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INDEPENDENT ASSESSMENT

HUME COAL PROJECT

Prepared for:

NSW DEPARTMENT OF PLANNING AND ENVIRONMENT

Report No. 1716-12/1b

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1.0 INTRODUCTION

This report has been prepared at the request of the Department of Planning and Environment (DPE) in relation to the mining method proposed in the EIS for the Hume Coal Project. The DPE requested advice:

- *to confirm that the levels of subsidence resulting from this method would be as predicted in the EIS;*
- *about the underground safety aspects of using this method; and*
- *about the risk of subsidence impacts and environmental consequences to natural and built features, including groundwater aquifers.*

The advice has been structured around providing an overview of the mining method and its geological setting, followed by a review of some basic physical and engineering principles relevant to the matter. These form the basis for then assessing stability aspects of the mine layout; surface subsidence predictions and impacts; and safety aspects of the proposed mining method.

2.0 APPROACH TO THIS REVIEW

The mine design proposed for the Hume Coal Project places a high reliance on the spanning capacity of massive sandstone strata in the overburden for ensuring a safe and stable mine layout that limits impacts on groundwater and the surface. The mine is effectively broken up into a series of, nominally, 60 m wide by 120 m long compartments. Four metre wide roadways, referred to as 'drives' or 'plunges', are driven within each compartment by mean of a remote controlled continuous miner so as to form up a series of narrow, 120 m long strip pillars, referred to as 'web pillars' or 'panel pillars'. The concept relies on the sandstone transferring some of the weight of the overburden from the panel pillars to the perimeter pillars of each compartment, thus enabling the use of narrower and, therefore, weaker panel pillars than would otherwise be the case.

There are a number of aspects of the mine design that are novel, unusual and/or which do not align with conventional mining guidelines and practices. Some points of note are:

- While the EIS states that similar mining systems have been used at various locations around the world, including the United States of America and Australia, it does not note a number of significant differences between these systems and that proposed for the Hume Coal Project. The similar systems identified by the proponent for the purpose of preparing this advice involve using remote controlled continuous miners in an underground environment to drive roadways for maximum distances of typically 15 m. The proponent has recently advised that to its knowledge, there is no previous experience of driving 120m long, narrow drives by remote control means in an underground coal mine.[1]

- The mine layout is referred to in the EIS as bord and pillar first workings and utilises panel (web) pillars that range in width from 3.5 m at a depth of 80 m to 6 m at a depth of 170 m. This contrasts with NSW legislation that specifies minimum pillar widths for bord and pillar first workings of 10 m to 17 m for this depth range. Application can be made to the regulator seeking approval to form narrower pillars but I am only aware of this being granted for isolated pillars and not for panels of pillars.

- The width to height ratio of the panel pillars ranges from 1 to 1.7 and their stability has been assessed utilising the UNSW Power Pillar Strength Formula (Salamon et al., 1996). Galvin et al (1995) recommended from the UNSW research that underpinned the development of that formula that, due to the sensitivity of the strength of low width to height ratio pillars to geological structure and to slight variations in pillar dimensions, a lower width to height bound of 2 should be applied when using pillar strength formulae.

- The determination of pillar load in the proposed mine layout is, as recognised by the mine designer and as in many mining layouts, indeterminate[2]. Numerical analysis is required to estimate pillar load in these situations and has found extensive application for this purpose in all forms of underground mining since the late 1960s. However, numerical modelling has not been employed on this occasion, with the assessment of web pillar stability in the EIS instead being based on what the designer considers to be upper and lower extreme values of pillar loads. This results in the predicted

[1] HCPL (2017b).
[2] Frith (2017c).

likelihood of pillar instability falling somewhere within a range of <0.000001% to 50%.

- The mine design relies on a judgement that should the peak load carrying capacity of the web pillars be exceeded, they will yield in a controlled and gradual manner and continue to provide some support to the immediate roof, rather than completely collapse, including in a dynamic and violent manner as can be the case for such small width to height ratio pillars. Theoretically, controlled yielding is plausible in the given circumstances. However, it is unusual for numerical modelling not to be undertaken to aid in quantifying the likelihood of success and the residual risk associated with such a critical design factor.

A number of fundamental engineering principles and guidelines need to be considered when addressing these types of aspects in so far as they impact on mining safely and controlling groundwater and subsidence related impacts. Some of the principles are complex. This review is founded on attempting to present the more basic and relevant principles and other background material in a summarised and simplified form, albeit that a level of complexity is still associated with some.

3.0 OVERVIEW OF THE PROPOSED MINE LAYOUT

3.1. EIS DESCRIPTION

The target coal seam is the Wongawilli Seam, which ranges in depth from typically 80 m to 170 m and generally dips to the east. Mine design has been based on a mining height of 3.5m. The mine layout is predicated on restricting the width of mining panels in order to promote the bridging of massive strata (Hawkesbury Sandstone) in the roof for the purposes of preventing caving of the superincumbent strata and shielding pillars within the mining panels from the full deadweight load of the overburden.

The proposed mine plan at the completion of mining in Year 21 is shown in Figure 1 and is based on the generic mining layout shown in Figure 2.

The EIS describes the generic mining layout and mining method as:

1. *It is based around the development of mains panels and discrete three heading production panels from which long "drives" will be driven left and right. In this regard it is similar to the panel set-up for the Wongawilli Method of secondary pillar extraction.*[3]

2. The drives are formed up remotely using a single pass continuous miner to form a 4 m wide, unsupported roadway that may be up to 120m long.

3. *The adopted mine design uses five fundamental coal pillar types:*

    a. *mains heading pillars;*

    b. *web pillars between drives/plunges;*

    c. *intra-panel barriers between a series of narrow drives and web pillars;*

    d. *inter-panel barrier pillars between a series of narrow drives and web pillars;*

    e. *solid barriers between mining panels and the main headings*.[4]

4. *The web pillars and intra-panel barriers represent the key elements of the mining system as they are required to be as narrow as possible to allow efficient mining, yet also retain stability as the primary foundation for longer-term overburden stability*.[5]

5. *The use of sub-critical geometries between intra-panel barriers is another key element of the mine design to achieve long-term stability, so as to prevent the low width to height web pillars ever being subject to full tributary area loading under a soft overburden loading system. The use of sub-critical panel geometries effectively negates the ability of the overburden to ever force the web pillars between plunges to a state of full collapse independent of the intra-panel barriers*.[6]

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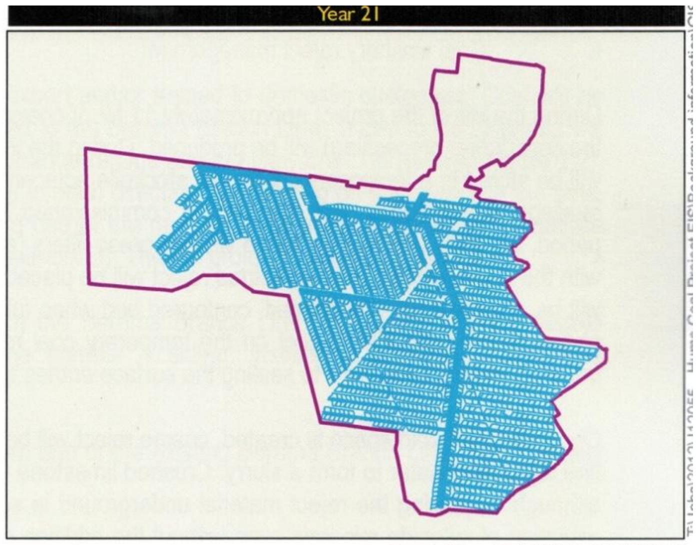
[3] Appendix L, Mine Advice Report: EMM01/2, page 24
[4] Volume 1, Executive Summary, page ES.12.
[5] Appendix L, Mine Advice Report: EMM01/2, page 25.
[6] Volume 1, page 355.



Source: Hume Coal (2016); EMM (2016)

Figure 1: Proposed mine plan at the completion of mining in year 21.

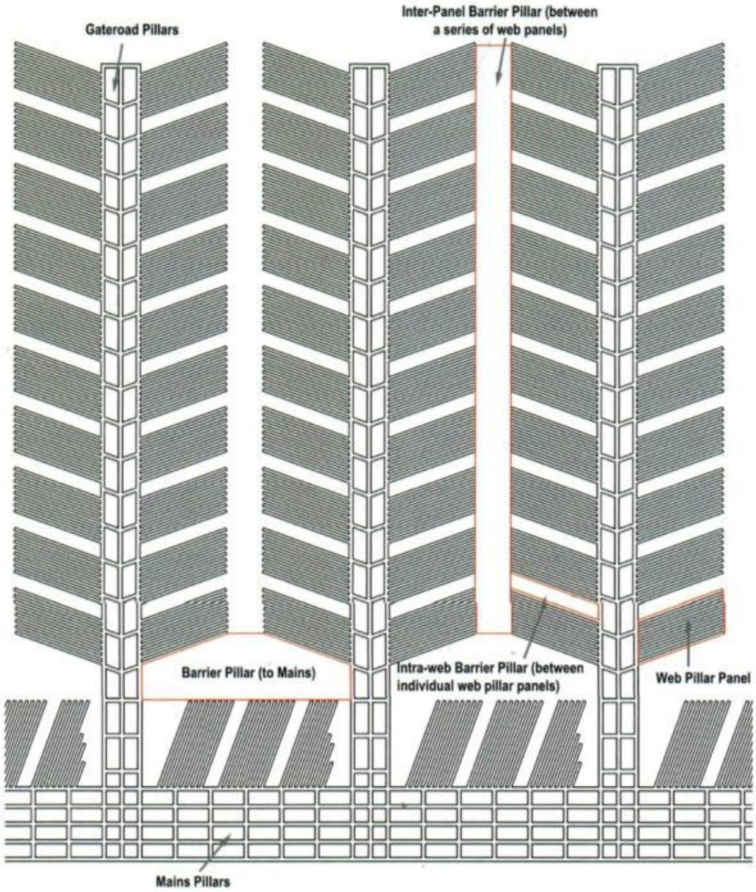


Figure 2: Generic mine layout for the Hume Coal Project.

Other relevant features of the proposed mine layout as reported in the EIS include:

- *The first workings mining method adopted for the project was specifically chosen so that subsidence related impacts will be negligible as a result of mining. In this regard, the principle design features of the mining layout are as follows:*
    - *To prevent overburden fracturing, the layout is similar to that of highwall mining, whereby a series of long drives are installed using a remote mining method, with long, slender pillars in between drives and interspersed wider barrier pillars to enhance geotechnical stability and reduce geotechnical risk.*
    - *A suitably high Factor of Safety (FoS) has been used as a design criteria, so that the coal pillar system left behind after mining is designed to be stable over a long-time*.[7]
- *The layout is not dissimilar to that of "highwall mining" whereby a series of long "drives" are formed up using a remote mining method using "spans" between coal pillars of no more than a standard mine roadway width – this is the key to preventing overburden fracturing*.[8]
- *The mining layout draws upon elements of other commonly used underground and surface mining techniques*. [9]
- *Proven mining plant and equipment from highwall mining and traditional underground coal mining will be used.*[10]
- *Similar mining systems have been used at various locations around the world, including the United States of America and Australia. The innovative aspects of the project involve the manner in which proven techniques and equipment are combined to form a new mining system.*[11]

The EIS reports that mining constraints are:

1. The need to keep surface subsidence movements and impacts to an "imperceptible" level.
2. The need to minimise the hydrogeological impact on sub-surface strata above the targeted coal seam (Wongawilli Seam).
3. The need to emplace all reject material from the CHPP back into underground workings.

These are referred to as 'environmental requirements' and are said to guide the following outcomes and to be mandatory both during and after mining:[12, 13, 14]

[7] Volume 1, page 349.
[8] Appendix L, Mine Advice Report: EMM01/2, page 5.
[9] Appendix L, Mine Advice Report: EMM01/2, page 5.
[10] Volume 1, Executive Summary, page ES.16.
[11] Volume 1, Executive Summary, page ES.15.
[12] Appendix L, Mine Advice Report No: Hume13/2, page 2.
[13] Appendix L, Mine Advice Report: EMM01/2, page 23.

1. No overburden caving can be allowed during or following mining. Therefore, narrow extraction panels between barriers and a long-term stable coal pillar system are intrinsic to the mining method.

2. Overburden fracturing must be either prevented or at worst maintained at insignificant levels.

3. No tensile opening of pre-existing jointing within the overburden as this would substantially increase the permeability of the overburden.

4. Roadway roof instability should be minimised wherever possible so as to reduce the surface area for groundwater inflow into the mine workings.

5. In any areas where thin aquicludes material is present between the coal seam and overburden strata, it should ideally be left in place to assist in reducing ground water inflows into the mine. However practical mining considerations may not always allow this to occur.

6. Completed mine workings must remain accessible by persons and be suitably stable for CHPP reject emplacement and disposal.

7. The mine layout must be subdivided into discrete mining panels that can be permanently sealed soon after mining to allow the workings to become flooded as soon as possible. Following flooding, pre-mining ground water levels and pressure can be re-established

The most significant constraint to mining is stated to be *the direct hydraulic connection of the coal seam aquifer to be mined with other near-surface water-bearing strata. To address this major constraint to mining, the proposed system of mining has been developed to prevent overburden fracturing and/or collapsing as well as assisting the rapid re-establishment of water pressure within the mine workings, the aim being to: (a) minimise the hydrogeological impact during the period of mining and then (b) return the groundwater regimes to their pre-mining state as soon as possible after the cessation of mining.*[15]

The mine design and associated stability assessments in the EIS for the web pillars and intra-panel pillars (described above as being the key elements of the mining system) have been based on the dimensions shown in Table 1. This review for DPE has had regard primarily to the two highlighted depths (80 and 160 m) as these are the lower and upper ranges on which the *Mine Design Justification Report, Hume Project* (Frith, 2017a) has been based.

