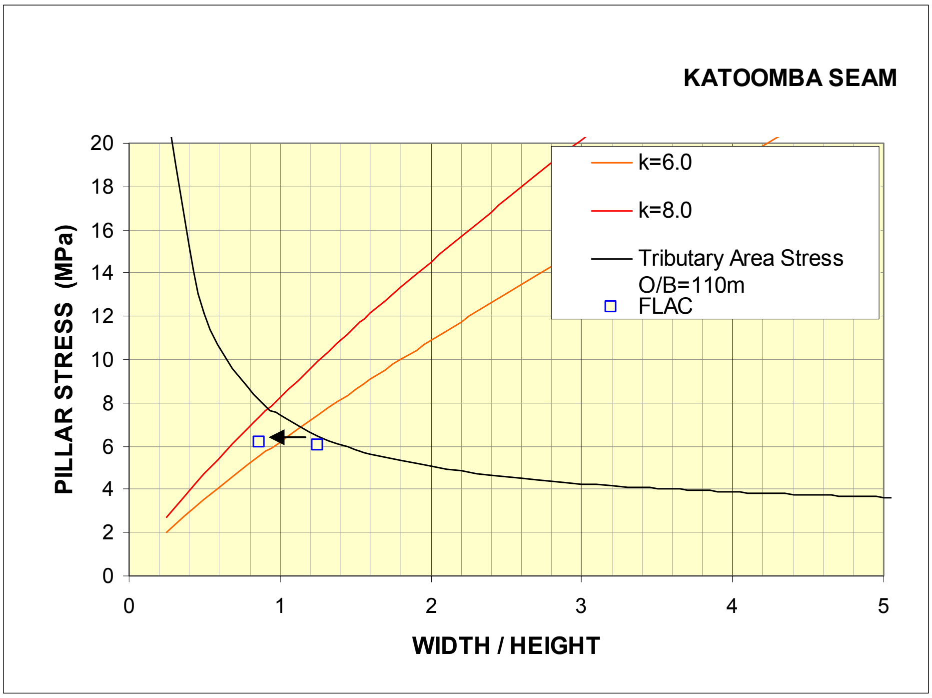

Figure 12(e): Generic SHM Pillar Stability Chart for Katoomba Seam

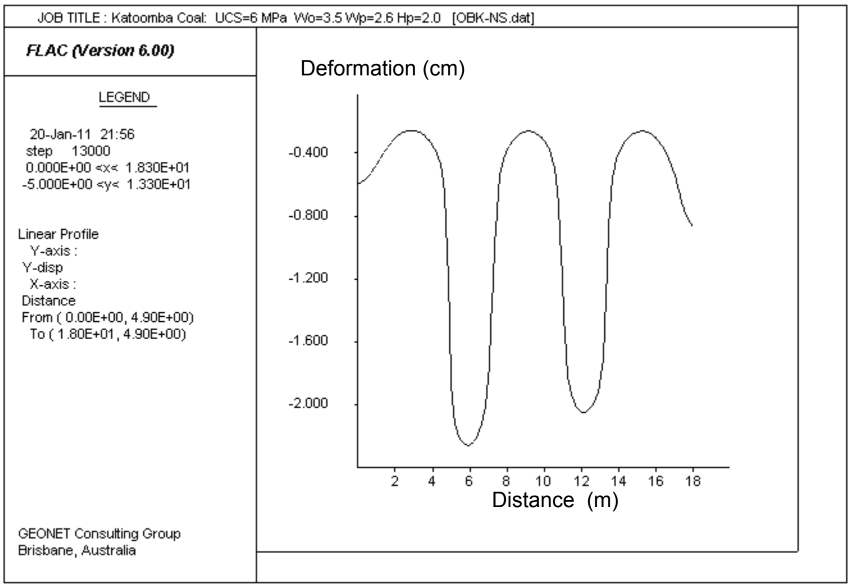

Figure 12(f): Deformation profile over pillars and spans within the Katoomba seam

4.4.2 Moolarben Seam

Figure 13(a) shows the 2.1m wide SHM coal pillar and 3.0m span geometry. The detailed geology of the Moolarben seam is included according to geological log shown in Figure 3(b). In this model the coal cleat is explicitly modelled as are the bedding planes and joints in the overburden and interburden strata.

Figure 13(b): The simulated stress-strain behaviour of the Moolarben coal pillars are shown for the first two adjacent pillars. It can be seen that non-linear behaviour initiates at about 8 MPa and continues up to a peak stress of 29.1 MPa in the first pillar and 33.4 MPa in the second pillar. The residual strength of both pillars is the same at about 30 MPa.

Figure 13(c) shows the changes in SHM coal pillar stress during sequential excavation. The pre-mining stress in the coal seam is 3.4 MPa associated with the maximum 135m of overburden strata. Mining the first entry creates an abutment in which the stress increases to 5.0 MPa. Isolation of the coal pillar, when the second entry is driven, results in the first pillar stress increasing to 8 MPa while the new abutment stress increases to 5 MPa. Subsequent entries push the second formed pillar stress to 8 MPa. Note that the first pillar stress has stabilised to the same level of stress as the second pillar.

Figure 13(d) shows the stress affected condition in the coal pillars and surrounding rockmass strata subject to the maximum 135m overburden load. In the pillar side walls loosening of cleat is predicted to a depth of about 200mm behind the surface. There is no contiguous shear/tensile activity on cleat in the entire pillar. This indicates that the pillar is likely to remain stable.

There is a minor indication of tensile conditions in the coal roof which may manifest as spalling of the roof coal. Localised guttering at the corner of drives may develop due to shearing along cleat and jointing to about 1m into the roof. Some loosening of the floor coal / mudstone may develop to a depth of 0.250m.

Figure 13(e) shows the stability of the coal pillar to locate inside the 'Long Term Stable' sector.

Figure 13(f) shows the displacement profile over the SHM spans and coal pillars at the elevation of the top of SHM drive. Over the pillars the displacement will be about 3.6mm compared with a maximum of 5.2mm over the spans.

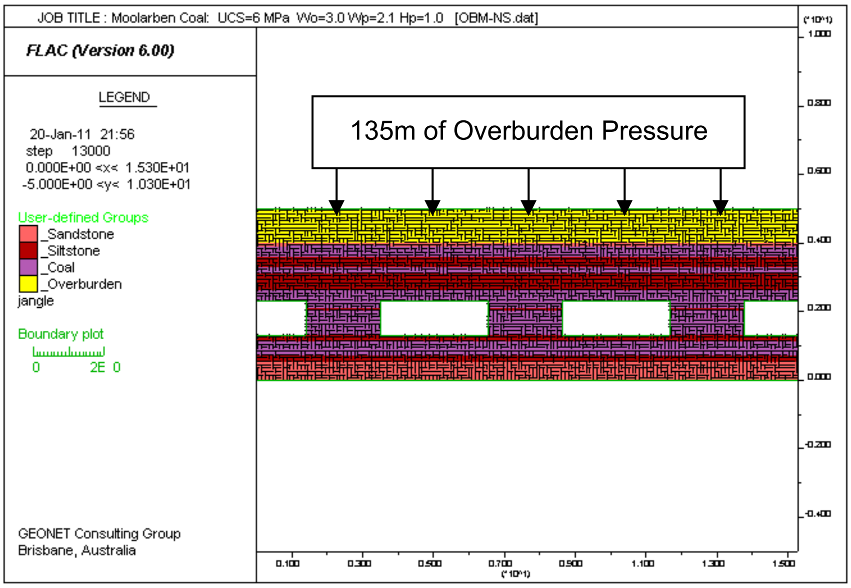

Figure 13(a): Coal pillar (W:H=2.1:1.0=2.1) geometry – Moolarben Seam

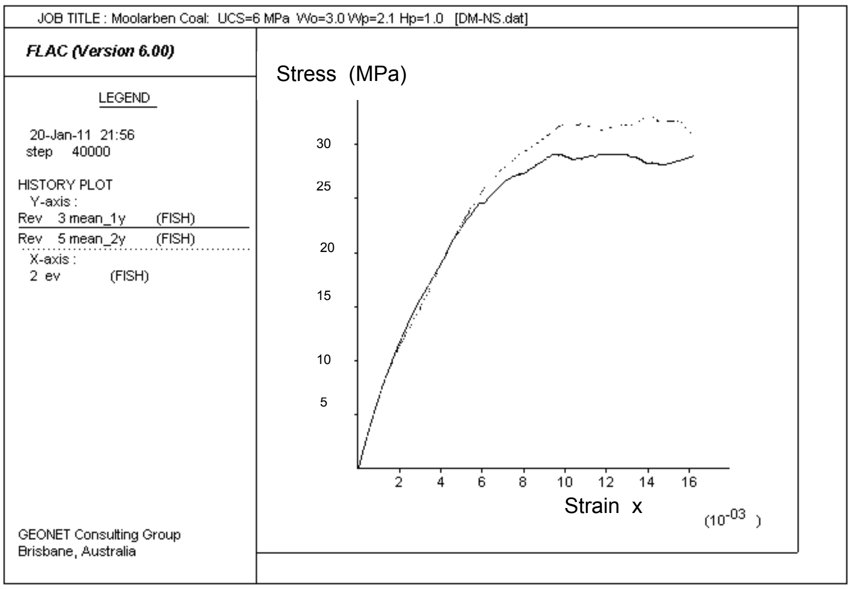

Figure 13(b): Coal pillar (W:H=2.1:1.0=2.1) strength – Moolarben Seam

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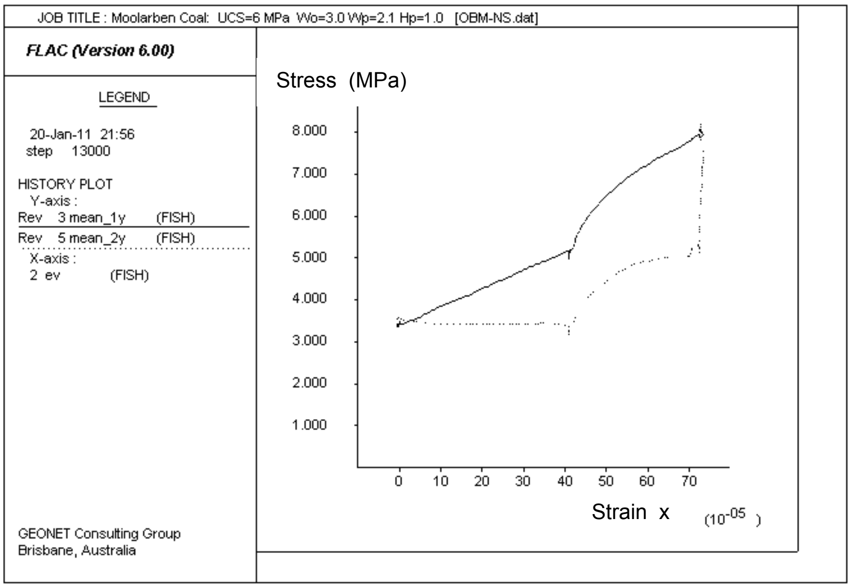

Figure 13(c): Average Stress in Coal pillar (W:H=2.1:1.0=2.1) – Moolarben Seam

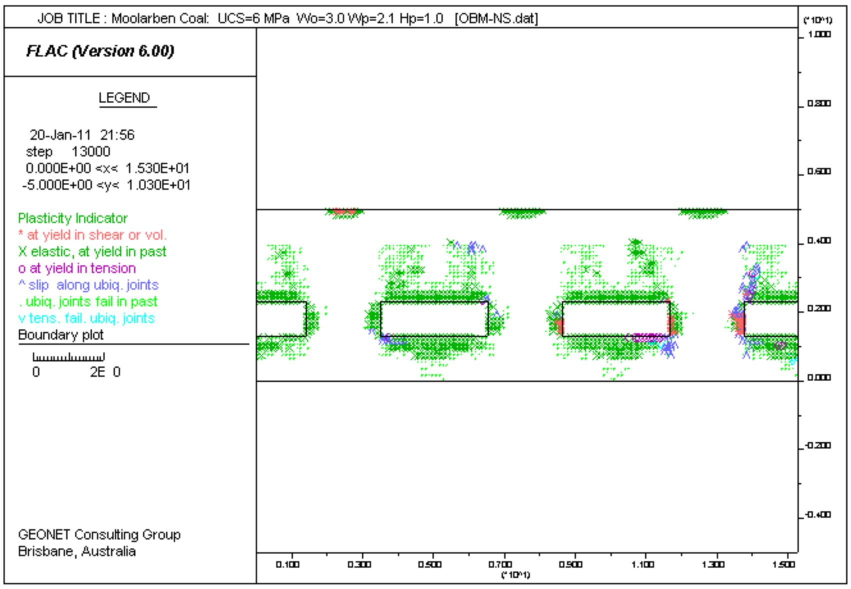

Figure 13(d): Condition within Coal pillar (W:H=2.1:1.0=2.1) – Moolarben Seam

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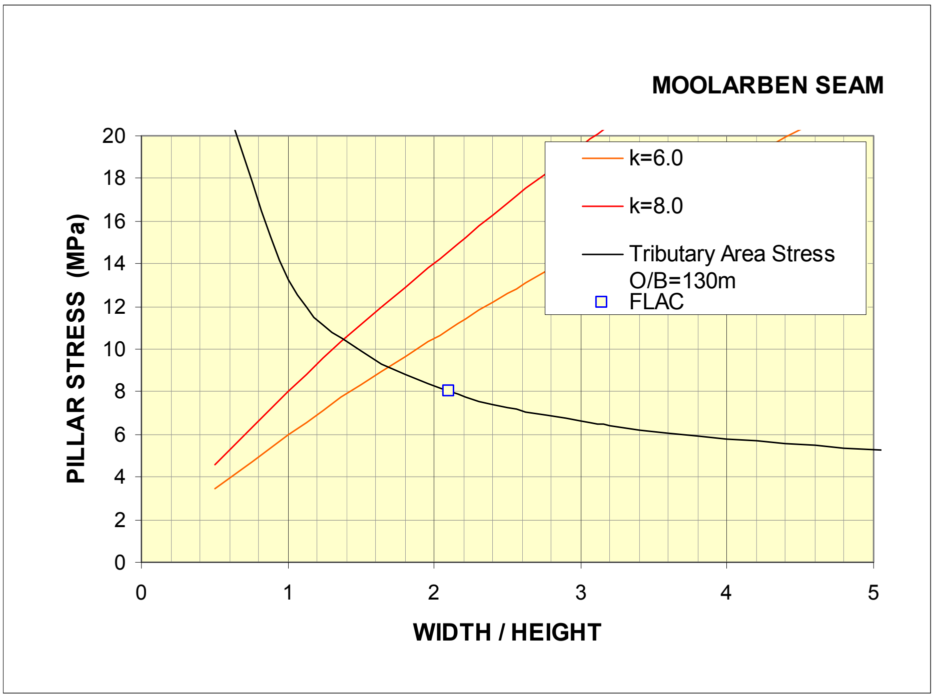

Figure 13(e): Generic SHM Pillar Stability Chart for Moolarben Seam

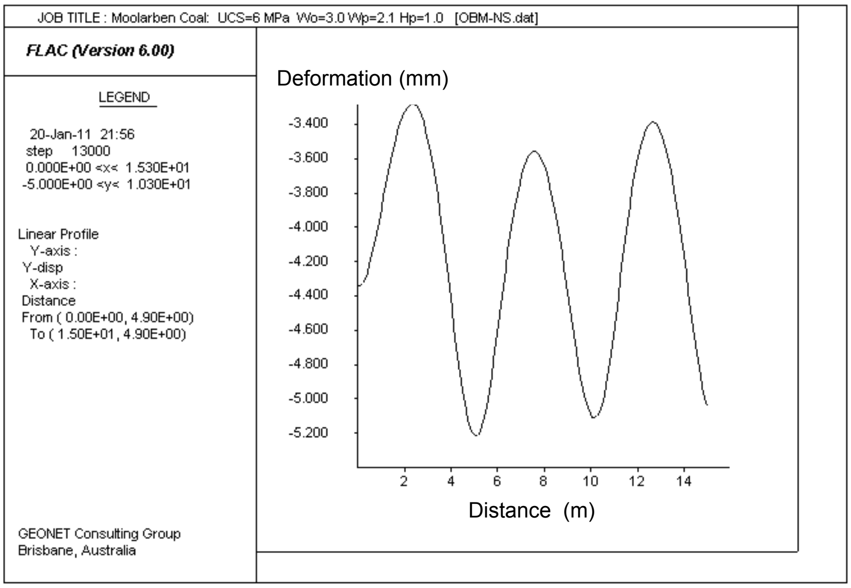

Figure 13(f): Deformation profile over pillars and spans within the Moolarben seam

4.4.3 Irondale Seam

Figure 14(a) shows the 2.4m wide SHM coal pillar and 3.0m span geometry. The detailed geology of the Irondale seam is included according to geological log shown in Figure 3(c). In this model the coal cleat is explicitly modelled as are the bedding planes and joints in the overburden and interburden strata.

Figure 14(b) shows the simulated stress-strain behaviour of the Irondale coal pillars for the first two adjacent pillars. It can be seen that non-linear behaviour initiates at about 8 MPa and continues up to a peak stress of 37.5 MPa in the first pillar and 33.5 MPa in the second pillar. The residual strength of the pillars is about 30 MPa.

Figure 14(c) shows the changes in SHM coal pillar stress during sequential excavation. The pre-mining stress in the coal seam is 4 MPa associated with the maximum 165m of overburden strata. Mining the first entry creates an abutment in which the stress increases to 6.0 MPa. Isolation of the coal pillar, when the second entry is driven, results in the first pillar stress increasing to 8.8 MPa while the new abutment stress increases to 6 MPa. Subsequent entries push the second formed pillar stress to 8.8 MPa. The stress levels in both pillars has stabilised to the same level.

Figure 14(d) shows the stress affected condition in the coal pillars and surrounding rockmass strata subject to the maximum 165m overburden load. In the pillar side walls loosening of coal cleat is predicted to a depth of about 200mm behind the surface. There is no contiguous shear/tensile condition developed within any of the pillars. This indicates that the pillars are likely to remain stable.

There is a minor indication of damage in the siltstone roof due to delamination of bedding planes. Bedding plane separations may form at interface between siltstone and sandstone roof strata. Localised guttering at the corner of drives may develop due to shearing along joints to between 1m and 2m into the roof. Some loosening of the floor coal / mudstone may develop to a depth of 0.400m.

Figure 14(e) shows the stability of the coal pillar to locate well inside the 'Long Term Stable' sector.

Figure 14(f) shows the displacement profile over the SHM spans and coal pillars at the elevation of the top of SHM drives. Over the pillars the displacement will be about 3.7mm compared with a maximum of 6.1mm over the spans.

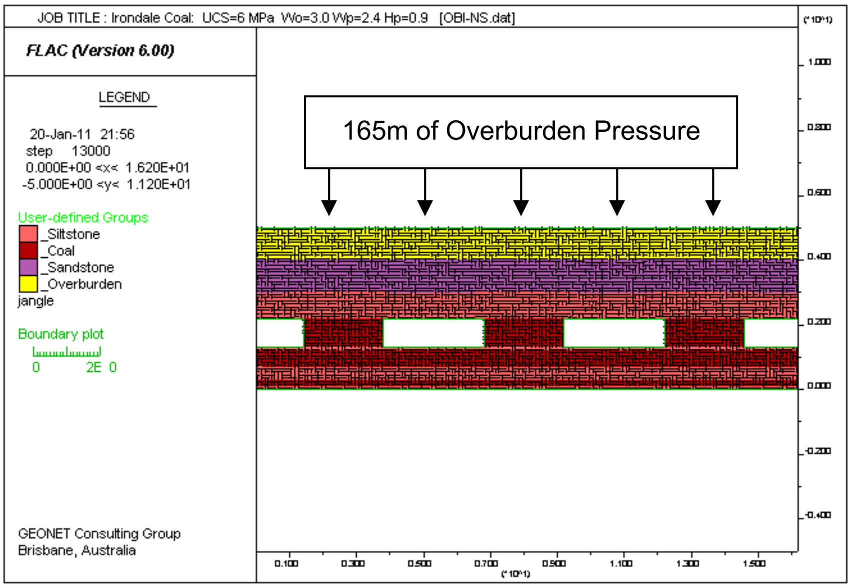

Figure 14(a): Coal pillar (W:H=2.4:0.9=2.7) geometry – Irondale Seam

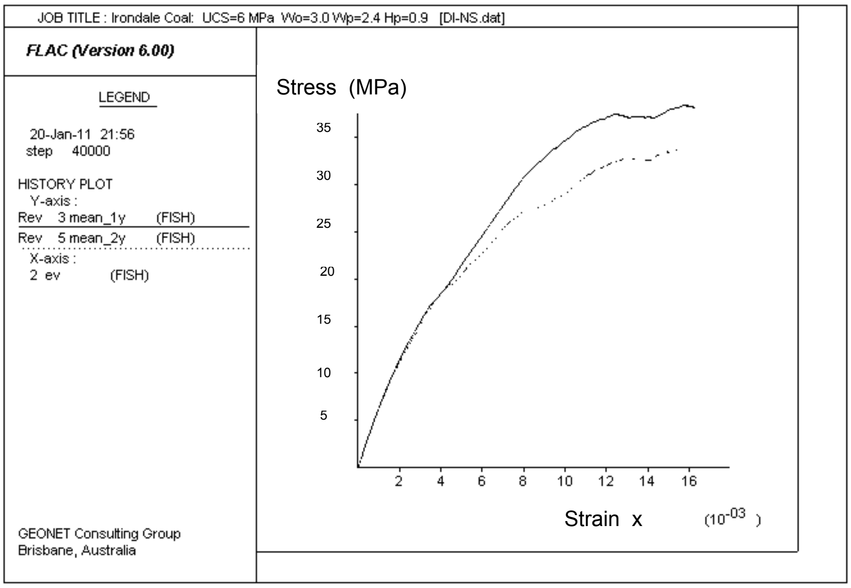

Figure 14(b): Coal pillar (W:H=2.4:0.9=2.7) strength – Irondale Seam

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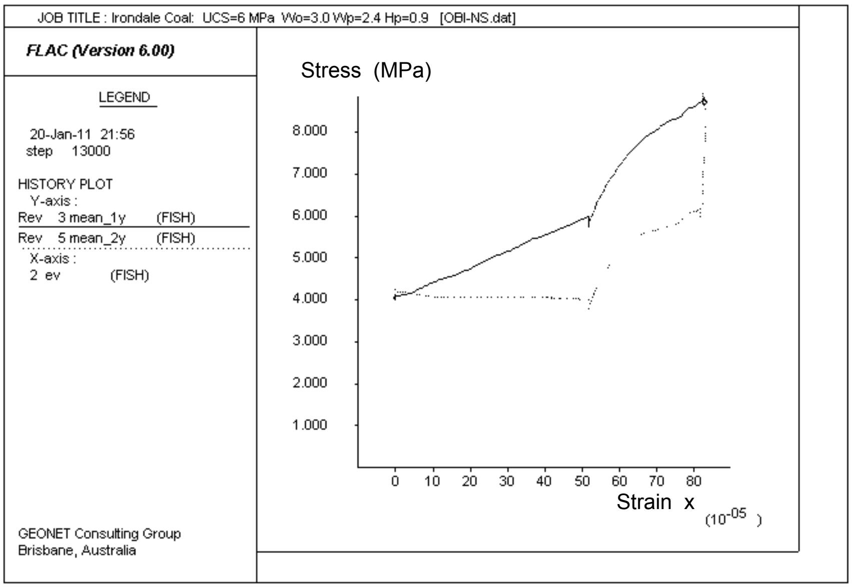

