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18 August 2018

Attn: Mr Alex Pauza
Manager, Mine Planning
Hume Coal Project

Report No. 1509/02.4

Re: Summary Independent Peer Review: Report on *"Pillar Design Analysis Using LaModel"* by Dr Keith Heasley (29 May 2018)

I have been asked to provide an independent peer review of the LaModel Report prepared by Dr Keith Heasley (May 2018 Report). I offer the following summary comments on the report which was provided to me in July 2018. Comments are provided in sequential order of issues as they appear in the report, and so do not indicate any relative priority or level of importance.

Prior to working through the content of the report, I would like to offer two introductory comments. Firstly, in seeking to undertake some meaningful three-dimensional modelling of the Hume Project mine layouts, I fully endorse the selection of the use of LaModel as one of, if not the most appropriate modelling software package for a task such as this. Secondly, I also reinforce the decision to engage Dr Keith Heasley directly to carry out this analysis. I have known Keith for many years and can attest to his professional reputation, as well as the fact that, as the primary author of the LaModel software, he is by far the most experienced user of the software and can apply it appropriately to the analysis at hand.

I will now proceed to offer specific comments, working through the report, making reference to section headings, page numbers and paragraphs, where appropriate.

Executive Summary

- I fully endorse the five-stage approach adopted by Heasley.
    - Stage 1 is essential to develop a meaningful set of material properties for the pillar coal and the chosen Mark-Bieniawski formula is a highly credible formula, closely linked to the algorithms in the LaModel "wizard".
    - Stage 2 is important to develop a representation of the overburden into a form of lamination representation. Note that the model does not seek to represent the exact overburden lithology in terms of either geometry (thicknesses) or properties – but it does provide a laminated representation of overburden behaviour which is as good as can be achieved with any modelling technique, whilst also considering the complexity of the 3D mine geometry. The use of data from the neighbouring Berrima Colliery is a valuable opportunity for back-analysis and hence calibration of the proposed model in similar geology.
    - Stage 3 is of value in comparing 2D cross-sectional results with the existing MineAdvice empirical design calculations (using ARMPS).
    - Stage 4 is the primary value of the LaModel study – providing a full 3D analysis of the mine layout and the multi-dimensional support offered by the different types of pillar systems within the layout, which cannot be truly and fully analysed using only 2D techniques.
    - Stage 5 is a valuable hypothetical analysis of some extreme scenarios – which are not expected to occur, but by analysing them in this way, the results should offer some degree of confidence in the robustness of the overall design.

- The results of both 2D and 3D analyses have confirmed that the web pillars have higher pillar safety factors than tributary area calculations would have indicated. This is intuitively correct and a good result, demonstrating the 3D nature of load-sharing across the regional pillar system as a whole. The results also confirm that as overburden stiffness varies, so too does the amount of load transferred to adjacent barrier pillars – again, an intuitively correct and valid outcome.

- The Stage 5 results are also very encouraged and do demonstrate very good robustness of the design. The failure (by removal) of a single web pillar reduces the adjacent pillar safety factors, but not to the point of failure, and surface subsidence is effectively unchanged. With the failure (removal) of an entire web pillar section, the adjacent barrier and chain pillars remain stable and surface subsidence only increases by between 16 and 24mm, which is well within an acceptable level of tolerance for such a mining system.

Background

- P1 - The 2D analysis has taken a section through a panel of web pillars and intra-panel barrier pillars. This is valid and represents the equivalent of an infinitely long series of roadways and pillars.

- P1 - Selection of pillar and panel widths is appropriate for the layout, and the use of pillar width:height ratio (w/h) and a Stability Factor (SF) as criteria for stability assessment are appropriate. Panel Width/Depth ratio (W/H) is also a critical design parameter.

- P2 – It is noted that for deeper areas, some areas of web pillars would have a tendency to be sheltered from full cover load by the inter-panel barrier pillars and chain pillars – where W/H decreases below 1. This comment is noted and is again intuitively valid, but it is for the numerical analysis to demonstrate this point, rather than rely on simple intuition.

- P2 – the three depths and relevant dimensions selected for analysis are considered reasonable and appropriate.