[14] Appendix L, Mine Advice Report No: Hume13/2, page 1.
[15] Appendix L, Mine Advice Report: EMM01/2, page 5.

Table 1: Dimensions of the web and intra-panel pillars described as key elements of the mining system.[16]

Depth of Cover (m)	Web Pillar		Intra-panel Barrier Pillar		Web Panel Width (excluding barriers) (m)
	Width (m)	w/h	Width (m)	w/h	
80	3.5	1	14	4	56.5
90	3.5	1	14	4	56.5
110	3.8	1.09	16.4	4.7	58.6
120	4.1	1.17	16.8	4.8	52.6
130	4.4	1.26	18.0	5.1	54.4
150	5.1	1.46	20.7	5.9	58.6
160	5.5	1.57	20.9	6	51.5
170	6.0	1.7	22.8	6.5	54.0

3.2. GENERAL ASSESSMENT

While the EIS describes the mine layout as being based on five types of pillars, six different pillar systems need to be assessed because intra-panel pillars comprise both strip barrier pillars and trapezoidal shape panel heading pillars, referred to as gateroad pillars in Figure 2.

The mining method is referred to variously in the EIS as:

- being not dissimilar to that of 'highwall mining';
- constituting 'first workings';
- being similar to the panel set-up for the 'Wongawilli Method' of secondary pillar extraction; and

[16] Appendix L, Mine Advice Report No: Hume13/2, page 25 & Mine Advice Report: EMM01/2, page 27.

- being substantially similar to a 'bord and pillar' only scenario in that there is no secondary coal extraction across extensive areas and as a direct consequence, no caving of the roof strata.[17]

A general understanding of these various mining concepts is important as some reliance has been placed on their meaning by other contributors to the EIS and because they inform this review for DPE. For example, it is reported in relation to groundwater modelling that:

> *Relaxation effects in the rock immediately above the mine were set to nominally 2 m. This is also the adopted height of groundwater drainage (desaturation). This approximate height of deformation has been described as typical for other first workings around the world .....*[18]

Highwall mining is a surface mining method in which roadways referred to as 'plunges' or 'drives' are driven at or close to right angles into the final highwall of a surface mine using a remote controlled continuous miner connected to a continuous haulage system (conveyor network) to transport the coal to the surface. If conditions permit, plunges can be up to 500 m long, although considerably shorter distances are the norm. The plunges are driven in a single pass of the continuous miner and are typically 3.5 to 4 m wide. They are not supported. A narrow continuous web or pillar of coal is left between each plunge for a given number of plunges, before then leaving a wider 'barrier' pillar. The primary purpose of these periodic barrier pillars is to act as abutments to the superincumbent strata bridging over the plunges since the web pillars do not necessarily have the capacity to carry the full deadweight load of the overburden.

Figure 3: An example of a highwall mining operation (Galvin, 2016).

The mining method for the Hume Coal Project resembles highwall mining in that it is proposed to remotely drive unsupported plunges of 4 m width for up to 120 m, leaving a web of coal between plunges that varies in width from 3.5 m to 6 m, depending on depth. Approximately every 60 m, the pattern of web pillars is to interrupted by a barrier or 'intra-panel' pillar that varies in width from 14 m to 22.8 m, Table 1.

Two significant differences between the proposed mining method and highwall mining are, firstly, in the Hume Coal Project plunges are being driven from an underground roadway that is only 5.5 m wide, as opposed to being driven from a bench on the surface that is typically 50 to 100 m or wider. Secondly, plunges in the underground environment are proposed to be

[17] Appendix L, Mine Advice Report: EMM01/2, page 31.
[18] Volume 4A, page 161.

developed at 70° to the coal face rather than close to or at right angles to the face. This means that in the underground environment, the continuous miner head does not commence each plunge by cutting a full face of coal. Rather, one end of the cutter head is in coal and the other in free air. This places a greater reliance on operator skill in forming the plunge at the correct separation distance from the previous plunge and in not breaking up the floor strata under the screwing action of the caterpillar tracks of the continuous miner.

Underground mine workings which comprise a regular layout of headings and cut-throughs, such as shown in Figure 4, are commonly known as bord and pillar (Australia , South Africa), room and pillar (USA) and pillar and stall (UK). When bord and pillar panels are left in an as-formed state, they are referred to generically as 'first workings'. If, subsequently, the coal pillars are partially or totally extracted, the workings are known as 'second workings' and the mining operations are referred to as 'secondary extraction'. First workings are usually employed in situations where surface subsidence has to restricted to minimal levels, with this outcome being highly dependent on the long term stability of the roof strata, the coal pillars and the floor strata.

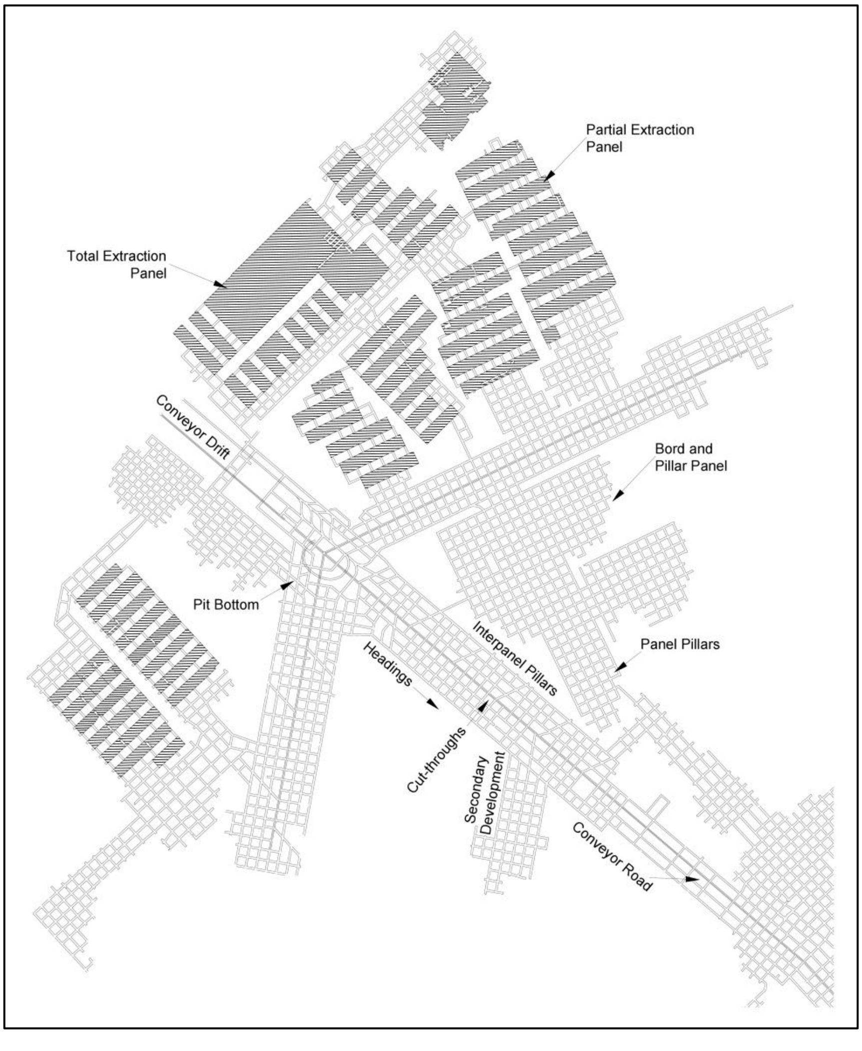


Figure 4: Bord and pillar first workings and select secondary pillar extraction workings (Galvin, 2016).

The mine layout proposed for the Hume Coal Project is similar to bord and pillar mining and first workings in that it comprises a network of roadways and pillars, with the pillars being left in situ as formed. However, the web pillar panels are dissimilar to conventional bord and pillar and first workings in two fundamental aspects. Firstly, they contain no cut-throughs and, secondly, the widths of the in-panel pillars (or web pillars, being 3.5 to 6 m, Table 1) are significantly less than standard practice for the given mining depths and as embedded in NSW mining legislation.

The proposed mine layout resembles many forms of partial and total secondary extraction in that (three) main panel headings, or gateroads, are first driven to the extremities of a working section (or panel) and then the section is opened out on the retreat. Two versions of the Wongawilli method of secondary pillar extraction are shown in Figure 5. They illustrate that, as stated in the EIS, the panel set-up for the Hume Coal Project layout is similar to that of the 'Wongawilli Method' of secondary pillar extraction. Figure 5(b) is particularly relevant as it shows a similar mine layout in the Newcastle Coalfield with the important exceptions that the depth of a remotely mined cut is limited to 15 m, the plunges (run-outs) are supported as they are developed, and the web pillars are only some 15 m wide and are extracted on the retreat.

It is stated in the EIS that:

> *In keeping with modern mining practice, individual mining panels are separated by wide solid barrier pillars and also sealed as soon as possible after mining, in this case to allow the completed workings to flood and so re-develop hydrostatic pressures within the coal seam. This is a necessary pre-cursor for the overlying near-surface strata also re-charging over time.*[19]

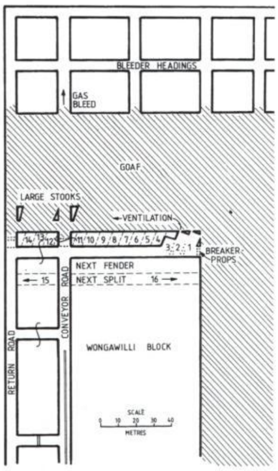
The separation of individual panels by wide solid barrier pillars is recommended good mining practice that dates back to at least the findings of the inquiry into the collapse of bord and pillar first workings at Coalbrook Colliery in 1960 which resulted in the loss of 427 lives (Moerdyk, 1965). However, while barrier pillars are used for the purpose of damming water underground, I am unaware of them also being utilised to permit flooding and re-development of hydrostatic pressures within the coal seam as soon as possible after the completion of mining in a panel; that is, while mining is still occurring elsewhere in the mine.

The Hume Coal Project mine design concept of exploiting the presence of massive strata in the roof to limit caving of the superincumbent strata by restricting the span of mining excavations and supporting the weight of the bridging roof strata on coal pillars is one that has found wide application in underground coal mining in Australia. Examples are shown in Figure 4 and Figure 6 (with Figure 6(a) showing a layout at Clarence Colliery, being one of the mines nominated by the proponent as using a similar mining system to that proposed for the Hume Coal Project). However, the Hume Coal Project mine layout differs in two significant aspects from those shown in Figure 4 and Figure 6, namely:

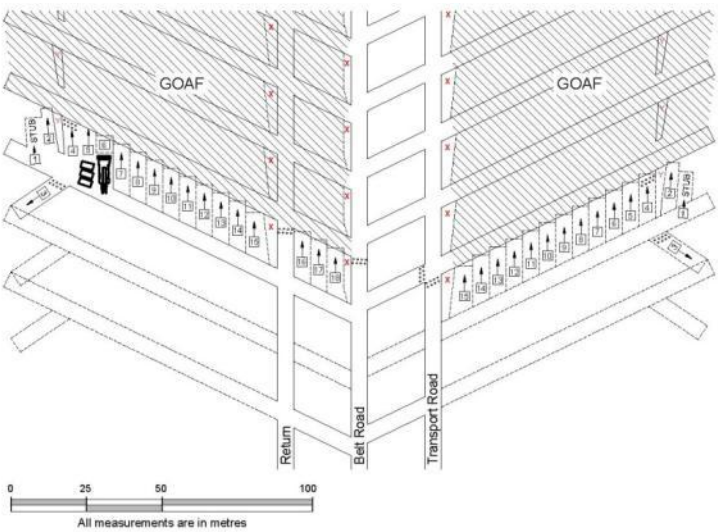
- It has a reliance on narrow web pillars with very small width to height ratios (w/h) remaining stable in the long term. The widths of the web pillars are substantially less than long advised in NSW coal mining legislation and in some mine design guidelines.

- It strives to prevent any roof falls or caving of the immediate roof.

[19] Appendix L, Mine Advice Report: EMM01/2, page 5.

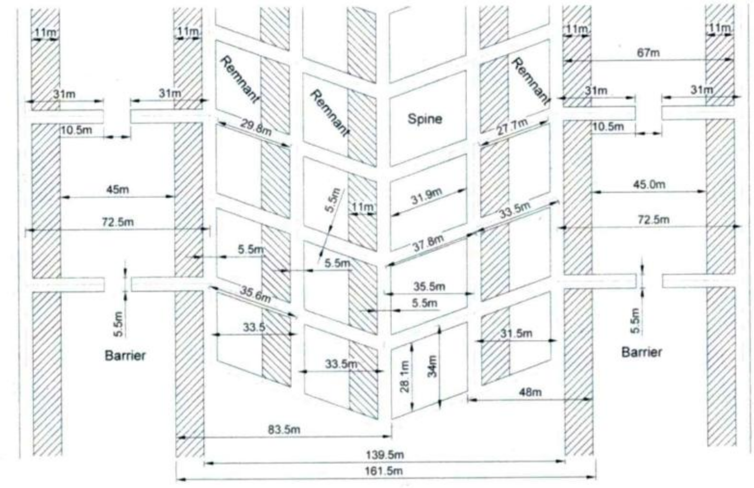


(a) Wongawilli method of pillar extraction (after Sleeman, 1993).

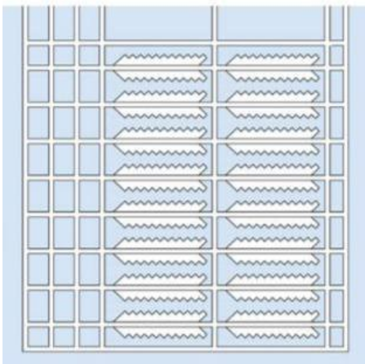


(b) An example of an Australian pillar extraction layout and sequence plan based on Wongawilli mining method and utilising continuous haulage (after Galvin, 2016).