Figure 14(c): Average Stress in Coal pillar (W:H=2.4:0.9=2.7) – Irondale Seam

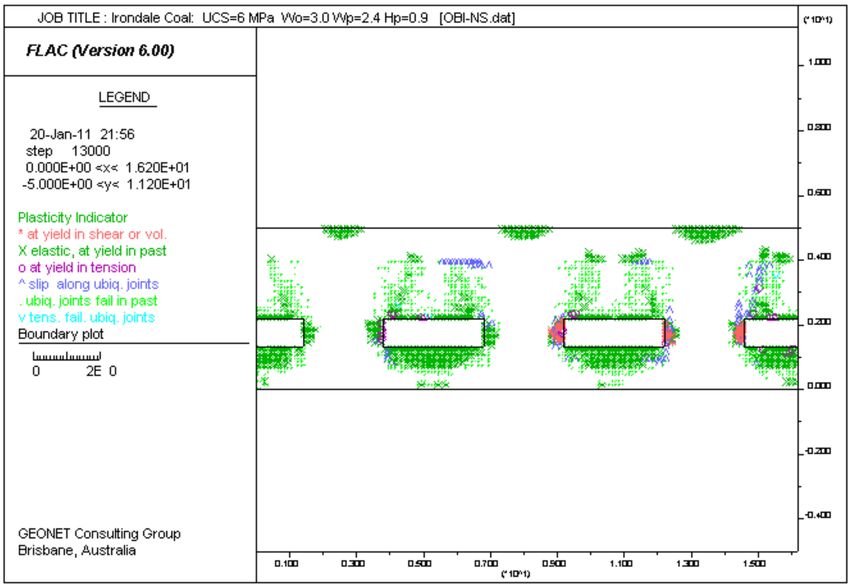

Figure 14(d): Condition within Coal pillar (W:H=2.4:0.9=2.7) – Irondale Seam

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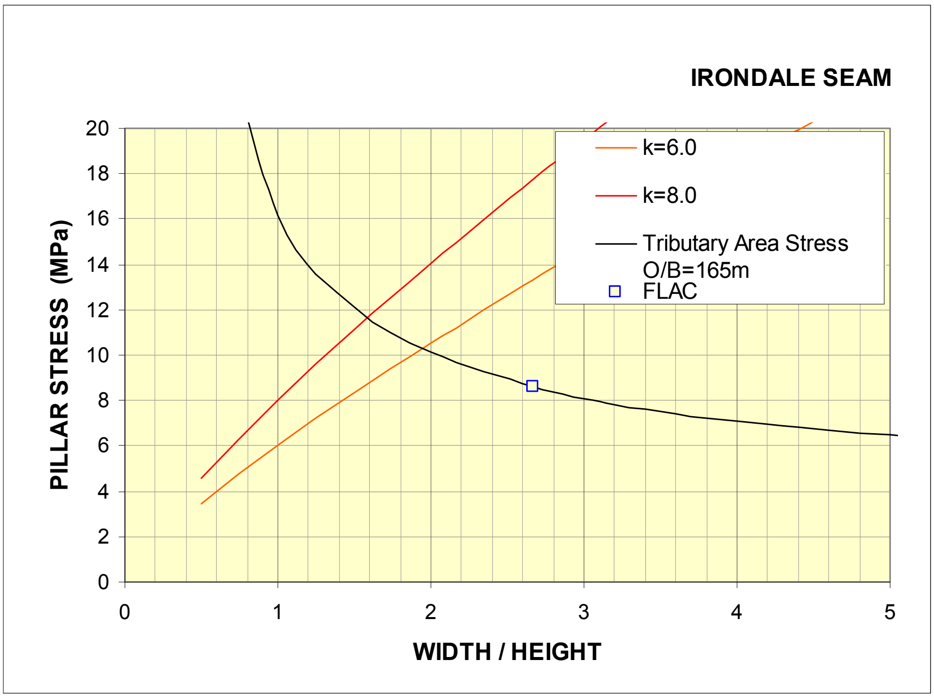

Figure 14(e): Generic SHM Pillar Stability Chart for Irondale Seam

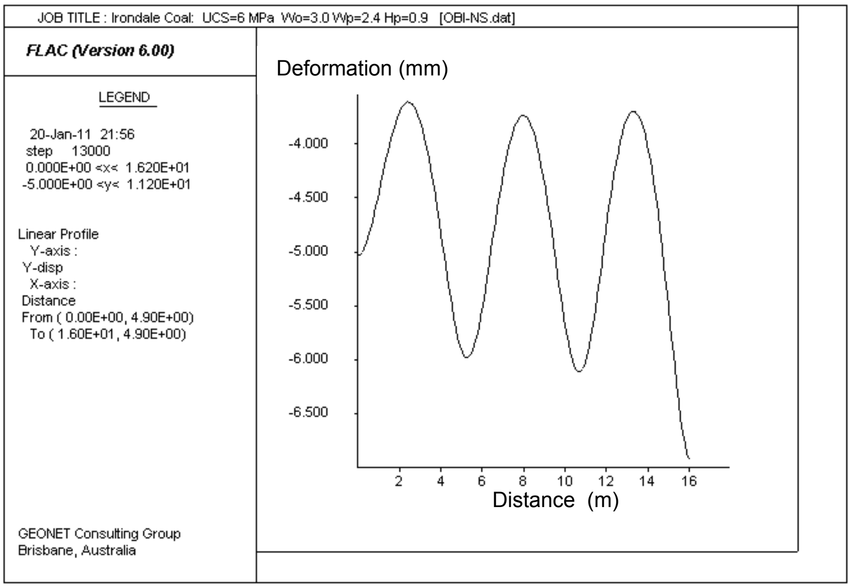

Figure 14(f): Deformation profile over pillars and spans within the Irondale seam

4.4.4 Lithgow Seam

Figure 15(a) shows the 4.6m wide SHM coal pillar and 3.5m span geometry. The detailed geology of the Lithgow seam is included according to geological log shown in Figure 3(d). In this model the coal cleat is explicitly modelled as are the bedding planes and joints in the overburden and interburden strata.

Figure 15(b) shows the simulated stress-strain behaviour of the Lithgow coal pillars for the first two adjacent pillars. It can be seen that non-linear behaviour initiates at about 6 MPa and continues up to a peak stress of 22 MPa in the first pillar and 22.5 MPa in the second pillar. The residual strength of the pillars is about 19 MPa.

Figure 15(c) shows the changes in SHM coal pillar stress during sequential excavation. The pre-mining stress in the coal seam is 4.8 MPa associated with the maximum 185m of overburden strata. Mining the first entry creates an abutment in which the stress increases to 5.9 MPa. Isolation of the coal pillar, when the second entry is driven, results in the first pillar stress increasing to 7.1 MPa while the new abutment stress increases to 5.8 MPa. Subsequent entries push the second formed pillar stress to 7.0 MPa. The stress level in both pillars stabilises to the same level at 7.0 MPa.

Figure 15(d) shows the stress affected condition in the coal pillars and surrounding rockmass strata subject to the maximum 185m overburden load. In the pillar side walls loosening of coal cleat is predicted to a distance of about 800mm behind the surface. There is no contiguous damage extending through any of the pillars. However, the presence of the mudstone/claystone bands in the upper half of the pillar has caused localised shearing along these surfaces extending more than 1m into the pillar.

There is also separation along the stone band in the immediate roof resulting in spalling of the roof coal up to 1m into the roof. Shears may form at the corners of the drives extending through the coal seam up to a competent stratum in the roof. The effect of this could be that the pillar height increases by at least 1m due to roof falls to about 3.2m, thus pushing the pillar W:H ratio to 1.44.

Minor loosening of the floor siltstone may develop to a depth of 0.100m.

Figure 15(e) shows the stability of the coal pillar to locate well inside the ‘Long Term Stable’ sector. However, if roof falls occur then the data point could relocate closer to the ‘Progressive Failure’ sector as shown by the second point on the graph. Evidence from inspections of unsupported spans is that the coal roof is ‘Long Term Stable’ after 60 years of standing open [3].

Figure 15(f) shows the displacement profile over the SHM spans and coal pillars at the elevation of the top of SHM drives. Over the pillars the displacement will be about 2mm compared with >96mm over the spans.

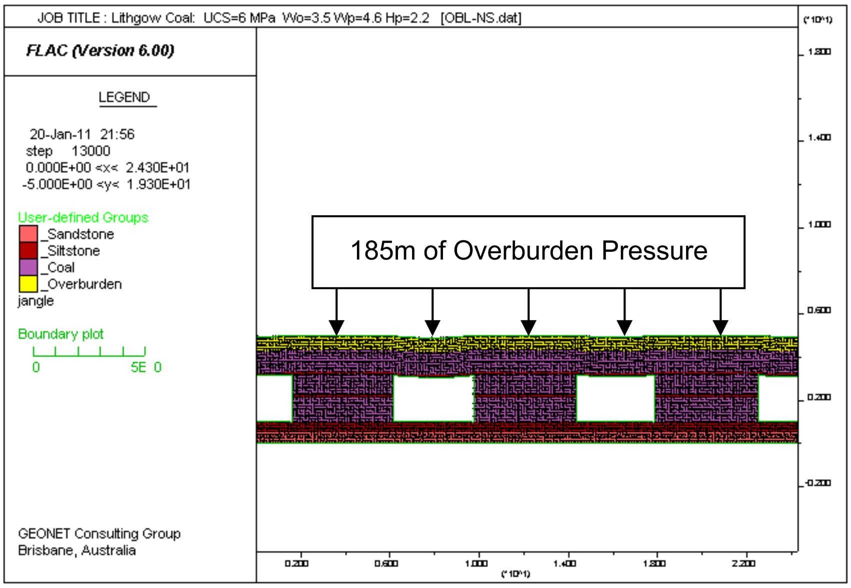

Figure 15(a): Coal pillar (W:H=4.6:2.2=2.1) geometry – Lithgow Seam

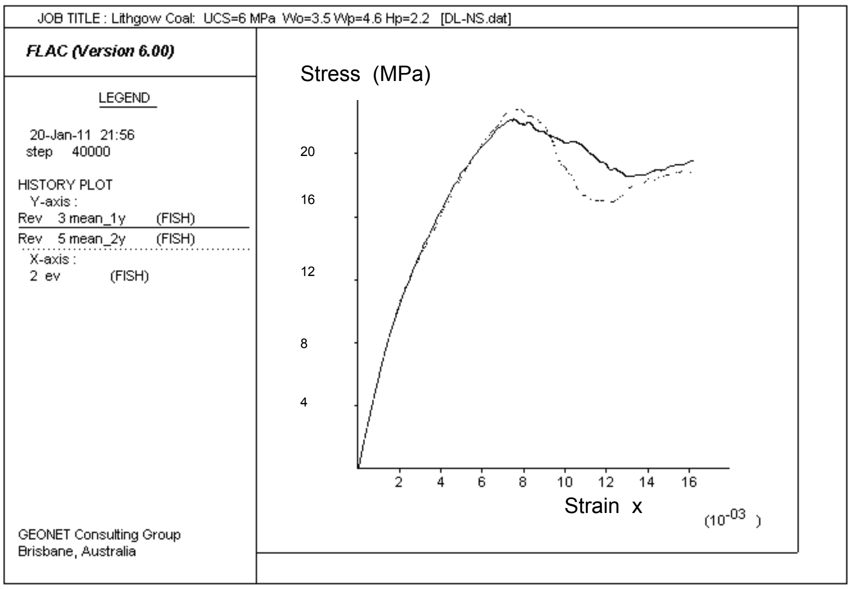

Figure 15(b): Coal pillar (W:H=4.6:2.2=2.1) strength – Lithgow Seam

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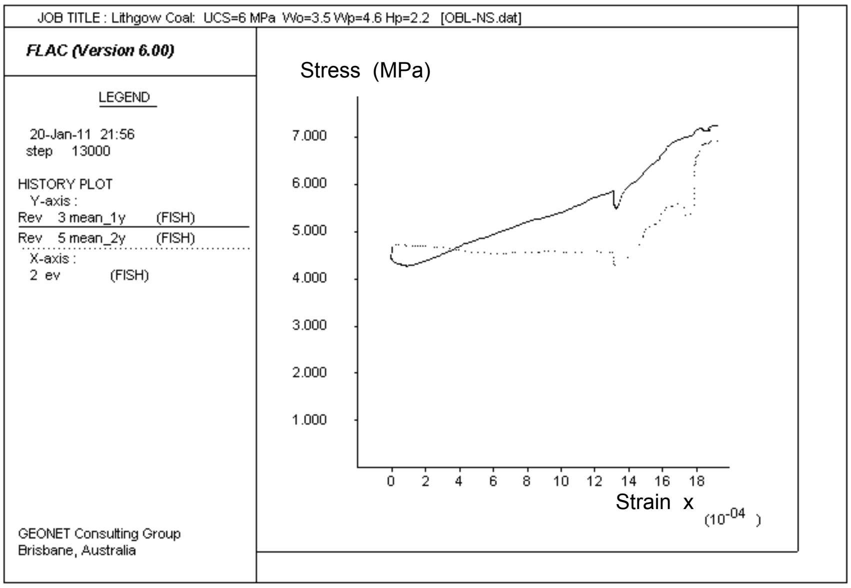

Figure 15(c): Average Stress in Coal pillar (W:H=4.6:2.2=2.1) – Lithgow Seam

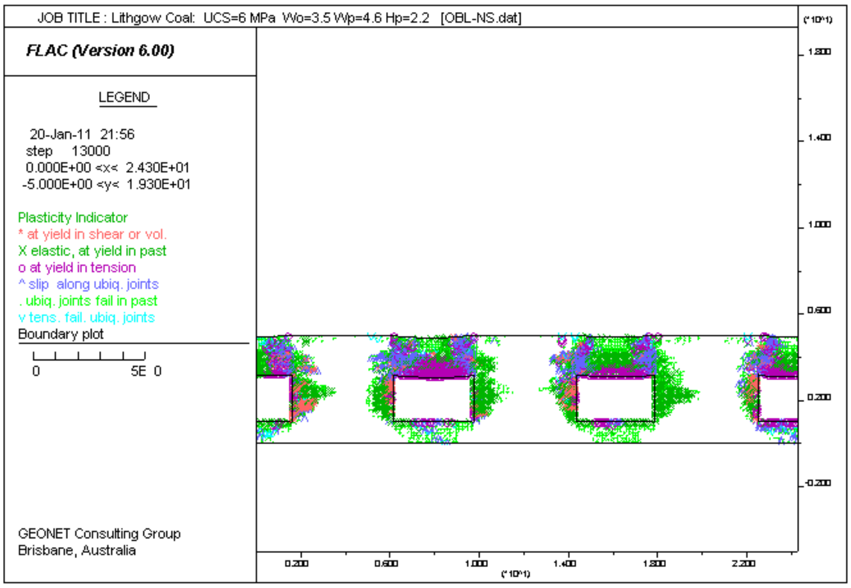

Figure 15(d): Condition within Coal pillar (W:H=4.6:2.2=2.1) – Lithgow Seam

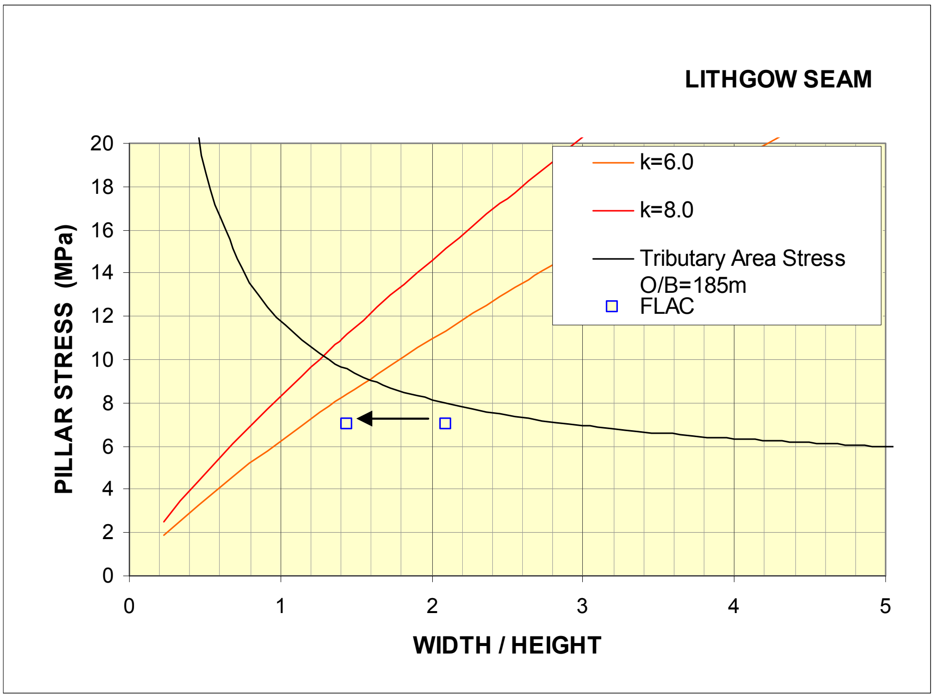

Figure 15(e): Generic SHM Pillar Stability Chart for Lithgow Seam

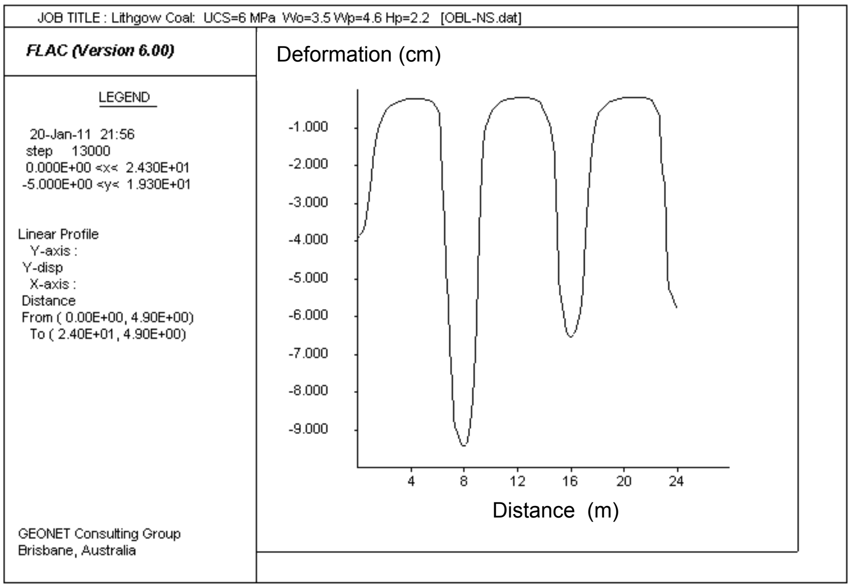

Figure 15(f): Deformation profile over pillars and spans within the Lithgow seam

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5.0 SIMULATION OF SHM MINING OPERATIONS

In the previous section the behaviour of SHM coal pillars was analysed to establish their stability under maximum loading conditions. The estimated pillar dimension for each of the coal seams was shown to be stable. Actual site conditions may vary due to:

i) steep topography;
ii) historic underground mining in the Lithgow seam;
iii) changes in confining stress when the open cut is developed;
iv) sequential effect of SHM entries; and
v) final backfilling against the open pit walls.

In order to ensure that localised failures will not develop to compromise the subsidence sensitive landscape a full three-dimensional analysis was carried out to simulate each of the different stages of mining.

5.1 Model Geometry and Geology

A plan view and an aerial oblique view of the model showing topography and geology are presented in Figures 16(a) and 16(b), respectively. The location of the area in relation to the overall project was shown in Figure 1. The model extends over the following coordinate range:

224850E to 225850E	1000m
6311400N to 6313400N	2000m
RL800m to RL1080m	280m

Note that in the subsequent text the northing coordinates are referred to by the last four digits, i.e. the initial 631 is omitted.

The rockmass model simulates the two major joint orientations and gently dipping bedding by invoking the ubiquitous joint constitutive model. The coal seam cleat is similarly included in the model.

The orientations (dip/dip direction) of the major rockmass joint sets are:

Bedding:	02 / 088
Joint set #1:	90 / 045 (90 / 057)
Joint set #2:	92 / 315 (92 / 276)

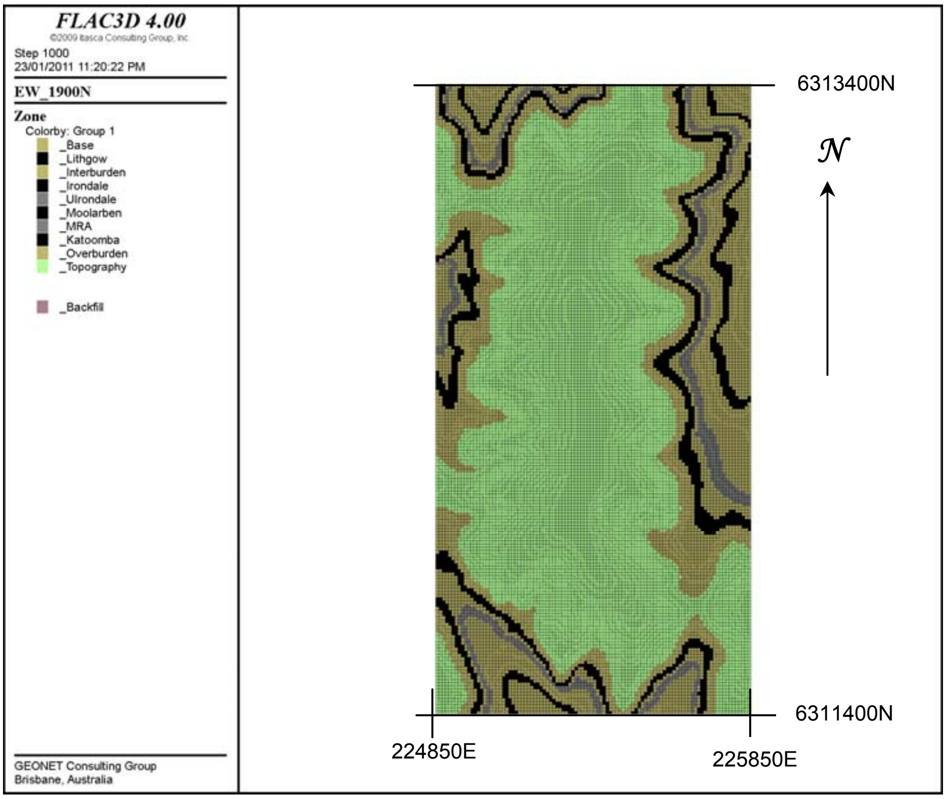

Figure 16(a): Aerial plan view of model showing topography and geology.