The LaModel Program

- See earlier introductory comments on the suitability of this software for an analysis such as this; and also the appropriateness of using Dr Keith Heasley to drive this modelling exercise.

Hume Mine Models

Stage 1 – Investigation of Coal Models (p18)

- The evaluation of two different coal models is considered reasonable, using the 2D analysis for comparison – effectively representing the maximum loading regime, as compared to load sharing available when 3D analysis is used. The analysis discusses some minor differences in results which are effectively identical, within the practical limits of modelling technology. It is therefore accepted that the forward modelling study making use of the M-B elastic-plastic model is reasonable for this study. (It is unfortunate that Dr Heasley did not provide further detail of the comparison using the two different coal models, although his findings, as reported, are accepted).

- The only section where further use of what is referred to as the RF strain-softening model may have been interesting would have been in the Stage 5 analysis of a single pillar failure. Results here may have been slightly more adverse than with the M-B coal model (although Dr Heasley has stated that none of the coal elements in any of the analyses exceeded peak strength, hence strain-softening would not be a factor). However, once the full web panel of pillars was removed, this difference would again become almost irrelevant and so the final results for a full panel failure are considered to be reflective of either coal model.

Stage 2- Investigation of Rock Mass Lamination Thickness (p19)

- The use of actual Hawkesbury Sandstone data (essentially elastic modulus) provides the modelling with credibility – particularly with the use of a range of values – 8.2, 16.5 and 23.2 GPa.

- Selection of lamination thickness in the model has been carried out – it is important to remember that his is in effect, an artefact, not an actual rock thickness. Hence, the calibration back-analysis with the Berrima Colliery data to reproduce surface subsidence at 10mm was a useful means of selecting the appropriate lamination thickness values for use in the model, which were chosen to be 20m and 40m, representing conservatively low values for the study.

Stage 3 – 2D Models (p20)

- Selection of a 0.5m wide coal pillar element was appropriate to achieve as close as possible to actual web pillar and roadway dimensions, and sufficient level of element density to achieve meaningful results.

- Output results were presented as convergence, stress (vertical) and safety factor, and compared with ARMPS empirical results.

- The results presented in Table 3 demonstrate the point commented on earlier, about a degree of protection of the web pillars from full tributary load (as is assumed in the ARMPS calculations).

- All results demonstrate acceptable stability levels for both the web pillars (centre and outer) and the adjacent barrier pillars.

Stage 4 – 3D Models (p21)

- The same modelling properties and parameters as used for the 2D analysis were used for the 3D analysis.

- The model grid analysed is considered to be adequate to be meaningful, covering two full panels and adjacent pillars, over an area of 675m by 750m. It is this sheer size of model, and level of detail within the mine layout contained within it that makes a LaModel study such as this quite unique, being one of the few if only numerical techniques that can address such a problem to this level of detail. It will never be 100% real in reflecting every detail of overburden, for example, but it does provide a meaningful assessment of the 3D nature of the mine layout, and the critical regional load-sharing and load distribution in both horizontal directions.

- The corresponding surface grid was extended to an equivalent of a 45-degree angle of draw on all sides, beyond the vertical projection of the mine grid boundary.

- Results were presented in the same way as for the 2D analysis, with the addition of inbye, middle and outbye results for the web pillars, to demonstrate the end effects of load sharing along the finite length of the pillar system.

- The results once again clearly demonstrate the effectiveness of protection or load-sharing between the stiffer stronger pillars on all sides of the web pillar system. Virtually all results show lower loading and hence higher safety factors than the empirical ARMPS calculations. The only exception to this result is for the outbye ends of the web pillars adjacent to the chain pillars for softer overburden stiffnesses (less than 5% difference). Heasley offers a plausible explanation for this very minor difference associated with the 3D nature of the load distribution which is not taken into account in the ARMPS results.

Stage 5 – Worst Case Scenarios (p24)

- As mentioned earlier, in this stage, sections of one and then all web pillars in a particular panel were completely removed, with no attempt to replace them with any form of load-carrying goaf material to support the overlying roof.