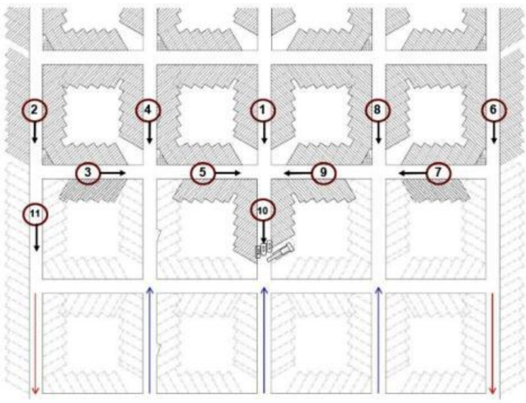
Figure 5: Examples of the Wongawilli method of pillar extraction.



(a) Partial extraction mining at Clarence Colliery, Australia (Hill & White, 2017).



(b) Concept of lifting left and right on two sides to form the final pillar size, based on a mine layout employed at Cooranbong Colliery, Australia (Galvin, 2016).



(c) Lifting left and right on four sides to form the final pillar size, Tasman Mine, Australia (after Tyler & Sutherland, 2011).

Figure 6: Examples of partial pillar extraction methods.

Section 53BA of the NSW Coal Mines Regulation Act 1912 (CMRA., 1912), which was current to 1984, required that an exemption had to be obtained from the regulator to use a pillar width of less than 8 m when mining at a depth equal to or greater than 60 m. Maximum bord width was stipulated to be 5.5 m in all circumstances. I am aware of blanket exemptions being granted to utilize a bord width of up to 6.5 m to mitigate against the risk of rib falls. However, I am unaware of any exemptions being granted to employ smaller pillar widths on a routine basis.

Since 1982, relevant legislation pertaining to pillar size in underground coal mining in NSW has been repealed and replaced on four occasions (Coal Mines Regulation Act 1982 and associated regulations; Coal Mines (Underground) Regulation, 1999; Coal Mines Health and Safety Regulation, 2006; and Work Health and Safety (Mines) Regulation, 2014). In each instance, and as is currently the case, minimum pillar width was specified to be 10 m or equal to one-tenth depth, whichever is greater.

One outcome of the mine design for the Hume Coal Project being founded on empirically based guidelines developed in the USA for surface highwall mining and underground pillar extraction is that the design is premised on restricting the width of individual web panels to, nominally, 60 m at a depth of 80 m. Web panel width has then been kept almost constant with further increases in depth. The ramifications of this and other features for coal resource recovery are shown in Table 2.

Table 2: Comparison based on percentage extraction and pillar safety factor between Hume Coal Project web panels and typical bord and pillar first workings that are compliant with NSW legislation.

Depth (m)	**In-Panel %Areal Extraction per Panel Pillar (UNSW Power Factor of Safety for Web Pillars if Subjected to Full Overburden Load)**		**Overall Panel % Extraction - Panel and Barrier Pillars**	
	Hume Coal Design	**NSW Legislation 10 m or 0.1H**	**Hume Coal Design**	**NSW Legislation 10 m or 0.1H**
80	54% (1.3)	58% (2.0)	45%	49%*
160	43% (1.0)	45% (1.7)	33%	39%**

* based on a 8 heading panel, 28 m wide interpanel pillar (w/h=8), with an overall width of 157.5 m
** based on a 6 heading panel, 28 m wide interpanel pillar (w/h=8), with an overall width of 162.5 m

Table 2 illustrates that if the mine design was based on conventional bord and pillar mining, it would result in a marginally higher resource recovery and coal pillars with substantially higher factors of safety. Because the roof would be supported and the coal pillars would be larger and stiffer, the conventional design could also be expected to result in less surface subsidence and in the workings being safely accessible for extended periods of time after mining. As a point of reference, the mine layout for Clarence Colliery shown in Figure 6(a) achieves an overall areal percentage extraction of around 48% and typically results in 55 to 70 mm of surface subsidence (Hill & White, 2017).

Against this background, the main benefits of the mine design for the Hume Coal Project would appear to be of a financial nature arising out of substantial cost savings due to not having to support all roadways, increased production rates due to minimising delays in installing support and forming breakaways for cut-throughs, and improved productivity. This is consistent with the EIS statement that *the challenge in an underground setting has been to find a way of forming up a number of closely spaced long drives that generate suitably high rates of production whilst maintaining adequate levels of underground mine safety and using readily available underground mining technology.*

As previously noted, the proponent has advised that it is unaware of any previous experience in driving 120m long, narrow roadways remotely underground in an underground coal mine.[20] The readily available mining technology referred to in the EIS has not been applied previously to the underground mining circumstances being proposed by Hume Coal. For example, the maximum cut-out distance of remote control continuous miners in underground situations to date is typically limited to the order of 15 m (some trails have been conducted of distances up to 30 m). While aspects of the proposed mining method are evident in some existing underground mining methods, as reflected in Figure 6 for example, the entire mining system remains untested. It is apparent from responses to questions that the company is placing a high reliance on the success of technologies that are still under development or just emerging, especially for keeping the mining dimensions and directions strictly in accordance with the mine plan and for detecting adverse geological conditions that are out of sight during the formation of web pillars.[21]

Hume Coal has also advised that:

> *We are also unaware of any underground mining project that possess the fairly unique geological, geotechnical and environmental attributes and constraints that the Hume project possesses. It is these attributes that facilitate the implementation of such a system.*[22]

While the combination of factors which make up geology may be unique to the site, the concept of massive strata bridging over panels and protecting panel pillars from load, together with the associated geotechnical constraints, are not unique and have found international application for many decades. For example, the concept has found extensive application for restricting subsidence of residential developments, lake foreshores and tidal waters in the Lake Macquarie, Wyong and Newcastle regions of NSW. It is employed at Clarence Colliery to restrict surface subsidence to <100 mm in accordance with the mine’s Development Approval (Hill & White, 2017). The disposal of coal washery rejects in underground mine workings is also an established mining practice internationally and in NSW that dates back decades. However, the concept of deliberately storing water under pressure in old workings in an active mine is a novel concept as far as I know. It is the norm to remove water from underground mine workings in order to reduce the risk of inrush and inundation and to minimise seepage into active areas of the mine. Water seepage can create slippery and boggy

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[20] HCPL, 2017b.
[21] See, for example, HCPL, 2017a, 2017b.
[22] HCPL, 2017b.

conditions which present a risk of slips and trips and cause difficulties in operating mobile plant and equipment, especially when the floor is not comprised of competent stone.

In summary, the concept of designing mine workings to take advantage of the capacity of massive roof strata to bridge across mining panels and be supported by a regular array of interpanel pillars finds extensive application in underground coal mining. However, the formation of narrow and very small width to height ratio web pillars between interpanel pillars with the intention that the web pillars will remain stable in the long term is unique as far as I know. The concept has many similarities to the theoretical concept of a 'yield pillar' mining layout and, in fact, the Hume Coal Project places reliance on the web pillars behaving as yield pillars and failing in a controlled manner should their peak load carrying capacity be exceeded.

4.0 GEOLOGICAL CONSIDERATIONS

4.1.1. Geology

The descriptions of the geology are taken as read. The mechanical properties of the various stratum reported in the EIS are generally within the range associated with these types of materials in the Sydney Basin.

The depth of weathering is reported and plotted to be greatest in the western part of the mine lease and to extend to within 5 to 10 m of the Wongawilli Seam roof in the shallow western area of the mining area and to within a few metres of the Wongawilli Seam west of the Hume Highway.[23] This aspect warrants more discussion given the high reliance of the mine design on the spanning capacity of the overlying strata and the potential for weathering to decrease this capacity.

The maximum thickness of the Wongawilli Seam is 7.5m.[24] The EIS notes that the coal above the working section is typically of poor quality from a product perspective (increased ash) and therefore, based on findings at other comparable mines in NSW (and elsewhere in Australia), can be expected to be stronger and stiffer than the values quoted for the proposed mined section.[25] A similar conclusion has been reached in respect of some 0.5 m of J ply coal that constitutes the immediate floor and also for which no test data exists.[26] The current floor assessment criterion of there being limited tendency for it to deteriorate when exposed to moisture in drill core trays may be adequate for the purposes of conceptual mine design but I do not consider it adequate for final design purposes. Given the sensitivity of the stability of the proposed coal pillars to any deterioration in roof or floor conditions (see Section 6.2.4) and that this deterioration may be aggravated by water seepage from old workings that have been filled with water under pressure, further quantification of immediate roof and floor material properties is warranted.

The EIS conclusion that seam dip is not expected to have an adverse impact on either mineability or, more importantly, pillar system design for long term stability is considered reasonable.

Cleat and jointing are not discussed in the EIS. Both are important factors when considering pillar stability but are particularly critical in situations where coal pillars have low width to height ratios. For example, one joint with a dip of 45° in a 3.5 m high by 3.5 m wide web pillar can extend right through the pillar and cause it to collapse under gravity. Similarly, rib spall from roof to floor on a joint or cleat plane dipping at only 15° can reduce the effective load bearing area of a web pillar by over 25% while also causing an increase in load on the remainder of the pillar. The nature of the mine layout for the Hume Coal Project is such that it is almost inevitable that cleat and jointing will be sub-parallel to pillar sides in some parts of the mine, thus creating conditions conducive to rib spall.

In situ stress predictions are based on only one stress measurement site to date and this has led to the conclusion that horizontal stress is *substantially lower than the range of the NSW Southern Coalfield and other coalfields in NSW.* Given the shallow depth of mining, the

[23] Appendix L, Mine Advice Report: EMM01/2, page 11.
[24] Appendix L, Mine Advice Report No: Hume13/2, Drawing No. 5.
[25] Appendix L, Mine Advice Report: EMM01/2, page 42.
[26] Appendix L, Mine Advice Report: EMM01/2, page 16.

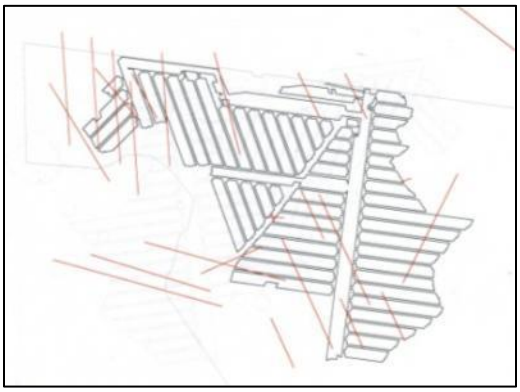
geographic location of the site and the history of mining in the nearby Berrima Colliery, this appears a reasonable conclusion.

4.1.2. Geological Structures

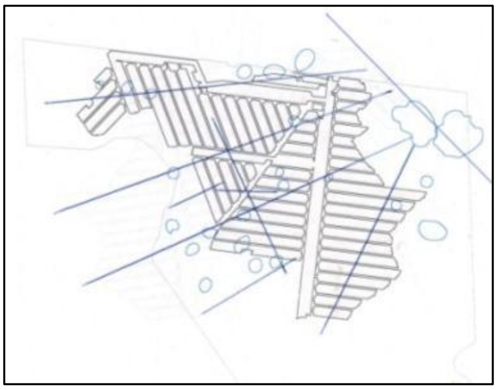
Figure 7(a) shows geological faults and Figure 7(b) shows dykes and diatremes as presented in the EIS. The two plans have been turned into a composite plan of geological structures in Figure 7(c) for the purpose of this advice. This plan also shows floor contours, sequence of extraction and direction of retreat mining.

Figure 7(a) and Figure 7(b) are devoid of basic information that would normally be shown on such plans. In particular, they do not show fault throw and displacement direction and dyke thickness. The EIS refers to the structures as ‘inferred’, which suggests a lack of confidence in their characterization.

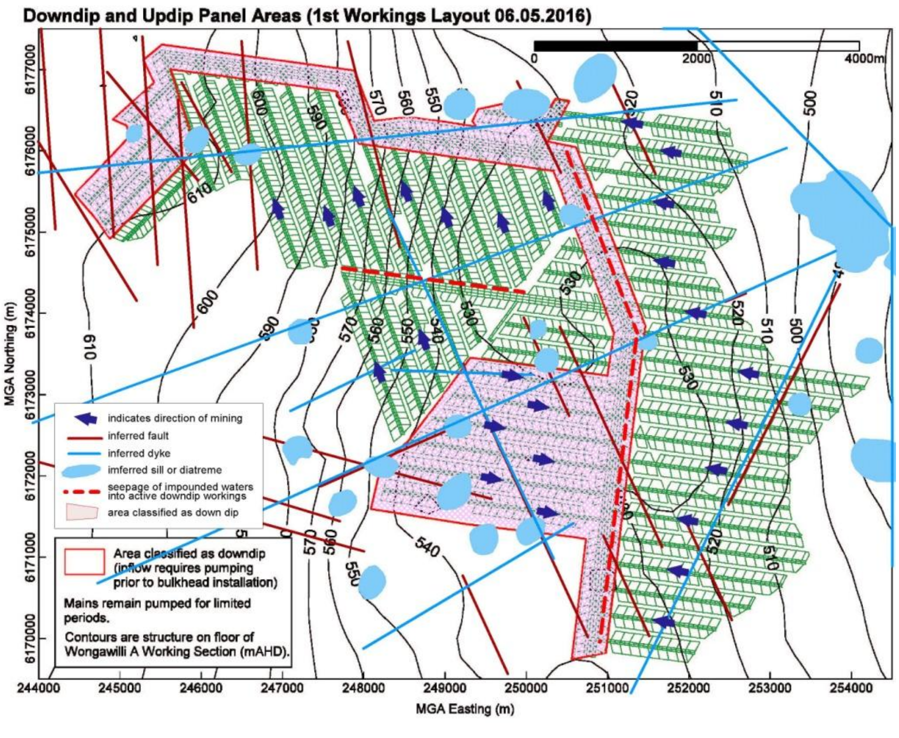
The potential impacts of diatremes (plugs of volcanic material) on mine stability and water management are not discussed in the EIS.