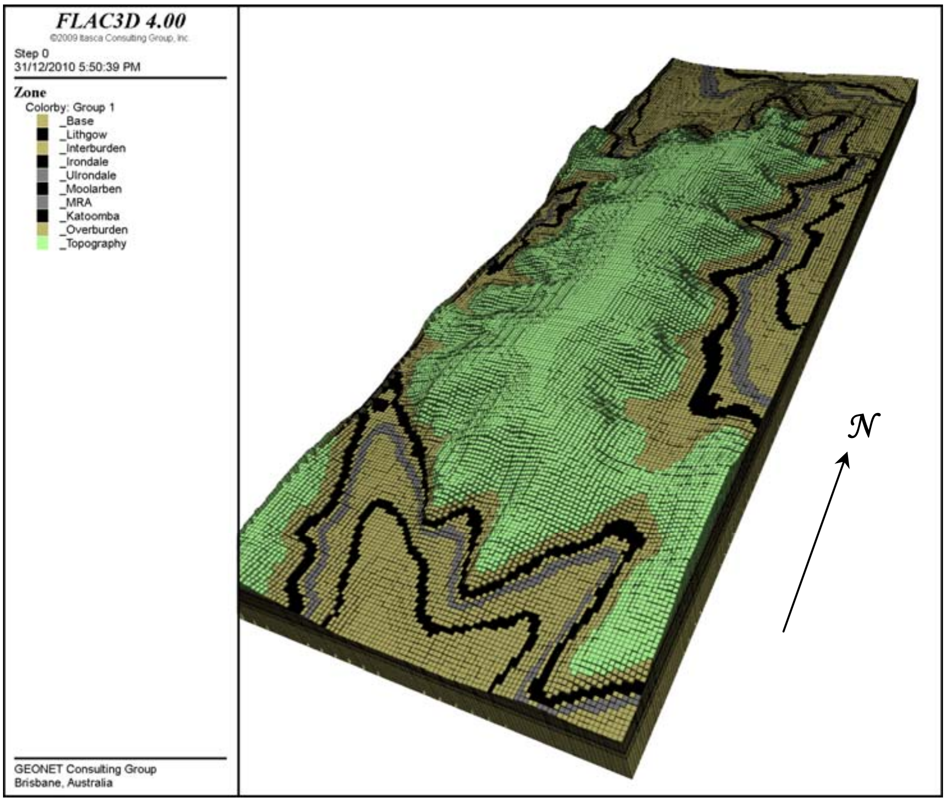

Figure 16(b): Aerial oblique view of model showing topography and geology.

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5.2 Pre-Mining Geotechnical Conditions

The pre-mining geotechnical conditions will be discussed in terms of the following plotted results:

i) stress affected condition,

ii) condition of joints (expressed as a Factor of Safety against shear) , and

iii) subsidence (vertical displacement).

Plots will be presented as aerial views and cross-sections at different northing coordinates. These plots will provide the basis for comparison against subsequent stages of mining.

In Figure 17(a) the stress condition over the proposed mine site is shown. The variously coloured zones indicate that the zone is currently, or has in the past, been at a stress level to induce tension or shear on the joints and/or within the intact rock. The legend for the different colours has been omitted because it presents 56 combinations of state. For the purposes of this discussion it will be sufficient to consider the presence of a coloured zone to indicate the potential condition or loosening of joints in the rockmass.

By looking at the stress condition projected onto cross-section at 2650N it is noticeable that the stress affected zones are predominantly on surface and confined to the steep slopes. There is no effect within the rockmass. It is concluded that the condition in rockmass has been invoked by a combination of stress relief effects and reduced confinement on steeply dipping joints at the cliff faces which is a natural condition that over time causes the landscape to change. Exposure to the elements promotes weathering and exacerbates this process.

Figure 18 presents the condition of the joints calculated in terms of their propensity to fail in shear or tension, i.e. a Factor of Safety (FoS). In plan view, Figure 18(a), the contours indicate FoS typically greater than 1.3. The more critical values are almost certainly associated with exposed steeply dipping joints. As such it is concluded that the modelled results correspond with the expected insitu rockmass condition.

Subsidence (vertical displacement) over the higher elevation topography shows negligible displacement, typically less than 10mm. Over the valleys the displacements are positive, up to 80mm, indicating uplift due to elastic rebound. These are historic deformations which have occurred during the formation of the current topography, a natural formational process of uplift due to erosion of sedimentary basins over geological time.

At the completion of this first stage of modelling all displacements and damage indicators were reset to zero so that the effect of mining could be more readily quantified.

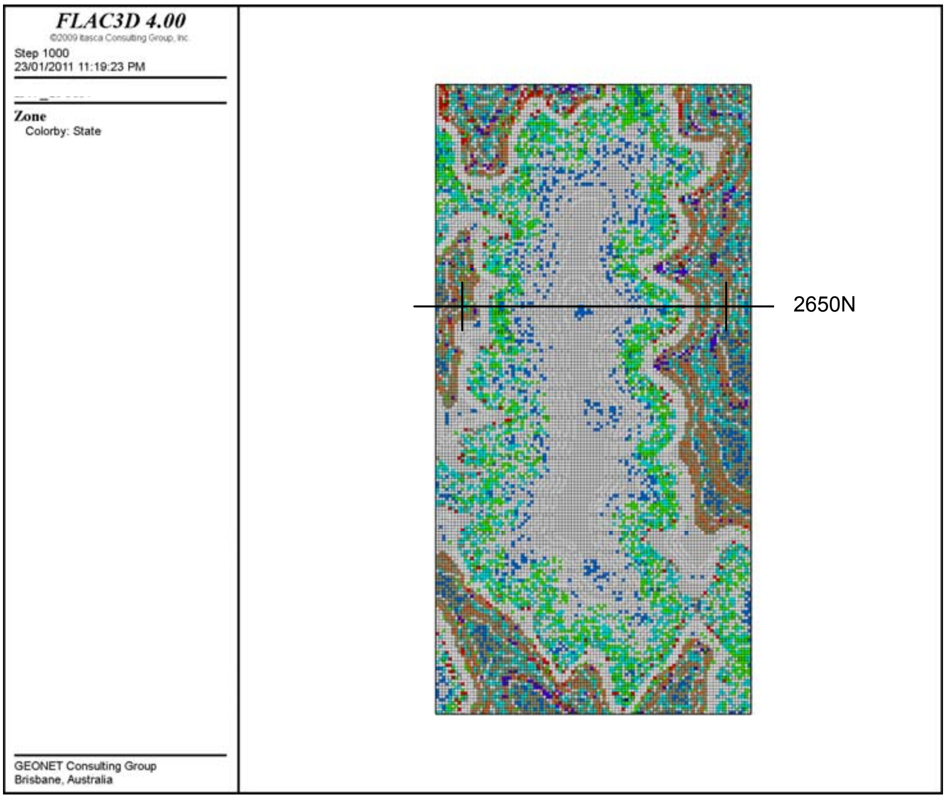

Figure 17(a): Stress condition in pre-mining rockmass

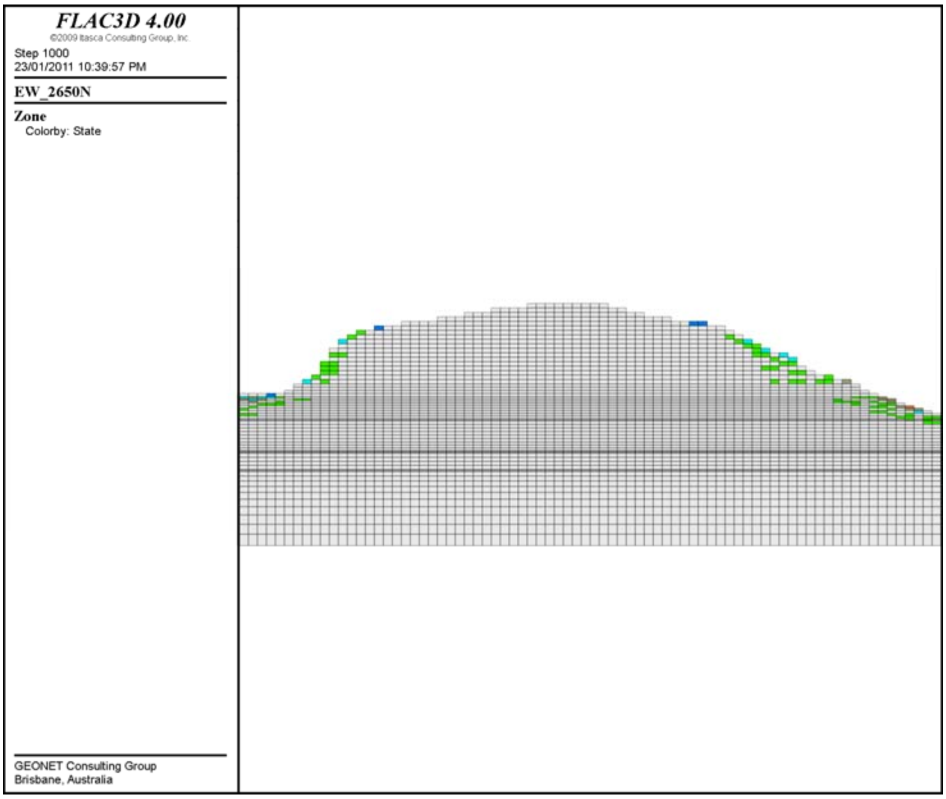

Figure 17(a): Stress condition on section at 2650N for pre-mining rockmass

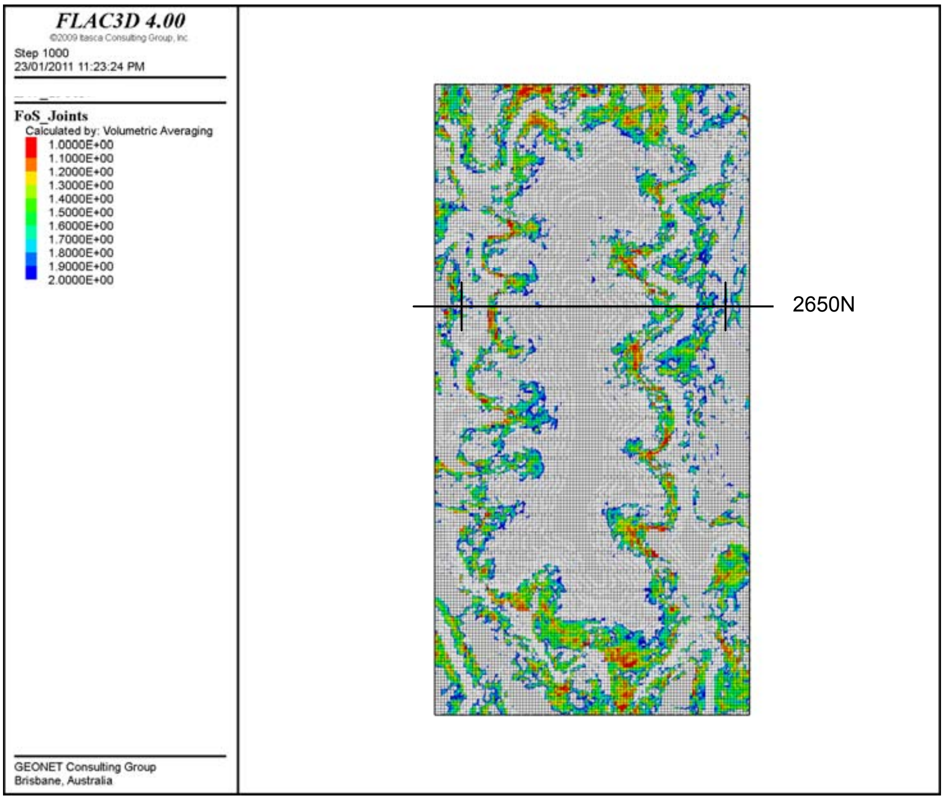

Figure 18(b): Condition of joints expressed as FoS in pre-mining rockmass

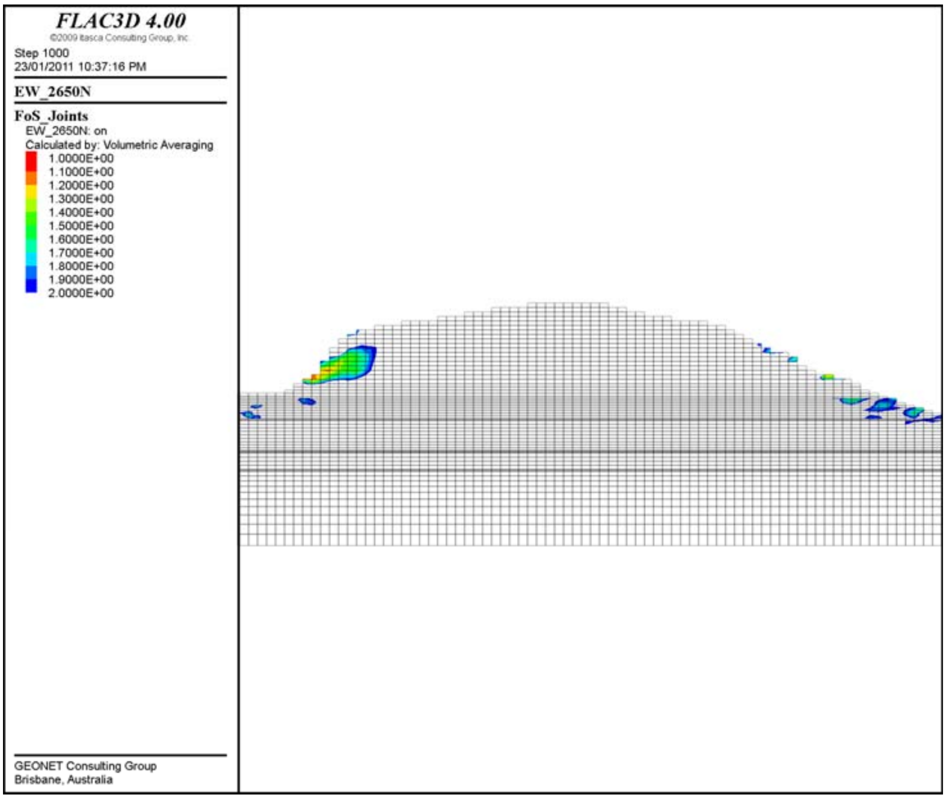

Figure 18(b): Condition of joints expressed as FoS at 2650N for pre-mining rockmass

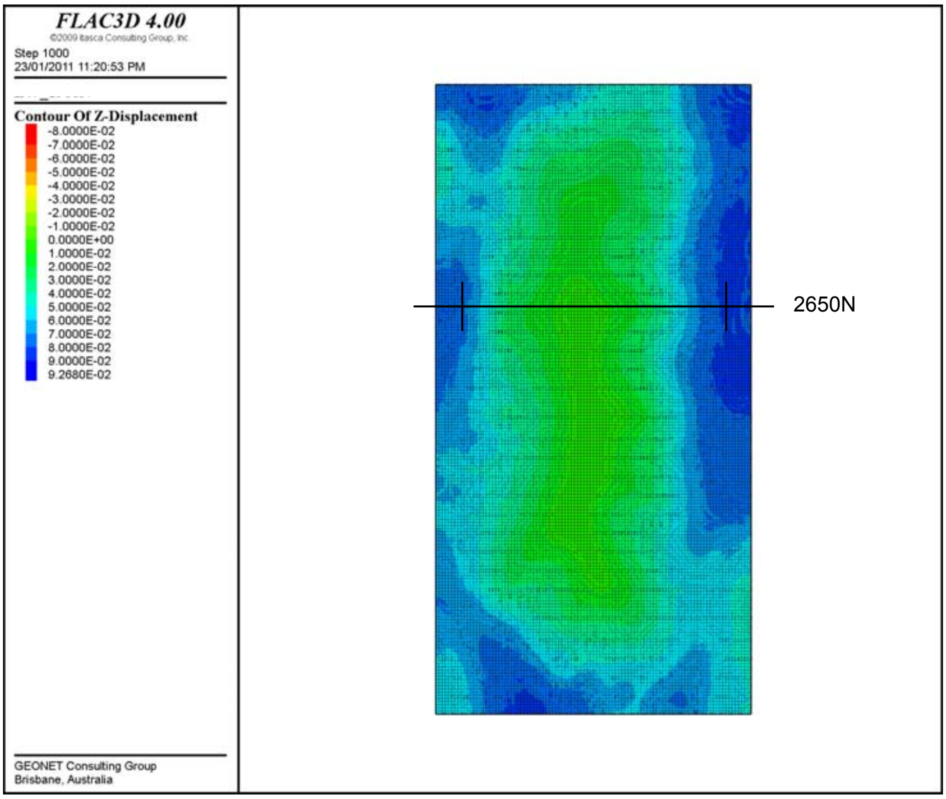

Figure 19(c): Subsidence contours over pre-mining rockmass

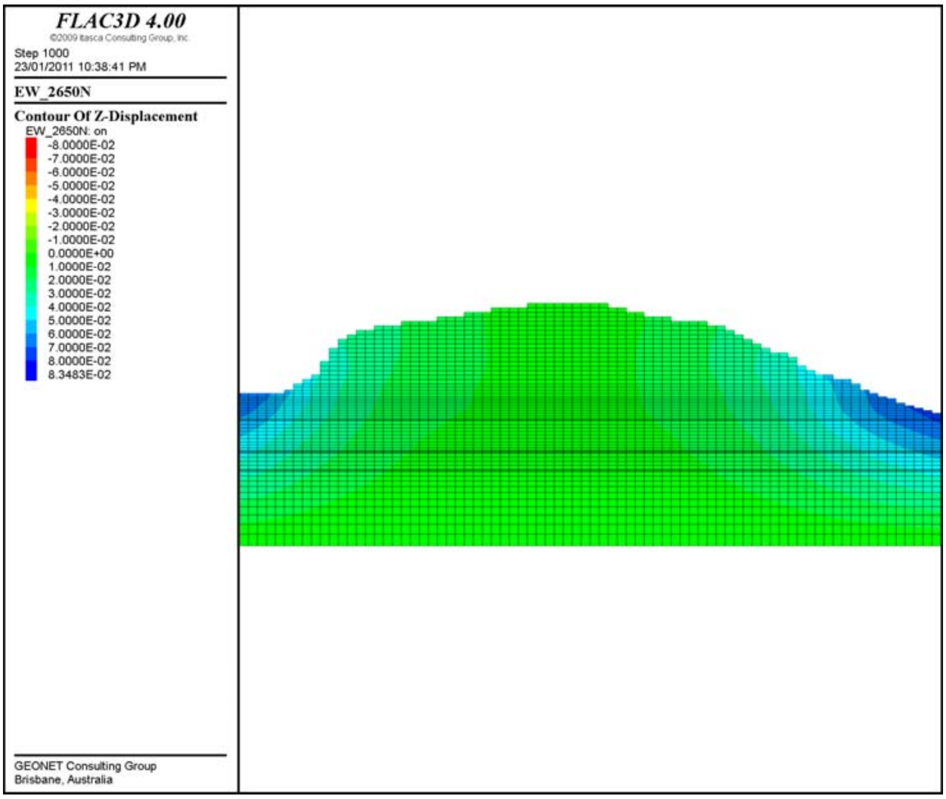

Figure 19(c): Subsidence contours at 2650N for pre-mining rockmass

5.3 Effect of Historic Underground Mining in Lithgow Seam

Previous bord and pillar mining in the Lithgow seam extends over 800m of the southern section of the model as shown in Figure 20. Given the relatively shallow overburden, it is possible that these excavations have had some impact upon the overburden strata and topographic surface. The effect of this will be to reduce the mass strength of the different overburden strata. It is important, therefore, to include this stage of mining prior to simulating the SHM highwall mining.

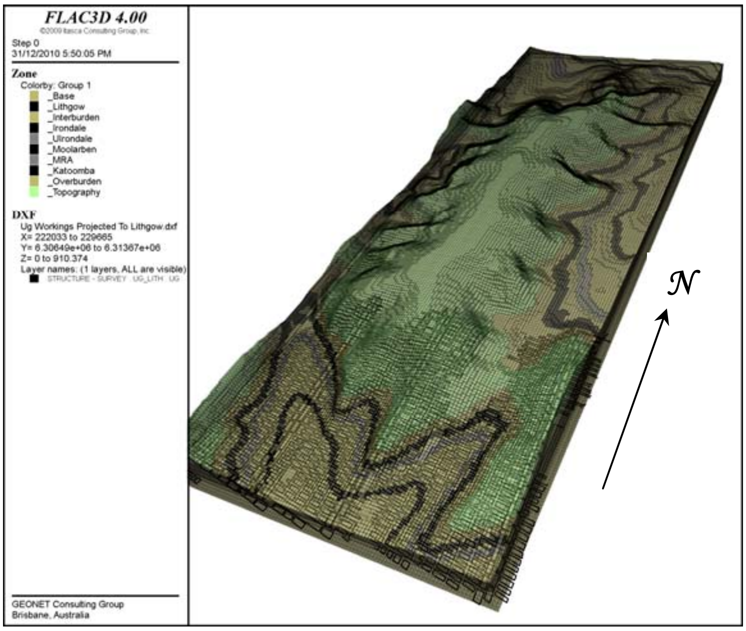

Figure 20: Layout of underground workings in Lithgow seam

The plots of stress condition, Figures 21(a) and 21(b), show that the bord and pillar workings in the Lithgow seam may have affected 5m to 15m of interburden above the seam, probably extending locally to the base of the Irondale seam. This modelled prediction is supported by inspections of the abandoned underground workings in the current open cut areas at Invincible Colliery. The cross-section shows that the effect may also be trans-located at the base of the Triassic rockmass, again associated with unconfined steeply dipping joints. However, this may also have been initiated by movements associated with the underground workings. Since the underground workings are circa 1930's, the observed stable conditions effectively confirm the long-term stability of workings in these strata.