- The results from these scenarios clearly show increased loads on adjacent pillars, but in both models (80m and 160m deep), neither the adjacent barrier pillar nor the chain pillar approach failure – both remaining in a stable condition, and surface subsidence only increased by a maximum of 24mm in the worst case scenario modelled – which is a minimal amount which would not be expected to result in any adverse impacts on surface or on underlying strata/aquifers.

Overall Comment

- Within the limits that must be placed on the credibility and confidence of any numerical modelling study, the results obtained by the LaModel work conducted by Dr Keith Heasley have provided very reassuring results with respect to the Hume Project mine layout. In particular, they have demonstrated:
    - An ability to achieve close correlation with previous Berrima Colliery outcomes, to enable a meaningful and credible modelling approach to be adopted;
    - Remarkably consistent correlation between the 2D numerical results and the empirical ARMPS results previously obtained as part of the Mine Advice design study;
    - Demonstrated some degree of load protection of the narrow web pillar panels due to the stiffer surrounding pillar systems, resulting in loading marginally lower than the full tributary area loading;
    - Significant load sharing and regional load distribution over the 3D analysis representing a meaningful section of the mine layout – demonstrating that the layout does make use of a 3D array of stiffer, stronger pillars surrounding the production web pillar panels. The results demonstrate further protection of the production panels in a true 3D environment, by comparison to the 2D results.
    - Even in the highly unlikely event of a web pillar failure, or even panel failure, the surrounding pillar system has sufficient robustness to maintain regional stability with negligible impact on surface.

I trust these review comments are of value to you. Feel free to contact me if you have further questions.

Yours sincerely,

Bruce Hebblewhite

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19th August 2018

Attn: Mr Alex Pauza
Manager, Mine Planning
Hume Coal Project

Report No. 1509/02.5

Re: Summary Independent Peer Review: Report on *"Interpretation of the Numerical Modelling Study of the Proposed Hume Project EIS Mine Layout"*
by Mine Advice – Dr Russell Frith (June 2018) – HUME22/1

I have been asked to provide an independent peer review of the above Mine Advice Report prepared by Dr Russell Frith (June 2018). I offer the following summary comments on the report which was provided to me in July 2018. Comments are provided in sequential order of issues as they appear in the report, and so do not indicate any relative priority or level of importance.

I have provided previous review commentary on Mine Advice Reports and related documents for this project. Where material is contained in the current report which is essentially the same or similar to previous material, I will not repeat my previous commentary unless the matter is considered pertinent to any new findings or discussion points.

I will now proceed to offer specific comments, working through the report, making reference to section headings, page numbers and paragraphs, where appropriate.

Introduction (p1)

- Reference is made to the Hume Coal EIS design study for the proposed mine layout; the two independent expert reviews conducted for DPE by Galvin & Associates, 2017 and Canbulat, 2017; and the numerical modelling study carried out by Dr Keith Heasley (May 2018). It is noted and agreed that the primary point of interest and the "key layout design attribute" that is directly linked to surface subsidence control is coal pillar stability, particularly the issue of overall regional stability achieved by the design.

- Reference is made to the criteria and the basis of the Hume mine design, as outlined in Mine Advice 2016a. No new commentary is required here.

Summary of Initial Layout Design Logic (p4)

- This section refers back to previously reviewed work based on the use of the empirical 2D ARMPS-HWM model. Only specific new or relevant issues are commented on below.

- P5 – Reference is made to the previous design studies that adopted an "overall system Safety Factor" concept. The current report then rightly points out that this concept is somewhat contentious and has not been relied upon in the assessment of pillar stability for this project. I have been previously critical of the use of such a concept and am pleased to note that it does not form part of the design approach or justification.

- P5 – makes reference to use of more conservative design criteria than those allowed for within the ARMPS-HWM model, due to the need to ensure "long-term remnant pillar stability at Hume". I agree with the approach here, but I have some concerns about the terminology of referring to "remnant pillars". This is usually a term used in association with pillar extraction mining systems. In this case, I do not believe there is any intention of partially extracting pillars, hence I think the term 'remnant pillars" may be a bit misleading.