(a) Inferred faulting



(b) Inferred dykes and diatremes



(c) Composite plan of geological structure overlaid on a plan of floor contours, noting that the mine layout is different to shown in (a) and (b).

Figure 7: Floor contours and geological structures

4.2. GENERAL ASSESSMENT

The nature of geological structures is important when considering any mine layout but takes on added significance when layouts involve pillars that have very small width to height ratios. This is because the impacts on mine stability of factors such as reductions in material strength, roof and rib spalling and falls of ground, off-line driveage and redistribution of stresses are more adverse as pillar width to height ratio reduces. The EIS acknowledges that:

> *Major geological discontinuities such as faults and dykes have the potential to adversely impact coal pillar stability due to both reducing local coal pillar strength and increasing coal pillar loading within otherwise sub critical panels between barriers.*[27]

It appears from Figure 7(c) that geological features impact a significant area of the mine workings. The mine plans shown in Figure 1 and Figure 7(c) appear to reflect the presence of structures in some instances but not in all cases. In preparing this advice for DPE, the proponent was asked as to the reasons for the disruptions in the regular layout of mining panels and, if these were due to geological structures, to please provide a description of these structures. Hume Coal (HCPL, 2017b) responded that:

- *These are inferred faults and dykes for which there is a reasonable degree of confidence in their presence and orientation.....Faults are interpreted to be typically up to 10m in throw.........it is unlikely that there are any faults with very large throws (significantly greater than 10m) within the footprint of the mine plan.*

- *Faults and dykes that are inferred, but for which there is a lower degree of confidence, have not been taken into account in the layout of the plunges.*

- *It is not contested that there remains the potential for un-mapped structure to be present in the middle of each 163m wide block, however it is contested that the impact of such a structure would be equivalent to its presence in the middle of a longwall panel. This is due to the inherent flexibility of the proposed mining system to deal with such features.......If, for example, a full-face fault, or a 3m thick 200MPa dyke is encountered part-way down a plunge, the plunge (and subsequent plunges) will simply be pulled up short.*

Diatremes usually contain a high density of cooling (shrinkage) induced fractures and, therefore, have an enhance conductivity. It appears from Figure 7(c) that some diatremes may span the barrier pillars between panels. If this is the case in the final mine layout, it could compromise the concept of storing water under pressure in compartments.

Against this background, it is concluded that:

- The final mine plan may vary significantly from that shown in Figure 1 and Figure 7(c).

- Final overall percentage areal extraction from the mining lease could be considerably less than that based on Figure 1.

- The stability of the mine layout is likely to be very sensitive to the presence of geological structures.

[27] Appendix L, Mine Advice Report: EMM01/2, page 21.

5.0 BASIC FOUNDATION INFORMATION

5.1. FACTOR OF SAFETY CONCEPT

The mine design for the Hume Coal Project places a reliance on the concept of 'factor of safety'. Factor of safety (FoS) is used in engineering to described the ratio of the peak load carrying capacity of a structure, or its strength, to the loads imposed on it. In a perfect world, a factor of safety marginally greater than 1 would imply stability (strength greater than load) and a factor of safety marginally less than 1 would imply instability (load exceeds strength). Hence, a factor of safety of 1 equates to a 50% probability of stability (or instability). In reality, however, neither the strength of a structure nor the loads imposed upon it can be precisely determined and so instabilities can be experienced when the predicted factor of safety is greater than 1 and stable outcomes can result when the predicted factor of safety is less than 1.

This problem can be addressed by developing probability distributions through back-analysis of the performance of a specific design procedure. This enables a level of confidence to be assigned to a given factor of safety derived from that procedure. It is important to appreciate that the factor of safety–probability relationship is specific to a particular design methodology and is not transferrable to other design approaches.

One of the most utilised factor of safety–probability relationships in mining geomechanics is that developed by Salamon and Munro (1967) for coal pillar design in South Africa. This approach was extended by Salamon et al. (1996) for use in Australia, who named it the UNSW Pillar Design Methodology. It is referred to in the Hume Coal Project EIS as the 'UNSW PDP'. The EIS reports that *'The design process was (a) an initial assessment using ARMPS-HWM* [a USA methodology] *which is specifically targeted at highwall mining (HWM) whereby similar low w/h ratio pillars are commonly formed up from highwall exposures followed by (b) a review of the ARMPS-HWS design outcomes using the UNSW PDP including limitations being placed on panel widths between barriers to ensure sub-critical overburden behaviour above low w/h pillars.*[28]

Research into coal pillar strength dating back to the mid 1960s in South Africa and the early 1990s in Australia (e.g. Salamon & Munro, 1967; Salamon & Oravecz, 1976; and Salamon et al., 1996) has led to the conclusion that if coal pillars are required to be stable in the long term but, nevertheless, the consequences of failure are not severe, they generally need to be designed to a minimum safety factor of around 1.6, corresponding to a likelihood of failure of about 1 in 1000. However, Salamon & Oravecz (1976) advise that the factor of safety of pillars between 3.0 to 4.5 m in width should be at least 1.7 when using the Salamon & Munro strength formula (to account for the sensitivity of such small pillars to variations in actual versus designed dimensions).

Hence, in order to assess the factor of safety of coal pillars, consideration has to be given to the load acting on the pillars, the capacity (or strength) of the pillars to resist this load, and the reliability of the methods utilised to estimate pillar loads and strengths.

5.2. LOAD DISTRIBUTION BETWEEN PILLARS

When a material is loaded, it compresses or stretches. That is, it undergoes displacement. Conversely, compressing or stretching a material induces a change in load within it. Different

[28] Appendix L, Mine Advice Report No: Hume13/2, page 31.

loads are generated in different materials and structures when subjected to the same displacement, and vice-versa. 'Stiffness' is the engineering term used to describe the relationship between load and displacement.

In bord and pillar mining, the stiffness of a coal pillar is a function of its elastic modulus (a material property that cannot be changed), its height and its area. Hence, pillars of different height or width will undergo a different amount of deformation when subjected to the same load. Of particular note to the matter under consideration is that the stiffness of a pillar decreases as its width to height ratio, w/h, decreases, meaning that it will compress more under load.

The load in bord and pillar mining comes from the weight of the superincumbent strata. The extent to which the superincumbent strata will sag and load coal pillars is also controlled by the stiffness of this strata, which is a function of the elastic modulus of the strata, the thickness of the strata (or depth below surface, H) and span (or width of the a mined area, W). Of particular note to the matter under consideration is that the stiffness of the roof strata decreases as the mining width to depth ratio, W/H, increases. This means that if the width of a mining panel is held constant, as in the case of Hume Coal, the roof strata bridging across the excavation will sag less as depth increases.

Hence, the load induced in a coal pillar is a function of the deformation characteristics (or stiffness) of both the coal pillar and the surrounding strata. Except for one special case, which does not apply to the proposed mine layout for the Hume Coal Project, the determination of pillar load is what is referred to in engineering as 'statically indeterminate' and requires assumptions and the application of numerical (mathematical) modelling. A range of techniques have been developed for this purpose since the 1970s and they find routine application in a wide range of underground mining.

5.3. PEAK PILLAR STRENGTH

Pillar strength is not a parameter that can be determined with precision, for reasons that include:

- Coal is a natural material and its mechanical properties are variable.
- The factors that influence coal pillar strength are not fully understood.
- It is not feasible to fully account for all the factors that are known to influence coal pillar strength.
- Coal pillar strength (load carrying capacity per square metre) is a function of pillar size.
- It is not practical to generate in a laboratory the loads required to determine the strength of full size coal pillars (e.g. typically 100,000 tonnes is required to fail a 3.5 m high, 10 m square pillar).

Fortunately, there is one special situation which can be utilised to developed a probabilistic basis for predicting the strength of coal pillars. This is when a mine layout comprises a laterally extensive array of coal pillars that are not impacted by adverse geological conditions, are all uniform in size and shape and are laid out on a regular grid. If the pillar array has a diameter at least equal to depth, then it can be assumed in most situations with a reasonable degree of confidence that the superincumbent strata in the centre of the array will transfer its full deadweight load to the underlying coal pillars. Hence, the load acting on the pillar is known. If the mining layout is uniform, then all the pillars will have the same stiffness and, therefore, will carry an equal share of the overburden load. If these conditions are satisfied, pillar strength can be approximated from a process of back-analysing successful and unsuccessful cases of pillar stability.

This approach to determining pillar strength was devised by Salamon & Munro (1967) and has been used with great success in South Africa. As at 1985, it had been associated with the successful design of over 1.2 million coal pillars in South Africa (Salamon & Wagner, 1985). It was applied to Australian case studies in the early 1990s by researchers at the University of New South Wales (Salamon et al., 1996) and produced very similar pillar strength outcomes.

Because care was taken to only include cases in the database where the load acting on the pillars was reasonably well known, pillar strength could be equated to a known failure load. This then permitted a statistical approach to be applied to deriving formulations that most closely predicted the strength of a coal pillar and also probability distributions that reflected the likelihood that these formulations would produce successful (that is, reliable) outcomes. This approach accounts for all the assumptions and unknowns that are associated with predicting pillar strength.

If the knowledge base was perfect then, as previously noted, a factor of safety of marginally greater than one would indicate that pillar strength exceeded the working stress acting on the pillar and so stability would be assured. Similarly, a factor of safety of marginally less than one would indicate that instability was assured. Because this situation does not arise in reality, a level of uncertainty is associated with any safety factor. The approaches of Salamon & Munro (1967) and Salamon et al. (1996) are the only known approaches to coal pillar design that quantity the relationship between factor of safety and probability of a successful or unsuccessful outcome. These relationships for the Salamon and Munro Pillar Strength Formula and the so-called UNSW Power Pillar Strength Formula are shown in Table 3.

Table 3: Relationship between factor of safety and probability of failure of a coal pillar designed on the basis of the UNSW Power Pillar Strength Formula, assuming that pillar load is reasonably well known.

UNSW Power Safety Factor	**Probability of Failure**	
0.87	80%	8 in 10
1	50%	5 in 10
1.22	10%	1 in 10
1.3	5%	5 in 100
1.38	2%	2 in 100
1.44	1%	1 in 100
1.63	0.1%	1 in 1,000
1.79	0.01%	1 in 10,000
1.95	0.001%	1 in 100,000

Any formula can be applied to predicting pillar strength. Table 3 effectively presents the likelihood that a pillar designed to a particular factor of safety utilising the UNSW Power Pillar Strength Formula will, in-reality, have a factor of safety less than one. Because these probabilities are specific to all the assumptions and approximations associated with deriving this specific formulation, it is not valid to assign the same probabilities to factors of safety derived using different methodologies.

As previously noted, Galvin et al (1995) concluded from UNSW research that when geological structures are present in pillars, empirical pillar strength formulae may underestimate pillar strength, especially at pillar width to height ratios less than 4. They recommended that, due to the sensitivity of pillar strength at low width to depth ratios to geological structure and to slight variations in pillar dimensions, a lower width to height bound of 2 should be applied when using pillar strength formulae. In reiterating this advice, Galvin (2006) advised that the absolute size of a pillar must also be taken into account at low w/h ratios, with the stability of slender pillars of small cross-sectional area being very susceptible to collapse in the presence of geological structure.

5.4. YIELD PILLARS

Once the load acting on a coal pillar exceeds the peak load carrying capacity of the pillar, the pillar may fail in a controlled or uncontrolled manner. This outcome is determined by the ratio of the stiffness of the coal pillar system to that of the overlying strata. If the coal pillar is loaded by the deadweight of the overburden at the time of exceeding its peak load carrying capacity, it will be driven to collapse in a violent manner. However, if after sagging sufficiently to cause a coal pillar system to fail, the superincumbent strata still retains some residual stiffness (or self supporting capacity) that retards further sagging, then the roof and pillar system may reach a temporary or permanent state of equilibrium. Similarly, if the coal pillar system still retains some residual stiffness after failing, it will continue to provide some resistance against further roof convergence. The loading system is complex because the behaviour of the coal pillar system and the behaviour of the superincumbent strata are interactive and can only be analysed with the assistance of numerical (mathematical) modelling.