The condition of the joints as shown in Figures 22(a) and 22(b), indicate values of FoS>1.3. Overall, stable conditions should prevail at this stage.

The subsidence plots, Figures 23(a) and 23(b), show a localised concentration of deformation over the thickest section of overburden. This is almost certainly initiated by the underground workings in the Lithgow seam.

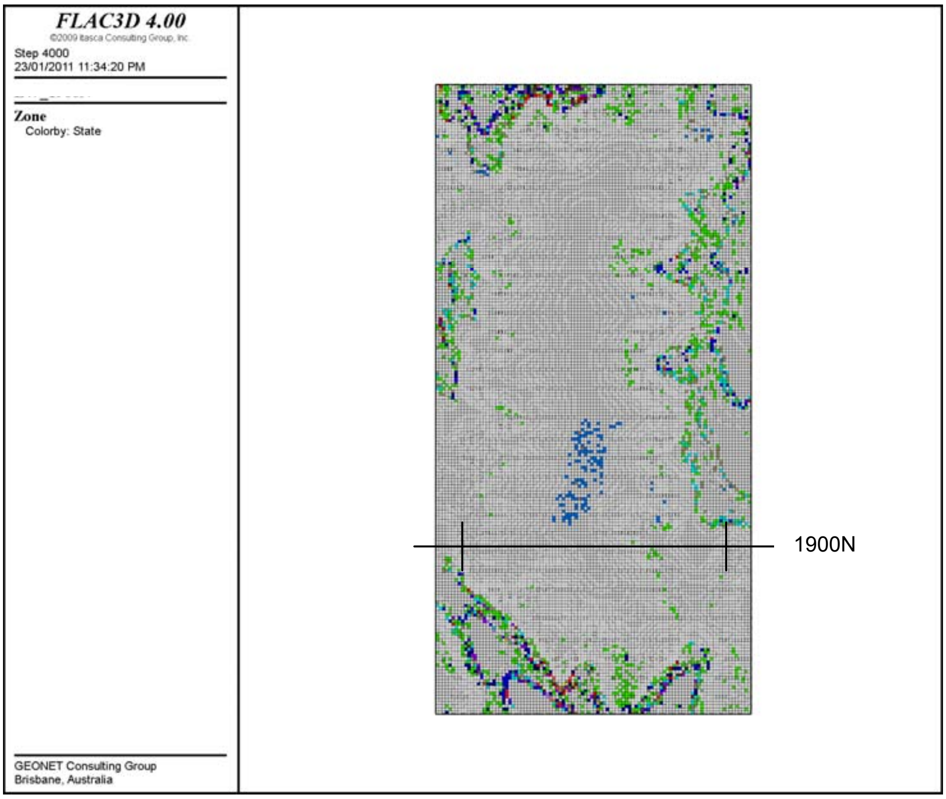

Figure 21(a): Stress condition in exposed rockmass after historic underground mining (c.1930's)

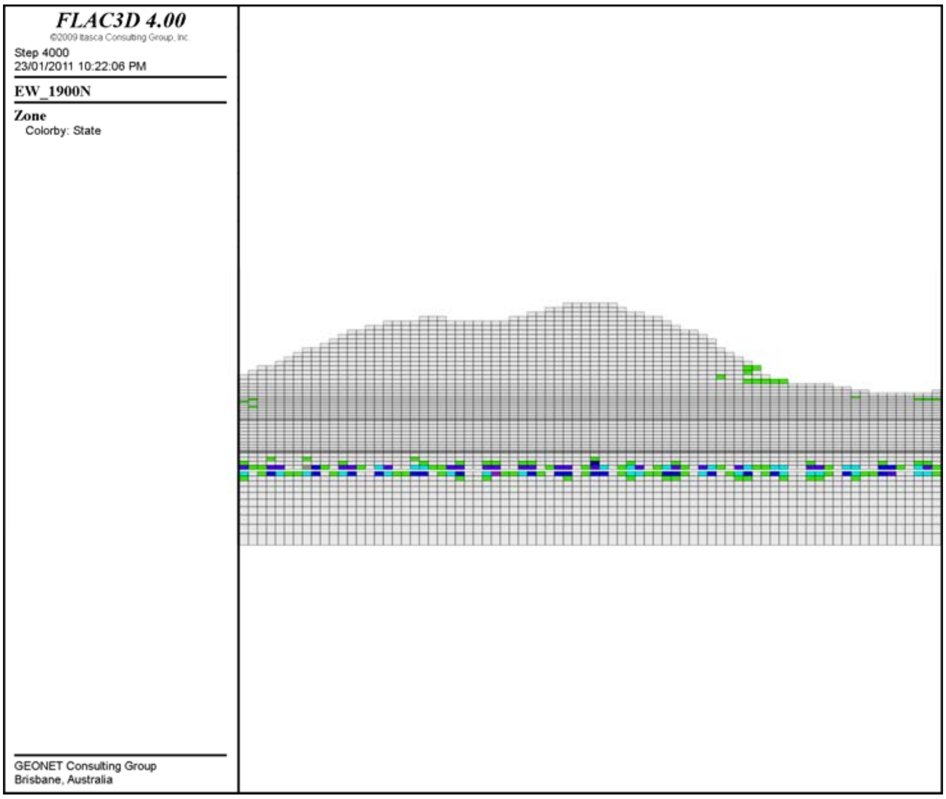

Figure 21(b): Stress condition on section at 1900N after Lithgow underground mining (c.1930's)

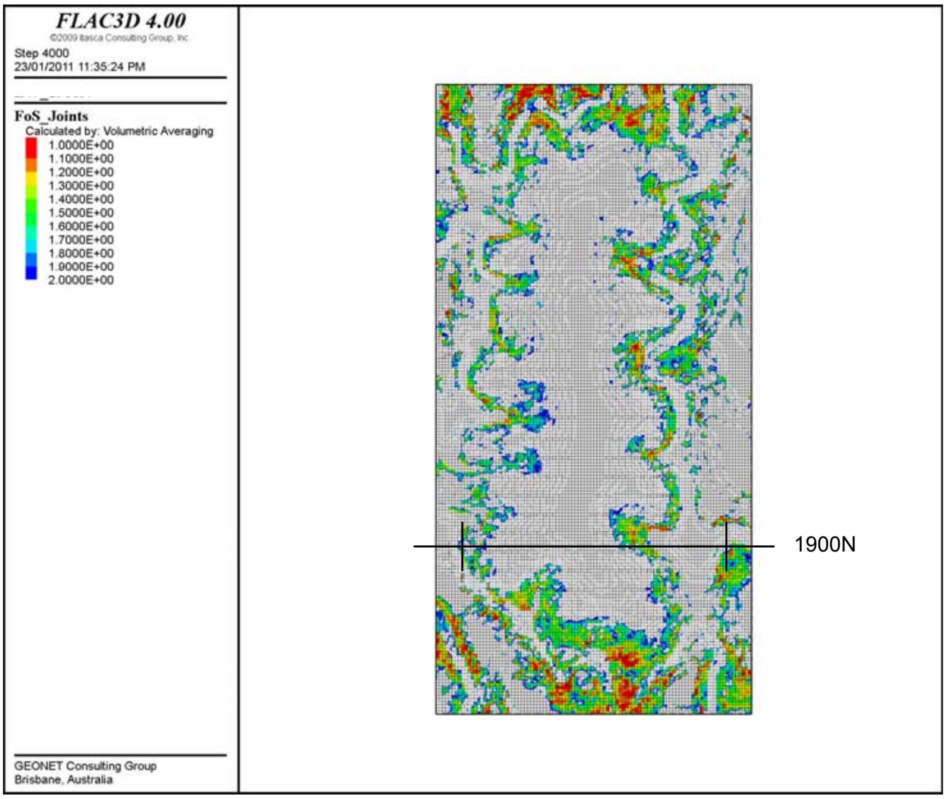

Figure 22(a): Condition of joints expressed as FoS following underground mining

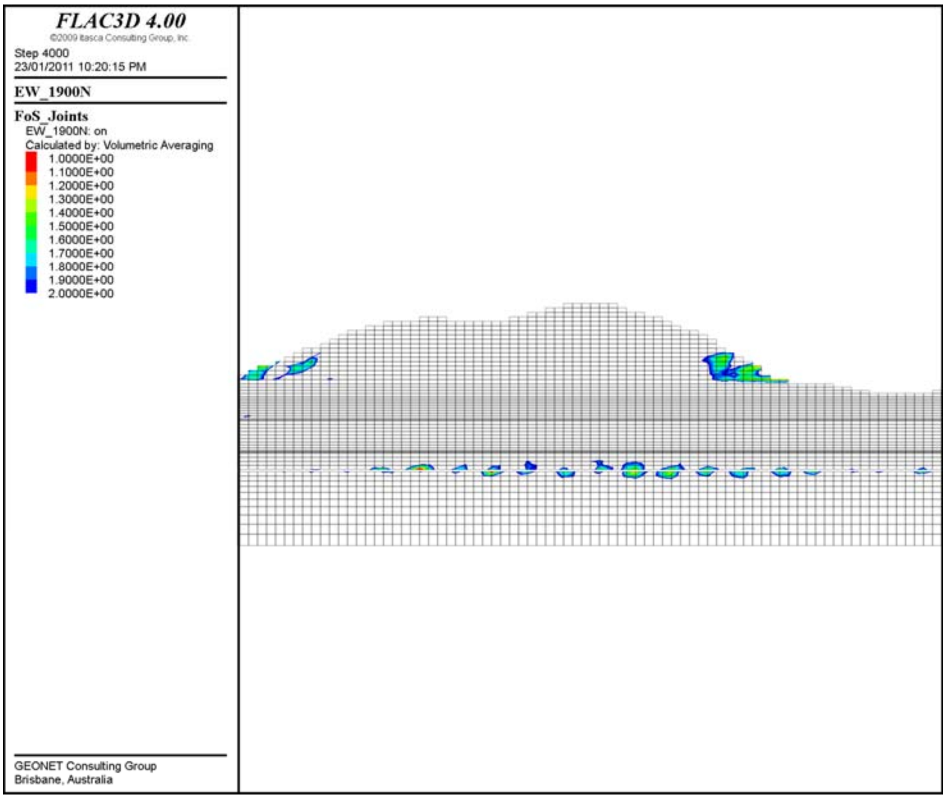

Figure 22(b): Condition of joints expressed as FoS on section at 1900N

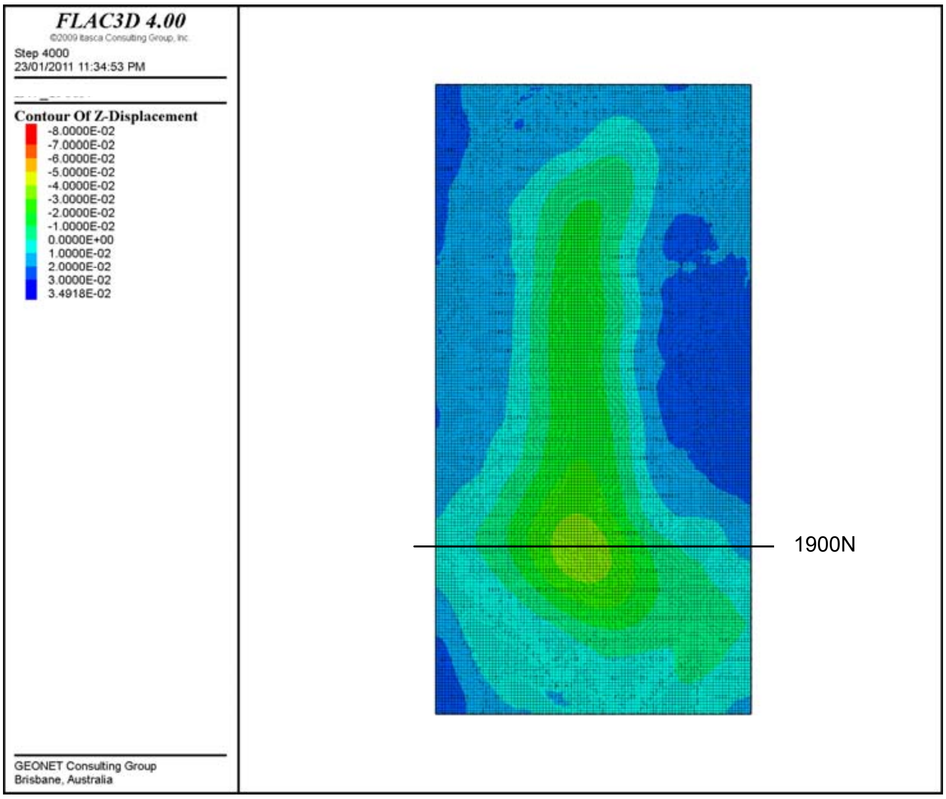

Figure 23(a): Subsidence over mine site following Lithgow underground mining (c. 1930's)

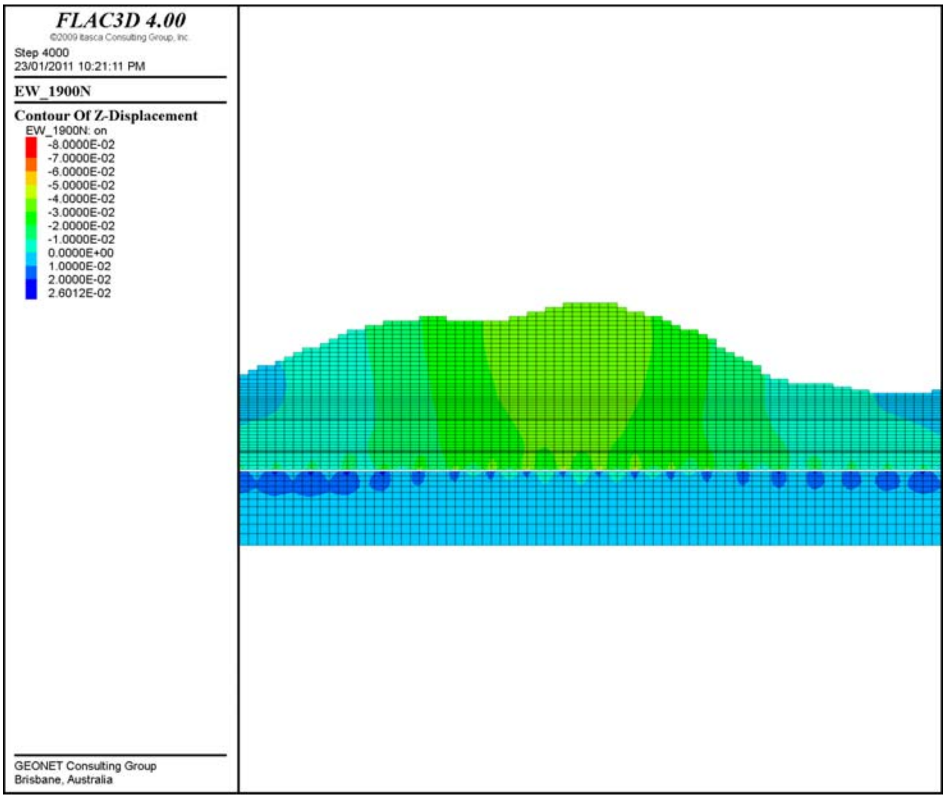

Figure 23(b): Subsidence on section at 1900N after Lithgow underground mining (c. 1930's)

5.4 Effect of Open Cut Mining

The proposed schedule of mining will require open cut mining down to the Lithgow seam so as to create the highwalls for future SHM mining, Figure 24. This will be done in finite sections starting on the northern boundary of the area. Once the highwalls have been created, then the SHM will mine the successive seams from bottom to top. After completion of the SHM mining in each seam, backfill will be placed against the highwall to the level of the next seam to be mined. Finally the open pit will be backfilled to seal the Katoomba seam.

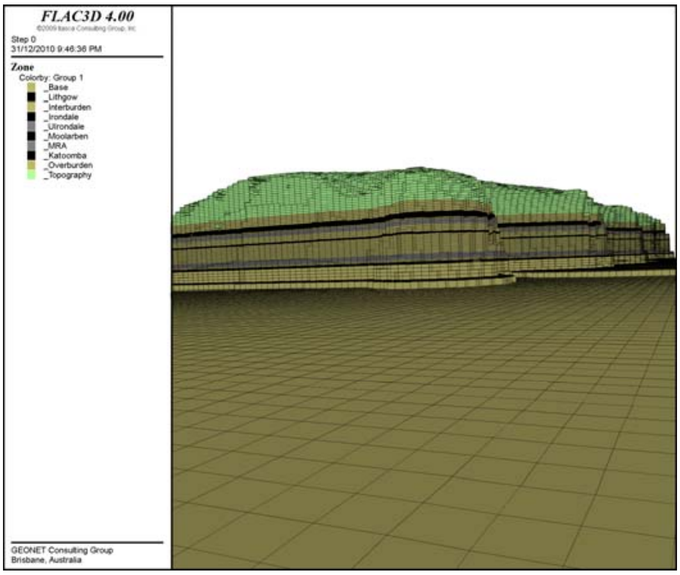

Figure 24: Perspective view of western highwall geology following open cut mining

Open pit mining effectively removes confinement to the rockmass making up the topography resulting in tensile conditions over the surface strata as shown by the high concentration of blue and light blue coloured zones, Figure 25(a). The cross-section plot, Figure 25(b) shows tensile opening of joints extending to a maximum of 20m below surface. On the western highwall, stress relief on joints may develop in the interburden between the Irondale and Katoomba seams extending to 40m behind the highwall face.

The joint condition plots, Figure 26(a) and 26(b) show that joints may open the exposed Lithgow to Irondale interburden strata extending to 30m behind the face. The joints on the surface of high topography will all be unaffected by mining and remain absolutely stable.

Relaxation of the rockmass into the open cut excavations may manifest as overall deformation of the topography to a maximum of 80mm, Figures 27(a) and 27(b). This deformation does not represent failure of the material. It represents the dilation of the jointed rockmass due to reduced confinement following open cut excavation. This phenomenon occurs in all mining excavations and does not affect the stability of rockmass conditions. This is confirmed in the experience of both current mining operators who will testify to good highwall stability conditions [11, 12, 13, 14, 15].