- P6, para (i) – this point is at the centre of the design principle for this mining layout and is the basis for the previous encouragement to the project team to adopt a 3D numerical modelling approach to seek validation of the nature and extent of load-sharing achieved in all directions by the four coal pillar types acting in combination. This mine layout is not a simple 2D problem. Whilst a 2D analysis is a good starting point, as was done in the initial studies, it does represent a worst case with respect to load distribution for a layout such as this. A 3D analysis has the potential to more realistically demonstrate the regional load distribution in all directions, relative to the different panel and pillar systems and orientations in the mine layout.

Interpretation of Numerical Modelling Outcomes (p10)

- This section should be read in conjunction with my separate independent peer review of the Heasley LaModel Report. I will not repeat specific comments that have been addressed there, other than for critical discussion points or where further emphasis is required in the context of this current review. (Note: It is apparent that Mine Advice has access to the LaModel study result files and so this review report by Mine Advice actually presents more results than were available in the original LaModel report, albeit that the findings were summarised in tabular form by Dr Heasley).

- Selection of LaModel, and of using Dr Heasley for this study – both fully endorsed, as per separate review report.

- P11 – Absence of vertical joints and horizontal stress in the LaModel overburden: The argument put forward by Mine Advice draws on a large extent of other work relating to the role of joints on subsidence behaviour, especially above *"remnant partial extraction areas"*. I do not intend to enter a lengthy review of this issue and the supplementary Frith and Reed, 2018 paper provided in an Appendix, as I do not believe it is necessary. I am satisfied that in a non-extraction, low W:H ratio mining environment adopted by Hume, it is quite reasonable to assume that the overburden can be reasonably modelled as a continuum, even if in reality it contains a set of vertical joints which are clamped together by horizontal stresses.

  Modelling will never be able to represent every geotechnical feature present in the rock mass, and certain assumptions and simplifications need to be made. In this case, without offering any commentary on the other work referred to by Mine Advice, I am satisfied that the assumptions in the LaModel overburden continuum model are reasonable. I support the final sentence of section 3.1.1 that states *"… it can be reliably inferred that the absence of vertical joints and horizontal stresses within the overburden model used by LaModel, is of no significance to the reliability of the modelling outputs"*. This statement definitely holds true for a LaModel study of a mine layout such as that proposed by Hume.

- P12 – The significance of pillar load distributions within LaModel: It is noted that within LaModel, pillars are subdivided into multiple elements within the overall grid. This is normal for any numerical modelling approach and provides for a better representation of the loading on the pillars, rather than working with a single "average pillar load" approach commonly adopted by empirical techniques. The remainder of the discussion by Mine Advice explains how LaModel treats coal pillars and pillar loading, yielding and overall stability assessment. Once again, given the largely elastic behaviour evident in the Hume layout pillars, the detailed manner in which LaModel treats yielding and failure is more of academic interest and does not have any significant impact on the results of the current analysis.

- P15 – Some discussion is given to the Stage 5 LaModel analysis of hypothetical extreme cases of full web pillar failure, or even failure of an entire panel of web pillars. This was included in the LaModel scope, not because such scenarios were considered feasible, but to deliberately evaluate an absolute "worst-case" scenario, in order to test the ability of the surrounding pillar system to maintain regional stability even under such extremes. The intention, as stated by Mine Advice, was to test and hopefully demonstrate the robustness and confidence in the overall pillar system layout.

- P15 – Calibration with Berrima Colliery data: Whilst the available data from Berrima was not comprehensive, it did provide a valuable point of reference in similar geological conditions to allow for a back-analysis of overburden characterisation and hence a calibration point for the model used for Hume going forward. The main point of calibration was surface subsidence at 10mm. This was a reasonable point of calibration, and certainly added confidence to the LaModel study for Hume. The result was a set of overburden elastic modulus values together with lamination thicknesses for the LaModel work that represented a quite conservative view of the overburden behaviour. This is considered to be a prudent and hence appropriate way forward for the properties used in LaModel.

- 2D LaModel Results (p18) – The results obtained by LaModel have demonstrated the impact of the low W:H ratio web pillar panels, whereby the web pillars do not see the full tributary loading (as compared to the empirical ARMPS-HWM results). The results are therefore marginally more favourable than the "worst-case" 2D empirical loading results but are certainly intuitively meaningful and considered to be valid.