The likelihood of a coal pillar failing in an uncontrolled manner after its peak load carrying capacity has been exceeded increases as its width to height ratio, w/h, decreases, especially at values less than about 4. The design of mining layouts in which pillars yield in a controlled manner is complex and has been the subject of much discussion and research since Salamon made his pioneering advances in the late 1960s in understanding the stiffness of mining systems and how it determines pillar load and pillar failure mode (Salamon, 1968, 1969, 1970). Salamon & Oravecz (1976) reported in 1976 that:

> *Large-scale underground tests on coal pillars have revealed that the residual strength of pillar in the post-failure regime is not sufficient to permit the utilization in South Africa of the so-called "yield-pillar" technique of extraction where by judicious design of panel and barriers the load and stiffness of the system are so controlled that the danger of violent failure is eliminated.*

5.5. NSW LEGISLATION

Clause 5 of the current Work Health and Safety (Mines) Regulation 2014 [NSW] defines a 'principal mining hazard' as *any activity, process, procedure, plant, structure, substance, situation or other circumstance relating to the carrying out of mining operations that has a reasonable potential to result in multiple deaths in a single incident or a series of recurring incidents, in relation to.......(a) ground or strata failure, (b) inundation or inrush of any substance (c).....*

Clause 1 (1) of Schedule 1 of the regulation prescribes matters that must be considered in developing control measures to manage the risk of ground or strata failure. One of these is:

> *(u) in the case of an underground coal mine – the strata support requirements for the mine and the pillar strength and stability required to provide that support and the probability of instability of any pillar taking into account the pillar's role.*

Schedule 3 of the current Work Health and Safety (Mines) Regulation, 2014 pertains to "high risk activities" for the purpose of Clause 33, Division 4, Subdivision 1, of the Regulation. Clause 15 states:

> *(1) In this clause:*
>
> ***conforming pillar*** *means a pillar, the shortest horizontal distance of which is no less than:*
>
> *(a) one tenth of the thickness of the cover (to the surface), or*
>
> *(b) 10 metres, if the thickness of the cover is less than 100 metres.*
>
> *(2) The formation of a pillar other than a conforming pillar is identified as a high risk activity*

Clause 16 deals with ***Secondary extraction or pillar extraction, splitting or reduction.*** It states

> *(1) The following are identified as high risk activities:*
>
> *(a) secondary extraction by longwall mining, shortwall mining or miniwall mining.*
>
> *(b) pillar extraction*
>
> *(c) pillar splitting*
>
> *(d) pillar reduction*
>
> *(2).......*
>
> *(3) The information and documents that must be provided in relation to any such activity are as follows:*
>
> *(a)........*
>
> *....*
>
> *(d) in the case of a pillar extraction, details of the procedure for the recovery of buried and immobile mining plant in or around a goaf.*

A goaf is *an area in which mining has been completed and left in a partially or totally collapsed state or in an inadequately supported state to assure safe entry* (Galvin, 2016)

6.0 STABILITY ASSESSMENT

6.1. SUPERINCUMBENT STRATA

The proposed mine layout for the Hume Coal Project relies on a dominantly sandstone unit (Hawkesbury Sandstone) of between 80 m and 120 m total thickness spanning across panels that are nominally 60 m wide, with a portion of the weight of the bridging sandstone being carried by the intra-panel pillars. The EIS contends that a portion of the weight of the bridging strata will also be carried by the chain pillars in the development headings and the inter-panel pillars. I concur, although those portions of the web pillars midway between chain pillars and the inter-panel pillars are likely to receive little if any benefit from this as they are too far away.

The EIS also notes that it is inevitable that the sandstone will contain some horizontal planes of weakness within it.[29] It is also reported that the depth of weathering extends to within 5 to 10 metres of the Wongawilli Seam roof in the shallow western area of the mining area and to within a few metres of the Wongawilli Seam west of the Hume Highway.[30] Weathering reduces mechanical properties of rocks. In my opinion, the implications of this weathering for the spanning capacity and stiffness of the overlying strata, mine stability, groundwater and surface subsidence warrants more consideration in the EIS because:

- As it reads, it appears that the weathering extends throughout nearly the full thickness of the sandstone.
- This occurs in the shallower areas of the mine where the spanning capacity of the overburden may be least due to the higher panel width to depth ratio (W/H = 0.75).
- The combination of weathering, parting planes and relatively high panel width to depth ratio has the potential to seriously jeopardise the spanning capacity of the sandstone overburden and result in failure of the web pillars, leading to caving and increased surface subsidence.

6.2. PILLAR SYSTEM STABILITY

6.2.1. Generally

The EIS reports that the initial panel layouts were based around the application of the ARMPS-HWM (Analysis of Retreat Mining Pillar Stability – Highwall Mining) method from NIOSH (National Institute of Occupational Safety and Health) in the USA[31]. It goes on to state that to complete the mine layout design process to a standard that can be considered as part of a mining application in NSW whereby retaining long-term stability of the global remnant pillar system and overburden is a critical design requirement, the proposed mining layout(s) methodology have also been evaluated using a coal pillar analysis in an underground

[29] Appendix L, Mine Advice Report No: Hume13/2, page 16.
[29] Appendix L, Mine Advice Report No: Hume13/2, page 16.
[30] Appendix L, Mine Advice Report: EMM01/2, page 11.
[31] Appendix L, Mine Advice Report No: Hume13/2, page 12.

mine setting rather than a surface HWM setting by using the UNSW Pillar Design Procedure or UNSW PDP (Galvin et al., 1998).[32, 33]

It needs to be appreciated that the factors of safety derived from the two different design procedures (ARMPS-HWM and UNSW PDP) cannot be equated. This is because they have been developed on the basis of different assumptions and approximations and, therefore, have different levels of reliability. My assessment only has regard to the factors of safety associated with the UNSW PDP because these enable the design outcomes to be correlated to a level of reliability (or probability of success). However, there are still serious limitations with that approach in the given circumstances since, due to the range of pillar shapes and sizes and the restricted mining spans associated with the mine layout, the load acting on the pillars cannot be determined with confidence. This is not such a concern for the large width to height ratio pillars in the mine design because it transpires that most have considerable excess load carrying capacity. It is a serious issue for the small width to height ratio pillars because, as shown later in this review, a small variation in load can cause a significant change in stability.

6.2.2. Main Pillars

I concur with the design calculations and the conclusions that the main pillars can be expected to be stable in the long term.

6.2.3. Barrier & Gateroad Pillars

The mine design is premised on the massive sandstone over the web panels transferring a portion of the weight of the overburden transversely onto the intra-panel pillars. However, in this case, a portion of this weight will also be transferred longitudinally onto the barrier and gateroad pillars. Numerical modelling is required to quantify how this load is apportioned. In its absence, I have assumed that load is redistributed on the basis of perimeter. This means that the barrier and interpanel panels each support 1/6th of the load transfer.

The worst case is the total loss of load carrying capacity of the web pillars in the deeper areas of the mine, in which case my analysis indicates that the factors of safety for the barrier pillars still remain extremely high (>8) while those for the gateroad pillars could be reduced in the worst case to the order of 1.2. As mining is proposed to commence in the shallower areas of the lease, this is not an immediate concern and can refined with the aid of numerical modelling and as need be in the light of experience.

6.2.4. Intra-panel & Web Pillars

The EIS reports that web pillars and intra-panel barriers represent the key elements of the mining system. I concur

Intra-panel pillars and web pillars constitute an interactive system and, therefore, need to be evaluated as one engineered structure. Theoretically, once panel length exceeds twice panel width, the stability of the web pillars in the centre of the panel is determined primarily by

[32] Appendix L, Mine Advice Report No: Hume13/2, page 13.
[33] Galvin et al., (1998) includes the seminal research report of Salamon et al., (1996) in which the methodology is embedded.

strata behaviour across the minimum span (or width) of an excavation. However, web pillars towards the outbye and inbye ends of a web panel will still be shielded from some load to some extent by the interpanel pillars at the longitudinal ends of each panel.

The EIS reflects this in reporting that the combination of thick massive roof strata and mining plunges limited to a maximum length of 120 m should result in a portion of the weight of strata over the web panels still being carried by the gateroad pillars and the inter-panel pillars. It is contended that this will contribute to the stability of web pillars and intra-panel barrier pillars over and above that determined from the simplified two-dimensional analysis that are presented in the EIS.[34] I concur in respect of the outbye and inbye ends of the web pillars. However, the central portion of each web pillar may receive little benefit from load transfer to the interpanel pillars (assuming that the plunges to form the web pillars are driven to their full planned length of 120 m).

Hence, the only way in which the loading on the intra-panel and web pillars in this mine layout can be quantified to a reasonable level of confidence is through the use of sensible numerical modelling, recognising that numerical modelling also requires assumptions and approximations. The consultant to Hume Coal has attempted to deal with situation without the aid of numerical modelling, being of the opinion that *reliably predicting pillar load distributions within and outside the AMZ (active mining zone) for credible layout design optimisation is almost certainly beyond the limit of current technical understanding of overburden mechanics and therefore also numerical simulation techniques* (Frith, 2017c). I do not concur.

There is a range of 2D and 3D numerical modelling programs available that have the capacity to simulate the proposed layout for Hume Coal and permit sensitivity analysis of pillar loading situations. An example of particular relevance is the numerical model developed by NIOSH in 2010 that resulted in modification to the ARMPS pillar design methodology (Esterhuizen et al., 2010). This numerical model already contains the framework for evaluating the Hume Coal mine layout, as evidenced in Figure 8. This shows plots of load in pillars of various width to height ratios in the centre of bord and pillar panels of various width at a depth of 450 m. These outcomes indicate that very small width to height ratio pillars such as associated with the Hume Coal Project, can go into yield at relatively small panel widths at depths much greater than associated with the Hume Project.

However, the situation is simpler to analyse for the Hume Project because if the drives (plunges) are driven to their planned length of 120 m, the layout can be analysed numerically as a 2D problem, just as it has been assessed analytically as a 2D problem in the EIS. This produces worst case outcomes, since any reductions in the length of plunges only improves stability because it results in a reduction in pillar load.

[34] Appendix L, Mine Advice Report No: Hume13/2, page 16.

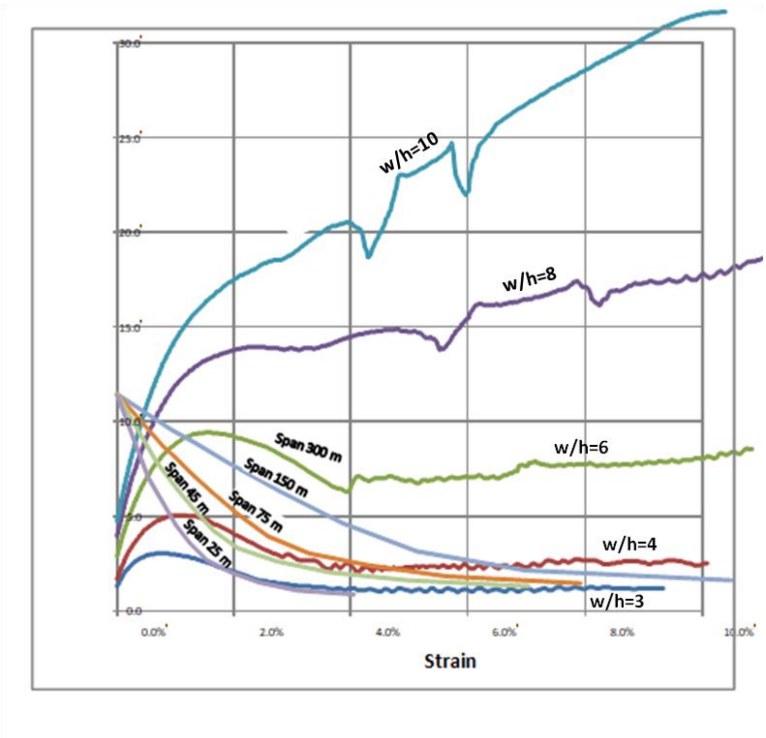


Figure 8: Pillar stress-strain curves and ground response curves at mid-span of first workings panels of various widths at a depth of 450 m under strong overburden strata (Esterhuizen et al., 2010).

Mine Advice has advised that *In response to this dilemma* [of pillar load being indeterminate], *when the principles for determining the mine layout were being established, it was recognised that the design process needed to evaluate two "extreme" cases in terms of the load-distribution between web pillars and intra-panel barriers, namely:*

- *Full tributary area loading on individual pillars, and*
- *A load distribution onto the intra-panel barriers as would be more commonly applied in longwall chain pillar design for example.*

The first approach has already been discussed in this review report and I agree that it represents an upper limit situation. However, as discussed later and as suggested by Figure 8, it may not necessarily be 'extreme' in the sense that tributary area load values for web pillars midway between panel abutments may not be that far off being correct. The factors of safety and associated probabilities of instability associated with basing stability assessment of web pillars on the upper extreme case of tributary area loading are shown in Table 4. These are based on the best environmental circumstances, whereby the dimensions of as-formed pillars are in complete agreement with design values and pillar integrity is not adversely impacted by geological structures.

Table 4: Comparison between stability assessment outcomes for web pillars based on tributary area loading, equal load sharing 21° abutment angle model and distributed load sharing 21° abutment angle model.

Depth (m)	Tributary Area Loading Model (all web pillars carry equal overburden load to surface)		Equal Load Sharing 21° Abutment Angle Model[35] (all web pillars carry equal load within abutment triangle)		Distributed Load Sharing 21° Abutment Angle Model (mid-span pillar most highly loaded)	
	FoS	Probability of Instability	FoS	Probability of Instability	FoS	Probability of Instability
80	1.3	8%	2.3	<0.01%	1.3	4%
160	1.0	50%	4.6	<0.000001%	2.1	~0.0001%

The Table shows that the probability of failure of the web pillars if designed on the basis of the UNSW Power Pillar Strength Formula and subjected to full tributary load ranges from 8% to 50%. Assuming that the stiffness and spanning capacity of the superincumbent strata is not compromised by weathering, these values are upper end values because the web pillars will, as correctly argued in the EIS, be shielded to some extent from full tributary area, or deadweight loading. The unknown is the extent of the shielding.

However, the required level that the pillars would need to be shielded from load in order to satisfy what has come to be accepted as the minimum requirement for long term stability can be calculated. That minimum requirement is a UNSW Power Factor of Safety of at least 1.6 which, from Table 2, equates to a probability of failure of around 1 in 1,000. Satisfying that criteria would require that the actual load acting on web pillars at depths of 80 m and 160 m to be less than 82% and 63% of tributary load, respectively. Without the benefit of numerical modelling, one cannot assess how close the proposed mine layout comes to achieving these load reductions.

The approach of Mine Advice to what it considers the lower extreme is based on Figure 9. This model assumes that the load transferred to the intra-panel pillars is delineated by lines that extend from the edge of the intra-panel out over the web pillars at some ‘abutment angle’, measured from the vertical. The abutment lines are based on a conceptualisation of how load is transferred to the side abutments of total extraction panels as a result of the caving and subsidence of the roof strata. Outcomes are quite sensitive to the assumed value of the abutment angle. The weight of the strata in the triangular area under the abutment lines is presumed to be transferred to the floor of the mine workings, with the load acting on the floor at a point being directly proportional to the height of strata in the overlying triangle at that

[35] Appendix L, Mine Advice Report No: Hume13/2, page 26, Table 4.

point. Hence, load transfer to the floor is minimal adjacent to the intra-panel pillars and a maximum at the mid span of the panel. The concept can be quite useful, especially at shallow to moderate depths and does find application in both analytical and numerical modelling.