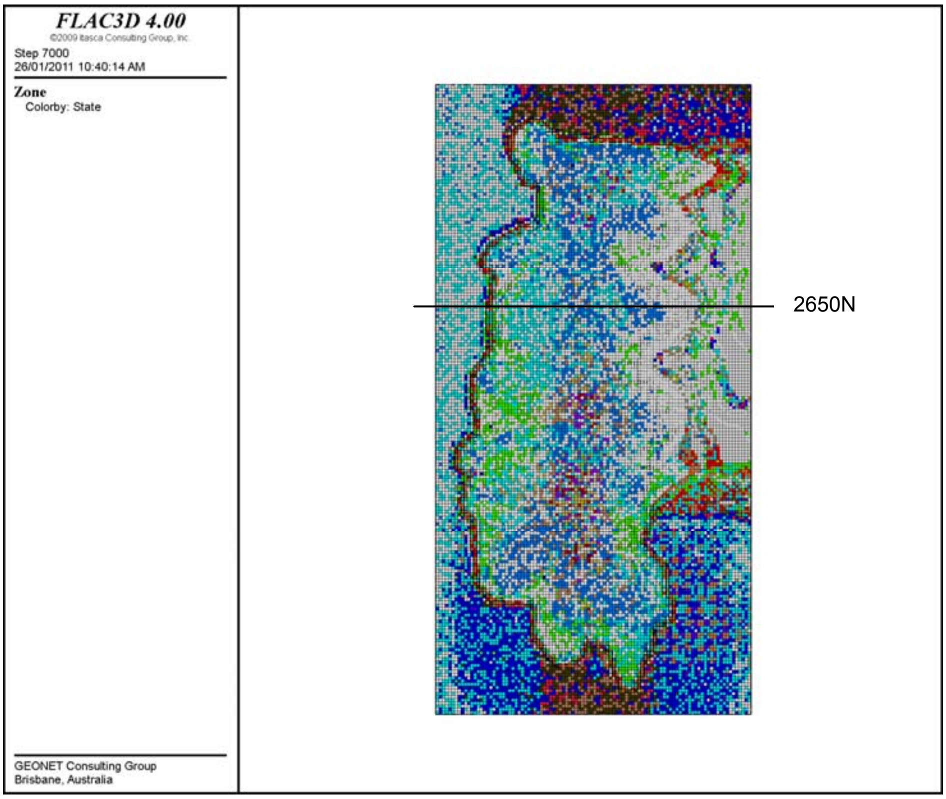

Figure 25(a): Stress condition in exposed rockmass after open cut mining

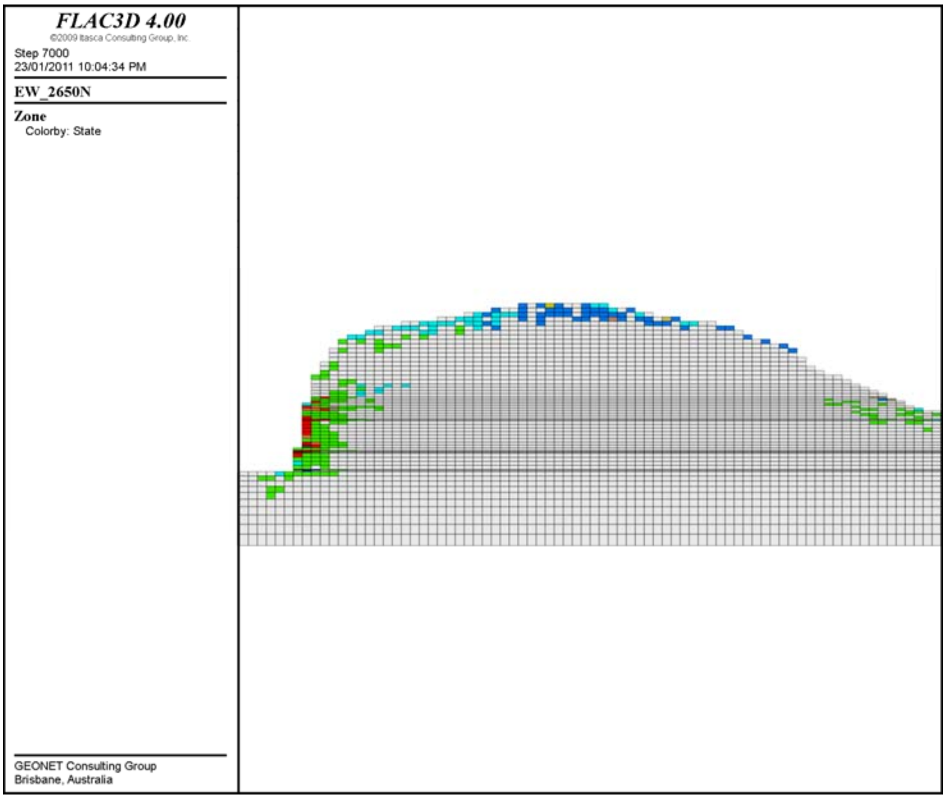

Figure 25(b): Stress condition on section 2650N following open cut mining

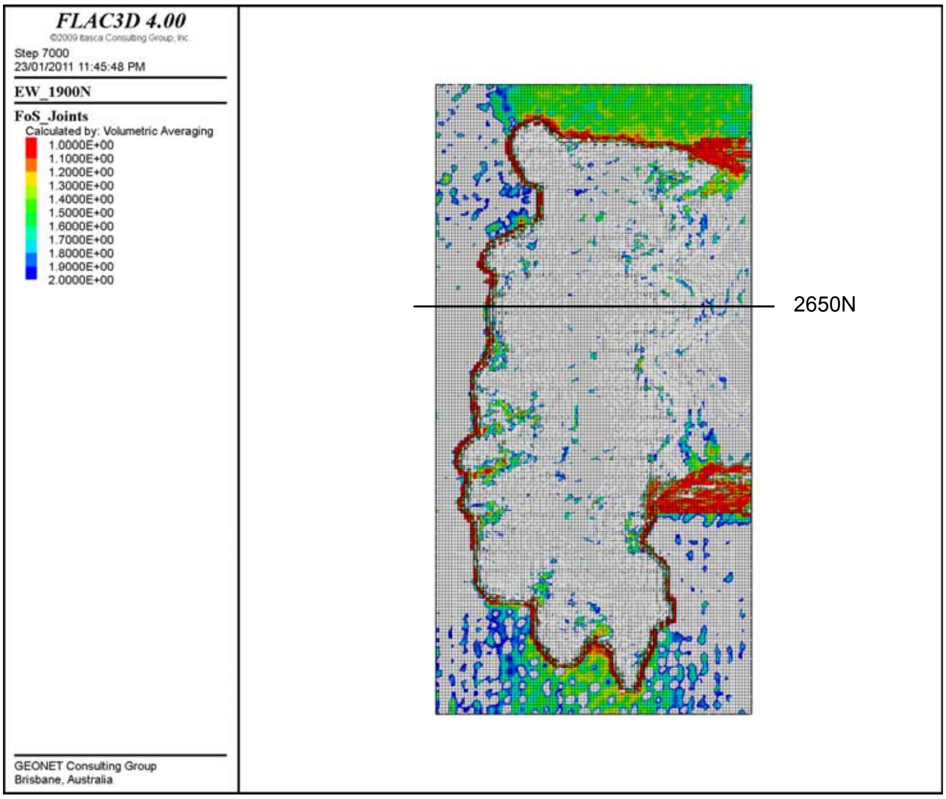

Figure 26(a): Condition of joints expressed as FoS after open cut mining

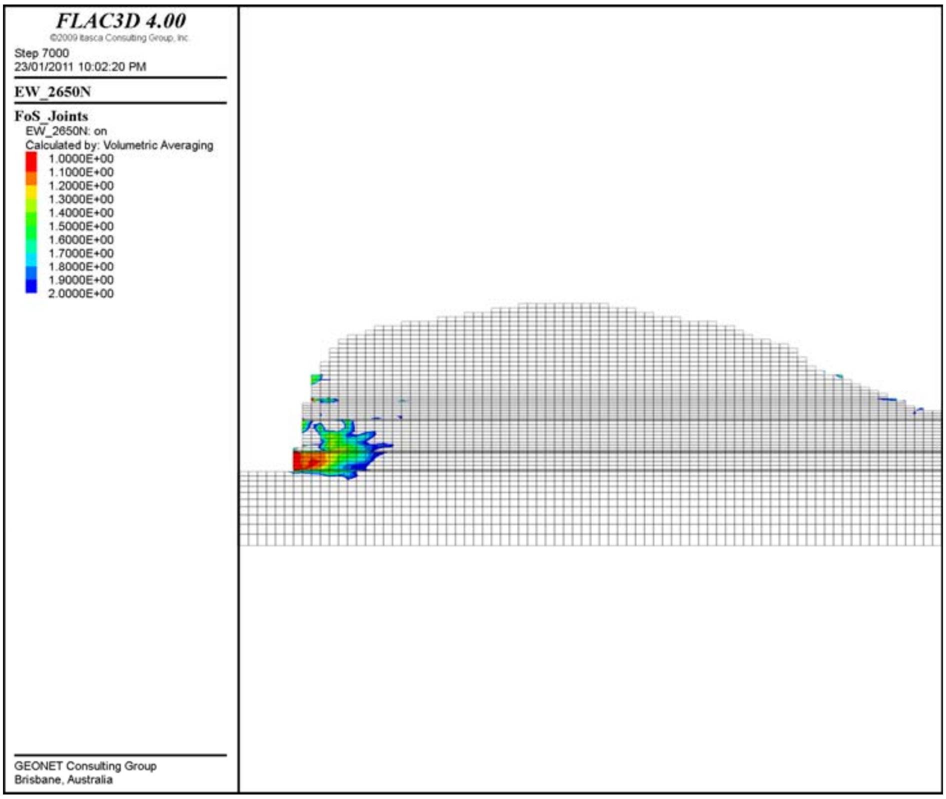

Figure 26(b): Condition of joints expressed as FoS on section 2650N after open cut

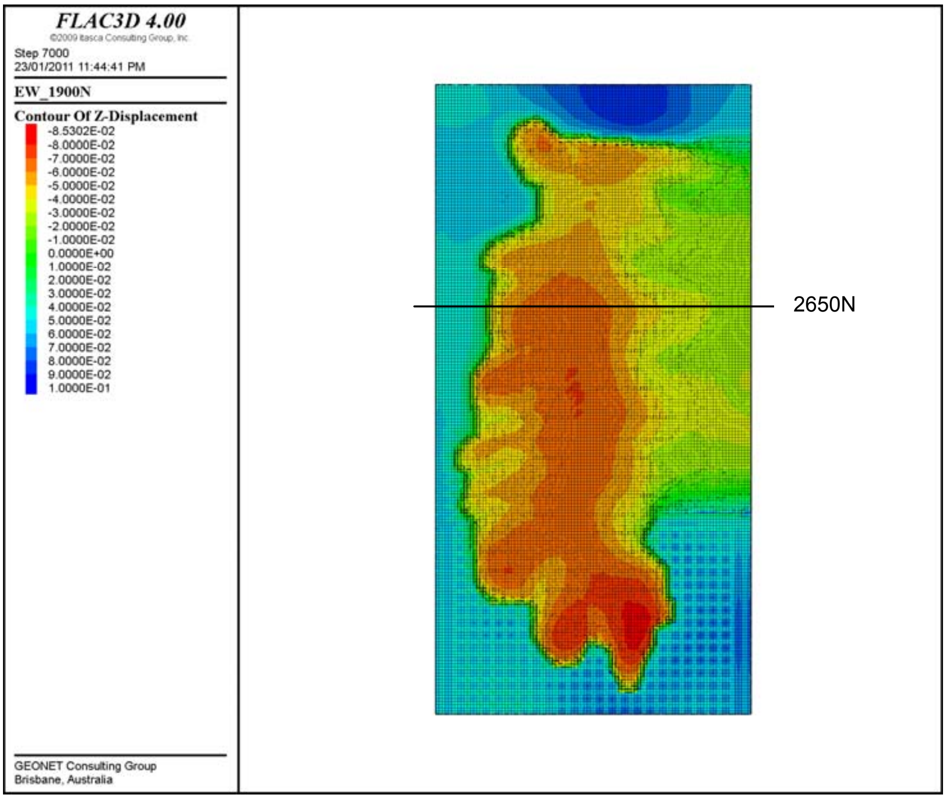

Figure 27(a): Deformation contours over mine site after open cut mining

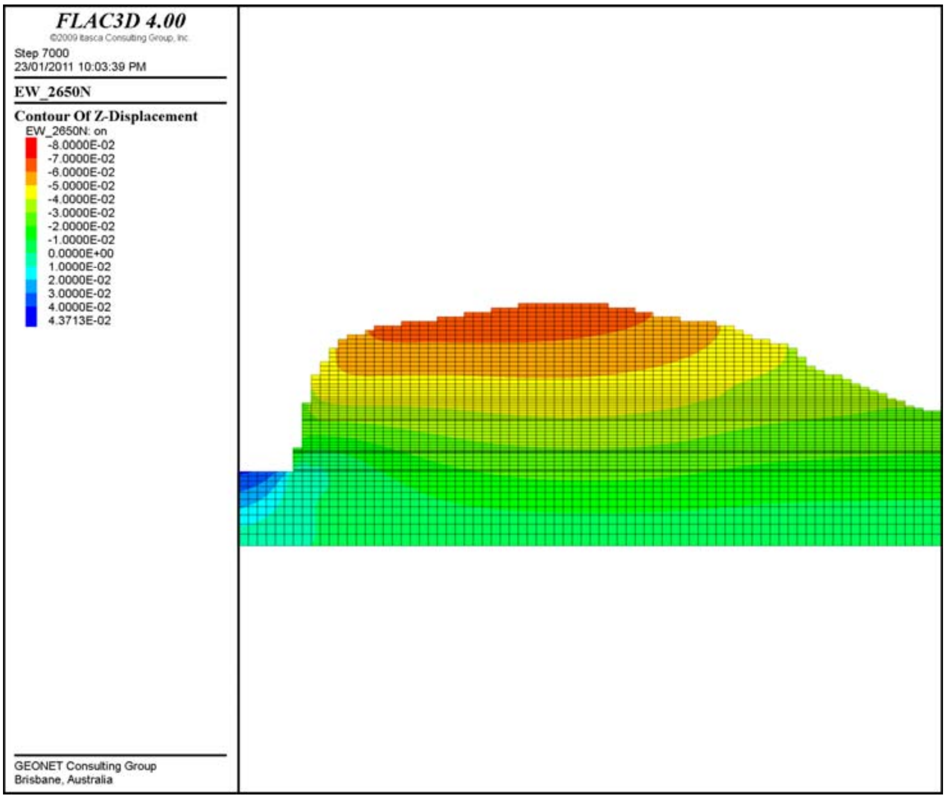

Figure 27(b): Deformation on section at 2650N after open cut mining

5.5 SHM Mining

Starting with the northern panel, followed by the western, southern and eastern panels, SHM drives were cut into successive coal seams from bottom to top. After each stage of SHM mining backfill is placed in the open pit to the elevation of the next seam to be mined to provide the platform for the miner to relocate. The penetration depth of the SHM drives is limited to 305m as can be seen in Figure 28(a). Following SHM mining in the Katoomba seam, backfill was placed to RL980m to fully seal the entries, Figure 28(b).

Stress conditions indicate tensile relaxation of joints on high elevation topography, Figure 29(a). On the cross-section plot at 1900N, Figure 29(b), it can be seen that relaxation on joints typically extends to a depth of 15m to 20m below surface. These open joints are a natural phenomenon unrelated to mining. The potential formation of a shallow subsidence (tension) crack in the saddle on high elevation topography poses no risk to the pagoda structures as they are located well away from the highwall crests. Coalpac have subsequently setback the final highwall position, further ensuring pagoda stability.

Bedding plane separation forms in roof strata above both the Katoomba and Lithgow seams. Shearing on joints and bedding planes will develop in the Irondale roof strata about 40m behind the eastern highwall face. There is localised shearing in backfill in contact with the highwall due to self-weight consolidation and compaction.

Stress relief on rockmass jointing is concentrated on the western highwall between the Lithgow and Irondale seams and extending 70m behind the face, Figures 30(a) and 30(b). On the eastern highwall similar conditions prevail, also extending to about 70m behind the face. The placement of backfill in the open pit tends to stabilise the highwalls, as is clearly demonstrated in the Factor of Safety on Joints plots where interburden strata typically show FoS>1.3. Rockmass jointing in the overburden strata are unaffected and stable. Localised shearing / tension in rockmass jointing and bedding planes is present in the immediate roof strata of underground workings in Lithgow seam.

Surface subsidence of less than 20mm is predicted for the overburden topography above the western highwall above underground workings in Lithgow seam, Figures 31(a) and 31(b). Again this deformation is in response to stress relief of the jointed rockmass. The consolidation profile after successive stages of backfill placement has maximum consolidation at about 80mm.

A series of plots to demonstrate conditions in rockmass previously unaffected by underground mining is shown for cross-section at 2350N in Figures 32(a) to 32(d).

There is minor stress relief in the highwall of Lithgow-Irondale interburden and also in the roof strata of the Katoomba seam, Figure 32(b). Natural stress relief on joints is shown in the surface topography. Stable joint conditions will prevail throughout the rockmass, Figure 32(c). The maximum subsidence in the rockmass is predicted to be less than 15mm. On the western highwall crest and extending up into the Triassic the subsidence should be less than 5mm.

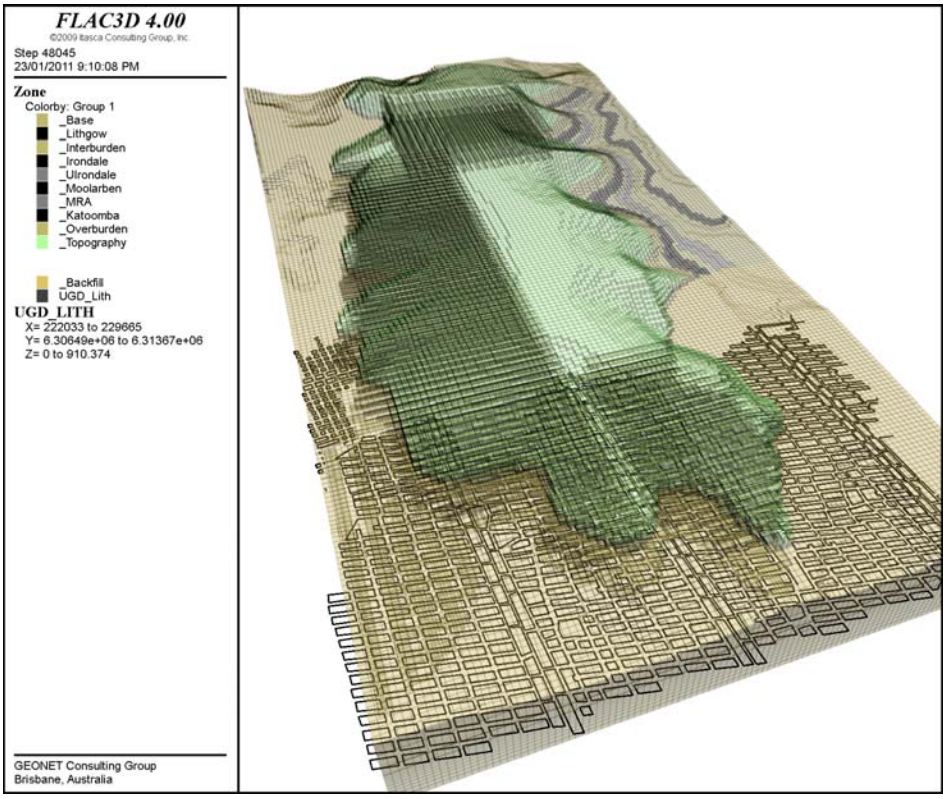

Figure 28(a): Layout of SHM drives and historic underground workings

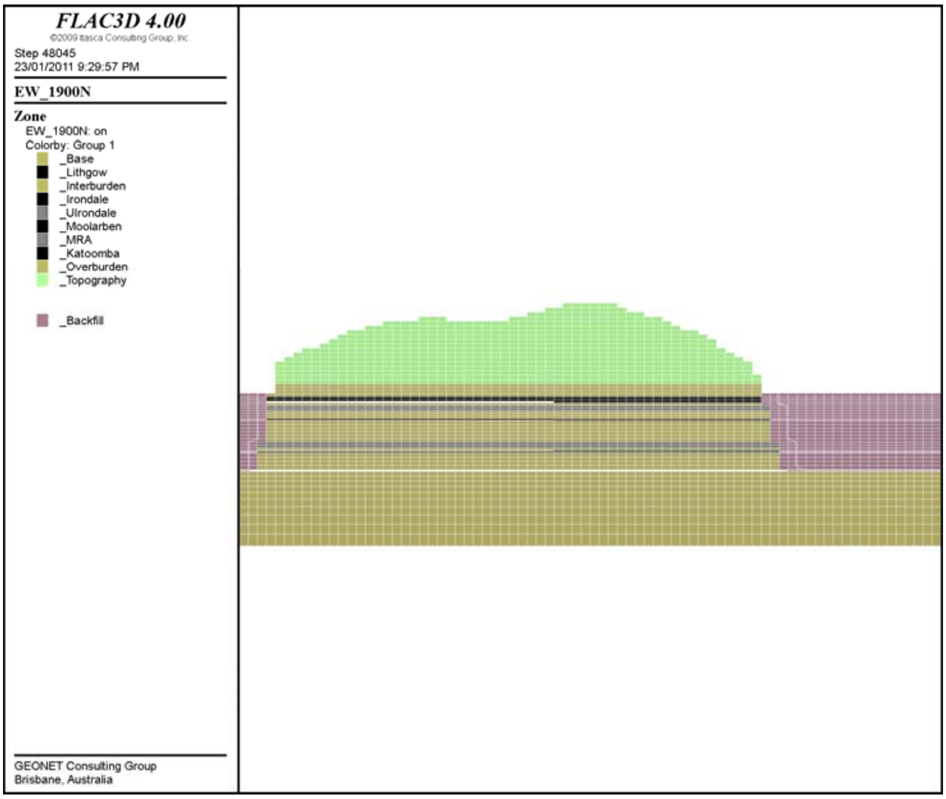

Figure 28(b): Cross-section at 1900N showing geology and backfill in final open pit