- 3D LaModel Results (p21) – The use of a 3D modelling study was the primary focus and objective of undertaking the LaModel study. As has been commented on already, this mine layout cannot be meaningfully represented by simple 2D cross-sections – that is not to say such 2D studies are of no value, since they do provide a "worst-case" set of outputs. However, the mine layout is based on regional load-sharing by a series of different pillar systems in all directions. The web pillar panels are not infinitely long, as is assumed in any 2D analysis, and the 3D analysis provides a meaningful way of assessing the load-sharing effects or benefits in all directions.

  The 3D analyses considered the range of depths from 80m to 160m as well as the impacts of different levels of overburden stiffnesses. Detailed discussion on these differences is contained in the Mine Advice report. Suffice to say that the 3D results for all combinations demonstrate improvements in pillar stability due to these 3D effects, with all combinations proving satisfactory from an overall stability perspective – even with overburden stiffnesses de-rated to a level well below that expected in reality. In particular, the 3D modelling has demonstrated the role, and the stability levels, of the inter-panel barrier pillars and the chain pillars. The 3D modelling results also predict surface subsidence levels, which, even over the 80m deep layouts, are negligible (< 5mm).

- Hypothetical web pillar failure scenario modelling (p28) – These models were appropriately run using the lowest level of overburden stiffness, and the two extremes of depth – 80m and 160m. These combinations are considered appropriate. The results for removal of a single web pillar show negligible difference. However, as discussed in my review of the LaModel report, it may have been more appropriate to have used the strain softening coal pillar elements for this scenario modelling, especially with respect to the immediately adjacent web pillars. However, even using such elements, any differences would be expected to only be localised and so not a serious issue.

  The scenario where a full panel of web pillars was removed is probably not impacted greatly by the choice of coal element type. The results do show much more significant impacts in terms of load re-distribution, with intra-barrier pillar SF values dropping from 4.4 to 2.7, and chain pillar SF values dropping from 2.6 to 1.9. In the case of surface subsidence, the maximum predicted subsidence has increased from 3mm to 24mm at 80m depth, and from 4mm to 16mm at 160m depth.

  Firstly, this scenario modelling has been a useful exercise and the results appear to be plausible and valid outcomes. Importantly, they again demonstrate the robustness of the overall mine layout and pillar system design, with no evidence of any seriously adverse or unacceptable impacts. It is once again confirmed that this panel removal scenario is a truly "worst-case" situation which is not considered to be a realistic possibility but was included purely to test the principles of the regional pillar system design.

Displacement-Based Stability Criteria (p33)

Mine Advice makes reference to a comment by the expert review panel of Galvin and Canbulat, chaired by Professor Ted Brown, which requested some consideration of use of a displacement-based stability criteria. Mine Advice presents an extensive database of information and analysis relating to the nature of overburden stability (or otherwise) linked to displacement. Once again, this technical discussion is of great technical interest, but I feel it goes well beyond what was envisaged when the comment was made by Professor Brown, important as it was. I do not propose to critically review all of the material discussed here by Mine Advice.

The conclusions with respect to Hume, on p46, argue that major displacement-driven overburden instability is only likely to be feasible beyond displacement levels of 150mm, whereas the figure for the Hume layout is closer to 20mm. I am confident that the 20mm maximum subsidence predictions are reasonable, within probably ±10mm. In such an environment, the issue of a major displacement-driven overburden instability is simply not an issue of concern for this layout.

Weathering of the Hawkesbury Sandstone (p47)

Further analysis of the exploration data regarding Hawkesbury Sandstone (HBSS) has found that only a very small area of the proposed mine layout in the western area of the lease contains some degree of weathering. More importantly, in re-analysis of available bore core data, the extent of weathering has been found to be very minor: 79% of core is classified as unaffected by weathering, faintly weathered or slightly weathered; 3% of the core is classified as highly or completely weathered. Where weathering exists in borecores, it us generally in selected bands between intervening fresh or unweathered rock.

Overall, the issue of weathering is one which should remain a consideration with respect to specific panels in these limited areas of the lease, but it is agreed that the extent of weathering should not pose serious problems to the proposed overall mine layout and regional stability.

I trust these review comments are of value to you. Feel free to contact me if you have further questions.

Yours sincerely,

Bruce Hebblewhite