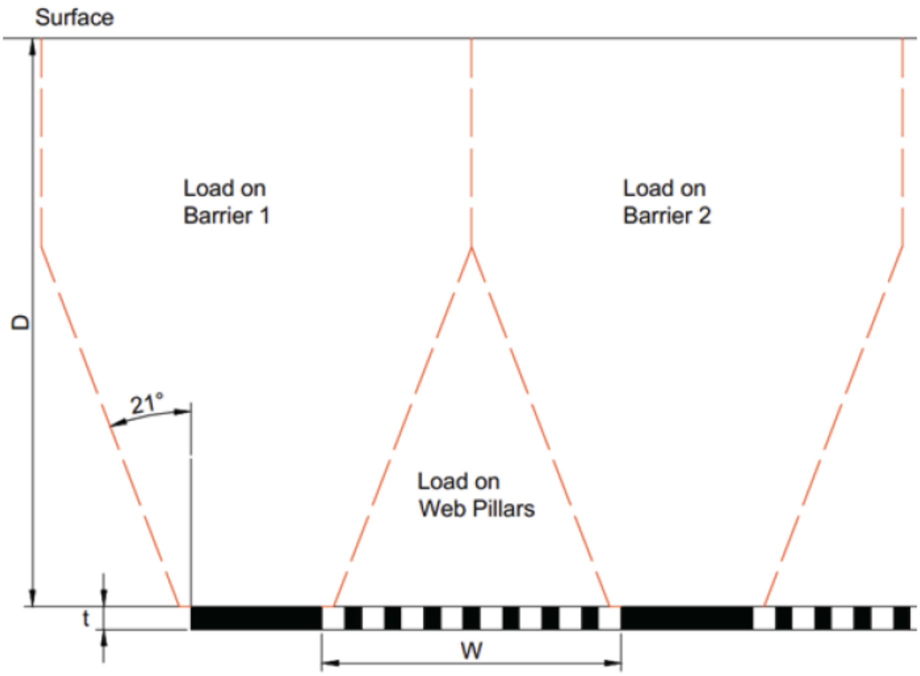


Figure 9: Double goaf loading model of intra-panel pillar adopted in EIS.[36]

However, it is unusual to see the concept applied to a first workings situation. Basic questions arise concerning the validity of applying it to a situation where caving and subsidence of the roof strata are not supposed to occur so as to generate the abutment lines and also what abutment angle should be employed in the analysis. Furthermore, Mine Advice has assumed that the weight of the triangular wedge of material overlying the coal pillars is distributed equally over all pillars. This contrast with theoretical principles and practice, whereby pillar load is greatest in the centre of a panel (because the roof converges most at its midspan).

I concur that the model is indeed a 'lower extreme'. A more reasonable approach may have been to allocate pillar load in the manner that is conventionally done in other applications of the abutment angle model. That is, by distributing it on the basis of the height of the overlying deadweight load between the abutment lines. A comparison between this approach and that of Mine Advice is presented in Table 4. Effectively, the factor of safety of the web pillar in the centre of a web panel based on the equal loading approach of Mine Advice is double that derived from a distributed load approach.

The wide range in factors of safety and probabilities of instability associated with the various approaches to assessing web pillar stability, Table 4, confirms the view of Mine Advice that determining web pillar load does present a dilemma because pillar load is indeterminate.[37]

[36] Appendix L, Mine Advice Report No: Hume13/2, page 15, Figure 15.
[37] Frith (2017c).

While numerical modelling is required to gain a better insight into pillar load, practical considerations associated with the very small width to height ratios of the web pillars could well end up being of more importance. This is because the very low width to height ratio of the web pillars makes their stability extremely vulnerable to localised changes in material properties, such as in the vicinity of geological structures, and to small changes in mining dimensions due to factors such as operator error, offline driveage and falls of roof and rib. The corresponding reduction in pillar strength can negate the load reduction benefits derived from the bridging superincumbent strata.

Table 5 shows the individual and combined impacts of just 0.2 m of rib spall and/or 0.2 m of roof fall. The analysis outcomes are consistent with the earlier noted advice of Galvin et al (1995) that, due to the sensitivity of the strength of low width to height ratio coal pillars to geological structure and to slight variations in pillar dimensions, a lower width to height bound of 2 should be applied when using pillar strength formulae.

Hume Coal has advised to the effect that if adverse geological structures are encountered, mining will be curtailed at that site.[38] This constitutes good mining practice. However, because of the nature of the mine layout, it may not prevent instability progressing back through the existing workings within a web panel, either at the time of mining or sometime later. Once the load carrying integrity of one web pillar is compromised, its load is transferred to adjacent pillars which, in turn, can compromise their stability.

It is important, therefore, to consider the potential for geological structures and changes in dimension and material strength to impact the Hume Coal Project. Geology and geological structures have already been discussed in Section 4.0, with cleating and jointing being particular concerns that have not been addressed in the EIS.

[38] HCPL, 2017b.

Table 5: Analysis of sensitivity of web pillar stability to 0.2m of spall.

Depth (m)	**Situation**	**Tributary Area Loading**	
		UNSW PDP Factor of Safety	**Probability of Failure**
80	As-designed	1.30	8%
	0.2 m rib spall	1.19	20%
	0.2 m roof fall	1.24	12%
	0.2 m rib & 0.2 m roof spall	1.13	28%
160	As-designed	1.01	50%
	0.2 m rib spall	0.96	61%
	0.2 m roof fall	0.97	63%
	0.2 m rib & 0.2 m roof spall	0.91	70%

As to the potential for rib and roof spall and falls, the EIS advises variously that:

- *In any areas where thin aquiclude material is present between the coal seam and overburden strata, it should ideally be left in place to assist in reducing ground water inflows into the mine. However practical mining considerations may not always allow this to occur.*[39]
- *Inevitably, mining at Hume will encounter localised areas of geologically disturbed strata (e.g. intense jointing zones, localised seam rolls etc) as well as what are termed "major" geological structures such as faults and dykes.*
- *Even allowing for the thin stone/mudstone band that is commonly located at or very close to the base of the WWD Ply, the analysis still concludes that roof stability in the proposed 4 m wide, unsupported drives will typically be globally stable across the full*

[39] Appendix L, Mine Advice Report: EMM01/2, page 23.

drive width with instability being limited to no more than skin falls most likely consisting of section of the thin stone band at the base of the WWD Ply.

- *...........all add to the conclusion that under normal background geotechnical conditions, roof stability in the proposed 4 m wide unsupported drives will routinely be globally stable, with instability being limited to skin falls that do not in themselves threaten global roof stability.*

- *For the Hume Project, the situation is slightly complicated .....the immediate roof strata can vary from coal, through coal and laminated stone material and finally sandstone and/or conglomerate material associated with the Hawkesbury Sandstone.*[40]

- *For any roof falls that occur after the completion of a drive, the fallen material will not be removed by the conveying system and may act to provide some level of lateral confinement at the base of the adjacent coal pillars that otherwise could not exist, similar to the pillar confinement provided by rib spall as discussed in Canbulat and Ryder 2002.*[41]

These statements suggest that it is not unreasonable to expect 'skin falls' of roof and rib to occur to a depth of at least 200 mm. The reliance on fallen material to provide some meaningful confinement to coal pillars would require the ribs to spall significantly more than 200 mm (at least 700 mm on each side of the roadway) or the roof to fall to a significant height (at least 1.5 m). In both circumstances, this behaviour on a panel basis would assure the failure of the web pillars under tributary area loading situations. This, in turn, would cause an increase in effective roof span and, thus, increase the potential for fracturing of the overburden and the height of relaxation effects.

In response to questions from DPE, Hume Coal has advised that

> *Given that the low cover depth and subcritical geometry between intra-panel barrier pillars, it is concluded that the likelihood of coal rib spall resulting in a significant increase in the effective drive width and so adversely affecting roof stability in unsupported drives under normal or background geotechnical conditions is in the highly-unlikely to practically-impossible category.*[42]

Incidents in geotechnical engineering verify that great care is required in ruling anything out as 'practically-impossible' but especially in this case where basic factors such as cleat dip, density and direction are not considered in the EIS and where there is still a lack of experience in bord and pillar layouts that place a reliance on pillars yielding in a controlled manner, notwithstanding that the theoretical knowledge base was developed more than 40 years ago.

The EIS does not exclude the possibility of failure of the web pillars and gives consideration to whether this may occur in an uncontrolled (sudden) manner or controlled (gradual) manner. I concur that in the deeper parts of the mine, where panel width to depth ratio, W/H, is least (~0.35), any pillar failure is likely to occur in a controlled manner. Without more information concerning overburden weathering, rock partings and geological structure within coal pillars

[40] Frith (2017b).
[41] Frith (2017b).
[42] Frith (2017b).

and in the absence of sensible numerical modelling, I am not prepared to comment on the likelihood of the pillars yielding in an uncontrolled manner in the shallower areas of the mine.

Failure and yielding of the web pillars can be expected to result, in turn, in the overlying sandstone transferring load to the intra-panel pillars. Should the intra-panel pillars not be able to sustain this increased load and yield, pillar instability can progress from one web panel to the next. For this reason, interpanel pillars are often designed to have a minimum width to height ratio of 8 to 10 so as to prevent failure propagating to adjacent panels. In the case of the Hume Coal Project, the width to height ratios of the intra-panel pillars range from 4 to 6.5. The worst case is web pillars failing in adjacent panels and causing the full weight of the overburden to be transferred to the intra-panel pillars, in which case the factor of safety of the intra-panel pillars is reduced to 1.2 at a depth of 80 m and 1.3 m at 160 m. Given the limited dimensions of the web panels (60 x 120 m), the intra-panel pillars are unlikely to be subjected to this load over their full length. Hence, their width is probably acceptable at this stage and can be changed later if need be.

The justification of the design of the web pillars and panels for the Hume Coal Project has placed some reliance on the graph reproduced in Figure 10. [43] Care is required in utilising this graph as its construct is unsound and prone to produce unreliable design criteria (Galvin 2006; 2010; & 2016).

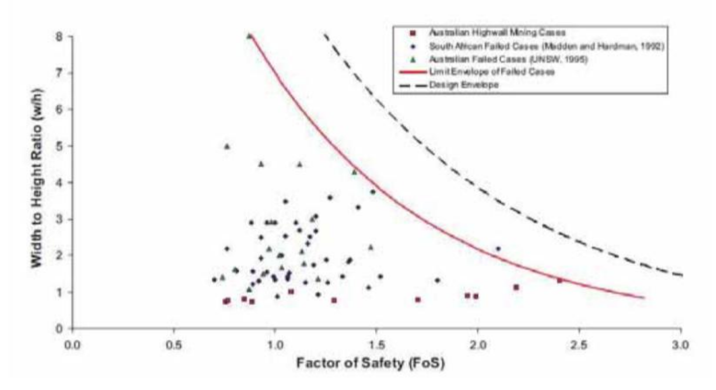


FIGURE 5. Database of Pillar Collapses – Width to Height Ratio v FoS (Hill 2005)

Figure 10: Plot of factor of safety –v- pillar width to height ratio reproduced from the EIS. [44]

Figure 11 shows the South African and Australian databases for failed case studies in Figure 10 replotted in the same format to a common point of reference, being the UNSW Power Pillar Strength Formula. (The circled point is associated with a very shallow mining depth of only 22 m which is thought to bring other factors into play). Figure 12 shows the distribution of UNSW Power Factors of Safety for the combined South African and Australian databases, excluding highwall pillars. It should be noted that a number of failed pillars with moderate to high width to height ratio were identified in the UNSW research but these were excluded from the back analysis due to a lack of confidence in the load acting on the pillars at the time of failure. Subsequently, a number of other failures of high width to height ratio pillars have been identified including that of Crandall Canyon in the USA in 2007 (Gates et al., 2008).

[43] Appendix L, Mine Advice Report No: Hume13/2, page 6, Figure 5.
[44] Ibid.

Figure 10 to Figure 12 illustrate that

- Highwall pillars with a width to height ratio up to 1.4 can fail at very high UNSW power formula factors of safety (up to 2.8), indicating that conventional pillar strength formula are unreliable for these pillars and/or other factors such as cleating and jointing primarily control the strength of small width to height ratio pillars.

- The trend to fewer failures but at higher factors of safety, up to 1.8, as pillar design formulae have evolved and caused low factor of safety designs to become less common.

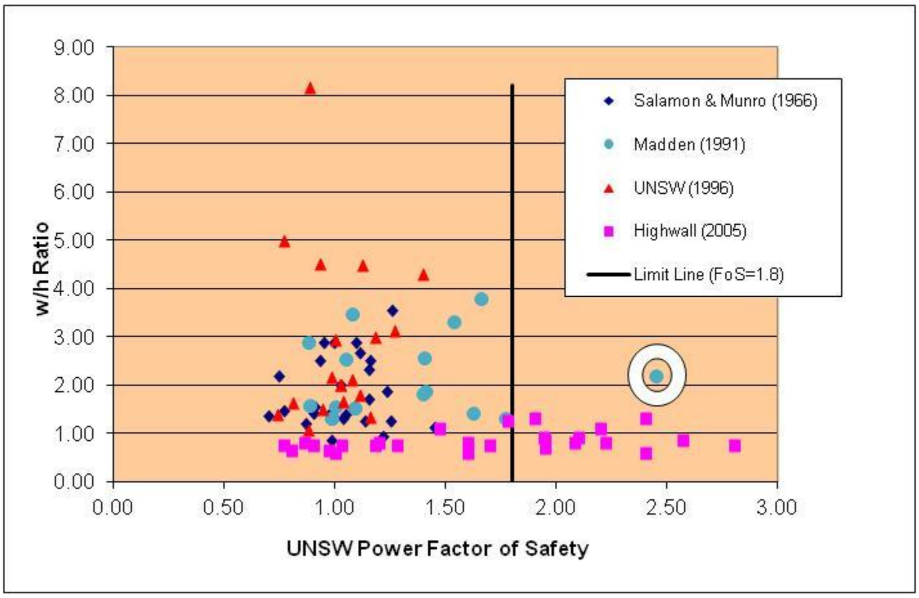


Figure 11: Australian and South African failed coal pillar cases plotted to a common point of reference, being the UNSW Power Pillar Strength Formula.