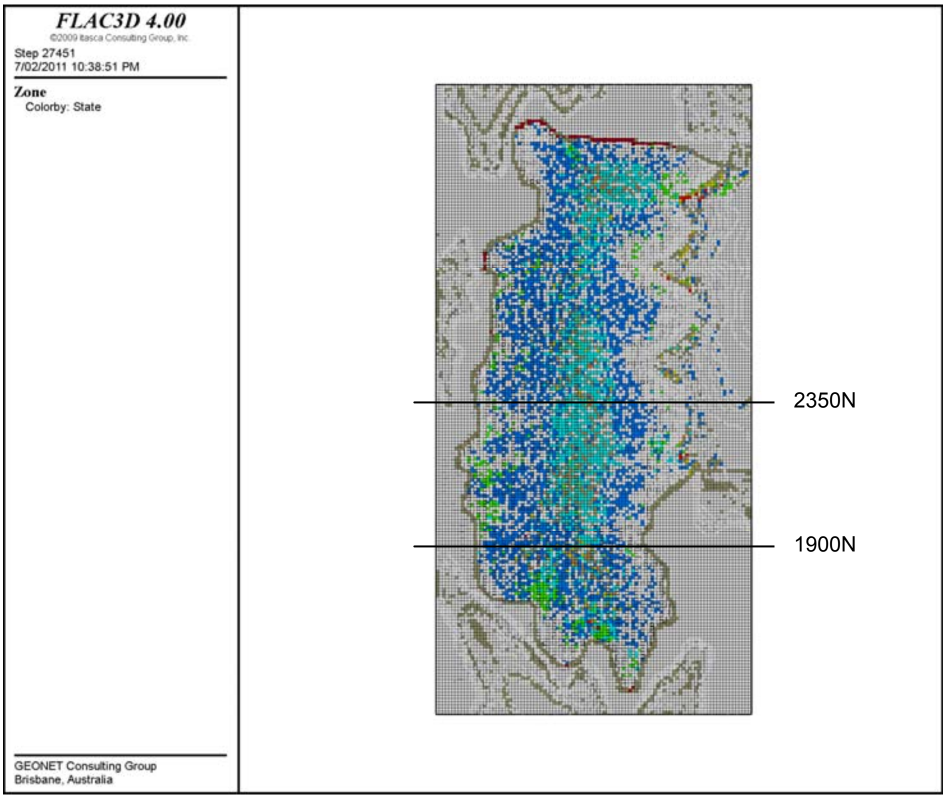

Figure 29(a): Stress condition in rockmass after SHM and backfilling

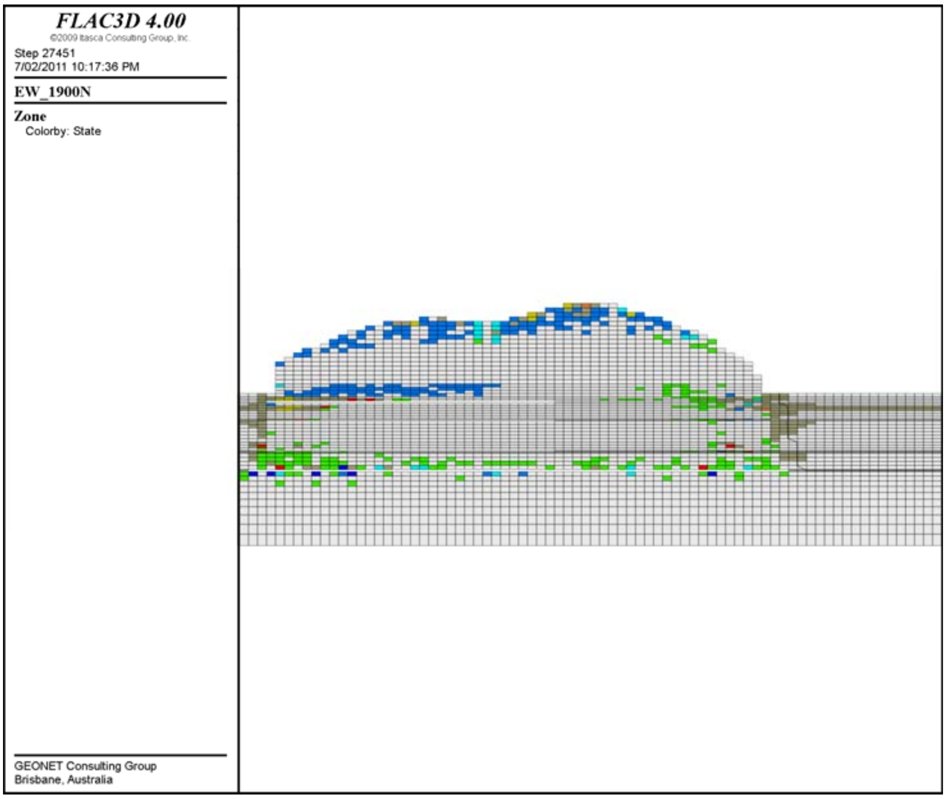

Figure 29(b): Stress condition on section at 1900N after SHM and backfilling

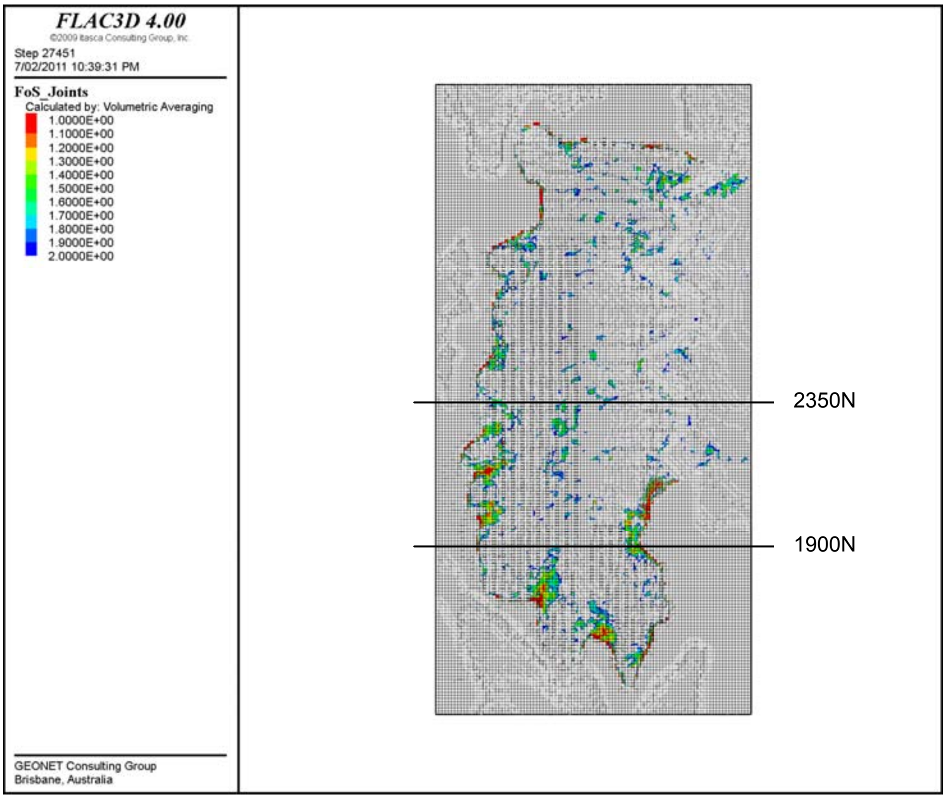

Figure 30(a): Condition of joints expressed as FoS after SHM and backfilling

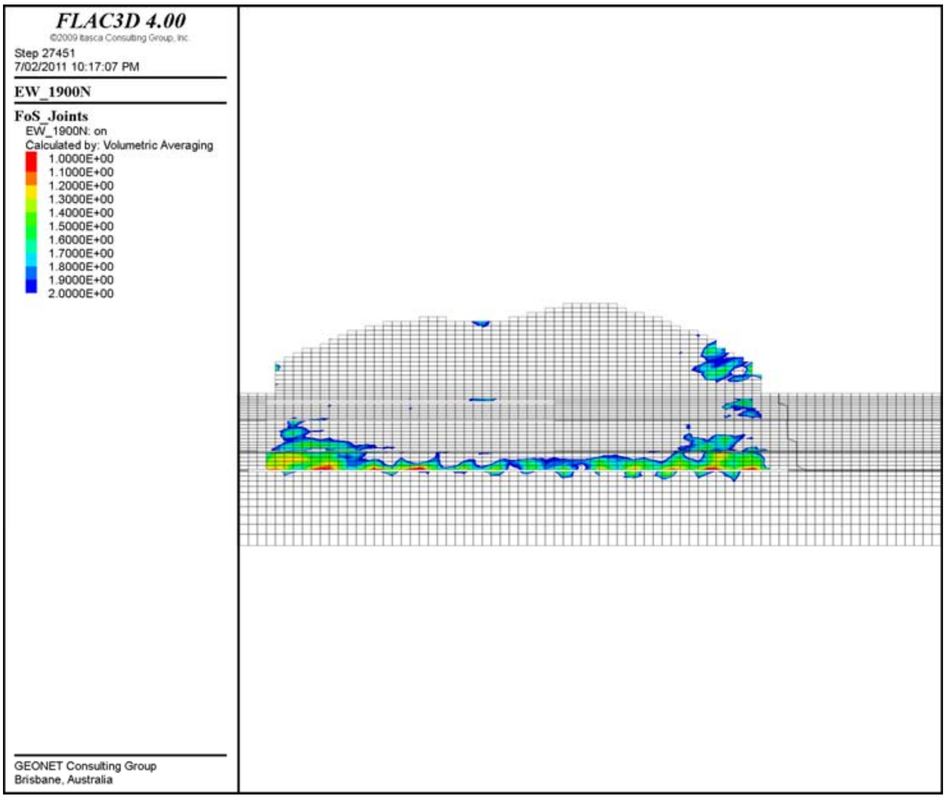

Figure 30(b): Condition of joints expressed as FoS on section at 1900N after SHM

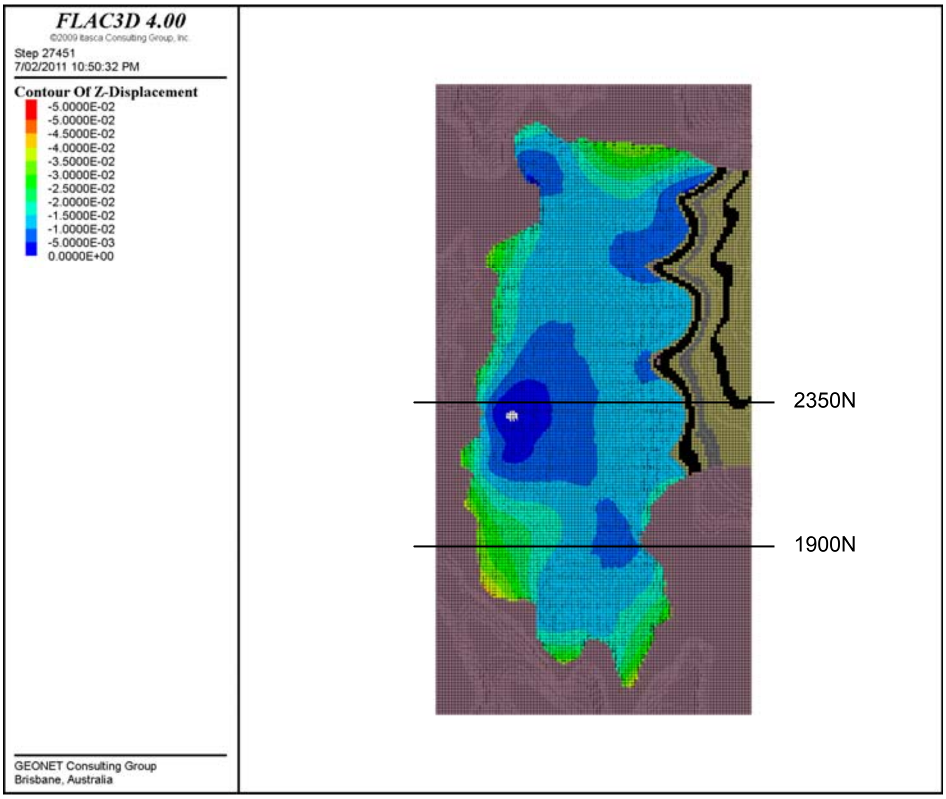

Figure 31(a): Subsidence contours over mine site after SHM and backfilling

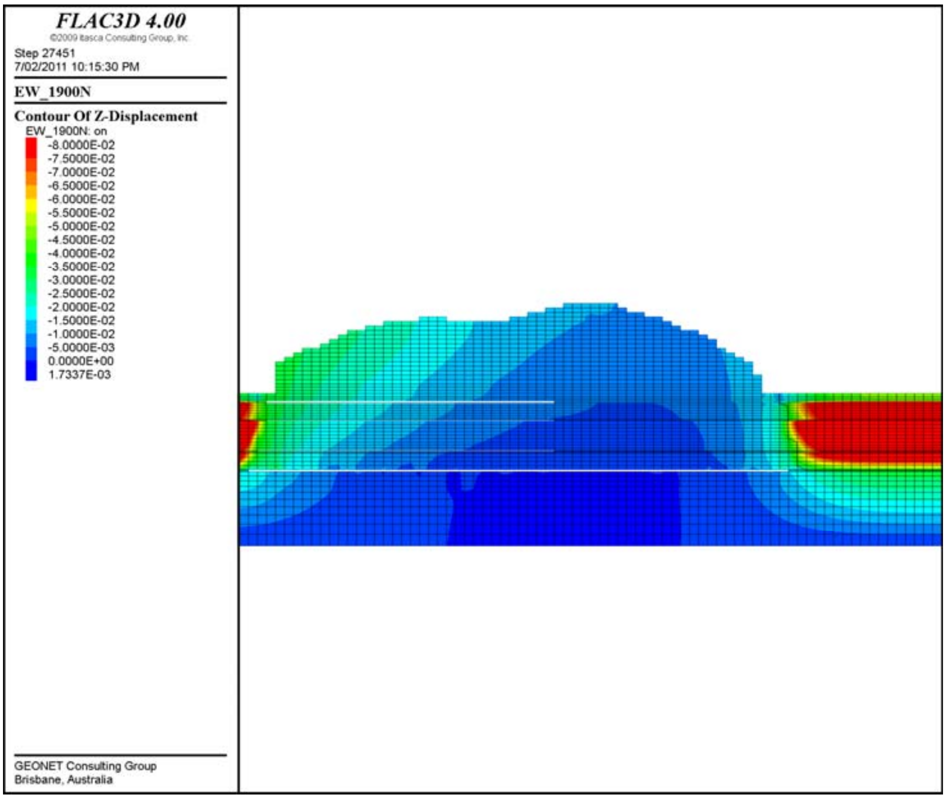

Figure 31(b): Subsidence projected onto section at 1900N after SHM and backfilling

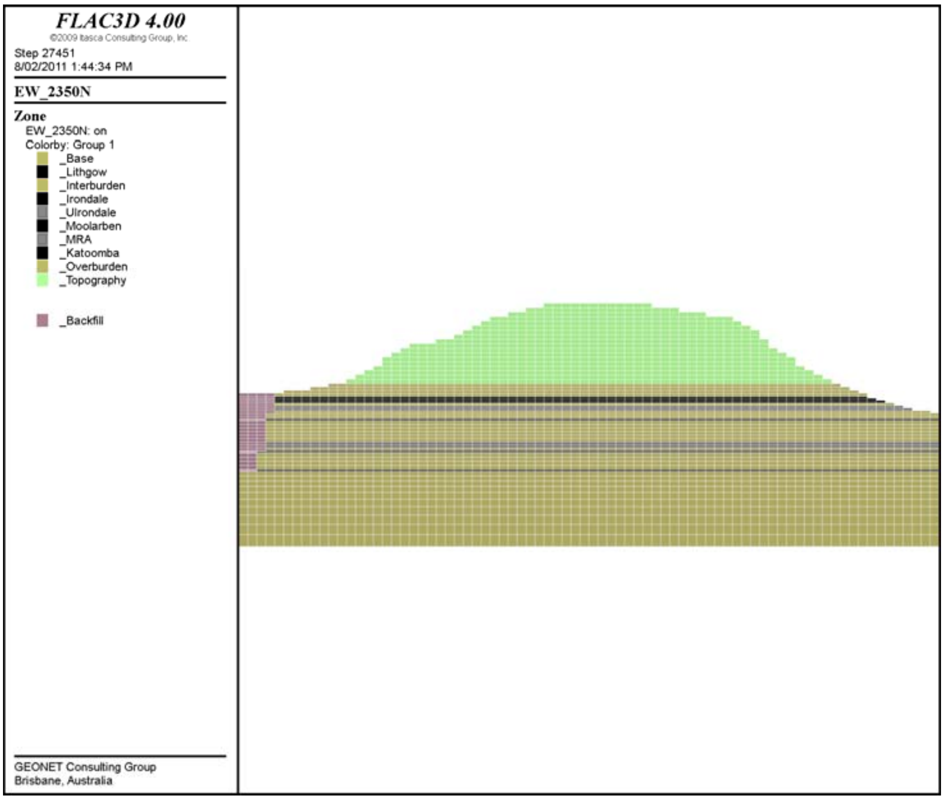

Figure 32(a): Cross-section at 2350N showing geology and backfill in final open pit

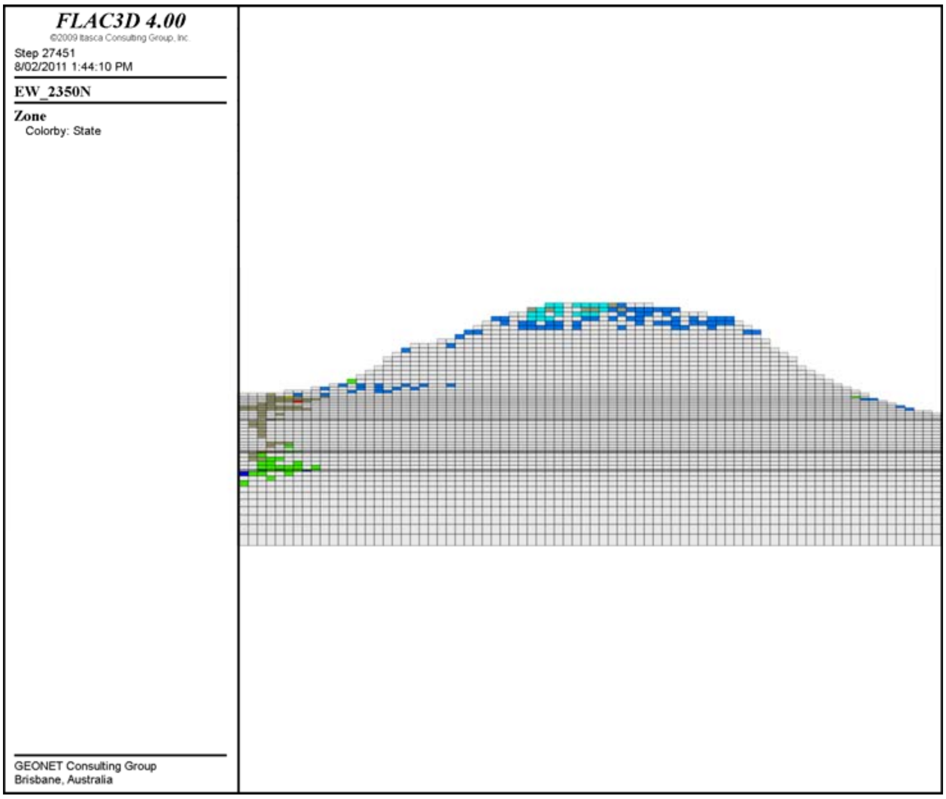

Figure 32(b): Stress condition on section at 2350N after SHM and backfilling

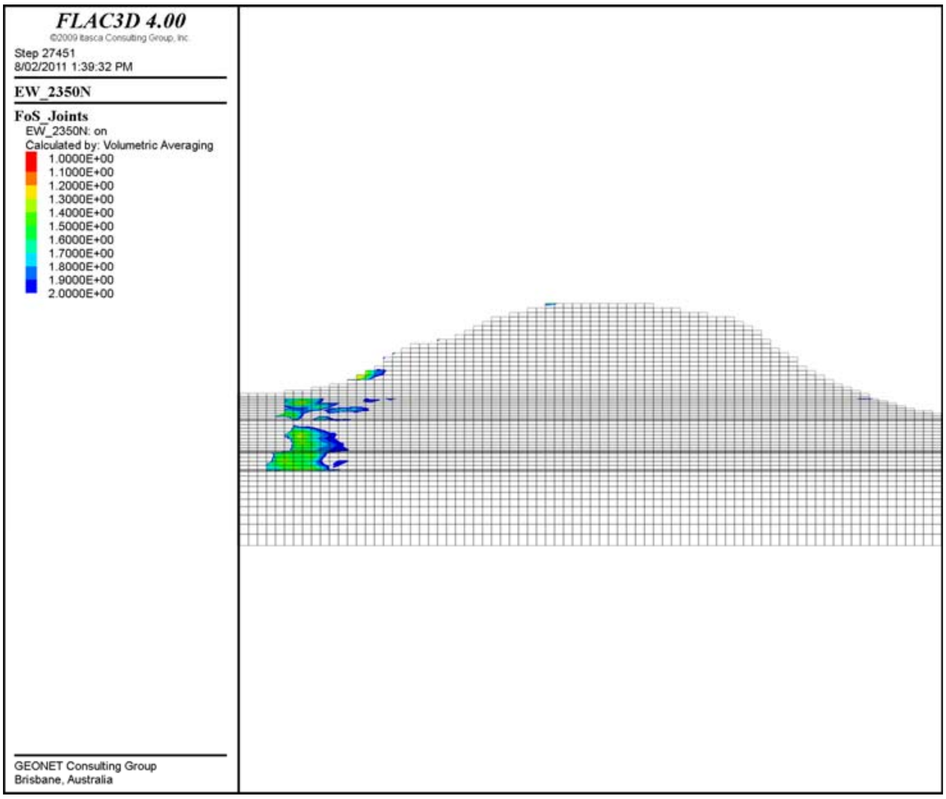

Figure 32(c): Condition of joints expressed as FoS on section at 2350N after SHM

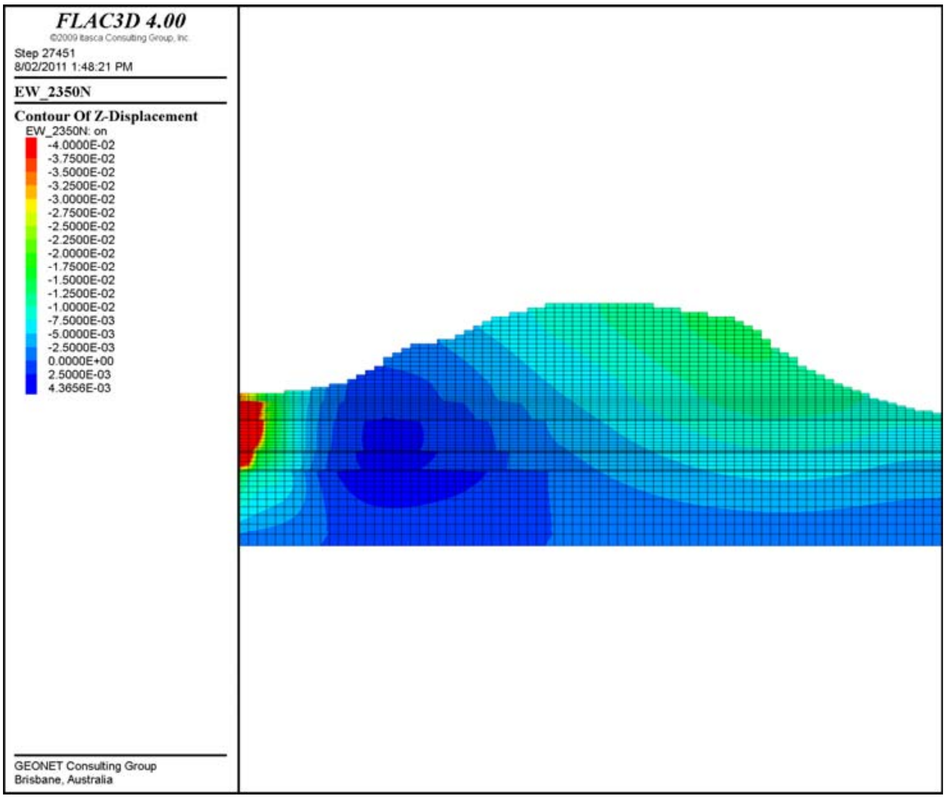

Figure 32(d): Subsidence projected onto section at 2350N after SHM and backfilling

6.0 SHM DESIGN CONSIDERATIONS

6.1 Revision of Katoomba Seam Pillar Width

The original estimate for pillar width in the Katoomba seam subject to maximum 110m of overburden load was 2.6m (W:H=1.3). When the condition of the pillar was simulated it was shown in Figure 12(d) that damage extended through the entire pillar. It was further indicated that the pillar may develop progressive failure, Figure 12(e), if pillar height increased due to roof falls. Initial 3D analysis of the stress condition over the Lithgow underground workings showed that tensile conditions could have developed in the Katoomba seam which may manifest as weaker coal. Given the criterion for limited subsidence, it is essential that the pillar width be increased to ensure long term stability.

If the pillar width is increased to 3.6m (W:H=1.8) then the damage would be limited to cleat loosening at the excavation surfaces, Figure 33. The cores of the pillars now remain intact indicating that the pillars should remain stable. The average pillar stress would then also decrease to 5.0 MPa so that Long Term Stability is more probable.

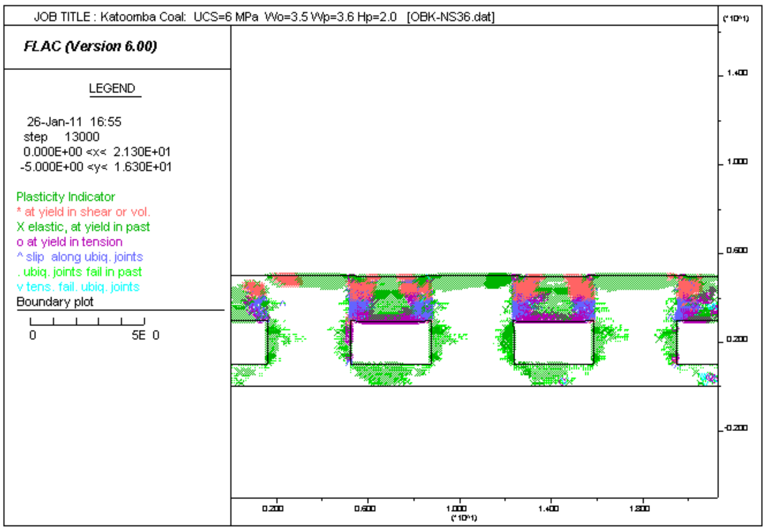

Figure 33: Stress condition in coal pillar (W:H=3.6:2.0=1.8) – Katoomba seam

It is concluded that the original estimate for coal pillars in the Katoomba seam be increased to 3.6m to ensure long term stability. Undersize pillars subject to an applied constant overburden load may be stable in the short term but would yield progressively on cleat and jointing ultimately manifesting as time dependent failure of the pillars. The proximity of this seam to the Triassic rock structures demands that stable conditions are provided and maintained into the future.

6.2 Effect of SHM Misalignment

The importance of maintaining horizon and direction of the SHM is to minimise offsets between adjacent drives. Where there is some deviation of SHM entries, either vertically or horizontally, the risk of shearing through a pillar is increased. Given the limited seam height there is unlikely to be any significant variation in vertical alignment of holes.

Where adjacent holes deviate or intersect, a larger span is created resulting in disruption of the local stress field. At the level of the coal seam local stress concentrations in the undersized pillar may result in the stress increasing a factor of five times the initial insitu stress. Also, there could be significantly more damage because of effectively reducing the design pillar width. Such variations can generally be tolerated within the Factor of Safety of 1.3 with stresses accommodated in the adjacent larger pillar and formation of a stress arch over the under-sized pillar. However, any local concentration of undersized pillars must be avoided as this could result in localised pillar failure which could lead to increased subsidence on surface.

6.3 Orientation of SHM Holes

The highwalls presented for SHM highwall mining follow the highwall contour in all four seam horizons. Thus, entries are driven in a N-S direction along the northern highwall and an E-W direction from the western and eastern highwalls. This is consistent with the intended panel and drive orientation provided by Coalpac.

The reason for recommending the N-S and E-W SHM drive orientations is to maximise the angle between the dominant joint sets and the excavation walls. Cutting parallel to the major joint orientation may promote slabbing and/or roof falls.

6.4 Effect of Previous Mining in Lithgow Seam

Underground mining using bord and pillar methods was previously carried out in the Lithgow seam at the southern end of the area. The mining method involved cutting spans of 5-7m adjacent to substantially wide pillars. The interburden strata between the Lithgow and Irondale seams are 18m thick comprising interbedded siltstone and sandstone. These strata are sufficiently competent to bridge the spans, i.e. assuming that the spans indicated on the mine plans are accurate of the ‘as-mined’ condition. Interburden strata damage exposed in current open cut workings where previous underground Lithgow Seam pillars are now mined, consistently show the same extent of damage as predicted by the model. The well developed jointing in the rockmass may facilitate further localised roof falls which could migrate through the interburden to the Irondale seam. Although there is no observed behaviour of this nature in current mining operations, it is concluded that seam conditions in the Irondale seam may be affected by previous mining in the Lithgow seam.

An overall effect of the Lithgow underground workings will be to alter the confining stress in the rockmass (refer Figure 11(b)). It was shown that tensile conditions could have developed in the Katoomba seam associated with the stress arch formed over the entire working area. This may manifest as weaker coal strength which may facilitate SHM penetration rates but which may more seriously reduce the pillar bearing capacity. Hence the decision to increase the pillar width in the Katoomba seam to 3.6m. Notwithstanding the excellent ground conditions observed and experienced to date, it must be anticipated that there could be changed mining conditions in all the seams above the historic underground workings compared to the undisturbed rockmass.

Water may have accumulated in the historic underground workings in the Lithgow Seam, however, this is expected to be minor according to the detailed groundwater study presented by Australian Groundwater & Environmental Consultants [17]. AGE also predicted that no groundwater exists in any of the other seams. It is recommended that SHM mining in the vicinity of flooded workings should not encroach within 20m in order to minimise any potential risk of promoting seepage or flow conditions in the barrier pillar.

6.5 Long Term Stability of Pillars

The most critical factors determining the long term stability of coal pillars are the pillar dimensions and stress level induced in the pillar with groundwater providing a possible additional factor. The effect of pillar dimension and induced stress in pillars formed in each of the major coal seams was discussed in detail in section 4.4 of this report. It was established that the proposed pillar dimensions will be long term stable in all seams with a slight tendency to progressive failure forming in the Katoomba and Lithgow seams.

Experience and observations to date in unsupported spans in the Lithgow seam clearly indicate stable conditions after 60 years. In other mines stable conditions have been observed after more than 100 years.

The long term seepage of groundwater leading to flooding of workings was calculated by AGE [17] to take over 80 years. Then there are the observed conditions in flooded workings under the city of Newcastle where no deterioration of bord and pillar workings has been detected after 120 years.

It may be concluded that the presence of groundwater and flooding of workings is unlikely to affect the long term stability of adequately designed pillars. The key criterion is to ensure that the pillars are designed not to exceed their elastic limit stress level. Then it may be considered that so long as there are no significant changes in conditions, confidence in the stability should increase with the time that the pillar remains stable.

6.6 Deformation and Subsidence

Coalpac Consolidation Project is located in an environmentally sensitive subsidence area which demands that surface subsidence is limited because the sandstone ridges may be damaged if significant surface subsidence occurs. Surface subsidence can only be initiated if there is widespread collapse of the SHM pillars. Since the pillar design layout is based on achieving a minimum FoS of 1.3 under the maximum overburden height in any panel, it is safe to assume that most of the pillar length will be over-designed in this regard.

In order to estimate the extent of surface subsidence that can be anticipated during highwall mining, plots of surface deformation are presented as:

i) Histories of deformation monitored at five locations on the slope topography overlying the SHM panels as shown on margin sketch, Figure 34.

ii) Contour plan view of deformation over the site, Figure 35.

In Figure 34 the cumulative subsidence following successive stages of backfilling and SHM highwall mining is shown to increase to between 10mm and 22mm after mining in the Irondale seam. During mining in the Moolarben seam the displacements stabilise and then progressively decrease, continuing so through mining in the Katoomba seam. This phenomenon is attributed to the formation of stable stress arches in the interburden. The total magnitude of subsidence reduces and stabilises completely after final backfilling in the open pit. The ultimate subsidence induced by SHM highwall mining at the monitoring locations will be between 10mm and 15mm. This correlates with the total of 13.3mm predicted by the initial 2D analyses (refer p23). Similar magnitudes of subsidence are confirmed in the contour plot for most of the topography, Figure 35.

The most critical area is located on the angled southern point of the western highwall where deformation may increase to 40mm. This is clearly an effect of the major joint orientation being exposed in the highwall. A similar, though much smaller area of joint controlled deformation is indicated at the southern-most point of the eastern highwall. Such structurally controlled areas of subsidence (circled on Figure 35) can be controlled by locally optimising the orientation of the final open pit highwalls in relation to the major joint sets, i.e. realign and step the angled sections of highwall to orientations N-S and E-W. To further assist the stability of this area, Coalpac have set-back the maximum final highwall position by 50m. Coalpac have also committed to stability surveys and modified blasting practices in order to further promote stability of the open cut highwalls and the surrounding pagodas and escarpment environment.

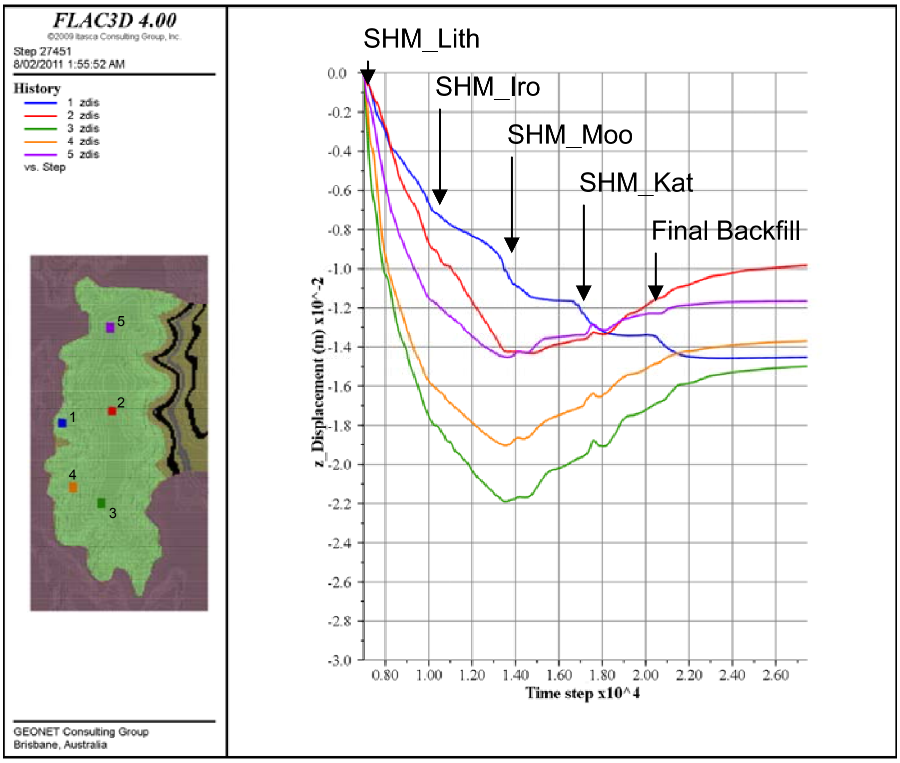

Figure 34: Subsidence histories at different locations during SHM mining

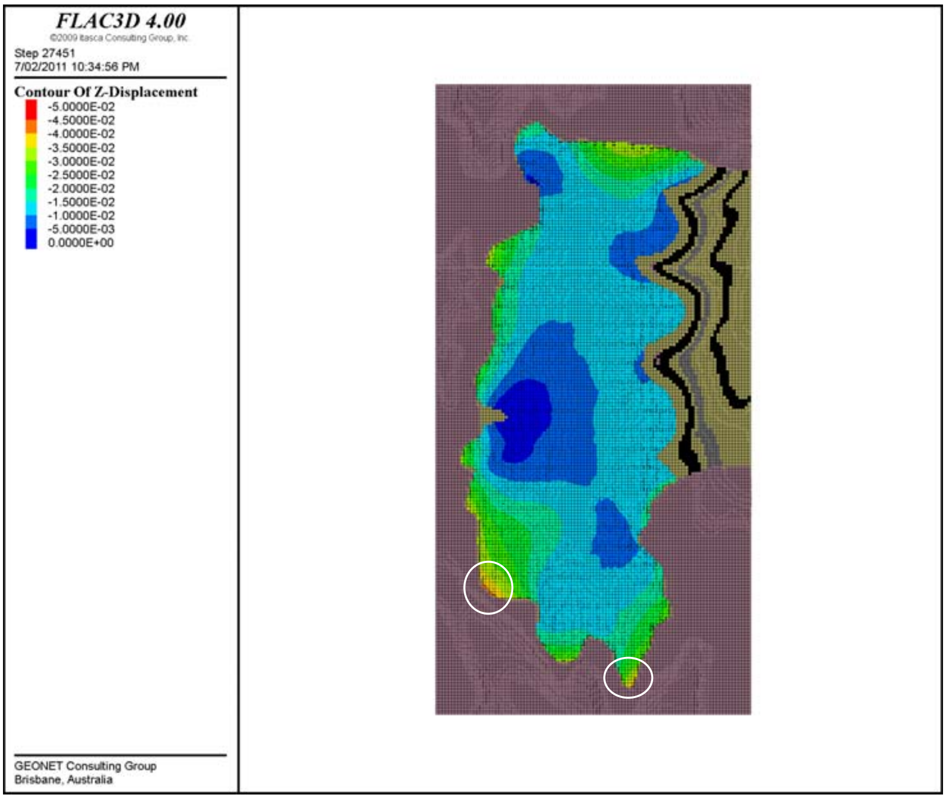

Figure 35: Subsidence contours: Final Backfilled Open Pits
(Circles indicate areas of localised opening of joints in the exposed highwall)

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7.0 LAYOUT OF BARRIER PILLARS

This section presents considerations for the design and layout of barrier pillars in compliance with Annexure B of the NSW I&I Mine Safety Operations document, Coal Technical Reference CTR-001.

The Coalpac Consolidation Project is located in a subsidence sensitive area which demands that surface subsidence be limited. There is a significant risk that the sandstone ridges may be damaged if substantial surface subsidence occurs. Damaging surface subsidence may be initiated if there is widespread collapse of the SHM pillars. The method used to provide assurance against such pillar collapse is to include barrier pillars. The philosophy of the barrier pillar design is to include larger pillars which will arrest any progressive collapse of regular SHM pillars. Obviously within this design approach will be the objective to maximise resource recovery without compromising overall SHM panel stability. A panel is defined as a series of SHM entries with barrier pillars on either side.

Since the SHM pillar design layout is based on achieving a minimum Factor of Safety of 1.3 under the maximum overburden height in any panel it is safe to assume that most of the pillar length under steep topography will be over-designed. The explanation for this is that the same width pillar under shallower cover depths will be more stable. In Figure 36, for an overburden depth of 110m a pillar width of 2.6m will be stable with FoS=1.3. However, the same pillar under 80m of overburden will provide an operating FoS of 1.8. Thus it is concluded that the SHM pillars should be absolutely stable for the first 100m of entry (assuming the highest overburden occurs over the back of the SHM entry). Note that the additional stability provided by the increased pillar width under shallower cover also serves to overcome potential losses in strength of the rockmass associated with blast damage and stress relief effects in the highwalls.

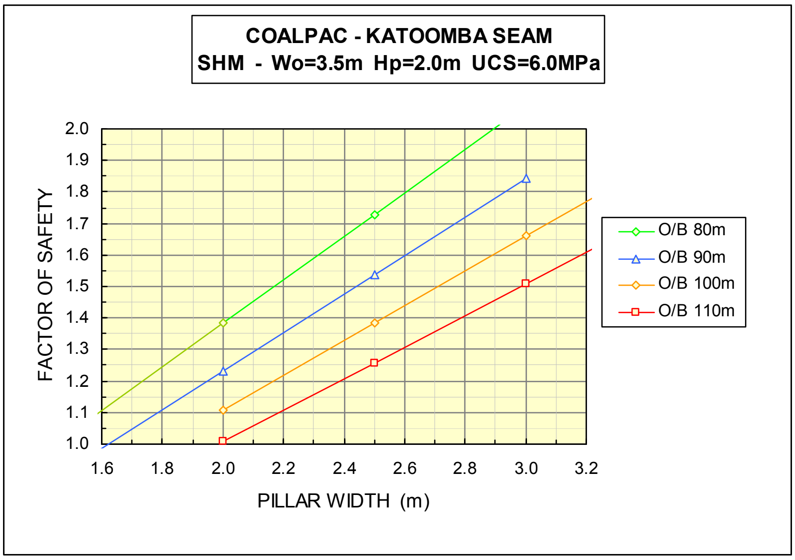

Figure 36: Pillar Design Chart for SHM mining in Katoomba Seam

The placement of barrier pillars within the highwall panels must be based on a number of well established rock mechanics principles. These include:

i) Barrier pillar geometry;
ii) Critical span between barrier pillars; and
iii) Formation of stable stress arch over SHM panels.

7.1 Barrier Pillar Geometry

The most critical aspect governing pillar stability is its geometry, not the strength of the material. It is well established in the rock mechanics literature that stable pillars will occur when the width to height ratio increases above a value of 3. Infinitely strong pillars are achieved with W:H>5. A reasonable criterion for defining the geometry of barrier pillars is 3<W:H<5. However, to ensure long term stability W:H must be greater than 5.

In the current area each of the four seams presented for highwall mining will be mined with different spans, heights and pillar widths. For typical highwall mining operations the barrier pillar is created by leaving every n^{th} entry unmined, where *n* is determined in relation to the critical span as defined and discussed below in section 7.2. The width of the barrier pillar for each coal seam is then a function of the established pillar width and opening span as summarised below.

Barrier Pillar Dimensions

Panel	Pillar Width (m)	Span Width (m)	Pillar Height (m)	Width Barrier Pillar (m)	W:H Barrier Pillar
Katoomba	3.6	3.5	2.0	10.7	5.3
Moolarben	2.1	3.0	1.0	7.2	7.2
Irondale	2.4	3.0	0.9	7.8	8.6
Lithgow	4.6	3.5	2.2	12.7	5.8

It is concluded that stable barrier pillars formed by leaving one entry unmined will meet the criterion W:H>5 for stable pillar design. At the SHM mining design stage there will be scope to design the barrier pillars to optimise pillar width to meet W:H=5 and therefore maximise recoveries. If barrier pillars are included then recoveries may be further optimised by reducing the SHM pillar widths but this will require detailed analysis for specific local mining conditions at the time of mining.

7.2 Span between Barrier Pillars

The spacing between barrier pillars is determined by the critical span associated with the local overburden thickness. The critical span is generally defined to be equivalent to twice the maximum overburden height. Where multiple seams are to be mined the “overburden” thickness is the interburden thickness between successive seams. To maintain stability in the previously mined panels of overlying seams it will be essential to space barrier pillars so as to create a stress arch which does not impinge on the overlying seam. A diagram illustrating this concept is presented in Figure 37.

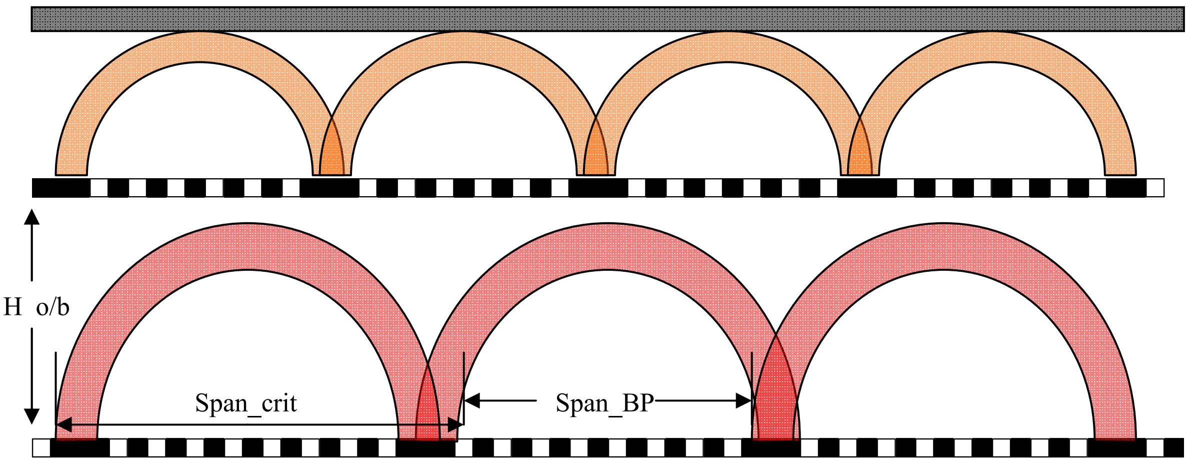

Figure 37: Location of Barrier Pillars for multi-seam highwall mining operations

If the stress arch intersects the overlying seam workings it is most likely that the previously mined panels will collapse under the additional stress.

Given the steep topography of the Coalpac Consolidation Project area and the convoluted profile of the highwall there are two types of barrier pillar formed, described as follows:

a) Uniform width barrier pillars in panels which have highwall face length greater than the critical span.

b) Some panels have been deliberately separated from the adjacent panel because of changes in highwall orientation. The unmined area between such panels may form an effective barrier pillar.

The width of the uniform barrier pillars for SHM panels in the various coal seams is calculated based on the seam interburden thickness, SHM span and pillar width. These data are summarised for each seam horizon below.

Panel	Width Pillar (m)	Width Span (m)	Height Interburden (m)	Critical Span (m)	Width Barrier Pillars (m)	Span between Barrier Pillars (m)
Katoomba	3.6	3.5	15	30	10.7	17.7
Moolarben	2.1	3.0	17	34	7.2	23.4
Irondale	2.4	3.0	33	66	7.8	57.0
Lithgow	4.6	3.5	18	36	12.7	19.7

7.3 Formation of Stable Stress Arch over SHM Panels

By locating the barrier pillars at the sub-critical spans the intermediate SHM pillars in each sub-panel will be subject to reduced overburden stress loading conditions. The barrier pillars will now carry the load difference. An additional benefit of forming a stable stress arch in the overburden is that subsidence of the surface strata will be minimised.

8.0 COAL RECOVERY

The preliminary SHM layout has considered single pass drives in each of the target coal seams. A summary of the potential coal recoveries that may be achieved in one area of the project site (as analysed in this report) is presented in Table 8.1. These have taken into consideration the placement of barrier pillars by leaving every n^{th} entry unmined. Actual recoveries will depend on the final SHM design for the selected area of the Coalpac Consolidation Project. Each in turn will depend on local geology, specification of barrier pillar dimensions and the blends of coal required at the time of mining. There will also be opportunities to optimise the final SHM design to take into account first and foremost subsidence and highwall stability followed by coal quality requirements, open cut mining and waste emplacement schedules.

TABLE 8.1: POTENTIAL SHM RECOVERIES

Coal Seam	Highwall Face (m)	Width Pillar (m)	SHM Holes	Recovery (Tonnes)	Extraction (%)
Katoomba Seam	2120	3.6	241	672,934	37
Moolarben Seam	2120	2.1	347	415,144	49
Irondale Seam	2120	2.4	328	353,162	51
Lithgow Seam	1280	4.6	131	415,332	32
TOTAL			**1,047**	**1,856,572**	**42**

Details of the SHM potential recoveries from each designated block are presented for each of the candidate coal seams in Table 8.2. The coal recoveries are based on achieving the full penetration depth of 305m in every hole except in the eastern highwall where penetrations must be limited to 260m so as not to intersect with entries from the western highwall.

TABLE 8.2: DETAILS OF POTENTIAL RECOVERIES IN EACH SEAM PANEL

Seam	Panel	Wp (m)	Wo (m)	Ho (m)	Pd (m)	Den (t/m^3)	Panel (m)	Scrit_W (m)	BP's	Entries	Recovery (tonnes)
KAT	North	3.6	3.5	2	305	1.35	390	36.6	10	45	129,701
	West	3.6	3.5	2	305	1.35	1090	36.6	29	124	357,399
	South	3.6	3.5	2	305	1.35	190	36.6	5	21	60,527
	East	3.6	3.5	2	260	1.35	450	36.6	12	51	125,307
							2120		56	241	672,934
Seam	**Panel**	**Wp (m)**	**Wo (m)**	**Ho (m)**	**Pd (m)**	**Den (t/m^3)**	**Panel (m)**	**Scrit_W (m)**	**BP's**	**Entries**	**Recovery (tonnes)**
MOO	North	2.1	3	1	305	1.35	390	30.6	12	64	79,056
	West	2.1	3	1	305	1.35	1090	30.6	35	178	219,874
	South	2.1	3	1	305	1.35	190	30.6	6	31	38,292
	East	2.1	3	1	260	1.35	450	30.6	14	74	77,922
							2120		67	347	415,144
Seam	**Panel**	**Wp (m)**	**Wo (m)**	**Ho (m)**	**Pd (m)**	**Den (t/m^3)**	**Panel (m)**	**Scrit_W (m)**	**BP's**	**Entries**	**Recovery (tonnes)**
IRO	North	2.4	3	0.9	305	1.35	390	32.4	12	60	66,703
	West	2.4	3	0.9	305	1.35	1090	32.4	33	168	186,769
	South	2.4	3	0.9	305	1.35	190	32.4	5	30	33,351
	East	2.4	3	0.9	260	1.35	450	32.4	13	70	66,339
							2120		63	328	353,162
Seam	**Panel**	**Wp (m)**	**Wo (m)**	**Ho (m)**	**Pd (m)**	**Den (t/m^3)**	**Panel (m)**	**Scrit_W (m)**	**BP's**	**Entries**	**Recovery (tonnes)**
LITH	North	4.6	3.5	2.2	305	1.35	390	48.6	8	40	126,819
	West	4.6	3.5	2.2	305	1.35	890	48.6	18	91	288,513
	South	-	-	-	-	-	-	-	-	-	-
	East	-	-	-	-	-	-	-	-	-	-
							1280		26	131	415,332
TOTAL							**7,640**		**212**	**1,047**	**1,856,572**

9.0 CONCLUSIONS

To facilitate the Coalpac Consolidation Project plan for SHM highwall mining of coal reserves in the Katoomba, Middle River, Moolarben, Irondale and Lithgow seams across their various mine sites Geonet Consulting Group was requested to develop a generic highwall mining plan for the most critical area of mining in the Ben Bullen State Forest where subsidence sensitive landscapes must be preserved. This area was chosen as a worst case scenario, represented by the maximum overburden thickness. The purpose of the report is to provide an assessment of stability and subsidence associated with SHM highwall mining in the landscape around Cullen Bullen.