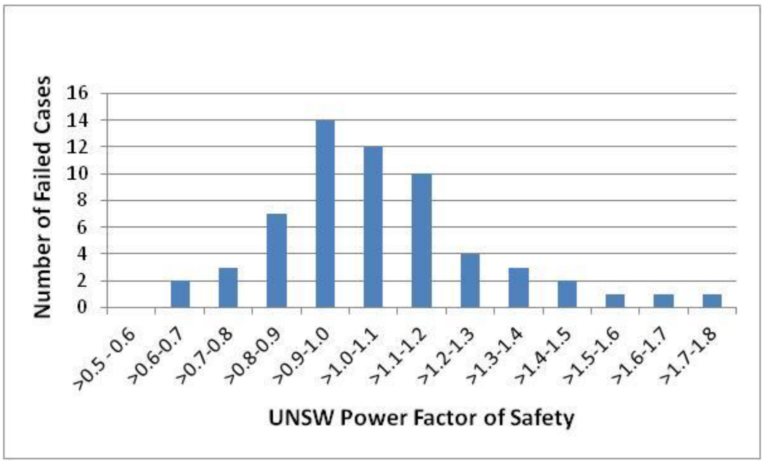


Figure 12: Distribution of UNSW Power Formula Factors of Safety for the combined South African and Australian databases, excluding highwall pillars.

The EIS also puts forward a concept of 'System Factor of Safety' and interprets the outcomes by reference to UNSW Power Formula Factors of Safety.[45] I consider this approach to be flawed because:

1. The concept relies on the cumulative load carrying capacity of the pillars making up the mining system without regard to the likelihood that each pillar in the system can support the load assigned to it. Hence, for example, reliance is being placed on pillars that have a 50% likelihood of failing.[46]

2. It interprets the outcome of dividing the cumulative pillar total load by the cumulative pillar load carrying capacity (to produce the so-called System Factor of Safety) on the basis of the relationship between factor of safety and probability of stability for the UNSW Power Pillar Strength Formula that was derived for a very different set of circumstances. This results in a system that contains key elements which have a 50% probability of failing being assessed as having less than 1 in 1,000,000 (0.0001%) likelihood of failing.

6.3. BACKFILL

HCPL, 2017b has advised that *the pillar system has been designed without the assumption of any potential rib confinement benefit associated with the backfill.* Similar advice is contained within the main body of the EIS. Nevertheless, there are a number of references to stability being further enhanced by the placement of rejects back into the mine. [47, 48, 49, .50, 51]. No information is provide in the EIS as to the physical and mechanical properties or rheology of the backfill material and where, when and how it is to be placed. I do not know if it is proposed to fill each web panel immediately after it has been mined or whether backfilling is to be delayed until all web panels have been mined in a gateroad panel.

This lack of information is probably of little consequences as there is extensive knowledge and experience regarding the properties and behaviour of backfill which indicate that it is very unlikely that the reject backfill will offer any stabilising benefits in the case of the Hume Coal Project (e.g. Wagner & Galvin, 1979; Galvin, 1982; Galvin & Wagner, 1982; Gowan & Galvin, 2001). Backfill needs to be placed to at least two thirds of the pillar height to be effective in confining a pillar at its usual weakest point, being at the pillar mid-height (Salamon & Oravecz, 1976; Galvin, 1982). Uncemented backfill relies on pillar dilation to generate confinement. Due to the low stiffness of typical CHPP reject and the small width to height ratios of the web pillars, pillar dilation will result in pillar failure well before it generates sufficient confining pressure in the backfill to arrest the dilation and, therefore, also arrest pillar failure.

[45] Appendix L, Mine Advice Report No: Hume13/2, page 25.
[46] Appendix L, Mine Advice Report No: Hume13/2, page 25, Table 3.
[47] ibid.
[48] Appendix L, Mine Advice Report No: Hume13/2, page 6.
[49] Volume 1, Executive Summary, page ES.16.
[50] Appendix L, Mine Advice Report No: Hume13/2, page 17.
[51] Appendix L, Mine Advice Report No: Hume13/2, page 27.

7.0 SUBSIDENCE EFFECTS, IMPACTS AND CONSEQUENCES

7.1. SUBSURFACE

If the web pillars prove to be long term stable and the intra-panel pillars prove to be capable of carrying the combined load of the immediately overlying strata and that transferred to them by the bridging Hawkesbury Sandstone, then deformation of the superincumbent strata can be expected to be minimal, as predicted in the EIS. However, if the web pillars do not prove to be stable in the long term then the height of deformation could be significantly higher than that of 2 m adopted in the groundwater assessment for the project, especially in areas where geological structures are present.

7.2. SURFACE

The EIS reports that the main objective of the subsidence assessment is to address the various agency requirements and Secretary's Environmental Assessment Requirements (SEARs) as contained in NSW Planning and Environment 2015.[52] It then goes on to list these requirements.

Without meaning to trivialise the matter, should vertical displacement of the surface not exceed Hume Coal's prediction of 20 mm, a detailed assessment of surface subsidence is virtually pointless (as evident in the assessment undertaken by Mine Advice).[53] The effects of mining on the surface are within the range of normal seasonal movements and well outside those likely to impact any natural or man-made features.

Surface subsidence will increase if the web pillars fail and will be a function of both the percentage areal extraction of coal from within the web panels and the panel width to depth ratios, W/H. In-panel percentage areal extraction ranges from 54% at a depth of 80 m to 43% at a depth of 160 m (see Table 2). Panel width to depth ratio ranges from 0.75 at 80 m depth to 0.38 at 160 m depth. Worst case subsidence estimates over a single panel of failed pillars can be made on the basis of relationships derived between these parameters from total extraction operations. This requires the volume of coal planned to be recovered from partial extraction operations at the Hume Coal Project to be equated to an equivalent total extraction mining height, which turns out to be 1.89 m at a depth of 80 m and 1.5 m at a depth of 160 m[54].

Based on the relationship presented in Figure 9 of Frith (2017a), this process predicts a maximum subsidence due to sag of the overburden of about 420 mm at a depth of 80 m, decreasing to about 50 mm at a depth of 160 m. In reality, these values are likely to be of the order of 30% to 50% less as the failed coal pillars will not flatten out completely. Maximum subsidence is likely to occur over the middle section of each web panel and decrease towards and over the panel abutments. However, the subsidence will increase if web pillars in adjacent panels fail since compression of the intra-panel pillars and the floor and roof strata surrounding them will also contribute to surface subsidence. The amount of additional surface subsidence due to pillar compression is dependent on whether the intra-panel pillars can sustain the additional load or whether they also fail.

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[52] Appendix L, Mine Advice Report: EMM01/2, page 6.
[53] Appendix L, Mine Advice Report: EMM01/2.
[54] Equivalent total extraction mining height = actual mining height x percentage areal extraction.

Due to the larger panel width to depth ratio at shallower depths, it is possible that subsidence will, in fact, be greater at shallower depth. The subsidence profile on the surface may also be more undulating at shallow depth. The situation is difficult to assess further without the aid of numerical modelling. In general, it is concluded that failure of the web pillars could result in up to 200 to 300 mm of surface subsidence and a surface profile that is quite undulating at shallow depth.

The EIS also gives consideration to settlement effects and impacts due to dewatering. The predicted movements are so small as to be of no concern.

Against this background, it is considered that a detailed critique of the subsidence assessment undertaken by Mine Advice[55] would serve little purpose. However, the following points are noted in case they become relevant in the future.

- There is a degree of confusion and some incorrect concepts in the EIS assessment regarding conventional and unconventional subsidence parameters and behaviours (for example, far field movements are confused with valley closure).

- The maximum depth of subsidence induced cracking from the surface is based on a model that does not apply in all situations and has, as far as I am aware, not been validated by sub-surface field investigations.

[55] Appendix L, Mine Advice Report: EMM01/2.

8.0 MINE SAFETY

Safety issues that have some connection to mining and geotechnical engineering aspects of the proposed mine design are noted in this section. The list is not exhaustive.

8.1. IMPOUNDING WATER UNDER PRESSURE

The proposal to impound water underground and under pressure in many panels while the mine is still working is novel and would need to underpinned by robust risk assessment. Apart from the obvious risk of inrush and inundation that impounded water and CHPP rejects might present, impoundments can have implications for everyday health and safety, strata control and mining operations.

Following the Judicial Inquiry into the 1996 inrush event at Gretley Colliery in NSW that resulted in the death of four mineworkers, I chaired a panel charged with implementing aspects of the Inquiry's findings. This included the writing of a guideline for addressing the risk of inrush and inundation which was reviewed and updated in 2007 and now constitutes *MDG 1024 Guideline for Inrush Hazard Management. NSW Department of Primary Industries.* More recently, I facilitated the development of the Inrush Bowtie risk analysis module as part of the ACARP RiskGate research project. These and other similar international guidelines recommend that the primary and most effective control is to eliminate the risk by removing the source of the inrush and inundation.

The feasibility and merits in impounding water to facilitate the recovery of groundwater pressure is a matter for other subject experts.

Operational issues that need careful consideration include designing bulkheads to minimise the volume of water in that space behind a bulkhead that is above the floor level of a bulkhead's spill point. For example, if a bulkhead is constructed at the top of a steeply dipping roadway, the volume of water that can be released should the bulkhead fail is limited. Conversely, if the workings behind the bulkhead are relatively level and extensive, or up dip, a large volume of water could be released over a very short period of time if the bulkhead or the strata surround it failed.

In response to questions from the advisors to DPE, Hume Coal has advised (HCPL, 2017b) that:

> *......panels have been designed so that where possible, they are down-dip from the mains, not up-dip......The mine has been purposely designed this way, to limit inrush hazard. The principal exception to this design feature is in the central part of the mine, where the seam is flat dipping. The panels in this part of the mine will have localised seam undulations, but are not considered to be "down dip' of the mains. These panels are the last to be mined.......a full hydrostatic head will not have been developed behind the bulkheads of these panels by the time that the mine is rehabilitated – in fact, these panels are unlikely to even been completely flooded at that point in time.*

Figure 13 shows the sequence and direction in which it is proposed to extract panels, seam dip and geological structure. Matters which warrant careful consideration include:

1. The potential for geological structures to compromise the impoundment and confinement of water under pressure in segregated panels.

2. Seepage of impounded waters into active down dip mine workings through the Wongawilli Seam aquifer and along faults, dykes, joints and cleats. There appears to be potential for this to occur in the areas delineated by the dashed red lines in Figure 13. Excessive seepage and water inflow is a well known problem when mining in the vicinity of flooded abandoned mines and has caused many to be pumped out despite the presence of +50 m wide barrier pillars (e.g. Kerosene Vale Colliery and Renown Colliery in the Lithgow region of NSW).

3. The potential for water under pressure to migrate along bedding parting planes in the immediate roof and floor and induce bed separation and falls of ground. This is of particular concern in the web pillar panels.

4. The potential for seepage in conjunction with mobile plant to cause the coal floor to break up and the consequences that this may have for pillar stability.

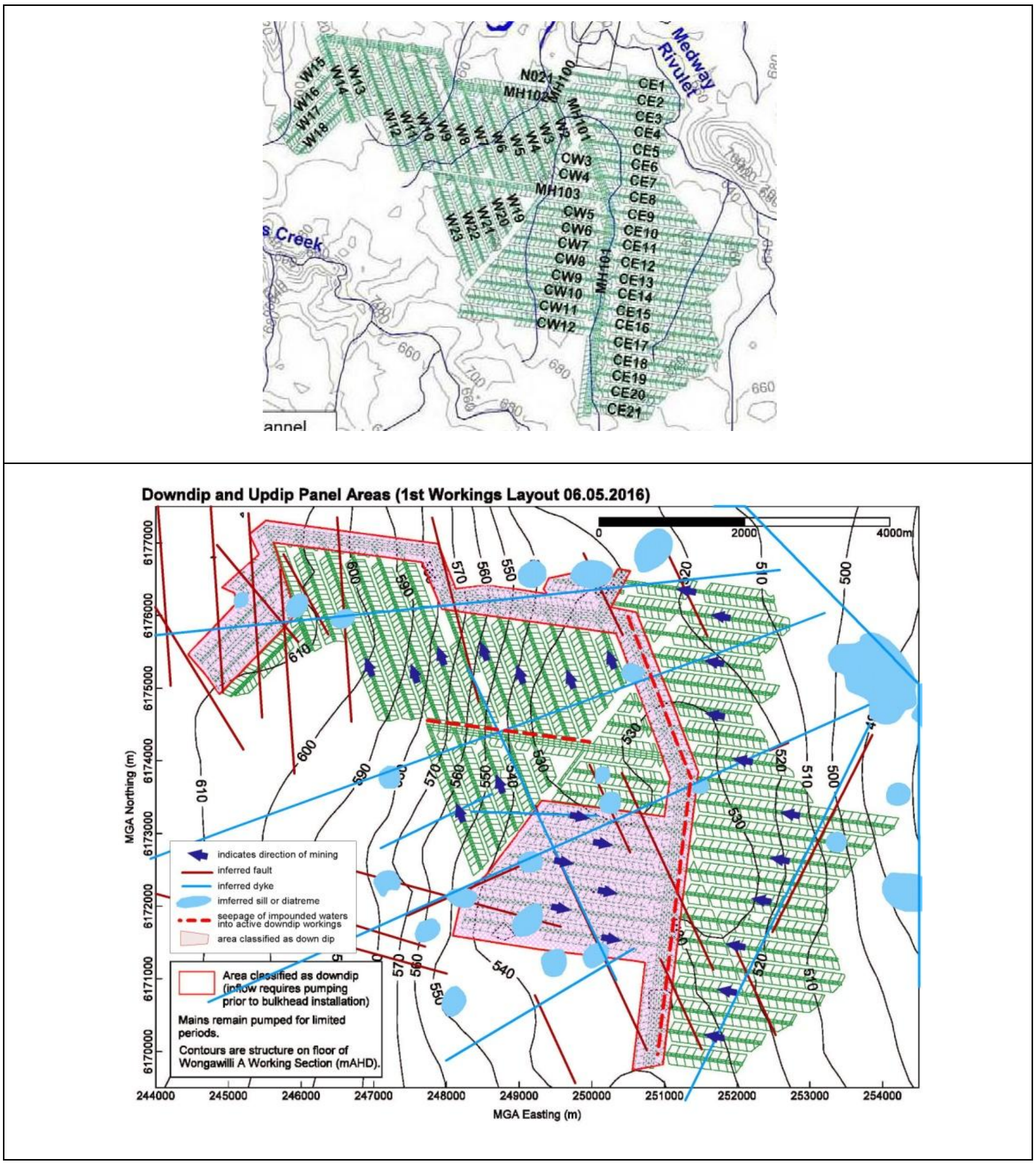

Figure 13: Plan showing panel extraction sequence and direction, seam dip and geological features.