The methodology for making the assessment of subsidence and stability involved geotechnical analysis and simulation of the following:

- Estimation of coal seam strengths for each of the proposed mining horizons;
- Recommended pillar dimensions for single pass SHM mining in each seam;
- Evaluation of highwall and overburden conditions that might affect safe and productive highwall mining operations;
- Simulation of historic underground mining and proposed open cut and SHM;
- Estimation of likely subsidence over highwall mined panels, and
- Assessment of potential impact of subsidence on the integrity of local topography.

It is concluded that the total subsidence of landscape ridges induced by SHM highwall mining will be less than 20mm. It is estimated that the maximum subsidence will be in the range 10mm to 15mm in areas overlying previous underground mining in the Lithgow seam. The maximum subsidence in the rockmass previously unaffected by underground mining is predicted to be less than 15mm. At 2350N on the western highwall crest and extending up into the Triassic strata, subsidence is predicted to be less than 5mm.

The SHM site modelling identified local exceptions to the subsidence criterion on the southern point of the western highwall where subsidence may increase to 40mm associated with exposure of unconfined joints in the highwall. These are clearly located within the open cut highwalls and as such would be excluded from the landscape subsidence criterion. These structurally controlled areas of subsidence may be controlled by optimising the orientation and profiles of the final open pit highwalls in relation to the major joint sets. It is recommended to realign and step all angled highwall faces to align N-S and E-W. This should promote stability in the exposed jointed highwalls and reduce subsidence to within the 20mm criterion. Following the Coalpac decision to setback the final highwall position by 50m, the long term stability of pagoda and escarpment features will be ensured.

From an operational point of view, the simulation of SHM highwall mining indicates that:

- The most critical factors determining the long term stability of coal pillars are the pillar dimensions and stress level induced in the pillar with groundwater providing a possible additional factor. The presence of groundwater and flooding of workings is unlikely to affect the long term stability of adequately designed pillars. The key criterion is to ensure that the pillars are designed not to exceed their limit of elastic stress level.
- Seam conditions in the Irondale seam may be affected by previous mining in the Lithgow seam. SHM entries in overlying zones of higher stress in Irondale seam may experience conditions similar to the effect of mining stronger (harder) coal.
- Conditions in the Katoomba seam may also be affected by previous mining in the Lithgow seam. This will become obvious only when the open cuts have been excavated. A tensile zone may form in the Katoomba seam located 50m into the western highwall and 30m into the eastern highwall and extending for 100m along the seam. These changes in stress condition in the coal seam and interburden strata may affect SHM mining rates and overall stability of pillar sidewalls, roof and floor. This should be taken into consideration in any final SHM design.
- Water may have accumulated in the historic underground workings in the Lithgow Seam, however, this is expected to be minor according to the detailed groundwater study presented by Australian Groundwater & Environmental Consultants. They also predicted that no groundwater exists in any of the other seams.
- SHM drives in the Lithgow seam should maintain a minimum 20m offset from previous underground mining operations in order to avoid breaching any flooded workings or initiating instability from previously damaged rockmass conditions.
- Experience and observations to date in unsupported spans in the Lithgow seam clearly indicate stable conditions after 60 years. Stable conditions have been observed after more than 100 years including in the flooded workings under the city of Newcastle where no deterioration of bord and pillar workings has been detected after 120 years. These observations provide definite confidence in the long term stability of coal pillars.
- In order to create long term stable barrier pillars with geometry of W:H≥5 it is recommended to leave at least one entry unmined. The spacing of the barrier pillars depends on the overlying interburden thickness. By locating the barrier pillars at the sub-critical spans the intermediate SHM pillars in each sub-panel will be subject to reduced overburden stress loading conditions. An additional benefit of forming a stable stress arch in the overburden is that subsidence of the surface strata will be minimised.
- Once highwall mining proceeds, then regular visual inspections of these ridges should be made, as well as remote rib and roof stability inspections.

- The overall stability of highwalls at Coalpac Consolidation Project area has not been inspected as part of this study. Notwithstanding the reported excellent highwall conditions in these open pit mines it is recommended to conduct regular surveys of highwall joint condition, joint orientations and overall stability of the highwalls.
- Calculation of a potential coal recovery of 1.856 Mtonnes (in the project area modelled) was based on achieving the full penetration depth of 305m except in the eastern highwall where penetrations must be limited to 260m so as not to intersect with entries from the western highwall. Estimated recoveries from the area presented for analysis in this report are:

Coal Seam	Highwall Face (m)	Width Pillar (m)	SHM Holes	Recovery (Tonnes)	Extraction (%)
Katoomba Seam	2120	3.6	241	672,934	37
Moolarben Seam	2120	2.1	347	415,144	49
Irondale Seam	2120	2.4	328	353,162	51
Lithgow Seam	1280	4.6	131	415,332	32
TOTAL			**1,047**	**1,856,572**	**42**

10.0 RECOMMENDATIONS

This report has provided an analysis of the overall stability of a maximum (worst case) overburden thickness condition for SHM mining in four seam horizons. Future SHM designs will be required under the MOP for all highwall mining areas proposed for the Coalpac Consolidation Project. The recommended design considerations shall include:

1. Optimisation of seams to be mined, considering stability and restricting potential subsidence to <20mm (i.e. design to be long term stable) versus reserve recovery.
2. Highwall orientations to be determined and final highwall positions designed to ensure stability of any nearby pagoda and escarpment formations.
3. The most critical factors determining the long term stability of coal pillars are the pillar dimensions and stress level induced in the pillar. The key criterion is to ensure that the pillars are designed not to exceed their limit of elastic stress level. The presence of groundwater and flooding of workings is unlikely to affect the long term stability of adequately designed pillars.

4. Design of SHM pillars shall take into account the likely entry azimuth deviations based on OEM advice.
5. It is recommended that SHM mining in the vicinity of flooded workings should not encroach within 20m in order to minimise any potential risk of promoting seepage or flow conditions in the barrier pillar.

11. COMPLIANCE WITH RECOMMENDED CTR-001

This geotechnical design report for the proposed highwall mining at Coalpac Consolidation Project complies with the recommended procedures as documented in Annexure B of the NSW I&I Mine Safety Operations document, Coal Technical Reference CTR-001.

Eight specific activities are identified in CTR-001. Our assessment of each of these criteria is summarised in the following table. The superscripted numbers refer to the additional comments following this summary.

	Geotechnical Design Criterion	**Yes**	**No**
1.	Estimate the strength of coal webs employed in the layout	Y[1]	
2.	Determine the probable Factors of Safety of coal webs	Y	
3.	Determine the span stability for the entry between each web	Y[2]	
4.	Determine maximum permissible panel span between barrier pillars	Y[3]	
5.	Determine minimum width for barrier pillars	Y[4]	
6.	Identify geological/structural factors that may impact on design	Y	
7.	Assess stability of immediate highwall face taking into account its age prior to mining, its weathering capacity and batter angle	Y[5]	
8.	Establish monitoring and reporting systems to enable variations in mining conditions to be geotechnically assessed.		N[6]

Additional comments in relation to summary of compliance tasks:

1. Coal strength is unique to every mine site and is critically affected by the seam geology. The effects of specific local geological conditions were taken into consideration in defining the coal seam strength assigned to each seam.
2. Span stability is assessed using numerical modelling of the pillar and span configurations for each coal seam geology and geometry including the immediate roof and floor strata.
3. The inclusion of barrier pillars in a panel design is geotechnically assessed based on local geological and mining conditions. The formation of stress bridges between individual pillars or successive barrier pillars is entirely controlled by the strength and condition of the overburden strata. There is no universal pillar design layout and each site has to be individually assessed. The geotechnical design layout of SHM holes and placement of the barrier pillars takes all of these factors into consideration.

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4. Following on from the previous discussion point, our method of barrier pillar design ensures long term stability by constructing the barrier pillars with geometry of W:H>5. Each barrier pillar comprises the width of two pillars and the SHM span. These pillars are effectively twice the width of the generally recommended practice. Also, by locating the barrier pillars at the sub-critical spans the intermediate SHM pillars in each sub-panel will be subject to reduced overburden stress loading conditions. An additional benefit of forming a stable stress arch in the overburden is that subsidence of the surface strata will be minimised.

5. A geotechnical assessment of actual highwall stability could not be included in the design report as no open pit mining has commenced in the area presented for analysis in this report. This will be carried out as part of the Mining Operations Plan.

6. The establishment of monitoring and reporting systems is an essential part of the actual SHM mining operations and should be included in the Mining Operations Plan. The location of critical areas was indicated and recommendations made to establish appropriate monitoring systems at those locations.

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APPENDIX 1:

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2 April 2011

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FINAL REVIEW STATEMENT ON REPORT
"ASSESSMENT OF STABILITY AND SUBSIDENCE – SHM IGHWALL MINING – COALPAC CONSOLIDATION PROJECT"
FOR
HANSEN & BAILEY

1. Introduction

Boyd Mining has considered the response by Geonet Consulting Group to the review comments of 25 February 2011. Final review, including consideration of the issues raised from the initial review is provided as highlighted commentary below.

2. Review Comments by Report Section

Comments are provided only for those report sections for which clarification is requested or any inconsistency was observed. Overall it tis the reviewers understanding that the report addresses the title by the following scheme

- Define indicative seam strength from back-analysis of auger entries in the Lithgow Seam (for which web pillars were formed at a width to height ratio of 0.5).
- Determine rectangular pillar dimensions for select opening heights and cover depths using empirical formulae
- Generate stability chart linking pillar stress to pillar dimensions for a minimum design FoS=1.3
- Numerical model empirically determined pillar dimensions for average strength under expected load conditions
- Simulate the sequence of mining including historical underground mining of Lithgow Seam then surface open cut mining/highwall mining/backfilling of Lithgow, Irondale, Moolarben and then Katoomba Seams in that sequence
- Final disturbed area backfilling

There are carried dependencies within this sequence i.e. outputs at any one stage of the sequence impacts the veracity of subsequent stages.

Section 2.1:

- Para 4: No definitive data on joint orientations provided ; this could be critical in open cut mining phase and later reference is made to impact on joint orientations on pitwall stability. **Data sighted and confirmed as adequate**

- Figures 3b, c and d do not indicate proposed SHM working section as does Figure 3a; the analysis of pillar strength includes impact of seam, roof and floor geology and clear demarcation of these horizons needs to be understood.
  Confirmed that working sections adequately defined

Section 2.3

- Para 1: Would there not be large amount of data on Coal seam properties in the literature particularly NERDDC and/or ACARP programs
  Response accepted as adequate explanation
- Para 3: assume reference to W/H=0.5 is for auger web pillars, therefore Fig 5 data relates to auger pillars and derived strength (6MPa) also is derived from auger pillars; the author recommends all SHM designs should be based on UCS=6MPa for all coal mass in pillars; query the use of web pillar back-analysis for rectangular pillar strength.
  Misunderstanding explained although greater clarity in tying solid strength to UCS standard sample aspect ratio would have been suggested in initial review; matter resolved

Section 2.4

- Cohesion for backfill is 320kPa; if loose dumped and subject to self weight compaction then value is high
- Cohesion for bedding planes suggests planes are intact; is this correct.
  Explanation adequate in light of minimal impact to analysis results

Section 3.2

- The use of pillar stress/strength including tributary loading curve shown in Figure 6b is used for each seam in Figures 7b, 8b, 9b, 10b. Pillar strength with varying W/H ratios is developed using the CSIR formula (as distinct from Hustrulids)
- If understood the ordinate for each selected W/H ratio should intercept values on the tributary load and stress (strength)=6MPa curves for each seam such the ratio of these values equals the target FoS=1.30. They don't, e.g. Figure 7b shows that at pillar strength at W/H=1.3 is equal to pillar load (tributary) and therefore FoS=1.0 assuming a k value of 6MPa. Same results in Fig 8b, close result in Fig 9b and in Fig 10b FoS is about 1.15.
- Are these seemingly very useful charts plotting correctly.
  Working example explained and understood; calculations for remaining seams checked and verified as FoS >=1.3

Section 4.3

- Again reference to stability of auger web pillars is used to suggest stability of rectangular pillars when it is well understood web pillars are inherently more stable due to shape.
  Intent of statement understood and accepted

Section 4.4

- Check calcs for pillar stress using tributary load theory ok for Katoomba and Moolarben Seams but at odds for Irondale (9.1MPa vs 8.8MPa) and Lithgow Seam (7.98MPa vs 7.0MPa).
  Issue remains but impact does not detract from result or outcome
- How does the author rationalise pillar strengths of up 33.5MPa as tabled to the 6MPa recommended from back analysis by numerical modelling (Section 2.3).
  Misunderstanding clarified
- Does tabled max pillar deformation reflect tabled pillar strengths or the 6MPa strength
  Misunderstanding clarified

- Subsequent sections on the strength and deformation characteristics for each seam pillar analysed draw on the plots of average stress in coal pillars in either the first or second abutment formed; in most figures e.g. 12c etc., the curves does not represent stabilised stress conditions (curves still rising, some at steep gradients). Also does this stage of initial panel opening give rise to highest abutment pressures??
  Response unclear but reviewer defers to authors expertise in the analysis outputs
- The abutment loads however all equate to average coal pillar mass strength lying in the "linear elastic" portion of the stress/strain curve which denotes expected stability.

Section 5.5

- **Para 2:** Why are tensile conditions in near surface joints a natural phenomenon and related to SHM. Compare Figures 22b and 29b after deformation shown in Fig 22b is reset to zero. These figures suggest deformation is post SHM.
  Misunderstanding of analysis criteria understood

Section 6.2

- Para 1: It is stated that due to "limited seam height" vertical misalignment will be similarly limited. This is not in accord with selective working sections being a small proportion of total seam thickness (Figs 3a to 3d) and that vertical misalignment can happen and present different seam geology to pillar, hence pillar strength.
  The response suggests issue remains outstanding
- Para 2: horizontal deviation correctly described as to impacts which are significant. Given the significance should there not have been a simulation of such deviation (convergence) of adjacent holes to test the robustness of FoS=1.3
  Response accepted

3. Conclusion

The Geonet report is a well structured coverage of the issues confronting the planned sequence of mining in coal leases held by Coalpac Corporation at Cullen Bullen. The process of analysis is appropriate and mostly consistent with the purpose of the study as stated.

Queries arising from the 25 February review have been explained and explanations found acceptable to the reviewer with respect to interpretation, process understanding and impact on analysis outcomes.

The author agrees that the impact of full convergence of the stacked sequence of openings be analysed to demonstrate panel stability is well invested with the adoption of an FoS=1.3. It is agreed this analysis can be performed as part of the final plan of operations.

In conclusion the report "ASSESSMENT OF STABILITY AND SUBSIDENCE – SHM HIGHWALL MINING – COALPAC CONSOLIDATION PROJECT" is regarded as adequately responding to the brief of the study and the study purpose.

GL Boyd.

Graeme L Boyd
Principal
Boyd Mining Pty Ltd

APPENDIX 2:

REPLY TO PEER REVIEW

A review of this GEONET report was made by Boyd Mining Pty Ltd, included in this document as Appendix 1. In response to the various queries presented in the review document, this section provides a reply to each point raised. In the interests of succinctness, the replies are presented in the order that they appear in the Boyd Mining review to provide clarification as requested.

Section 2.1

- Jointing is included in the simulations of material strength and in the mine scale model. Definition of the rockmass jointing is presented in Section 5.1 under the section Model Geometry and Geology (p40).
- The SHM sections for mining are clearly marked on Figures 3(a) to 3(d) with the red coloured overlay.

Section 2.3

- Substantial data base of materials testing in extensions of the Lithgow seam at Ulan Mine were drawn on. The various material input parameters have been validated in previous analyses of open cut mining at Invincible Colliery. The basis of the original comment in the report referred to there being no specific testing made for the site under consideration.
- There is a misunderstanding here in relation to the definition of material strength and pillar strength. Material strength is typically defined in terms of the unconfined (uniaxial) compressive strength. The geometry of the UCS test is based on the ISRM standard dimension of width to height ratio equal to 0.5.

  It is well established in the rock mechanics literature that strength depends on the sample dimensions, in particular width:height ratio. Similarly for pillars. Hence the strength of a pillar is always referenced with its dimensions. Thus, a pillar of rock with dimensions W:H=0.5 will have a strength equal to the UCS, but a pillar of the same rock with dimensions W:H=5.0 will be infinitely strong.

  In the case of the coal seams at CullenValley Mine the rockmass strength established for the coals is 6 MPa, i.e. based on sample dimensions W:H=0.5. The strength of a squat pillar in coal will always be greater than this value.

Section 2.4

- The cohesion assigned to the backfill in the model was 320 kPa. Agree that this value is high for loose dumped material. However, the shear strength of the backfill will not be mobilised in the current open pit where the backfill is fully constrained by the highwall. It can be concluded that in this particular case, the assignment of a lower cohesion value would not have made any difference to the highwall and general rockmass behaviour.
- The cohesion assigned to the bedding planes refers to the strength on these surfaces before mining takes place. Obviously, any changes in stress associated with mining will affect the condition of the joints.

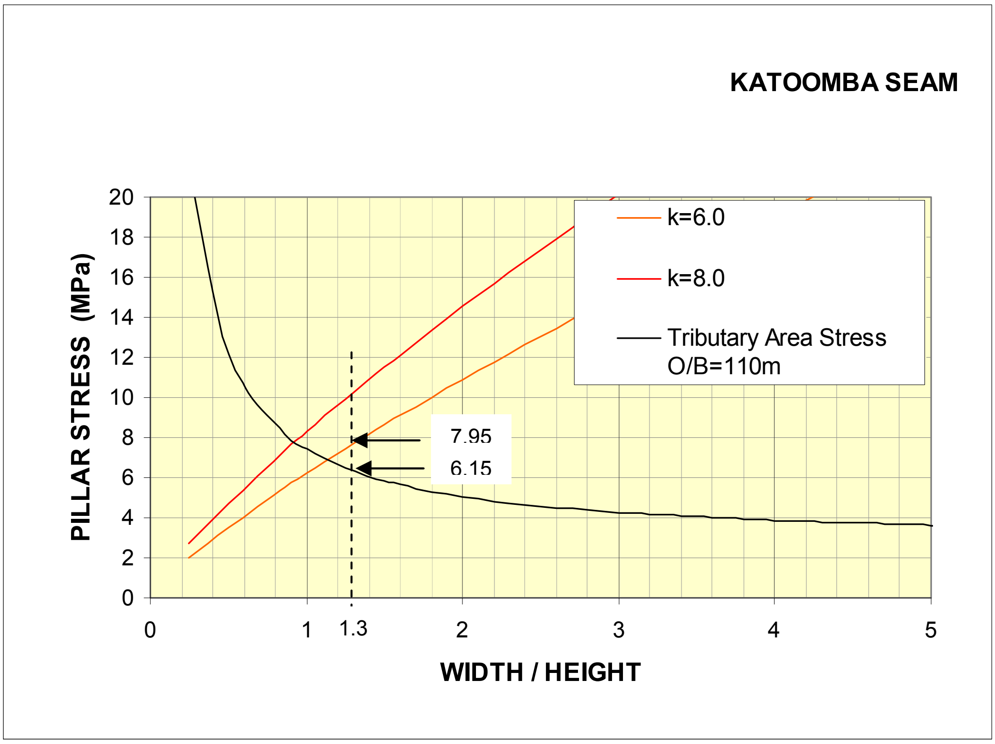
Section 3.2

- Taking the example cited in the Boyd Mining review for Katoomba seam coal it is established from the empirical design chart that a pillar width of 2.6m will be required to achieve a FoS=1.3 (refer to Figure 7(a)). Based on a cutting height of 2.0m then the proposed pillar width:height ratio will be 2.6/2.0=1.3.

  Now the ordinate values corresponding to W:H=1.3 are shown in the figure below to be:

Tributary Pillar stress:	6.15 MPa
W:H=1.3 Pillar strength:	7.95 MPa
Factory of Safety:	$7.95/6.15 = 1.29 \approx 1.3$

  This result corroborates the accuracy of the plotted graphics and validity of the method of presentation. Similar analyses of conditions in other seams produce the same results.



Section 4.3

- Reference to stability of auger pillars was included only to illustrate that highwall mining in the Irondale Seam located above underground workings has remained stable since excavation two years ago. This suggests that conditions in the Irondale seam have not been significantly affected by historic underground mining.

Section 4.4

- Tributary calculations verified as correct, refer to discussion under section 3.2 above.
- Refer to discussion under previous section 2.3 in relation to the definitions of material strength and pillar strength.
- Again a misunderstanding by the reviewer in relation to the definition of material strength and pillar strength. Deformations are for the pillar dimensions analysed.
- The stress-strain curves are absolutely stabilised. The fact that the final points end at the same position and that there is no further change in stress or strain indicates definitively that the condition has stabilised.
- Correct.

Section 5.5

- Deformation is reset; the stress state is not reset. The condition indicated in the plots relates to the cumulative changed stress condition in the rockmass. The indicated tensile condition in joints has evolved during the formation of the current topography and additional changes to the condition of joints are imposed during excavation of the open pit (refer to Figure 25(b)).

Section 6.2

- This is strictly correct for the condition in Katoomba and Lithgow seams, but not for the Moolarben and Irondale seams which are constrained by their limited height.
- These analyses were considered beyond the scope of the current project. However, it is agreed that these analyses should be made as part of the Mining Operations Plan.