8.2. IMPLICATIONS ASSOCIATED WITH NARROW WEB PILLARS

Although the theory that underpins how load is distributed between coal pillars and how coal pillars yield in a controlled or uncontrolled manner was developed more than 30 years ago, small width to height ratio yield pillars have only found limited application to date and on a very localised basis (limited to one or two rows), primarily in longwall mining. I am aware of one attempt to utilise them on a regional scale to control goaf behaviour in pillar extraction but strata behaviour proved to be very unpredictable and hazardous and was abandoned. History attests to the difficulties of designing yield pillar layouts that satisfy risk management standards in the case of bord and pillar panels. However, on this occasion and as advocated in the EIS, the restricted web panel spans associated with the Hume Coal Project might remove the risk of uncontrolled collapse of web pillars that comply with as-designed dimensions. Consideration still needs to be given for the potential for uncontrolled failure of undersize web pillars and pillars adversely affected by geological structure.

Other safety implications associated with the use of very small width to height ratio web pillars include:

1. A very small change in physical conditions or deviation from as-designed dimensions can result in a very large decrease in stability of a pillar.

2. Development of instability in an individual web pillar has a high likelihood of then initiating instability in surrounding pillars.

3. If equipment becomes immobilised in a plunge, it may not be sufficient to install support only in the affected plunge in order to access the equipment. Rib bolting a very narrow strip pillar on only one of its sides does not preclude the risk of rib spall in the workplace that is initiated by rib instability on the other side of the pillar. Hence, it may also be necessary to support at least the preceding plunge, assuming that it is still safe to enter.

4. As surface mining experience has shown, a roof fall in a plunge or the uncontrolled failure of a web pillar can result in the ejection of material and fluid from a plunge. The potential consequences of such an event are greater in the confined space of an underground mine than on the surface.

8.3. GOAVES

As mining retreats out of a mining (gateroad) panel, the web panels constitute goaves. Roof falls and pillar failures in the goaf can displace the goaf atmosphere into the active mine workings. Backfill and flooding will also displace goaf atmosphere. The EIS does not provide information as to the likely gas composition and gas content of the goaves and the manner in which mining operations are to be ventilated to safely control goaf gases.

The driveage of each plunge results in the formation of a ‘T’ intersection. The EIS does not provide information as to whether the entrance to each plunge will be supported to permit ongoing entry into the flanking gateroads to undertake backfilling and other mining related activities (such as pumping and the construction and maintenance of ventilation devices).

As plunges are not supported and are not accessible during routine mining operations, the question arises as to whether an active plunge constitutes a goaf. Preceding plunges satisfy the definition of goaf.

9.0 SUMMARY AND DISCUSSION

1. The concept of exploiting massive strata in the roof to limit caving of the superincumbent strata by restricting panel width to depth ratio, W/H, has found wide application in underground coal mining in Australia. These applications generally involve driving a series of supported roadways within a mining panel and then widening the roadways on retreat out of the panel. Such operations are classified as partial pillar extraction.

2. The Hume Coal Project utilises this concept but is distinguished from other applications of it by:

   a. remotely driving unsupported roadways up to 120 m long within a panel;

   b. separating unsupported roadways with strip pillars that are narrow and have very small width to height ratios;

   c. relying on the narrow and very low width to height ratio pillars remaining stable in the long term; and

   d. by relying on the strip pillars yielding in a controlled manner should they become overloaded.

3. The proposed method for driving the unsupported roadways by remote control mining to form the long narrow pillars has not been applied previously in an underground coal mine.

4. The method is claimed to constitute bord and pillar mining first workings.

5. The widths of the proposed strip pillars are significantly less than established regulatory requirements in NSW for bord and pillar first workings. Presumably, therefore, exemption will need to be obtained to form the pillars.

6. The structural integrity and load carrying capacity of narrow and very low width to height ratios pillars is extremely sensitive to geological structures and discontinuities and to deviations from as-designed mining dimensions. For these reasons, a range of guidance material advises against using such small pillars in standard bord and pillar mining layouts. In the case of the Hume Coal Project, it is possible that any reductions in web pillar loading due to bridging overburden could be offset by reductions in coal pillar strength brought about as a result of non-conformance to design dimensions and to the impact of geological structures.

7. The EIS provides very limited information on geological structures. It does not give due recognition to some geological factors critical to the performance of very low width to height ratio pillars and to pillar performance in general. The proponent has acknowledged that some geological features will only be detected at the time of mining.

8. The proponent is relying on a range of emerging and new technologies to assist in controlling pillar width and for the timely detection of adverse geological structures.

9. Factor of safety is an engineering concept that compares the peak load carrying capacity (or strength) of a structure against the load acting on the structure.

a. Because neither pillar strength or pillar load can be precisely calculated, a safety factor greater than one (meaning predicted load capacity exceeds predicted working load) does not assure stability. Different probabilities of success are associated with different factors of safety and are specific to the design methodology employed.

b. The UNSW pillar design methodology has been applied in the Hume Coal Project for assessing the strength of coal pillars and the probability that the pillars will be stable under a known load.

c. As in all but one special case in mining in general, the load acting on the coal pillars is statically indeterminate as it is a function of the ratio of the stiffness of the coal pillars to the stiffness of the loading system. It is standard and routine practice to utilise numerical (mathematical) modelling to evaluate pillar load in these circumstances and to quantify the level of confidence in these loads.

d. The Hume Coal design has not utilised numerical modelling to estimate pillar load. The designer is of the view that reliably predicting pillar load distributions is almost certainly beyond the limit of current technical understanding of overburden mechanics and therefore also numerical simulation techniques.

e. While no numerical simulation technique can be relied upon to accurately predict load, parametric and sensitivity analysis can be used to define a sensible range in pillar loads and can be supported with more sophisticated stochastic analysis to improve reliability.

f. Rather than utilise numerical modelling, the designer has utilised an upper extreme loading model for some types of coal pillars and also a lower extreme model in the case of web pillars.

g. The upper extreme model produces useful and conservative estimations of load for all five types of coal pillars that make up the mine design. However, the use of both an upper extreme and an lower extreme bound model for the most critical pillars in the mine design results in the predicted likelihood of web pillar instability falling somewhere within a range of <0.000001% to 50%. This is obviously too wide a range for assessing reliability and stability.

h. Hence, the predicted performance of the web pillars in the EIS is largely based on qualitative assessments of pillar behaviour, on an unsound empirical design curve and on engineering judgement. Nevertheless, in the absence of geological structure and rib and roof spall, the designers assessment could proved to be reasonable.

10. The proposed mine design ultimately relies on:

a. a judgement that the (unknown) load acting on the very low width to height ratio web pillars will not exceed their strength.

b. a judgement that the web pillars will yield in a controlled manner should pillar load exceed pillar strength.

c. confidence that the likelihood of coal rib spall resulting in a significant increase in the effective width of plunges so as to adversely affect roof stability in unsupported plunges under normal or background geotechnical conditions is in the highly-unlikely to practically-impossible category.

d. confidence that adverse geological features will be identified ahead of mining or during the mining process and result in mining ceasing in the area.

11. It is a matter for groundwater specialists to determine if in-panel pillars (such as web pillars) are required for groundwater management purposes.

12. If the web pillars prove to be long term stable and the intra-panel pillars prove to be capable of carrying the combined load of the immediately overlying strata and that transferred to them by the bridging Hawkesbury Sandstone, then deformation of the superincumbent strata can be expected to be minimal, as predicted in the EIS. However, if the web pillars do not prove to be stable in the long term then the height of deformation could be significantly higher than that of 2 m adopted in the groundwater assessment for the project, especially in areas where geological structures are present.

13. If the web pillars do not prove to be long term stable, then based on approximate analysis and my experience, it is estimated that to 200 to 300 mm of surface subsidence could result, along with an undulating surface profile at shallow depth. It is also possible that as a result of keeping the panel width to depth ratio constant in the mine design, subsidence could be greater over shallower rather than deeper workings. Numerical modelling would aid in better assessing this situation.

14. The concept of filling panels with water after extraction and while mining is still occurring elsewhere in the mine for the purpose of restoring hydrostatic conditions as soon as possible is novel as far as I know. I defer to groundwater specialists but on the basis of my practical mining experience, I question the extent to which pressure recovery may be achieved given that the mine is a sink and will continue to draw down water from panels that have been sealed and flooded.

15. There are a number of safety implications associated with the use of very low width to height ratio pillars that are not associated with pillars of moderate to high width to height ratio.

There is a range of mining systems that exploit the spanning capacity of massive overburden to restrict surface subsidence while also minimising the amount of ground support that has to be installed and its associated negative impacts on cost and productivity. These are mostly based on some form of partial pillar extraction, as apparent in the examples shown in Figure 4 and Figure 6. For the given depth range of the Hume Coal Project, these systems achieve a comparable or higher percentage extraction of the coal resource than the mining system proposed for the Hume Coal Project. They also utilise pillars of much greater width and width to height ratios and, therefore, are less sensitive and more resilient to adverse geological conditions and deviations from as-designed mining dimensions. These systems are also amenable to developing a limited number of roadways through a geologically disturbed zone to recover coal on the other side and/or to recovering this coal from a different direction. As in the case of Clarence Colliery (Hill & White, 2017), numerical modelling can be utilised to optimise mine design.

In comparison, the mining system proposed for the Hume Coal Project offers the benefit of having to install less ground support and, therefore, presumably has associated cost and productivity advantages. Provided that the web pillars remain stable, persons are also not exposed to goaf falls running into the workings place. However, as noted above, the method achieves a lower areal extraction of the coal resource than most other alternative systems and panel pillar stability is much more vulnerable to geological structure and deviations from as-designed mining dimensions. As claimed in the EIS, the system is flexible in dealing with geological features. However, this comes at the expense of percentage extraction since mining is abandoned to avoid both equipment becoming immobilised or lost in a plunge and the stability of the existing web pillar being compromised.

The web panels associated with the Hume Coal Project have similar or lower panel width to depth ratios than associated with some other systems designed to limit surface subsidence. The EIS attributes this to the need to maintain long term stability of the pillar system in order to prevent relaxation and fracturing of the immediate roof strata for the purpose of managing groundwater impacts. It results in the unusual situation of panel width being held constant with increasing depth and hence, a reduction in panel width to depth ratio with increasing depth. Consequently, the likelihood of pillar instability is highest at shallow depth. Numerical modelling may confirm that surface subsidence associated with pillar instability is also greatest and more irregular above shallower workings.

In some other systems designed to limit surface subsidence, panels not much smaller in dimension than the web panels in the Hume Coal layout are totally extracted by driving splits (or roadways) through pillars and then extracting the coal from one or both sides of the roadway. Examples are shown in Figure 4 and Figure 6(b). Given that the widths of the web pillars in the Hume Coal layout fall well below the regulatory requirement for bord and pillar first workings in NSW, the question arises as to whether the proposed mining method actually constitutes a form of partial pillar extraction based on driving long run-outs (roadways) as in the Wongawilli method of pillar extraction, but without then lifting off (extracting) the sides of the run-outs on the retreat. In that case, it might be considered a version of the panel and pillar method of 'take a row, leave a row'. Alternatively, it might be regarded as constituting pillar splitting on the goaf line, which is provided for in legislation.

Many of the matters raised in this report could reasonably be expected to have been evaluated by the mine owner(s) in a risk assessment of the mining concept prior to deciding to lodge a Development Application. The EIS does not provide insight into the status of risk assessment.

10.0 OVERALL CONCLUSIONS

In theory, a mining system that is based on exploiting the spanning capacity of strong overburden to shield narrow and very low width to height ratio pillars from load while still restricting surface subsidence and disturbance to the groundwater system is plausible.

In practice, the safety of such a mining system and its success are highly dependent on geological conditions, the capability to maintain very tight control over mining dimensions, the reasonably accurate prediction of pillar loads and pillar strengths, and a high level of confidence in how pillars will behave if their peak load carrying capacity is exceeded.

The EIS does not address all of these issues in sufficent detail to enable a full and proper assessment of the safety of the proposed mine design for the Hume Coal Project. Suffice to state that the stability of narrow and very low width to height ratio pillars is very sensitive to deviations from planned mining dimensions and to geological conditions. If the pillar system proved to be unstable, surface subsidence is still likely to be at the lower end of the range and manageable. Impacts on groundwater are a matter for subject experts.

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